Early Drop Scheme for Providing Absolute QoS Differentiation in Optical Burst-Switched Networks

Qiong Zhang, Vinod M. Vokkarane, Biao Chen, and Jason P. Jue
Dept. of Computer Science, The University of Texas at Dallas, Richardson, TX 75083-0688
{qzhang77, vinod, bchen, jjue}@utdallas.edu

Abstract—**There have been several schemes proposed to provide relative differentiated service in OBS. One such scheme is the proportional QoS scheme. However, to meet requirements of a wide variety of applications, the backbone OBS network must provide absolute QoS differentiation. There is no work in the literature to provide support for this crucial QoS model. In this paper, we propose an absolute QoS model in the backbone network with admission control and resource provisioning at the edge nodes and with loss guarantee at each core node. We also propose two approaches to guarantee worst-case loss probability at the core nodes: Early Drop by Threshold (EDT) and Early Drop by Span (EDS). We compare the performance of these proposed approaches with the proportional QoS scheme. Simulation results showed that the EDS outperforms EDT and the proportional QoS scheme in providing loss guarantee and also reduces the loss of other non-guaranteed traffic.**

Index Terms: IP, DWDM, Optical Burst Switching, Relative QoS, Absolute QoS.

I. INTRODUCTION

The explosive growth of the Internet demands a high-speed transmission technology to support rapidly increasing bandwidth requirements. Currently, DWDM technology achieves multiplexing of 160-320 wavelengths in one fiber, with 10-40 Gb/s transmission rate per wavelength. In order to efficiently utilize the raw bandwidth in DWDM networks, an all-optical transport system, which can avoid optical buffering while handling bursty traffic, and which can also support fast resource provisioning and asynchronous transmission of variable sized packets, must be developed.

Optical burst switching (OBS) [1] is a promising DWDM switching technology. OBS has higher wavelength utilization than wavelength-routed optical networks. While, on the other hand, OBS does not have synchronization issues, large buffer requirements, and high switching overheads of optical packet switching. The most common signaling protocol in OBS is Just-Enough-Time (JET). In JET, a control packet is sent to the destination to reserve necessary channels at each of the intermediate core nodes along the path. After an offset time, the data burst is transmitted all-optically through the core. Since JET is a one-way reservation signaling protocol, it can only provide very limited QoS guarantee to the upper layer.

In OBS, the primary reason for packet loss is the contention of data bursts in the bufferless core nodes. When the burst scheduler cannot find an available outgoing channel based on the arriving time of a burst, the burst will be dropped upon its arrival. In order to reduce the packet loss, many contention resolution schemes have been proposed such as, buffering [2], wavelength conversion [3], deflection [4], and segmentation [5].

QoS support is an important issue in OBS networks. Applications with diverse QoS requirements urge the Internet to guarantee QoS. There are two models for providing service differentiation: relative and absolute. In the relative QoS model, traffic is classified into classes. Performance of each class is not defined quantitatively in absolute terms based on loss, delay, and bandwidth. Instead, the QoS of one class is defined relatively to other classes. For example, class of high priority is guaranteed to receive lower loss than class of lower priority. However, no upper bound on the loss is guaranteed for the high priority class.

The absolute QoS model aims to provide worst-case guarantee on the loss, delay, and bandwidth to applications. This type of hard guarantee is essential for the classes of delay and loss sensitive applications, which include multimedia and mission-critical applications. Efficient admission control and resource provisioning mechanisms are needed to support the absolute QoS model.

Several schemes have been proposed to support the relative service differentiation in OBS. In [6], a proportional QoS scheme based on per-hop information was proposed to support burst loss probability and delay differentiation. Also, an additional-offset scheme that provides relative burst loss probability differentiation was proposed in [7].

Absolute QoS in OBS network is primarily to guarantee burst loss probability for the prioritized traffic. For the delay and bandwidth QoS metrics, since core nodes are bufferless and data bursts are transmitted all-optically, the delay is mainly propagation delay, while the bandwidth is a direct function of loss probability. Though it has been well accepted that absolute QoS support is important, there is no scheme in the literature to provide absolute QoS in OBS.

In this paper, we propose the absolute QoS model for OBS networks. The paper is organized as follows. Section II provides the description of the proportional and absolute QoS models for OBS. In section III, we propose two approaches

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to guarantee worst-case burst loss probability using early drop scheme. Section IV compares the performance of the two proposed approaches with the proportional QoS scheme. Section V concludes the paper.

II. QoS Models for OBS Networks

In this section, we describe the proportional and absolute QoS models for OBS networks:

A. Proportional QoS Model

We now describe the proportional QoS model to provide relative service differentiation in OBS networks as in [6]. The proportional QoS model quantitatively adjusts the QoS metric to be proportional to the differentiation factor of each class. If P_i is the loss metric and S_i is the differentiation factor for class i, then using the proportional differentiation model,

$$\frac{P_i}{P_j} = \frac{S_i}{S_j}, \tag{1}$$

for all classes.

In order to implement this model, each core node needs to maintain traffic statistics for each class, such as the number of burst arrivals and the number of bursts dropped. Hence, the online blocking probability of class i, P_i is number of bursts dropped of class i divided by the number of burst arrivals of class i at time t. To maintain the proportionality factor between the classes, an intentional burst dropping scheme is employed.

B. Absolute QoS Model

The most intuitive approach to provide absolute QoS is to design a hybrid optical backbone network consisting of wavelength-routed lightpaths [8] to carry the guaranteed traffic, and a classic OBS network to carry non-guaranteed traffic. This approach is inefficient, since it leads to the wastage of bandwidth over the wavelength-routed sub-network. In order to efficiently utilize bandwidth, all the wavelengths in the network should be available for the statistical multiplexing and dynamic bandwidth allocation of data traffic. Hence, we develop a new scheme based on the above design considerations.

An OBS transport network consists of a collection of edge and core nodes as shown in Fig. 1. The traffic from multiple client networks is accumulated at the ingress edge nodes and transmitted through high capacity DWDM links over the core. The egress edge nodes, upon receiving the data, provide the data to the intended client networks.

Since core nodes are bufferless and data bursts go through an all-optical path from source to destination, the delay is mainly propagation delay, while the bandwidth is a direct function of loss probability. Therefore, in this paper, we intend to guarantee end-to-end loss probability for the prioritized traffic. We need to employ admission control at the ingress nodes and suitably provision the network resources. At the core nodes, we employ early drop scheme to satisfy the loss requirement. In this paper, we address the core node issues.

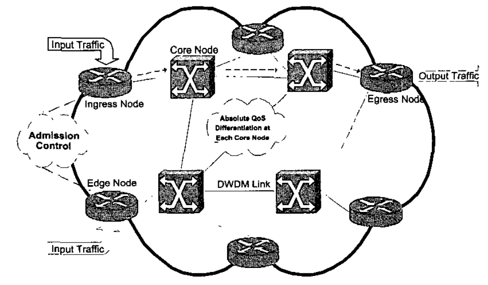


Fig. 1. Absolute QoS model for OBS transport network.

Here, we decide the maximum loss probability at each node based on the network level loss guarantee for each class. We assume that each class has an end-to-end maximum loss requirement. Therefore, based on the network diameter, we decide the upper bound of loss probability for each class at every node. We also assume that the loss guarantees at each node are same for each class. Let D be the network diameter, which is the maximum number of hops between any source-destination pair. Let P_i^{MAX} be the maximum loss probability at each node, and P_i^{NET} be the maximum loss probability over the entire network for the i^{th} class. To guarantee end-to-end loss for the longest path in the network with D hops, we have:

$$P_i^{NET} = 1 - (1 - P_i^{MAX})^D. \tag{2}$$

Therefore,

$$P_i^{MAX} = 1 - e^{(ln(1-P_i^{NET}))/D}. \tag{3}$$

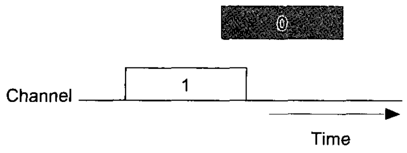
If the loss P_i^{MAX} can be guaranteed at every node along the path, the end-to-end loss P_i^{NET} can be guaranteed for all source-destination pairs.

In the next section, we propose a probabilistic early drop scheme to guarantee the maximum packet loss probability, P_i^{MAX}, at each OBS node.

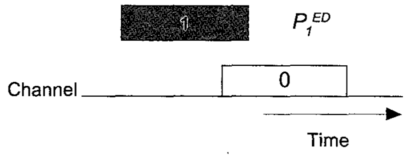
III. Early Drop Scheme

At each OBS node, without employing any service differentiation scheme, bursts have the same drop probability in the event of a contention. To guarantee the loss probability for the prioritized traffic, we adopt the early drop scheme. Early drop scheme is a probabilistic service differentiation technique in which the bursts of a low-priority class j are intentionally dropped with probability P_j^{ED}, before possibly contending with the bursts of a high-priority class i (where $i < j$).

In Fig. 2(a), a class 1 burst (low-priority) reserves the channel earlier than the class 0 burst (high-priority). The latter-arriving class 0 burst is dropped due to contention. In order to avoid the likelihood of such a scenario, we employ the early



(a) Standard drop scheme



(b) Early drop scheme

Fig. 2. Contention resolution using drop schemes.

drop scheme, in which we drop the class 1 burst with early dropping probability P_1^{ED} before the class 1 burst possibly contends with the class 0 burst (Fig. 2(b)). P_1^{ED} is computed based on the maximum loss probability of the class 0 burst and the online loss probability of class 0 burst. The key is to decide when to trigger the early drop scheme and how to set the early dropping probability P_1^{ED}.

In order to provide loss guarantees, each OBS core node has to maintain traffic statistics for each supported class. For each output port of an OBS node, let A_i be the burst arrival counter, D_i be the burst drop counter, and $P_i = (D_i/A_i)$, be the online measured burst loss probability for the burst of the i^{th} class. Let P_i^{MAX} be the maximum burst loss probability for the i^{th} class burst, based on the end-to-end loss requirement of each class. Without loss of generality, we assume that there are two classes of bursts supported in the core, namely class 0 and class 1, with class 0 having the higher priority. We propose the following two approaches to support loss guarantee: *Early Drop by Threshold (EDT) and Early Drop by Span (EDS).*

A. Early Drop by Threshold (EDT)

The basic idea of EDT is to drop class 1 bursts when P_0 reaches the maximum loss probability, P_0^{MAX}. When the loss probability of class 0 burst, P_0, reaches the pre-set P_0^{MAX}, EDT starts to drop the arriving bursts of class 1, in order to reduce the contention probability of class 0 bursts, until P_0 is less than P_0^{MAX}. This early dropping bursts of lower priority class is a simple way to provide loss guarantee for higher priority class. The early dropping probability of class 1 bursts is given by

$$P_1^{ED} = \begin{cases} 0 & P_0 < P_0^{MAX} \\ 1 & P_0 \geq P_0^{MAX}. \end{cases} \tag{4}$$

The EDT approach can be extended to support more than one class with guaranteed loss probability. In this case, bursts of lower priority classes are dropped when the loss probabilities of higher priority classes are exceeded.

In the EDT approach, the class 1 bursts suffer from high loss when P_0 exceeds P_0^{MAX}. Since we have a single trigger point, the approach takes extreme steps in order to regulate P_0. In order to reduce the side effects of EDT, we propose EDS, which is triggered over a span.

B. Early Drop by Span (EDS)

In this approach, a span, δ_0, for class 0 is chosen. The EDS approach is triggered when the loss probability of class 0 bursts, P_0, is between P_0^{MIN} and P_0^{MAX}, where, $P_0^{MIN} = P_0^{MAX} - \delta_0$. The span can be chosen as a percentage value of P_0^{MAX}. The class 1 bursts are dropped with a probability, P_1^{ED} given by:

$$P_1^{ED} = \begin{cases} 0 & P_0 < P_0^{MIN} \\ (P_0 - P_0^{MIN})/\delta_0 & P_0^{MIN} \leq P_0 < P_0^{MAX} \\ 1 & P_0 \geq P_0^{MAX}. \end{cases} \tag{5}$$

The EDS approach can also be extended to support multiple classes with guaranteed loss probability. In this case, the loss probability of each class burst is dependent on the maximum loss probabilities and span values of all the higher priority classes.

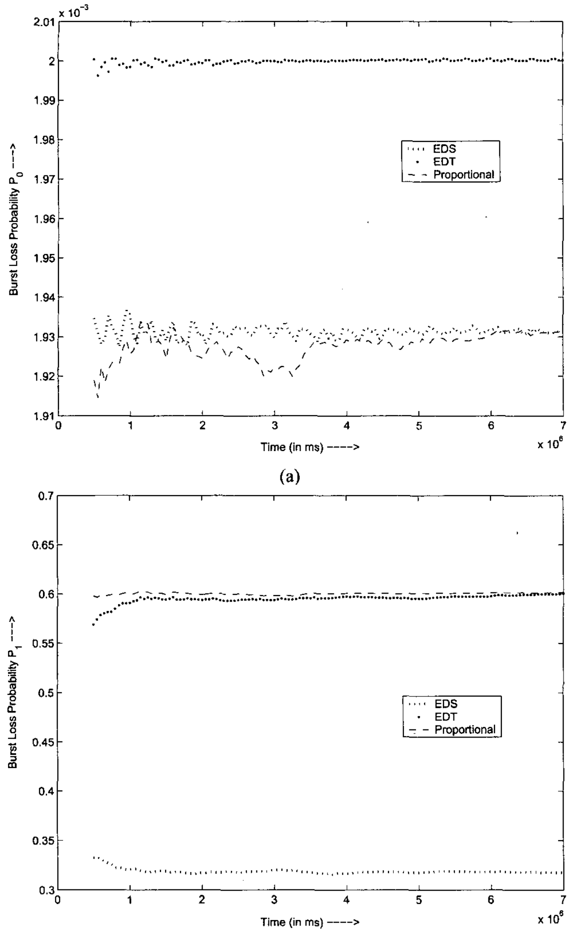
IV. SIMULATION

In order to evaluate the performance of the proposed early drop approaches, a simulation model is developed. The simulation studies the burst loss probability at an OBS core node. We consider two traffic classes, class 0 (high-priority) and class 1 (low-priority). We compare the performance of early drop approaches with the proportional QoS scheme. The following are the assumptions and parameter values:

- Burst arrivals are Poisson distributed with rate λ.
- Burst length is exponentially distributed with an average burst length of $1/\mu = 10$ ms.
- Transmission rate is 10 Gb/s.
- No buffering at the core node.
- Number of wavelengths per link is 4.
- Absolute loss guarantee is provided for class 0 traffic with $P_0^{MAX} = 0.002$.
- Class 1 is best-effort service class.
- 20% of traffic is class 0 and 80% of traffic is class 1.

When we compare the EDT and EDS approaches to the proportional scheme, we adjust the proportionality factor in the proportional scheme, based on the loss guarantee, P_0^{MAX}, such that the average loss probability of the class 0 traffic in the proportional scheme is mapped to the average loss probability of the class 0 traffic in EDS.

Figures 3(a) and (b) show the online measured burst loss probability versus time for the class 0 and class 1 bursts respectively. We observe in Fig. 3(a) that the loss of class 0 bursts is guaranteed in EDS and the proportional scheme; while in EDT, P_0^{MAX} is occasionally exceeded, since the EDT approach has a single point of control and the approach takes



(a)

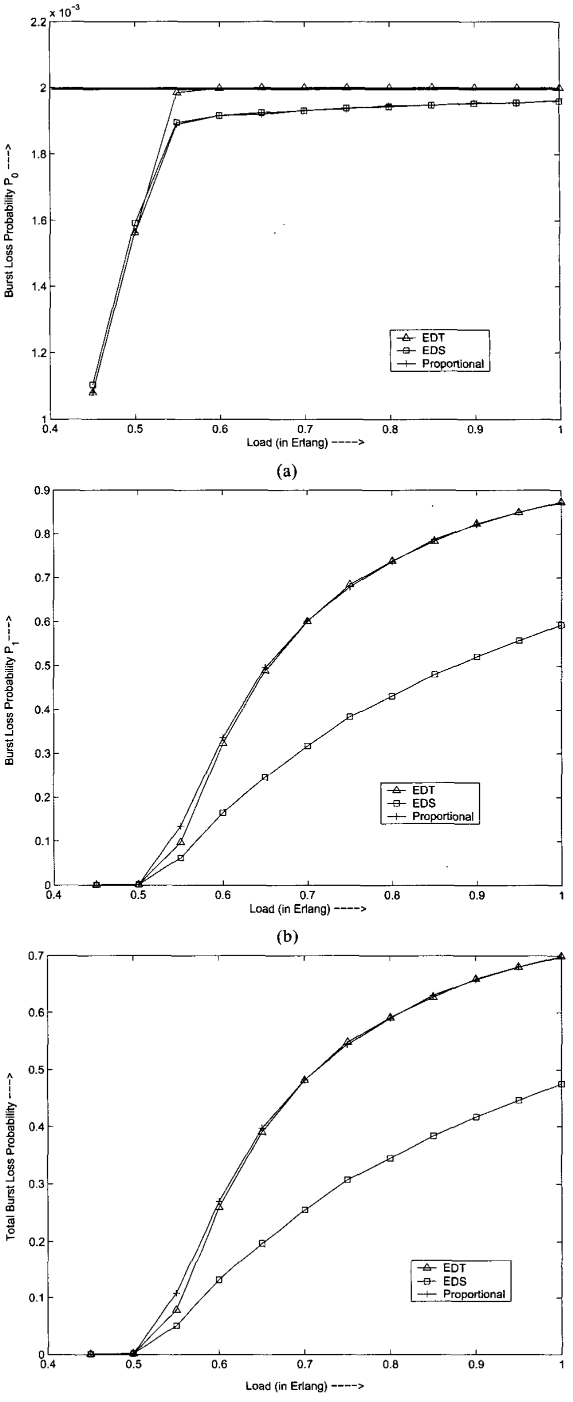
(b)

Fig. 3. (a) class 0, and (b) class 1 burst loss probability versus time with Load = 0.7 Erlang and Span = 0.0001.

corrective measure only after P_0^{MAX} has been exceeded. In Fig. 3(b), the class 1 bursts suffer from high loss in the EDT and proportional schemes, as compared to EDS. The reason is that the EDT and proportional schemes drop all of the class 1 bursts when triggered. On the other hand, the EDS approach probabilistically drops class 1 bursts over the entire span.

In EDT, since the loss probability of the guaranteed class 0 traffic exceeds the maximum value, we can set the maximum loss probability of the class 0 traffic to be slightly lower than the actual loss probability to be guaranteed. However, this modification in EDT will increase the loss probability of the class 1 bursts, thus further reducing the network performance.

Figure 4(a), 4(b), and 4(c) plot the class 0, class 1, and total average burst loss probability versus load, respectively. We observe from Fig. 4(a) that the loss probability of class 0 bursts in the EDS and proportional schemes is lower than



(a)

(b)

(c)

Fig. 4. (a) class 0 (b) class 1 and (c) total average burst loss probability versus load for EDT, EDS (Span = 0.0001) and proportional.

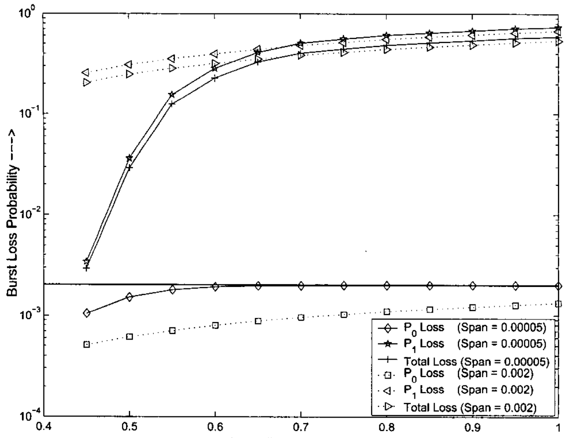


Fig. 5. Burst loss probability versus load with different values of span.

the loss guarantee, $P_0^{MAX} = 0.002$. On the other hand, EDT exceeds the guaranteed loss occasionally. In Fig. 4(b), at low loads, we see that the early drop based approaches are not triggered, since the loss probabilities are lower than their trigger points. At higher loads, EDS outperforms the other two schemes. For instance, at a load of 0.9 Erlang, traffic of class 1 suffers 85% loss using the EDT and proportional approaches, but only 55% loss with the EDS approach. From Fig. 4(c) we observe that the total loss is much higher in the EDT and proportional schemes as compared to EDS. In EDT, the class 1 bursts are always dropped when the maximum loss probability is exceeded. While in the proportional approach, the loss probabilities changes according to the proportional factor, leading to higher loss. We can see that by using EDS, the throughput is significantly higher as compared to the EDT and proportional schemes.

As EDS is the best scheme to provide loss guarantee, we study the performance of EDS for different span values. Fig. 5 plots the burst loss probability versus load with different values of span in EDS. We observe that at high loads, the total loss probability decreases with longer spans, since there is a longer range of span over which the loss probability of class 0 bursts can be corrected. At low loads, the total loss probability increases with longer span, since the EDS scheme is triggered earlier.

Table 1 provides a summary for the performance of the different schemes. We observe that EDS outperforms the other two schemes in terms of supporting loss guarantee and achieving high throughput in an OBS backbone network.

V. CONCLUSION

In this paper, we address the issues of providing absolute QoS guarantee in an OBS network. We proposed two approaches, namely EDT and EDS, that use the early drop scheme to provide loss guarantee in OBS networks. We compared the performance of the two proposed approaches to the proportional scheme. From the simulation, we observed that EDS performs better than the EDT and proportional QoS schemes in terms of loss probability of the low-priority class and total loss probability, while also guaranteeing the loss of high-priority class. On the other hand, since EDT exceeds the loss guarantee, we suggest that the maximum burst loss probability in the EDT scheme should be set lower than the loss requirement of the corresponding application in order to provide the necessary loss guarantee.

TABLE I

SUMMARY OF THE PERFORMANCE OF THE DIFFERENT SCHEMES.

Approach	P_0 Loss	P_1 Loss	Total Loss
Proportional	Guaranteed	High	High
EDT	Non-Guaranteed	High	High
EDS	Guaranteed	**Low**	**Low**

Areas of future work are to develop a framework for admission control and resource provisioning at the edge OBS nodes. We would also like to observe the performance of these schemes over an entire network with suitable admission control based on the provisioned resources. In this paper, the value of P_i^{MAX} is obtained based on the longest path in the network; thus, source-destination pairs with shorter paths will experience lower loss. We would like to develop a group-based model based on the path length of source-destination pairs, where each group has a unique P_i^{MAX}.

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