A Forward-Backward Optical Wavelength Path Establishment Scheme with Low Blocking Probability in WDM Networks

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Abstract—we study dynamic routing and wavelength assignment scheme when there are any available wavelengths on a route in the wavelength-routed networks. An optical wavelength path request is blocked when there are no available wavelengths over the selected route. In this paper, we present a new optical path establishment scheme for achieving low-blocking probability and shortening mean setup delay. It consists of two schemes. One is to start optical wavelength path establishment process from a source node on least hops route (LHR) when used wavelength is released. The other is to start it from a destination node on least load route (LLR) after reservation failure on LHR. We simulated two different topologies. It is shown the proposed scheme is better than existing schemes in both the topologies.

I. INTRODUCTION

Wavelength division multiplexing (WDM) technology divides the huge transmission bandwidth of an optical fiber into multiple communication channels [1]-[3]. Networks employing this scheme are referred to as wavelength-routed networks.

In such networks, data can be transferred without optical-electric switching at intermediate nodes on the route, which is known as an optical wavelength path [4]. An optical wavelength path has to occupy the same wavelength on all fibers form a source to a destination node. This is known as the wavelength-continuity constraint [1]-[5].

Under the dynamic traffic pattern, the blocking probability may increase because it is difficult for a source node to determine a route over which the wavelength continuity constraint is satisfied. This is known as the Routing and Wavelength Assignment (RWA) problem [1]-[3].

Methods using distributed management protocols can offer a solution to the RWA problem [3], [4]. It is available to lower the blocking probability by distributing link-state advertisements (LSAs), containing information regarding the state of wavelength usage, to the other nodes. This protocol comprises two approaches, i.e., the link-state approach and the distributed approach. In the link-state approach, LSAs is regularly broadcasted to all nodes. In the distributed approach, LSAs are only sent to neighboring nodes when an optical wavelength path is established or released. However, in this case, the blocking probability may increase due to the transmission delay of LSAs, especially in highly congested networks. This delay causes gaps between the time when an optical wavelength path request arrives and LSAs are received at the source node.

In the least-hops route (LHR) algorithm, routes with the least number of hops are selected. However, as the selected route its statically determined, a detour to avoid highly congested routes is not possible. In the least-load route (LLR) algorithm [3], routes with the least load are selected based on LSAs. Therefore, the blocking probability of LLR is lower than that of LHR. However, the blocking probability also increases when the link-states are not monitored accurately due to LSA delay.

In this paper, we propose a new optical wavelength path establishment scheme for achieving low blocking probability by monitoring the networks status. In the proposed scheme, the first route candidate is selected by LHR, which is affected by LSAs. The route establishment process begins when wavelength release notifications are received. The notifications are sent by the intermediate nodes. If route establishment fails, the proposed scheme tries to establish a path with the second candidate based on LLR.

The rest of this paper is organized as follows. In Section II, we briefly outline the existing wavelength reservation schemes. Next, we describe the proposed scheme in Section III, Section IV presents the performance of the proposed scheme via simulation and compares the proposed and existing schemes. Finally, Section V presents the conclusion.

II. RESERVATION SCHEMES

In this section, we introduce two existing wavelength reservation schemes. One is the forward reservation protocol (FRP) [5] that can reduce the setup delay if there are a certain number of available wavelengths on a route. The other is the backward reservation protocol (BRP) [5] whose blocking probability is lower than that of FRP because, in this scheme, optical wavelength path establishment starts after the state information on a route is gathered.
II-1. Forward Reservation Protocol (FRP)

The setup process of the forward reservation protocol (FRP) in the case of a successful reservation is shown in Fig. 1. The source node sends a reservation (RESERVE) packet that reserves a wavelength. The wavelength is selected from the available wavelengths in a route between the source and destination nodes.

Every intermediate node receiving the RESERVE packet temporarily locks a wavelength on the next link for the connection. If no suitable wavelength is found on the next link, the intermediate node sends a failure (NACK) packet to the source node. The NACK packet unlocks all the reserved wavelengths. The source node receiving a NACK packet restarts the optical wavelength path establishment process after waiting for a random period of time.

Finally, the destination nodes receiving a RESERVE packet send a confirmation (ACK) packet to the source node to inform that an optical wavelength path has been established. The source node receiving an ACK packet starts to transfer data as soon as it receives the ACK packet. After the data transfer is completed, the source node sends a release (RELEASE) packet to the destination node in order to release the used wavelength.

II-2. Backward Reservation Protocol (BRP)

The setup process of the backward reservation protocol (BRP) in the successful case is shown in Fig. 2. The source node sends a probing (PROBE) packet that contains information regarding its own available wavelengths on the next link. It does not reserve any wavelengths. Instead, the source node gathers information regarding the available wavelengths on each link in a route with the PROBE packet. If there are no available wavelengths on a route, a NACK packet is sent to the source node, notifying failure.

After the PROBE packet reaches the destination node, the destination node selects one wavelength from the available wavelengths listed in the PROBE packet. The destination node sends a reserve (RESERVE) packet to the source node in order to reserve the selected wavelength along the route.

Occasionally, there are no available wavelengths on an intermediate node because all the wavelengths have already been used by other request. In the reservation failure, the intermediate node sends NACK and RELEASE packets to the source and destination nodes, respectively. The source node waits for a random period of time after receiving the NACK packet and restarts the optical wavelength path establishment process.

In the successful case, the source node starts to transfer data on receiving an RESERVE packet. After the data transfer is completed, the source node sends a RELEASE packet in order to release the used wavelengths.

III. Proposed Scheme

In this section, we propose a new optical wavelength path establishment scheme with a lower blocking probability and shorter mean setup delay than that of the existing schemes. A flowchart of the proposed scheme is shown in Fig. 3.

The proposed scheme consists of two sub-schemes. One involves notifying the nodes of wavelength releases as is described in Section III-1. The other is the second optical wavelength path establishment scheme initiated by a destination node as is described in Section III-2.

III-1. Notification of Wavelength Release (by Intermediate Nodes) Sub-Scheme

The flowchart shown in Fig. 4 outlines the process of transmitting information regarding wavelength release from an intermediate node to a source node. When the intermediate node on LHR releases a wavelength, it sends a packet to the source node notifying it that the wavelength has just been released. We refer to this packet as the information of released wavelength (IRW) packet.

It is possible to reduce the blocking probability as a source node can restart the path establishment process immediately after the used wavelength is released. Information regarding a single link becomes more important as the number of links reduces. Thus, this information is effective for our scheme because a route is established based on LHR.
An available wavelength is selected at the destination node.

LLR is selected at the destination node.

LHR is selected at the source node.

LLR is selected at the source node.

Do any available wavelengths exist at the intermediate node? YES

Next node = intermediate node? NO

An available wavelength is selected at the destination node.

If any available wavelengths exist at the intermediate node? YES

Next node = intermediate node? NO

An available wavelength is selected at the destination node.

If any available wavelengths exist at the intermediate node? YES

Next node = intermediate node? NO

A NACK packet is not sent, but an RELEASE is sent back.

Link is switched from LHR to LLR.

Fig. 3. Flowchart in proposed scheme

Fig. 4. Control message in proposed scheme1

III-2. Second Optical Wavelength Path Establishment (Initiated by Destination Nodes) Sub-Scheme

The process of establishing an optical wavelength path with the second candidate in the case of failure in establishing an optical wavelength path based on LHR is shown in Fig. 5.

In any existing schemes, an optical wavelength path establishment fails if the selected wavelength has already been used. The intermediate node sends a NACK packet and a RELEASE packet to the source and the destination node.

In the proposed scheme, the intermediate node sends only a RELEASE packet to the destination node. The destination node restarts the optical wavelength path establishment process based on the LLR-BRP method on receiving the RELEASE packet.

Fig. 5. Control message in proposed scheme2

The control process in the failure case on LLR in the proposed scheme is shown in Fig. 6.

To avoid increasing the mean setup time, the intermediate node sends a NACK packet to the source node if the node blocks the PROBE packet. If the RESERVE packet is blocked at the node, the node sends NACK and RESERVE packets to the source and destination nodes, respectively. The source node receiving the NACK packet restarts the path establishment process based on LHR after waiting for a random period of time.

Fig. 6. Control message in proposed scheme3

(a) Failure of PROBE packet

(b) Failure of RESERVE packet

Fig. 6. Control message in proposed scheme3
IV. PERFORMANCE EVALUATION

In this section, we compared the blocking probability and mean setup delay of the proposed scheme with that of the existing schemes via simulation and demonstrated that the proposed scheme performs best.

IV-1. Simulation Model

The performances are compared of the FRP, BRP, BRP with LLR, and proposed schemes via simulation. The two following simulation models are adopted:

Model 1) a 14-node and 21-link NFSNET backbone network as shown in Fig. 7.
Model 2) a 64-node and 112-link 8 × 8 mesh network, shown in Fig. 8.

No wavelength conversion at nodes is assumed. A path can be set up only if the same wavelength is available on all links in a route. Each link is a bidirectional fiber. All nodes function as source, destination, and intermediate nodes. At all nodes, the traffic arrival rate follows the Poisson distribution with an average arrival rate \( \lambda \). It is also assumed that each link has 64 or 128 wavelengths. Each node takes 0.1 ms to compute the LLR. The route is determined by using Dijkstra's algorithm wherein the cost is the number of wavelengths used. The connection holding time is exponentially distributed with a mean \( 1/\mu \). We predetermined the LHR. We employed random wavelength assignment, and the LSAs are broadcast to all nodes at intervals of 15 ms. In order to evaluate the performance comparison between the proposed scheme and existing schemes, we used the following index ratio.

\[
\text{Index ratio} = \frac{B_{\text{existing scheme}}(\lambda)}{B_{\text{proposed scheme}}(\lambda)} \tag{1}
\]

In the above equation, \( B \) and \( \lambda \) denote the number of blocked requests in a scheme and the arrival rate, respectively. Thus, represents the number of blocked requests with the proposed scheme when the arrival rate is \( \lambda \). If the index ratio \( \lambda > 1.0 \), then the performance of the proposed scheme is better than that of the existing one.

IV-2. Simulation Result

The blocking probabilities are shown in Figs. 9 and 10 of the FRP, BRP, BRP with LLR, and proposed schemes against the arrival rate for the NFSNET backbone network, and in Figs. 11 and 12 for the 8 × 8 mesh network.

In the simulation results show that the proposed scheme has a blocking probability lower than that of all existing schemes. As the networks become larger, the number of occupied links in a path also increases. Several links are occupied for transmission after the optical wavelength paths are set up with LHR, which is a static route. Therefore, many requests will
be blocked if no wavelength on a route can be used and its load increases. On comparing the blocking probability in the NFSNET backbone network and the 8 \times 8 mesh network with the same number of wavelengths, it is observed that the proposed scheme helps reduction of the blocking probability even when the load is higher in both the networks, especially in the 8 \times 8 mesh network. One of the reasons for this is the notification of wavelength release. A path setup is executed on the LHR when a used wavelength is released. This results in a suitable path setup. Thus, the proposed scheme has a lower blocking probability than BRP with LLR. In the lower traffic case, the blocking is mainly caused due to a gap between the time when the selected wavelength is reserved and the information regarding wavelength usage on a route. In the proposed scheme, the reservation blocking is not regarded as a path establishment result, and the destination node restarts the optical wavelength path establishment process based on BRP with LLR.

BRP with LLR has the lowest blocking probability among the existing schemes. Therefore, the ratio of the number of blocking in the proposed scheme to that in BRP with LLR is represented by a dotted line in a dotted line in Figs. 9, 10, 11, and 12. This ratio is higher than 1.0 throughout the simulation results. The mean setup delay of the FRP, BRP, BRP with LLR, and proposed schemes against the arrival rate are shown in Figs. 13 and 14 for the NFSNET backbone network, and in Figs. 15 and 16 for the 8 \times 8 mesh network. In all simulations, the proposed scheme shows lower mean setup delay than the existing schemes. In the existing schemes, an optical wavelength path establishment process is started after the random period of time in order to avoid blocking again. However, it is not certain that there exist available wavelengths after the time.

On the other hand, in the proposed scheme, the path establishment process can be started when a wavelength release notification is received. Therefore, the setup delay time of the proposed scheme is smaller than those of the existing schemes. Especially, those of existing schemes are much higher than our method in high loaded network, because the random period of time increases exponentially as the number of blocking increases.

In the existing schemes, the waiting random time after the request blocking functions as a distribution of load by restarting at difference time each node. But the more the blocking probabilities increase, the more time in entire setup delay it spends establishing optical wavelength path.
V. Conclusion

In this paper, we proposed a new scheme to establish an optical wavelength path for wavelength-routed WDM networks. The proposed scheme applies wavelength release notifications, and uses LHR and LLR effectively. With LHR approach, the number of the intermediate links is small. Thus a wavelength release in a link is important. We proposed a wavelength release notification method for LHR approach. This notification can significantly decrease the blocking probability and the mean setup delay in not highly loaded network. However, the performance of this method declines as the load increases because of its statically determined route. We applied the LLR approach for this issue. We evaluated the blocking probability and mean setup delay for two different network models by conducting simulations. In both models, the proposed scheme reduces the blocking probabilities and the mean setup delay as compared to the existing schemes.

References