Delay-on-Demand: A Signaling Protocol to Reduce Blocking Probability in Optical Burst-Switching Networks

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Delay-on-Demand: A Signaling Protocol to Reduce Blocking Probability in Optical Burst-Switching Networks

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Abstract. Optical burst switching (OBS) is emerging as one promising switching paradigm for the next generation optical networks. To support multiple services in burst-switching networks, the OBS paradigm should support some quality-of-service (QoS) provisioning. A major design issue in such networks is to reduce the blocking probability of the bursts arising due to resource contention at the intermediate core router. In this paper, we propose a signaling protocol which we call 'Delay-on-Demand' (OBS-DoD), to reduce blocking probability and support QoS in optical burst-switching networks. The proposed scheme guarantees that at least one of the bursts succeeds depending on its priority, propagation delay from the ingress router, and the burst-size when contention occurs at the core router. For this, we use a control packet to delay, in case of a contention, the transmission of bursts at the ingress router. We compare the performance of our proposal, by simulation, with an earlier proposed scheme, and show that the proposed OBS-DoD outperforms the earlier scheme in reducing the blocking probability. For simulation, we generated bursty traffic using an M/Pareto distribution.

Keywords: WDM, optical burst switching, optical Internet, blocking probability, QoS

1 Introduction

There has been a phenomenal growth in demand for bandwidth due to the ever increasing number of Internet users and the increase in the variety of Internet applications. Internet applications configured around multiple media elements require different levels of quality-of-services (QoS). It is widely believed that the next generation optical Internet built on Wavelength Division Multiplexing (WDM) technology would satisfy the increasing demand for bandwidth. However, WDM provides only the required bandwidth without guaranteeing the QoS requirements of different applications. Today's Internet based on the packet switching paradigm supports still predominately only best-effort service and starts to take into account different levels of QoS requirements. Therefore, the increasing demand for multiple levels of QoS necessitates that the Internet should generally support some form of QoS. The future optical Internet should not only meet the bandwidth requirements but also support the QoS needs of different applications.

Circuit switching and packet switching are the two main switching paradigms and are well studied to carry IP traffic. Optical burst switching (OBS) is an emerging new one [13]. Each switching paradigm has its own limitations when applied to optical Internet. Circuit switching also known as wavelength routing in WDM networks is not bandwidth-efficient unless the duration of transmission is much longer than the circuit establishment period. Setting up the circuits (lightpaths) takes considerable amount of time and it is shown that lightpath routing in optical networks is an NP-hard problem [2], though many heuristics and approximation algorithms exist, see [3] and the references therein. On the other hand, optical packet switching is flexible and bandwidth-efficient. However, the technology for optical buffers

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and processing in the optical domain is yet to mature for commercialization.

In this context, OBS which is an hybrid of the circuit and packet switching paradigms, is emerging as a potential new switching paradigm for future optical networks. It encapsulates the fine-granularity of packet-switching and the coarse-granularity of circuit switching, and thus it combines benefits of the both while overcoming some of their limitations. It requires lesser complex technology than the technology needed for packet switching.

Recently many studies have been done for OBS networks, e.g., [9,10]. On the basis of the signaling used, OBS may be broadly classified into two types: Just-Enough-Time (JET) and Tell-n-Go (TAG) [11,13]. OBS-JET uses an offset time (mostly called base-offset time) between each burst and its control packet. The base-offset time is the total time involved in processing the control packet from source to destination. In OBS-JET, a node sends out a control packet and transmits the burst after the base-offset time. If any of the intermediate node fails to reserve the required resources, the burst is dropped at that node. To efficiently utilize the resources, OBS-JET uses a delayed reservation (DR) technique where resources are reserved at the time that the burst is expected to arrive. In OBS-TAG, the burst is sent immediately after the control packet. In such OBS-TAG networks the intermediate node requires fiber-delay lines to buffer the bursts while the control packet is being processed at the node.

One of the key design issues in OBS is the reduction in blocking probability of the bursts arising due to resource contention at an intermediate router. Due to the absence of optical buffers contending bursts are simply dropped at the intermediate core router, e.g., [12,14]. Fiber-delay lines have been proposed as an alternate to buffers, e.g., [15], however they can handle delays only for a fixed duration. Therefore, such lines are not suitable in the context of bursts which are characterized by variable delays.

In such a technological scenario, burst-switching networks have no buffer at the intermediate nodes. For buffer-less networks, the conventional priority schemes such as fair-queuing which requires the use of buffers can no longer be applied. Therefore, one of the alternatives to support QoS in a buffer-less optical burst-switching network is to reduce the blocking probability of the bursts due to resource contention at intermediate node. To support the QoS requirements of different applications, QoS provisioning must be built into OBS. Additionally, any scheme to reduce blocking of high priority traffic should not increase blocking of lower-priority traffic sensitively. Also, in prioritized traffic the delay experienced by high priority traffic should be lower.

Different mechanisms to support QoS in optical burst-switching networks for prioritized traffic classes have been proposed in the literature. For example, Yoo and Qiao [12,14] and Yoo et al. [15] proposed a scheme based on extra-offset time. They assigned an extra-offset time to each priority class in addition to the base-offset time. The highest priority class is assigned the maximum extra-offset time while no extra-offset time is assigned to the lowest priority class. In other words, in their scheme the traffic of the highest priority class has to wait for a maximum duration before it is transmitted while the lowest priority class traffic is transmitted immediately after the base-offset time and is delayed for a minimum duration. However, in prioritized classes of traffic, it is desirable that the traffic belonging to the highest priority class should have a minimal waiting period at the source while the traffic of the lower priority class may be delayed for a longer duration. Moreover, in [12,14,15] if more than one requests of the same priority arrive at an intermediate node and request for the same resources, all the requests are dropped.

There are many other studies done by other researchers, too. Boudriga [1] assigned a different delay time to each class in order to isolate the higher priority class from the lower priority class. Lee and Griffith [6] presented a traffic engineering technique to support QoS in optical Internet. The mechanism proposed by them tries to utilize the available wavelengths efficiently in order to provide lower delays. Kim et al. [5] proposed a deflection routing mechanism to reduce burst losses. They defined threshold functions to reroute the contending bursts. Deflected bursts may take a longer path to reach its destination. Yoo et al. [15] and Fan et al. [4]

calculated the blocking probability of each class when fiber delay lines are deployed at the intermediate nodes. Most of the researchers have attempted to reduce the blocking probability of different classes of traffic in order to provide differentiated services.

In this paper, we present a scheme to support QoS in optical burst-switching networks for prioritized classes of traffic. Our aim is to reduce the blocking probability of the bursts arising due to resource contention at intermediate nodes. We call our scheme "OBS with Delay-on-Demand" (OBS-DoD) which inherits the delay-reservation technique of JET. However, it differs in the signaling protocol. When contention occurs at an intermediate node, OBS-DoD takes the following three parameters into account to allocate resources: (i) Priority of the request, (ii) propagation delay of the request from the ingress node, and (iii) burst-size of the request. OBS-DoD guarantees that at least one of the bursts succeeds when contention occurs due to arrival of the requests of the same priority; this is not the case with other OBS schemes where all the bursts get dropped. Thus, the proposed scheme reduces the overall burst-loss in networks due to contention.

The rest of the paper is organized as follows. Architecture and notations used are described in Section 2. In Section 3, the signaling protocol and the structure of the control packets are detailed. Working of the protocol is illustrated in Section 4, and it is shown that dropping of bursts is reduced. Simulation results are presented in Section 5 and compared with another OBS protocol. Finally, some conclusions are drawn in Section 6.

2 Architecture and Notations

We model an optical network by means of a directed graph $G(V, E)$ where V is the set of vertices (nodes) and E represents the set of links/edges in the network. Two types of nodes (here after, we use the terms node and router interchangeably) are identified: edge routers and core routers (Fig. 1). Dark circles indicate the edge routers (ingress and egress) and Squares indicate the core routers. Every edge router has $(n_e - 1) \times N_p$

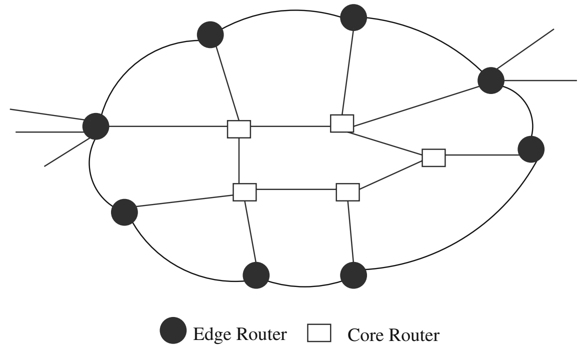

Fig. 1. A burst-switching network.

electronic buffers where n_e is the number of edge routers and N_p is the number of priority classes supported in the network. Each buffer belongs to a specific pair of priority class and egress router. The core router has no buffer; this is a desirable feature of the optical burst-switching network. Besides, processing and forwarding the control packet, a core router has the capability of generating its own control packets depending on the conditions as will be mentioned in Section 3. A core router acts as a transit router for data-traffic. Thus, the data-traffic remains in the optical domain from ingress to egress router. Propagation delay between every pair of adjacent vertices in graph G is assumed to be t_p. Let D_N be the number of nodes along the diameter of graph G. Then, the maximum propagation delay of a control packet between any two edge routers in graph G is $T_p = (D_N - 1) \times (t_p + \tau_p)$. Here τ_p is the processing delay of a control packet at each router. We assume this maximum propagation delay, T_p, in graph G to be the base-offset time in the burst-switching network that we consider.

We define the following three situations that can occur when an intermediate router receives a reservation request:

- *No contention* (NC):- When no contention for resources occurs at the intermediate core router.
- *Contention resolved* (CR):- When contention occurs at an intermediate core router, and the propagation delay between the core router and the (contending) requesting ingress router is $\tau \leq T_p/2$. In this case if a request is sent from the core router to the

ingress router to delay the transmission of the burst, the request can reach the ingress router before the expiry of the base-offset time (T_p). Hence, the transmission of the burst can be delayed and the burst will not dropped at the core router.

- *Contention-not-resolved* (CNR):- When contention occurs at an intermediate core router and the propagation delay between the core router and the requesting ingress router is $\tau > T_p/2$. In this case a request sent from the core router to the ingress router to delay the transmission of the burst, cannot reach the ingress router before the expiry of base-offset time (T_p). Thus, the burst transmitted immediately after the base-offset time will be dropped at the core router.

3 Signaling Protocol and Control Packets

In most of the burst-switching networks, when resource contention occurs at an intermediate node the contending burst is dropped at that node. To reduce such a burst-drop, the burst-switching networks proposed by Yoo's research group [9–11,13] assign an extra-offset time to each class of traffic in addition to the base-offset time. They attempted to reduce overlap of bursts in time. In such schemes, the traffic of the highest priority class is assigned the maximal extra-offset time whereas no offset time is assigned to the lowest class traffic. In other words, high priority traffic has to wait for a longer duration at the ingress router even if the required resources are available at the core routers. On the other hand, it is always expected, for a prioritized traffic, that the traffic of the high priority class should experience lower delay at the ingress router. Moreover, such schemes do not resolve resource contention if two requests have the same priority and arrive at an intermediate core router at the same time. In addition, the low priority requests in case of a contention are always dropped leading to starvation.

In this work, we propose a scheme which we call "OBS with delay-on-demand" (OBS-DoD). Unlike in other OBS schemes, where a contending request is always dropped, in OBS-DoD the decision to drop or delay the transmission is taken on the basis of the propagation delay of the request from the ingress router. Moreover in OBS-DoD if contention arises due to the arrival of requests of the same priority at the same time, the contention is resolved on the basis of following three parameters: (i) Priority of the request, (ii) propagation delay of the request from the ingress node, and (iii) burst-size of the request. OBS-DoD guarantees that at least one burst succeeds when a contention occurs. A burst whose request was not further delayed, is transmitted after the base-offset time. The decision to delay the transmission is taken at the intermediate core router where contention has occurred. Thus, in OBS-DoD the transmission of a burst is delayed on-demand where as in schemes based on extra-offset time, each priority class traffic is delayed by a pre-determined period of time in addition to the base offset-time.

We use two types of control packets: (i) *forward* (F), and (ii) *reverse* (R) control packets. OBS-DoD inherits all the other features of JET, e.g., the delayed reservation technique and the separation of data and control channels. The basis of our scheme is that the ingress router sends a F-control packet for requesting reservation. If resources have been reserved the burst is transmitted; this is a trivial case. If resource contention occurs at an intermediate core router, the F-control packet is either dropped or modified on the basis of the three parameters mentioned earlier, and a R-control packet is sent back to the ingress router. On receiving the R-control packet, a router either releases the reserved resources or updates the reservation request as specified in the R-control packet. In our scheme, a F-control packet is modified only once.

In the following subsections, we describe the F and R control packets and the OBS-DoD signaling protocol.

3.1 Control Packets

3.1.1 F-control packet

When a burst arrives at an ingress router, it sends out a F-control packet requesting for reservation. Resources are reserved using the delayed reservation technique, analogous to the one discussed in [13]. The structure of the F-control

f − path	r − path	t	T	w	s	d	*rid*	m	p

Fig. 2. F-control packet.

packet has been shown in Fig. 2. It consists of the following fields:

- f-path is the explicit forward path that the F-control packet takes from the ingress to the egress router. The burst follows this path from the ingress to egress router,
- r-path is the reverse path of the forward f-path. For example, if f-path is $1 \rightarrow 4 \rightarrow 7 \rightarrow 9$, then r-path is $9 \rightarrow 7 \rightarrow 4 \rightarrow 1$,
- t is the propagation delay from the ingress router to the current core router. When a router receives the F-control packet, it updates the value of t to $t + t_p$,
- W is the wavelength requested for reservation by the ingress router,
- s is the source/ingress router,
- d is the destination/egress router,
- If a F-control packet is modified, the value of T indicates the time at which the required resources are to be reserved by the current router (initially the value of T is set to *zero* by the ingress router),
- Value of m equal to *one* indicates that the F-control packet has been modified (initially the value of m is set to *zero* by the ingress router). An intermediate node modifies the F-control packet by setting the value of m to *one*.
- *rid* is the request identity, and
- p indicates the priority of the request.

When an intermediate core router receives the F-control packet, one of the following three possible situations arises : (i) NC, (ii) CR, or (iii) CNR. The action taken by the core router depends on the value of m in the F-control packet and one of the above three situations. The intermediate core router updates the value of t in the F-control packet to $t + t_p$. The actions taken by the core router for both values of m and for all the three possible situations are discussed below.

Case I: *When the value of m in the F-control packet is equal to zero*. One of the following happens:

1. NC: Required resources can be reserved at the core router and the F-control packet is forwarded to the next node in the path.
2. CR: This is a situation in which $t \leq T_p/2$. The following actions are taken at the router: (i) the time at which the required resources available is determined, and the resources are reserved from this time onwards, (ii) the value of T in the F-control packet is set to this value, (iii) the value of m in the F-control packet is set to *one*, (iv) a R-control packet is formed (formation of R-control packet is explained below) and is sent to the ingress router "s", and (v) the F-control packet is sent to the next node in the path.
3. CNR: This is a situation in which $t > T_p/2$. The following actions are taken at the core router: (i) a R-control packet is formed and sent to the ingress router 's', and (ii) the F-control packet (reservation request) is dropped.

Case II: *When the value of m in the F-control packet is equal to one*. One of the following happens:

1. NC: Following actions are taken at the core router: (i) value of T in the F-control packet is updated to $T + t_p$, (ii) resources are reserved from time T, and (iii) the F-control packet is sent to the next node in the path.
2. CR: Following actions are taken at the core router: (i) value of T in the F-control packet is updated to $T + t_p$, (ii) if the required resources are available from the time T onwards *then* (a) they are reserved from time T, and (b) the F-control packet is sent to the next node in the path. *Else* (a) a R-control packet is formed and sent to the ingress router 's', and (b) the F-control packet is dropped.
3. CNR: The following actions are taken: (i) a R-control packet is formed and the value of the r-field is set to *one*, (ii) the R-control packet is sent to the ingress router "s", and (iii) the F-control packet is dropped.

f–path	t	T	w	s	d	*rid*	r

Fig. 3. R-control packet.

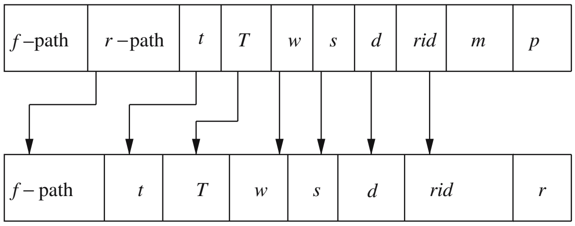

Fig. 4. Formation of a R-control packet from a F-control packet.

3.1.2 R-Control Packet

A R-control packet is formed at an intermediate core router where the resource conflict has occurred, The structure of a R-control packet has been shown in Fig. 3. Each of the fields of a R-control packet is as follows:

f-path is the explicit path that the R-control packet takes from the core router to the ingress router "s". The semantics of the t, T, w, s, d and *rid* fields of the R-control packet are identical to that of the F-control packet. A value of r equal to *zero* indicates that resources are to be reserved from the time specified in field T, and a value equal to *one* indicates the resources are to be released. A R-control packet is formed from the F-control packet and the formation is explained below:

The r-path of the F-control packet is copied into the f-path of the R-control packet and all the other fields of the F-control packet are copied to the corresponding fields of the R-control packet (Fig. 4). Copying the r-path of the F-control packet into the f-path of the R-control packet is illustrated in Fig. 5. In this illustration, we have assumed a resource conflict occurred at core router 6. Remaining elements of the r-path of the F-control packet excluding node 6 is copied into the f-path of the R-control packet. The R-control packet follows this f-path to reach ingress router 1 for whose reservation request, the resource contention has occurred.

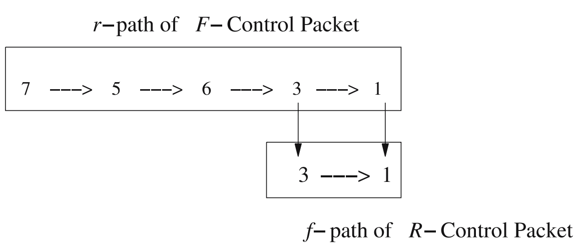

Fig. 5. Copying of a f-path to a r-path.

3.1.2.1 Processing of a R-control packet. On receiving a R-control packet, a node updates the values of t and T in the control packet to $t+t_{\mathrm{p}}$ and $T-t_{\rho}$, respectively. If the value of $t<T_p$ and the value of r is *zero then* the reserved resources for request number *rid* from the ingress router "s" to the egress router "d" are updated and reserved from the time T onwards, *else* resources are released. If the node is the ingress router "s", the R-control packet is dropped after processing. If the value of $t<T_{\mathrm{p}}$ then the R-control packet is forwarded to the next node in the f-path else the R-control packet is dropped at that node.

When a contention occurs at an intermediate core router the following rules are applied to modify the F-control packet and to form a R-control packet:

Rule 1: *An arriving request finds the required resources busy*. For an m value equal to *zero* and $t \leq T_{\mathrm{p}}/2$ do the following: modify the F-control packet by setting the value of m field to *one* and the value of the T field to the time at which required resources are available. Form a R-control packet and set the value of r-field to *zero*. For value of m equal to *one* or $t>T_{\mathrm{p}}/2$ do the following: form a R-control packet, set the value of r-field to *one*, and drop the F-control packet.

Rule 2: *Two requests of different priorities arrive at a core router at the same time*. Reserve the resources for the high priority request and forward its F-control packet to the next node in its path. For *zero* value of m of the low priority request and $t \leq T_{\mathrm{p}}/2$ do the following: modify its F-control packet and form a R-control packet as stated in Rule 1, For m value of low priority request equal to *one* or $t>T_{\mathrm{p}}/2$ do the following: form a R-

control packet, set value of r-field to *one*, and drop the F-control packet.

Rule 3: *Two requests of same priorities arrive at a core router at the same time*. The following actions are taken: (i) If their t-values are different, find the request with maximal value of t, reserve the resources for this request and send its F-control packet to the next node in its path. The other request is processed as stated in Rule 2 for a low priority request. Here we accept the request which has the maximum propagation delay from the ingress router so that the resources reserved will be efficiently utilized. (ii) For the same values of t in both requests, find the request with maximal burst-size. Reserve the resources for this request and forward its F-control packet to the next node in its path. The other request is processed as stated in Rule 2 of a low priority request. By choosing the larger burst-size, we aim to reduce the loss rate of the bursts in the whole network.

3.2 OBS-DoD Signaling Protocol

The signaling protocol specifies the actions taken by both the ingress and the core router. The following actions are taken at the *ingress* router.

(1) F-control packet is sent out when a burst arrives,
(2) Burst is transmitted at the time for which resources are reserved, and
(3) On receiving a R-control packet depending on the value of the r-field of the R-control packet, resources are either released or updated to a time as specified in the R-control packet.

The actions taken at the *core* router are : On receiving a F-control or R-control packet it is processed as explained in the previous subsection.

Summarizing, actions that are needed to transmit a burst are: (i) send F-control packet, (ii) process F-control packet, (iii) process R-control packet, if any and (iv) transmit a burst during the reserved time.

4 Illustration with an Example

In this subsection, we highlight the differences between our proposed OBS-DoD with another OBS [14] by working on an example. We consider two situations—contention resolved (CR) and contention-not-resolved (CNR)—shown in Figs. 6 and 7, respectively for illustrating the operation of our protocol. We assume the base-offset time, T_p, to be $T_p = 6 \times t_p$ where t_p is the propagation delay between adjacent nodes. For explanation we assume that one of the request is from the ingress router 0, and the second request is from some other ingress router which is not shown in Figs. 6 and 7. The second request has one of the following characteristics: (i) Higher priority, (ii) longer propagation delay, or (iii) larger burst-size.

First we consider the situation CR (Fig. 6) where contention has occurred on link "a". We consider the following three cases:

Case-I *Resources on link "a" are busy and the request from ingress router 0 arrives at router* 1. In OBS, the request from ingress router 0 is dropped. In OBS-DoD, the F-control packet from node 0 is modified and forwarded to the next router in the path. A R-control packet is generated and sent to the ingress router 0. This is because it is a CR situation in OBS-DoD ($t \leq T_p/2$). Therefore, transmission of burst from node 0 is delayed. The period of delay is determined at node 1. Thus, in OBS-DoD the burst from ingress router 0 is not dropped at router 1 while it is dropped in OBS.

Case-II *Two requests of different prorities arrive at router* 1. We assume that request from ingress router 0 is of lower priority. The low priority request is dropped in other OBS schemes, while in OBS-DoD, the F-control packet of the low priority request is modified and sent to the

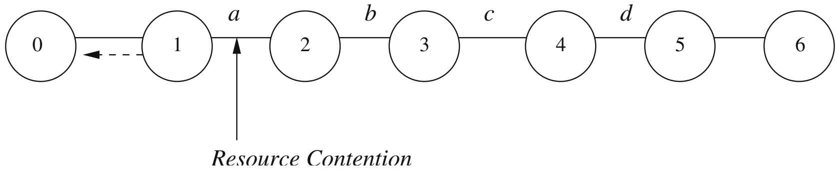

Fig. 6. An example to illustrate working of OBS-DoD protocol under a contention resolved (CR) situation.

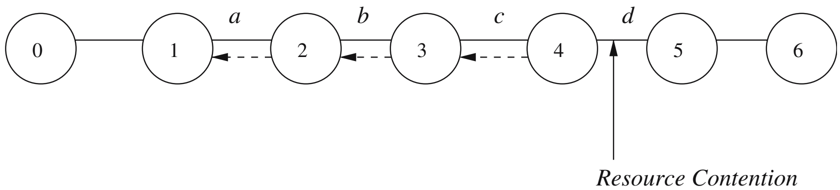

Fig. 7. An example to illustrate working of OBS-DoD protocol under a contention-not-resolved (CNR) situation.

next node in the path. A *R*-control packet is generated and sent to the ingress router 0. Transmission of a low priority burst is delayed at ingress router 0 by some extra-time determined at router 1 in addition to the base-offset time. Thus, in OBS-DoD the low priority burst is not dropped at router 1 but delayed while it was dropped in other OBS schemes.

Case-III *Two requests of same priority arrive at router* 1. In other OBS schemes, both the requests are dropped at router 1. This is because the ingress routers of both the requests wait for an equal period of time and transmit their bursts. Both the bursts collide and are dropped at router 1. While in OBS-DoD, the request with higher propagation delay or with larger burst-size succeeds (this is the second request and not shown in Fig. 6). The first request from ingress router 0 is modified and sent to the next node in the path. A *R*-control packet is sent to ingress router 0 and the transmission of burst from ingress router 0 is delayed by some extra-time determined at router 1. Thus, in OBS-DoD, none of the bursts are dropped while both are dropped in OBS.

Thus, we conclude that in situations when contentions can be resolved (as depicted in Fig. 6) none of the bursts is dropped in OBS-DoD. This is in contrast to the situation in other OBS schemes where one or both were dropped. The contending burst, in OBS-DoD, is delayed by a time-period determined at the node where the contention has occurred.

Next we consider the situation CNR (Fig. 7) where contention has occurred on link "*d*". Analogously, we consider the three cases again:

Case-I *Resources on link "d" are busy and a request from ingress router 0 arrives at core router* 4. The request from ingress router 0 is dropped at router 4 both in OBS and OBS-DoD. However, in OBS-DoD a *R*-control packet is generated at core router 4 and sent to the ingress router 0 requesting the intermediate core routers to release the resources reserved. By the time ingress router 0 starts transmitting the burst that is after the base-offset time, T_p, the *R*-control packet from router 4 reaches router 2. Resources reserved at link "*b*" and "*c*" for the request from ingress router 0 are released within the base-offset time. Subsequently, the burst transmitted from ingress router 0 is dropped at router 1 and the resources reserved on link "*a*" are released. In contrast, the resources once reserved, in other OBS scheme, are held up in all the links till the transmission was completed.

Case-II *Two requests of different priorities arrive at router* 4 *at the same time*. The lower priority request is dropped in both OBS-DoD and other OBS scheme. However, in OBS-DoD as explained in Case-I, a *R*-control packet is sent to ingress router 0, and the resources reserved for the lower priority request from ingress router 0 on the links "*a*", "*b*" and "*c*" are released.

Case-III *Two requests of same priority arrive at router* 4 *at the same time*. In other OBS schemes, both the requests are dropped at router 4 while in OBS-DoD one of the requests succeeds. We have assumed that the request from the ingress router 0 has a lower propagation delay and/or lower burst-size when a contention occurs. So the request from router 0 is dropped, a *R*-control packet is sent to it, and the resources reserved on the links "*a*", "*b*" and "*c*" are released.

Thus, we conclude that in situations when contentions cannot be resolved, fewer requests are dropped and resources are better utilized in OBS-DoD than in other OBS schemes.

The situations as depicted in Figs. 6 and 7 exemplify two typical cases — (i) contentions can be resolved, and (ii) contentions cannot be resolved, respectively. We conclude that fewer bursts are dropped in OBS-DoD giving better resource utilization This is not the case with other OBS schemes.

5 Simulation Results

We simulate a burst-switching network consisting of edge routers (ingress and egress) and core routers as shown in Fig. 1. The propagation delay, t_p, between any two adjacent nodes in the burst-switching network is assumed to be 1 ms. The processing time of each control packet at the router is assumed to 0.25 ms. The maximum propagation delay, T_P, between any two edge routers calculated as mentioned in Section 2 is 5 ms. We assume the maximum propagation delay T_P to be the base-offset time of the burstswitching network. We take the number of wavelengths available on each link in the range of 6–8. We assume there is no wavelength conversion and there exist no optical buffers in the switches.

We consider bursty traffic in our simulation as the traffic in the Internet is reported to be bursty in nature [8]. For this, we assume exponential inter-arrival of bursts, and the burst size to be determined by an M/Pareto distribution [7]. For simplicity and without loss of generality, we consider two classes of traffic: class 0 (low priority) and class 1 (high priority). We generate high priority traffic with a probability of 0.4 and consider the burst size of high priority traffic twice the size of low priority traffic, We treat load as the number of requests made by the edge routers. Traffic is generated at the edge routers only.

We compare the simulation results of our scheme with that of Yoo and Qiao [14]. The extra-offset time for high-priority traffic in [14] is taken to be 1 ms, we use the same quanta of time in our simulation. We consider burst blocking probability as the performance metric for comparison.

First, we include the plots for overall blocking probability of bursts in Fig. 8. The number of wavelengths available in each link is assumed to be *six*. It is evident from Fig. 8 that the blocking probability across the load in OBS-DoD is much lower than that in their OBS scheme [14]. The lower blocking probability in OBS-DoD is attributed to the signaling mechanism that we adopt in resolving resource contention. This is already discussed and illustrated by an example in the previous section.

Then we include the plots for blocking probability of high and low priority bursts in Figs. 9 and 10, respectively. It is observed that the blocking probability of high and low priority bursts in OBS-DoD is lower than those obtained in OBS [14]. This is due to the resource contention resolution technique that we adopt in OBS-DoD. This can be trivially shown by suitable examples taking different priorities.

To study the effect of number of wavelengths on the blocking probability, we varied the number of wavelengths available on each link form six to eight. The wavelength selection strategy

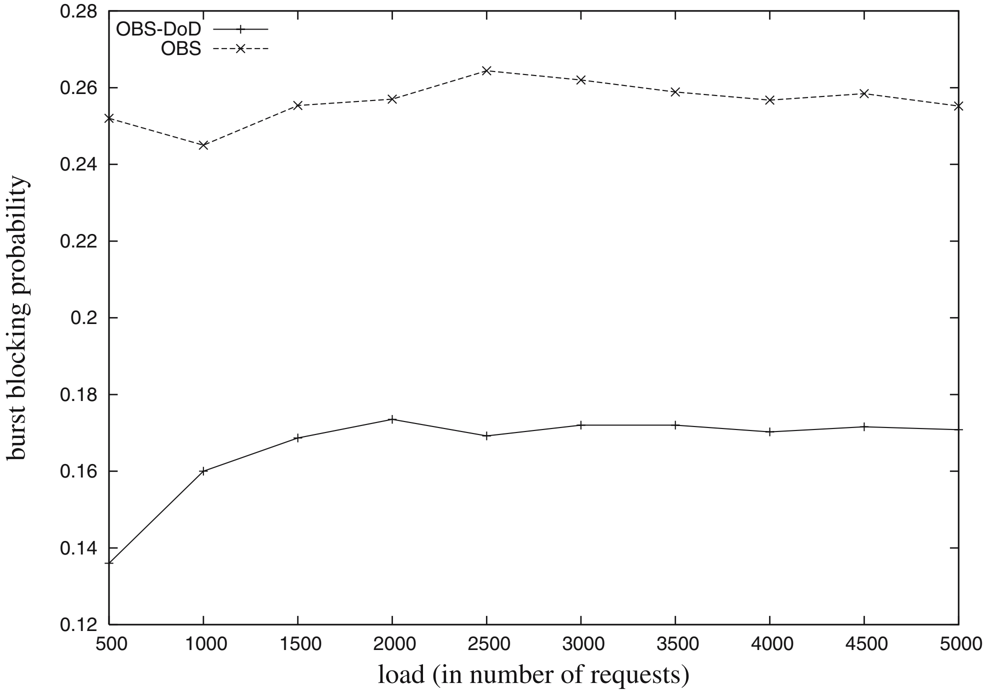

Fig. 8. Overall Blocking probability of bursts. (The number of wavelengths on each link is 6.)

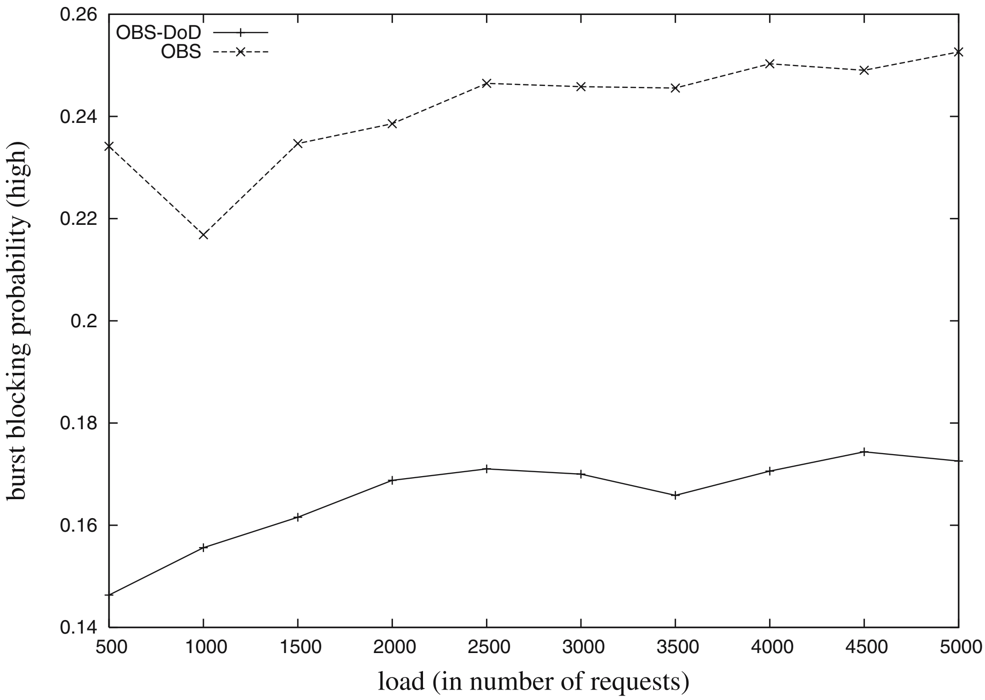

Fig. 9. The blocking probability of higher priority bursts. (The number of wavelengths on each link is six.)

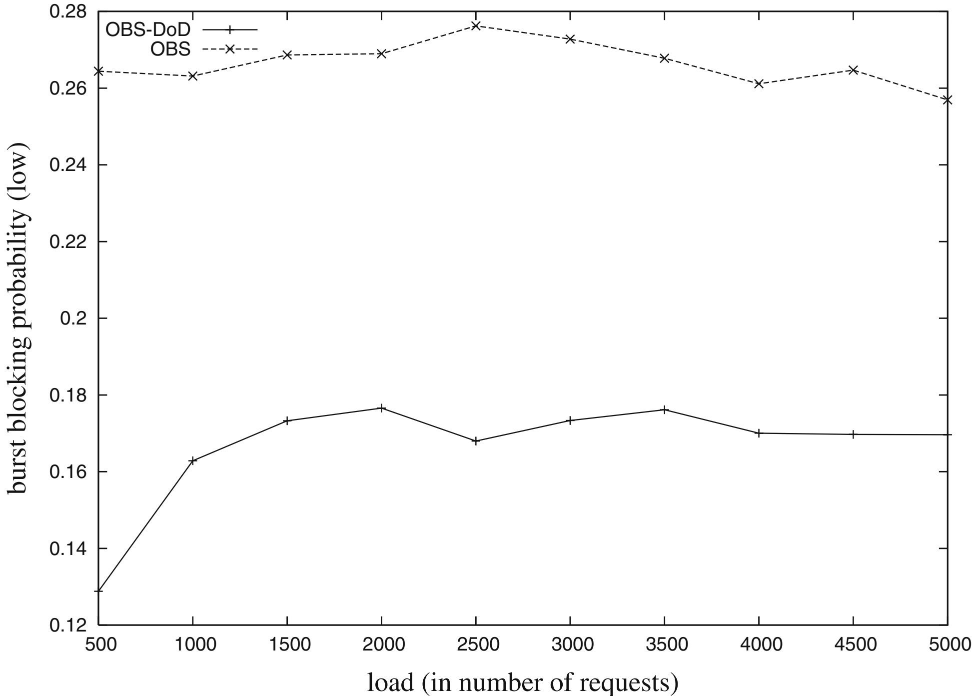

Fig. 10. The blocking probability of lower priority bursts. (The number of wavelengths on each link is six.)

that we adopted in our simulation for both OBS and OBS-DoD is to select the available wavelength with the lowest index. We plotted the overall blocking probability of bursts by varying the number of wavelengths in Figs. 11 and 12 for OBS-DoD and OBS [14], respectively. From Fig. 11, it is observed that the blocking probability in OBS-DoD decreases with increase in the number of wavelengths while the blocking probability for OBS remains the same as shown in Fig. 12. Since the request pattern remains the same in our simulation, the contention among the requests also remains the same. As a result the increase in number of wavelengths in OBS [14] could not reduce the blocking probability.

This is an interesting phenomenon that we can reduce the blocking probability by increasing the wavelengths in OBS-DoD though this is not the case with other OBS schemes. Nonetheless, in other OBS schemes too, we may reduce the blocking probability by adopting some other wavelength selection strategy at the ingress router. We envisage that the OBS-DoD will still outperform the other OBS schemes employing any other wavelength selection mechanism.

From our simulation we, therefore, conclude that OBS-DoD, in general, outperforms OBS [14] in reducing the blocking probability. As expected with increase in the number of wavelengths the blocking probability decreases in OBS-DoD, and thus, the scheme scales well with the wavelengths. Additionally, in OBS-DoD, if a request is blocked the reserved resources are partly released resulting in an efficient resource utilization; this is not the case with other OBS schemes.

The above observations are made based on comparing our OBS-DoD scheme with one of the OBS schemes developed by Yoo's research group [14]. The main contribution in performance improvement of OBS-DoD is due to the reason that our scheme also drops or delays a burst under certain consideration, however, we *always* admit *at least* one of the bursts in case of a contention. We expect to get a performance improvement in terms of blocking probability over most of the other variants of OBS schemes, e.g., [1,5,11].

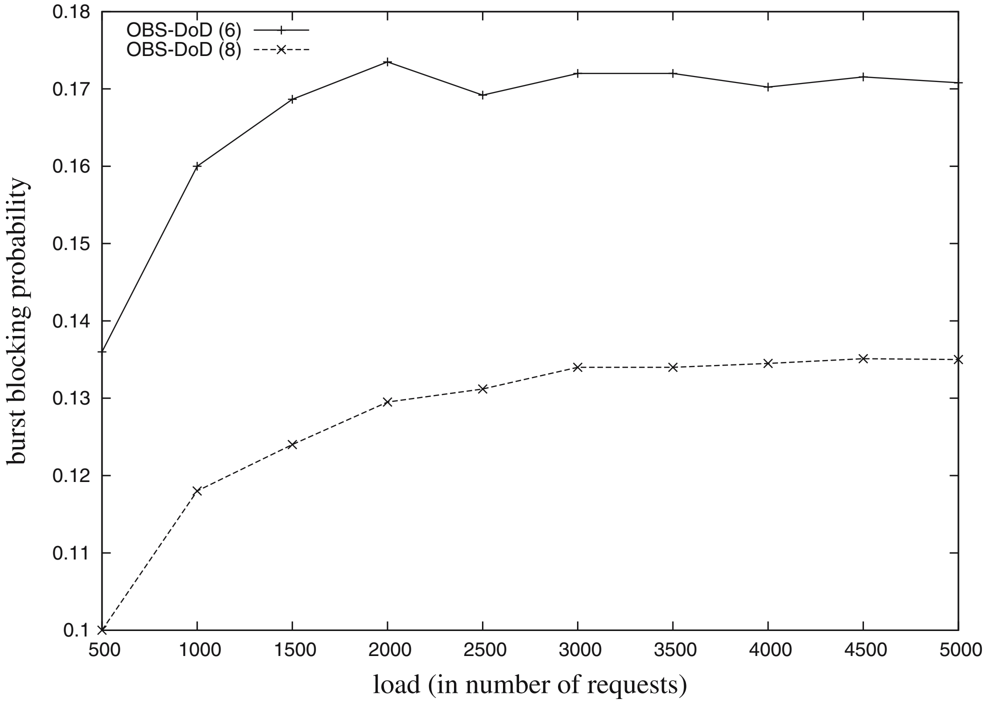

Fig. 11. The blocking probability in OBS-DoD for different number of wavelengths.

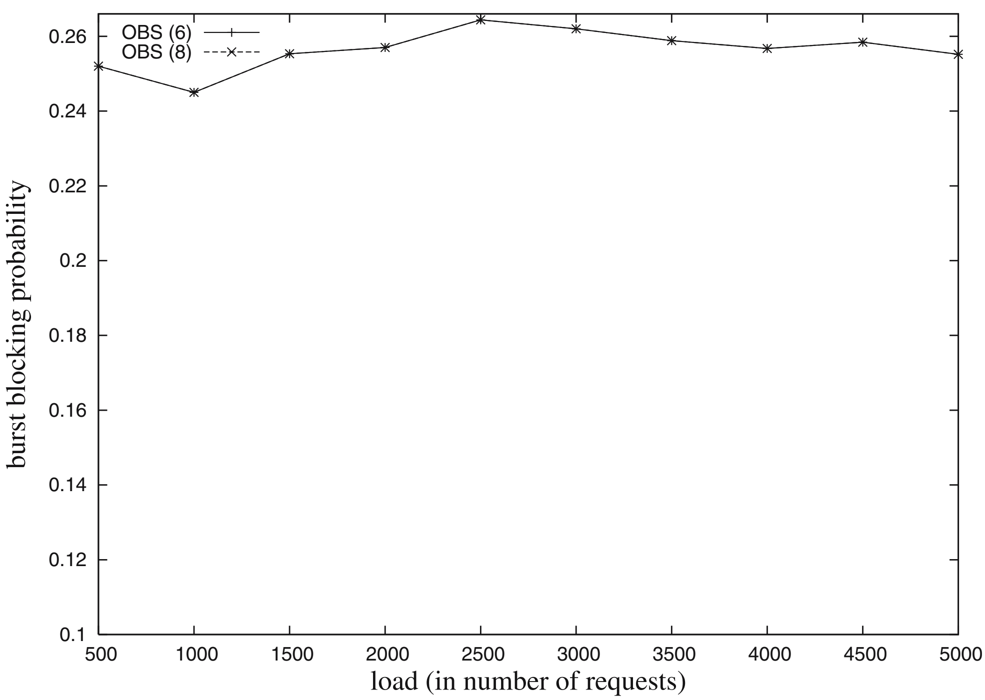

Fig. 12. The blocking probability in other OBS [14] for different number wavelengths.

6 Conclusions

In this paper, we have proposed a scheme called OBS-DoD for QoS provisioning by reducing the blocking probability of the bursts in optical burst-switching networks. In OBS-DoD when resource contention occurs the decision to drop or delay a burst is decided on the basis of the following three parameters: Priority, propagation delay, and burst-size. OBS-DoD guarantees that at least one of the bursts succeeds when contention occurs and thus reduces the overall blocking probability. We compared the blocking probabilities of the bursts in OBS-DoD with another OBS scheme [14] by simulation as well as working on some examples. We found that OBS-DoD outperforms the other OBS scheme in terms of the blocking probability. With increase in the number of wavelengths on each link we found that the blocking probability in OBS-DoD decreases while in other OBSs it remains the same. This is because burst contention is not resolved in other OBSs since there is no wavelength conversion in the burst-switching networks that we have considered. In absence of wavelength conversion, other schemes need an efficient wavelength selection strategy at the ingress router to reduce the blocking probability.

Future work may extend this work to multiple classes of services, proposal of an efficient wavelength selection strategy, study of the delay experienced by the bursts at the ingress router, and study of the effect of the DoD strategy on end-to-end delays and jitter.

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