Implementation and evaluation of fast lightpath setup method in wavelength-routed WDM networks

Masatoshi Ohashi*, Shin'ichi Arakawa, Masayuki Murata
Graduate School of Information Science and Technology, Osaka University, 1-5 Yamadaoka, Suita, Osaka, Japan 565-0871

ABSTRACT

One approach to effectively utilize WDM networks is to transfer the data on-demand basis through a fast wavelength reservation. Then, the data is transferred using the assigned wavelength channel. If the wavelength reservation fails, the data transfer delay, which is defined as the time from when the data transfer request arises at the source node to when the data is successfully received by the destination node, is much affected since retrial of the wavelength reservation is delayed by propagation delay. We have proposed a fast lightpath setup method that tries to establish a lightpath twice during a round-trip propagation time, and have evaluated the method by computer simulations where there is neither packet processing delay nor OXC configuration delay. In this paper, we present overview of our implementation and experimental results showing that our setup method takes smaller lightpath setup delay than the backward reservation protocol.

Keywords: Wavelength Division Multiplexing, Photonic Network, Lightpath, Wavelength Reservation, Backward, Setup Delay

1. INTRODUCTION

One approach to effectively utilize WDM networks is to transfer the data on-demand basis through a fast wavelength reservation [1]. That is, when a data request arises at a source node, a wavelength is dynamically reserved between the source and destination nodes, and a lightpath is configured. Then, the data is transferred using the assigned wavelength channel. After the data transmission using the lightpath, the lightpath is immediately torn down (i.e., the wavelength is released). If the wavelength reservation fails, the source node must keep trying to setup a lightpath until the lightpath is successfully configured in order to transfer the data. Then, lightpath setup delay, which is defined as the time from when the lightpath request arrives at the source node to when a lightpath is successfully configured between source and destination nodes, is increased by reservation retrials due to the link propagation delay along the path. These dynamic lightpath setup or tear down will be adapted for the bursty nature of the Internet traffic and utilize the bandwidth efficiently. GMPLS (Generalized Multi-protocols Label Switching) is an extension of MPLS for applying to circuit switched networks such as WDM-based optical networks. Currently, GMPLS has achieved a common control plane for optical and electronic data transmission in the Internet Engineering Task Force (IETF). A label is assigned to a wavelength on GMPLS and it is possible to establish lightpath between source and destination nodes using label switching.

Two methods have previously been presented to set up lightpaths in a distributed manner; forward reservation and backward reservation methods. In both methods, the lightpaths are established by exchanging control packets between the source and destination nodes. The actual reservation of the link resources is performed while the control packet is traveling from either the source node to the destination node (forward direction) or from the destination node to the source node (backward direction) [2]. There have been several studies on reservation schemes aimed at reducing the blocking probability for lightpath requests [3] [4]. However, a more important measure for these reservation models is lightpath setup delay.

In both these existing reservation methods, there is only one trial for lightpath establishment during the round-trip propagation time. Therefore, we have proposed a new method for lightpath setup based on integrating the forward and

* m-oohashi@ist.osaka-u.ac.jp; phone 6-6879-4542; fax 6-6879-4544; www.anarg.jp

backward reservation schemes, which tries to establish a lightpath twice during a round-trip propagation time [5]. However the method have evaluated by computer simulations where there is neither packet processing delay nor OXC configuration delay. One possible drawback of our method is that since our method increases the number of control packets for establishing one lightpath. In this works, we implement our method on PCs and confirm that the method works in actual environment. We then compare our method with RSVP-based lightpath setup method.

The rest of the paper is organized as follows. Section 2 outlines existing distributed lightpath setup methods and presents our proposed method, Section 3 presents overview of our implementation, Section 4 presents the experimentation results, and Section 5 includes a brief summary.

2. DESTRIBUTED LIGHTPATH SETUP METHOD

2.1 Network model

The networks we consider consist of nodes and optical fibers. The nodes consist of OXC (Optical Cross Connect) and its controller. The nodes are connected by optical fibers. One wavelength in the fibers is used to exchange control packets. The other wavelengths are used to transfer data from source node to destination node and they are connected to. OXC is the device for switching an input optical signal to an output fiber without converting to electric signal. When a lightpath setup request arises at a node-pair, the source node sends control packets toward destination node so that OXCs along the path is configured, and then a lightpath is established for the node-pair. Note that in this paper, we consider the networks without wavelength conversion and thus a lightpath is set up with identical wavelength at all links along the path.

2.2 Forward reservation method

In forward reservation, the source node sends a RESV packet to destination node when a lightpath setup request arises. The RESEV packet reserves a wavelength from the source node to the destination node. More specifically, the reservation is performed at ever intermediate node which exists on the source-destination route.

In the first place, the source node selects a wavelength for reservation from an available wavelength group in next link and sends a RESV packet toward the destination node. When an intermediate node receives a RESV packet, it extracts the candidate wavelength for lightpath from the wavelength information part of the control packet. Then, it checks the next link state whether the candidate wavelength is available or unavailable. If the wavelength is available in the next link, the intermediate node reserves the wavelength and forwards the RESV packet to the next node. The lightpath establishment is completed as soon as RESV packet reaches the destination node. Since the source node only knows that which wavelength is now available in the neighbor node, there is no guarantee that the selected wavelength will be also available in each link which is distant from the source node.

When the reservation fails, an intermediate node discards a RESV packet and sends back a NACK packet and a RELEASE packet immediately. A NACK packet informs the source node that reservation fails at an intermediate node and a RELEASE packet tear down the half-finished lightpath. When source node receives a NACK packet, it chooses a wavelength and sends a RESV packet again. These series of the exchange of the control packets will be repeated until the lightpath is successfully established.

2.3 Backward reservation method

In backward reservation, the reservation of the network resource is performed more accurately. That is, the source node sends a PROBE packet before a wavelength reservation. A PROBE packet collects the information on usage of wavelength along the forward path, but no wavelengths are reserved at this time. In the first place, the source node checks which wavelength is available in the next link and writes the information of available wavelength on a PROBE packet as available-list and sends the packet toward destination node. Every intermediate node which receives a PROBE packet examines that each wavelengths written in a PROBE packet is available or unavailable in the next link. If a wavelength is unavailable or in-use, the wavelength is removed from the available-list in a PROBE packet. When the destination node receives a PROBE packet, it will know that which wavelength is now available on the path between the source and destination. Based on this information, the destination node determines a wavelength for reservation, and then sends a RESV packet toward the source node. Figure 1(a) shows this successful case.

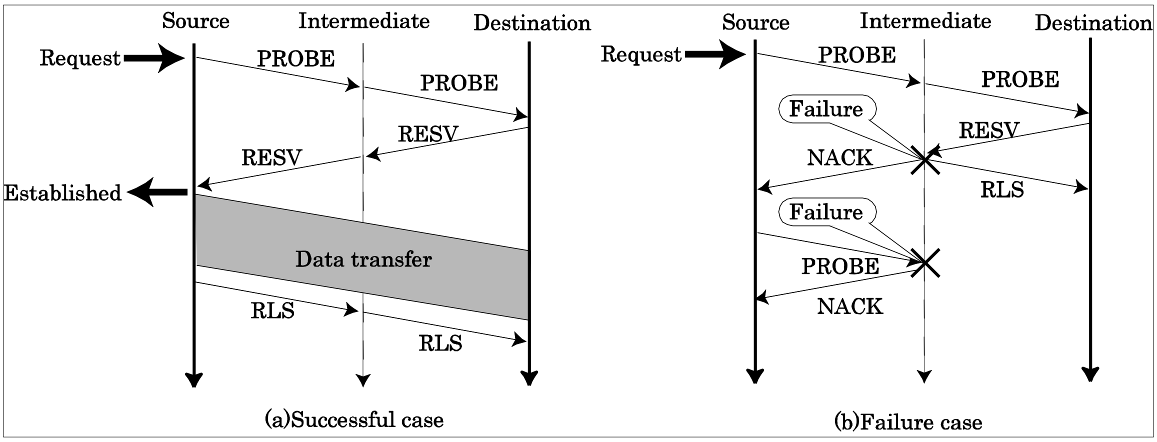

Fig. 1. Backward reservation

Although the reservation in backward scheme is more precisely due to PROBE-based reservation policy, the reservation failure is still unavoidable. There are two cases where the reservation failure occurs in backward scheme. The first one is the PROBE-failure. If there is no wavelength which is available through the entire path, an intermediate node is aware of it because there is no wavelength in a PROBE packet. In this case, the node returns a NACK packet and then the source node re-sends a PROBE packet. At this time, back-off time may be required. The wavelength converter will be a powerful solution of this problem. But, applying the wavelength converters will produce another issue, i.e., facility cost. Note that, in this paper, we do not consider the wavelength conversion facilities. That is, a lightpath uses the same wavelength along the entire path, which is known as the wavelength continuity constraint. The second one is the congestion between RESV packets. Because of the propagation delay, the information collected by a PROBE packet may be different from the current actual link state. There is no guarantee that a wavelength which was free until a few seconds ago is still available. In dynamic WDM networks, the link state changes from moment to moment. It is impossible for edge nodes to know the current actual link state exactly. If the destination node sends a RESV packet based on the outdated information, the reservation may be failure because the wavelength has been already reserved by the other lightpath establishment request. Figure 1(b) shows this case of reservation failure.

2.4 Hybrid reservation method

In both these existing reservation methods, there is only one trial for lightpath establishment during the round-trip propagation time. We therefore propose a new method for lightpath setup, based on integrating the forward and backward reservation schemes, which tries to establish a lightpath twice during the round-trip propagation time.

Figures 2 illustrate our proposed scheme. A RESV (or NACK) _PROBE packet performs just like sending a RESV (or NACK) packet and a PROBE packet simultaneously. In our scheme, when a lightpath setup request arises at a source node, the source node sends a PROBE packet toward the destination node, just like in backward reservation. However, in contrast to backward reservation, when the destination node receives a PROBE packet, it sends a RESV_PROBE packet (or NACK_PROBE packet) toward the source node. The RESV_PROBE packet reserves a wavelength like RESV packet and collects the information on wavelength usage from the destination node to the source node like PROBE packet. If the reservation failed, a RESV_PROBE packet is changed into a NACK_PROBE packet. A NACK_PROBE packet does not reserve a wavelength but still collects the wavelength information. When the source node receives a NACK_PROBE packet, it selects a wavelength based on this information. The main feature of the proposed scheme is that not only PROBE packet but also the other all packets (except for ACK packet) collect the link state information in both forward and backward direction. Below we explain the details of our proposed reservation scheme.

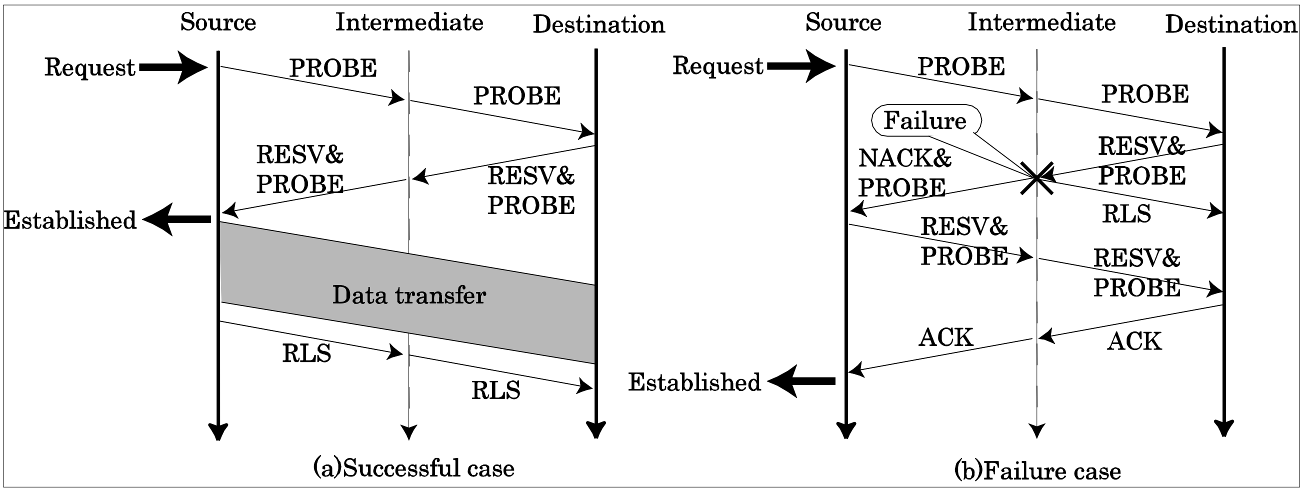

Fig. 2. Hybrid reservation

2.4.1 Behavior of the source node

(S1) When a data transfer request arrives from a terminal, the source node creates a PROBE packet and sends it toward the destination node. Before it sends a PROBE packet, it examines which wavelength is available in the next link, and writes it in the wavelength information area.

(S2)When a RESV_PROBE (or ACK) packet arrives, the lightpath establishment is complete. And then the data transmission will start.

(S3)When a NACK_PROBE packet arrives, the source node sends a RESV_PROBE packet to destination node. This is the case where the reservation failure occurs in the backward direction. The original features of our proposal relate to this behavior. Although a NACK packet only informs the reservation failure in forward and backward schemes, a NACK_PROBE packet additionally has the same function as a PROBE packet. Therefore the source node always can perform the lightpath setup based on probed information.

(S4)When the data transmission is completed, the source node sends a RELEASE packet to tear down the lightpath.

(S5)When a RELEASE packet arrives, the source node discards it.

2.4.2 Behavior of intermediate nodes

(I1)When the intermediate node receives a PROBE packet or a NACKE_PROBE packet, it calculates the intersection between the wavelength list carried by the packet and the wavelength list which is available in the next link. Then, it renews the wavelength information in the packet and forwards the packet to the next node.

(I2)When a RESV_PROBE packet arrives, the intermediate node extracts the candidate wavelength from the wavelength information area of a RESV_PROBE packet. If the wavelength is available in the next link, the intermediate node reserves the wavelength. If the wavelength is unavailable or in-use, the intermediate node changes a RESV_PROBE packet into NACK_PROBE packet and has to return a RELEASE packet to tear down the half-finished lightpath. A RESV_PROBE packet and a NACK_PROBE packet have the same information area as a PROBE packet and it is processed in the same way in (I1) regardless of weather the reservation succeeds or fails.

(I3)When a RELEASE packet arrives, the intermediate node releases the wavelength immediately and forwards the packet to the next node.

(I4)An ACK packet is forwarded to the next node without any processing.

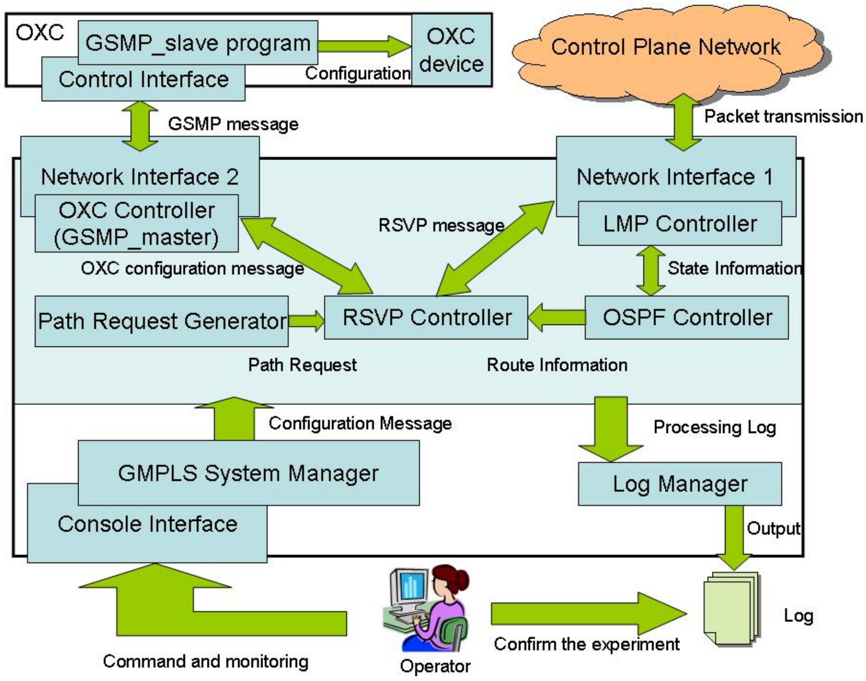

Fig. 3. Modules for our GMPLS implementation

2.4.3 Behavior of the destination node

(D1)Basically, the behavior of the destination node is similar to that of the source node. When a PROBE packet or a NACK_PROBE packet arrives, the destination node sends a RESV_PROBE packet. If the packet carries an empty set and no wavelength is found, the destination node sends a PROBE packet toward the source node. When a RELEASE packet arrives, the destination node discards it.

(D2)When a RESV_PROBE packet arrives, the destination node sends an ACK packet toward the source node to notify that a lightpath has been established in forward direction.

3. IMPLEMENTATION OF HYBRID LIGHTPATH SETUP METHOD

3.1 GMPLS implementation

We implemented RSVP-based backward reservation method and our hybrid reservation method on PCs running Linux kernel 2.6.9 by the C++ language. A control plane that sends control packets has four fundamental modules; resource reservation module (RSVP controller), OSPF-based routing module (OSPF controller), link management module (LMP controller), and OXC control module (OXC controller). We then implemented reservation methods in the UDP transmission layer. Figure 3 shows the modules we implemented. In our system, a Path Request Generator generates lightpath establishment requests to the RSVP controller. The RSVP controller sends and receives RSVP signaling messages. The signaling messages are passed along the route specified by OSPF controller. The LMP controller manages link up/link down events. In our implementation, the LMP controller also manage the current status of wavelength resource usage, and if the status changes, the controller send the information to neighboring nodes. OXC controller manages the status of OXC and configures the input / output binding table of the OXC. We use generalized switch management protocol (GSMP) to change the OXC configuration, and implement this protocol on the controller. The Console Interface works as the configuration command interpreter for administration for network monitoring. The GMPLS System Manager receives messages from the Console Interface and sends commands to other signaling and controller modules. In addition to the command-line interface, we also prepare an interface to specify the routing algorism for the OSPF controller and the arrival rate of lightpath and holding time of the lightpath, which will be used by our experiments in Sec. 4. The Log Manager collects the processing logs to monitor the processing time for each module.

3.2 Implementation of OXC controller

OXC Controller of our GMPLS implementation program controls an OXC via GSMP. Since the OXC we used has the functionality of GSMP_slave, we implement GSMP_master program onto our OXC Controller by using add branch and delete branches messages specified by GSMP. On starting our GMPLS implementation program, OXC Controller sends an adjacency message to establish a connection between the GSMP_master and GSMP_slave programs. After this, keep-alive messages to keep the connection are transferred periodically. Our GMPLS implementation program controls OXC by sending GSMP's control messages through this connection.

4. EVALUATION OF LIGHTPATH SETUP DELAY

In this section, we evaluate the average lightpath setup delay of our hybrid lightpath setup method through experiments. We first show our experimental environment and the results of measurement of OXC configuration delay. Then, we evaluate lightpath setup delay by hybrid reservation method. For the performance comparison, we use the backward reservation method since it generally outperforms the forward reservation method.

4.1 Experimental environment

Our experimental environment consists of three Linux PCs, each of which our implementation program is running, and these PCs form a three-node tandem network. In this experiment, fixed routing is adopted and the OSPF controller does not calculate a route. The intermediate node has one OXC that is running GSMP program, while other two PCs do not have its own OXC. The two PCs instead have CWDM interface with 1550nm wavelength, and the interface is used for transmitting IP packets. For the control plane that exchanges control packet, we use a gigabit Ethernet network.

4.2 OXC configuration delay

In establishing lightpaths, OXC configuration delay increases the lightpath setup delay. In this subsection, we present the result of measurement of OXC configuration delay, which is defined as the time from when it begins to configure OXC to when data can be transferred through the lightpath. OXC configuration delay includes the time for configuring OXC, the time required to release previous configuration, the time required to bind new OXC configuration, and the time required to process GSMP messages. **I**n the environment showed in section 4.1, UDP packets are transferred from node 3 to node 1 via data plane at the rate of 80Mbps by IPerf [6]. In this case, the interval of sending UDP packets on node 1 is 0.1 ms. We observe the arrival of the UDP packets on node 1 by binding or releasing OXC configurations. As a result, it requires 9 ms to start transferring the data.

4.3 Lightpath setup request arrival model

We show our lightpath setup request arrival model in figure 5. The lightpath setup requests are generated at the arrival rate of λ. The requests arrive in accordance with the Poisson process. The lightpath holding time is set to follow an exponential distributed with mean 1 [sec]. Eight wavelengths are available on GMPLS implementation program, but only one wavelength is actually used to configure OXC because of our experimental environment. Note that our observation on this wavelength to any other wavelengths since the wavelength selection is random and characteristics about OXC configuration delay are identical for each wavelength. It should be also note here that only the lightpaths from node 1 to node 3 are actually configured on both control and data plane. Lightpaths from node 1 to node 2 and from node 2 to node 3 are configured only on control plane due to the lack of E/O, O/E converters. However lightpath requests experience the OXC configuration delay by configuring the OXC. Note that the direction of UDP packets (from node 3 to node 1) is not consistent with the lightpath direction (from node 1 to node 3) because the observation in control plane and data plane should be used the same timer on node 1.

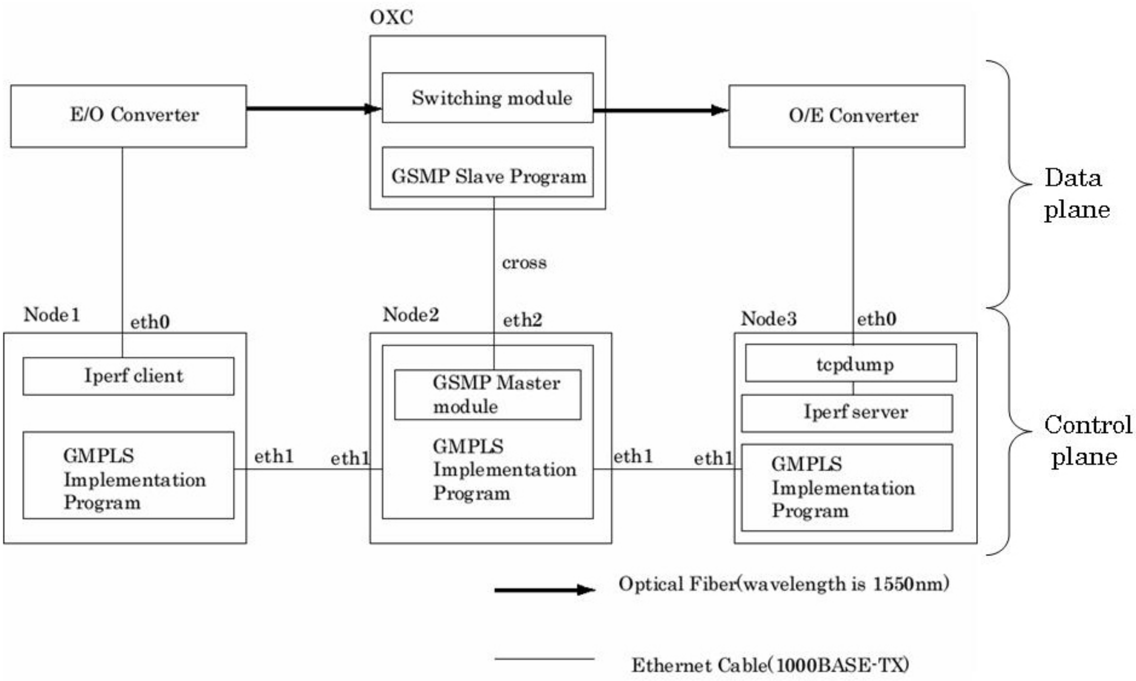

Fig. 4. Experimental environment

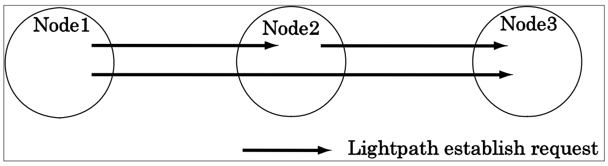

Fig. 5. Lightpath setup request arrival model

4.4 Compare with backward reservation protocol

Fig. 6 shows the mean setup delay dependent on the request arrival rate of 2-hop connection. From this figure, we observe that if the arrival rate is under the 0.0018 [requests/ms], our hybrid lightpath setup method takes smaller lightpath setup delay comparing with the conventional backward reservation method. However, under the heavy-load, the lightpath setup delay of hybrid lightpath setup method is greater than that of the backward reservation method. As stated in Ref. [5], the reason why the proposed scheme was inferior to the backward reservation under a high load is the inaccuracy of the probed information. When the information collected by a PROBE packet is not accurate due to link propagation delay, the information becomes out-of-date. If the information is too old, the edge node may select a wavelength that has already been reserved by another source-destination pair. This increases the number of half-finished lightpaths illustrated in Fig. 7. The half-finished lightpath is caused by confliction on two or more RESV packets, and appears only when the lightpath request reserves wavelength resources on a link but is finally rejected. Note that wavelengths are reserved until RELEASE message arrives. As the number of half-finished lightpaths increases, it will be hard to reserve a wavelength on all links along the path. In our proposed method, the edge nodes make more attempts to set up lightpath compared with the backward reservation. This is why lightpath setup delay increases at the heavy-load.

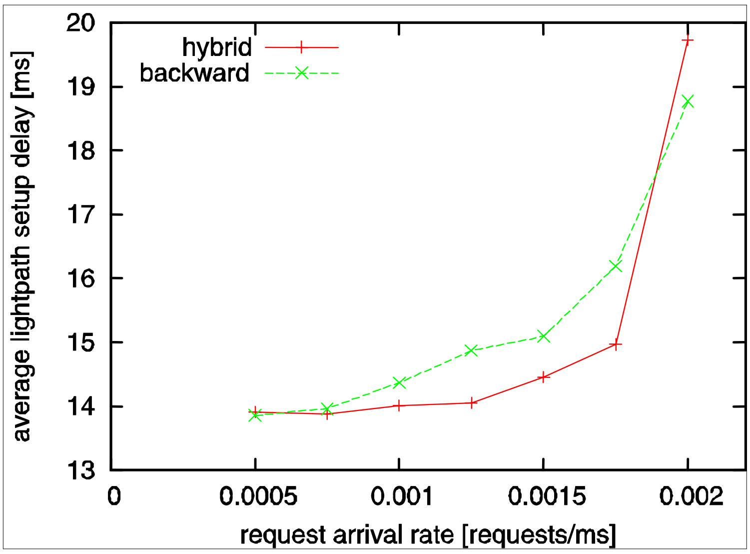

Fig. 6. Lightpath setup delay

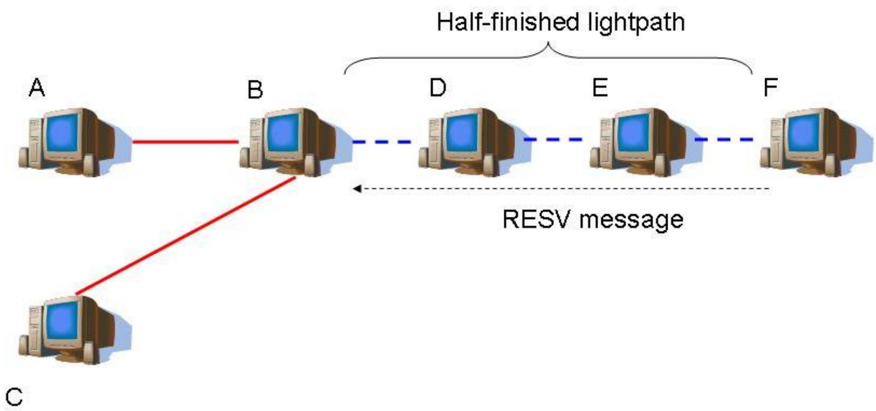

Fig. 7. An illustrative example of half-finished lightpath: The situation is that two lightpath requests from node A to node C and from node A to node F, occur at the same time, and the lightpath between nodes A and C succeed. The RESV message from node F to node A reserves a wavelength on several links, but is blocked at node B since the wavelength between node A and node B is already reserved. In this case, the lightpath from node B to node F becomes the half-finished lightpath.

5. CONCLUSIONS

We have proposed a new lightpath setup method that reserves wavelengths in both forward and backward directions. The main objective of the method is to reduce lightpath setup delay. The hybrid method that integrates features of two existing method performs lightpath establishment twice within a round-trip propagation delay, while the previous methods perform it only once.

In this paper, we have presented overview of our implementation and evaluated our method. The experimental results show that our lightpath setup method takes smaller lightpath setup delay than the backward reservation protocol under the middle to higher arrival rate. In our experiments, we found that different from computer simulations, the OXC configuration overheads have a significant impact on the lightpath setup delay.

Our future work is to examine various routing methods and evaluate the lightpath setup delay.

REFERENCES

1. I. Chlamtac, A. Ganz, and G. Karmi, "Lightpath communications: An approach to high bandwidth optical WAN's," IEEE Transactions on Communications, vol. 40, pp. 1171-1172, July 1992.
2. X. Yuan, R. Melhem, R. Gupta, Y. Mei, and C. Qiao, "Distributed control protocols for wavelength reservation and their performance evaluation," Photonic Network Communications, vol.1, no. 3, pp. 207-218, 1999.
3. J. Zheng and H. T. Mouftah, "Distributed lightpath control based on destination routing for wavelength-routed WDM networks," Optical Network Magazine, vol. 3, pp. 38-46, July 2002.
4. J. Zheng and H. T. Mouftah, "A nested path reservation protocol for multiplexed all-optical networks," in Proceedings of ONDM, pp. 401-411, Feb. 2003.
5. Y. Kanitani, S. Arakawa, M. Murata, and K. Kitayama, "Distributed wavelength reservation method for fast lightpath setup in WDM networks," in Proceedings of Optical Network and Technologies Conference, pp. 121-128, Oct 2004.
6. "Iperf - the TCP/UDP bandwidth measurement tool," available at http://dast.nlanr.net/Projects/Iperf/.