Parallel Reservation Protocols for Achieving Fairness in Optical Burst Switching

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Abstract— Optical burst switching (OBS) is one promising method for data transfer in photonic networks based on a WDM (Wavelength Division Multiplexing) technology. In the OBS scheme, the wavelength is exclusively reserved along the source and destination nodes, when the burst data is generated at the source. Then, efficient data transfer is expected. However, its performance is heavily dependent on the number of links that lightpath goes through. In this paper, we propose a new protocol for OBS networks, where the lightpath for the burst transmission is set up by parallel wavelength reservations. Through simulation results, we show that our protocol makes data transfer efficiently and improves the fairness among the connections with different number of hop counts.

I. INTRODUCTION

An exponential growth of the Internet traffic has led to demand for introducing photonic network, where the data are carried in all-optical domain. For a most promising solution to realize the network for effectively utilizing WDM, we consider the Optical Burst Switching (OBS) in which the wavelengths are reserved on demand basis. That is, when the burst transfer request arises at the source node, the available wavelength is sought and assigned dynamically between source and destination nodes, and the burst is transferred using the assigned wavelength. Here, the burst corresponds to the upper–layer protocol data unit such as the file or block in the case of file transfer. The wavelength is immediately released when the burst transfer is successfully finished. In such a method, the influence of the wavelength assignment time, which includes the propagation delay between the source and destination, becomes a key issue to achieve high performance such that the large bandwidth provided by the WDM technology can be enjoyed. However, several papers so far have ignored such an influence as in [1], [2] except [3], [4], [5].

In [3], [4], the authors proposed several methods for wavelength reservation. Those include forward reservation and backward reservation methods, where wavelength reservation is performed along the forward direction and backward direction, respectively. Following [3], an approximate analysis method has been developed in [5], [6], where the authors treat the above two reservation methods. The results in the above papers have shown that the backward reservation can improve the performance significantly when compared with forward reservation. However, it is also shown that the performance is dependent on the number of hops to a large extent. This is mainly because the wavelength reservation must be made at every link between source and destination nodes. Further, in WDM networks, the same wavelength should be reserved along its route (*wavelength continuity constraint*). Wavelength conversion is one of the solution to avoid the influence of the continuity constraint, but the conversion technology is still immature.

In this paper, we newly propose a parallel wavelength reservation method to resolve the unfairness among connections with different numbers of hop counts. Our basic idea is to limit the number of wavelengths for which the possibility of its use is checked, and the number of wavelengths that is checked for reservation is adjusted according to the number of hop counts of connections. That is, for the connection with a large number of hop counts, more wavelengths are inspected for wavelength reservation. For this purpose, we will first develop the approximate analysis. Then it is validated by comparing with simulation.

The rest of the paper is organized as follows. In Section II, we present a description on the protocols we will investigate. We then present our proposal in Section III. In Section IV, we demonstrate the performance of our proposed method by giving several numerical results. In Section V, we conclude our paper.

II. WAVELENGTH RESERVATION PROTOCOLS

We can classify the wavelength reservation scheme into the forward and backward reservation. In the forward reservation method, the list of available wavelengths is passed from the source to destination node. When the intermediate node receives the list, the available wavelengths contained in the list are all reserved. When the destination node receives the list, it selects one wavelength from the list and notifies it of the source node. The intermediate node receiving the acknowledgement releases the wavelength(s) except the chosen wavelength. The source node can then transfer the burst on the chosen wavelength.

In the backward reservation method, on the other hand, only the information on usage status of the wavelengths is collected along the forward path, and wavelength reservation is not made at this time. Each intermediate node actually makes wavelength reservation after the destination selects the wavelength in the list and returns it along the backward path. On the backward path, the chosen wavelength may be reserved by another connection. However, the reservation time for all available connections cannot be ignored and it seriously degrades performance of the forward reservation method. Actually, the backward reservation has already been shown to outperform forward reservation in the literature [3], [5], [6]. We therefore consider only the backward reservation in this paper.

The backward reservation is operated as follows. Note that our extension to parallel reservation is introduced in the next section.

1. When a wavelength reservation request arrives at the source, the available wavelengths (not reserved by other bursts) on the first link are sought.
    - If one or more wavelengths are available, then put those wavelengths into the list as $\tau_0 = \{\lambda_i, \ldots, \lambda_j\}$. Then, the PROBE signal with the list τ_0 is sent to the next node.
    - If there are no available wavelengths on the link (i.e., $\tau_0 = \phi$), the failure of the burst transfer request is notified to the source terminal.
2. As the k-th intermediate node from the source node receives the PROBE signal with the list τ_{k-1}, the unavailable wavelengths on the output link are deleted from the list to form the updated list τ_k.
    - If the new list τ_k becomes empty ($\tau_k = \phi$), then the NACK signal is sent back to the source node.
    - Otherwise, τ_k is written to the PROBE signal to be sent to the next node. Note that wavelengths in the list are not reserved at this time.
3. When the PROBE signal is finally received at the destination node, say, n-th node from the source node, the list τ_{n-1} in the PROBE signal is checked to update the available wavelength list τ_n.
    - If τ_n is not empty, then one wavelength is chosen (say, λ_u), and it written to the RES signal to be sent back towards the source node.
    - Otherwise, the NACK signal is sent back to the source node.
4. When the intermediate node receives the RES signal from the downstream node the wavelength, λ_u, written in the RES signal is examined. If it is still available, then the wavelength, λ_u, is actually reserved, and the RES signal is forwarded to the next upstream node. Otherwise, the NACK signal is sent to the source node. Also, the REL signal is sent to the downstream nodes to release the reserved wavelength λ_u.
5. If the RES signal is finally received at the source node, the connection setup is successfully completed, and the burst is sent by the source using the wavelength λ_u. When finishing the burst transfer, the reserved wavelength is released.
6. If the NACK signal is received from the intermediate or destination node, the connection setup fails.

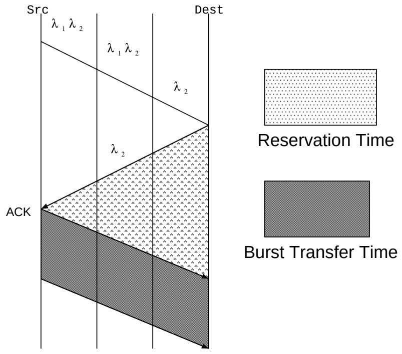

Figure 1: The case of acceptance in backward reservation.

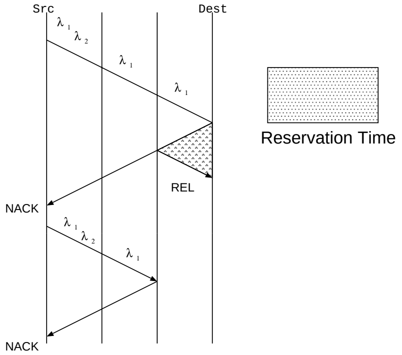

Figure 2: The case of blocking in backward reservation.

III. PARALLEL RESERVATION PROTOCOL

In this section, we newly propose a parallel wavelength reservation method by taking account of the fairness among connections with different numbers of hop counts. The basic idea of our protocol is to limit the wavelengths put into the list when the wavelength inspection is performed along the forward direction. See Figure 3 for an illustrative example. In the figure, the number of wavelengths on the WDM link is . In our protocol, we divide the number W of wavelengths into S groups. When the burst transfer request arrives at the source node, one group is selected. Then, the request tries to reserve the wavelengths within the selected group. That is, we limit the number of wavelength for inspection / reservation from W to M, where $M = W/S$ is the number of wavelengths in a group.

Formally, our protocol works as follows. Since the protocol behavior is similar to the backward reservation method described in the previous section, we only describe the difference below. That is, Step 2 of Section 2.2 is replaced as follows.

1. Let jth wavelength group be W_j $(1 \leq j \leq S)$. That is, the wavelengths $\lambda_{j\times(M-1)+1}$ to $\lambda_{j\times M}$ belong to the group W_j. When the burst transfer request arrives at the source node, one wavelength group is selected. Then, the usage of those wavelengths within the chosen group on the link connected to the source node is checked, and the resulting information is set in the list of τ_0.
    - If the one or more wavelengths are available in the list (i.e., $\tau_0 \neq \phi$), the list is put into the PROBE signal.
    - Otherwise, the failure of the burst transfer request is notified to the source.

In the original protocol, an initial number of wavelengths put in the list is W. In our protocol, on the other hand, the number of wavelengths is limited, which may decrease the possibility that the wavelength can be reserved. Actually, however, two or more reservation requests arriving at the node simultaneously is likely to be accepted by our protocol. We investigated the efficiency of our protocol via computer simulation. The results showed that by utilizing our parallel reservation protocol with an appropriate grouping, we can improve the performance in terms of burst blocking probability.

Furthermore, by appropriately setting the initial number of candidate wavelengths in the list, the fairness among connections can also be improved. As described before, the blocking probability of the longer hop counts tends to be increased in the optical burst switching. To improve the fairness among connections with different number of hop counts, the initial number of wavelengths with a smaller number of hop counts should be limited. In this way, the connection with longer hop count is likely to succeed in reservation. It can be achieved by changing the initial number of wavelengths in the list dependent on the number of hop counts. See Figure 4, where connections with one-hop and two-hop links initially use the numbers M_1 and M_2 of wavelengths, respectively.

An apparent difficulty in the above–mentioned method exists in determining the appropriate numbers of wavelengths dependent on the number of hop counts. Therefore, we first develop an approximate analysis method to derive the blocking probability of the reservation requests. The analysis described in [5], [6] derives the blocking probability based on a reduced–load–approximation [7], [8] under the assumption that burst arrivals at the connection follow the Poisson distribution, but the burst length is allowed to be generally distributed. The backward reservation method considered in [5] inspects entire wavelength at each link, while our parallel reservation protocol limits the number of inspected wavelength (denote M). To obtain the blocking probability with limited inspected wavelength, we simply change the variable W, which represents the number of wavelength at each link in [5], to M.

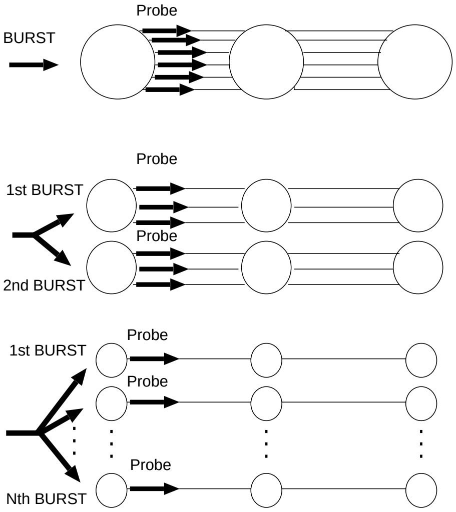

Figure 3: Parallel Reservation Protocol

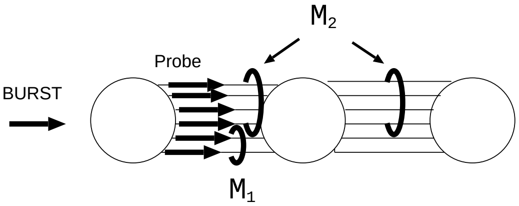

Figure 4: P (M_1, M_2) Parallel Reservation Protocol

TABLE IParameters

Capacity of wavelength	C	20 (Gbps)
Available wavelength per link	W	32
Link propagation delay	D	0.1 (msec)

IV. PERFORMANCE EVALUATION

In this section, we evaluate our parallel wavelength reservation method to investigate its fairness property. A three-node tandem network as shown in figure 5 is used for the network model. We consider three connections (R_0, R_1, R_2) as shown in Figure 5. We introduce $P(M_1, M_2)$, which represents the strategy in our protocol. That is, M_i shows the number of the candidate wavelengths that the i–hop connection tries to reserve. The protocol processing delay at nodes

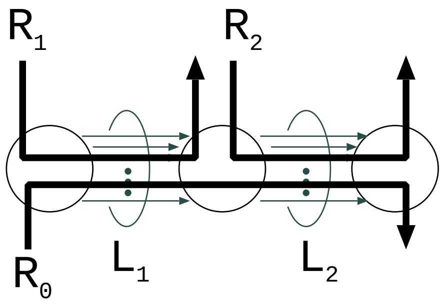

Figure 5: Network model

is assumed to be negligible. We assume that the mean arrival rate of burst transfer requests at all three connections are identically set to $e = e_a$ $[burst/msec]$. By letting the mean burst length to be $1/\mu = 1$ $[msec]$, the traffic load ρ [Gbps] is defined by the following equation.

$$\rho = e \times C \tag{1}$$

where C denotes the wavelength capacity. The other parameters are summarized in Table I.

In Figure 6, we first compare analytical and simulation results of mean blocking probability averaged over all three connections dependent on the traffic load ρ. For the wavelength hunting strategy, two cases of $P(2,2)$ and $P(32,32)$ are considered. Of course, the blocking probabilities of three connections are different. The blocking probability of the two-hop connection is much larger than that of one-hop connection. In what follows, we will fix the traffic load at 64 Gbps and M_2 at 32 in order to investigate the fairness property of our proposed protocol. That is, we will use $P(M_1, 32)$, and investigate the effect of changing the value of M_1.

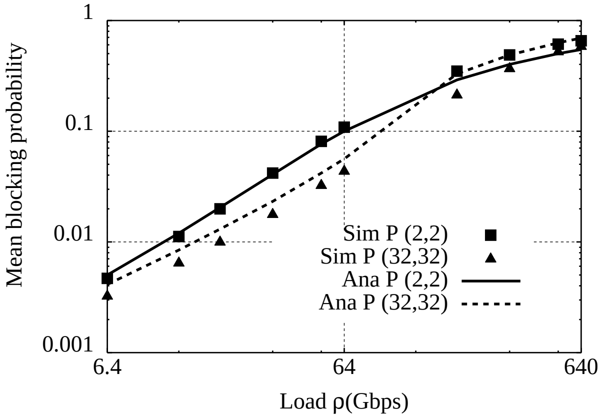

Figure 6: Mean blocking probability of each $P(M_1, M_2)$

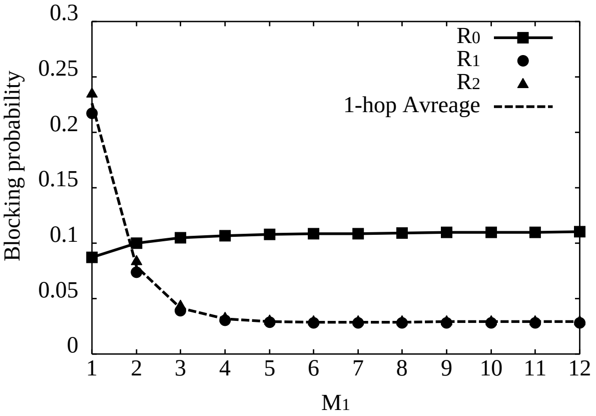

Figure 7: Analysis Results: $M_2 = 32$, $\rho = 64$ Gbps

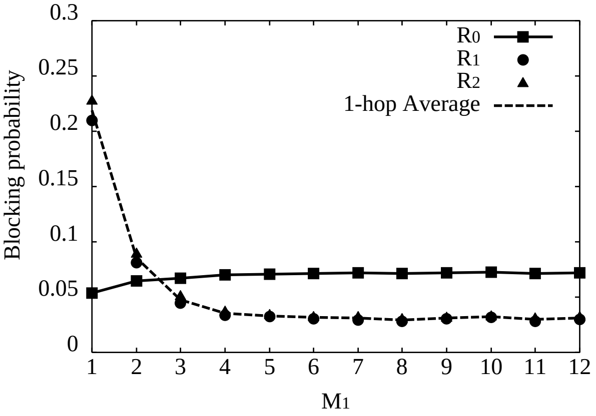

Figure 8: Simulation Results: $M_2 = 32$, $\rho = 64$ Gbps

Figures 7 shows the analytic results of blocking probability of each connection dependent on M_1. The simulation results are also shown in Figure 8. While two one-hop connections (R_1 and R_2) show different results, we ignore it for simplicity, and we only consider the average values of those two connections, which are also shown in the figure (labeled as "1-hop Average"). The cross point of two lines ("1–hop Average" and 2–hop connection "R_1") is the one that we want to find out; M_1 should be three in the current case. That is, $P(3, 32)$ is most appropriate for our purpose. In this case, the overall mean blocking probability become 0.0785 which is slightly increased at the expense of achieving the fairness. We last note that in the current paper, we only provide a very simple network model, but our analytic approach can allow a more general topology to determine the appropriate set of inspected wavelengths.

V. CONCLUDING REMARKS

In this paper, we have newly proposed a parallel wavelength reservation protocol in the optical burst switching in order to achieve the fairness among connections with different numbers of hop counts. We have developed an approximate analysis method to determine the appropriate number of inspected wavelengths for each connection. However, the more complex network model should be examined to validate our protocol.

One problem of our approach is to require that the traffic load of connections should be known a priori. A more dynamic way of determining the number of wavelengths is necessary such that the number of inspected wavelengths are adjusted based on the blocking/acceptance of wavelength reservation requests, but it is our future research topic.

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