A New Hybrid Architecture for Optical Burst Switching Networks

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Abstract. Optical Burst Switching (OBS) has been proposed as a new paradigm to achieving a practical balance between Optical Circuit Switching (OCS) and Optical Packet Switching (OPS). Hybrid Optical Networks (HON) that combines OCS and OBS has emerged to grant the OBS network the ability to support connection-oriented applications. Although efficient in terms of reducing the burst loss probability as well as improving the overall network performance, it provides a limited degree of Quality of Service (QoS). What we mean by QoS is the capability of a network to provide a guaranteed level of availability while satisfying strict limits on delay. In this paper, we propose new hybrid architecture for OBS networks. The proposed architecture qualifies the OBS network to support different classes of QoS.

1 Introduction

With the continuing advances of the Wavelength Division Multiplexing (WDM) technology, the amount of raw bandwidth transported through a single fiber optic has increased dramatically to an order of terabit-per-second (Tbps) of effective bandwidth. In order to efficiently harness this bandwidth in a cost-effective way, an appropriate switching architecture must be developed. This switching scheme must be able to handle different traffic patterns with various traffic characteristics as well as differentiated QoS requirements.

Optical Burst Switching (OBS) [1] has emerged as a promising balanced approach between coarse optical circuit switching and fine grain optical packet switching. In OBS, several data packets are assembled together to form a burst. A control packet is sent ahead of the burst on a control channel (separate from data channels) to setup a connection without waiting for acknowledgement for the connection establishment. The data burst follows the header after an offset time; a value is chosen to be long enough to allow the control packet to be processed at each intermediate node while the burst is buffered in the electronic domain at the source node. So, no fiber delay lines (FDLs) are necessary at intermediate nodes to buffer the burst while its header is being processed. Thus OBS is efficiently suitable for short traffic flows that are bursty in nature. However, for large and constant bit rate (CBR) flows, OBS is not

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appropriate for several reasons. First, due to the control packet processing overhead at intermediate nodes or, equivalently, the offset time during which the data burst must be buffered in electronic domain at the source node. Second, the burst assembly/disassembly overhead as well as the frequent switch fabric reconfiguration to switch a burst obscure the applicability of this technique for transporting such traffic flows.

Therefore, Hybrid Optical Network (HON) architectures that combine both Optical Circuit Switching (OCS) and OBS have been proposed recently [2, 3]. The current architecture of HON classifies the incoming traffic into short-lived (best-effort) and long-lived traffic. With the former, the best-effort traffic that is bursty in nature is supported by OBS, while in the latter; the real-time applications are transported using OCS. Therefore, this architecture consists of two main modules, namely the OBS module (HON-B) and the OCS module (HON-C). The HON-B module is responsible for best effort traffic in the form of small flows. While the HON-C module is responsible for large traffic flows. In [4] the authors proposed a QoS provisioning algorithm using flow-level service classification in the available HON. In particular, they proposed using OBS for transporting short-lived traffic including delay sensitive traffic while using OCS for transporting long-lived traffic including loss-sensitive traffic aiming at maximizing the network utilization while satisfying users' QoS requirements. Although the available HON architectures are efficient in terms of reducing the burst loss probability as well as improving the overall network throughput, they only provide a limited degree of QoS, in terms of the ability of the network to provide a guaranteed capacity (not best-effort) while satisfying the delay limits of the corresponding applications.

Internet traffic is a mixture of voice, real-time video and data. As the traffic load on the Internet grows, and as the variety of applications grows with it, providing differing levels of QoS to different traffic flows is imperative. More specifically, some short-lived traffic are delay sensitive (e.g., IP telephony) while others are not (e.g., FTP, email, web browsing). Similarly, not all long-lived traffic flows are delay insensitive. For example, a safety-critical application, such as *remote surgery* (the ability for a doctor to perform surgery on a patient even though they are not physically in the same location, also known as telesurgery) may require a guaranteed capacity and impose strict limits on maximum delay. Available OBS-based hybrid architectures will not be able to satisfy the versatile requirements of QoS-critical applications in foreseeable future.

In this paper we propose a framework under which an OBS network can support different classes of QoS in terms of traffic characteristics (e.g., bursty or constant bit rate) and performance requirements (e.g., delay sensitivity). In our architecture, delay sensitive traffic can be given preferential treatment as such applications do not tolerate the bottleneck of requesting a bandwidth that can not be reserved due to scarcity of resources or burst loss caused by resource contention at intermediate nodes. In this paper, in order to consider the QoS demands in an OBS network, we introduce the virtual topology concept to the available HON architecture such that the new HON structure combines OBS, OCS and Optical Virtual Circuit Switching (OVCS). With OVCS, the proper set of lightpaths is established constructing the virtual topology. Traffic with strict QoS requirement can be transported right away through an available lightpath. In this way, our proposed architecture will be able to providing an end-to-end guaranteed QoS.

The rest of this paper is organized as follows. In section 2, we review the virtual topology concept. In section 3, we present the proposed architecture for HON as well as the traffic classification model. We conclude the paper in section 4.

2 Virtual Topology Concept

The virtual topology optimization problem has been well studied in the literature [5,6]. Ideally for a network with N nodes, we would like to establish lightpaths between all $N(N-1)$ pairs. However, this is not practically feasible mainly due to the lack of resources (wavelength, transceivers) and the limited nodal degree of the network nodes. Therefore, the goal of virtual topology design problem aims at selecting a set of lightpaths that optimizes the performance (throughput, delay, packet loss,etc.) while satisfying certain constraint, which is proved to be NP-complete [7].

In this paper, the *physical topology* of the network refers to the set of all network nodes and the fiber-optic links connecting them. A *lightpath* between a node pair is an optical channel consists of a path between the node pair as well as a wavelength along all links of that path. A lightpath is established by reserving a wavelength channel on all links and configuring the switching nodes along the path. Two lightpaths that share the same link in the network must use different wavelengths (wavelength continuity constraint).

The virtual topology (also known as logical topology) consists of the set of all network nodes and lightpaths that have been established between all end nodes. A lightpath in the virtual topology is called a virtual link or virtual circuit (VC). An example physical topology is shown in Fig. 1 and its logical topology shown in Fig. 2.

In Fig. 1 and Fig.2 we assume that the network has a single wavelength per fiber. Note that, when there is no wavelength available in certain link in the physical topology, it is deleted from the virtual topology. Therefore, a physical topology and its virtual topology may not contain the same set of physical links.

The selection of the proper candidate lightpaths of the virtual topology as well as when the virtual topology can be reconfigured to be in tune with the dynamic changes in the traffic patterns have a great influence on the network performance. Therefore we dedicate an elaborate study of them, which is not in the scope of this paper.

The purpose of constructing the virtual topology in the new hybrid architecture is to overcome the following shortcomings of the current hybrid architecture.

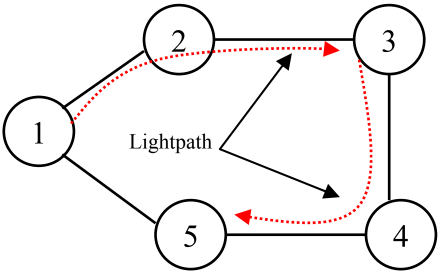

Fig. 1. Physical topology

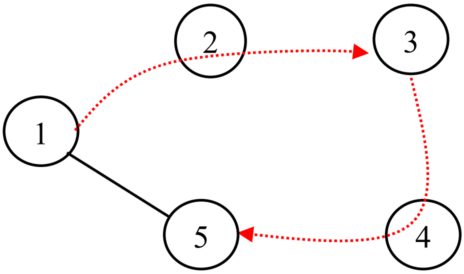

Fig. 2. Virtual topology

First, with HON-B, a connection needs to wait in electronic domain at the source node for a time interval equal to the offset time. This introduces a bottleneck when the connection is rejected several times. Consequently, it may fail to meet the delay requirements of a given request.

Second, HON-B only supports best-effort traffic. This means that, there is no guarantee of delivering this traffic. However, some short-lived traffic requires a guaranteed capacity.

Third, Fairness. The available HON architectures are sacrificing the performance of small flows for maintaining a good performance for large flows [2]. In other words, short-lived traffic will always be assigned to be transported by OBS. However, on the internet, some short-lived traffic (e.g., IP-telephony) requires strict limits on jitter and delay that makes it unsuitable for being transported by OBS. Therefore, we need to ensure that lower priority applications, like e-mail and web surfing, do not impact mission-critical applications such as ATM (Automatic Teller Machine) processing even if they are short lived traffic.

Fourth, although HON-B has been used for transporting delay-sensitive traffic [4], it can not guarantee a bounded delay due to resource contention at intermediate nodes. Even when employing a contention resolution mechanism, there is no guarantee that the burst will be delivered to its destination. It is also notable that, resource contention does not only influence the delivery delay, but also wastes the network bandwidth along the path between the ingress node and the node at which contention occurs, thus reducing the probability of accepting any upcoming traffic.

Therefore we are motivated to propose our hybrid architecture for OBS networks that overcomes the above mentioned shortcomings of the available HON architectures.

3 The New Architecture

The proposed HON architecture is shown in Fig. 3, in which the network consists of 3 main components namely, the optical burst switching (HON-B) component, the circuit switching (HON-C) component and the virtual circuit switching (HON-VC) component, responsible for transporting all classes of traffic. These components may share all wavelength channels, or we may dedicate a subset of the wavelength channels for each component. Our traffic classifier performs two types of classification. At first, we classify the traffic flow according to its traffic characteristics (short/long) then we conduct a finer classification for satisfying the QoS requirements in terms of delay. In our architecture, we provide three main traffic classes.

Traffic class 1: dynamic traffic flows (short-lived or long-lived traffic) with strict delay and/or packet-loss requirements are assigned to this supreme traffic class that uses HON-VC.

Traffic class 2: short-lived traffic that does not require an end-to-end guaranteed QoS will be served by HON-B.

Traffic class 3: long-lived traffic that does not impose a rigid requirement on delay will be suitable for HON-C.

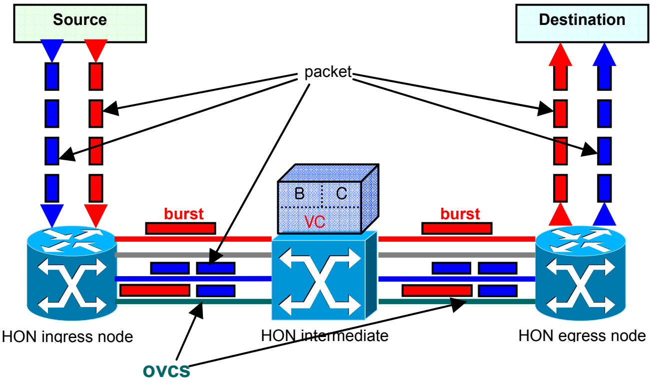

Fig. 3. The New Hybrid Switching Architecture

As mentioned in section 2, with OBS, the burst loss due to the contention degrades the performance in terms of throughput and delivery delay especially under high workloads. In our framework we make use of the HON-VC for resolving resource contention. Specifically, when contention occurs between two connection requests, instead of dropping one of the bursts, it can be rerouted to its destination through the available HON-VC. This introduces a new type of traffic we refer to as "Burst over OVCS". In this case, the burst is switched from the ingress node up to the intermediate node, at which contention occurs through burst switching. Then lightpath switching is used up to the egress node. Fig. 4 shows different traffic classes provided by the proposed architecture. Fig. 5 also shows the traffic classification flowchart at an ingress node of the new HON architecture.

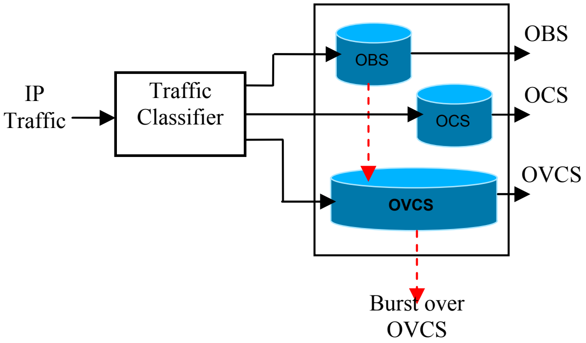

Fig. 4. Different traffic classes

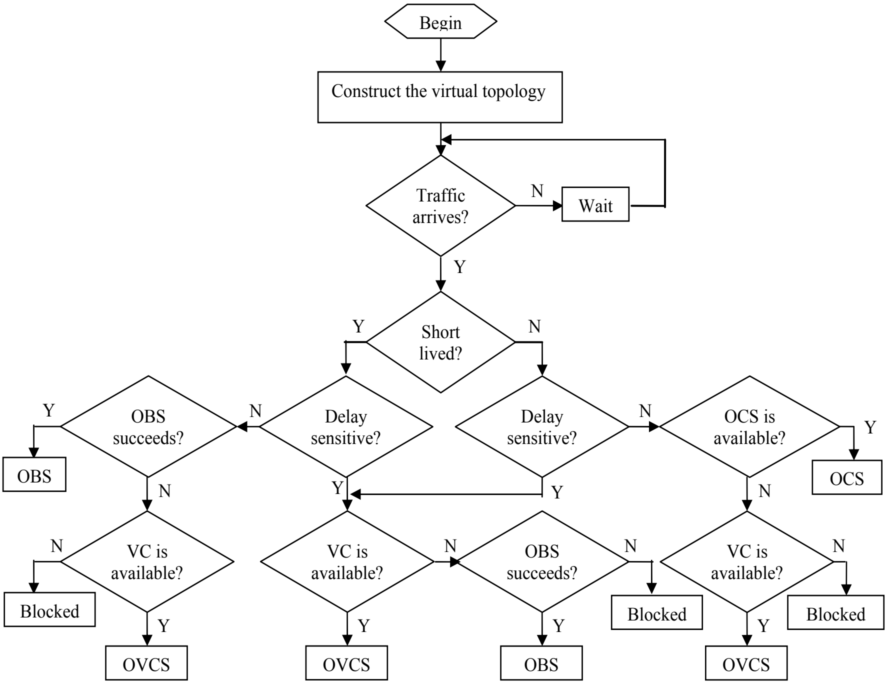

Fig. 5. Traffic classification flowchart at ingress node

The flowchart shown in Fig. 5 presents our proposed model for traffic classification. At first we establish the virtual topology, and then when a traffic flow arrives it is initially classified as short-lived or long-lived. According to the QoS requirement of each traffic flow, a finer classification is done based on the delay sensitivity of the application corresponding to the traffic flow. So, finally we have four groups of traffic and we have to select the most suitable switching technique for each group. Delay sensitive traffic best fits to be transported through OVCS. Therefore, delay-sensitive, short-lived traffic and long-lived traffic groups will be routed through HON-VC. If no VC is available for the corresponding connection, it may be routed through OBS; otherwise, it will be blocked. On the other hand, for non delay-sensitive applications their traffic flows will be routed based on their traffic characteristics. Short-lived traffic that is not sensitive to delay will be routed through HON-B. Long-lived traffic flows that can tolerate delay will be switched to HON-C. In either case, if the traffic can not be routed to the destination due to scarcity of resources, it may be routed through the available HON-VC. Otherwise it is blocked.

In summary, the new hybrid switching architecture aims at providing a guaranteed level of capacity as well as satisfying the user's QoS requirements by utilizing the available VCs. It provides the following advantages.

Traffic does not need to wait for an offset time as the case of OBS or for an acknowledgement after a round-trip propagation delay as the case of OCS. Alternatively; the traffic will be transported right away after being received at an ingress node.

Employing the virtual topology grants an end-to-end assured bandwidth (not best effort) that is suitable for loss-sensitive traffic as well as satisfying the QoS demands of such traffic.

The proposed model for traffic classification gives preferential treatment to delay sensitive traffic while not sacrificing the performance of the short-lived traffic for the sake of maintaining good performance of the long-lived traffic.

The embedded virtual topology will help resolving the resource competition at the contended nodes, thus reducing the overall burst loss probability.

4 Conclusion

In this paper, a new hybrid architecture for OBS networks that supports different classes of QoS has been proposed. Our architecture combines OBS, OCS, and OVCS for providing a finer class of QoS. In the proposed architecture, delay sensitive and packet-loss critical traffic can be given preferential treatment. We also proposed a model for traffic classification at an ingress node of a network. We expect that the framework proposed in this paper will be useful for providing guaranteed capacity as well as satisfying the QoS requirements of the real time applications of the next generation optical internet. Currently we are conducting extensive simulations to support our proposed architecture.

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