QoS differentiation scheme with multiple burst transmission and virtual resource reservation for optical burst switching networks

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Received April 12, 2007; revised June 14, 2007; accepted June 15, 2007;
published July 23, 2007 (Doc. ID 82050)

We propose what we believe to be a new scheme to provide basic quality of service (QoS) in optical burst switching networks. Our proposal consists of multiple burst transmission (MBT) and virtual resource reservation (VRR). With MBT, consecutive bursts headed to the same destination are serially transmitted, and, at the transmission of high-priority bursts, the wavelength resource reserved by the head burst is kept reserving for the following bursts. We call it VRR. Computer simulations show that our proposal offers a larger differentiation of burst loss than the conventional offset-based QoS differentiation scheme. Also, it can improve the burst loss rate of both high-priority and low-priority bursts. Moreover, it can minimize the burst loss rate of high-priority bursts even when the high-priority traffic occupies a large percentage of the network traffic. The proposed scheme can be applied to the future multiservice optical network architecture. © 2007 Optical Society of America

OCIS codes: 060.4250, 060.4510.

1. Introduction

The spread of broadband applications (such as P2P, data grid [1,2], and contents delivery network [3]) based on the low-cost and high-speed Internet is driving the continuous growth of the traffic that is approximately doubling each year [4].

As photonic switching technology has been greatly advancing recently, optical burst switching (OBS) [5–7] becomes a very promising candidate for the provisioning of highly dynamic bandwidth to satisfy the demand of those applications.

In an OBS network, several IP packets with the same destinations are assembled into a burst at an edge node. One-way resource reservation such as tell and go (TAG) [8], just enough time (JET) [5], and just in time (JIT) [9] is one of the main features of an OBS network. Although there are several resources in an OBS network, such as wavelength converters, a switching matrix, and an optical buffer, we mention resources as wavelength resources. The transmission of each burst is preceded by the transmission of a burst header packet, which usually takes place on a separate single channel. It starts transmitting the data burst soon after the transmission of the burst header packet. The burst header packet carries information about the burst, including the offset value, the length of the burst, its priority, etc. By configuring a switch fabric appropriately in advance based on the information of the header packet, the data burst cut through core nodes without being buffered. Of course, a burst will be buffered at core nodes only if necessary under the management of an intelligent buffer reservation scheme such as void filling [10] and the latest available unused channel (LAUC) [7]. Although the improvement methods such as a two-way [8] or hybrid [11] reservation scheme and buffer-dependent complicated scheduling algorithms [7] are proposed, basic JET [5] in which OBS is first proposed is adopted in this paper.

QoS differentiation is an important goal for an OBS network because the diversification of traffic is promoted by several network applications. Several schemes have been proposed for QoS provisioning in OBS networks [12–15]. QoS scheduling [12] is the general QoS differentiation scheme of the traditional electronic network; it assigns resources according to priority. Segmentation [13], in which the burst consists of several independent segments, drops a part of the bursts if there is congestion.

Intentional burst dropping [14] is used to provide proportionally differentiated loss probability. In this approach, a burst is intentionally dropped according to the equation that represents burst loss ratio. The above-mentioned schemes have the disadvantage that they increase both the complexity and the calculation amount at the core node. The offset-based QoS differentiation scheme [15] is the simplest way. In addition to the basic offset time needed for switch fabric configuration, an additional offset is set between the payload and its header. We describe this additional offset as a QoS offset. Altering the QoS offset yields different burst losses; i.e., different priorities. It is easy for a high-priority burst with a large offset to reserve the bandwidth, since the desired period is located in the future unused area. This is a very simple but effective approach.

There are, however, several problems associated with this approach. First, a delay due to the QoS offset increases according to the priority [14]. Second, utilization is degraded since a high-priority burst that has a large offset divides the bandwidth into small pieces. Third, the performance of high-priority bursts degrades when there are many high-priority bursts; the high-priority bursts of the same offset request the reservation of the same period.

To solve the above-mentioned problems of the offset-based QoS differentiation scheme, we propose a new QoS differentiation scheme with multiple burst transmission (MBT) and virtual resource reservation (VRR). We define a continuous series of bursts headed for the same destination as a burst group (BG). When many packets in a buffer are assembled into two or more bursts, these bursts are consecutively transmitted BG-by-BG. Special flags are set to identify a head and a tail of the BG. Wavelength reservation of each burst is independently performed as well as the conventional JET reservation protocol. Our extension of JET is that wavelength once reserved by the head burst of the BG is kept for the following bursts of the same BG; we call it VRR. The following bursts first check the virtually reserved wavelength (VRW). If available VRW exists, the reservation succeeds assuredly. Otherwise, a normal reservation is done by the JET method to the wavelength that has not been temporarily reserved. It means that the success of a head burst is equal to the success of whole bursts of the BG. Finally, VRWs are released by the tail burst promptly. Of course, if the number of wavelengths is small, a waste of available resource by VRR may increase the blocking probability. However, our proposed scheme requires only a slight change for realizing a QoS differentiation; all that is needed for VRR is to prevent the VRWs from being assigned to other bursts.

Computer simulations evaluate the burst loss probability under some conditions. They show that our proposal can obtain a QoS differentiation in terms of burst loss probability even when the ratio of high-priority bursts is high.

The rest of the paper is organized as follows. In Section 2, we present the conventional system including the JET reservation protocol, the MBT, and the offset-based QoS differentiation scheme that is mentioned as a conventional QoS mechanism in this paper. Our proposed scheme is described in Section 3. Performance evaluations are shown in Section 4. Finally, we discuss the results obtained in Section 5.

2. Conventional System

In this section, we first describe a delayed reservation in JET [5]. Second, we refer to a MBT scheme and a QoS differentiation scheme with JET.

2.A. Delayed Reservation

The basic concept of delayed reservation (DR) is shown in Fig. 1. When the control packet arrives (t_1') at the node, the bandwidth on the outgoing link is reserved from the time (t_1) the burst will arrive at this node to t_1+l_1, where l_1 is the burst duration. It enables the period from t_1' to t_1 to be used by other bursts. This results in higher bandwidth utilization, a lower blocking probability, and an improved performance.

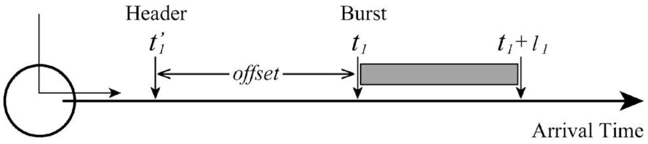

Fig. 1. DR of bandwidth in JET.

Moreover, if a burst can be buffered at the node, the blocking probability can be further reduced, and both bandwidth utilization and performance can be further improved.

2.B. MBT on JET

The importance of MBT is referred to in [16]. They consider grid computing and compact disk (CD) digital versatile disk (DVD) delivery as desired applications over OBS networks, and study an MBT scheme with forward error correction (FEC) that has been applied to recover burst loss [17,18]. If a burst among a BG is lost at some intermediate node, the lost burst will be recovered with the redundant burst at the destination. Since the redundant data degrade the efficiency, they aim to recover only one burst with one redundant burst. As a result, the performance improvement by FEC becomes small when the number of consecutively transmitted bursts increases.

2.C. Offset-based QoS Differentiation with JET

Offset-based QoS differentiation shown in Fig. 2 is considered to be the simplest and most effective approach [15], mentioned as a conventional QoS mechanism in this paper. In this scheme, bursts of higher priority are given a larger offset that consists of a basic offset and a QoS offset. In Fig. 2, the headers of each burst arrive at time t_1' and t_2', respectively, and request wavelength reservation based on the offset periods described in the headers. A low-priority burst is dropped because the desired period has already been used by another burst. A high-priority burst is not discarded because its reservation is a future unused period owing to the large offset. That is why the difference in offset results in a QoS differentiation.

There are, however, several problems associated with this approach [14]. First, the end-to-end delay increases with the number of classes. If the QoS offset difference between two adjacent classes is t_{diff} and the total number of service classes is n, the longest additional delay is $(n-1)\times t_{diff}$. Second, it tends to favor the small bursts in the low-priority service classes. The reason is that, since OBS is asynchronous, high-priority bursts with large offset will break the vacant parts of the channel into small discrete pieces, so short low-priority bursts are more likely to find sufficient capacity to permit their acceptance. Third, it encourages contention between the same priority bursts because each burst tries to reserve almost the same period, since they use the same offset. Therefore, if the ratio of high-priority bursts is high, collision increases the absolute loss rate of high-priority bursts, as shown in Fig. 3.

3. Proposed QoS Differentiation Scheme

Solving the above-mentioned problems is the goal of this research. Our proposed QoS differentiation scheme consists of MBT and VRR. We consider two (high and low) priorities in terms of the burst loss rate. MBT is applied to both high-priority and low-priority traffic. VRR is applied only to high-priority traffic.

3.A. MBT

We transmit multiple bursts to the same destination continuously in order to utilize the prereserved resource efficiently. The reservation scheme is described later. As shown in Fig. 4, packets are stored in buffers according to their destination and class. The burst scheduler selects the queue for burst generation based on queue length and waiting period. Here, we introduce the concept of a BG. A BG means the continuous arrival of data bound for the same destination. When many packets in a buffer are assembled into two or more bursts, these bursts are consecutively transmitted BG-by-BG. Two flags are used to indicate the head and the tail of each group. The head burst of the group triggers VRW construction, while the tail burst triggers VRW release. In

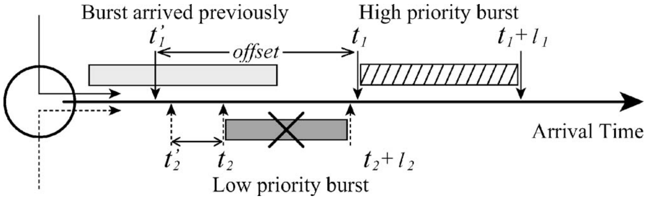

Fig. 2. QoS differentiation due to offset time.

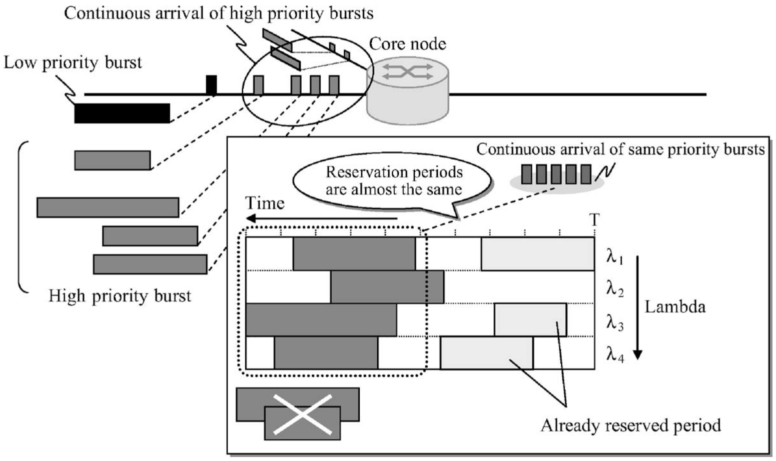

Fig. 3. Contention between high-priority classes.

MBTs that cannot be transmitted until all data are received compared with usual OBS, the delay of each burst might grow. However, it is thought that the delay until all data has been sent by using a long burst will be as long as those of the OBS that use MBT.

3.B. Virtual Resource Reservation

VRR holds the once-used wavelength resources for the following bursts to the same destination. Figure 5(a) shows resource reservation in the general OBS network with JET, where each burst tries to reserve the resources hop-by-hop. Since wavelength resources are reserved on a first-come–first-served basis, bursts are randomly dropped regardless of their priority.

VRR keeps the wavelength assigned to the head burst as a VRW for subsequent bursts in the same group, as shown in Fig. 5(b). Since the VRW prevents the reassignment of the resource, none of the bursts in the group experience a contention if the head burst succeeded. Even if the head burst fails to the reservation (i.e., VRW construction), the other following bursts are transmitted independently using the JET protocol. That is why VRW is superior to the transmission based on a long burst, for examples whose length equals group size, which is provided by a modified burst assembly technique. To prevent the reserved resource from being wasted, we add the above-mentioned MBT that transmits bursts group-by-group. VRW is assuredly released because the tail burst is absolutely transmitted when succeeding in the construction of VRW.

VRR is realized by extending the conventional JET reservation protocol. Figure 6 shows the flow chart of VRR. We use a VRW table that has one entry for each wavelength. The VRW table is associated with each output link of each node, and hence the flow chart is applied in each node once the outgoing link to send the burst has been decided. The value of an entry indicates whether the wavelength has been reserved as a VRW or not. When the header of a burst of group i arrives at a given node, the node first checks the VRW table. If a wavelength has already been assigned for group i, that wavelength is assigned to the burst. If no VRW has been assigned, the node searches for an available wavelength.

Intermediate nodes can assign only the same wavelength as the incoming burst, since they have no wavelength conversion capability. Only the source node has flex-

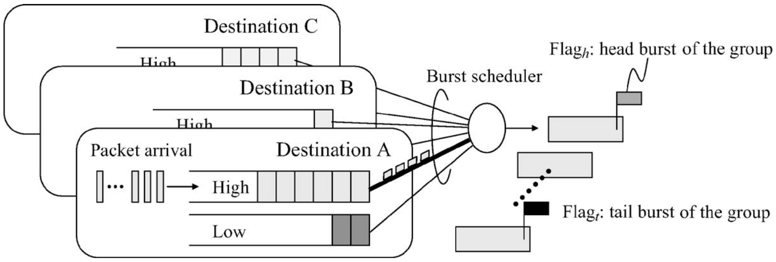

Fig. 4. Multiple burst assembly with QoS differentiation.

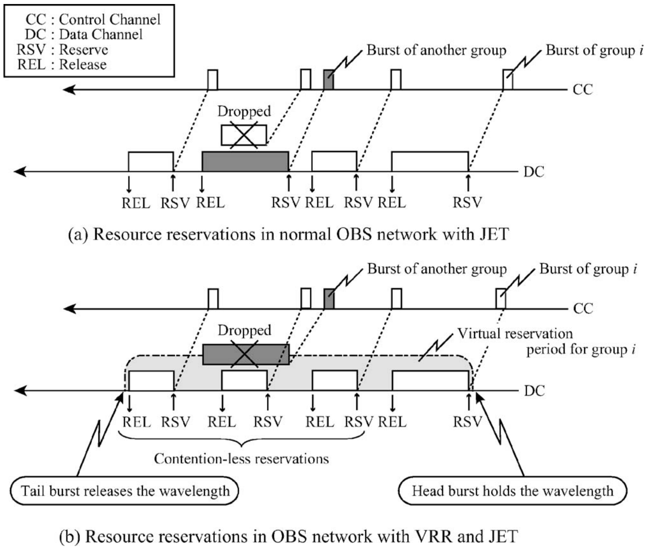

Fig. 5. Resource reservation: (a) Normal OBS network with JET (b) OBS network with VRR and JET.

ibility in wavelength assignment; it checks the availability of all wavelengths. If there are no available wavelengths, the burst is discarded. If several wavelengths can be used for transmission, one of them is randomly selected. As a wavelength assignment scheme, we use a random assignment that has been adopted in several wavelength routed wavelength-division-multiplexing (WDM) networks [19,20]. Other wavelength assignment schemes such as first fit [21] can be adopted without missing the advantage of our proposal. After that, wavelength resources are reserved using JET. After the reservation, the VRW table is updated according to the burst flag. If the flag shows a head burst, the node modifies the appropriate entry in the VRW table. If the flag shows the tail burst, it deletes the relevant entry.

4. Performance Evaluations

First, we confirm the effect of MBT and VRR by comparing them with a normal OBS. Next, we evaluate the priority control using it. We evaluate the performance of the

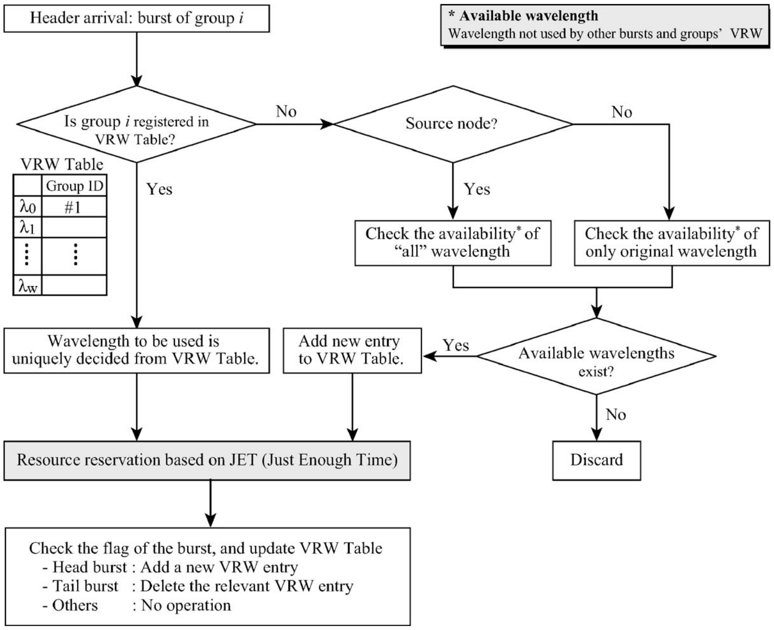

Fig. 6. Flow chart of the virtual resource reservation.

burst loss rate (BLR) in two kinds of network topology: bus topology and NSFnet. BLR is defined as the ratio of dropped bursts to arriving bursts.

4.A. Simulation Model

We use a simple bus topology with 14 nodes for evaluating a basic performance of MBT and VRR. Additionally, we evaluate on NSFnet with 14 nodes as shown in Fig. 7. In both topologies, each link consists of an optical fiber with 16 data channels and one control channel, and the transmission rate on each channel is 10 Gbytes/s. The link length in bus topology is 1000 km. The distances between adjacent nodes in NSFnet are from 300 to 2800 km. A static route between ingress and egress nodes is chosen according to the shortest path routing with Dijkstra's algorithm [22]. We assume that neither wavelength converter nor buffer are equipped in each node; of course, if this equipment exists, the performance of both the proposal and the conventional can be improved further. Our simulation program is written using C/C++.

At each edge router, the aggregate packet arrival process is superimposed by an independent ON/OFF source, because we assume bursty traffic of contents delivery network (CDN) and Grid. We assume that the durations of the ON and OFF periods are exponentially distributed; the minimum ON (OFF) period duration is 1 (0) burst. Bursts arrive at every time slot during the ON period, which is defined as a BG. Therefore, the ON period duration represents the number of bursts in a group. Burst length was fixed at 15,000 bytes based on the burst length distribution in [7] where a channel speed is 10 Gbytes/s and a burst assembly time is 8 μs. A lot of research [23–25] was performed for the burst length, and we think that the optimal burst length depends on the traffic condition of arrival IP packets such as self-similarity. To evaluate an exact performance of MBT and VRR, we fix the burst length. The average ON period carries four bursts with a maximum of 20 bursts. When the size of an arriving BG is two or more, VRR is applied. Otherwise, bursts are transmitted without using VRR as the same as a normal OBS, because it cannot release the VRW when the size of the BG is 1. The impact of an average ON period will be evaluated in Subsection 4.B. Our target is the application that transmits large data such as CDN. Continuous arrival data are assembled into some bursts, which are transmitted serially. That is why we assume that an interval between each burst in the same BG is 0. It is thought that our proposal wastes the bandwidth if a sparse arrival datum causes a long burst interval. However, there is no performance degradation by the proposal, because our proposal is not applied for such traffic. Of course, more research should be necessary for the method of predicting whether it is a continuous traffic or a discrete traffic.

4.B. Effect of MBT and VRR

Figure 8 plots the effect of MBT and VRR according to the input load in bus topology. "OBS with a long burst" means that bursts in BG are transmitted as a single long burst. From this figure, we see that BLR of OBS with a long burst is worse than a normal OBS. The reason is that a loss of a long burst is equal to the loss of many bursts of usual length. On the contrary, BLR of our proposal is improved. The reason is that the success of the head burst's reservation enables two or more following bursts to be transmitted without blocking. MBT and VRR are more effective on NSFnet, as shown in Fig. 9. The reason is that the room of the wavelength resource of each link is large because the load of NSFnet is distributed compared with a bus topology. The following figure proves it.

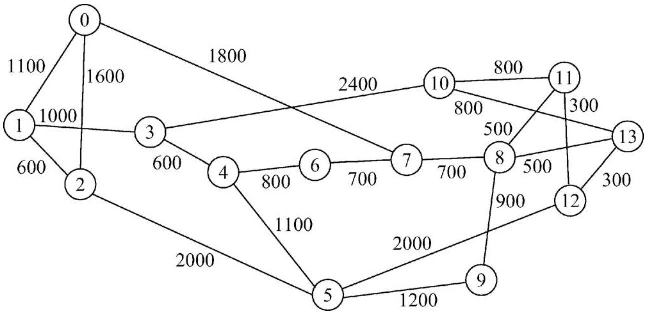

Fig. 7. Network model: NSFnet with 14 nodes.

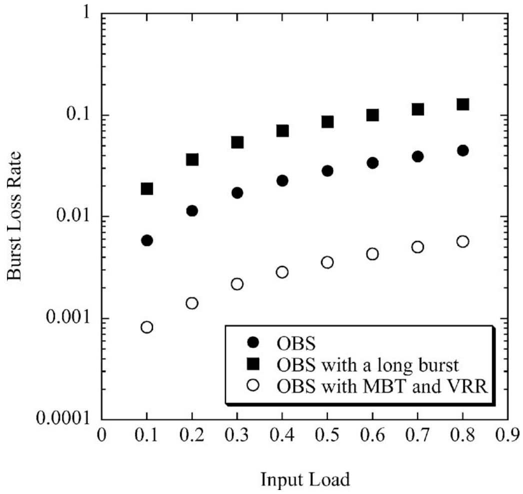

Fig. 8. Effect of MBT and VRR versus the input load (bus topology).

Figure 10 shows the BLR versus the number of wavelengths per link in the bus topology. In this evaluation, the input load is 0.4. From this figure, we can recognize that the effect of our proposal is small when the number of wavelengths is few (i.e., when the load of each link is high).

4.C. QoS Differentiation

Figure 11 shows the BLR QoS differentiation versus input load in bus topology. We assumed that high-priority bursts occupied 50% of the traffic. Our proposed scheme can match the QoS differentiation achieved by the conventional offset-based QoS differentiation scheme. In addition, the BLR value of both high-priority and low-priority traffic is better than those of the conventional scheme. Our proposal is also effective in NSFnet, as shown in Fig. 12. Also, we can see that our proposal maintains the BLR difference between high priority and low priority. The reason for the better performance of the NSFnet compared with the bus topology is that the average load per link in NSFnet is low, since traffic is globally distributed to a wide area.

In Fig. 13, we compare our proposal with a QoS differentiationless OBS in terms of the total BLR. The deterioration in total BLR is one of the major problems with the conventional offset-based QoS differentiation scheme. This is caused by the blocking effect created by the additional offset. To the contrary, the deterioration of our scheme is slight. The reason is that the performance improvement offered by the combination of MBT and VRR is large enough to cancel the performance degradation created by the waste of wavelength resource by VRR.

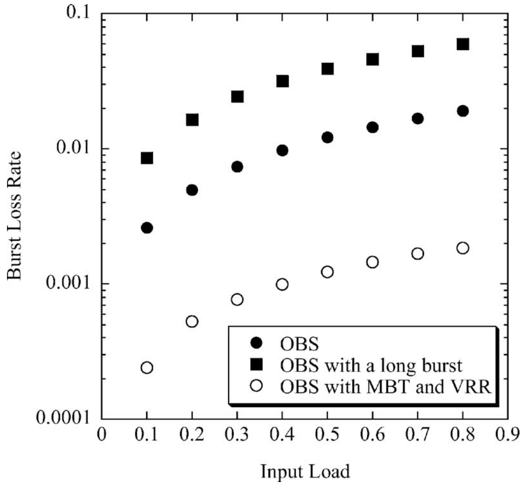

Fig. 9. Effect of MBT and VRR according to the input load (NSFnet).

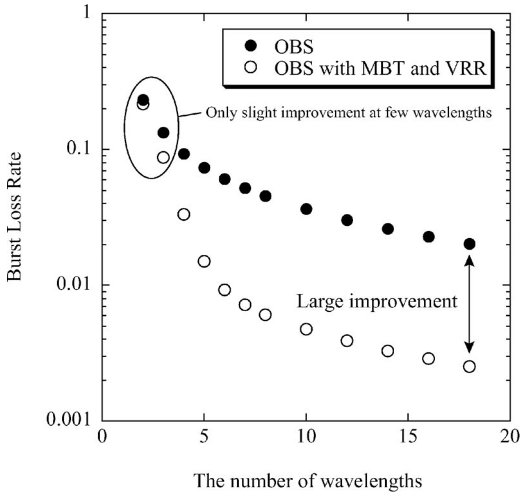

Fig. 10. BLR versus the number of wavelengths per link (bus topology).

Figure 14 shows the influence of the average group size, where high-priority bursts occupy 50% of the traffic. It is shown that the BLR of high-priority data to which our proposal is applied is much improved when the number of group size is large.

Figure 15 shows BLR versus the ratio of high-priority burst. With the conventional offset-based approach, burst loss of high-priority traffic increases with the high-

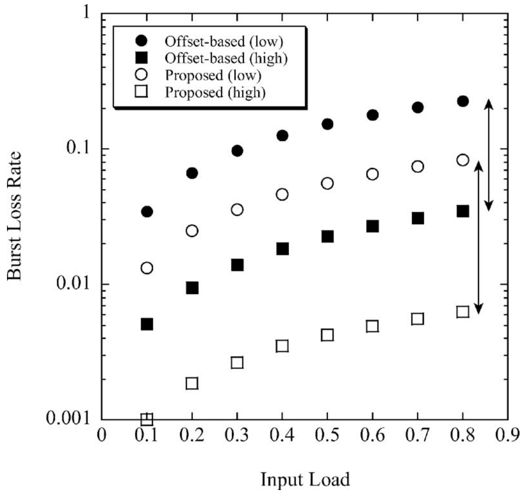

Fig. 11. Result of BLR QoS differentiation according to the input load (bus topology).

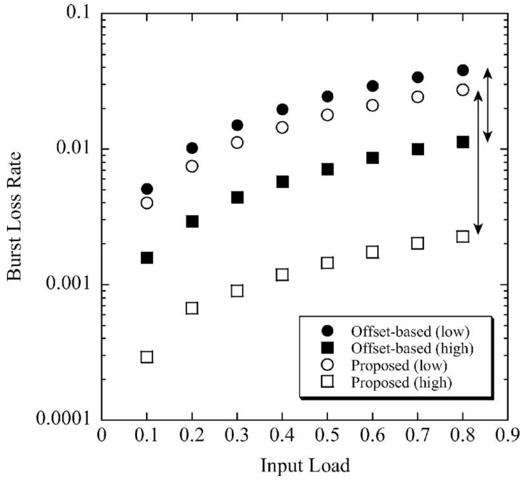

Fig. 12. Result of BLR QoS differentiation according to the input load (NSFnet).

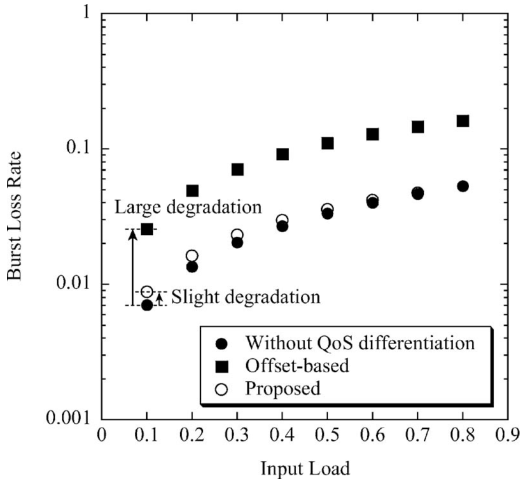

Fig. 13. Total BLR compared with QoS-differentiationless OBS (NSFnet).

priority ratio. The reason is that the conventional offset-based QoS differentiation scheme cannot avoid burst contention between the bursts with the same priorities. In the proposed scheme, on the other hand, high-priority bursts have low BLR even when the ratio of high-priority burst is high. The reason is that the VRWs assure the transmission of at least one high-priority group.

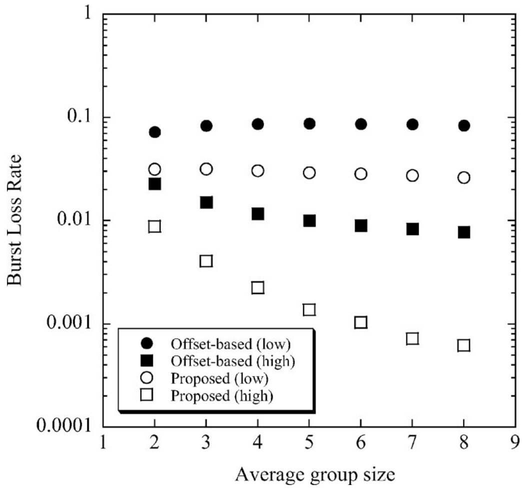

Fig. 14. BLR degradation effects versus the average group size (NSFnet).

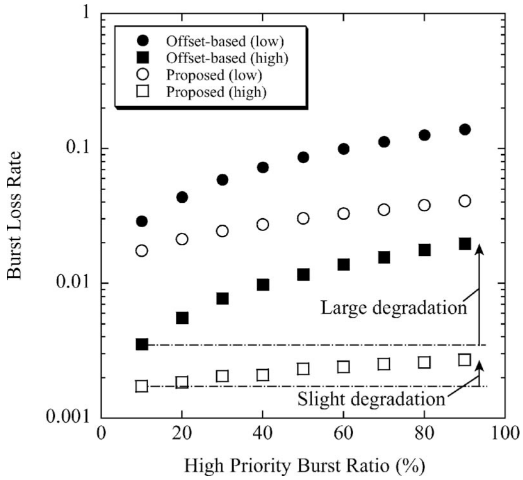

Fig. 15. BLR characteristics dependence on the high-priority burst ratio (NSFnet).

5. Conclusion

This paper proposed a new QoS differentiation scheme with multiple burst transmission and virtual resource reservation; the head burst of a group (a series of consecutive bursts traveling to the same destination) tries to reserve a wavelength for all bursts of the group. The following bursts are transmitted without fail across the resource, and the tail burst releases it. Computer simulations showed that our scheme can achieve a QoS differentiation while slightly degrading the total burst loss rate. We also showed that our proposed scheme can provide a QoS differentiation even when the ratio of high-priority bursts is high.

Acknowledgment

This work is partly supported by the National Institute of Information and Communications Technology (NICT), Japan and the Support Center for Advanced Telecommunications Technology Research, Foundation, and the Japan Society for the Promotion of Science (JSPS) grant-in-aid for Scientific Research.

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