Threshold-Based Burst Assembly Policies for QoS Support in Optical Burst-Switched Networks

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ABSTRACT

In this paper, we propose a threshold-based burst assembly scheme in conjunction with a burst segmentation policy to provide QoS in optical burst switched (OBS) networks. Bursts are assembled at the network edge by collecting packets that have the same QoS requirements. Once the number of packets in a burst reaches a threshold value, the burst is sent into the network. We investigate various burst assembly strategies which differentiate bursts by utilizing different threshold values or assigning different burst priorities to bursts that contain packets with differing QoS requirements. The primary objective of this work is to find the optimal threshold values for various classes of bursts. We show through simulation that there is an optimal value of burst threshold that minimizes packet loss for given network parameters.

1. INTRODUCTION

The amount of raw bandwidth available on fiber-optic links has increased dramatically with advances in dense wavelength division multiplexing (DWDM). In order to utilize this bandwidth efficiently, an all-optical transport method, which avoids optical buffering while also handling bursty traffic, is required. Furthermore, this transport method should support fast resource provisioning and asynchronous transmission of variable sized packets. Optical burst switching is one such method for transporting traffic directly over a bufferless optical WDM network.[1]

In an optical burst-switched (OBS) network, bursts of data consisting of multiple packets are switched through the network all-optically. A control message (or header) is transmitted ahead of the burst in order to configure the switches along the burst's route. The data burst follows the header after some offset time without waiting for an acknowledgment that the necessary resources have been reserved or configured. The offset time allows the header to be processed at each node while the burst is buffered electronically at the source; thus, no fiber delay lines are necessary at the intermediate nodes to delay the burst while the header is being processed. The control message may also specify the duration of the burst in order to let a node know when it may reconfigure its switch for the next burst, a technique known as *Delayed Reservation* (DR).[1]

A major concern in OBS networks is contention, which occurs when multiple bursts contend for the same link. Contention in an OBS network is particularly aggravated by the highly variable burst sizes and the long burst durations. Furthermore, since bursts are switched in a cut-through mode rather than a store-and-forward mode, optical burst-switched networks generally have very limited buffering capabilities. While existing contention resolution schemes for photonic packet networks, such as deflection and buffering, may be utilized in OBS networks, additional schemes may also be necessary in order to combat high contention rates and to achieve high network utilization.

Contention may be reduced by utilizing additional capacity in the form of multiple wavelengths and optical wavelength conversion.[2, 3] While optical wavelength conversion has been demonstrated in laboratory environments, the technology is not yet mature, and the range of possible conversions is somewhat limited.

Packet losses due to contentions can also be reduced through *burst segmentation*.[4] Burst segmentation is a process in which only those parts of a burst which overlap with another burst are dropped.

Another issue in OBS networks is QoS support. Several solutions have been proposed to support QoS in the OBS network. A prioritized offset scheme[2] was proposed to provide QoS in a buffer-less OBS core network. In this offset based reservation scheme, the higher-priority bursts are given a longer offset time as compared to the lower-priority bursts. By providing a longer offset time, the probability of reserving the resources for the higher-priority burst is increased, and therefore, the loss of higher-priority packets is decreased. Possible limitations of the prioritized offset based scheme include unfavorable end-to-end delay and the burst-selecting effect which favors shorter bursts over longer bursts.[5]

An alternate approach for providing priority in OBS networks is to include a priority field in the burst header packet (BHP) and to provide differentiated contention resolution in the OBS core based on this burst priority. Various burst differentiation policies[6] may be implemented through the selective use of burst segmentation. In such policies, higher-priority bursts may be allowed to preempt and segment lower-priority bursts in the case of contention.

Another important issue in OBS networks is burst assembly. Burst assembly is the process of aggregating and assembling input packets into bursts at the edge of the OBS network. The most common burst assembly techniques are *timer-based* and *threshold-based*. In timer-based burst assembly approaches, a burst is created and sent into the optical network at periodic time intervals[7]; hence, the network may have variable length input bursts. In threshold-based burst assembly approaches, a limit is placed on the maximum number of packets contained in each burst. Hence, fixed-size bursts will be generated at the network edge. A threshold-based burst assembly approach will generate bursts at non-periodic time intervals. Both timer and threshold approaches are similar, since at a given constant arrival rate, a threshold value can be mapped to a timeout value and vice versa, resulting in bursts of similar length for each case. In burst assembly, a significant issue is how to decide on the appropriate burst length for specific network parameters in order to minimize the packet loss probability in the OBS network. Longer bursts will reduce the total number of bursts injected into the OBS network; however, in the case of a contention, the average number of packets lost per contention will increase. On the other hand, generating smaller bursts will increase the number of bursts in the OBS network, leading to a greater number of contentions, and therefore higher packet loss probability. Thus, there exists a tradeoff between the number of contentions and the average number of packets lost per contention. Hence, the performance of an OBS network can be improved if the incoming packets are assembled into bursts of optimal length.

In this paper, we analyze burst assembly techniques which utilize a threshold-based policy. Bursts are characterized according to their destination (egress router) and burst priority, and each type of burst is assembled using a unique threshold value. We analyze the effect of varying the threshold for each type of burst. Incoming packets may belong to a specific *class*, which represents the QoS requirements of the packets. We assume that there are two classes of input traffic, namely, class 0 and class 1, where class 0 traffic is of higher-priority than class 1 traffic. Our objective is to find the optimal threshold range that minimizes the loss of class 0 packets for a given network under a given load.

We consider an OBS network which uses the DR technique with burst segmentation. Bursts may receive differentiated treatment in the OBS core based on the burst priority. The network does not support fiber delay lines (FDLs) or wavelength converters (WCs).

The paper is organized as follows. Section 2, discusses the architecture of core and edge routers. Section 3 describes the contention resolution policies at the core. In Section 4, we discuss threshold-based approaches used for providing QoS. In Section 5, we provide the simulation results and show how different threshold-based approaches provide QoS support in the network. We conclude the paper in section 6.

2. OBS NETWORK ARCHITECTURE

An OBS network consists of a collection of edge and core routers. The edge routers assemble the electronic input packets into an optical burst which is sent over the OBS core. The source edge router is referred to as the ingress node, and the destination edge router is referred to as the egress node. The ingress node pre-sorts and schedules the incoming packets into electronic input buffers according to each packet's class and destination address. The packets are then aggregated into bursts that are stored in the output buffer. The bursts are transmitted all-optically over OBS core routers without any storage at intermediate nodes within the core. The egress node, upon receiving the burst, disassembles the burst into packets and provides the packets to the upper layer. Basic architectures for core and edge routers in an OBS network have been studied elsewhere.[8]

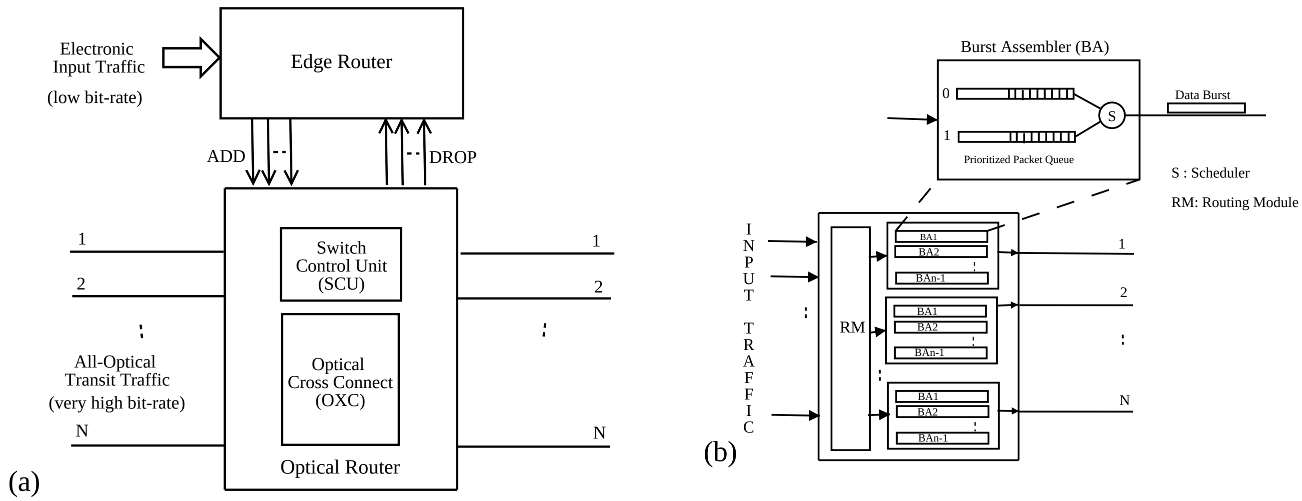

Figure 1. (a)Architecture of Core Router. (b)Architecture of Edge Router.

In our network architecture, each node supports both new input traffic as well as all-optical transit traffic. Hence, each node consists of both an edge router and a core router, as shown in Fig. 1(a). The detailed architecture of the edge router is shown in Fig. 1(b).

2.1. Core Router Architecture

The core routers primarily consist of an optical cross connect (OXC) and a switch control unit (SCU). The SCU creates and maintains a forwarding table and is responsible for configuring the OXC. When the SCU receives a BHP, it identifies the intended destination and consults the forwarding table to find the intended output port. If the output port is available when the data burst arrives, the SCU configures the OXC to let the data burst pass through. If the port is not available, then either the arriving burst is dropped or the current burst that is occupying the port is segmented or dropped depending on the contention resolution policy implemented in the network. In the case of a data burst entering the OXC before its control packet, the burst is simply dropped.

2.2. Edge Router Architecture

The edge router performs the functions of presorting packets, buffering packets, and assembling packets into bursts. The architecture of the edge router consists of a routing module (RM), a burst assembler (BA), and a scheduler. The RM selects the appropriate output port for each packet and sends each packet to the corresponding BA module. Each BA module assembles bursts consisting of packets which are headed for a specific egress router. In the BA module, there is a separate packet queue for each class of traffic. The scheduler creates a burst based on the burst assembly technique and sends the burst to the output port. At the egress router, a burst disassembly module disassembles the bursts into packets and send the packets to the upper network layers.

3. CONTENTION RESOLUTION IN OBS CORE

The primary protocols in the OBS core focus on contention resolution. When two or more bursts are destined for the same output port at the same time, contention occurs. There are many contention resolution schemes[9] which may be used to resolve the contention. The primary contention resolution schemes are optical buffering, wavelength conversion, and deflection routing. In optical buffering, fiber delay lines (FDLs) are used to delay the burst for a specified amount of time, proportional to the length of the delay line, in order to avoid the contention. In wavelength conversion, if two bursts on the same wavelength are destined to go out of the same port at the same time, then one burst can be moved to a different wavelength. In deflection routing, one of the two bursts will be routed to the correct output port (primary) and the other to any available alternate output port (secondary). The deflected packets may end up following a longer path to the destination, leading to higher end-to-end delay, and packets may also arrive at the destination out of order.

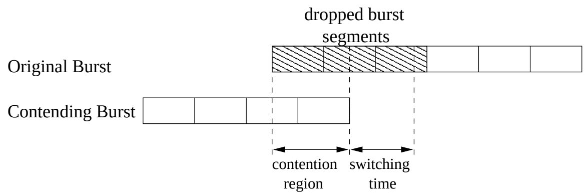

Figure 2. Selective Segment dropping for two contending bursts.

A combination of contention resolution techniques may be used to provide high throughput, low delay, and low packet loss probability.

To overcome some of the limitations of optical burst switching, we adopt the concept of burst segmentation.[4] In burst segmentation, the burst is divided into basic transport units called segments. Each of these segments may consist of a single packet or multiple packets, with each segment defining the possible partitioning points of a burst when the burst experiences contention in the optical network. All segments in a burst are initially transmitted as a single burst unit. However, when contention occurs, only those segments of a given burst which overlap with segments of another burst will be dropped, as shown in Fig. 2. If switching time is not negligible, then additional segments may be lost when the output port is switched from one burst to another. In this paper, we will refer to the burst which arrives to the switch first as the *original burst*, and the burst which arrives to the switch later as the *contending burst*.

There are two approaches for dropping burst segments when contention occurs between bursts. The first approach is to drop the tail of the original burst (Fig. 2), and the second approach is to drop the head of the contending burst.[6] A significant advantage of dropping the tail segments of bursts rather than the head segments is that there is a better chance of in-sequence delivery of packets at the destination, assuming that dropped packets are retransmitted at a later time.

In this paper, we consider a modified tail-dropping policy when determining which packets to drop. In this policy, the tail of the original burst is dropped only if the number of packets in the tail is less than the total number of packets in the contending burst. If the number of packets in the tail is greater than the number of packets in the contending burst, then the entire contending burst is dropped. This approach reduces the probability of a short burst preempting a longer burst and minimizes the number of packets lost during contention.

We consider the following policies for handling contention in an OBS network.

- *Drop Policy (DP):* Drop the entire contending burst.
- *Segment and Drop Policy (SDP):* The length of the tail of original burst and the length of the contending burst are compared. If the latter is longer, then the original burst is segmented, its tail is dropped and the contending burst is transmitted. Otherwise, the contending burst is dropped. In other words, SDP uses modified tail dropping to determine the winner of the contention.
- *Drop Tail Policy (DTP):* The contending burst wins the contention. The remaining tail of the original burst is always dropped regardless of the relative lengths. This policy is used for the case in which priorities are supported inside the core network and the priority of the contending burst is higher than the that of the original burst and the original.

When the network supports priorities, segmentation can be used to minimize packet loss for high-priority bursts. In an SDP scheme, when a contention occurs, the priorities of both the bursts are considered. Other segmentation policies may also be considered[6]; however, in this work, we restrict our consideration to SDP and DP. Table 2 enumerates the possible contention situations and the corresponding contention resolution policies.

Figures 3(a)-(c) show the three possible cases of contention that can occur when burst priorities are supported in the core. When the priority of the contending burst is higher than the priority of the original burst, then the tail of the

Table 1. various contention situations without burst priorities.

Condition	Longer Remaining Burst	Resolution Policies
1	Original	DP
2	Contending	SDP
3	Equal	DP

Table 2. Various contention situations with burst priorities.

Condition	Original Burst Priority	Contending Burst Priority	Resolution Policies
1	High	High	SDP
2	High	Low	DP
3	Low	High	DTP
4	Low	Low	SDP

original burst is dropped as shown in Fig.3(a). DTP is followed in case (a). For the case in which the priority of the two bursts are the same (Fig.3(b)), the modified-tail dropping policy is used. This case is common when the network does not support priorities. Fig.3(c) shows the contention between a high-priority original burst and a low-priority contending burst. In this case, the entire contending burst is dropped.

4. THRESHOLD-BASED BURST ASSEMBLY TECHNIQUE

For burst assembly, we utilize a threshold as a limiting parameter to determine when to generate a burst and send the burst into the optical network. The threshold specifies the number of packets to be aggregated into a burst. Until the threshold condition is met, the incoming packets will be stored in prioritized packet queues in the ingress node. Once the threshold is reached, a burst is created and will be sent into the optical network. Due to the threshold policy, all bursts will have the same number of packets when entering into the network; however, as a burst traverses the OBS core, the burst length can change based on the contention resolution policies, such as burst segmentation, followed at the core.

The burst length affects the total number of contentions and the average number of packets lost per contention. For a higher threshold, the bursts will be longer, and there will be fewer bursts as well as fewer contentions. However in each contention, as each burst is longer, the average number of packets lost per contention will be higher. In the case

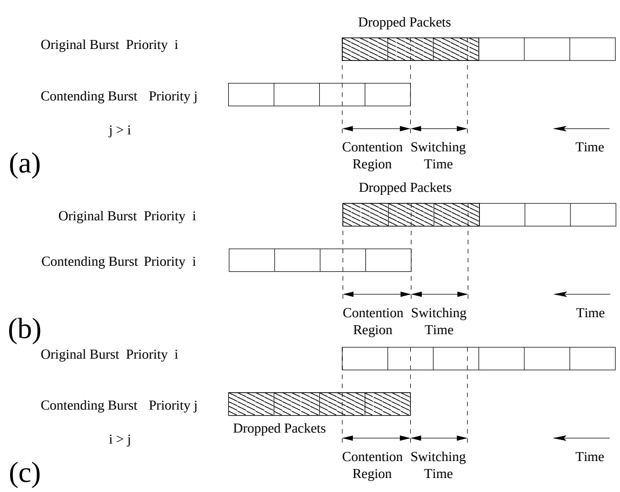

Figure 3. (a) Contention of low-priority burst with high-priority burst. (b) Contention of equal priority bursts. (c) Contention of high-priority burst with low-priority burst.

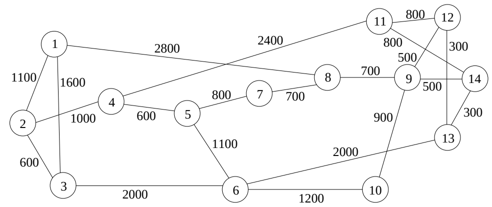

Figure 4. NSF Network with 14 nodes.

of smaller bursts, there will be greater number of bursts in the network, and as a result, there will be a greater number of contentions; however fewer packets will be lost per contention. Thus, there is a tradeoff between the number of contentions and the average number of packets lost per contention, and there is an optimum range of threshold values which will minimize the packet loss probability. The primary goal is to find the optimal threshold range for a given range of load in the network.

For the case in which there are multiple classes of packets, a single threshold may be applied to all packets regardless of class, or different thresholds may be applied to each class of packets. Having multiple threshold may be essential to satisfy the QoS delay and loss guarantees of each class. In this case, the objective is to find the optimal threshold for each class of packets such that the QoS requirements are met.

In the optical core, it it possible to further differentiate between bursts that contain different classes of packets by assigning priorities to each burst and by applying prioritized contention resolution policies. By combining class-based thresholds and multiple burst priorities, we can achieve a greater degree of differentiation for different classes of traffic.

5. SIMULATION RESULTS

In order to evaluate the performance of the burst assembly technique, we develop a simulation model. The following have been assumed to obtain the results:

- Packet arrivals to the network are Poisson with rate λ.
- Packet length is fixed and is 1250 bytes.
- Transmission rate is 10 Gbps.
- Switching time is 10 μs.
- Input traffic is uniformly distributed over all sender-receiver pairs.
- Shortest path routing is used to find the path between all node pairs.

Fig. 4 shows the 14-node NSFNET on which the simulation was implemented. The distances shown are in km. We have tested the various threshold schemes described above on the NSF network. The simulation was run until a finite number of packets were received at their destinations. We compare the performance of different threshold schemes under the standard drop policy (DP) and the segmentation policy (SDP) for contention resolution. We begin by considering one class of data traffic, and then extend the concept to two classes, showing how QoS is supported in each case. We have the following combinations over which we test the burst assembly technique:

- *Single threshold without burst priority*
- *Single threshold with two burst priorities*
- *Two threshold without burst priority*
- *Two threshold with two burst priorities*

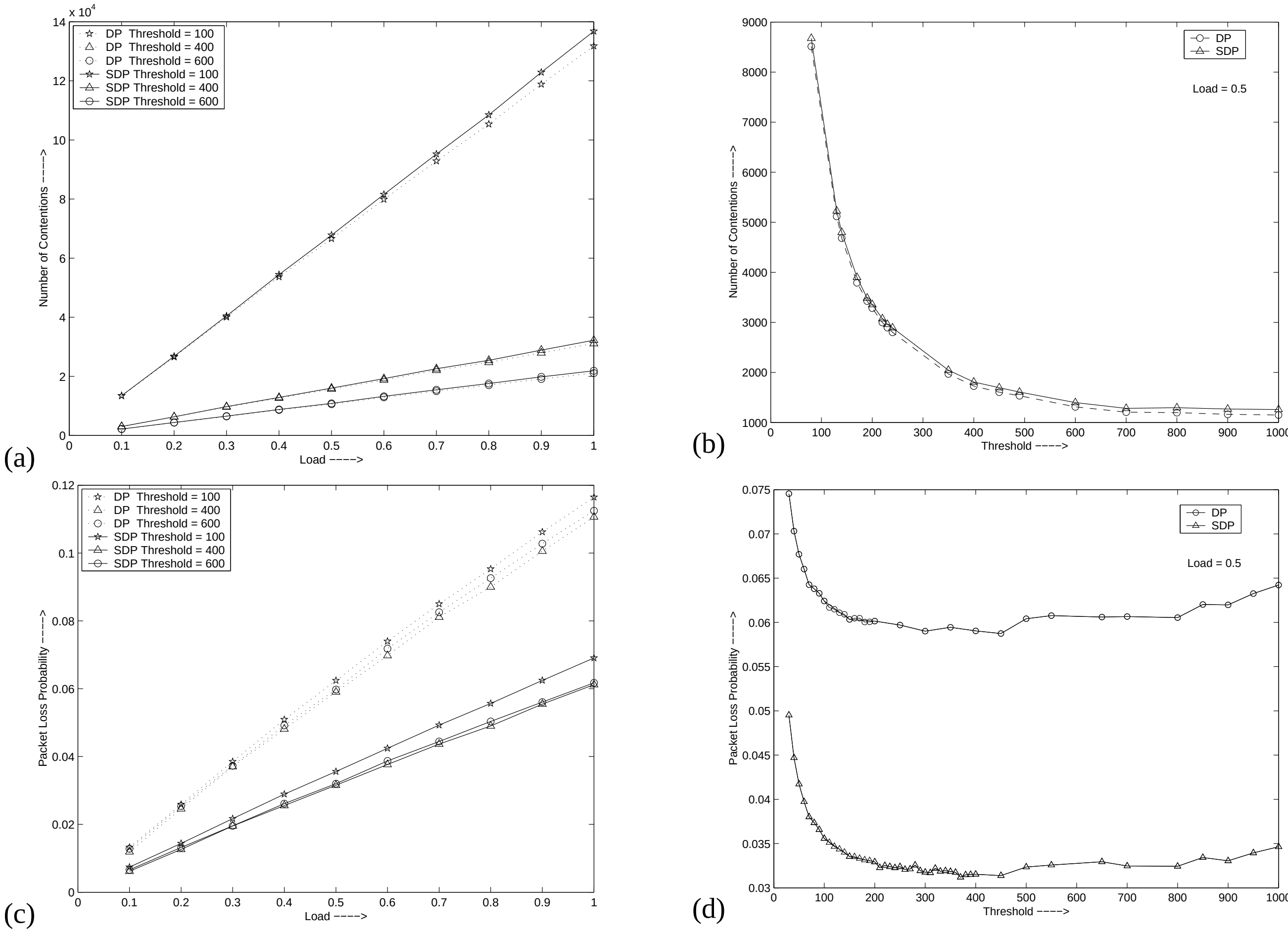

Figure 5. The graphs for DP and SDP with single threshold and no burst priority in the network. (a) Total number of burst contentions versus load. (b) Total number of burst contentions versus varying threshold values. (c) Packet loss probability versus load. (d) Packet loss probability versus varying threshold values.

5.1. Single Threshold Without Burst Priority

In the case of a single class of packets and a single burst priority level, a single threshold is used. The packet loss probability and the total number of contentions are analyzed for various loads and thresholds. From this single-threshold result we observe an optimum value of threshold for a given load and for a given network, for which the probability of packet loss will be minimum. Figures 5(a)-(d), give the performance of various parameters with DP or SDP as the contention resolution policy at the core.

Fig. 5(a) and Fig. 5(b) plot the load versus the total number of burst contentions. In this paper, we simulate for 10^8 fixed-size packets. We observe that, as the load increases, the number of bursts in the network also increases, which leads to a higher number of contentions. In Fig. 5(a), we illustrate the total number of contentions for fixed threshold values of 100, 400 and 600 packets. We observe that the number of contentions increases with increases in load. Also, the number of contentions increases as the threshold value of the burst decreases. This result can be better understood by observing Fig. 5(b). We also observe that the number of contentions is slightly higher when SDP is employed as compared to when DP is used. The higher number of contentions is an effect of segmentation. For every contention between two bursts in DP, one of the bursts is dropped. In SDP, when the original burst is segmented, the contending burst continues forward in the network; hence the segmented burst may collide with another burst during its journey toward its destination, which in turn leads to a higher number of contentions in the networks.

Fig. 5(c) plots the total packet loss probability versus the load for threshold values of 100, 400 and 600 packets for

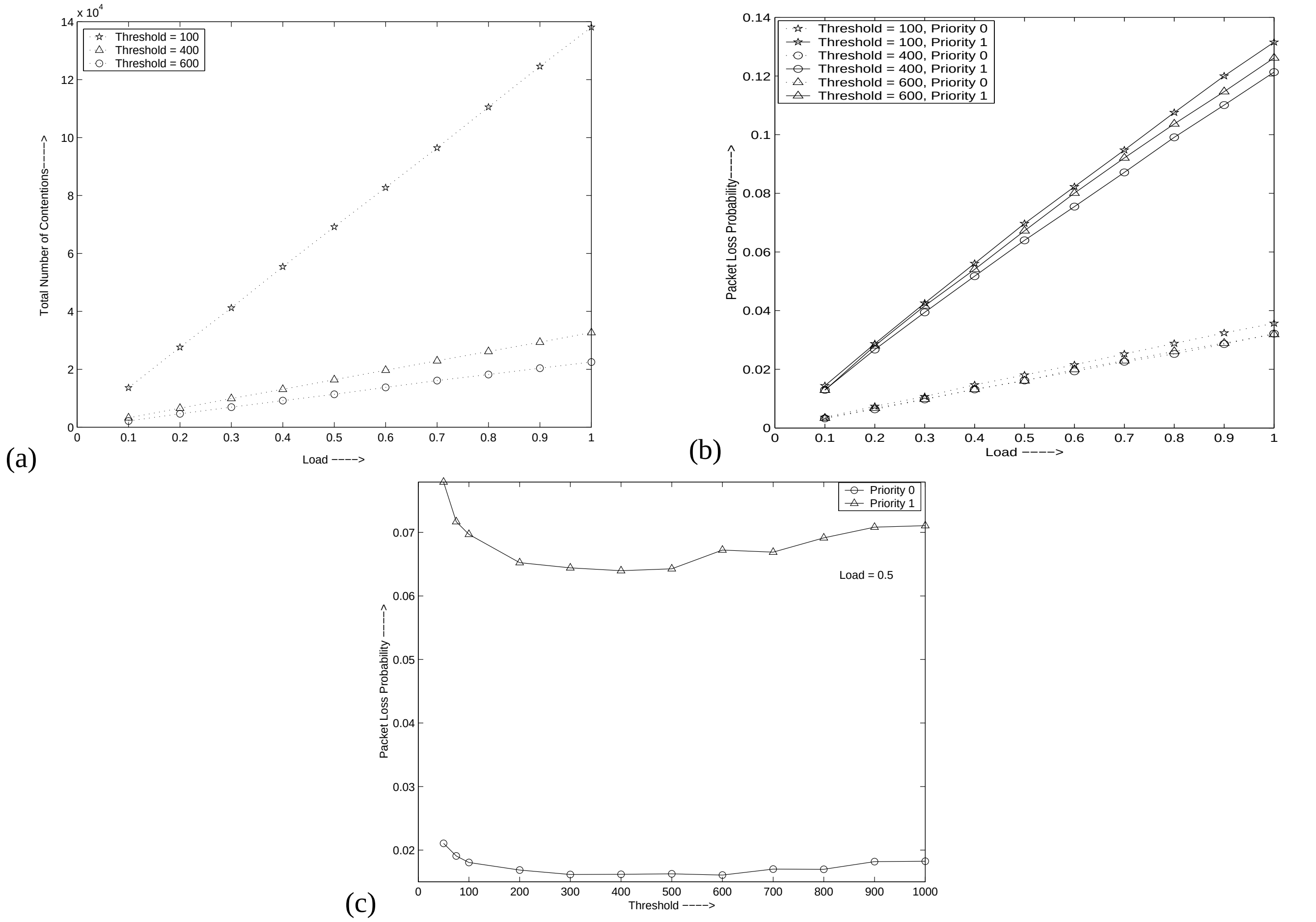

Figure 6. The graphs for SDP with single threshold and two burst priorities in the network. (a) Total number of burst contentions versus load. (b) Packet loss probability versus load for different threshold values. (c) Packet loss probability versus threshold for both classes of packets at a load of 0.5 Erlang.

both DP and SDP. We observe that a threshold of 400 performs better than the other two selected threshold values, 100 and 600. Hence it is essential to find an optimal threshold range to minimize loss. The need for optimal threshold can be better understood by analyzing Fig. 5(d). Here we observe that the loss initially decreases, hits a bottom, and then begins to increase. The loss is minimal when the threshold value is between 380-430 packets. The initial high loss can be attributed to the loss of packets during the reconfiguration of a switch during contention resolution. The steepness in the fall of packet loss is proportional to the switching time. As the switching time becomes insignificant with respect to the burst size, the loss remains steady between the range 300-450 packets. After 450, the loss increases, since an increase in the threshold results in an increase in the average number of packets lost per contention. We choose 400 packets to be the optimal threshold value for the NSFNET under a load range of 0 to 1 Erlang. The optimal threshold may vary based on the nodal degree of the network as well as the load range of the network.

5.2. Single Threshold With Burst Priority

For the case of two burst priorities and a single threshold, we evaluate the packet loss probability and the number of contentions for variations in load and threshold. The two burst priorities are priority 0 and priority 1. Priority 0 represents higher-priority traffic. We use the optimum threshold value obtained from Fig. 5(d), as the threshold value, since it minimizes packet loss. Fig. 6(a)-(c), gives the performance of various parameters with SDP as the contention resolution policy in the OBS core. We assume that the input data arrival ratio of both class of packets is the same.

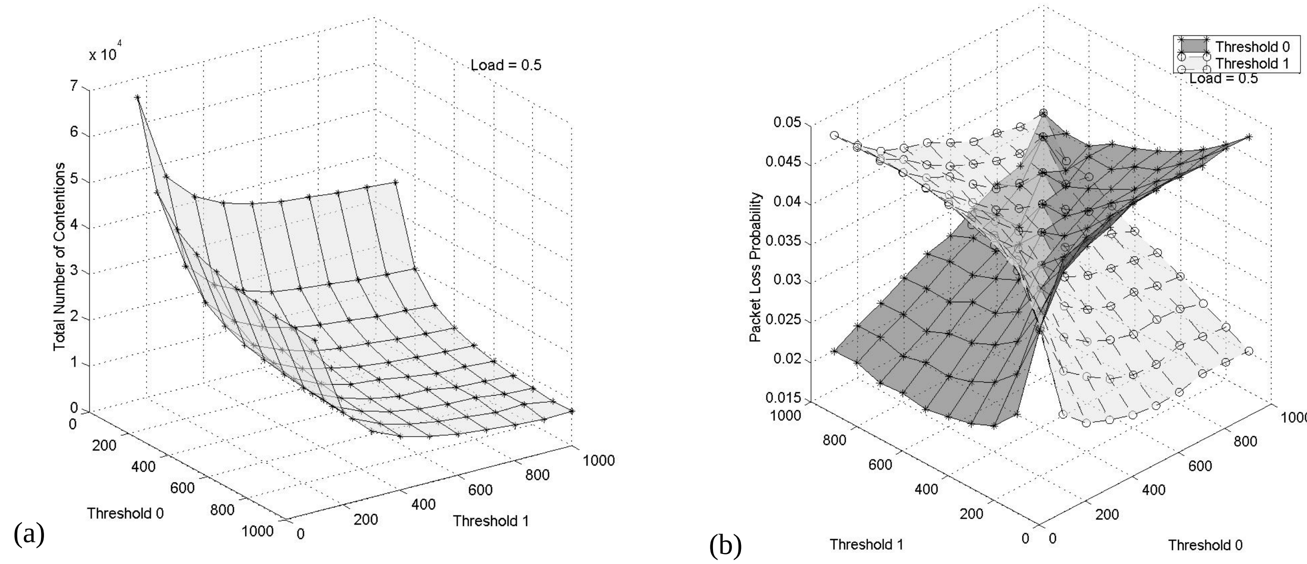

Figure 7. The graphs for SDP with two threshold and no burst priority in the network (a) Total number of burst contentions versus varying both threshold values. (b) Packet loss probability versus varying both threshold values for both priorities.

Fig. 6(a) plots the total number of burst contentions versus load. We observe that, as the load increases, the total number of contentions increases. Also, as the threshold increases, the total number of contentions decreases, due to fewer bursts. Fig. 6(b) plots the packet loss probability versus load for threshold values of 100, 400 and 600 packets for both burst priorities. We observe that the packet loss for higher-class packets is significantly lower than the packet loss for lower-class packets. We observe that, even with a higher number of contentions, we achieve lower loss for higher-class packets due to segmentation.

The combined graph of packet loss probability for both Priority 0 and Priority 1 bursts is plotted versus varying threshold values in Fig. 6(c). We observe that the loss of high-class packets is lower than that of low-class packets. Also, we can see that the loss increases as the threshold value increases beyond 400 packets. We observe that Priority 0 bursts have minimum loss at threshold values of 400 and 600 packets, while Priority 1 bursts have minimal loss at a threshold of 400 packets.

In the following section, we will see that varying individual threshold values for each burst priority results in better performance for both packet classes.

5.3. Two Threshold Without Burst Priority:

In case of two threshold values with no priorities in the bursts, we evaluate the packet loss probability and the number of contentions for variations in threshold. The results are shown in Figures 7(a)-(b). SDP is assumed to be adopted in the core, and the network load is 0.5 Erlang. The packet arrival rate for each class of traffic is identical.

Figure 7(a) plots the total number of burst contentions versus both threshold values. We observe that, as the threshold increases, the number of contentions decreases. In Fig. 7(b) we observe the packet loss probability for different values of threshold. Since there are no burst priorities in the network, during a contention, the burst length acts as the priority; hence longer bursts have lower loss than shorter bursts. We observe that the packet losses for the shorter burst is always higher than the packet loss for a longer burst. Therefore, the two planes in Fig. 7(b) meet when both thresholds are equal. Since no priority is incorporated into the network, the loss is symmetrical for bursts of both threshold values.

5.4. Two Threshold With Burst Priority:

Figures 8(a) and (b) show the network performance with two burst priorities and two threshold values, and with SDP as the contention resolution policy in the OBS core. We assume that the input data arrival ratios of both traffic classes are identical. We observe the service differentiation between the two different class of packets.

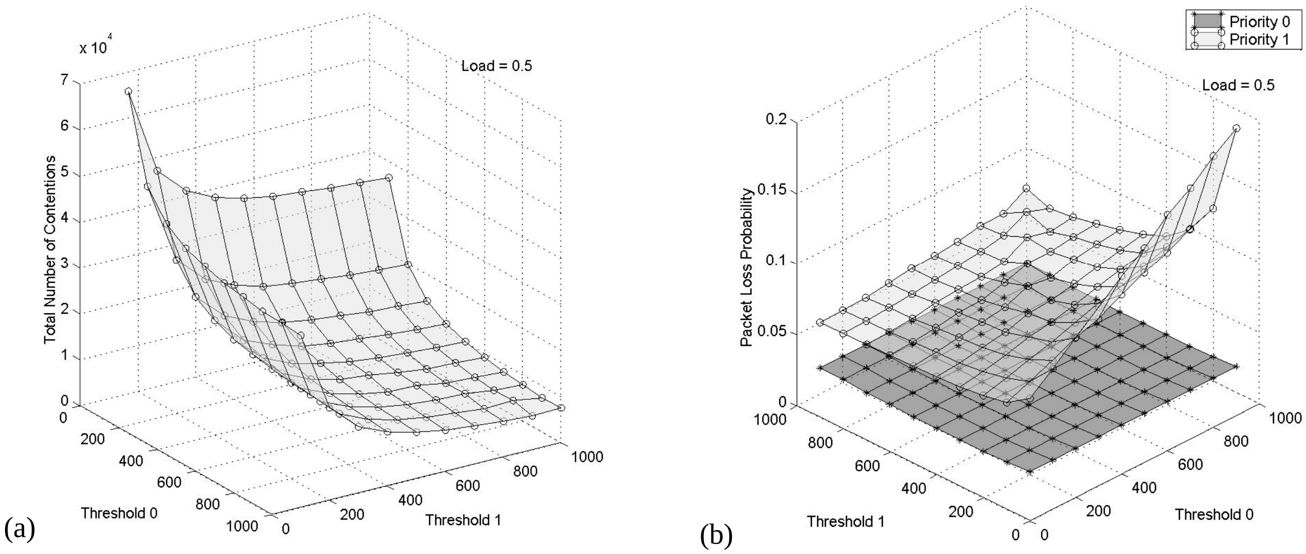

Figure 8. The graphs for SDP with two threshold and two burst priorities in the network (a) Total number of burst contentions versus varying values for both thresholds. (b) Packet loss probability versus varying threshold values for both priorities.

In Fig. 8(a) the total number of burst contentions is plotted versus both thresholds at a load of 0.5 Erlang. We observe that the number of contentions decrease as the threshold increases. Fig. 7(a) and Fig. 8(a) are similar with respect to the total number of burst contentions. Fig. 8(b) plots the packet loss probability versus varying threshold values for both priorities, under a load of 0.5 Erlang. We observe that the loss of high-class packets remains constant for different values of Threshold 1. The loss of low-class packets decreases as its burst size increases due to fewer contentions with higher-priority bursts. As the threshold increases, the loss increases due to the increase in the average number of packets lost per contention.

6. CONCLUSION

In this work, we considered an OBS network which uses the DR technique with burst segmentation. We investigated current timer-based and threshold-based burst assembly techniques, and we introduced a new threshold-based burst assembly technique to provide differentiated services for supporting QoS in the OBS network. We evaluated the relative performance of different threshold-based schemes for various threshold values and burst priorities, and we found that there is an optimal threshold value that minimizes the packet loss probability for a given network at a given load. We found that the optimal threshold range is between 380-430 packets for the NSFNET (Fig. 4) under a load which ranges between 0 and 1 Erlang. By using fixed-size bursts of optimal threshold value, the packet loss can be minimized.

Possible areas of future work are to analyze the end-to-end delay for the threshold-based schemes, to evaluate the performance in the case of more than two packet classes, and to investigate timer-based assembly techniques to support delay-based QoS. By combining both timer-based and threshold-based scheme, it may be possible to provide minimal loss while also guaranteeing end-to-end delay.

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