

# An Emission and Discard Priority Scheme for OBS Networks

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**Abstract**—A key issue in Optical Burst Switched (OBS) networks is resolving burst contention in an efficient and cost-effective manner. Although deflection routing has been identified as a cost-effective solution, its viability has been questioned. We propose an Emission and Discard Priority (EDP) scheme to alleviate the shortcomings of deflection routing by reducing late packet arrivals and hence improving network goodput. Simulation results show that the deflection with EDP scheme has a lower proportion of late packet arrivals than a basic deflection routing scheme. Furthermore, the deflection with EDP scheme has higher goodput when the normalized load  $L \geq 0.7$  and has higher efficiency than the basic deflection routing scheme in terms of goodput per deflection.

## I. INTRODUCTION

THE rapid growth of the internet over recent years, together with the increasing bandwidth requirements of new time-critical applications is driving the need to go beyond electronic switching in the optical network. Optical burst switching (OBS) is a promising switching technology for near-term deployment [1]. This technology supports bursty data traffic without requiring electronic and optical buffering.

The inherent challenge in OBS networks is the provision of QoS in a simple and cost-effective manner. OBS compromises the guarantee of packet delivery, through wavelength path reservation (optical circuit switching), for high bandwidth utilization and low transmission delay. As a result, burst loss increases because the probability of contention between bursts rises in the network. Contention occurs when multiple bursts compete for the same output port simultaneously. Resolving contention in an *efficient* and *cost-effective* manner is therefore a high priority to improve QoS and network efficiency in the OBS domain. Techniques to resolve contention include wavelength conversion, optical buffering, deflection routing [2]-[3], and burst segmentation [4].

Wavelength conversion is the most effective contention resolution technique in OBS. However, the high cost of Tunable Wavelength Converters means that network operators have to limit the use of wavelength conversion to remain cost-effective. In this paper, we focus on deflection routing for contention resolution in OBS networks because it requires no extra hardware for implementation and is therefore cost-effective.

Deflection routing has several shortcomings such as longer propagation delays in the network. This extra delay affects the end-to-end transmission delay of bursts. Hence, bursts may reach their destination late, and packets may be delivered out-of-sequence. Although deflecting bursts increases throughput at low loads, it has a negative effect on burst loss performance at high loads [5]. An increased number of deflections raises the

probability of burst contention causing high burst loss [5].

Hsu et al. [5] and Lee et al. [7, 8] have studied and analysed deflection routing. However, they were mostly concerned with the burst blocking effects of deflection routing. This paper focuses on the more important disadvantage of deflection routing, which is the added delay that bursts suffer when deflected. Although deflection routing will increase throughput in the network, it will not necessarily improve the goodput of the OBS network. Goodput can be defined as the useful throughput that reaches destination. Packets with stringent delay tolerances become useless when they arrive at their destination late. Hence, these packets should not be considered as throughput because they do not contribute to providing QoS. It is preferable to drop the bursts that contain these packets inside the network to release resources for other incoming bursts. Our objective is therefore to reduce the negative impact of burst deflections on late packet arrivals and to improve the goodput of deflection routing. For this purpose, we propose an Emission and Discard Priority (EDP) scheme.

The remainder of this paper is organized as follows. In Section II, we describe the Emission and Discard Priority (EDP) scheme and explain how the EDP scheme can optimize deflection routing in OBS networks. Simulation results are presented and discussed in Section III. The conclusions of our work are given in Section IV.

## II. EMISSION AND DISCARD PRIORITY (EDP) SCHEME

In this section, we introduce the concept of EDP to overcome the limitations of deflection routing in OBS networks. We describe the implementation of the EDP scheme at the burst assembly stage and explain how it optimizes deflection routing when resolving contention in the core network.

### A. Description

A good way to provide QoS is to have a service differentiation scheme that discriminates effectively between traffic types in order to meet their QoS requirements. The EDP scheme provides service differentiation at both the edge and the core by focusing on the performance requirements of current applications. In this way, the QoS constraints of the traffic can be met, and more importantly, the Quality of Experience (QoE) of users can be improved.

The *emission* priority determines the urgency of delivery of incoming traffic. This priority is based on the delay tolerance of each application type. For example, VoIP and video conferencing applications are highly sensitive to delay. Hence, these applications will have a high emission priority. On the

other hand, applications such as Email and File transfer, which are highly tolerant to delay, will have a low emission priority. Hence, traffic with a higher emission priority has precedence over traffic with a lower emission priority.

The *discard* priority determines the order in which bursts are discarded. The network can discard a burst when it contends for the same resources with other bursts or when its traffic class is out-of-profile, in the case of an absolute QoS mechanism. The discard priority gives further differentiation in the core network. We differentiate between bursts of equal emission priorities with the discard priority in the case of contention. Bursts with higher discard priorities are more eligible to be dropped than bursts with lower discard priorities. Considering discard priorities enables the creation of virtual queues at the edge nodes. Hence, a small number of hardware queues can still provide a large number of QoS levels.

The discard priority of a packet is based on its delay and loss requirements, as well as its transmission protocol. For example, interactive applications are UDP-based (Universal Datagram Protocol) and hence cannot retransmit lost or dropped packets. Furthermore, packet retransmission would be useless because interactive applications are real-time based. On the other hand, responsive applications are both UDP-based and TCP-based (Transport Control Protocol) and further have buffers to improve QoE. Hence, packet retransmission is possible and useful for responsive applications and timely applications because their requirements are not real-time based.

### B. Burst Assembly with the EDP scheme

When packets arrive at the edge of the network, they are aggregated in separate queues based on their destination and delay requirements. The delay requirements of the incoming traffic determine the emission priority of the assembled packets. Hence, the emission priority determines the importance of the burst in the network and provides static QoS classification at the edge node. A high emission priority means a high burst class. Fig. 1 shows the format of a burst header packet (BHP) when assembling with the EDP scheme.

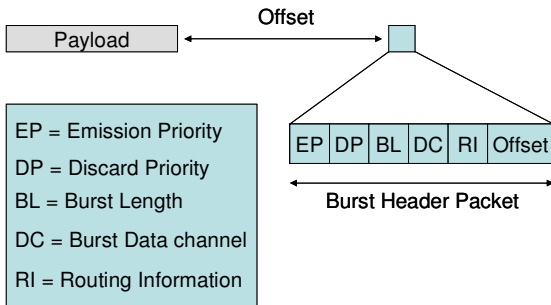


Fig. 1 Format of a burst header packet (BHP) for assembly with the EDP scheme

We can see that there is an emission priority field and a discard priority field in the burst header packet. These fields are read when the burst header packet reaches a core node. In the case of contention with another incoming burst, the core node uses the values in the EP, DP, and BL fields to resolve contention. The core node uses the rest of the fields to

determine whether the incoming burst can be reserved on an outgoing link.

In our OBS network, we assume that the assembly period of packets at the edge nodes is variable [8]. Hence, the emission priority also dictates the assembly period of each assembly queue. A higher emission priority implies a shorter assembly period whereas a lower emission priority implies a longer assembly period. However, short assembly periods imply short bursts and short bursts imply higher switching time requirements. Hence, the padding of short bursts may be needed to ensure that their length/size is within the switching capabilities of the core nodes in the network.

### C. Resolving Contention with the Emission and Discard Priority Scheme

Table I illustrates the QoS classification of internet traffic applications.

TABLE I  
QoS DIFFERENTIATION WITH THE EDP SCHEME

Traffic Category	Applications	Emission Priority	Discard Priority
Network Control	Critical alarms	3	0
	Critical OAM, Routing, Billing		1
Interactive	VoIP	2	0
	Interactive Gaming, Video Conferencing		1
Responsive	Streaming Video, Audio	1	2
	Client/Server Transactions		3
Timely	Email, non-critical OAM	0	3
	Best Effort		4

A high emission priority or a high discard priority is denoted by a large number (Table I). The emission priority corresponds to the traffic category and the number of hardware queues at every edge node. Discard priorities allow applications that are within the same traffic category to be subdivided. In this case, applications in the same traffic category are subdivided with two discard priorities. For example, in the interactive class, VoIP applications have a lower discard priority than interactive gaming and video conferencing applications because of the high real-time standards of telephony.

At any edge node in the network, each queue can only assemble a burst with one emission priority and one discard priority. Therefore, even though packets may have different discard priorities, the burst that they form can have only one discard priority. A solution to this issue would be to assign the burst with the lowest discard priority present in its group of packets, or assign it the most frequent discard priority in its group of packets.

Table II illustrates the possible cases of burst contentions when using the EDP scheme as a guide to resolve contentions. We attempt wavelength conversion for both contending bursts

before attempting deflection routing. Deflection routing is attempted for the losing burst. In case the emission and the discard priorities of contending bursts are equal, we use the burst length to differentiate. The shorter burst is deflected because it offers potentially lower throughput. Hence, higher priority is given to the longer burst.

TABLE II  
CONTENTION CASES WHEN USING THE EDP SCHEME

Contention	Emission Priority	Discard Priority	Burst Length	Deflection
Case 1	$A > B$	X	X	Burst B
Case 2	$A < B$	X	X	Burst A
Case 3	Equal	$A > B$	X	Burst A
Case 4	Equal	$A < B$	X	Burst B
Case 5	Equal	Equal	$A > B$	Burst B
Case 6	Equal	Equal	$A < B$	Burst A

The EDP scheme helps to limit the deflection of bursts that have a high risk of reaching their destination beyond the limits of their delay requirements. Fig. 2 shows the deflection routing algorithm that we use to improve goodput in the OBS network. The discard priority determines the number of possible deflections that a burst can suffer. When a burst is deflected, we decrement its discard priority. Hence, when the discard priority of a burst reaches zero, the burst cannot be deflected. Furthermore, when bursts with the same emission priority contend, the burst with a higher discard priority is dropped ahead of the burst with a lower discard priority. Thus, when a burst is deflected and its discard priority is consequently decremented, its importance in the network increases. In this way, we potentially enhance the chances of a burst reaching its destination within its delay limits.

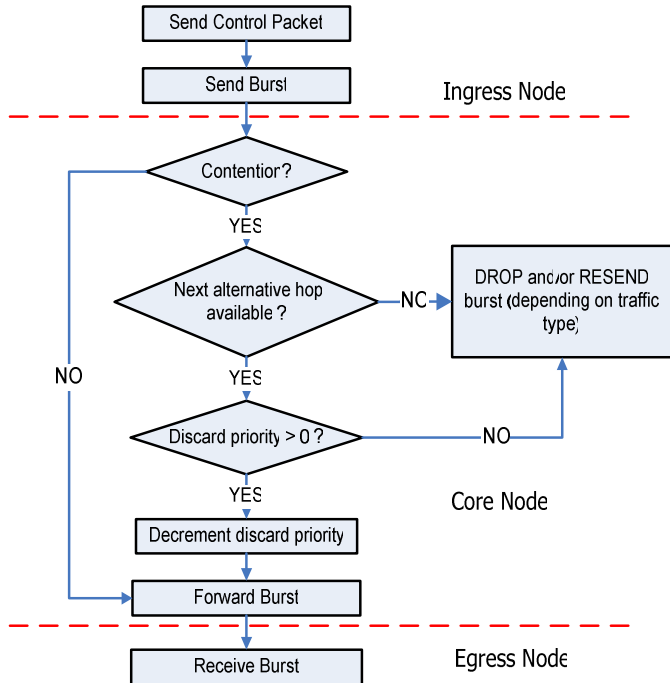


Fig. 2. Flow diagram describing the combination of deflection routing with the EDP scheme

As shown in Table I, timely bursts have a high discard priority whereas network control and interactive bursts have a low discard priority. Hence, delay tolerant applications, which are usually loss intolerant, can spend more time in the network to ensure delivery. On the other hand, delay intolerant bursts cannot afford many deflections because of time constraints. The overall effect is that the number of unnecessary deflections is reduced and goodput of the network is improved. This effect may not be obvious at low loads due to the low probability of contention. However, this effect can be noticeable at high loads where unnecessary deflections cause more contentions in the OBS network.

### III. SIMULATION RESULTS AND ANALYSIS

This section evaluates the performance of deflecting bursts with the EDP scheme using the Network Simulator 2 (NS-2.28) [9] framework and an OBS network simulation module (OBS-0.9a) [10]. Our objective is to reduce the late arrivals of delay intolerant packets at their destination due to deflection. Burst deflection would therefore have a lesser effect on packet latency in the network.

#### A. Simulation Setup

For our experiment, we use the network topology shown in Fig. 3. The topology consists of 12 edge nodes and 6 core nodes. Each edge node can be viewed as the link to a metropolitan area network. Nodes are connected with DWDM fiber links, which transmit data optically. The nodal degree of the network topology is  $N = 2.2$ . The nodal degree indicates the level of connectivity between the nodes in the network.

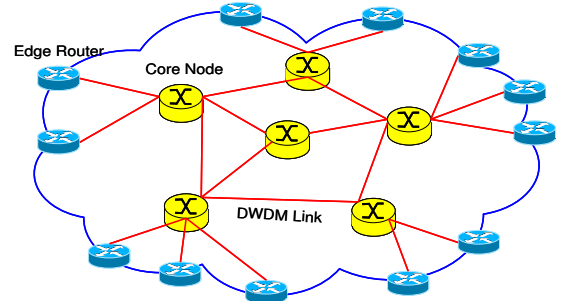


Fig. 3. Network topology with 12 edge nodes and 6 core nodes

Traffic is generated according to a heavy-tailed Pareto distribution to model the burstiness and self-similarity of data traffic. Authors in [11] show that multiplexing several heavy-tailed Pareto distributions into the same queue can generate self-similar traffic. Our experiments are done under the following assumptions:

- 1) The offset time is always large enough to prevent a burst from catching up with its corresponding burst header packet.
- 2) There is no wavelength conversion and no optical buffering (FDLs) at all nodes in the network.
- 3) The burst length depends on a variable period of assembly and a maximum burst length.
- 4) The Just-Enough-Time (JET) [12] signaling protocol is

- used to reserve network resources.
- 5) The LAUC-VF [13] algorithm is used to schedule bursts at all nodes.
  - 6) Dijkstra's shortest path routing algorithm is used for routing bursts in the network.
  - 7) There is a uniform distribution of packets within each traffic class.
  - 8) There is a uniform distribution of the delay requirements of packets within each traffic class.

Table III illustrates the configurations of our OBS network.

TABLE III  
OBS NETWORK CONFIGURATION PARAMETERS

Bandwidth per channel	1 Gbps
Number of control channels	1
Number of data channels	1
Link delay	1-3 ms
Offset time	50 $\mu$ s
Switching time	1 $\mu$ s
Packet size	1000 bytes
Maximum burst length (L)	1MB

We limit the number of data channels and control channels to 1 in order to prevent the use of wavelength conversion. This limitation allows us to strictly evaluate the effect of deflection routing in the OBS network. The maximum burst length was 1 MB. This length is reached if and only if the burst queue is filled before the burst assembly period is over. Hence, a 1 MB burst is a burst which is assembled based on the maximum burst length instead of a maximum period of burst assembly. We set an offset time of 50  $\mu$ s to ensure that burst payloads never reached their destination before their respective burst header packets. The link delay varies between 1 and 3 ms, which corresponds to a distance ranging from 300 to 900 km between a node pair.

Table IV illustrates the distribution of different application types and the range of their delay requirements. Network control and interactive applications each represent 20% of the data traffic while responsive and timely applications make up the remaining traffic. The emission and discard priorities of the data traffic vary between 0 and 3. Network control applications have the highest emission priority because they are necessary for the correct operation of the network. Although interactive applications have a high sensitivity to loss, they have the lowest discard priority. This low discard priority means that the application has stringent delay requirements and thus is not favorable to deflection. End-to-end delay ( $T_{\text{delay}}$ ) is more important than loss ( $P_{\text{loss}}$ ) in the case of interactive applications because late arrivals are unacceptable.

TABLE IV  
TRAFFIC CLASS CONFIGURATION FOR BURST ASSEMBLY

Traffic Class	Input Traffic Ratio	Delay Tolerance (ms)	Assembly Period (ms)	Emission Priority	Discard Priority
Network Control	20%	50-70	45-85	3	1
Interactive	20%	80-100	75-105	2	0
Responsive	30%	110-130	105-135	1	2
Timely	30%	140-160	135-165	0	3

### B. Throughput analysis

To evaluate the performance of deflecting bursts with the EDP scheme, our experiment investigates the cases of no-deflection, basic deflection and deflection with the EDP scheme. In the case of no-deflection, the only method of contention resolution is the drop policy. Hence, if a burst cannot be scheduled, it is dropped. In the case of basic deflection, we implement a basic deflection routing algorithm of order 1. In other words, deflection is only attempted on the next shortest alternative hop to destination. However, there is no limit to the possible number of deflections on a burst until it reaches its destination. If a burst cannot be scheduled on the next alternative hop, it is dropped. In the case of deflection with the EDP scheme, we also implement a basic deflection routing algorithm of order 1. However, the number of burst deflections is based on the emission and discard priority of the burst. If a burst cannot be scheduled on the next alternative hop, it is dropped. For the remainder of this paper, we refer to the no-deflection scheme as case 1, the basic deflection scheme as case 2, and the deflection with EDP scheme as case 3.

Fig. 4 plots throughput versus the normalized traffic load for each contention resolution scheme.

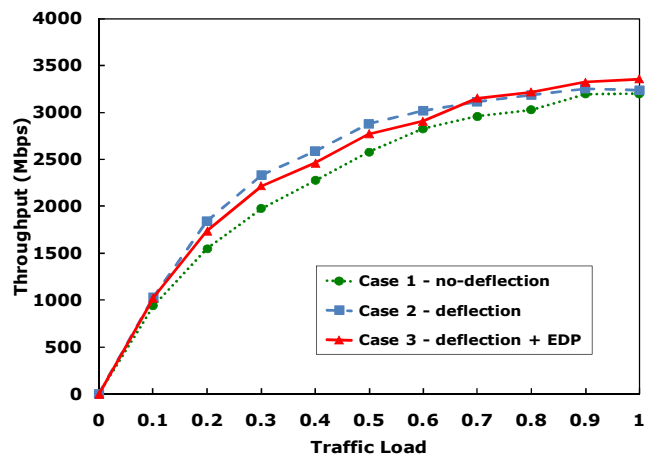


Fig. 4. Throughput versus normalized traffic load

We see that the throughput increases with increasing traffic load in all 3 cases. We observe that case 2 performs better than case 1 and case 3 for loads  $L < 0.7$ . However, case 3 has a higher throughput than case 1 and case 2 when  $L \geq 0.7$ .

### C. Delay Analysis

Fig. 5 plots the percentage of late packet arrivals versus the normalized traffic load for each contention resolution scheme. We observe that case 1 has the lowest percentage of late packet arrivals because it does not implement deflection routing. Hence, bursts do not incur any extra delay due to deflection routing. When  $L=0.5$ , case 2 has the worst performance with up to 13% of packets arriving late, which is 2% higher than in case 3. We notice that case 3 performs better than case 2 at all loads. In contrast to case 2, case 3 performs selective burst deflections based on the EDP scheme, and therefore minimizes the number of late packet arrivals.

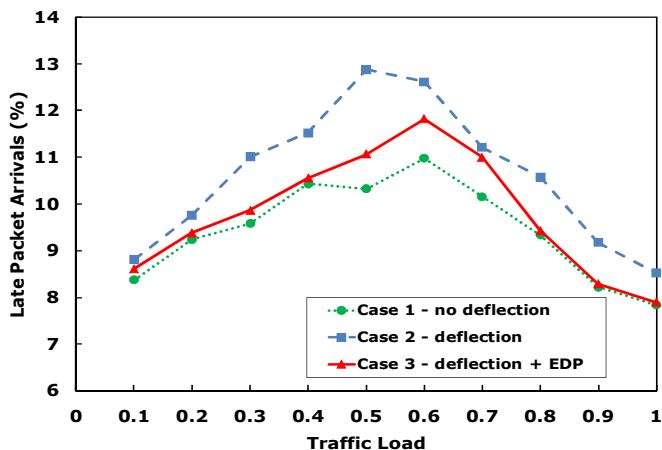


Fig. 5. Late packet arrivals versus normalized traffic load

### D. Goodput Analysis

Fig. 6 plots goodput versus the normalized traffic load for each contention resolution scheme.

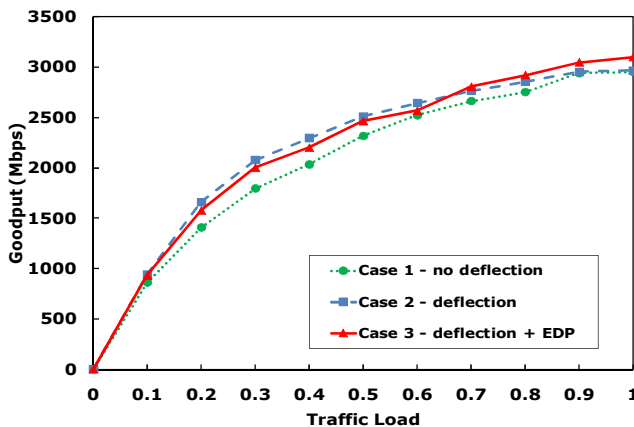


Fig. 6. Goodput versus normalized traffic load

In Fig. 6, we notice a higher goodput in case 2 than in case 3 when  $L < 0.7$ . However, at high loads ( $L \geq 0.7$ ) case 3 has a higher goodput than case 2. Case 3 performs better than case 2 because it has a higher throughput when  $L \geq 0.7$  (Fig. 4) and a lower proportion of late packet arrivals (Fig. 5). In addition, we see that the difference in goodput between case 2 and case 3 is minimal at low loads. It is important to note that

although case 1 performs better than case 2 and case 3 in terms of late packet arrivals, it has a lower goodput than case 2 and case 3 at all loads. Case 1 has the lowest goodput because it has a lower throughput than case 2 and case 3 (Fig. 4).

Fig. 7 shows the amount of goodput per deflection versus traffic load for the case of the deflection scheme and the deflection with EDP scheme. We observe that case 3 has a higher goodput per deflection ratio than case 2 at all loads. As the traffic load increases, the margin between case 3 and case 2 increases. As the load increases, the probability of burst contentions increases. Hence, it is important to selectively deflect bursts in an efficient manner at high loads. Case 3 applies the EDP scheme to perform selective burst deflections, and therefore has a higher goodput per deflection ratio than case 2.

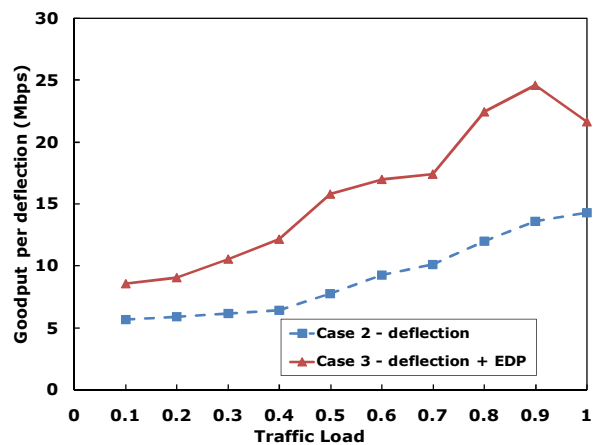


Fig. 7. Goodput per deflection versus normalized traffic load

## IV. CONCLUSION

In this paper, we investigate the combination of an emission and discard priority (EDP) scheme with deflection routing to better meet the QoS requirements of traffic in OBS networks. Through simulations, we compare the performance of the deflection with EDP scheme with the performance of a no-deflection routing scheme and the performance of a basic deflection routing scheme. Our results show that the deflection with EDP scheme has higher goodput than the no-deflection scheme at all loads. Furthermore, the deflection with EDP scheme has higher goodput than the basic deflection scheme for loads  $L \geq 0.7$ . Although the basic deflection scheme has higher goodput than the deflection with EDP scheme for loads  $L < 0.7$ , we have shown that the deflection with EDP scheme performs significantly better than the deflection scheme in terms of goodput per deflection. Hence, the proposed EDP scheme enhances the efficiency of deflection routing with selective burst deflections. This higher efficiency is more apparent at high loads where the performance of basic deflection routing is reduced in terms of goodput.

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