A Review of Optical Burst Switching in Wavelength Division Multiplexing Networks

Abstract—**Optical Burst Switching (OBS) is considered as an efficient switching paradigm for building the next generation optical Internet. This review has been motivated by the need for techniques that are capable of supporting the future bandwidth requirement of next-generation applications and services of Internet Protocol (IP) networks. The authors have discussed the basic concepts of OBS paradigm and outlined the signaling and scheduling issues related to OBS networks. Further, a brief summary on the issues that are essential for provisioning Quality-of-Service (QoS) in OBS networks has been outlined. Finally, an analytical model is presented to provide Burst Loss Probability (BLP) guarantees between every pair of source-destination nodes in the network.**

I. INTRODUCTION

Modern transport networks increasingly employ Wavelength Division Multiplexing (WDM) technology to utilize the vast transmission bandwidth of optical fibers [1], [2]. WDM enables the establishment of multiple non interfering wavelength channels on a typical optical fiber to provide good utilization of the potential network capacity [3]. WDM networks use switching techniques to establish static all-optical connections among the source-destination node pairs of the network for the entire duration of a communication session. These connections, either known as lightpaths, have the advantage of avoiding bottlenecks due to opto-electronic conversion at intermediate nodes of the network [4]. This switching paradigm is known as Optical Circuit Switching (OCS). Although commercially viable, this scheme does not provide an optimal utilization of network bandwidth, particularly in the case of bursty Internet traffic [3].

Optical Packet Switching (OPS) is a promising switching technique that has gained considerable attention to avoid non-optimal resource usage by OCS [5], [6]. In OPS, packet loss can be addressed with buffering strategies in the time domain and realized by holding the optical packets in Fiber Delay Lines (FDLs). FDLs suffer from the lack of flexibility; it is reported in the literature that a delay of $5\mu s$ for a single burst requires over a kilometer of fiber [7], [8]. Although attractive, OPS has not be employed yet, since the technology is not mature enough to deliver fast packet-level optical switching [2].

OBS [9], [10] has proved to be an aspiring switching technique, which utilizes the advantages of both OPS and OCS. The basic switching element in OBS is the data burst which is a collection of IP packets from different Class of Services (CoS). The transmission of each data burst is preceded by the transmission of a Burst Header Packet (BHP) whose purpose is to reserve switching resources along the path for the upcoming data burst. The BHP is processed electronically at every node in the network, and the data burst is transmitted transparently end to end without opto-electronic conversion at intermediate nodes [11]. An OBS source node does not wait for confirmation that an end-to-end connection has been set up; instead it starts transmitting a data burst after a delay (referred to as *offset time*) following the transmission of the BHP. The *offset time*, denoted by T, is bounded by the sum of the BHP processing time at every intermediate node and stated as:

$$T \geq \sum_{h=1}^{H} \Delta h \tag{1}$$

where Δh is the control delay at hop $1 \leq h \leq H$

The differences and similarities of the three switching paradigms just presented (OCS, OPS and OBS) are summarized in Table I [12], [13].

TABLE I
COMPARATIVE EVALUATION OF OPTICAL SWITCHING PARADIGMS

Criteria	OCS	OPS	OBS
Granularity	Coarse	fine	moderate
Bandwidth Utilization	low	high	high
Setup Latency	high	low	low
Switching Speed	slow	fast	moderate
Processing Complexity	low	high	medium
Traffic Adaptability	low	high	high

II. OBS NETWORK STRUCTURE

An OBS network consists of OBS capable nodes interconnected by optical fiber links supporting multiple WDM channels. The nodes can be either edge nodes or core nodes. The edge nodes assemble the electronic input packets into an optical burst which is sent over the OBS core nodes. The ingress edge node presorts 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 assembled bursts are transmitted all-optically over the intermediate core nodes. On the receiving side, the egress edge node disassembles the burst into packets and provides the packets to the upper layer [14], [15], [16].

Core nodes are mainly responsible for switching bursts from input ports to output ports and for handling contentions. These nodes comprise an optical switching fabric, a switch control unit, and processors for routing and signaling. In OBS networks, the control packet (i.e. BHP) and the data burst are transmitted separately on different wavelength channels. This separation between the control and the data planes allows for network flexibility and scalability [13]. The functions carried out by OBS edge nodes and core nodes are depicted in Figure 1.

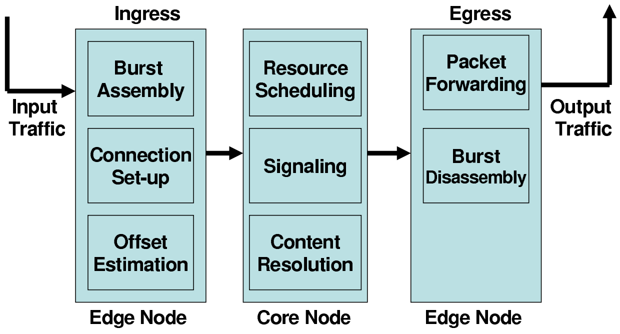

Fig. 1. Main Functions of OBS Nodes

III. OBS SIGNALING

Signaling specifies the protocol by which connection requests are handled, and its operation determines whether or not the network resources are efficiently utilized [13]. OBS is a buffer-less technology and OBS networks belong to the class of loss networks [17], [18]. The lack of efficient optical buffers makes the task of designing signaling protocols for OBS networks even more important when contention for resources leads to data loss.

An OBS signaling protocol is characterized by its reservation technique. A number of signaling protocols have been proposed for OBS networks. Two of the more widely known protocols are: Just-Enough-Time (JET) protocol and Just-In-Time (JIT) protocol , both of which use the offset-based signaling technique [19]. Figure 2 specifies how a BHP is sent relative to its corresponding burst transmission using offset-based signaling technique.

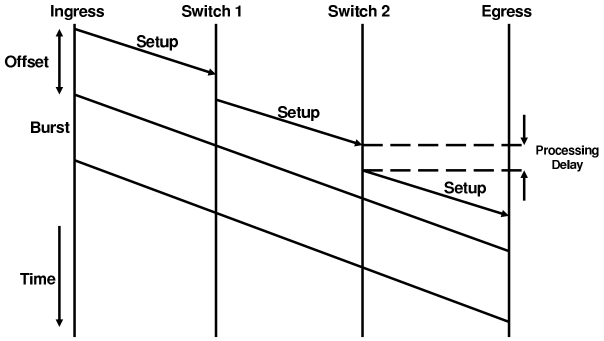

Fig. 2. Signaling in OBS Network

IV. OBS SCHEDULING

In OBS networks with multiple wavelength channels per link, a scheduling algorithm must be implemented to select the channel on which a burst should be forwarded. Scheduling algorithms can be broadly classified into two categories: non-void-filling algorithms and void-filling algorithms. In general, a non-void-filling scheduling algorithm is fast but not bandwidth efficient, while on the contrary void-filling scheduling algorithms provide better bandwidth utilization but have longer scheduling times. Scheduling policies which have received considerable attention in the current research trend are: Horizon, either called Latest Available Unused Channel (LAUC) [20], and LAUC with Void-Filling (LAUC-VF) respectively.

V. CONTENTION RESOLUTION IN OBS NETWORKS

One of the most significant issues in OBS networks is contention resolution [21]. In general, QoS mechanisms for OBS networks have to deal with wavelength contention when two or more bursts intend to take the same output port, on the same wavelength, at the same time [22]. In fact, reduction in BLP for OBS networks is guaranteed by reducing the level of wavelength contentions in the network.

In the context of multi-class traffic, the loss probability of a given class can be reduced by giving privilege to this class over others when contention occurs. In the literature, two kinds of QoS differentiation schemes for OBS networks have been reported, namely, relative QoS differentiation [23], [24] and absolute QoS differentiation [25], [26]. Although most of the QoS mechanisms proposed for OBS networks offer relative QoS guarantees only, still absolute QoS guarantees are required by critical applications. In order to provision absolute QoS in OBS networks, wavelength resources in network links have to be dimensioned properly [2]. The wavelength assignment approach for provisioning absolute QoS is a viable solution since the fiber links operate with dense WDM technology, and that the number of wavelengths is generally bigger than the number of nodes in the OBS network.

In buffer-less OBS networks, contention among bursts can be resolved in four ways [9]: Deflection, Dropping, Preemption, and Segmentation.

- Deflection: Through deflection, a burst is sent to a different output channel instead of the one initially scheduled.
  - When deflection is applied in the wavelength domain, the contending burst is sent on another wavelength through wavelength conversion.
  - When utilizing the space domain, the contending burst is diverted to a different output port and will follow an alternate route to its destination.
  - When utilizing the time domain, contending bursts are delayed using FDLs.
- Dropping: If a contending burst cannot be deflected due to the unavailability of wavelengths, output ports, or FDLs, then data loss becomes inevitable and the most common non-preemptive approach is to drop the incoming data burst.
- Preemption: As an alternative to dropping, it is possible for the incoming burst to preempt an existing burst based on some priority or service class.

- Segmentation: In addition, it is possible to break either the incoming or the scheduled burst into segments, and then deflect, drop, or preempt the segments.

Contention resolution to minimize BLP has been a subject of intense research and a significant number of QoS mechanisms are proposed in the literature to implement OBS networks with lower BLP [27]. In literature, either reactive or pro-active routing strategies are considered to resolve wavelength contention in OBS networks [28]. In reactive routing, the routing decision is taken on-line, for instance, when burst contentions occur whereas pro-active routing is usually offline. We reviewed the existing QoS mechanisms to handle contentions in OBS network and classified them in Figure 6.

VI. FRAMEWORK FOR QOS PROVISIONING IN OBS NETWORKS

In this section, we have summarized a Traffic Engineering (TE) approach [29] to provide BLP guarantees between every pair of source-destination nodes in the OBS network. We considered an OBS network without wavelength converters and FDLs. The OBS network is modeled as a graph $G(V,E)$ where $V = \{v_1, v_2, v_3, ..., v_N\}$ is the set of nodes and $E = \{e_1, e_2, ..., e_M\}$ is the set of directed links. Every node pair (v_i, v_j) is denoted by an index $k \in \{1, 2, ..., N(N-1)\}$. Let W be the number of allocated wavelengths to all the links e across the network.

A. Assumptions

We assumed source-based routing [30]. In addition, we assumed that the network operates with non-bifurcated routing. This single-path routing approach avoids the problem of the out-of-order burst arrival [31]. Let Z denotes the traffic matrix of dimension $N \times N$ where λ_{ij} is the long term traffic arrival rate that originates at node v_i and is destined for node v_j. Let $^1/_\mu$ denotes the mean burst holding time for all possible node pairs in the network. We use the notion $\rho_{ij} = {}^{\lambda_{ij}}/_{\mu}$ to denote the offered load of bursts from node v_i to node v_j. We assume that the traffic is characterized by a Poisson process [32].

B. Burst Loss Model

Let P denotes the set of explicit paths among all source-destination node pairs $(s_i, d_{j\neq i}) : 1 \leq i,j \leq N$. Let $P_e \subseteq P$ be the set of all paths through the link $e \in E$. A loss model of OBS network based on the Erlang fixed point approximation has been proposed in [17]. In particular, the traffic offered to a given link e, denoted by ρ_e, is obtained as a sum of the traffic offered to all the paths that cross this link reduced by the traffic lost in the preceding links along these paths and stated as:

$$\rho_e = \sum_{p\in P_e} \rho_p \prod_{e\in b_{pe}} (1-B_e);\ \exists (i,j)\in V\times V : \rho_{ij} \vdash \rho_p \quad (2)$$

where $b_{pe} \subset p$ identifies all the links that appear before link e along the path p

and

B_e is the BLP across the network link e and calculated by Erlang-B formula [33]:

$$B_e(\rho_e, W) = \frac{{(\rho_e)^W}/{W!}}{\sum\limits_{c=1}^{W} {(\rho_e)^c}/{c!}} \quad (3)$$

The formulation in [17] may bring some difficulty in the context of offline path optimization. Assuming low link losses observed in a properly dimensioned network, we considered the non-reduced load calculation technique [34], [35] to model the burst loss in OBS network where ρ_e is restated as below:

$$\rho_e = \sum_{p\in P_e} \rho_p \quad (4)$$

The burst loss probability, B_p, along the path p can be calculated as:

$$B_p = 1 - \prod_{e\in p} (1 - B_e) \quad (5)$$

In the perspective of network-wide QoS provisioning, the end-to-end burst loss guarantees can be achieved if the length of the longest path is limited. Let D denotes the maximum length of an explicit path in the network. Let B_{sd} be the acceptable BLP along a path and B_{link} be the acceptable link-level BLP respectively. Assuming a fixed value of B_{link} for all links in the network, B_{sd} is computed as:

$$B_{sd} = 1 - (1 - B_{link})^D \quad (6)$$

We studied the behavior of link blocking probability and path blocking probability in Figure 3 and Figure 4 respectively. We assumed that there are W wavelengths in each fiber link, there is no buffering at nodes of the OBS network, and D=6.

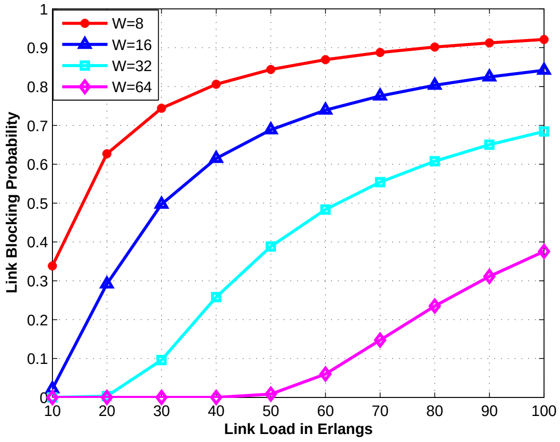

Fig. 3. Performance Study of Link Blocking Probability

The above discussion ends in attaining the following objectives:

$$\begin{aligned} B_p &\leq B_{sd} \\ B_e &\leq B_{link} \end{aligned} \quad (7)$$

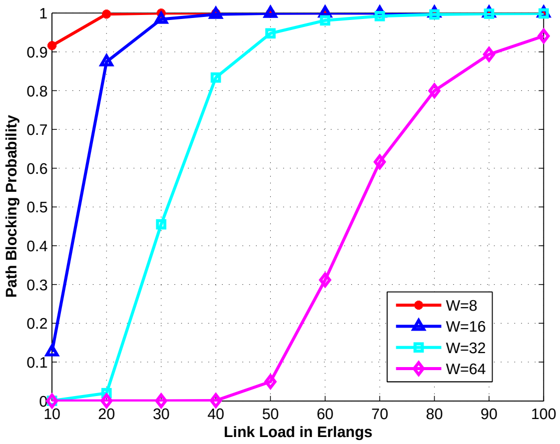

Fig. 4. Performance Study of Path Blocking Probability when D=6

The value of W must be wisely chosen to meet the above stated objectives. Let W_{min} be the minimum number of wavelengths that should be allocated to the network links so that $B_e \leq B_{link}$. Using inverse Erlang-B formula, we can calculate W_{min} as stated below:

$$W_{min} = B^{-1}(\rho_e, B_{link}) \tag{8}$$

Algorithm 1 computes the value of W_{min} and is given as follows:

Algorithm 1: Algorithm to Compute The Value of W_{min}

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Input: $B_e$, $B_{link}$
Output: $W_{min}$
$W = 0$;
while $B_e > B_{link}$ do
    $W++$;
$W_{min} \leftarrow W$;
return $W_{min}$;
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C. Traffic Flow Model

In the literature, path-link approach [36] has been used to formulate the traffic flow model in the OBS network. Using this approach, the cost of a network link $e \in E$ can be estimated as given below:

$$C_e(\rho_e, W) = B_e(\rho_e, W) \times \rho_e \tag{9}$$

Figure 5 plots the cost function $C_e(\rho_e, W)$ versus the value of ρ_e, when the number of wavelengths W=32. It is observed that the cost function is convex, monotonically increasing, and piecewise linear. The problem of fitting a convex curve by the use of a piecewise linear function has been studied in [37], [38], [39]. However, such an approximation is computationally expensive, and could result in a large number of line segments and increase the time complexity of solving the optimization problem. In order to obviate this problem, authors in [40] have used a simple interpolation to approximate the cost function $C_e(\rho_e, W)$ and maintained a trade-off between the quality of approximation and the complexity of computation.

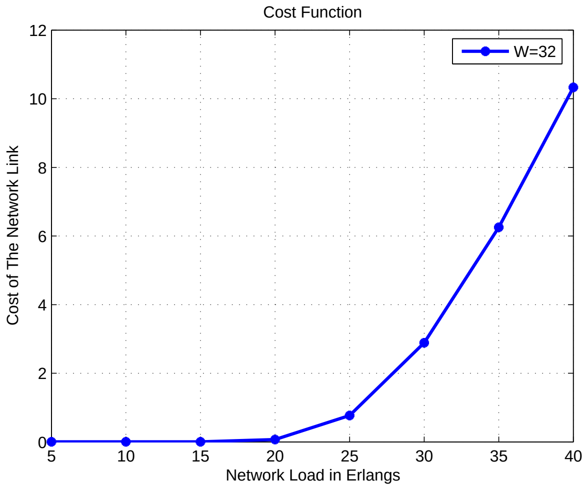

Fig. 5. Cost of Network Link when W=32

VII. CONCLUSION

Enormous research has been made in OBS since the last few years, and a number of successful testbeds have been implemented to demonstrate various OBS architectures and protocols. OBS has an increasing potential to be deployed in commercial environment; however additional work may still be needed to expand the role of OBS to support a wider range of services over a more diversified range of network applications.

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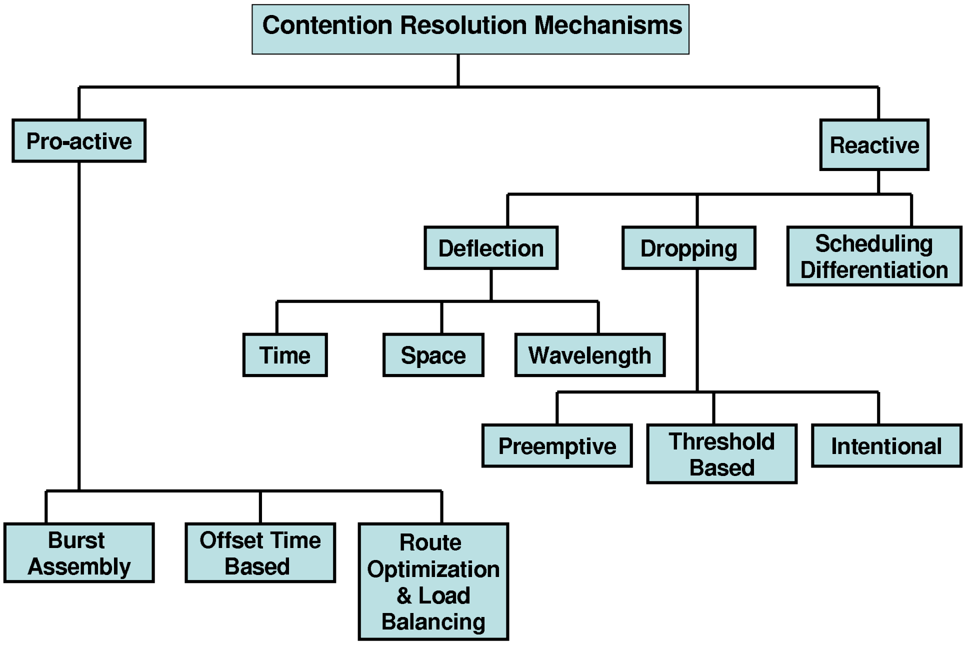

Fig. 6. Classification of Different Contention Resolution Mechanisms

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