A burst assembly method to reduce end-to-end delay in optical burst switching networks

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Abstract: Although the offset-time-based scheme can differentiate loss rates of packets according to their QoS levels in optical burst switching networks, it also increases end-to-end delay of packets with higher QoS level. This is because it increases offset time of bursts in proportional to QoS levels of packets which are included in the bursts. In this paper, we propose a burst assembly method that reduces end-to-end delay. Our proposed method includes packets that arrive during the offset time into the currently assembled bursts while the conventional method includes them into the burst assembled next time. Simulation results show that our method offers 12–23% delay reduction for packets with the highest QoS level.

Key–Words: Optical Burst Switching (OBS), Offset-time-based scheme, end-to-end delay, burst assembly method

1 Introduction

The traffic demand in the Internet is drastically increasing due to applications such as video conference, video streaming and P2P file sharing. Wavelength Division Multiplexing (WDM) networks [1, 2, 3] are attractive as a next generation backbone network in the Internet because it offers huge bandwidth in the order of Tbps in a single fiber.

Optical Burst Switching (OBS) [4, 5] is emerging as a switching technology for WDM networks. In OBS networks, the unit of transmission is *a burst* that consists of IP packets with the same destination and QoS level. Thus, less processing speed on intermediate nodes is acceptable compared with Optical Packet Switching (OPS) networks where processing is required on a per-packet basis. Because OBS networks permit multiple source-destination pairs to share a single wavelength path, they achieve higher link utilization than Optical Circuit Switching (OCS) networks where a single source-destination pair occupies a wavelength path. In addition, OBS networks offer protocol and bit rate transparency by transmitting data in optical region without optical-electronic-optical (OEO) conversion.

QoS provisioning is indispensable to cope with multimedia applications such as video conference and video streaming in OBS networks. The offset-time-based scheme [6, 7] is proposed for realizing QoS in terms of burst loss rate in OBS networks. This scheme adds *extra offset time* to bursts with higher priority in addition to *basic offset time* that is used to compensate the control packet processing time at core routers. They can reserve wavelength resource in the future that bursts with lower priority cannot reserve. As a result, bursts with higher priority achieve lower loss rate.

Although the offset-time-based scheme reduces loss rate of bursts with higher priority, it also increases end-to-end delay of packets included in those bursts. This is because packets that arrive during offset time must wait for the generation of the next burst. Multimedia applications require strict constraint on end-to-end delay. Thus, we need to improve end-to-end delay when the offset-time-based scheme is applied to OBS networks.

In this paper, we propose a burst assembly method that reduces end-to-end delay. Our method reduces the delay by including packets that arrive during the offset time to the currently assembled burst. Because the burst size must be determined at the beginning of the offset time, the volume of packets that will arrive during the offset time needs to be estimated. In our method, we estimate the volume based on the average arrival rate of packets in the past. Our method is more effective for bursts with larger offset time (i.e., bursts with higher priority in offset-time-based scheme). We evaluate our proposed method with simulation. In the simulation, we investigate the influence of important parameters (i.e., topology model and traffic model) on the performance.

The rest of the paper is organized as follows. In section 2, we describe an OBS network architecture, a wavelength reservation scheme, and a conventional burst assembly method. Then, we present the offset-time-based QoS provisioning scheme and its problem in section 3. In section 4, we propose our burst assembly method to reduce end-to-end delay. We evaluate our method with simulation in section 5, followed by the conclusion in section 6.

2 Burst Transmission in OBS Network

2.1 Network Architecture

Fig. 1 shows an OBS network. It consists of edge routers, core routers, and fibers. Edge routers are located at the boundary of an OBS network. Edge routers assemble IP packets from access networks into a burst and disassemble a burst into IP packets toward access networks. Core routers are located inside an OBS network. In the wavelength path set up phase, they reserve a wavelength based on the information (i.e., transmission start time and burst length) included in a control packet. In the burst transmission phase, they relay bursts in optical region without OEO transition. After they finish relaying bursts, they release the reserved wavelength.

2.2 Wavelength Reservation Scheme

As a wavelength reservation scheme, we assume Just-Enough-Time (JET) [4] protocol is adopted, because it effectively uses wavelength resource. We can apply our proposed method to other wavelength reservation schemes such as Just-In-Time (JIT) [8] as described later.

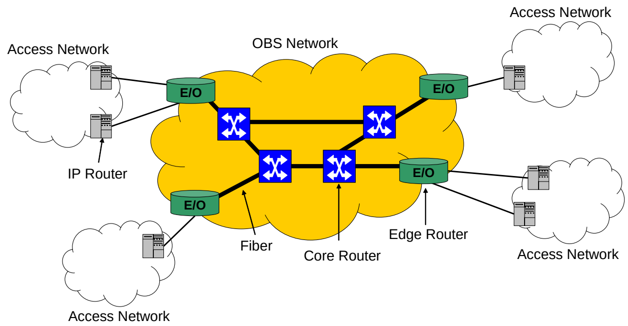

Figure 1: OBS network.

Fig. 2 shows an example of wavelength reservation with JET protocol. After a source edge router assembles a burst, it generates a control packet that includes information about the burst such as burst length. Then, the source edge router sends the control packet along the route. When each core router on the route receives the control packet, it converts the control packet into electronic signals and reserves a wavelength based on information in the control packet. The burst is buffered at the source edge router for *the offset time* after the control packet is sent. Offset time is used to compensate the control packet processing time at core routers. When the offset time passes, the source edge router sends the burst. The length of offset time must be long enough to prevent the burst from reaching the core routers before the reservation of a wavelength is completed. To meet this requirement, the offset time must be larger than t_{offset}:

$$t_{offset} = t_{proc} \times H \tag{1}$$

where t_{proc} is time required for processing the control packet on a core router and H is a hop count of the route.

2.3 Conventional Burst Assembly Method

The conventional burst assembly method aggregates a set of IP packets that arrive during a constant time into a burst [9]. Fig. 3 describes burst assembling with the conventional method. We express 1) time for the first packet to arrive at an ingress edge router, 2) time for a control packet to be sent out, and 3) time for a burst to be sent out, as t_0, t_1, and t_2 respectively. The volume

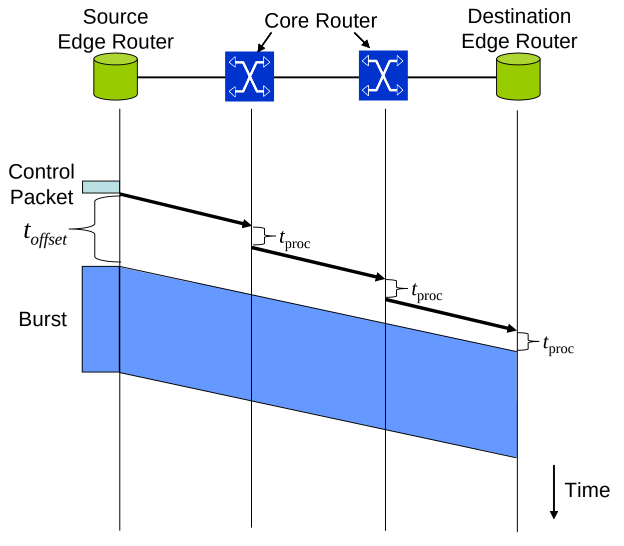

Figure 2: JET (Just-Enough-Time).

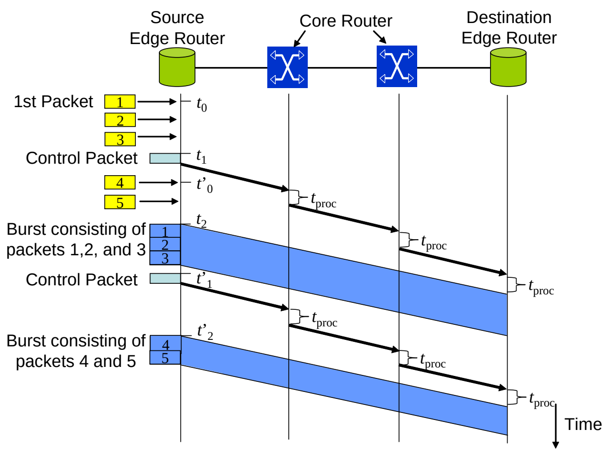

Figure 3: Burst transmission with conventional method.

of packets that arrive between a and b is expressed as $l(a, b)$. When the first packet (packet 1 in Fig. 3) arrives at an ingress edge router at t_0, it starts burst assembling process. The ingress edge router waits for the arrival of packets for a constant time from t_0 to t_1. Then, it assembles those packets into a burst. Packets that arrive during offset time from t_1 and t_2 (packets 4 and 5 in Fig. 3) are not assembled into the burst. Instead, they are assembled into the next burst. As a result, packets that arrive during the offset time experience larger delay because they must wait for the assembling of the next burst. The increase in end-to-end delay is remarkable when the offset time is set larger for QoS provisioning.

3 QoS Provisioning in OBS Networks

In IP networks, much work has been devoted to QoS provisioning. Most of them use buffer to isolate different classes of traffic. These schemes cannot be applied to OBS networks because 1) the use of electronic buffer necessitates OEO conversions at intermediate nodes, which leads to losing the protocol and bit rate transparency and 2) optical RAM is not yet available [7].

As QoS provisioning schemes for bufferless OBS networks, burst preemption scheme [10] and offset-time-based scheme have been proposed. The burst preemption scheme realizes differentiation of burst loss rate by allowing high priority bursts to preempt the resource reserved by low priority bursts. It needs an additional signaling to release the reserved resource when the preemption succeeds. In this paper, we use the offset-time-based scheme for QoS provisioning in OBS networks.

3.1 Offset-Time-Based QoS Provisioning

The offset-time-based scheme is proposed in [6] to introduce QoS into OBS networks. The scheme attains QoS in terms of burst loss rate by assigning different *extra offset-time* according to the burst's QoS class. Fig. 4 describes an example of QoS provisioning with the scheme. There are two classes of service: namely classes 0 and 1, where class 1 has priority over class 0. In Fig. 4, we assume that control packets of bursts in classes 0 and 1 are transmitted to reserve the same data channel for the same duration. In the offset-time-based scheme, we assign an extra offset time to class 1 in order to give class 1 a higher priority for wavelength reservation. With the extra offset time, the control packet in class 1 can reserve a wavelength earlier than the control packet in class 0. When the extra offset time is large enough, the loss rate of class 1 is only affected by the offered load in class 1, while the loss rate of class 0 is affected by the offered load in both classes 1 and 0.

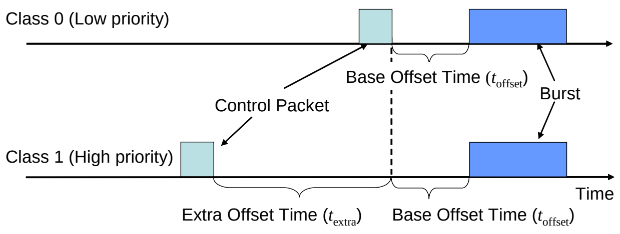

Figure 4: Differentiation of burst loss rate with offset-time-based scheme.

3.2 Problem in Offset-Time-Based QoS

Although the offset-time-based scheme can isolate the wavelength reservation of higher class bursts from that of lower class bursts, it also increases the end-to-end delay in higher class bursts [11]. When the difference of extra offset time between two adjacent classes is t_{extra} and there are N classes, the maximum additional delay is $(N-1) \times t_{extra}$. To cope with real time applications, we need to care about end-to-end delay in addition to loss rate.

4 Proposal of a Burst Assembly Method to Reduce End-to-End Delay

As described earlier, the offset-time-based scheme provides bursts with higher priority with lower loss rate. The scheme, however, also increases their end-to-end delay. To cope with this problem, we propose a burst assembly method that reduces end-to-end delay.

The key idea of our method is to include IP packets that arrive during offset time into the burst that is currently being assembled. As a result, those packets are transmitted earlier, and consequently the end-to-end delay is reduced.

Fig. 5 describes burst assembling with our proposed method. In our method, the burst length is set to $l(t_0, t_1) + e(t_1, t_2)$ at time t_1, where $e(t_1, t_2)$ is the estimated volume of packets that arrive during the offset time from t_1 to t_2. We calculate $e(t_1, t_2)$ as follows:

$$e(t_1, t_2) = (t_2 - t_1) \times B_{in} \tag{2}$$

where B_{in} is the arrival rate of M latest packets, M is a constant and is assumed to be predetermined. Note that the burst size must be determined at t_1 because

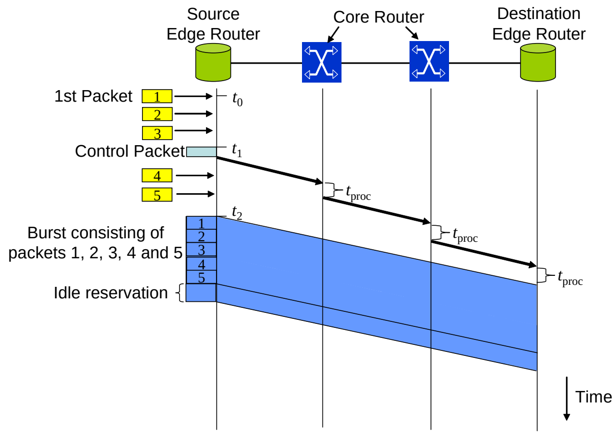

Figure 5: Burst transmission with proposed method.

the control packet sent at t_1 has to include the burst size.

In Fig. 5, packets 4 and 5, which arrive during the offset time, are also assembled to a single burst and they experience smaller delay than those in the conventional method in Fig. 3.

When the estimated burst size is larger than the actual size, the wavelength reservation time includes the idle reservation time, which may lead to lower wavelength utilization rate (i.e., higher loss rate). On the other hand, when the estimated burst size is smaller than the actual size, our method assembles estimated volume of packets into a burst and includes the overflowing packets into the burst assembled next time.

We can apply our method to immediate reservation schemes (JIT [8], JIT+ [12], and E-JIT [13]) as well as delayed reservation schemes (JET). For JIT and JIT+, which release the reserved wavelength with release packet (i.e., explicit release mechanism), our method performs the wavelength reservation based on the estimated burst size by delaying the release packet. For E-JIT, which releases the reserved wavelength based on the release time in control packets (i.e., implicit release mechanism), our method realize that by setting the release time large enough to transmit a burst with estimated size (i.e., the same way as that for JET).

5 Evaluation

In this section, we present numerical results obtained with simulation. We constructed a discrete event-driven simulator with C language and used it for the simulation. In simulation, we use 16-node mesh network (Fig. 6) and 14-node NSFNET (Fig. 7) as network models. A node corresponds to a core router. An edge router is attached to each core router. A link corresponds to a fiber with 128 wavelengths. The bandwidth of a wavelength is 10 [Gbps]. For simplicity, we assume that control channel has unlimited bandwidth and control packets are not lost. For 16-node mesh network, we set propagation delay of each link to 0.5 [ms]. For 14-node NSFNET, we set the propagation delay of each link to the value between 0.7 [ms] to 11.2 [ms] according to their length.

For traffic model, we use the following two models: 1) Pareto model (Fig. 8) and 2) Pareto ON/OFF model (Fig. 9). Pareto model has self-similarity and can generate Internet-like traffic. In Pareto model, packet inter-arrival time follows Pareto distribution with shape parameter 1.5. Pareto ON/OFF model is a more bursty traffic model. In Pareto ON/OFF model, packets are sent at fixed rate during ON period and no packets are sent during OFF period. The duration of ON period and OFF period follow Pareto distribution with shape parameter 1.5. The average duration of ON period and OFF period are set to 10 [ms]. In both models, IP packets arrive for each QoS level between all node-pairs. The input rate of IP packets for each QoS level between a node-pair is set to 1 [Gbps]. We use 4 classes of service (classes 0, 1, 2, and 3 in ascending order of priority). The offset time of one level higher class receives an extra offset time (t_{extra}). The lengths of IP packets are fixed to 1500 [byte].

In burst assembling, we set the time ($t_1 - t_0$) from the arrival of the first packet to sending the control packet to 10 [ms]. The time (t_{proc} in Fig. 2) for processing a control packet on a core router is set to 1 [ms] [14]. In our proposed method, we set the number (M) of packets used for estimating the packet arrival rate to 100. We select the minimum hop route as a route for burst transmission. As a wavelength assignment scheme, we use a random wavelength assignment, which randomly selects a wavelength among wavelengths that are idle on the first link of the route. We do not perform wavelength conversion and buffering with Fiber Delay Line (FDL). Table 1 summarizes the parameter settings.

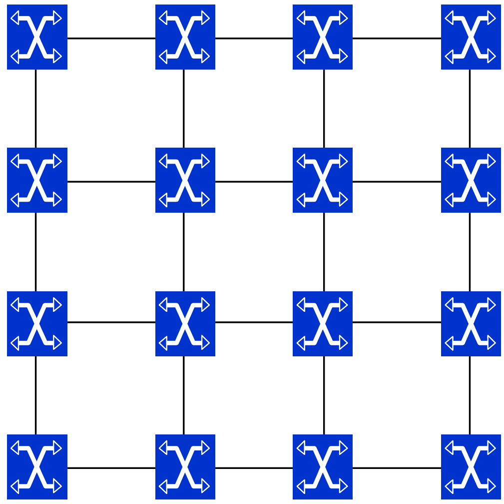

Figure 6: Mesh topology.

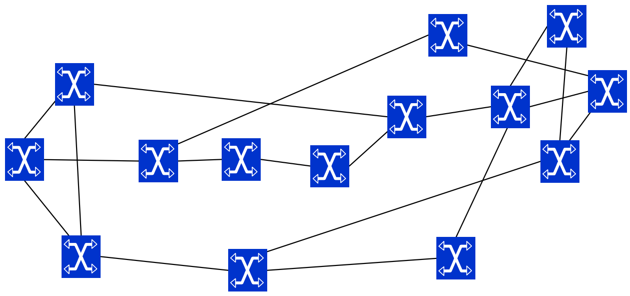

Figure 7: NSFNET topology.

Fig. 10 shows packet loss rate of each QoS class when topology model is mesh network and traffic model is Pareto model. The x-axis is the extra offset time (t_{extra}) used in the offset-time-based scheme. We express the simulation result of class i in our proposed method and that in the conventional method as (P, i) and (C, i), respectively. As the extra offset time becomes larger, the packet loss rate of packets with high QoS class decreases while that of packets with low QoS class increases. This is because larger extra offset time leads to the isolation of the wavelength reservation by higher class bursts from that by lower class bursts.

Packet loss rate of each QoS class becomes almost constant when extra offset time is greater than or equal to 3.0 [ms]. This means that setting t_{extra} to 3.0

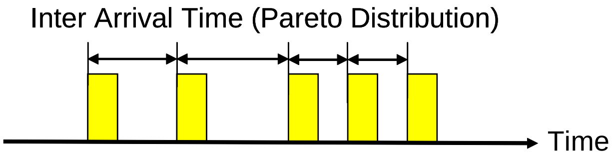

Figure 8: Pareto model.

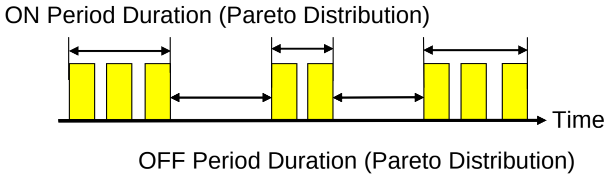

Figure 9: Pareto ON/OFF model.

[ms] is enough to isolate the wavelength reservation by higher class bursts from that by lower class bursts.

For the highest QoS level, our proposed method shows 3-9% higher loss rate than the conventional method because our method includes idle reservation time. The idle reservation time ratio (the ratio of idle reservation time to total reservation time) is 0.035. However, the increase in packet loss rate is negligibly small.

For the other QoS levels, on the other hand, our proposed method shows 1-17% lower loss rate than the conventional method does. The difference becomes larger as QoS level is lower. This can be explained as *the burst selecting effect* [11]. The burst selecting effect means that, for low QoS levels, larger *voids* lead to lower loss rate because lower class bursts have more chance to fit into voids. A void is a piece into which the wavelength reservation of higher class bursts broke free period of the wavelength. The size of void in our proposed method is larger than that in the conventional method. The size of void made by higher class bursts is proportional to the interval of sending those bursts. In our proposed method, the interval is $t_2 - t_0$ while the interval is $t_1 - t_0$ in the conventional method.

Fig. 11 shows the end-to-end delay when extra offset time (t_{extra}) varies. The end-to-end delay of level 0 bursts does not increase because the offset-time-based scheme does not give any extra offset time to the lowest level bursts. For all QoS classes, our proposed method shows smaller delay than the conventional method does. The difference between the delay in our proposed method and that in the conventional method in the same QoS level becomes larger as the QoS level increases. This is because higher level bursts are given larger offset time and our proposed method offers larger delay reduction in proportional to the offset time.

Table 1: Parameter settings

parameter	value
topology model	16-node mesh, 14-node NSFNET
# of wavelengths	128
bandwidth of a wavelength	10 [Gbps]
traffic model	Pareto, Pareto ON/OFF
shape parameter	1.5
average ON period duration	10 [ms]
average OFF period duration	10 [ms]
packet arrival rate for each QoS level	1 [Gbps]
# of QoS classes	4
packet length	1500 [byte]
burst assembling time (excluding offset time)	10 [ms]
control packet processing time	1 [ms]
M	100
routing	minimum hop
wavelength assignment	random

We compare the end-to-end delay of level 3 bursts (i.e., bursts with the largest delay) when the isolation of the wavelength reservation of higher class bursts is achieved. When t_{extra} is 3.0 [ms], the conventional method and our proposed method show 20.1 [ms] and 15.4 [ms], respectively. Our proposed method offers about 23% delay reduction.

Fig. 12 shows packet loss rate of each QoS class when topology model is NSFNET and traffic model is Pareto model. In both methods, packet loss rate of each QoS class is lower than that in 16-node mesh network because the average number of node-pairs whose route traverse a link in NSFNET is lower than that in 16-node mesh network. The average numbers in NSFNET and 16-node mesh network are 9.29 and 13.3, respectively. The difference of packet loss rate between both methods is almost the same as that in 16-node mesh network.

Fig. 13 plots the end-to-end delay when topology model is NSFNET and traffic model is Pareto model. When t_{extra} is 3.0 [ms], level 3 bursts in the conventional method and our proposed method show 29.0 [ms] and 24.5 [ms], respectively. The difference between the end-to-end delay in both methods is almost the same as that in 16-node mesh network.

Our proposed method offers about 16% delay reduction for level 3 bursts. Because the ratio of offset time in end-to-end delay becomes smaller in networks with larger propagation delay, our proposed method offers smaller delay reduction than that in the mesh network.

The simulation results for Pareto ON/OFF model are shown in Figs. 14, 15, 16 and 17. Figs. 14 (mesh network) and 16 (NSFNET) show packet loss rate of each QoS class when traffic model is Pareto On/OFF model. Packet loss rate of our proposed method in Pareto ON/OFF model becomes higher than that in Pareto model. This is because our method shows larger idle reservation time in Pareto ON/OFF model. In the model, when our method determines the burst size based on the packet arrival rate during the ON period and the OFF period begins during the offset time, our method frequently overestimates the burst size. The idle reservation time ratio of our method in Pareto ON/OFF model is 0.058 while that in Pareto model is 0.035. These values are not affected by topology model. Although the idle reservation time ratio in our method slightly increases in Pareto ON/OFF model, the difference of packet loss rate between the two method remains negligibly small in Figs. 14 and 16.

Figs. 15 (mesh network) and 17 (NSFNET) plot the end-to-end delay when traffic model is Pareto ON/OFF model. When t_{extra} is 3.0 [ms], our proposed method offers about 18% delay reduction for level 3 bursts in mesh network and about 12% delay reduction for level 3 bursts in NSFNET, respectively. The delay reduction in Pareto ON/OFF model becomes smaller than those in Pareto model because the number of packets which arrive during offset time and experiences smaller waiting time decreases. This situ-

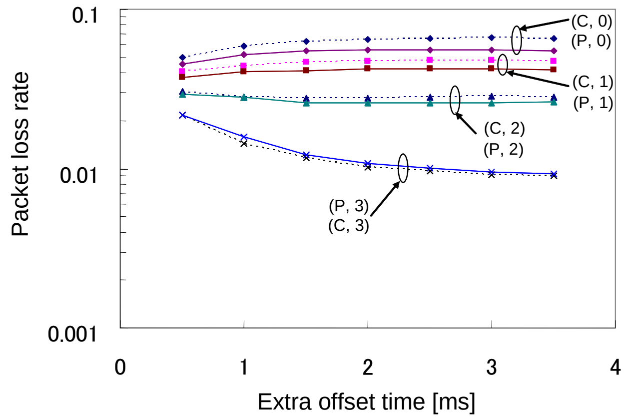

Figure 10: Packet loss rate (Mesh, Pareto).

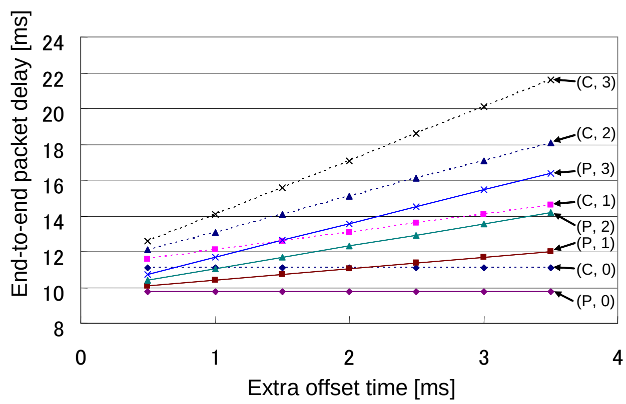

Figure 11: End-to-end delay (Mesh, Pareto).

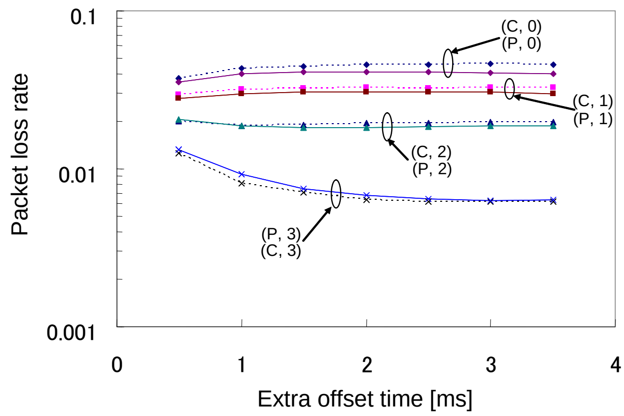

Figure 12: Packet loss rate (NSFNET, Pareto).

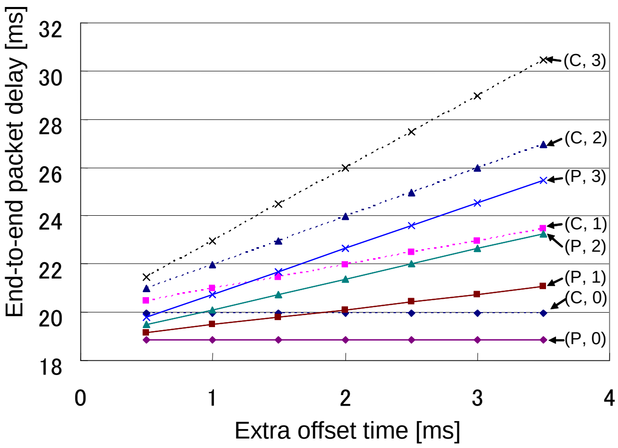

Figure 13: End-to-end delay (NSFNET, Pareto).

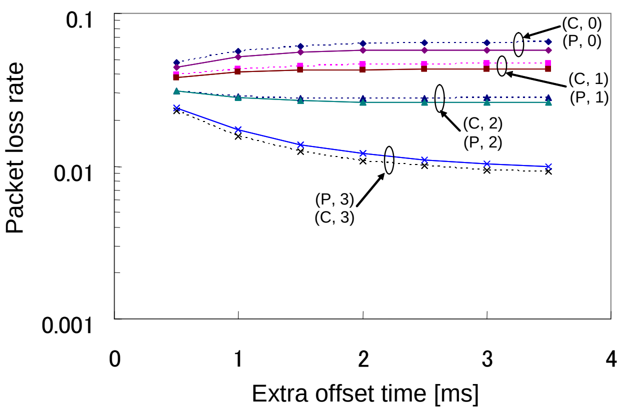

Figure 14: Packet loss rate (Mesh, Pareto ON/OFF).

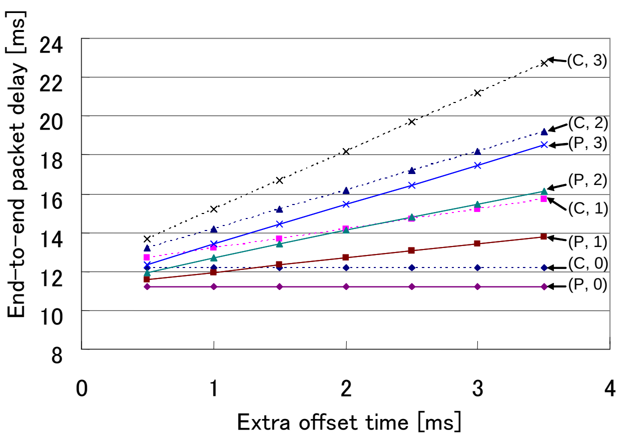

Figure 15: End-to-end delay (Mesh, Pareto ON/OFF).

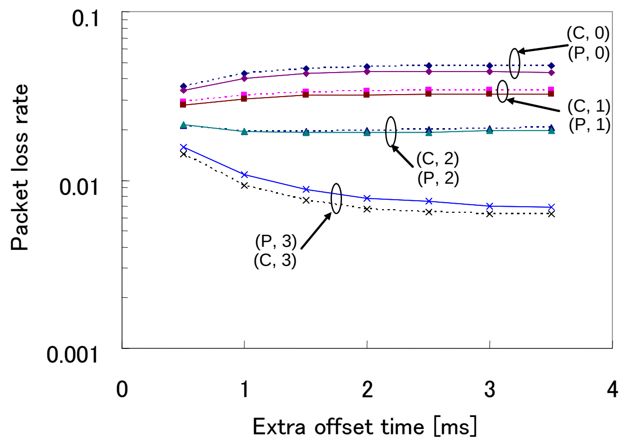

Figure 16: Packet loss rate (NSFNET, Pareto ON/OFF).

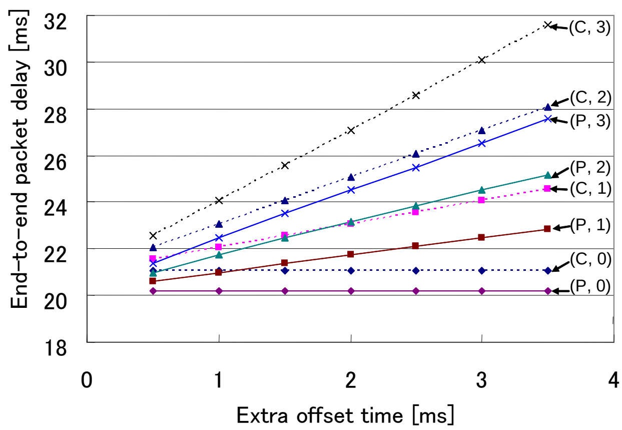

Figure 17: End-to-end delay (NSFNET, Pareto ON/OFF).

ation occurs when OFF period begins during the offset time. Although the delay reduction of our method decreases under more bursty traffic, it can still reduce end-to-end delay of packets.

6 Conclusion

In this paper, we proposed a burst assembly method that reduces end-to-end delay. Our proposed method includes packets that arrive during the offset time into the currently assembled bursts while the conventional method includes them into the burst assembled next time. Our method is more effective for bursts with larger offset time such as bursts with high priority in the offset-time-based scheme. In simulation, our method offered 12–23% delay reduction for bursts with the highest QoS level while achieving almost the same burst loss rate as the conventional method. Our method offered larger delay reduction in networks with smaller propagation delay and under less bursty traffic.

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