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Analysis of impact of control-plane on an efficient switching paradigm: OBS of IP/WDM networks

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ABSTRACT

In high speed optical burst switched (OBS) networks two parallel networks, namely a data and a control network (plane), suffers from contention, insufficient offset-time, average burst length and scheduling operations causing excessive delay in processing of control packets in an electronic core-node controller, thus as a result incur higher blocking probability, inefficient bandwidth utilization, etc. In this paper, to address this, we provide an analytical modeling, detailed analysis of control plane and its impact on OBS performance. Based on above, we select optimal performance oriented parameters such as average burst length, sufficient offset-time duration and scheduling and reservation operations in order to show that the impact of control-plane is negligible (as compared to data-plane) on OBS based system performance.

1. Introduction

To circumvent the potential bottlenecks of electronic processing in optical packet-type wavelength division multiplexed (WDM) networks, the basic data block to be transferred is macro-packet, called burst, which is a collection of data packets having the same network egress address and some common attributes, like Quality of Service (QoS) requirements.

The functional block diagram of an optical burst switched (OBS) network is shown in Fig. 1, which consists of optical core nodes (routers) and electronic edge nodes (routers) connected by WDM links. Packets are assembled into bursts at network ingress, which are then routed through the OBS network and disassembled back into packets at network egress to be forwarded to their next hops (e.g., conventional IP routers). In the OBS, a burst header must explicitly reserve the switching resources in advance at each hop along the path for its burst payload, while in store-and-forward packet switching, the reservation of switching resources is made implicitly, i.e., when a packet is sent out from an electronic buffer. The function of the switch control unit (SCU) is similar to a conventional electronic router. The routing processor runs routing and other control protocols for the whole OBS network. In arranging the transfer of a data burst and its corresponding BHP in the optical switching matrix and SCU, respectively, the SCU tries to resynchronize the data burst and the burst header packet (BHP) by keeping the offset time. If there are free data and control channels available from these groups, either when the data burst arrives to the optical switching matrix or after some delay in an fiber delay line (FDL) buffer, the SCU will then select the FDL of the optical buffer and configure the optical switching matrix to let the data burst pass through. Otherwise, the data burst is dropped. If a data burst enters the optical switching matrix before its BHP has been processed (this phenomenon is called early burst arrivals), the burst is simply “dropped.” Since a BHP and its data burst are switched in the SCU and the optical switching matrix, respectively, the delay introduced by the input FDL [1] should be properly engineered such that under the normal traffic condition data bursts are rarely dropped due to early arrivals.

The OBS network can be envisioned as two coupled overlay networks: a pure optical network transferring data bursts, and a hybrid control network transferring BHPs. The control network (plane) is just a packet-switched network, which controls the routing of data bursts in the optical network based on the information carried in their BHPs [2]. It is expected that the above separation will lead to a better synergy of both very mature electronic technologies and advanced optical technologies.

The control packet carries relevant forwarding information, as the next hop, the burst length and the offset time. It precedes the data burst by a basic offset time that is set to accommodate the non-zero electronic processing time inside the network and dynamically set up a wavelength path whenever large data flows are identified and need to traverse the network. Only the control

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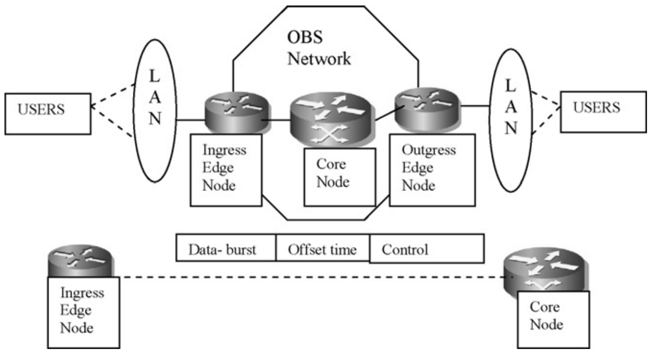

Fig. 1. Optical burst switched (OBS) network architecture.

packet is converted between optical and electronic domains, therefore is the only information delayed because of the conversion. The burst offset-time could also be adjusted to support QoS [3] and may play an important role in traffic scheduling/management for optical core routers without buffer or with buffer of very limited storage capacity.

The most used reservation protocol in OBS network is Just-Enough-Time (JET) [4]. JET is a delayed reservation protocol which allows reserving a wavelength channel just for the burst duration, starting at the predicted burst arrival time. The use of this reservation protocol does not allow to fully utilizing the bandwidth: in every channel there is portion of unused bandwidth between bursts that have made a reservation, called void. In order to get a good utilization of the available resources, an efficient reservation process is required. To this end, effective scheduling algorithms have to be developed [5]. The scheduling algorithm is implemented into the control unit as well [6]. The scheduler is responsible of scheduling and switching data burst on an output data channel and also of transmitting the control packet. There is a scheduler for each data and control channel pair and each scheduler only needs to keep track of the busy/idle periods of a single outgoing data and control channel. It first reads the arrival time and the burst duration in the control packet and then, using a given scheduling algorithm, it searches for an idle output data channel. Several scheduling algorithms have been proposed for OBS routers [7].

The focus of this paper is on the impact analysis on the performance factors of control plane (network) for OBS. The basic concept of OBS and related issues of OBS control plane are described in Section 1. In Section 2, the importance of control-plane in OBS networks has been identified and analytical model with performance oriented techniques for OBS has been formulated for reducing its effect on overall OBS blocking probability and hence throughput. It is observed in Sections 3 and 4 that by optimally selecting the combination of burst length and offset time in the proposed model, the control-plane impact to OBS system performance can be made negligible as compared to data-plane.

2. Proposed model of OBS control plane

The proposed model for the OBS control-plane explicitly accounts for the finite delay estimate of arriving headers. In order to alleviate an excessive variation in burst size, an efficient burst assembly scheme named as Adaptive-Threshold with Fixed Maximum Time Limitation Burst Assembly (ATH-FMTL) has been used in the proposed model, which uses optimal burst length threshold and fixed maximum time limitation as the condition for burst generation. The burst length thresholds are increased or decreased in case the burst queue size, at the time of burst generation, is larger than upper threshold or smaller than lower threshold respectively. The packets arrive at the corresponding port and service class assembly queue becomes operative. To classify the packets into the appropriate burst, the decision making is performed based on the fact that every packet has a delay tolerance that allows for flexibility during packet routing and on the assumption that no packet has a delay tolerance less that the amount of time it takes to route the packet through the OBS network, using the shortest route to it's destination. Each burst length is estimated at the end of t_p (prediction time) according to the past burst length value and current arrival traffic. Edge node determines the variable burst assembly duration (VBAD) by estimating burst size with current or previous load. Control packet is sent to OBS core network at time τ

$$\tau = t_a - t_0 \quad (t_a: \quad \text{assembly time}; \quad t_0: \quad \text{offset-time})$$

The following is the detailed working of the proposed model to have efficient use of bandwidth, low latency and high degree of transparency.

1. It is considered that a WDM link is having 'P' channels with 'Q' control channels and '$P-Q$' data channels ($1 \le Q \le P$).
2. Assume that the data channel rate is 'R' Gb/s and the control channel rate is 'r' Gb/s. The maximum link utilization is $U_{\text{LINK}} = (P-Q)R/[(P-Q)R + Qr]$.
3. As a data burst can be sent out on a data channel only if its BHP can be sent out on a control channel, there is a minimum requirement for the average data burst length in order to prevent congestion on control channels [8] (the basic time unit is assumed to be 1 μs).
4. Let 'L_{ab}' be the average duration of a data burst and 'L_{abhp}' be the average duration of a BHP. It is also considered that both control and data channels are fully loaded.
5. Under above conditions, the maximum average BHP transmission rate is Q/L_{abhp} BHPs per microsecond and the maximum average burst transmission rate is $(P-Q)/L_{ab}$ data bursts per microsecond.
6. Since, $(P-Q)/L_{ab} \le Q/L_{abhp}$, therefore $L_{ab} \ge (P-Q)L_{abhp}/Q$. Let $\bar{\gamma}$ denotes the mean arrival rate of headers to a core node. If the arriving traffic is the aggregate of a large number of independently generated traffic streams, the header-arrival process can be well-approximated by a Poisson process [9]. It is also defined that '$\delta_{\min\,header}$' is the minimum of the header transmission duration (on the control channel) and the duration required to process a single header in a core-node controller. In physical terms, '$\delta_{\min\,header}$' is therefore equal to the inverse of the maximum rate at which headers can be serviced in a core-node processor (i.e., the rate at which headers exit the system during periods when the header-processing queue is not empty).
7. In a constant-offset OBS architecture, the time required to process each header is independent of the state of the system, so '$\delta_{\min\,header}$' is a constant. Using the above assumptions, the offered load of the control plane processor is therefore equal to $\rho_{cpp} = \bar{\gamma}.\,\delta_{\min\,header}$ and its value can be computed as follows [10];

$$\rho_{cpp} = \frac{\delta_{\min\,header} \cdot \rho_{dp} \cdot W_{dc} \cdot l_{dp}}{L_{ab}}$$

(ρ_{dp}: offered load per data channel; W_{dc}: the number of data channels in the system; l_{dp}: the data channel line rate and L_{ap}: average burst size).
8. At a given core node, headers arrive randomly and are queued for service in the header queue and processed in first-come-first-serve order. Loss occurs if a header exceeds its delay