An Evaluation of Wavelength Reservation Protocol with Delayed Link State Information

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extended abstract

***Abstract*— Previous studies on routing and wavelength assignment algorithms assumed that the global link state information is obtained without delays. However, in distributed lightpath establishment, the probability of request blocking strongly depends on both the accuracy of the global link state information and the distributed protocol for wavelength reservation. In this paper, we evaluate how the frequency of link state information exchange affects the blocking probability in lightpath establishment. The evaluation is performed based on forward and backward reservation protocols. Simulation results show that while the forward reservation protocol is greatly affected by the frequency of link state information exchange and the amount of this information, the backward reservation protocol does not need as detailed information about the link state and as frequent link state exchange for routing as does the forward protocol.**

I. Introduction

Wavelength division multiplexing (WDM) is used to multiplex wavelength channels on a single fiber, and it enables high–capacity parallel transmission. One way to use the WDM technology is to establish wavelength channels (called *lightpath*) on demand basis. That is, when a data transfer request arrives at the sender node, one wavelength is reserved along the route between the sender and receiver nodes [1], [2]. After the data have been transferred using the lightpath, the wavelength is released immediately. However, because several lightpaths cannot share a wavelength on a fiber, a method is needed to control the process of lightpath establishment in lightpath networks.

There are two approaches to establishing lightpaths: a centralized approach, in which a special node sets up and tears down lightpaths, and a distributed approach, in which each node can set up and tear down lightpaths. In the distributed approach, because nodes do not know whether the other nodes are trying to reserve wavelengths, a conflict may occur. To minimizing the probability of such conflicts in distributed lightpath establishment, it is important to properly select the route and wavelength for a lightpath at the sender node. A number of routing algorithms have been proposed for distributed lightpath establishment [1]–[4].

However for the routing to be efficient, each node must have precise information about the use of wavelength resources in the network. In a distributed network, each node knows only the state of the adjacent link, so the nodes must exchange link state information to enable effective routing. However if the nodes periodically exchange the information the blocking probability increases because of the discrepancy between the actual usage of wavelength resources and the link state information exchanged [1]. Even when the nodes exchange link state information every time the link state changes, propagation delays prevent this information from arriving at all the nodes at the same time, which affects the route and wavelength selection at the sender node. In many studies on wavelength reservation, a sender-node-oriented reservation protocol (forward reservation protocol) is assumed [1], and the sender node can use currently available wavelengths in the network [2]–[4].

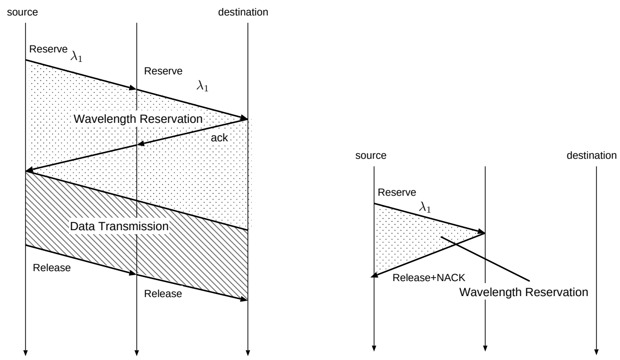
In [5], a destination–node–oriented reservation protocol (backward reservation protocol) is described. The backward reservation protocol collects information about available wavelength resources during wavelength reservation, and the sender node only selects the route. Therefore, there is no need for frequent link state information exchange and detailed link state information, for example, about the use of wavelength resources. In this paper, we investigate how the frequency of link state information exchange affects the probability of request blocking in lightpath establishment with both forward and backward reservation protocols.

This paper is organized as follows. In Section II, we first explain the existing routing and wavelength selection methods, and wavelength reservation protocols. In Section III, we investigate how the frequency of link state information exchange affects the blocking probability by using computer simulation. Our conclusion is presented in Section IV.

II. Routing and Wavelength Reservation Protocol

A. Forward reservation protocol

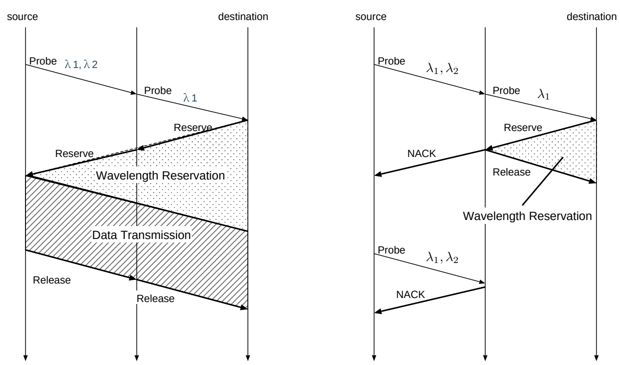
When a request for lightpath establishment arrives at the sender node, the sender node selects a route and a wavelength for the lightpath. Next, the sender node transmits a RESERVE signal and reserves the wavelength along the selected route. When an intermediate node receives the signal, it obtains the wavelength from the signal, and reserves the wavelength on the next link. When the RESERVE signal arrives at the receiver node, a lightpath is established and the receiver node transmits an ACK signal to the sender node (Fig. 1(a)). The sender node transfers the data upon receiving the ACK signal, and it transmits a RELEASE signal to the receiver node at the end of the data. The RELEASE signal releases the wavelength used for the lightpath. Figure 1(b) shows a case of when the



(a) A successful case of a lightpath establishment

(b) A failure case of a lightpath establishment

Fig. 1. Forward reservation protocol



(a) A successful case of lightpath establishment

(b) A failure case of lightpath establishment

Fig. 2. Backward reservation protocol

lightpath establishment fails. The RESERVE signal arrives at the intermediate node, but the wavelength is already reserved or is used by another lightpath. In this case, the lightpath establishment request is rejected, and the intermediate node transmits a NACK signal to the sender node.

B. Backward reservation protocol

When a lightpath request arrives at the sender node, the sender node selects only the route for the lightpath. Next, the sender node generates a PROBE signal containing a set of available wavelengths on the next link, and transmits it to the receiver node. When an intermediate node receives the PROBE signal, it intersects the sets of available wavelengths on the next link and contained in the PROBE signal, and write in the PROBE signal. After updating the PROBE signal, the node transmits the signal to the next node. The set of wavelengths in the PROBE signal contains available wavelengths on the route when the PROBE signal arrives at the receiver node. The receiver node selects a wavelength from the available wavelengths in the PROBE signal, and transmits a RESERVE signal to reserve the wavelength on the path. Upon receiving the RESERVE signal at the sender node, the sender node acknowledges that the lightpath establishment has been successfully completed, and starts transferring the data. After the data have been transferred, the reserved wavelength is released via a RELEASE signal. Figure 2(a) shows a case of successful wavelength reservation. There are two cases when a request for wavelength reservation can be rejected with the backward reservation protocol (Fig. 2(b)); one is when during the available wavelengths are being probed (a PROBE sequence), and the other is when the wavelength has already been reserved (a RESERVE sequence). Rejection upon the receipt of a PROBE sequence occurs when the set intersected by the intermediate node is empty. In this case, there are no available wavelengths on the route, and the intermediate node sends a NACK signal to the sender node. Rejection upon the receipt of a RESERVE sequence occurs when wavelength reservation conflicts with the establishment of another lightpath. When the wavelength reservation fails, a NACK signal is transmitted to the sender node, and a RELEASE signal is transmitted from the intermediate node to the receiver node to release the reserved wavelength.

C. Routing in distributed networks

The purpose of routing in a network is to ensure connectivity among all nodes and to reroute highly loaded or failed links. The load on WDM networks is defined as the number of wavelengths used on each link, so the link state information containing the number of available wavelengths on the link is sufficient for rerouting highly loaded link. However, because the forward reservation protocol needs to select a route as well as a wavelength at the sender node, the link state information should include information about the use of each wavelength on each link. We can use the number of available wavelengths as a link state information; however, the sender node may select the wrong wavelength because of this less–detailed link state information, and the blocking probability will increase. In contrast, the backward reservation protocol selects only the route at the sender node. In this case, information about the number of available wavelengths on each link is enough for the route selection.

Another important issue in routing in distributed networks is the interval between link state information exchanges. Upon the arrival of link state information, each node updates its information about the wavelength use in the network. Each node calculates the route (and wavelength in forward reservation) for each lightpath request. To reduce this processing overheads, a method is needed to enable less frequent link state exchange using less detailed link state information.

III. Performance evaluation

A. Simulation Model

Figure 3 shows the network topology used in our performance evaluation. The network consists of 15 nodes and 28 duplex links. The propagation delay of each link was set by multiplying the length of each of link in Fig. 3 by

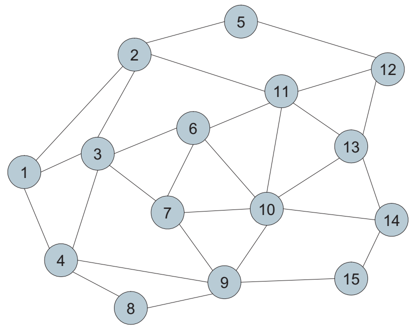


Fig. 3. Network Model

scale factor α. All network nodes can acquire the information about the wavelength use on the neighboring fibers. Each node distributes the acquired information as link state information to other nodes (i.e., link–state routing is assumed [2], [6]). In this paper, we assume that there is no processing delay in the routing, wavelength selection, and wavelength reservation processes at each node, so the delay in the arrival of control signals and link state information comes only from the link propagation delay.

We perform the simulations on computer with the following parameters.

- Requests arriving at each node follow the Poisson arrival with mean P.
- The service time of a lightpath has an exponential distribution with mean $1/\mu$.
- The number of multiplexed channels on each optical fiber is $W + 1$. One channel is used as a control channel on which the nodes exchanges control signals and link state information. Other W channels are used for lightpath establishment.
- The link state information is updated at T intervals.

B. Route and wavelength selection algorithms

Route and wavelength selection algorithms for the forward and backward reservation protocols are described as follows. In both forward and backward reservation protocols, the least loaded route is selected from k–shortest paths. The least loaded route is defined as the route such that the maximum number of wavelengths used in each link on the route is minimal among the k-shortest paths.

In the forward reservation protocol, the sender node selects the route with at least one available wavelength. If there are two or more available wavelengths, one is randomly selected. Note that information about the wavelength use in each link is distributed as link state information. In the backward reservation protocol, the sender node selects the least loaded route from the k–shortest paths. Then, the receiver node selects a wavelength randomly from the set of available wavelengths in the PROBE signal as described in Sec. II-B. Note that information about the number of wavelengths used in each link is distributed as link state information in this protocol (See Sec. II-C).

C. Numerical Results

In Fig. 4–6, we show the blocking probability of a lightpath request for different link state update intervals with both the forward and backward reservation protocols. The x–axis is the arrival rate of a lightpath request, and the y–axis is the blocking probability of a lightpath request. "Global" means that the sender nodes obtain global link state information assuming that each node exchange link state information with no propagation delay, which is an ideal case. Here, "T=0" means that the link state information is exchanged immediately after there has been a change in the link state, "T=15sec" means that the link state information is exchanged every 15 seconds.

Figure 4 shows the blocking probability at arrival rate P. The number of multiplexed channels (W) was set 8 and the average service time ($1/\mu$) was set 1.0ms. The average link propagation delay was 0.1ms (α = 0.0557 ms). In the figure, the result of blocking probability for the "global" is almost the same as for "T=0" with both the forward backward reservation protocols. This is because the average link propagation delay is short, and the link state information is transmitted with smaller delays. If we compare the results for "T=15sec" and those for "T=0", the blocking probability increases with for both the forward and backward reservation protocols. The results for the backward reservation protocol show a smaller increase than for the forward reservation protocol. The reason is that when the link state information is exchanged periodically in the forward reservation protocol, the probability that the route and wavelength selected by the sender node have already been reserved increases because the wavelength is selected based on the old link state information. In the backward reservation protocol, the difference of blocking probability between with the link state information and with the actual link state is small because the PROBE signal dynamically collects information about the wavelengths on the route. Therefore the blocking probability decreases slightly with the backward reservation protocol. Note that when the arrival rate is low (lower than 0.004), there is no significant difference between the results for "T=0" and for "T=15sec" due to the less frequent link state information exchange.

Figure 5 shows the blocking probability when the average service time is 100ms. In this figure, we can see that a longer service time significantly increases the blocking probability based on the difference between "T=0" and "T=15sec" in both the forward and backward reservation protocols. In this situation, lightpaths are held longer than in other situations, but the link state information intervals are longer than the mean service time. Because the received link state information often fails to reflect the actual link state, the selected wavelength is likely to have already been reserved for other lightpaths in the forward reservation protocol. In the backward reservation protocol, a long service time affects PROBE sequence because the available wavelengths do not often change. The discrepancy between the available wavelengths in the PROBE signal and the actual available wavelengths infrequently occurs and the rejection on RESERVE sequence decreases. Therefore, the

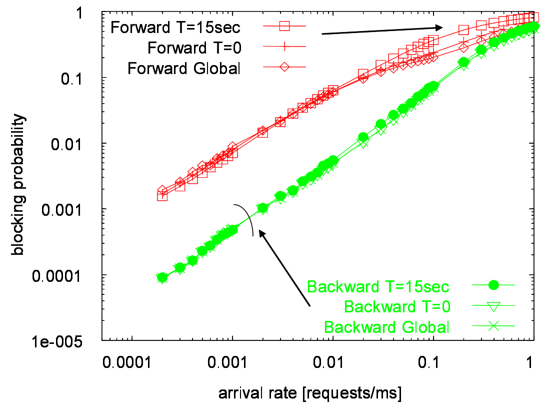


Fig. 4. blocking probability and link state update interval : $W = 8$, $1/\mu = 1.0$ms, the average of link propagation delay 0.1ms ($\alpha = 0.0557$ms)

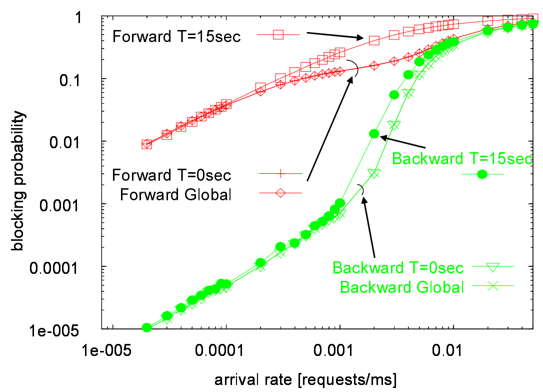


Fig. 5. blocking probability and link state update interval : $W = 8$, $1/\mu = 100$ms, the average of link propagation delay 0.1 ms ($\alpha = 0.0557$ms)

rejection on PROBE sequence is dominant for the blocking in this situation. Rejection upon the receipt of a PROBE signal occurs when there is a discrepancy between the selected route and actual available wavelengths in routing at the sender node, therefore periodic link state exchange affects the blocking probability. Thus, both the forward and backward reservation protocols need precise link state information when the service time is long; however, the blocking probability in the backward reservation protocol is small because the available wavelength collection based on PROBE sequence works well.

We now explain how the link state information interval affects the wavelength selection by using a 3–node tandem network as a simulation topology. The route for the lightpath is fixed, so this result shows only the affect of the discrepancy between the actual usage of wavelength resources and the link state information exchanged on the wavelength selection. Figure 6 shows the blocking probability depending on the arrival rate. Because the backward reservation protocol does not use link state information at the sender node for wavelength selection, interval T was set to 0 in this simulation. From this figure, we can see that as the link state information update interval increases, so does the blocking probability. With regard to wavelength selection, a smaller link state update interval is needed in the forward reservation protocol.

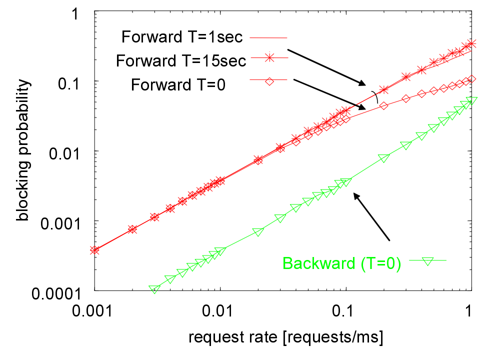


Fig. 6. blocking probability in 3 node tandem network : $W = 8$, $1/\mu = 1.0$ms, the average of link propagation delay 0.1 ms

In contrast, in the backward reservation protocol, wavelength selection depends on the link state information, and a smaller interval is not necessary.

IV. Conclusion

We investigated the effect of the frequency of link state information exchange on the blocking probability in both forward and backward reservation protocols. The simulation results show that when the backward reservation protocol is used, the routing can be done with less frequent link state information exchange using less detailed information than the forward reservation protocol is used. The forward reservation protocol is greatly affected by the frequency of link state information exchange and propagation delays.

In the future, we will evaluate the processing time at each node and to investigate other routing strategies, such as alternate routing for the backward reservation protocol to avoid highly loaded links.

Acknowledgments

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