Performance Analysis of Optical Burst Switched Node with Deflection Routing

Yang Chen[1], Hongyi Wu[2], Dahai Xu[1] and Chunming Qiao[1]
[1]Computer Science and Engineering Department, State University of New York at Buffalo
[2]The Center for Advanced Computer Studies, University of Louisiana at Lafayette

Abstract—**As the optical network evolves from static long haul connection provider to an adaptive and "smart" backbone solution, Optical Burst Switching (OBS) becomes an attractive scheme for its flexibility and efficiency. However, how to reduce data loss is a crucial issue in such an asynchronous and one way reservation system. In this paper, we study one contention resolution strategy in OBS networks: deflection routing. We extend an existing work to provide approximate and accurate models for the data loss analysis of single OBS node with and without wavelength conversion capability. The accuracy of our models are evaluated by simulation results.**

I. INTRODUCTION

Optical communication is now ubiquitous in the telecommunication and the Internet infrastructure for its huge bandwidth provision and good transmission quality [1]. As the basis of the optical network, various optical switching technologies have been developed. Optical circuit switching (e.g. wavelength routing) is relatively easy to implement but lacks flexibility to cope with the sporadic and sub-λ connection requests. Optical Packet Switching (OPS) is conceptually ideal, but the essential technologies such as optical buffer and optical logic are immature for it to happen anytime soon. A new approach called Optical Burst Switching (OBS) was proposed as a balance between the immature optical devices and the flexible transmission requirement [2].

In OBS networks, bursts are usually transmitted before acknowledgement using one way reservation protocols such as Just-Enough-Time (JET) [2]. Bursts with variable sizes are switched asynchronously at the OBS node. In addition, since limited or no optical buffering is available, switching is done in a by-pass manner rather than store-and-forward as in an electronic packet switched core node. This will further aggravate the data loss at the OBS node and throughout the OBS network.

Deflection routing was first proposed as one contention resolution scheme for optical networks with regular topology in [3], [4]. The authors of [5], [6] discussed the implementation and performance of deflection routing in OBS network. In [6], a Markov model is established to derive a closed-form expression for the burst loss analysis at an OBS node.

In this paper, we proposed new Markov models for burst loss analysis of an OBS node with deflection routing. Unlike previous model which works only for OBS node with a single output port[6], the proposed analytic models can be applied to a system with any number of ports. In addition, we provided models for OBS node with and without wavelength conversion capability. Simulation results show that our approximate model gives good result when the system operates under a normal traffic load while the accurate models take more system information into consideration and yield precise result regardless of traffic load situation.

The paper is organized as follows, Section II sets the background for our analytic model for deflection routing study in OBS network. We extend the work in [7] for ad hoc wireless network to the performance study of deflection routing at OBS node in Section III. Approximate and accurate Markov models are also given in this section. We verify the accuracy of our models by simulation in Section IV. Section V concludes this paper.

II. DEFLECTION ROUTING

Deflection routing was first used as a contention resolution in mesh optical network with regular topology [3], [4]. When a data unit arrives at the intermediate node in the network but finds that all wavelengths at the preferred port are not available, it will be switched to an alternate port, i.e. the data unit is deflected. A deflection routing protocol for OBS network was then proposed in [5]. As shown in [5], applying deflection routing in an OBS mesh network can reduce the data loss and the average delay compared with data retransmission from the source. In addition, it is shown that the performance of deflection routing will degrade when the traffic load is beyond some threshold for unslotted system such as OBS Network [3], [4], [5]. Providing limited Fiber Delay line or Access Control of the local traffic were suggested in order to keep the network stable [3], [4].

We propose to solve this problem in another approach by intentionally limiting the deflection when the system is in heavy load situation. A parameter called deflection routing probability p, $(0 < p < 1)$ is introduced in this paper. When contention between bursts happens, a burst will be deflected to the alternate output port with a probability p instead of 100%. With this parameter, we enable deflection routing for all burst with $p = 1$ when traffic load is low and we disable deflection routing for all bursts when $p = 0$ when traffic load is heavy. The value of this parameter can be set before operation according to statistical records or adjusted during the system's operation regarding to the traffic load monitoring.

Unlike the analysis in [6], where OBS node with only single output port was considered, our models in the following sections are suitable for multi-port node. In addition, OBS nodes with and without wavelength conversion are both studied. We first give approximate models which give good result for a system with any number of ports when the traffic load is within a reasonable range. Accurate models with higher computing complexity are also provided with demonstrations on a system of two output ports.

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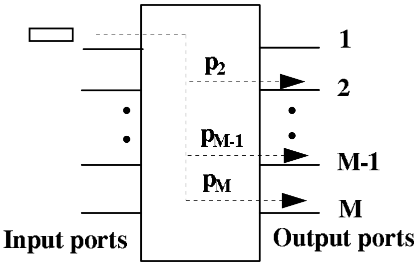


Fig. 1. An example of OBS node with deflection routing

In our analytic models proposed in the following section, we will use fixed p for simplicity. How to pick up a proper p for an OBS network and possible adjusting scheme are beyond the scope of this paper. Further more, we assume the OBS node is a symmetric system, i.e. if an OBS node has M output ports, and the primary output port for a burst is i, the probability (p_j) that the burst will be deflected to output port j is evenly distributed. Figure 1 shows an example with port 1 as primary port and $p_2 = \ldots = p_{M-1} = p_M$. And we have $\sum_{k=1}^{M}\{p_k | k \neq i\} = p$.

III. ANALYTIC MODELS

In this section, we study the burst loss at an OBS node with the deflection routing using (multi-dimensional) Markov chains. Since wavelength conversion can significantly reduce the burst loss probability, we will discuss the models for OBS node with wavelength conversion first. However, due to the currently immature technology and high cost for full wavelength conversion capability provisioning, we also provide analytic models for OBS node without wavelength conversion.

A. Approximate Models

To obtain the approximate burst loss rate at the output port of an OBS node, we assume that the traffic intensity and burst loss rate in other output port will not be affected by the deflected bursts, i.e. if we want to analyze the burst loss performance at port 1 in Figure 1, we assume the traffic intensity and burst loss in port 2 to M are not affected by bursts deflected from port 1. In addition, no burst will be deflected from other ports to the port that we analyze. This assumption will be nullified in the accurate model (to be discussed in Sec III.B), and our simulation results (see Sec IV.A) show that the accuracy of this model will not be affected much by this assumption when the burst loss rate is low, i.e. deflection routing rarely happens.

A.1 With wavelength Conversion

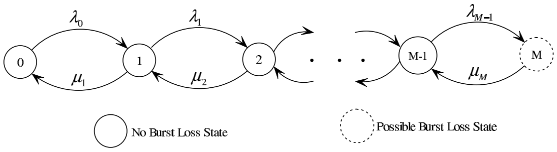


Fig. 2. State transition for approximate model with wavelength conversion

We discuss the model for OBS node with wavelength conversion first. Suppose the number of wavelength in a port is M, the state transition diagram is illustrated in Figure 2, where state i means that i wavelengths are occupied by some bursts, λ_i is the burst arrival rate and μ_i is leaving rate of the burst at state i. When a burst arrives at state $0 \leq i < M$, the state will change to $i+1$; on the other hand, when a burst finishes its service and leaves the OBS node, state i will change to $i-1$.

Denote the steady probability of state i as $Q(i)$. We list state equations as follows.

For $0 < i < M$:

$$(\lambda_i + \mu_i) \cdot Q(i) - \lambda_{i-1} \cdot Q(i-1) - \mu_{i+1} \cdot Q(i+1) = 0 \tag{1}$$

For $i = 0$:

$$\lambda_0 \cdot Q(0) - \mu_1 \cdot Q(1) = 0 \tag{2}$$

For $i = M$:

$$\mu_M \cdot Q(M) - \lambda_{M-1} \cdot Q(M-1) = 0 \tag{3}$$

And,

$$\sum_{i=0}^{M} Q(i) = 1 \tag{4}$$

The probability that an arriving burst finds all the wavelengths on the primary output port are reserved is $Q(M)$. With deflection routing, the burst will be dropped if and only if:

- The system's state is at M (with the probability as $Q(M)$).
- Deflection routing is not applied (with a probability of $1-p$) or the deflection routing is applied but none of other M-1 output ports has available wavelength.

More specifically, the probability that a burst will be dropped is $Q(M) \times [(1-p) + \sum p_j \times l_j]$, where l_j is the burst loss probability in neighboring output port j. If the burst loss rates in those alternate output ports are equal to l, the burst loss probability is $Q(M) \times [(1-p) + p \times l]$.

For simplicity, we assume Poisson traffic which is widely used for data loss analysis in OBS network [8], [9], [6]. In order to compute $Q(M)$, we solve the state transition equations with some classical assumptions: burst arrival is independent of the state i and the leaving rate is proportional to the state i, thus, we have $\lambda_i = \lambda$ and $\mu_i = i\mu$. Applying these to Equation 1 to 4, we will have:

$$Burst\,loss\,rate = \frac{\rho^M/M!}{\sum_{k=0}^{M} \rho^k/k!} \times [(1-p) + p \times l] \quad \rho = \frac{\lambda}{\mu} \tag{5}$$

Here the l can be computed by Erlang's loss formula:

$$l = \frac{\rho^M/M!}{\sum_{k=0}^{M} \rho^k/k!} \tag{6}$$

A.2 Without wavelength Conversion

For an OBS node without wavelength conversion capability, a burst arrives on wavelength i can only be deflected to wavelength i on an alternate port with a probability p. The independence between bursts arrive on different wavelengths helps to simplify the model.

We only need to observe the state of one wavelength assuming the traffic intensities on different wavelengths are equal. The

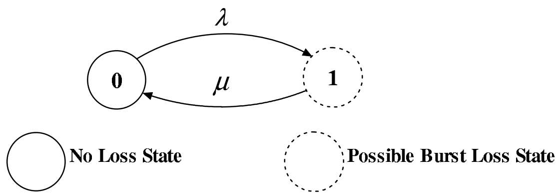


Fig. 3. State transition for approximate model without wavelength conversion

state of the wavelength can be 0, which means it is free for reservation, or 1, which means it is occupied by a burst. Following the assumptions and notations for the approximate model discussed in the previous sub-section, burst loss probability is $Q(1) \times [(1-p) + \sum p_j \times l_j]$, where l_j is the burst loss probability in neighboring output port j.

However, approximate model does not give good result when traffic load is heavy and loss probability is high since the assumption that deflected burst traffic does not affect the loss in alternate ports will not hold. This will also be shown in simulation results (see Section IV). Regarding to high loss probability at OBS node without wavelength conversion, we will not discuss this model further.

B. Accurate Models

In the approximate model, we have ignored the effect of the deflected traffic to other output ports. More important, we don't consider the bursts deflected from other ports to the particular output port. In order to obtain the accurate results when the portion of deflected traffic can not be ignored, the state of the system should not only include the number of reserved wavelengths in the primary output port but also in the alternate output ports. The general solution will be demonstrated by an OBS node with two output ports A and B.

B.1 With Wavelength Conversion

The state transition diagram for OBS node with wavelength conversion is shown in Figure 4, state (i, j) represents that there are i reserved wavelengths in output port A and j reserved wavelengths in output port B. $\lambda_{A(i,j)}$ and $\lambda_{B(i,j)}$ are the arrival rate of the bursts in port A and B respectively while $\mu_{A(i,j)}$ and $\mu_{B_{(i,j)}}$ are the burst leaving rates. As explained in the approximate model, we will assume: $\lambda_{A(i,j)} = \lambda_A$ and $\lambda_{B(i,j)} = \lambda_B$ while $\mu_{A(i,j)} = i\mu$ and $\mu_{B_{(i,j)}} = j\mu$.

When $0 \leq i, j < M$, the state transitions are similar to those in approximate model. The differences are at the boundary states. When $i = M$ and a burst arrives at output port A, it might be deflected to port B if $j < M$, i.e. not all the wavelengths are reserved in port B. Thus, there are deflection transitions such as from (M, j) to $(M, j+1)$. Similarly, there are state transitions reflecting the burst deflection from port B to port A.

Denote the steady state probability that the system in state (i, j) as $Q(i, j)$. By solving $(M+1) \times (M+1)$ equation set representing the state transitions and $\sum_{i=0}^{M} \sum_{j=0}^{M} Q(i, j) = 1$, we can get the steady state probabilities of the system $Q(i, j)$ $(0 \leq i, j \leq M)$ and compute the probability of burst loss as (a) the system's state is (M, M), or (b) the system's state is either (M, j) or (i, M) and deflection routing is not applied to the burst with a probability $(1-p)$.

Accordingly, the burst loss probability of port A and B are:

$$l_A = Q(M, M) + \sum_{j=0}^{M-1} Q(M, j) \cdot (1-p) \tag{7}$$

$$l_B = Q(M, M) + \sum_{i=0}^{M-1} Q(i, M) \cdot (1-p) \tag{8}$$

Note that, we can use different deflection probability in port A and port B as p_A and p_B respectively instead of a equal probability p. The state transition diagram and Equation 7 and 8 will take corresponding modifications.

For an OBS node with n output port, the general solution becomes a $n-$dimensional Markov Chain. When n is large, the computation complexity will be quite high. However, if the traffic intensity is in reasonable range, the approximate model which has much less computation complexity will give satisfiable results.

B.2 Without Wavelength Conversion

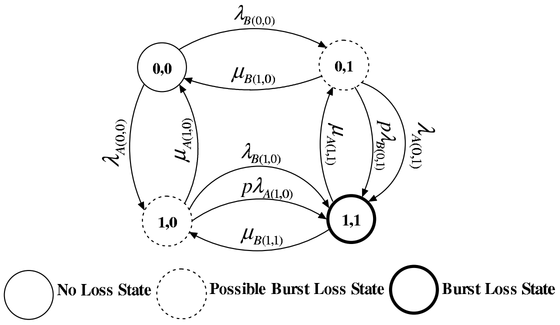


Fig. 5. State transition for accurate model without wavelength conversion

We present the state transition diagram of same wavelength i at port A and B in Figure 5. State (i, j) is the wavelength i's availability on each port. 1 means the wavelength is occupied by burst while 0 means the wavelength is free.

Similar to the discussion in previous sub-section, the burst loss probability of port A and B are:

$$l_A = Q(1, 1) + Q(1, 0) \cdot (1-p) \tag{9}$$

$$l_B = Q(1, 1) + Q(0, 1) \cdot (1-p) \tag{10}$$

The steady state probability $Q(i, j)$ can be obtained by solving a linear equation set.

IV. SIMULATION RESULTS

In this section, we will compare the burst loss probabilities predicted by our analytic models and the results got from simulations.

Poisson traffic is used in the simulation. The burst length follows exponential distribution with an average size as 100KByte. Each output port has 32 or 64 wavelength, each wavelength has a transmission capacity as 800Kbps. We assume the OBS node has full wavelength conversion capability in Sec IV.A and IV.B. Performance of accurate model for OBS node without wavelength conversion is discussed in Sec IV.C. First-Fit scheduling algorithm [10] is used for burst reservation.

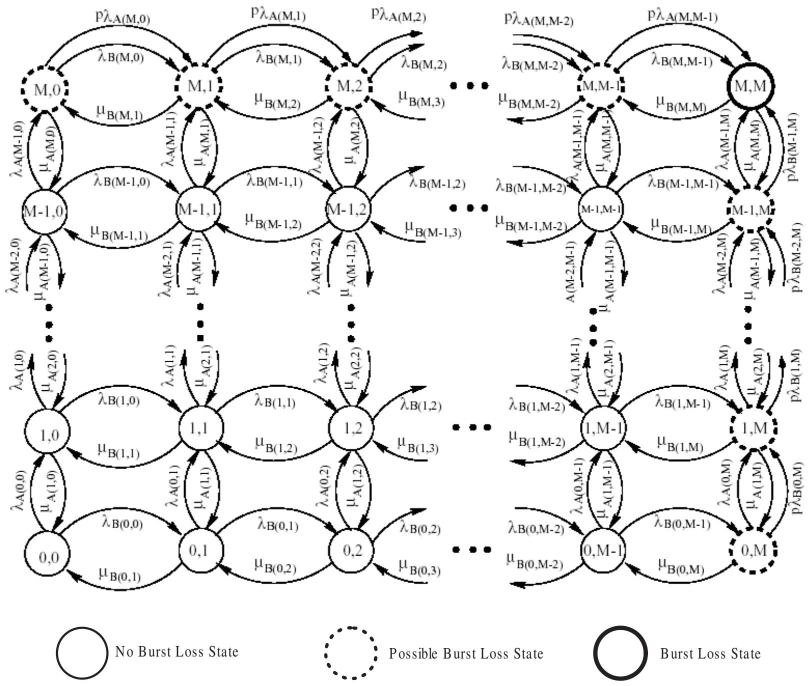


Fig. 4. State transition for accurate model with wavelength conversion

A. Scenario 1

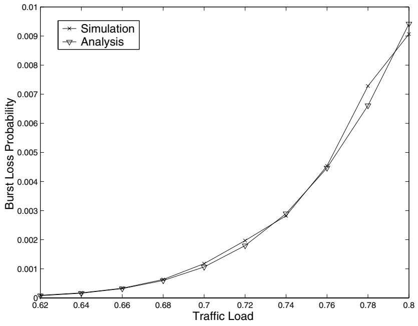
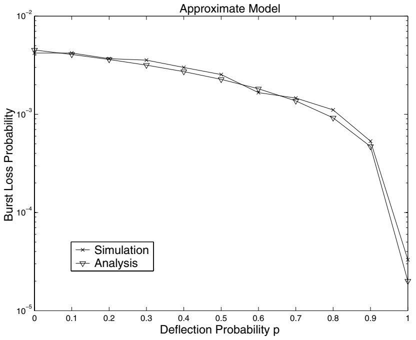


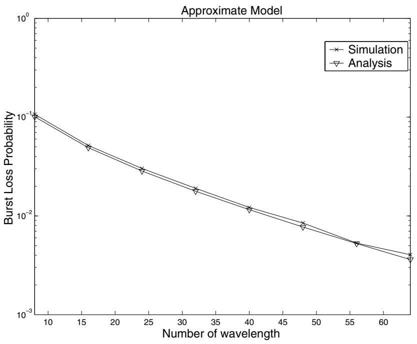
Fig. 6. Verification of approximate Model

In this section, we show the results of the approximate model for an OBS node having 4 output ports. We assume that there are 64 wavelengths on each output port. The deflection routing probability p is equal to 0.2 by default. Figure 6 shows that simulation result matches the burst loss probability predicted by the approximate model as the load changes from 0.62 to 0.8.

We then keep the traffic load as 0.75 (burst loss probability around 0.5%) and compare the burst loss predicted by our approximate model with the simulation results with respect to varying deflection routing probability and wavelength number. We apply different p's (Figure 7(a)) while fix all the other parameters. We also test the model with various wavelength number (Figure 7(b)). Although our approximate model assumes no burst will be deflected into the primary port, it still gives good prediction when the burst loss in other port is low, in other words, the portion of data deflected from alternate output ports to the primary output port is negligible. Normally, a practical system should have a loss probability lower than 1%. Thus, our



(a) Deflection probability



(b) Number of wavelength

Fig. 7. Verification of Approximate Model with different parameters

approximate model will provide satisfiable result regarding to its small computation complexity.

B. Scenario 2

The most important difference between our approximate model and accurate model lies at whether we take the correlations of burst loss and traffic intensity among different output ports into consideration. When the burst loss probability is not negligible, the accurate model will give more precise result. We show this by comparing the results from both models and simulation result for a two output ports OBS node with 32 wavelength in each port under heavy load, from 0.85 to 1.0. The burst loss probability shown by simulation result is as high as around 10%. Although the approximate model tends to predict a lower burst loss probability, the result from accurate model fits the simulation curve quite well.

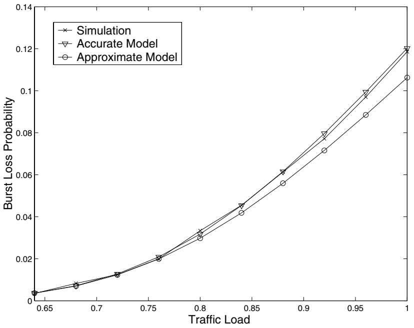


Fig. 8. Comparison of Accurate model and Approximate model

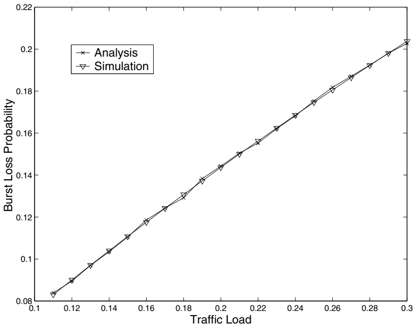
C. Scenario 3

The burst loss probability of an OBS node without FDL and wavelength conversion capability would be very high. Thus, the assumption for approximate model will not hold any more. We only compare the analytical result from our accurate model and the simulation result in this section.

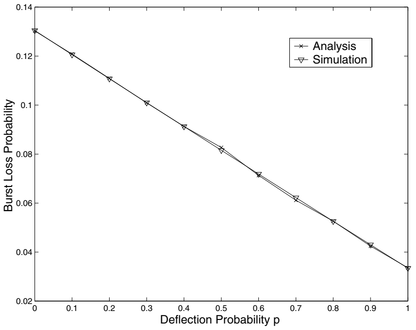
We first test the accuracy of the model with various traffic load at an OBS node with 32 wavelengths. The result (Figure 9(a)) shows a good matching between the analysis and simulation result. By keeping traffic load as 0.15, we show the performance of our model in Figure 9(b) with various deflection probability p.

V. CONCLUSION

In this paper, we have studied one effective contention resolution scheme in Optical Burst Switched network: deflection routing. Based on a set of reasonable and practical assumptions, we propose Markov chain models to analyze the burst loss performance of an OBS node with deflection routing. Both OBS nodes with and without wavelength conversion are studied. Unlike previous model which works only for OBS node with a single output port, the proposed analytic model can be applied to a system with any number of ports. The approximate model gives satisfiable result when the system operates under a normal traffic load. On the other hand, the accurate model takes more system information into consideration and yields precise result even when the traffic load is heavy.



(a) Traffic Load



(b) Deflection probability p

Fig. 9. Verification of Accurate Model for OBS node without wavelength conversion

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