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A mechanism of QoS differentiation based on offset time and adjusted burst length in OBS networks

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Abstract: Quality of service (QoS) differentiation is an integral component of any networking system, particularly, with the current and future great diversity of users' applications and their manifold requirements. In optical burst switching (OBS) networks, there are two approaches for QoS differentiation: one is based on offset time and the other is based on burst length. This paper presents a mechanism of QoS differentiation based on both offset time and burst length, in which the offset times are calculated to achieve a complete isolation of data loss between priority classes and the burst length is adaptively adjusted according to the feedbacked void size. The simulation results show that the mechanism of QoS differentiation based on offset time and adjusted burst length not only increases the successful scheduling rate but also reduces the burst delay.

Key words: Optical burst switching, quality of service, feedback, adaptive control, performance evaluation

1. Introduction

Optical burst switching (OBS) technology has been proposed as a promising switching solution for the exploitation of terabit bandwidth in next-generation dense wavelength division multiplexing (DWDM) optical transport networks [1, 2]. In an OBS network, ingress nodes aggregate IP packets electronically coming from access networks into bursts that optically come through the core OBS network. As soon as a burst is completed, a burst control packet (BCP) is created and sent to the core OBS network to attempt to reserve wavelength resources at each intermediate node. After an offset time, the burst follows its BCP without waiting for acknowledgment. At each core node, if the wavelength resource requirement has been satisfied, the burst will come through successfully; otherwise, it will be dropped. When the burst reaches its egress node successfully, the IP packets are retrieved. Figure 1 shows the architecture of an OBS network.

With the great diversity of media communication services, such as real time video, telemedicine network, video conferencing, on-line banking and other multimedia applications, quality of service (QoS) differentiation is an integral component of any networking system. For traditional IP networks, QoS differences can be made through coding mechanisms [3] or routing/switching policies with intelligent control [4, 5] in wired or wireless networks [6]. In OBS networks, QoS differentiation can be made at the ingress node in one of two approaches, which is based on offset time [7, 8] or burst length [9, 10]. With the offset time-based differentiation, the high priority burst is set to the offset time which is greater than that of the low priority burst; If a contention occurs, the burst with large offset time is scheduled, while the burst with short offset time is dropped. In case of the

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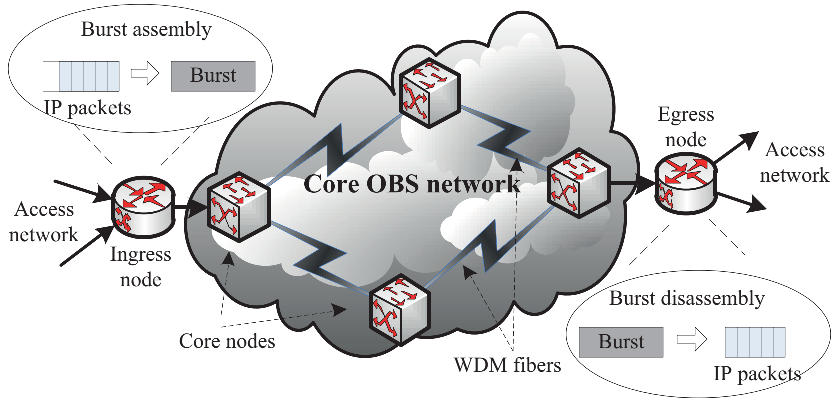

Figure 1. The architecture of an OBS network.

burst length-based differentiation, the high priority burst is set to short length, while the low priority burst has longer length; The reason is because the burst with short length has the probability of successful scheduling with void filling which is higher than that of the burst with long length.

QoS differentiation which is based on both offset time and burst length can be a better approach, because on one hand the offset time-based differentiation has been integrated in the just-enough-time (JET) protocol [11], which has been implemented in almost OBS networks, and on the other hand the burst length-based differentiation increases the probability of successful scheduling with void filling for the burst with short length. However, the scheduling with void filling is only successful if the burst length is smaller than the void size and the head/tail overlapping does not occur. In other words, if there is a mechanism to adjust the size of bursts so that successfully filling them into voids and adjust the arrival time of bursts to eliminate overlap, the scheduling performance will be significantly improved.

This paper proposes a mechanism of QoS differentiation based on offset time and adjusted burst length, in which the offset time is calculated to achieve a complete isolation of data loss between priority classes and the burst length is adaptively adjusted based on the feedbacked void size. Specifically, this mechanism includes a proposal on how to set the offset time for two consecutive priority burst classes so that the isolation of data loss based on offset time is also used to differentiate priority bursts in JET protocol. To increase the probability of successful scheduling with void filling, another proposal is to adjust the burst length generated at the ingress node based on the void size feedbacked from the core nodes. Simulation results show that the proposed mechanism of offset time and adjusted burst length differentiation (OT-ABLD) is efficient in terms of burst loss and delay reduction.

The organization of next sections is as follows: Section 2 introduces the works related to QoS differentiation in OBS networks that focuses on the mechanisms based on offset time and burst length. Section 3 provides a detailed description and analysis on the proposed mechanism of QoS differentiation based on offset time and adjusted burst length; an improved control packet structure is also proposed for feedbacking void size. Simulation results and analysis are presented in Section 4. The conclusion is in Section 5.

2. Related works

The mechanisms of QoS differentiation in OBS networks can be integrated in the operations of burst assembly and resource allocation at ingress nodes or the operations of burst scheduling and contention resolution at core nodes. With the burst assembly, QoS differentiation can be made by setting differential offset times [7, 8] or burst lengths [9, 10] for priority classes. In the case of resource allocation-based QoS differentiation, wavelengths can be statically or dynamically grouped to allocate for priority classes [12]. QoS aware resource allocation can be done during the operation of routing and wavelength assignment (RWA), that is formulated as a bi-objective optimization problem and an evolution algorithm is used to find routing strategies for priority classes [13]. The QoS aware RWA problem is also extended with the time-slot allocation when it is considered in time-sliced OBS networks and an ant colony optimization is used to solve the multiobjective problem [14]. Regarding the QoS aware scheduling, the proposal in [15] is a combination algorithm that latest available unscheduled channel (LAUC) [16] is called for scheduling the high priority burst in order to keep a low complexity, whereas first fit unscheduled channel with void filling (FFUC-VF) [16] is employed for scheduling the low priority burst in order to exploit idle voids and get a reasonable complexity. The QoS aware contention resolution is probably the most interesting with the proposals based on fiber delay lines (FDLs) [17], deflection routing [18], or a combination of FDLs and deflection routing. In this paper, we focus on the mechanisms of QoS differentiation based on offset time, burst length or both offset time and burst length at ingress nodes.

In order to support QoS differentiation, the architecture of ingress nodes may be inherited from [19] which is described as in Figure 2. In this architecture, the routing module (RM) selects the appropriate output port for each packet and sends the packet to the corresponding burst assembler (BA) module. Each BA module has priority queues for corresponding egress nodes and each queue just collects the packets with the same priority class. As shown in Figure 2, there are two queues for two priority classes, $q(0)$ for high priority (HP) and $q(1)$ for low priority (LP); When the timer or length threshold of a queue is reached, scheduler (S) creates a burst and send it to the output port.

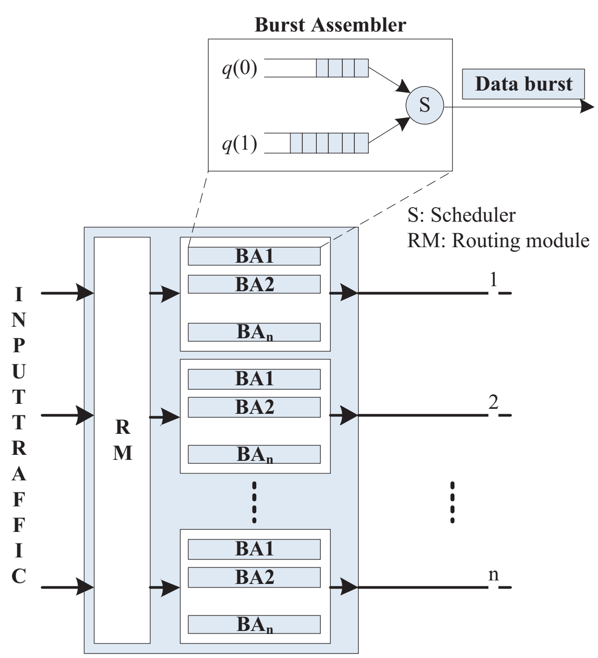

Figure 2. The architecture of ingress OBS nodes which supports QoS differentiation.

There are two approaches for QoS differentiation at ingress nodes: offset time-based differentiation (OTD) [7, 8] and burst length-based differentiation (BLD) [9, 10]. With OTD, the HP burst is added an extra offset time, instead of only the basic offset time as in the LP burst. Therefore, when a contention occurs, the LP burst with short offset time is dropped to save resources for the HP burst with large offset time (Figure 3a). The OTD approach has the advantage that it has been integrated into the JET protocol. However, due to the extra offset time, the HP burst suffers from an extra delay. In addition, according to the communication principle of OBS networks, the offset time is gradually deducted as the burst passes through each intermediate node and decreases as it gets closer to the destination; a HP burst with short offset time (because it is closer to the destination) can be dropped when contending with a LP burst with longer offset time (because it just left the source). This is an unfair issue in OBS networks [20, 21], but not within the scope of this paper.

With BLD, the HP burst is limited to small size in order to increase the probability of successful scheduling with void filling, while the LP burst with larger size will be hard to fill the voids (Figure 3b). However, a problem in BLD is that the ingress node does not know the size of voids generated at the related core nodes, so it is necessary to feedback the value of void size from the core nodes so that the ingress node can resize the generated bursts appropriately.

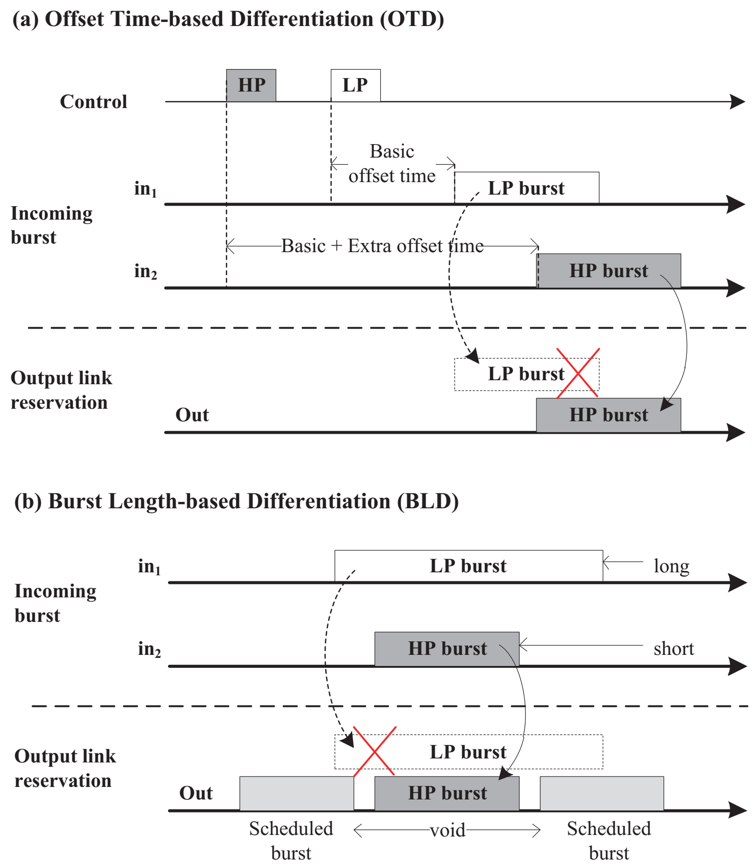

Figure 3. Types of QoS differentiation at ingress nodes: (a) based on offset time and (b) based on burst length.

The value of void size feedbacked from core nodes can be carried in the control packet whose structure is described as in Figure 4 [22]. There are four proposed types of control packet: SETUP is used to reserve resources and configure switches in core nodes; ACK is used to announce a delivery success; NACK is used to notify a delivery failure and RELEASE is used to free up resources that were previously reserved at upstream nodes. In this structure, PDU CTRL field only uses 10 of 16 bytes and 6 remaining bytes are idle; therefore these idle bytes can be used to carry the value of void size.

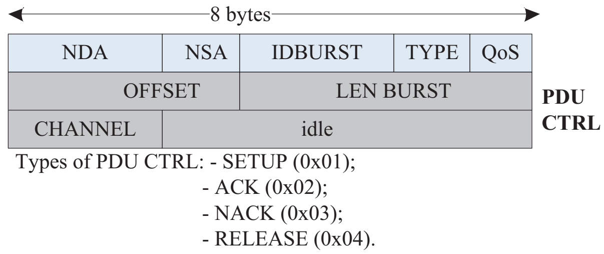

Figure 4. The structure of control packets in the JET protocol.

3. Mechanism of QoS differentiation based on offset time and adjusted burst length

The mechanism of QoS differentiation proposed in this paper is a combination of OTD, BLD and the burst length adjustment based on feedbacked void size. This is therefore called the mechanism of offset time and adjusted burst length differentiation, abbreviated as the OT-ABLD mechanism.

3.1. Void size feedbacked from core nodes

Using the algorithm of scheduling with void filling at core nodes, a burst that cannot be scheduled into a void due to three following reasons: the burst length is larger than the void size (Figure 5a), the burst length is smaller than void size but the arrival time of burst is before the start time of void ($s_b < s_v$), called the head overlap (Figure 5b), and the burst length is smaller than the void size but the end time of burst is after the end time of void ($e_b > e_v$), called the tail overlap (Figure 5c).

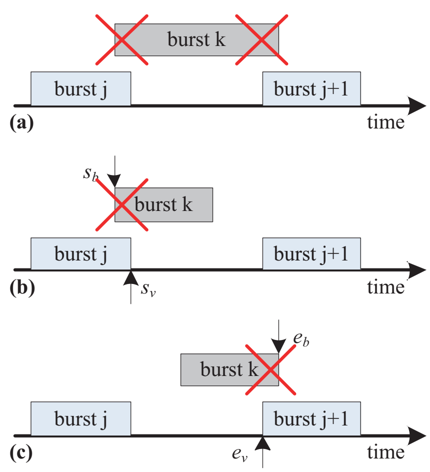

Figure 5. The cases of unsuccessful scheduling with void filling.

In order to increase the probability of successful scheduling, the ingress node need to know the size of voids to adjust the burst length and know the length of head/tail overlaps to send the burst at appropriate time. In fact, with different arrival loads, the size of created voids and the length of head/tail overlaps are varied arbitrarily. Particularly, when the arrival load is heavy, more bursts with large length are generated and more voids with small size is created. A simulated survey was performed in which the following four values were calculated: the rate of successful void fillings to the total arrival bursts, the rate of bursts being greater than voids to the total arrival bursts, the rate of head overlaps to the total arrival bursts and the rate of tail overlaps to the total arrival bursts (Table 1). The simulation is performed in 1s with the BLD mechanism and the normalized arrival load increases from 0.1 to 0.9.

Table 1. The rate (%) of successful void filling, of bursts being greater than voids, of head overlaps and of tail overlaps to the total arrival bursts.

Normalized loads	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
Successful void fillings	100	93.55	87.92	70.51	63.37	47.75	32.70	20.62	10.89
Bursts being greater than voids	0	2.82	5.06	16.03	28.96	47.90	63.12	76.25	82.88
Head overlaps	0	3.63	7.02	13.46	7.33	3.77	3.68	2.56	5.64
Tail overlaps	0	0	0	0	0.34	0.58	0.51	0.56	0.58

Based on the simulation results in Table 1, void filling is only successful with low loads. In the case of scheduling failure, the main reason is because the burst length is larger than the void size, while the effect of head/tail overlaps is negligible. Therefore, the OT-ABLD mechanism will focus primarily on adjusting the length of generated bursts so that they can fit into voids.

Adjusting the length of generated bursts is based on the value of void size which is carried in the NACK packet feedbacked from the core nodes. With the structure of a NACK packet as shown in Figure 4, the idle bytes in the PDU CTR field are utilized to carry this value. Specifically, 4 of 6 idle bytes are proposed to carry the value of void size, because the LEN BURST (burst length) field is only 4 bytes. The structure of PDU CTR is therefore modified as shown in Figure 6.

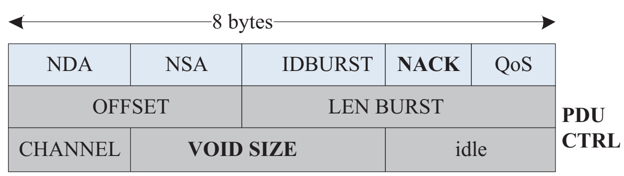

Figure 6. The structure of the NACK packet with 4 bytes dedicated to carry the value of void size.

To implement the OT-ABLD mechanism, the best fit void filling (BF-VF) algorithm [23], the best scheduling algorithm to date, is chosen. Because BF-VF tests all voids and chooses the most fitting void, the average size of voids is easy to calculate in the OT-ABLD mechanism. The value of void size is feedbacked whenever a scheduling failure occurs.

3.2. QoS Differentiation based on offset time and burst length at ingress nodes

The OT-ABLD mechanism uses the offset time as an indication of QoS differentiation, so it is convenient to be implemented with the JET protocol. In addition, to increase the probability of successful scheduling with void filling, the HP burst is adjusted to be shorter than the LP burst. With the case of two priority classes: high priority (HP) and low priority (LP), the HP burst will have the short size and the long offset time, while the LP burst is set by a long size and a short offset time. Given that the basic offset time (basic OT) is the shortest time required for a burst to be successfully transmitted from source to destination of a connection, basic OT is set as the offset time of the LP burst. For the HP burst, an extra offset time (extra OT) is added to this basic OT; the offset time of the HP burst is thus the sum of basic OT and extra OT. The authors in [7] stated that the offset time of the HP burst must take 3 to 5 times the length of the LP burst to ensure a complete isolation. In the OT-ABLD mechanism, the offset time of the HP burst is proposed to be greater than the total length of the LP burst and their offset time. Specifically, as shown in Figure 7, the offset time of a HP burst, $OT(0)$, is greater than or equal to the sum of the basic OT, $OT(1)$, and the length threshold (in time) of queue $q(1)$,

$L_a(1)$. This idea stems from the observation that if two control packets of a HP burst and a LP burst arrive simultaneously at an output port, they will not contend with each other for resources (Figure 7). This approach not only ensures a large offset time for the HP burst, but also reduces the loss of the LP burst.

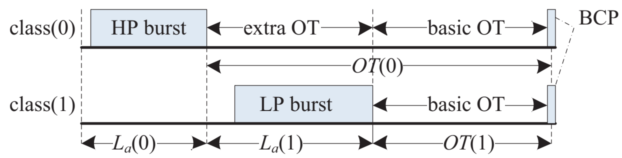

Figure 7. The offset time of the HP burst, $OT(0)$, is greater than or equal to the sum of basic OT, $OT(1)$, and the length threshold (in time) of queue $q(1)$, $L_a(1)$.

The size of the HP burst can be adjusted to be as small as possible to increase the probability of successful scheduling with void filling, but the size needs to be greater than a minimum length threshold ($MinB$). However, creating multiple bursts of small size increases the number of bursts across the core network, thereby this increases the contention probability. As recommended in [24, 25], the value of $MinB$ should be in the range from 1.25 to 30KB and the maximum burst length ($MaxB$) is not greater than 60KB. Limiting the burst length is implemented in the operation of burst assembly where the preset length threshold specifies the maximum length of completed bursts. In order to have the size of completed bursts within the above range, the length threshold specified for the HP queue is $L(0) \in [1.25, 30]KB$ and that of the LP queue is $L(1) \in [30, 60]KB$. In the case of light arrival load, the length of completed bursts can be smaller than $MinB$, burst padding [26] can be performed to ensure the burst length is always larger than $MinB$.

To support the OT-ABLD mechanism, the ingress and core nodes are added with supplemental function modules as shown in Figure 8, where a module at the core node is for measuring the average void size whenever there is a scheduling failure; the value of void size is then sent back to the ingress node by a NACK packet. At the ingress node, another module is for adjusting the length threshold $L_a(0)$ of the HP queue according to the feedbacked void size. This adjustment can be done periodically or every time the ingress node receives a NACK packet.

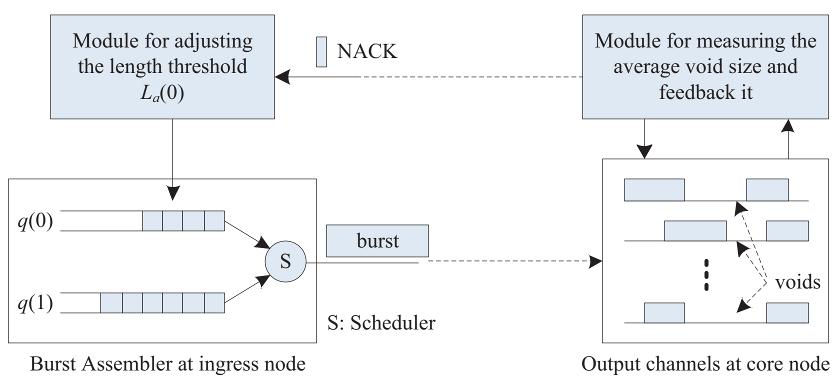

Figure 8. The schema of measuring the average void size at the core node and send it to the ingress node to adjust the length threshold of the queue $q(0)$.

4. Simulation and result analysis

Simulation is done on a PC with 2.4 GHz Intel Core 2 CPU, 2G RAM. The simulation network is an NSFNET and the simulator is NS2 with obs-0.9a package.

The packets arriving at queues are assumed to belong to two priority classes, so two priority queues, $q(0)$ for the high priority and $q(1)$ for the low priority, are allocated for each destination. Time and length thresholds are initially set for $q(0)$: $T_a(0) = 1000\mu s$ and $L_a(0) = 20KB$, and for $q(1)$: $T_a(1) = 1500\mu s$ and $L_a(1) = 40KB$ (as recommended in [25]). Other simulation parameters are described as in Table 2.

Table 2. Simulation parameters.

Parameter	Value	Description
Δp	$3.5\mu s$	Processing time at each node (as recommended in [24])
Δt	$5\mu s$	Transmission time
$MinB$	5KB	Minimum burst thresholds
$MaxB$	60KB	Maximum burst thresholds
W	8	The number of wavelengths per output link
Bw	1Gbps	The bandwidth of each link

The simulation is performed in a duration of 2 s, which is divided into two periods: (1) from 0.1s to 1.0s, the same normalized load of 0.2 arrives at $q(0)$ and $q(1)$, and (2) from 1.1s to 2.0s, the arrival load at $q(0)$ increases to 0.4, while there is no change for the arrival load at $q(1)$. The idea of not increasing LP load in the second period is to avoid the impact of increasing LP load which can make many LP bursts to contend with HP bursts for resources, which this will evaluate the OT-ABLD mechanism inaccurately.

Simulation objectives include:

- comparing the average burst loss rate of both priority classes (the total loss rate) and that of each individual class between the mechanisms of undifferentiated (abbreviated as *undiff*), OTD, BLD and OT-ABLD .
- comparing the average delay of packets which are carried in the HP burst between the mechanisms of *undiff*, OTD, BLD and OT-ABLD. The fact is that the average packet delay is caused by the operation of assembly time and the offset time. With a given end-to-end connection, only reducing the assembly time will reduce the end-to-end delay of packets. Therefore, comparing the average packet delay here is equivalent to comparing the assembly time between the mechanisms.

4.1. Comparison of the burst loss rate

Figure 9 shows a comparison of the total loss rate between the mechanisms of QoS differentiation. Simulation results showed that OT-ABLD achieves the lowest total loss rate in both periods. Specifically, in the first period (from 0.1s to 1.0s), OT-ABLD achieves the total loss rate that is 10% lower than BLD and OTD, and 20% lower than *undiff*. In the second period (from 1.1s to 2.0s), OT-ABLD has the burst loss rate that is 15% lower than BLD, 25% lower than OTD and nearly 30% lower than *undiff*. To clarify this issue, the burst loss rate of each priority class is considered.

As shown in Figure 10, OT-ABLD achieves the lowest HP burst loss rate in both periods. In the first period, the HP burst loss rate of OT-ABLD is zero since the load arriving at the two queues is quite small (0.2), so the size of created voids is relatively large in size compared to the length of completed bursts (two above curves of Figure 11). When the HP load increases to 0.4 in the second period, the created voids are smaller than the completed bursts (two below curves of Figure 11), so the probability of successful scheduling with void filling decreases and, as a result, the burst loss rate increases.

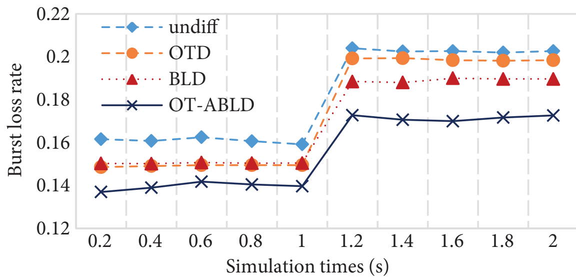

Figure 9. Comparison of the total loss rate among *undiff*, OTD, BLD, and OT-ABLD.

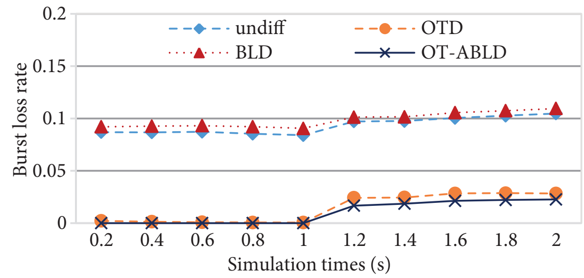

Figure 10. Comparison of the loss rate of HP bursts between the mechanisms of *undiff*, OTD, BLD, and OT-ABLD.

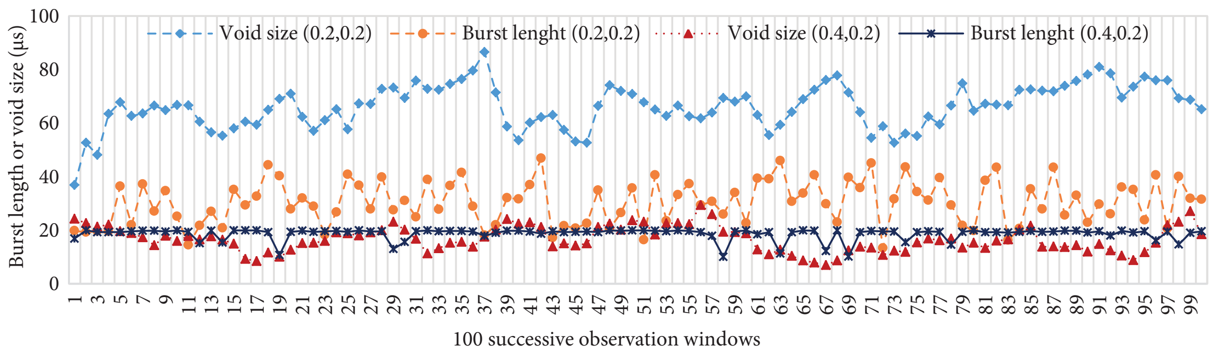

Figure 11. A comparison between the void size and the burst length (measured by μs) in 100 successive observation windows with two cases of incoming loads: (0.2, 0.2) and (0.4, 0.2).

Figure 12 shows that the LP burst loss rate of OT-ABLD is greater than that of *undiff* and BLD. This is because OT-ABLD reserves more resources for scheduling HP bursts, so it remains few resources for LP bursts. However, OT-ABLD still has the lower LP burst loss rate than that of OTD thanks to setting the offset time of HP bursts which is large enough to avoid contention with LP bursts (see Figure 7).

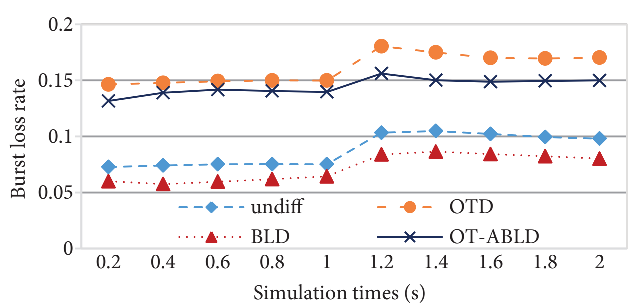

Figure 12. Comparison of the loss rate of LP bursts between the mechanisms of *undiff*, OTD, BLD, and OT-ABLD.

Note that the total loss rate and the loss rate of each priority class increase in the second period because the higher the total loads arrive, the more contentions occur; the burst loss rate of the second period therefore is higher then that of the first period.

4.2. Comparison of the average delay of HP packets

For the comparison of the average delay of HP bursts (packets), Figure 13 shows that OT-ABLD causes the lowest end-to-end delay when it is compared to OTD, BLD and *undiff*; OTD and *undiff* have the same average delay; and the delay tends to decrease in the second period.

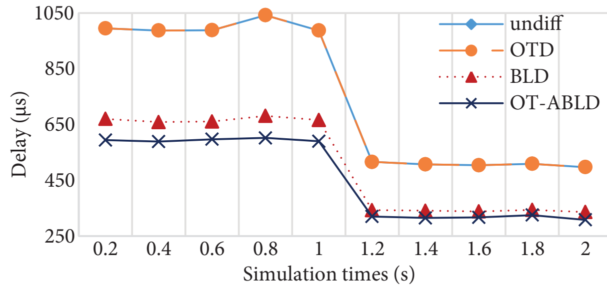

Figure 13. The average delay (μs) of HP bursts (packets).

OTD and *undiff* have the same delay because they all use the timer-based assembly mechanism, so bursts are delayed by the timer threshold T_a. Whereas BLD has a lower average delay due to the use of a hybrid assembly mechanism, which is based on bold time and length thresholds; in cases where the length threshold is reached first, i.e. the assembly time is shorter than the timer threshold T_a, thus creating a shorter delay for HP bursts. With OT-ABLD, due to the requirement of fitting into void, the burst length is sometimes limited to be smaller than the initial length threshold. It means that the actual assembly time is shorter. Therefore, OT-ABLD has the lowest average assembly time and results in the lowest average delay of bursts.

For OTD and *undiff*, although their assembly time is practically the same in both periods, but in the second period, when the density of arriving HP bursts is high, the length threshold $L_a(0)$ always reaches first and as a result, the delay of HP packets tends to decrease. Figure 14 shows a comparison of the delay (μs) of HP bursts (packets) in 100 successive observation windows with two cases of incoming loads: (0.2, 0.2) and (0.4, 0.2).

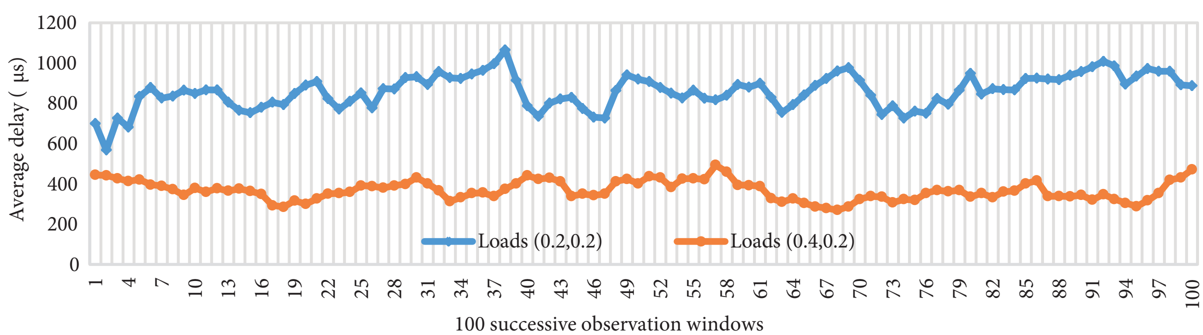

Figure 14. A comparison of the delay (μs) of HP bursts (packets) in 100 successive observation windows with two cases of incoming loads: (0.2, 0.2) and (0.4, 0.2).

For the LP bursts, since no priority mechanism is applied, there is no difference in the assembly time of all mechanisms of QoS differentiation in both periods (Table 3).

In summary, by reasonably setting the offset time for bursts of priority classes and adaptively adjusting the length of completed bursts according to the void size feedbacked from core nodes, the OT-ABLD mechanism has been demonstrated to be efficient in term of the low burst loss rate (Figures 9, 10 and 12) and the reduced

Table 3. The average delay (μs) of LP bursts (packets).

Simulation time (s)	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
undiff/OTD/BLD/OT-ABLD	1006	1029	1005	1027	1006	1011	988	1017	1015	995

average delay (Figure 13). Despite the void size feedbacking, the OT-ABLD mechanism does not increase the throughput of control channels by taking advantage of the idle fields of the NACK packet to carry the value of void size. However, a supplemental function module needs to be implemented in the core node to support the void size feedbacking and another function module is added in the ingress node to adjust the burst length based on the feedbacked void size. Another issue of setting a large offset time of the HP burst, which is the sum of the length and the offset time of the LP burst, significantly increases the delay of the HP burst and limits the number of priority classes that can be implemented with the OT-ABLD mechanism. Therefore more research is needed to find a compromise solution to this problem.

5. Conclusion and future works

The paper has proposed a mechanism of QoS differentiation, called the OT-ABLD mechanism, which is the result of a combination of OTD, BLD and the burst length adjustment based on the feedbacked void size. Thanks to adjusting the length of completed bursts adaptively based on the feedbacked void size and setting the isolated offset times for priority bursts, the HP burst loss rate of the OT-ABLD mechanism has reduced significantly in comparison with the mechanisms of *undiff*, OTD and BLD. Not only increasing the efficiency for the HP burst, the OT-ABLD mechanism also contributes to reduce the loss of the LP burst by avoiding direct contentions with the HP burst by setting up their isolated offset times. However, the OT-ABLD mechanism is only suitable in light and medium loads; In the case of heavy loads, the scheduling with void filling is no longer feasible.

For the future works, the OT-ABLD mechanism can be improved with adjusting the time for sending bursts into the core network because the scheduling failure is not only due to the reason that the burst length is larger than the void size, but also due to the head/tail overlaps. Moreover, it is necessary to study a method of determining the time offsets so that they cannot only ensure a complete isolation between priority classes but also increase the probability of successful scheduling.

Acknowledgement

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