Burst-Cluster Transmission: Service Differentiation Mechanism for Immediate Reservation in Optical Burst Switching Networks

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Abstract

In this paper, we propose a service differentiated burst transmission called burst-cluster transmission to provide the service differentiation in terms of burst loss for optical burst switching networks. The proposed method consists of burst assembly algorithm and burst transmission scheduling, and it works only at ingress edge node. A mixed timer/burstlength-based assembly algorithm is considered for burst assembly, and bursts with different service classes are assembled simultaneously according to the algorithm. A burst-cluster is generated so that the bursts in the cluster are arranged in order from the lowest priority to the highest one. Then the burst-cluster is transmitted according to the burst transmission scheduling. We also consider the application of the burst-cluster transmission to delay-sensitive traffic. We evaluate by simulation the performance of the burst-cluster transmission for a mesh-torus network. Numerical examples show that the burst-cluster transmission succeeds in providing different service grades even though the burst loss probabilities of high-priority service classes are affected by the traffic load of low priority ones.

Index Terms: Optical Burst Switching, Immediate Reservation, Service Differentiation, Burst Assembly Algorithm, Burst Transmission Scheduling

I. Introduction

Optical burst switching (OBS) is the promising technology for supporting the next-generation Internet over wavelength division multiplexing (WDM) networks. In OBS networks, a bursts is assembled with multiple IP packets and is transmitted from its ingress to egress nodes with a control packet. The control packet is transmitted before the burst transmission, and it reserves or releases a wavelength at each core node in order to transmit the burst. The wavelength reservation is classified into two categories: Delayed Reservation and Immediate Reservation.

In the delayed reservation which is used in Just-Enough-Time (JET) protocol, a control packet has information about the arrival time of the corresponding burst [9]. Each node predicts the arrival epoch of the corresponding burst with this information. If there exist available resources such as output wavelength and optical switch matrix inside the OBS switch, the wavelength reservation succeeds and the resources are configured just before the arrival epoch of the burst. The burst is transmitted to the next node with the configured resources. If there exist no available resources at some node, the wavelength reservation fails and the burst is lost at the node.

On the other hand, in the immediate reservation which is used in Just-In-Time (JIT) protocol, a control packet has no information about the burst arrival time. When the control packet arrives at each node, it reserves a wavelength immediately and the resources inside the OBS switch are configured [12]. Note that the resources are already configured before the arrival of the corresponding burst. Hence, the immediate reservation can not utilize wavelengths more effectively than the delayed reservation. However, the delayed reservation requires complex scheduling and vast memory at each core node [1]. The strong point of the immediate reservation is the simplicity of implementation and it has been adopted in JumpStart project with this reason.

In OBS networks, for supporting multimedia applications such as Voice over IP (VoIP), video conference, and video-on-demand, several schemes to provide the service differentiation have been studied in the literature [9]. In the delayed reservation, the service differentiation schemes such as extra offset time [13] and segmentation [11] have been proposed. In the extra offset time scheme, a high priority burst has a large offset time and the setup message can reserve a wavelength for the burst prior to low priority bursts. As a result, the small loss probability is provided for the high priority burst. However, a large offset time makes end-to-end transmission delay large, and hence the extra offset time should be determined carefully for delay-sensitive bursts.

As for the immediate reservation protocol, a probabilistic preemptive scheme has been studied [2], [3]. In the probabilistic preemptive scheme, when a new SETUP message for a high priority burst arrives at a congested node, it can preempt a low priority burst transmission with a given preemption probability. [10] has proposed a preemptive technique where two RELEASE messages are used when preemption occurs, and the effect of preemption rules on the service differentiation has been investigated. However, the preemption scheme requires the complex processing at both edge and core nodes, and to the best of our knowledge, other service differentiation mechanisms in the immediate reservation has not been considered yet.

In this paper, we focus on the burst loss probability as a measure of the service differentiation, and propose a service differentiation mechanism called *burst-cluster transmission* which works with the immediate reservation. The burst-cluster transmission consists of burst assembly algorithm and burst transmission scheduling, and those are performed at ingress edge node. A mixed timer/burstlength-based assembly algorithm [4] is considered for burst assembly, and bursts with different service classes are assembled simultaneously. A burst-cluster is generated so that the bursts in the cluster are arranged in order from the lowest priority to the highest one. Then the burst-cluster is transmitted according to the burst transmission scheduling. We also consider the application of the burst-cluster transmission for the delay-sensitive traffic. We evaluate the performance of the burst-cluster transmission for a mesh-torus network with simulation. In numerical examples, we compare the performance of the proposed method with the conventional immediate reservation and show the effectiveness of the proposed method.

The rest of the paper is organized as follows. Section II summarizes the immediate reservation and Section III describes the burst-cluster transmission in detail. Section IV presents the modified immediate reservation for the burst-cluster transmission. Simulation results are shown in Section V and finally, conclusions are presented in Section VI.

II. Immediate Reservation

In this section, we summarize the immediate reservation. In the immediate reservation, a bursts is transmitted from its ingress to egress nodes with a control packet called *SETUP message*. The SETUP message is transmitted before the burst transmission, and it configures the resources inside the OBS switch at each node (see Fig. 1). After the configuration, the SETUP message is forwarded to the next node. If there exist no available resources at some node, the SETUP message fails in the configuration and the corresponding burst is lost at the node.

In terms of the release of the resources, two methods have been developed: explicit release and

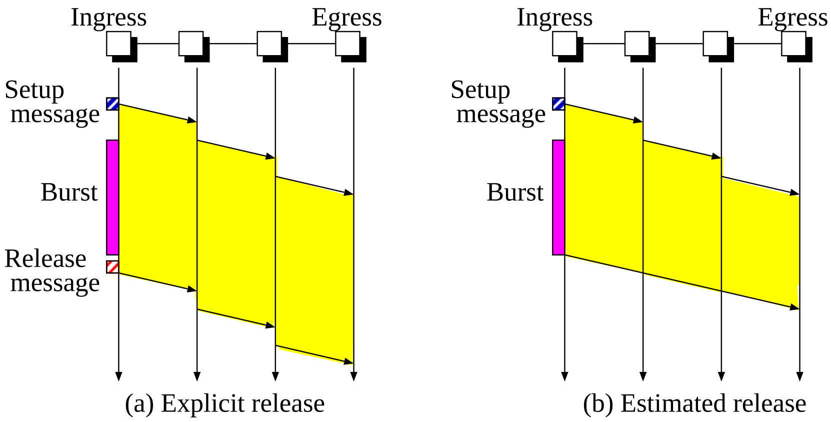


Fig. 1. Immediate reservation.

estimated one.

Explicit Release: In the explicit release, a burst is transmitted with two control packets; SETUP and RELEASE messages. Both the SETUP and RELEASE messages have a field for *call reference value*, and a unique call reference value is allocated for each burst transmission [12]. The SETUP message configures the resources in the OBS switch, and the switch stores the information of the configured resources with the unique value and the address of the ingress node. The RELEASE message releases the resources associated with the same call reference value and with the address of the ingress node.

Estimated Release: In the estimated release, a burst is transmitted only with a SETUP message. The SETUP message has information about the duration of the burst so that no RELEASE message is needed to mark the end of the burst [1]. The end of the burst is determined by the switch from the arrival of the SETUP message and the information about the duration of the burst. The configured resources are released after a timer reaches the end of the burst.

Comparing these two release methods, burst scheduling for the estimated release is more complex than the explicit release because the former requires the accurate estimation of release time. While the estimated release may have a potential positive effect on the overall burst blocking probability, the switch hardware becomes significantly more complex.

III. Burst-Cluster Transmission

The burst-cluster transmission can provide M service classes in terms of the burst loss probability. In the following, we consider the immediate reservation with the explicit release. In the case of the immediate reservation with the estimated release, the RELEASE message is not utilized.

At the ingress node as shown in Fig. 2, arriving IP packets are classified according to their egress nodes and then stored in M separate queues depending on their service classes by a classifier. A burstifier generates M bursts from the queues and the M bursts comprise a burst-cluster. In the cluster, the bursts are arranged in order from the lowest priority to the highest one. Then the burst-cluster is forwarded to a scheduler. The remarkable feature of the burst-cluster transmission is that each burst in the cluster has its own SETUP message but doesn't have its own RELEASE message. A cluster of bursts has its own RELEASE message. The scheduler determines when the M SETUP messages, the cluster (M bursts), and the RELEASE message are sent into the OBS network.

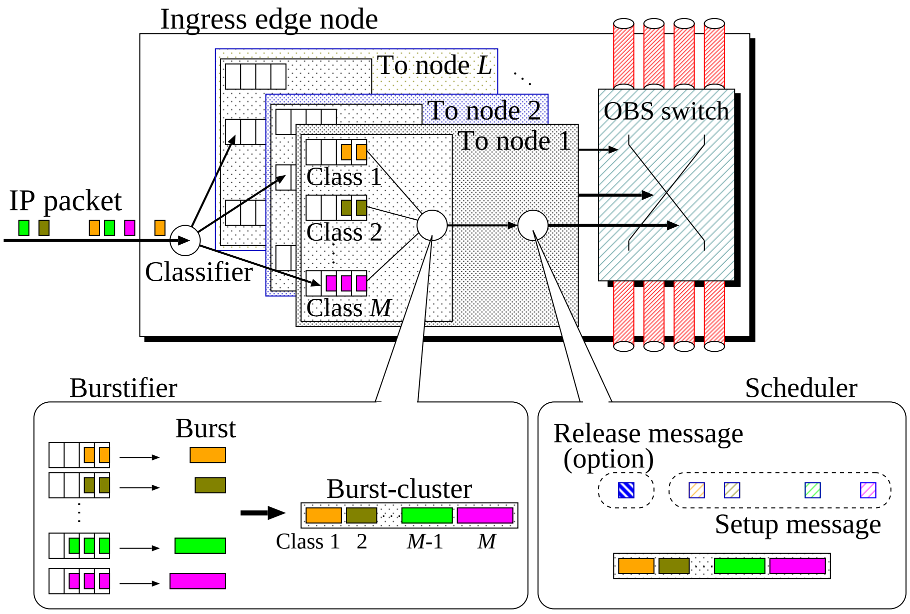


Fig. 2. Edge node for Burst-cluster transmission.

A. Burst Assembly Algorithm

In this subsection, we consider the burst assembly algorithm performed at the burstifier.

Remind that the number of the service classes is M. The class i has high priority over the class j when $i < j$ and the class i requires smaller burst loss probability than the class j. The burstifier has M queues and the queue for the class i ($i = 1, 2, \cdots, M$) is referred to as queue i. Let b_i denote the total size of packets stored in queue i just after a packet arrives at the queue. In addition, let $b_{sum} = \sum_{j=1}^{M} b_j$ denote the total size of packets stored in the burstifier. We define B_i as the size of the class i burst assembled from IP packets, and $B^{\min}$ as the minimum size of burst. Moreover, we define $BC_{\max}$ as the maximum size of a burst-cluster.

The burstifier has a timer which starts when an IP packet arrives at the burstifier in idle state. Let T denote the timer value and $T_{\max}$ the timeout value of T. Note that each queue doesn't have its own timer.

Suppose that the burstifier is in idle state, that is, there are no IP packets in any queue in the burstifier. The procedure of burst assembly is as follows. (See Fig. 3(a).)

(1) When the first packet arrives at the burstifier and is stored in queue i, the timer starts, and b_i and b_{sum} are updated with the size of the packet.

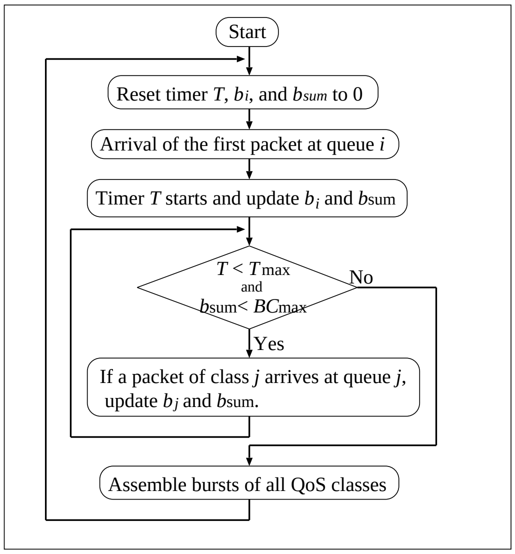
(2) Until T becomes $T_{\max}$ or b_{sum} becomes $BC_{\max}$, arriving packets of the class j ($j = 1, 2, \cdots, M$) are stored in queue j with the update of b_j and b_{sum}.

(3) When T becomes $T_{\max}$ or b_{sum} becomes $BC_{\max}$, bursts of all service classes are simultaneously assembled as follows.

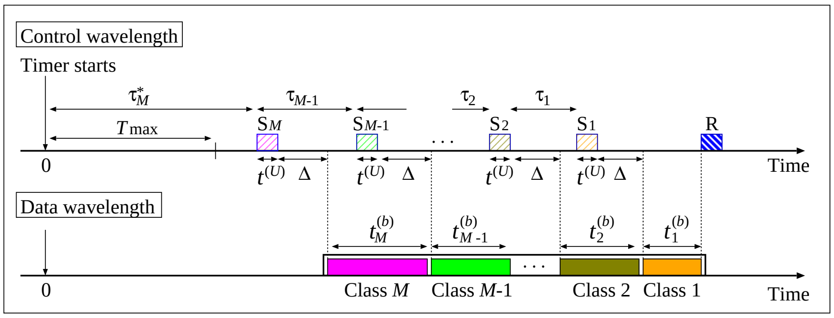
- In the case of $b_i \geq B^{\min}$, a class i burst with $B_i = b_i$ is assembled.
- In the case of $b_i < B^{\min}$, a class i burst with $B_i = B^{\min}$ is assembled with padding.

(4) T, b_i, and $BC_{\max}$ are reset to 0 and this operation is repeated.

When b_{sum} is calculated, $B^{\min}$ is used instead of b_j when b_j is smaller than $B^{\min}$. Here, $B^{\min}$ is determined with regard to the electronic processing speeds of SETUP messages, switching speed,



(a) Burst assembly algorithm.



(b) Burst transmission scheduling.

Fig. 3. Burst assembly algorithm and burst transmission scheduling.

and the maximum size of a single IP packet [8].

With the assembled bursts, a burst-cluster is generated as shown in Fig. 2. Then the burst-cluster is forwarded to the scheduler.

B. Burst Transmission Scheduling

After the burst-cluster is generated, the cluster is transmitted to the egress node according to the following burst transmission scheduling. Let S_i $(i = 1, 2, \cdots, M)$ denote the SETUP message for a class i burst in the burst-cluster and R the RELEASE message. The M SETUP messages, the cluster which includes M bursts, and the RELEASE message are transmitted from the scheduler as shown in Fig. 3(b).

In this figure, a control wavelength for SETUP and RELEASE messages and a data wavelength for bursts are depicted. Here, we assume that both transmission speeds of the wavelengths are C. The principal idea for the burst-cluster transmission is that the transmission of low-priority burst in a cluster precedes high-priority one in the same cluster.

Let τ_M^* denote the time interval between the start time of the timer and the transmission time of S_M, τ_i the transmission interval between S_{i+1} and S_i $(i = 1, 2, \cdots, M-1)$, and U the size of SETUP message. We define $t_i^{(b)} = B_i/C$ as the burst transmission time of the class i, $t^{(U)} = U/C$

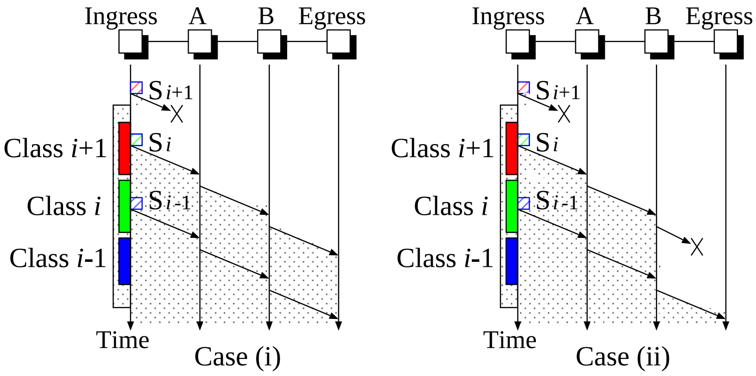


Fig. 4. Efficiency of burst transmission scheduling on the burst loss probability.

as the SETUP message transmission time, and Δ as the initial burst delay [12]. Here, Δ is given by $(H+1)\delta$ where H and δ denote the number of hops and the SETUP-message processing time at each node, respectively. We assume that the inequality $t^{(U)} \leq B^{\min}/C \leq t_i^{(b)}$ holds for $i = 1, \cdots, M$, so that consecutive SETUP-message transmissions do not overlap.

For simplicity, we assume that the timer starts at time zero. (See Fig. 3(b).) The scheduler sends the first SETUP message S_M at τ_M^*. Note that τ_M^* is larger than $T_{\max}$. The SETUP message of the class i burst $(1 \leq i \leq M-1)$ is transmitted at $\tau_M^* + \sum_{n=i}^{M-1} \tau_n$ where $\tau_n = t_{n+1}^{(b)}$, $n = 1, \cdots, M-1$. This enables consecutive burst transmissions without gap as shown in Fig. 3(b). Just after the burst-cluster is transmitted, the corresponding RELEASE message is transmitted. Note that the M bursts in the burst-cluster are transmitted with the same wavelength on each link.

C. Efficiency of the Burst-Cluster Transmission

Fig. 4 shows how the burst-cluster transmission works between ingress and egress edge nodes. If the SETUP messages S_M to S_{i+1} fail in the configuration of resources at the ingress node and S_i eventually succeeds in the configuration of resources at all nodes, bursts of classes from M to $i+1$ are lost at the ingress node, while the bursts of classes from i to 1 are successfully transmitted to the egress node (see Case (i) in Fig. 4). Because the resources are configured by S_i, S_n $(1 \leq n \leq i-1)$ does not configure other resources.

When S_i succeeds in the configuration at both the ingress node and the node A but fails in the configuration at the node B due to congestion, the class i burst is lost at the node B (see Case (ii) in Fig. 4). However, the class $i-1$ burst can be transmitted if S_{i-1} configures the resources at the node B. Therefore, it is expected that the burst-cluster transmission can provide small burst loss probability for high priority class bursts.

D. Application to Delay-Sensitive Traffic

In this subsection, we consider the application of the burst-cluster transmission to delay-sensitive traffic such as VoIP.

In the burst assembly algorithm for the burst-cluster transmission, the timer starts when the first IP packet arrives at the burstifier. A burst is assembled after the timer becomes the timeout value. After the whole burst arrives at the egress node, the burst is disassembled into multiple original IP packets. Therefore, the maximum transmission delay of the first IP packet is comprised of the time-out value $T_{\max}$, the propagation delay P, the initial burst delay Δ, and the maximum transmission

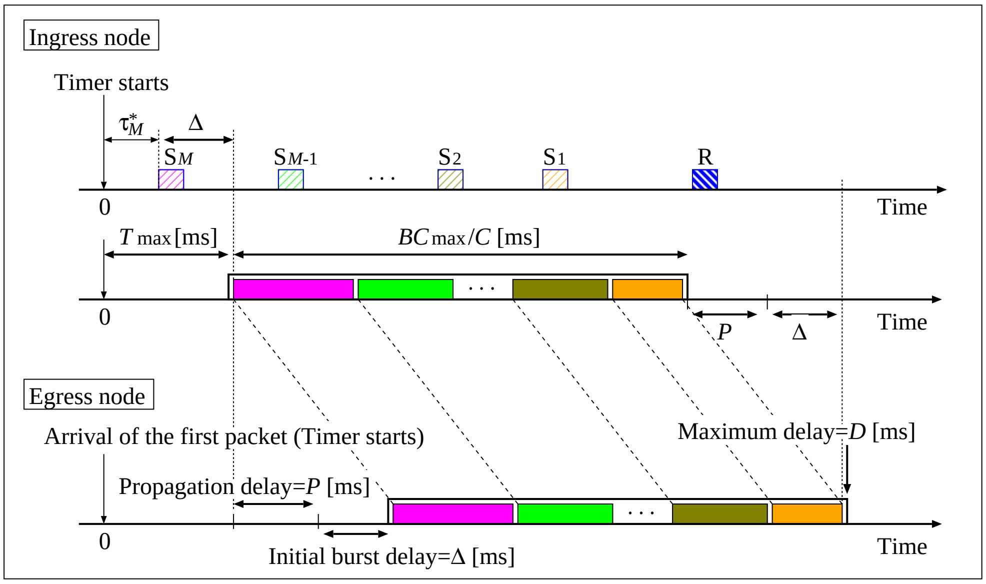


Fig. 5. Burst transmission scheduling for delay-sensitive traffic.

time of a burst-cluster $BC_{\max}/C$ where C denotes the transmission speed of a wavelength.

When the tolerable maximum delay of IP packets in an OBS network is D, $T_{\max}$ and $BC_{\max}$ should satisfy $T_{\max} + BC_{\max}/C + P + \Delta \leq D$. Moreover, the first SETUP message S_M has to be transmitted from the scheduler at $\tau_M^* = T_{\max} - \Delta$ before the burst is assembled. (See Fig. 5.)

As for VoIP, end-to-end transmission delays between 150 and 400 ms are acceptable for long distance communications [5]. We assume that the end-to-end transmission delay is 150 ms and that the tolerable maximum delay of IP packets in the OBS network is D =40 ms. We also assume that the maximum number of hops is $H = 10$ and that the SETUP and RELEASE messages processing time is $\delta = 1$ ms [8]. Therefore, the initial burst delay $\Delta = (H+1)\delta$ is equal to 11 ms. We consider the OBS network whose diameter and propagation delay are 2,000 km and $P = 10$ ms, respectively. We assume that the transmission speed of both control and data wavelengths is $C = 10$ Gbps.

From the above assumptions, $D - P - \Delta = 19$ [ms] and hence we have $T_{\max} + BC_{\max}/C \leq 19$. $T_{\max}$ and $BC_{\max}$ are decided such that $T_{\max} + BC_{\max}/C$ is smaller than or equal to $D - P - \Delta = 19$ [ms]. When we set $T_{\max} = 15$ [ms], $BC_{\max}$ is set to 4 [ms] $\times$ 10 [Gbps] = 40 Mbits in the burst assembly algorithm. In this case, τ_M^* becomes about 4 ms in the burst transmission scheduling.

Now consider how many users can be accommodated in one burst-cluster. In IPv4, eight service classes are provided by using three bits in Type Of Service (TOS) field. Here, we assume that VoIP traffic is assigned to the highest priority class. Under the condition where the amount of traffic for each class is almost the same, a burst-cluster includes one highest-priority burst for maximum 5 Mbits VoIP traffic. When the simplest voice codec (G.711) is utilized for VoIP traffic, a VoIP packet is generated every 20 msec with 160 byte voice data and 40 byte header (RTP+UDP+IP) [14]. In this case, a burst-cluster can accommodate a maximum of 5[Mbit]/(200 $\times$ 8)[bit] $= 3,125$ users. Using the recent codec such as G.729 and G.723.1 [7], it is expected that the burst-cluster can accommodate more users than G.711.

IV. Modified Immediate Reservation for Burst-Cluster Transmission

In this section, we modify the immediate reservation with the explicit release and that with the estimated release in order that the burst-cluster transmission will work.

A. The Explicit Release Case

In the case of the explicit release, we modify the following points:

- Resource status is identified with a call reference value and the address of ingress node.
- A unique call reference value is allocated to M SETUP and one RELEASE messages for a burst-cluster.
- Each SETUP message checks resource status at every OBS node.
- The SETUP message S_i succeeds in the resource configuration if for $i+1 \leq j \leq M$, S_j fails and there exist available resources at S_i's arrival epoch.
- If S_i succeeds in the resource configuration, S_k $(1 \leq k \leq i-1)$ is sent to the next core node without any configuration procedure.

Note that the reference procedure of each SETUP message prevents the switch resources from redundant configuration. This reference procedure may cause longer SETUP-message processing time than that in the original immediate reservation with the explicit release. However, the processing time of a RELEASE message in the original immediate reservation is almost the same as that of a SETUP message in the burst-cluster transmission and hence the overhead of SETUP messages in the burst-cluster transmission is similar to that of RELEASE messages in the original immediate reservation.

B. The Estimated Release Case

Next, we consider the modification of the immediate reservation with the estimated release. Here, we assume that the burst size of the class i is B_i. The estimated release is modified for the following points:

- The SETUP message S_i of the class i has information $\bar{B}_i = \sum_{j=1}^{i} B_j$ i.e., the sum of the burst sizes from the class 1 to i.
- SETUP message is modified so that a call reference value is included.
- Resource status is identified with the call reference value and the ingress node address.
- A unique call reference value is allocated to M SETUP messages for a burst-cluster.
- Each SETUP message checks resource status at every OBS node.
- The SETUP message S_i succeeds in the resource configuration if for $i+1 \leq j \leq M$, S_j fails and there exist available resources at S_i's arrival epoch.
- If S_i succeeds in the resource configuration, S_k $(1 \leq k \leq i-1)$ is sent to the next core node without any configuration procedure.
- S_i configures the resources for the duration $\bar{B}_i$ and then the resources are released.

As is the case with the explicit release, the SETUP message configures the resources with a unique call reference value. This modification causes large configuration processing time, however, this overhead is the same as that of the explicit release case.

V. Numerical Examples

In this section, we evaluate the performance of the burst-cluster transmission in a 3×3 mesh-torus network. Each link consists of an optical fiber with 16 data wavelengths and the transmission speed of a wavelength C is equal to 10 Gbps. The distance between adjacent nodes is 200 km and hence the transmission delay is 1.0 ms. A single static route between ingress and egress nodes is chosen using a routing algorithm shown in [6]. We assume that the processing time of SETUP and RELEASE messages δ, is equal to 1.0 ms and that burst loss occurs only when all 16 wavelengths are utilized.

We assume that IP packets arrive at the network according to a Poisson process with rate λ [packets/ns] and that the pair of ingress and egress nodes of an arriving packet is distributed uniformly. The size of an IP packet is fixed equal to $1,250$ bytes. In addition, we assume that the number of service classes M is equal to 4, and that the service class of an arriving packet is i ($i = 1, 2, 3, 4$) with probability p_i. The timeout value $T_{\max}$ is set to 1.0 ms or 5.0 ms, and the maximum size $BC_{\max}$ of a burst-cluster is set to 300 Mbyte. The minimum size of burst $B^{\min}$ is set to 64 Kbytes [8] and τ_4^*, the time interval between the completion time of burst assembly and the transmission time of the first SETUP message, is set to 0. In this scenario, we calculate the burst loss probability by simulation.

We also evaluate the performance of the immediate reservation with the explicit release (see Fig. 1(a)). Note that this does not provide service differentiation. When a SETUP message fails in the reservation at some intermediate node, we assume that the corresponding RELEASE message is not transmitted from the intermediate node to its ingress node.

A. Impact of Packet Arrival Rate

First, we investigate how the packet arrival rate λ affects the performance of the proposed method. Here, we set $p_1 = 0.1$, $p_2 = 0.2$, $p_3 = 0.3$, and $p_4 = 0.4$. We also consider the burst transmission with the conventional immediate reservation in which a burst is assembled according to timer-based burst assembly algorithm with timeout value $T_{\max}$.

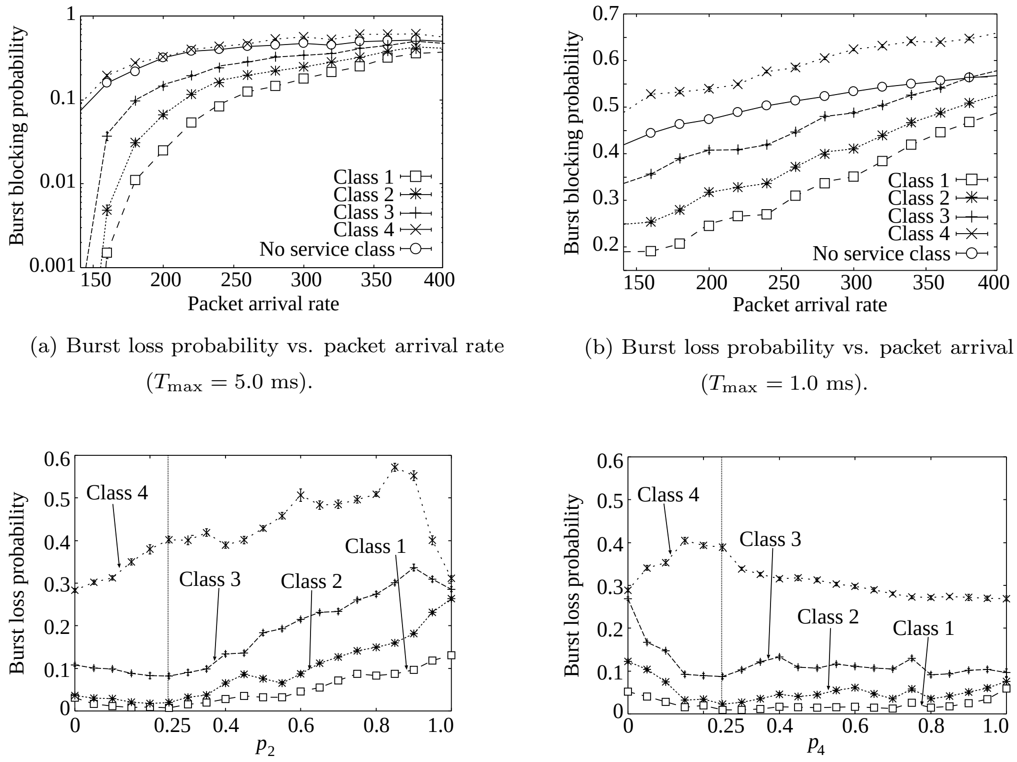
Fig. 6(a) shows the burst loss probability against the packet arrival rate in the case of $T_{\max} = 5.0$ ms. From this figure, we observe that the burst loss probabilities of four service classes are different and this implies that the proposed method succeeds in providing different service grades in terms of the burst loss probability. We also see that the difference between the burst loss probabilities becomes small as λ becomes large. Note that in this case, the burst size also increases and this results in the consecutive burst losses.

Comparing our proposed method with the conventional immediate reservation in Fig. 6(a), we observe that the burst loss probabilities of the classes 1 to 3 are smaller than that of the conventional immediate reservation. In particular, the discrepancy is remarkable when the packet arrival rate is small. Therefore, the burst-cluster transmission is significantly effective for a network with a number of wavelengths multiplexed into a fiber or a mesh-torus type network whose nodes have many output links.

B. Impact of Timeout Value

Next, we consider how the timeout value for the burst assembly affects the performance of our proposed method. Here, we set $p_1 = 0.1$, $p_2 = 0.2$, $p_3 = 0.3$, and $p_4 = 0.4$, and we also compare the burst-cluster transmission with the conventional immediate reservation.

Fig. 6(b) shows the burst loss probability against the packet arrival rate in the case of $T_{\max} = 1.0$ ms. Similarly to Fig. 6(a), we observe that the burst loss probabilities of four service classes are different. However, comparing it with the case of $T_{\max} = 5.0$ ms in Fig. 6(a), we observe that the burst loss probabilities in the case of $T_{\max} = 1.0$ ms are larger than those in the case of $T_{\max} = 5.0$ ms. Note that there exist two types of overhead time during the reservation period for a cluster: one is the overhead time from the setup completion to the first burst-arrival and the other is the



(a) Burst loss probability vs. packet arrival rate ($T_{\max} = 5.0$ ms).

(b) Burst loss probability vs. packet arrival rate ($T_{\max} = 1.0$ ms).

(c) Burst loss probability vs. p_2.

(d) Burst loss probability vs. p_4.

Fig. 6. Simulation results.

overhead time from the end of the transmission of the last burst to the instant at which configured resources are released. These overhead times are independent of the burst size. When $T_{\max}$ is small, the number of clusters to be transmitted becomes large and this results in the increase of the overhead times. This is the reason why small $T_{\max}$ increases the burst loss probabilities.

C. Impact of burst size of each service class

Finally, we consider how the burst size of each service class affects the burst loss probabilities. We set $\lambda = 200$ and $T_{\max} = 5.0$ ms. When p_i $(i = 2, 4)$ is a variable parameter, p_j's $(j \neq i)$ are given by $(1.0 - p_i)/3$. Here, p_i is set to the value in the range from 0.0 to 1.0. In the case of $p_i = 0.25$, p_j's are also equal to 0.25. Note that the mean burst size of each service class changes depending on p_i while the mean size of a burst-cluster does not change.

Figs. 6(c) and (d) show the burst loss probability against p_2 and p_4, respectively. From these two figures, we observe that different service grades in terms of the burst loss probability are provided.

From Fig. 6(c), we observe that the burst loss probabilities of the classes 1 and 2 are almost the same in the case of $p_2 = 0$, i.e., the burst size of the class 2 is the smallest. The small burst size of the class 2 causes the small interval between the SETUP messages S_1 and S_2. This results in the consecutive losses of bursts for the classes 1 and 2 and hence the discrepancy between those becomes small.

In the case of $p_2 = 1.0$ where the burst size of the class 2 is the largest, the discrepancy between the classes 1 and 2 becomes large while the loss probabilities of the classes 2, 3, and 4 are almost the same. The large burst of the class 2 results in the large interval between S_1 and S_2 and hence the discrepancy between the classes 1 and 2 becomes large. However, the large burst of the class 2 also causes small bursts of the other classes. These small bursts result in small intervals between S_2 and S_3 and between S_3 and S_4, and the corresponding burst loss probabilities become close. We observe the same tendency in Fig. 6(d). (We investigated p_1-variable and p_3-variable cases and observed the same tendency.)

In Fig. 6(c), the burst loss probability of each class increases when p_2 is larger than 0.25 while in Fig. 6(d), the burst loss probabilities do not change so much. When the traffic load of low priority class is large, the SETUP messages for high priority ones are delayed and this may increase the probability that the corresponding configuration succeeds.

On the other hand, when the traffic load of high priority class is large, the SETUP messages for low priority ones are likely to be sent consecutively and the resulting burst loss probabilities become large. Even in this case, the burst-cluster transmission succeeds in providing different service grades.

VI. Conclusion

In this paper, we proposed the burst-cluster transmission which consists of the burst assembly algorithm and the burst transmission scheduling. We also considered the application of the burst-cluster transmission to the delay-sensitive traffic. As for VoIP with G.711, it was shown that more than 3,000 users can be accommodated in one burst-cluster. We evaluated the performance of the proposed method for the mesh-torus network with simulation. Numerical examples showed that the proposed method is effective for a network with a number of wavelengths multiplexed into a fiber or a mesh-torus type network whose nodes have many output links. Though the loss probabilities for the burst-cluster transmission are sensitive to the traffic intensity of each service class, the burst-cluster transmission can provide several service grades in comparison with the conventional immediate reservation.

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