Dynamic Burst Ordering for Burst-Cluster Transmission to Improve Fairness in OBS Networks

Badr Oulad Nassar*, Takuji Tachibana†, and Kenji Sugimoto‡

Abstract— **In hop-based burst-cluster transmission, multiple bursts are assembled simultaneously and sorted from the smallest number of hops to the largest one. By doing so, the burst loss probability for a large number of hops decreases, improving fairness. However, in mesh networks, the amount of traffic on each link is not necessarily the same, and hence degrades the performance of hop-based burst-cluster transmission. In this paper, we propose dynamic burst ordering to solve this problem. Here, each source node calculates the burst loss probability for each number of hops using ACK and NACK messages. Based on the calculated probabilities, the source node changes the order of bursts within a burst-cluster dynamically. It is expected that this method can improve local fairness for each source node. We evaluate the performance of the proposed method in tandem networks by simulation. Numerical examples show that the proposed method is effective for improving fairness for each source node regardless of the amount of traffic on each link.**

Keywords: OBS, burst-cluster transmission, fairness, dynamic burst ordering

1 Introduction

Recently, an ultra-high speed optical switch sub-system has been developed [1], and the switching time of the optical switch is now less than 3.0 ns. The hardware processing technology and the multiprocessing technology have also been developed to decrease the packet processing time [2]. In the future, the performances of optical burst switching (OBS) networks will be improved significantly by using those technologies.

In terms of signaling protocols, as the processing time of the control packet becomes small, the performance of immediate reservation protocol approaches that of delayed reservation protocol [3]. This is because redundant wavelength utilization time for the immediate reservation becomes small compared with the average burst size. Therefore, in the future, the immediate reservation will be utilized due to its easy implementation.

In OBS networks with immediate reservation, the higher the number of hops, the larger the burst loss probability. Therefore, burst loss probabilities are dependent on the number of hops, resulting in unfairness. In order to solve the unfairness issue, several methods have been proposed [4, 5].

In [6], hop-based burst-cluster transmission has been proposed. In this method, a burst-cluster is generated from multiple bursts, and bursts are arranged within the burst-cluster in order from the smallest number of hops to the largest one. By using this method, bursts with a large number of hops have many chances for wavelength reservation, and hence the loss probability for these kind of bursts decreases. The performance of hop-based burst-cluster transmission has been evaluated in a unidirectional ring network, and it has been shown that this method can not only improve fairness but also decreases the overall burst loss probability.

On the other hand, in the hop-based burst-cluster transmission, the loss probability of a burst for each number of hops is affected by the amount of traffic on its last-hop link. For instance, if there is a high traffic load on the last-hop link, a burst is more likely to be lost, and thus increasing the burst loss probability. This is because, in this method, each control packet often performs the wavelength reservation process only at its last-hop link. Therefore, we may have a situation where the burst loss probability of a small number of hops is higher than that of a large number of hops. As a result, local fairness for each source node is never improved by using the hop-based burst-cluster transmission.

In this paper, we propose dynamic burst ordering for hop-based burst-cluster transmission, so that local fairness can be improved for all source nodes and global fairness can also be improved. In the proposed method, each source node calculates the burst loss probability for each number of hops from the number of ACK or NACK

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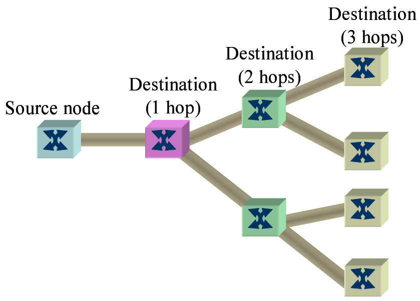


Figure 1: An OBS network with eight nodes.

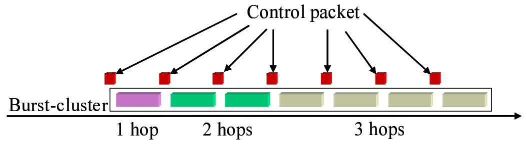


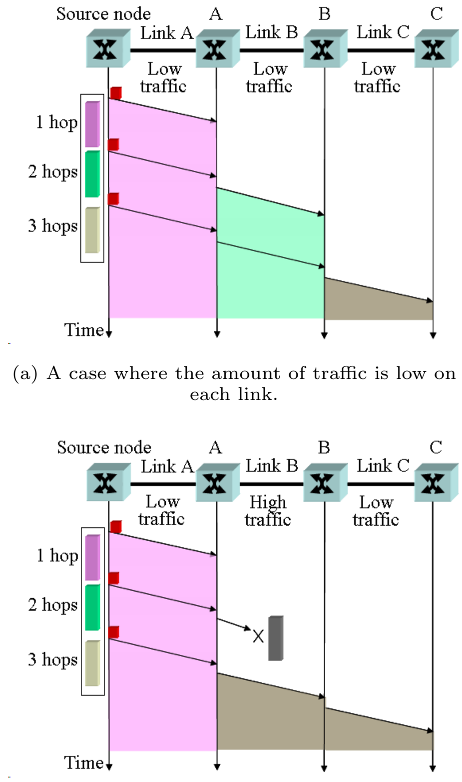
Figure 2: A burst-cluster in the case of Fig. 1.

messages. Based on the calculated loss probabilities, the source node changes the order of bursts within a burst-cluster dynamically. When the burst loss probability for i-hop is larger than that for j-hop, the i-hop burst is arranged behind the j-hop burst. This is because a burst in the rear part of a burst-cluster can reserve a wavelength with a higher probability. Therefore, it is expected that burst loss probabilities are almost the same regardless of the number of hops for each source node. We evaluate the performance of the proposed method in tandem networks by simulation, and we investigate the effectiveness of the proposed method.
The rest of the paper is organized as follows. Section 2 summarizes the hop-based burst cluster transmission, and Sect. 3 explains our proposed dynamic burst ordering. Simulation results are shown in Sect. 4 and finally, conclusions are presented in Sect. 5.

2 Hop-based Burst Cluster Transmission

2.1 Overview

Burst-cluster transmission has been proposed to provide service differentiation in terms of the burst loss probability [7]. This method has been extended to resolve unfairness as hop-based burst-cluster transmission [6].
Figure 1 shows an OBS network with eight nodes, and we focus on the leftmost node which is denoted as source node. This node has one link and seven destination nodes. In this method, each source node generates a hop-based burst-cluster for each output link. At the source node, seven bursts are assembled simultaneously. Then, a hop-based burst-cluster is generated from the assembled bursts so that the bursts in the cluster are arranged in order from the smallest number of hops to the largest one (see Fig. 2). As shown in Figs. 1 and 2, the number of bursts in a burst-cluster is the same as the number of



(a) A case where the amount of traffic is low on each link.

(b) A case where the amount of traffic is high only on link B.

Figure 3: Hop-based burst-cluster transmission.

destination nodes for each number of hops. When there are multiple destination nodes at two or more hops, the order of these bursts is determined at random. Note that each burst has its own control packet.
Then, the burst-cluster is transmitted to destination nodes along with the control packets. The fundamental difference between the hop-based burst-cluster transmission and the original immediate reservation is that the preceding control packet reserves a wavelength not only for its own burst but also for the successive bursts within the burst-cluster.

Figure 3(a) shows an example of hop-based burst-cluster transmission. In this figure, a control packet of one-hop burst reserves a wavelength on link A from one-hop burst to three-hop burst. The three bursts are transmitted to node A with the reserved wavelength. On the other hand, control packets of the two-hop and three-hop bursts are transmitted to node A without wavelength reservation. If the control packet of one-hop burst can not reserve a wavelength on link A, the one-hop burst is lost. In this case, the successive control packets can perform the wavelength reservation process. Because the destination node of one-hop burst is node A, this burst is extracted from the burst-cluster at node A. Then the same procedure is performed at nodes B and C.

As shown in this figure, each control packet reserves a wavelength on only one link, if wavelength reservations do not fail. Consequently, the number of wavelength reservations for each burst is almost the same regardless of the number of hops, improving fairness. Moreover, this method can decrease the redundant wavelength reservation which is required in the original immediate reservation, decreasing the overall burst loss probability.

2.2 Impact of Traffic on the Last-Hop Link

As shown in the previous subsection, in the hop-based burst-cluster transmission, it is expected that the number of wavelength reservations is only one regardless of the number of hops. This denotes that the wavelength reservation for each burst is performed only at its last-hop link.

Figure 3(b) shows a tandem network where only the amount of traffic on link B is high. In this network, link A, link B and link C are the last-hop link of the one-hop burst, the two-hop burst, and the three-hop burst, respectively.

On link A, the control packet for the one-hop burst can reserve a wavelength easily due to low traffic, and the transmission of the one-hop burst succeeds. However, on link B, it is difficult for the control packet of the two-hop burst to reserve a wavelength due to congestion, and the two-hop burst is likely to be lost. Nevertheless, the control packet of the three-hop burst can reserve a wavelength on link B if the congestion has been resolved. Moreover, the control packet for the three-hop burst can reserve a wavelength on link C easily due to low traffic.

From the above, the loss probability of the three-hop burst tends to be smaller than that of the two-hop burst. Therefore, the hop-based burst-cluster transmission can not always improve the local fairness for all source nodes.

3 Burst Cluster Technique with Dynamic Burst Ordering

In this paper, in order to improve local fairness for each source node and improve global fairness significantly, we propose dynamic burst ordering for the hop-based burst-cluster transmission.

In the conventional hop-based burst-cluster transmission, a burst-cluster is generated from multiple bursts, and bursts are always arranged within the burst-cluster in order from the smallest number of hops to the largest one. On the other hand, in our proposed method, the order of bursts within a burst-cluster is changed dynamically. The proposed method utilizes an ACK (NACK) message which is received by a source node when the burst transmission succeeds (fails). Let $A(i)$ denote the number of received ACK messages for i-hop and $N(i)$ denote the number of received NACK messages for i-hop. $A(i)$ and $N(i)$ increase by one when the source node receives ACK and NACK messages, respectively (see Fig. 4). Then,

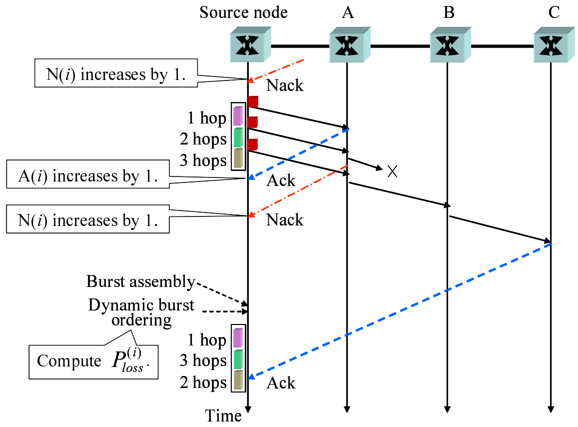


Figure 4: Dynamic burst ordering with ACK and NACK messages.

(a) Case 1: $P_{loss}^{(1)} \leq P_{loss}^{(2)} \leq P_{loss}^{(3)}$. (b) Case 2: $P_{loss}^{(1)} < P_{loss}^{(3)} < P_{loss}^{(2)}$. (c) Case 3: $P_{loss}^{(3)} < P_{loss}^{(2)} < P_{loss}^{(1)}$.

Figure 5: Dynamic burst ordering based on the calculated burst loss probabilities.

the burst loss probability for i-hop, $P_{loss}^{(i)}$, is calculated as follows.

$$P_{loss}^{(i)} = \frac{N(i)}{A(i) + N(i)} , \qquad (1)$$

where the initial value of $P_{loss}^{(i)}$ is equal to zero for every i. When multiple bursts are assembled simultaneously, the source node determines the order of bursts in a burst-cluster based on $P_{loss}^{(i)}$. When $P_{loss}^{(i)}$ is smaller than $P_{loss}^{(j)}$, the burst for i hop is arranged ahead of that for j hop. When $P_{loss}^{(i)}$ is equal to $P_{loss}^{(j)}$, the burst with a smaller number of hops is arranged ahead of that with a larger number of hops.

Figure 5 shows how dynamic burst ordering is performed when the maximum number of hops is three. If $P_{loss}^{(1)} \leq P_{loss}^{(2)} \leq P_{loss}^{(3)}$ is satisfied, the order of the three bursts is the same as in the conventional method (see Fig. 5 (a)). Remind that the transmission of a burst in the front part of the burst-cluster succeeds with higher probability than that in the rear part of the burst-cluster.

If the burst loss probabilities satisfy $P_{loss}^{(1)} < P_{loss}^{(3)} < P_{loss}^{(2)}$, the order of bursts changes as shown in Fig. 5(b). Moreover, in the case of $P_{loss}^{(3)} < P_{loss}^{(2)} < P_{loss}^{(1)}$, the order of the bursts changes as shown in Fig. 5(c). The generated burst-cluster is transmitted along with multiple control

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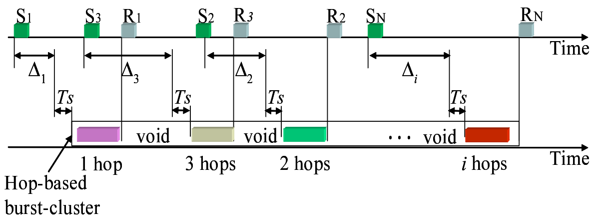
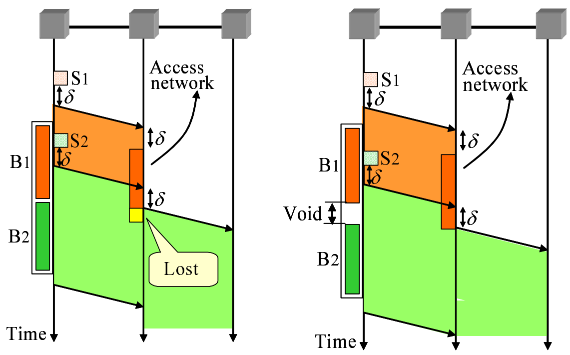


Figure 6: Hop-based burst-cluster transmission with dynamic burst ordering.



(a) Without void between two bursts.

(b) With void between two bursts.

Figure 7: The impact of void on burst preemption.

packets, as is the case with the conventional method. Figure 6 shows how a burst-cluster is forwarded from a source node when dynamic burst ordering is used. In this figure, N denotes the number of destination nodes and H is the maximum number of hops for the burst-cluster. S_m and R_m $(1 \leq m \leq N)$ denote the $SETUP$ and the $RELEASE$ messages for the mth burst in the burst-cluster.

As shown in Fig. 6, hop-based burst-cluster transmission requires a void between two consecutive bursts although it increases the wavelength reservation time. Here, Fig. 7(a) shows a case where there is no void. As shown in this figure, when two bursts are forwarded to different output links, a preceding burst is preempted by the next one. This preemption occurs even if the number of hops of the next node is smaller than that of the preceding burst. In order to avoid such an undesirable preemption, a void is used, as shown in Fig. 7(b). The size of each void can be determined from the number of hops of the next burst, the processing time of a control packet δ, and at which transmission hop the two bursts are switched to different output links. In order to decrease the redundant wavelength reservation, the accurate size of each void is required, and hence the information about the route of each burst is required. In addition, in the proposed method, the order of bursts changes dynamically. For the simple implementation, we set the size of a void to $(i-1) \times \delta$ when the number of hops for the next node is i.

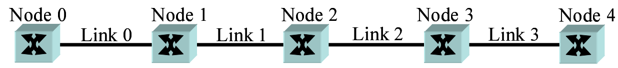
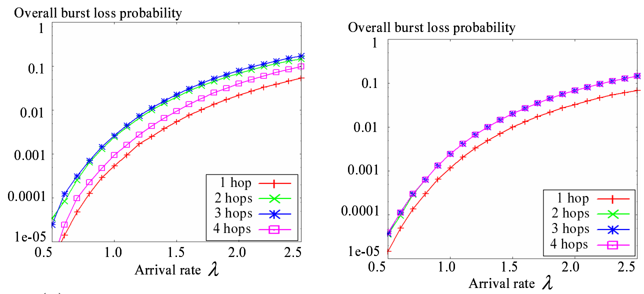


Figure 8: A tandem network with five nodes.



(a) Hop-based burst-cluster transmission.

(b) Dynamic burst ordering.

Figure 9: Burst loss probability vs. arrival rate (node 0 and link 0).

4 Numerical Examples

In this section, we evaluate the performance of our proposed dynamic burst ordering in a tandem network with five nodes by simulation. Figure 8 shows a tandem network, where each node and each link are numbered. The number of wavelengths on each link is eight and the transmission speed of a wavelength is 10 Gbps. The length of each link is 200 km. In addition, the processing time of a control packet is equal to 1.0 μs and the optical switching time is 1.0 μs.

We assume that IP packets arrive at the tandem network according to the Poisson process with rate 200 [packets/μs]. Source and destination nodes of an arriving IP packet are selected at random. The size of an IP packet is fixed equal to 1,250 bytes.

From the arriving IP packets, a burst-cluster is generated according to the timer/threshold based assembly algorithm, where the timeout value is 10 ms and the maximum burst-cluster size is 60 Mbits. The order of bursts is determined by using the dynamic burst ordering, and the generated burst-cluster is transmitted from the source node. We assume that the time interval between consecutive burst-cluster transmissions at the source node is exponentially distributed with rate λ [clusters/ms].

For the performance comparison, we also evaluate the performance of the conventional hop-based burst-cluster transmission. In this method, dynamic burst ordering is not used. In addition, we evaluate the performance of the original immediate reservation. For this method, we set the maximum burst size to 20 Mbits, so that the burst sizes for the three methods are almost the same.

4.1 Effect of Local Fairness

First, we investigate the impact of dynamic burst ordering on local fairness. Figure 9 shows the burst loss prob-

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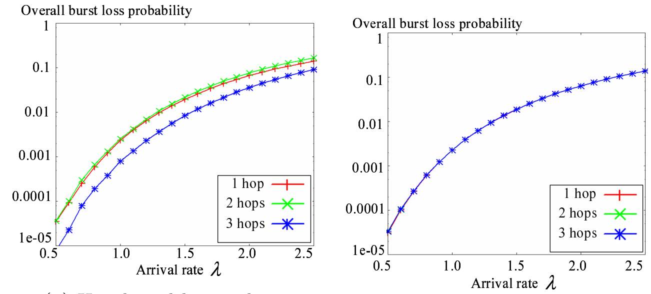
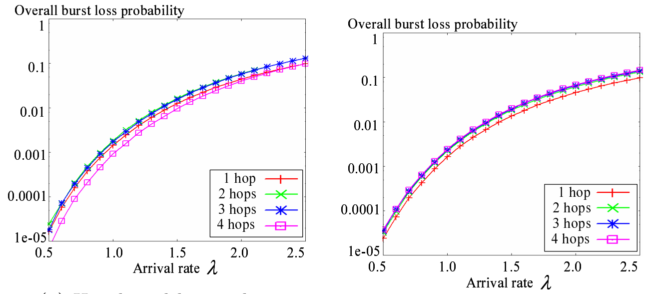


(a) Hop-based burst-cluster transmission.

(b) Dynamic burst ordering.

Figure 10: Burst loss probability vs. arrival rate (node 3 and link 2).



(a) Hop-based burst-cluster transmission.

(b) Dynamic burst ordering.

Figure 12: Burst loss probability in the tandem network vs. arrival rate.

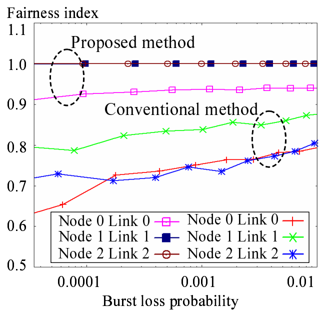


Figure 11: Fairness index vs. overall burst loss probability for each pair of source node and output link.

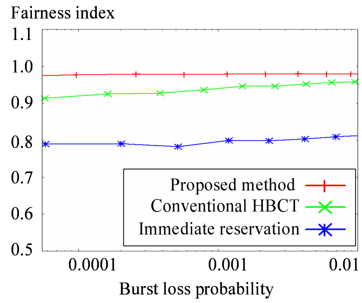


Figure 13: Fairness index in the tandem network vs. overall burst loss probability.

ability of each number of hops for the burst-cluster transmission from node 0 with output link 0. From Fig. 9(a), we find that the burst loss probabilities of one hop and four hops are smaller than those of two hops and three hops. This is because the amount of traffic on link 0 and 3 are small, which are the last-hop links for one-hop burst and four-hop burst, respectively. Therefore the conventional burst-cluster transmission can not improve local fairness. However, as shown in Fig. 9(b), the proposed method can improve the local fairness so that the burst loss probabilities of two hops and three hops never exceed that of four hops. Note that in the proposed method, the burst loss probability of one hop does not increase anymore without intended loss.

Figure 10 shows the burst loss probability of each number of hops for the burst-cluster transmission from node 3 with output link 2. Note that there is no burst transmission of four hops. From Fig. 10(a) and (b), we also find that the conventional method can not improve the local fairness but the proposed method can provide almost the same burst loss probability for each number of hops.

Figure 11 shows the fairness index [8] against the overall burst loss probability for some pairs of source node and output link. Here, when the fairness index is close (not close) to one, this index denotes that fairness is improved (not improved). From this figure, we find for all three cases, that the fairness index of dynamic burst ordering is much closer to one compared to that of the conventional hop-based burst-cluster transmission. Therefore, dynamic burst ordering is effective for improving fairness.

4.2 Effect of Global Fairness

Next, we investigate the impact of dynamic burst ordering on global fairness. Figures 12(a) and (b) show the burst loss probability of each number of hops, in the tandem network, for the conventional method and the proposed method, respectively. From these figures, we find that the discrepancies among the burst loss probabilities for the proposed method are smaller than those for the conventional method.

Figure 13 also shows the fairness index, in this network, against the overall burst loss probability. For the performance comparison, a result of the original immediate reservation is also shown. From this figure, we find that the conventional hop-based burst-cluster transmission can improve fairness further than the original immediate reservation, as expected. Besides, by using the proposed dynamic burst ordering, fairness can be improved significantly.

4.3 Effect of Burst Loss Probability

Finally, we investigate how the burst loss probability changes by using the proposed method. Figure 14 shows the overall burst loss probabilities for the proposed method, the conventional hop-based burst-cluster transmission, and the original immediate reservation. From

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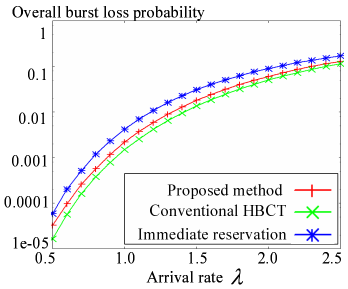

Figure 14: Overall burst loss probability vs. arrival rate.

Table 1: The largest burst loss probability for each pair of source node and output link when λ=1.0.

Source node, Output link	Conventional method		Proposed method	
	Loss	Hop	Loss	Hop
Node 0, Link 0	2.64e-03	3 hop	2.45e-03	4 hop
Node 1, Link 1	2.44e-03	2 hop	2.27e-03	3 hop
Node 2, Link 1	2.37e-03	1 hop	1.94e-03	2 hop
Node 2, Link 2	2.39e-03	1 hop	1.93e-03	2 hop
Node 3, Link 2	2.53e-03	2 hop	2.28e-03	3 hop
Node 4, Link 3	2.72e-03	3 hop	2.50e-03	4 hop

this figure, we find that the overall burst loss probability for the proposed method is larger than that for the conventional hop-based burst-cluster transmission. This is because burst loss probabilities which are small by using the conventional hop-based burst-cluster transmission increase in order to improve local fairness. Nevertheless, the proposed method can provide a smaller overall burst loss probability than the original immediate reservation.

Table 1 shows the largest burst loss probabilities and its number of hops for some pairs of source node and output link. From this table, it is shown that with the proposed method, each source node can decrease the largest burst loss probability among the ones for all destination nodes further than the conventional hop-based burst-cluster transmission. These results denote that all bursts can use wavelengths more fairly.
We have evaluated the performance of the proposed method when the number of nodes is ten and we have found that the effectiveness of the proposed method increases. However, these results are omitted due to page limitation.

5 Conclusions and Future Work

In this paper, we proposed dynamic burst ordering in order to improve the local fairness for each node regardless of the amount of traffic on each link. We evaluated by simulation the performance of the proposed method for tandem networks. From the numerical examples, we found that the burst loss probabilities become almost the same for each source node by using the proposed method. In addition, the fairness index for the proposed method is much close to one, and we found that the proposed method can improve global fairness in the tandem network significantly. Although the proposed method increases slightly the overall burst loss probability, each source node can decrease the largest burst loss probability among the ones for all destination nodes further than the conventional hop-based burst-cluster transmission. Therefore, wavelengths are used more fairly among all pairs of source and destination nodes. In our future works, we will investigate the performance of the proposed method in other network topologies such as ARPA2. Moreover, this method will be extended so that exponential moving average is used to estimate burst loss probabilities.

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