Self-learning route selection scheme using multipath searching packets in an OBS network

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In an optical burst switching (OBS) network, some contention resolution schemes at a core router have been proposed. However, in terms of the optical device technology, it is difficult to implement the contention resolution schemes such as optical buffers at a core router. In this paper, we propose the scheme that reduces the probability of burst contention by controlling the route at an edge router without resolving burst contention at a core router. Each edge router learns a suitable route to the destination edge router autonomously by using newly employed feedback packets and search packets. Due to the self-learning at each edge router, the traffic load is distributed in an OBS network. Therefore, our proposed scheme can reduce the probability of burst contention. According to computer simulations, under nonuniform traffic, our proposed scheme can reduce approximately one decade smaller burst loss probability compared with the conventional shortest path routing method. © 2005 Optical Society of America

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1. Introduction

The explosive growth of Internet Protocol (IP) traffic on the Internet is driving the demands for new high-speed transmission and switching technologies. Wavelength division multiplexing (WDM) is a core technology for realizing the next-generation IP backbone network. To realize IP-over-WDM networks, however, the data are processed electrically by use of optical-to-electrical (O/E) and electrical-to-optical (E/O) conversion at intermediate routers, since all-optical packet switches and routers are still not practical. The switching capacity of intermediate routers results in a bottleneck, since the electrical processing speed of intermediate routers does not keep pace with the transmission capacity of an optical fiber.

Optical burst switching (OBS) [1, 2] has been proposed as a scheme to realize IP-over-WDM networks. In an OBS network, several IP packets with the same destination are assembled into a burst and are forwarded through the network in the optical domain. Figure 1 shows basic schematics of an OBS network. The network consists of optical core routers and electronic edge routers connected by WDM links. Edge routers provide the burst assembly/disassembly functions, and the legacy interfaces (e.g., gigabit Ethernet, IP/ATM). A core router is mainly composed of an optical switching matrix and a switch control unit.

A burst consists of a control packet and a burst payload. A control packet is the header packet of a burst and is transmitted to reserve an output channel at a core router before a burst payload is transmitted. And a burst payload follows a control packet on a separate channel after some offset time, without waiting for acknowledgement of channel allocation. Channels carrying data bursts are called data channels, and channels carrying control

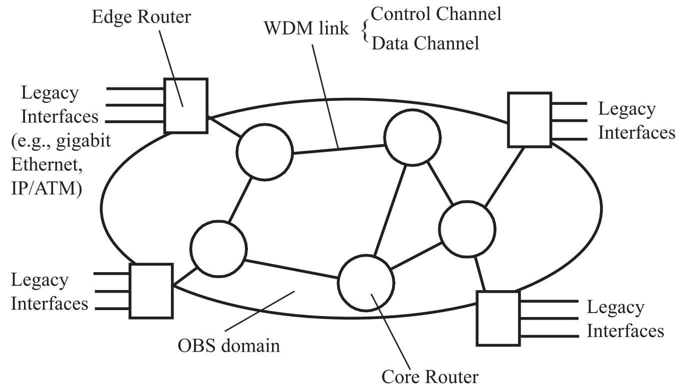


Fig. 1. OBS Network.

packets are called control channels. In a core router, only a control packet is processed electrically, and a burst payload is forwarded through the network in the optical domain. In an OBS network, transmitting several IP packets as a burst and processing only a control packet electrically can reduce bottlenecks caused by the electrical processing in intermediate routers.

One of the main problems in an OBS network is the handling of burst contention: two or more incoming bursts are simultaneously directed to the same output data channel. Only one burst can be transmitted; the others must be discarded. Therefore, burst contention causes an increase of packet loss, since a burst contains several IP packets.

To resolve burst contention, the contention resolution schemes at a core router have been examined in the literature. Optical buffering and wavelength conversion are technologies that can be used in a core router to suppress contention. For example, fiber delay lines can be used for temporary storage of the bursts until the resources become available. However, as current optical buffers are typically limited to delay values of a few tens of ms [3, 4], it is not easy to store long optical bursts. Moreover, implementing optical buffers involves a great amount of hardware and complex electronic controls.

Wavelength conversion is another key functionality that offers contention in WDM networks; it converts the wavelength of one burst to another wavelength. The performance improvement possible with wavelength conversion has been extensively studied with analytical and simulation-based methods [5]. However, the problem with wavelength conversion is the immaturity of the technology [6, 7]. All-optical conversion technologies without optical-to-electrical and electrical-to-optical conversions are desirable and have been developed over a number of years. However, all-optical conversion technologies are no longer practical because of issues with performance and cost. Eliminating wavelength conversion can greatly simplify the switching fabric and reduce the cost. Therefore, we assume that optical buffering and wavelength conversion are not used in core routers in order to resolve burst contention.

In this paper, we propose a scheme that reduces the probability of burst contention by controlling the transmission of bursts at an edge router without resolving burst contention at a core router. An edge router can control a burst length, an offset time, a route, the wavelength used in the transmission, and the transmission rate. In our proposed scheme, each edge router controls the route to the destination edge router. In a conventional OBS network, a burst is forwarded on the shortest path route. A deterministic routing using a shortest path route is easy to apply in term of costs. In particular, considering the operation costs at the link failure, a deterministic routing is useful. However, in a deterministic routing, the traffic load is concentrated on a certain link, and it causes burst contention. In our proposed scheme, each edge router learns a suitable route to the destination edge router autonomously by using newly employed feedback packets and search packets. Because of the self-learning at each edge router, the traffic load is distributed in an OBS network. Therefore, our proposed scheme can reduce the probability of burst contention. According to computer simulations, under nonuniform traffic, our proposed scheme can reduce approximately one decade smaller burst loss probability compared with the conventional shortest path routing method.

The rest of the paper is organized as follows. We present our proposed self-learning route selection scheme using feedback packets and search packets in Section 2. The simulation results are shown in Section 3. Finally, we discuss the obtained results in Section 4.

2. Proposed Route Search Scheme

Our proposed scheme introduces the transmission of feedback packets and search packets. By using feedback packets and search packets, each edge router learns a suitable route to the destination edge router autonomously.

2.A. Self-Learning Method

Each edge router keeps the information of all routes to each destination edge router by using the link-state routing protocol such as the open shortest path first (OSPF) protocol. The priority is set for each route. The source edge router receives a feedback packet after sending a burst. Figure 2 shows the reception of a feedback packet. When a burst was forwarded successfully, the destination edge router sends back the feedback packet that indicates the success of the transmission as shown in Fig. 2(a). When a burst was discarded at an intermediate core router, the core router sends back the feedback packet that indicates the failure of the transmission as shown in Fig. 2(b). Note that core routers can detect burst contention with control packets. In other words, an optical domain transfers optical burst signals without any sophisticated function. Feedback packets are forwarded on the control channel as well as control packets.

Each ingress edge router receives feedback packets and updates the priority of the route based on the information of feedback packets. And, the next time, an edge router sends a burst on the route that has the highest priority of all the routes. The update of the priority is as follows. Each route has two values, P and N_f. P is the priority $(0 \le P \le 1)$, and N_f is the number of received feedback packets. The default value of P is 1, and the default value of N_f is also 1. On receiving feedback packets, edge routers update P and N_f by use of formulas [8] written below:

- When the feedback packet indicates the success of the transmission,

$$P = \frac{P \times N_\mathrm{f} + 1}{N_\mathrm{f} + 1}, \quad N_\mathrm{f} = N_\mathrm{f} + 1. \tag{1}$$

- When the feedback packet indicates the failure of the transmission,

$$P = \frac{P \times N_\mathrm{f}}{N_\mathrm{f} + 1}, \quad N_\mathrm{f} = N_\mathrm{f} + 1. \tag{2}$$

Figure 3 shows an example of updating the priority. In Fig. 3, at first, the source edge router receives the feedback packet that indicates the failure of the transmission on route 2. P and N_f on route 2 are updated as shown:

$$P = \frac{1.0 \times 3}{3 + 1} = 0.75, \quad N_\mathrm{f} = 3 + 1 = 4. \tag{3}$$

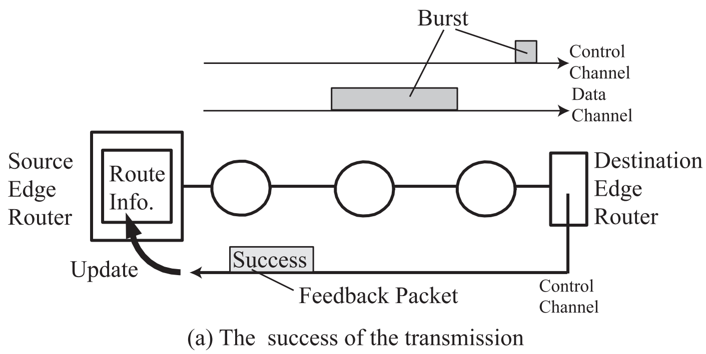


Fig. 2. Reception of a feedback packet.

In Fig. 3, second, the source edge router receives the feedback packet that indicates the success of the transmission on route 1. P and N_f on route 1 are updated as shown:

$$P = \frac{0.80 \times 5}{5+1} \fallingdotseq 0.83, \quad N_f = 5+1 = 6. \tag{4}$$

When the priority P is close to 1, the route has a high probability of success. When the priority P is close to 0, the route has a high probability of failure.

2.B. *Transmission of a Search Packet*

In our proposed scheme, in order to improve the performance of self-learning, the source edge router sends not only a burst but also some search packets on the control channel. Search packets are forwarded on several routes except the route used for the transmission of a burst. In our proposed scheme, the number of search packets N_s is set. An edge router selects $N_s + 1$ routes in descending order of the priority, transmits a burst on the route that has the highest priority, and transmits search packets on the remaining N_s routes. When N_s is larger than the total number of the routes, an edge router transmits a burst on the route that has the high priority, and transmits search packets on all the other routes. Figure 4 shows an example of transmitting search packets. Figure 4 shows the case that the source edge router E0 sends a burst to the destination edge router E1. In Fig. 4, the number of search packets N_s is set to 2. In the case of $N_s = 2$, the source edge router sends search packets on the route that has the second highest priority and on the route that has the third highest priority. A search packet includes the burst length, offset time, and data channel of the burst forwarded. A search packet is forwarded on a control channel and is processed electrically at core routers as well as a control packet. Also, the burst is not forwarded on the route where a

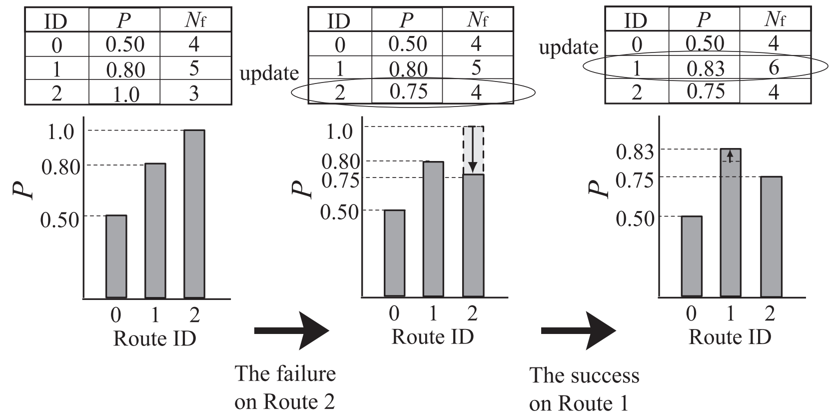


Fig. 3. Example of updating the priority.

search packet is forwarded. On receiving a search packet, a core router judges whether, when the burst arrives at the core router, burst contention occurs. When burst contention does not occur, the core router forwards the search packet to the next router. When burst contention occurs, the core router returns the feedback packet that indicates failure of the transmission. On receiving a search packet, the destination edge router returns the feedback packet that indicates success of the transmission. By sending search packets, an edge router searches whether the transmission of a burst has succeeded or failed on the route, except for the route used in the transmission of the burst. The transmission of search packets enables an edge router to learn a suitable route without sending a burst payload, and a discarded burst number can be reduced in the process of the self-learning. Also, the transmission of search packets enables an edge router to receive feedback packets for several routes at the transmission of one burst. Therefore, an edge router can respond immediately to changes in traffic. The transmission of search packets improves the performance of self-learning. In our proposed scheme, each edge router learns a suitable route by using feedback packets and search packets. The traffic load is distributed as a result of the self-learning at each edge router. Therefore, our proposed scheme reduces the probability of burst contention.

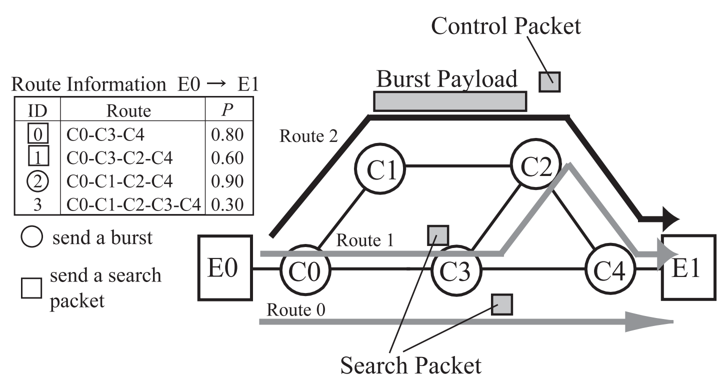


Fig. 4. Example of transmitting search packets ($N_s = 2$).

3. Simulation Results

3.A. Simulation Model

Computer simulations are carried out to evaluate the performance of our proposed scheme. We compare our proposed scheme with the conventional scheme where a burst is forwarded on the shortest path route. We consider a mesh network as shown in Fig. 5. The number of core routers is 6, and each core router connects one edge router. There is no wavelength converter and optical buffer in all core routers. In Fig. 5, there are 30 combinations of source edge router and destination edge router: 20 combinations have 4 routes, 8 combinations have 5 routes, and 2 combinations have 8 routes. The distance between two successive routers is taken to be 10 km. Each link is assumed to have W-wavelengths data channel and one-wavelength control channel. We assume that each wavelength runs at 10 Gbit/s. Each edge router generates the bursts according to an ON–OFF model. The burst length is assumed to be exponentially distributed with an average of 12,500 Bytes [9]. We assume nonuniform traffic where the traffic load is different in each combination of source edge router and destination edge router.

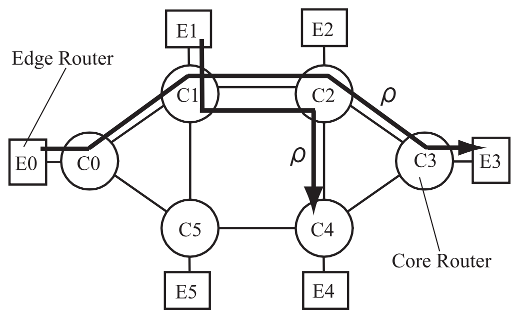


Fig. 5. Simulation network model.

In our simulation, we set the offered load for each combination of source edge router and destination edge router. ρ is defined as the offered load of the traffic from edge router E0 to edge router E3, and the traffic from edge router E1 to edge router E4. ρ/α is defined as the offered load of the other traffic $(\alpha \geq 1.0)$, which emulates traffic imbalance or a hot-spot in the network. Therefore, when a burst is forwarded on the shortest path route, the traffic load is concentrated on link C1 $\rightarrow$ C2. With increasing the value of α, the load of link C1 $\rightarrow$ C2 is larger than that of the other links. In this paper, α is called the traffic bias.

3.B. Simulation Results

Figure 6 shows the burst loss probability versus the number of search packets N_s in our proposed scheme. This was done at number of wavelengths $W = 32$, offered load $\rho = 0.50$, and traffic bias $\alpha = 20$, 40. It shows that our proposed scheme with search packets offers lower burst loss probability than that without search packets. This is because the transmission of search packets enables edge routers to get more information and to reduce the number of discarded bursts in the process of self-learning. However, it also shows that increasing search packets does not improve burst loss probability. The reason for this is as follows. When the route with many hops is used, a burst is more likely to be discarded at an intermediate core router. Therefore, each edge router does not need routes with many hops and has to search only those routes with a few hops. From Fig. 6 it is clear that, in the network shown in Fig. 5, $N_s = 2$ is sufficient.

Figure 7 shows the burst loss probability versus the offered load ρ. This is done at number wavelengths $W = 32$ and with a traffic bias α of 20. N_s is denoted as the number of search packets in our proposed scheme. It shows that our proposed scheme offers lower burst loss probability than the conventional scheme. This is because in our proposed scheme, due to the self-learning at each edge router, the traffic is not concentrated on link C1 → C2. Also, our proposed scheme with $N_s = 2$ offers lower burst loss probability than that with $N_s = 0$, where N_s is the number of search packets. This is because the transmission of search packets enables edge routers to get more information and to reduce the number of discarded bursts in the process of self-learning. From Fig. 7 it is clear that our proposed scheme improves that burst loss probability because of self-learning at each edge router, and the transmission of search packets improves the the performance of self-learning.

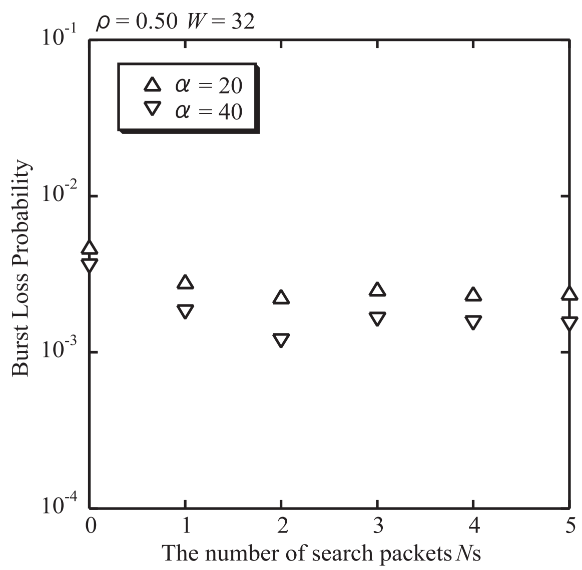


Fig. 6. Burst loss probability versus the number of search packets N_s.

Figure 8 shows the improvement rate I of the burst loss probability versus the traffic bias α. The improvement rate I is defined as

$$I = \frac{B_{\text{conventional}}}{B_{\text{proposed}}}, \tag{5}$$

where $B_{\text{conventional}}$ is the burst loss probability of the conventional scheme and B_{proposed} is the burst loss probability of our proposed scheme. This was done at number wavelengths $W = 32$ and offered load $\rho = 0.40$. In our proposed scheme, the number of search packets N_s is set to 2. When the value of α is large, the improvement rate I is high. This reason is as follows. In the conventional scheme, the load of link C1 → C2 is larger with α increasing, and the number of bursts discarded on link C1 → C2 is increased. On the other hand, in our proposed scheme, the traffic load is distributed, and the loss of many bursts on link C1 → C2 can be avoided. From Fig. 7, it is clear that our proposed scheme improves the burst loss probability under the nonuniform traffic where the traffic load is different in each combination of source edge router and destination edge router.

Figure 9 shows the hop distribution. This was done at the number of wavelength $W = 32$, the offered load of $\rho = 0.40$, the traffic bias of $\alpha = 20$, and the number of search packets N_s of 2. We see that, in our proposed scheme, the probability of the lower number

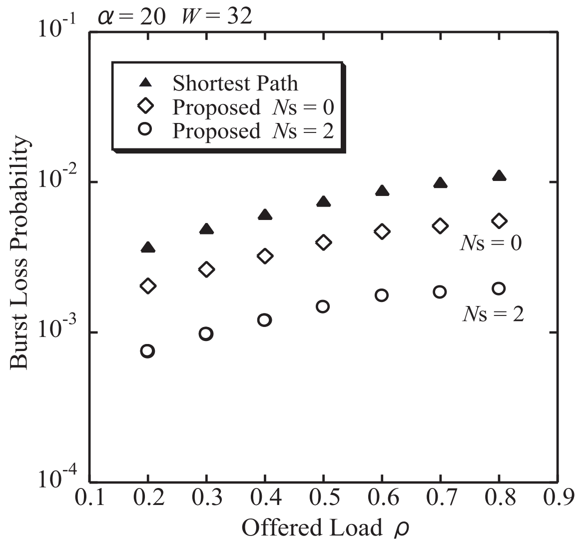


Fig. 7. Burst loss probability versus the offered load ρ.

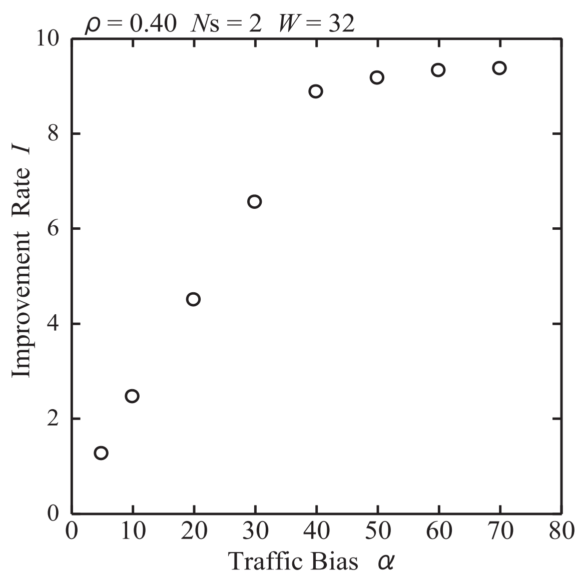


Fig. 8. Improvement rate *I* versus the traffic bias α.

of hops is reduced and that of the higher number of hops is increased. This reason is that, in our proposed scheme, each edge router learns a suitable route, and selects the route except the shortest path route for the transmission of a burst. From Fig. 9 we see, in our proposed scheme, each edge router changes the route based on the result of learning, and the probability of burst contention is reduced. However, increasing of the number of hops requires more network resources. So it has a negative impact on the network load. Both route selection and the number of hops determine the burst loss probability.

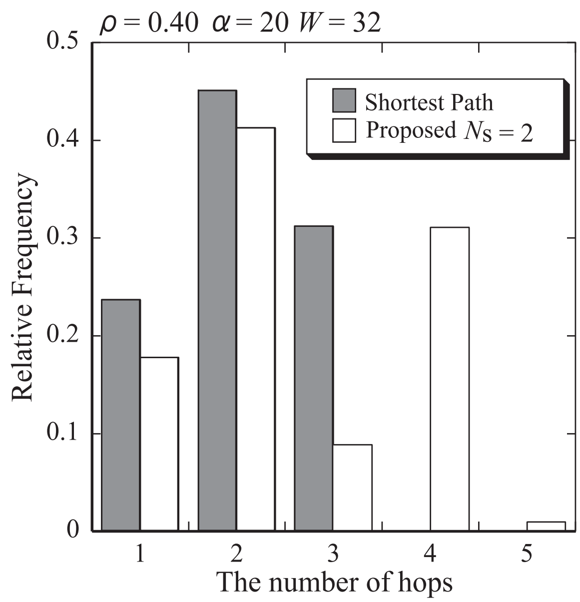


Fig. 9. Hop distribution.

Figure 10 shows the number of changing routes at intervals of 0.01 μs. From Fig. 10, it is shown that the number of changing a route is large at the start of the learning, and the number of changing a route is few after about 1.0 μs. Therefore, each edge router can determine only one suitable route by our proposed scheme. However, after time passes, the number of changing a route does not become zero. This result shows that some combinations of source edge router and destination edge router cannot determine only one route and uses a few routes. Therefore, for perfect stability, some damping mechanism is needed.

Figure 11 shows the burst loss probability versus the number of wavelengths W. This was done at offered load $\rho = 0.40$ and with traffic bias $\alpha = 20$. In our proposed scheme, the number of search packets N_s is set to 2, which shows that, regardless of the value of W, our proposed scheme offers lower burst loss probability than the conventional one. This reason for this is as follows. As the value of W increases, the number of bursts transmitted in one link increases. So, as the value of W increases, the probability of burst contention decreases. However, in the conventional scheme, regardless of the value of W, the traffic load is concentrated on link C1 → C2, and many bursts are discarded on link C1 → C2. On the other hand, in our proposed scheme, the traffic load is distributed, and the traffic load is not concentrated on link C1 → C2. From Fig. 11, it is clear that our proposed scheme is effective regardless of the number of wavelengths, and our proposed scheme can achieve a desired performance about the burst loss probability with a smaller number of wavelengths than the conventional scheme.

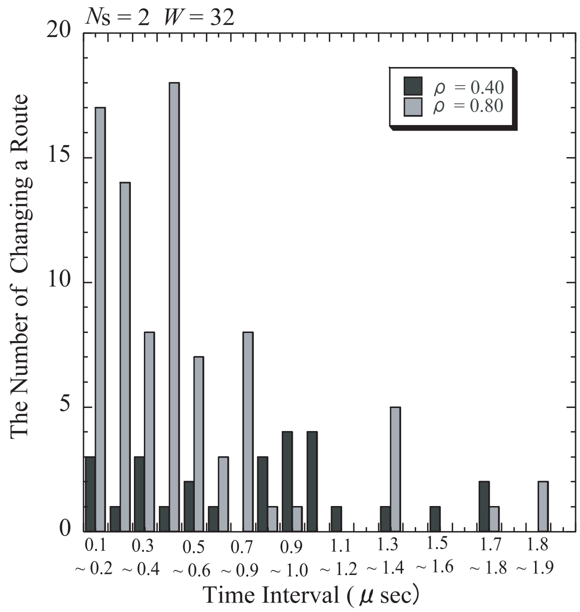


Fig. 10. Number of changing routes.

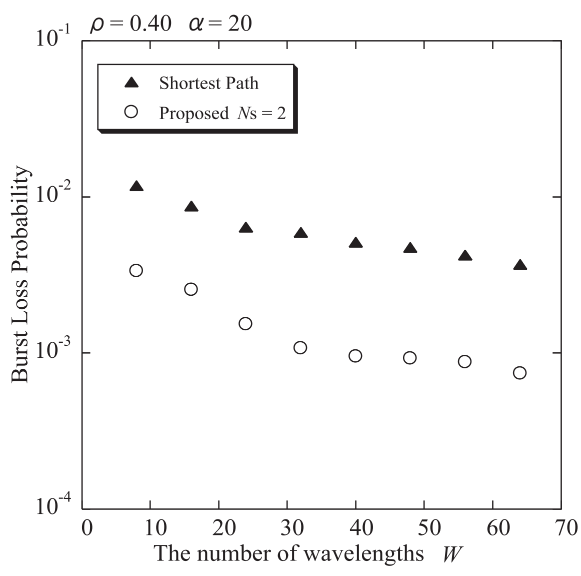
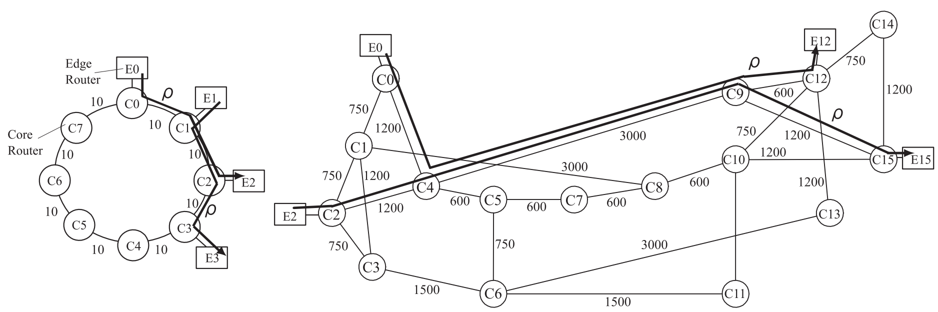


Fig. 11. Burst loss probability versus the number of wavelengths W.

3.C. Study about Network Topologies

In this section, we evaluate the performance of our proposed scheme on the 8-node dual-ring network and on the 16-node NSFNET network shown in Fig. 12. In both topologies, there is no wavelength converter or optical buffer in all core routers. Also, each core router connects one edge router shown as Fig. 5. The numbers on the links represent link distances in units of 1 km.

In Fig. 12(a), ρ is defined as the offered load of the traffic from edge router E0 to edge router E2 and the traffic from edge router E1 to edge router E3. ρ/α is defined as the offered load of the other traffic $(\alpha \geq 1.0)$. Therefore, when a burst is forwarded on the shortest path route, the traffic load is concentrated on link C1 → C2. Also, in Fig. 12(b), ρ is defined as the offered load of the traffic from edge router E2 to edge router E15 and the traffic from edge router E0 to edge router E12. ρ/α is defined as the offered load of the other traffic $(\alpha \geq 1.0)$. Therefore, when a burst is forwarded on the shortest path route, the traffic load is concentrated on link C4 → C9. In the network shown in Fig. 12(b), there are a large number of routes for each combination of source edge router and destination edge router. So, in our proposed scheme, each source edge router selects the routes for the transmission of bursts and searches packets among the shortest path route, the routes with one hop more than the shortest path route, and the routes with two hops more than the shortest path route.



(a) 8-node ring network (b) 16-node NSFNET network

Fig. 12. Eight-node dual-ring network and the 16-node NSFNET network.

Figure 13 shows the burst loss probability versus the offered load ρ in the 8-node dual-ring network [Fig. 12(a)]. This is done at the number of wavelength $W = 32$, and the traffic bias $\alpha = 20$, 100. In our proposed scheme, the number of search packets N_s is set to 2. On a simple mesh network like the one in Fig. 5, at the traffic bias $\alpha = 20$, our proposed scheme can improve the burst loss probability. However, on the ring topology, our proposed scheme cannot improve the burst loss probability at the traffic bias $\alpha = 20$, and our proposed scheme can improve the burst loss probability at the traffic bias $\alpha = 100$. This is because on the dual-ring network, only two routes can be used. The route that is not the shortest path route has many hops. So, when this route is used, a burst is more likely to be discarded because of burst contention. Therefore, except when a large traffic load is concentrated on a certain link, the use of the route that is not the shortest path route is not effective. From Fig. 13, our proposed scheme is effective on the network where several routes that have small hops can be used except for the shortest path route.

Figure 14 shows the burst loss probability versus the offered load ρ on the 16-node

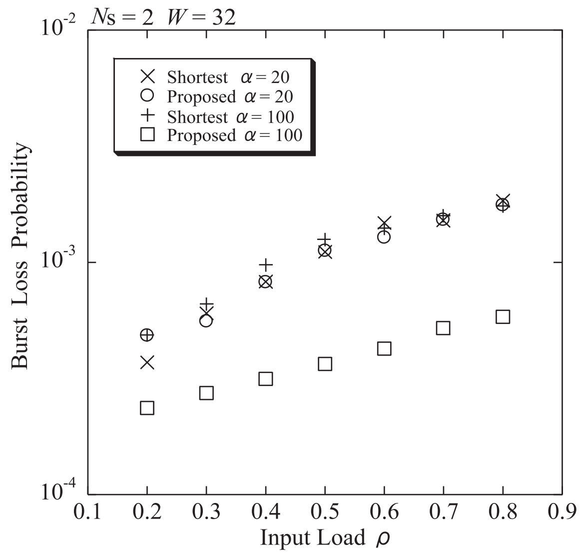


Fig. 13. Burst loss probability versus the offered load ρ in the 8-node dual-ring network.

NFSNET network [Fig. 12(b)]. This is done at number of wavelengths $W = 32$ and traffic bias $\alpha = 20$, 100. In our proposed scheme, the number of search packets N_s is set to 2, which shows that, like in a dual-ring network, our proposed scheme cannot improve the burst loss probability at traffic bias $\alpha = 20$, and our proposed scheme can improve the burst loss probability at traffic bias $\alpha = 100$. This reason for this is as follows. When the shortest path routes are used on a simple mesh network like in Fig. 5, many combinations of source edge router and destination edge router use the same link. However, when the shortest path routes are used on the NFSNET network, many combinations do not use the same link. So, when the traffic load is concentrated on a certain link, few combinations are affected, and total performance is not greatly improved. Therefore, when the large traffic load is concentrated on a certain link, our proposed scheme is effective. From Fig. 14, our proposed scheme is effective on the network where many combinations of source edge router and destination edge router use the same link.

From Figs. 13 and 14, our proposed scheme is effective on the network topology where several routes that have small hops can be used, except for the shortest path route, and many combinations of source edge router and destination edge router use the same link.

4. Conclusion

In this paper, we have proposed a contention resolution scheme not at a core router but at an edge router. In our proposed scheme, each edge router learns a suitable route to the destination edge router autonomously by using feedback packets and search packets anew. Because of the self-learning at each edge router, the traffic load is distributed in an OBS network. Therefore, our proposed scheme can reduce the probability of burst contention.

The performance of our proposed scheme is evaluated by computer simulations. As a result, we show that, under nonuniform traffic, our proposed scheme can reduce approximately one decade smaller burst loss probability compared with the conventional shortest path routing method. Also, it is shown that our proposed scheme is effective on network topology where several routes that have small hops can be used, except the shortest path route, and many combinations of source edge router and destination edge router use the

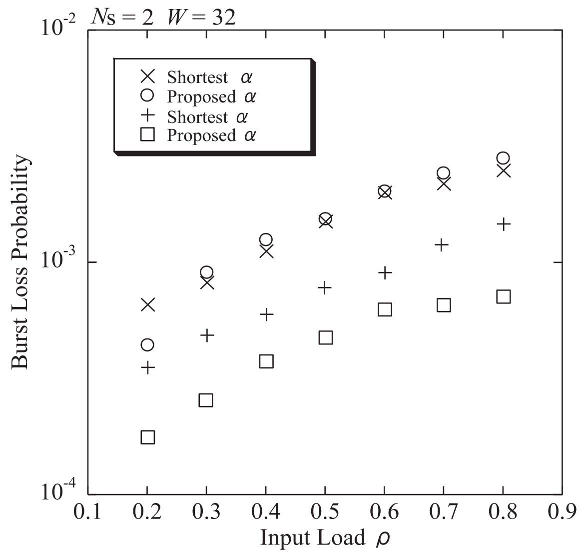


Fig. 14. Burst loss probability versus the offered load ρ on the 16-node NFSNET network.

same link.

In this paper, we have adopted a simple learning scheme in order to investigate the effect of the route selection by self-learning. It is shown that route selection by the simple learning scheme is effective. However, on a large topology, a complex topology, or a ring topology, the simple learning is not very effective. Therefore, in order to improve the performance of the proposed scheme in these topologies, we need to examine the learning scheme in consideration of intelligent schemes [10–12]. Also, future research directions include adding some damping mechanism for perfect stability and studying a combination of our proposed scheme and contention resolutions using optical buffering and wavelength conversion at a core router.

Acknowledgments

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