In Proc. of 3rd International Symposium on Telecommunications (IST2005), Shiraz, Iran, September 2005

Impact of Burst Assembly on the Performance of FDL Buffers in Optical Burst-Switched Networks

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Abstract

Optical burst switching (OBS) is a new approach proposed with the objective of utilizing the huge transmission capacity available with WDM links both efficiently and cost effectively. Burst assembly is one of the main building blocks of this approach, which is performed at the edge of an OBS domain in order to generate bursts whose lengths are much larger than the switching time of all-optical switches in the core. It is also known that burst assembly can greatly affect statistics of traffic in such a network. In this paper, we investigate effect of burst assembly on performance of fiber delay line (FDL) buffers, which may be deployed in core switching nodes as a means of contention resolution. Among other important properties, our simulation-based analysis reveals that the burst assembly process can result in a substantial reduce in the loss rate. It is shown that this improvement in the loss rate can be as much as several orders of magnitude.

Keywords: burst assembly, contention resolution, FDL buffering, optical burst switching.

1. Introduction

Introducing wavelength division multiplexing (WDM) to the available fiber-based backbone links of the Internet has provided a huge amount of capacity available for transmission. The question that may arise is, which technology and switching paradigm may have the ability to utilize the available capacity both efficiently and cost effectively. There are two general approaches that can be taken to build an optical network. Namely, either optical circuit switching (OCS) or optical packet switching (OPS) can be deployed. The former one enjoys a simplicity that makes it easily realizable, and provides the so-called lightpaths with granularity of a full wavelength as a service to the higher layer IP networks. Optical packet switching, on the other hand, provides a connectionless service that leads to much higher efficiency due to the statistical multiplexing gain. Nevertheless, pure OPS is still many years away because of immature optical technology. As a result, many different solutions have been proposed to bypass technological limitations that preclude realization of OPS. One of the most promising proposals in this direction is optical burst switching (OBS) [1]-[4], which has received a great deal of attention in recent years. OBS, as an intermediate step toward all-optical packet-switched networks, relaxes the requirements of packet switching, and has the capability to utilize the available bandwidth at sub-wavelength granularity.

Contention resolution in OBS/OPS networks has been a hot research topic in recent years. One of the powerful techniques to deal with contention in such networks is to use fiber delay lines (FDL) to delay contending data packets until a channel becomes available. However, since they merely provide discrete-time delays, FDL buffers behave fundamentally different from their electronic counterparts. As a result, many efforts have been devoted to modelling and performance analysis of the behavior of these kinds of buffers (e.g., see [7]). On the other hand, while statistics of the burst traffic is still under debate, most of the works in direction of performance analysis of OBS networks assume Poisson burst arrivals and exponentially distributed burst lengths. In this paper, we study, by means of simulation, the loss performance of an OBS core node that is equipped with FDL buffers and fed by assembled burst traffic. The simulation results suggest that ignoring the impact of burstification process can produce the results that are totally inaccurate and in some cases differ from the real ones as much as several orders of magnitude.

The rest of this paper is organized as follows. In section 2, general architecture of OBS and its distinguishing features are described. In section 3, contention resolution techniques and specially FDL buffering are discussed. Section 4 presents the simulation results and discussions. Finally, section 5 concludes the work.

2. Optical Burst Switching Architecture

In OBS paradigm several small packets are aggregated together to form jumbo packets, which are then called bursts. Burst assembly process is performed by the ingress nodes, which bridge between electrical and optical domain. Once a data burst enters the network, it is converted to the optical domain and remains there all along a path to its destination. In order to reserve the resources and configure the switches along a path, a *burst header packet* (BHP) is also generated and sent over a separate control channel, i.e., out-of-band signaling. While data channels within OBS domain are switched all-optically, all control channels are dropped at every intermediate node to allow BHPs get processed electronically. Switching the data in OBS domain may be performed in two different ways. In the first solution, there should be an offset time between a data burst and its BHP, which accounts for the time that intermediate nodes need to process a BHP and configure the switch ports accordingly. In this way data bursts cut through the switches. The most commonly discussed protocol which has been developed using this idea is *just enough time* (JET) protocol [1]. Alternatively, it is possible to release both a data burst and the associated BHP to the network at the same time. In this way, a small FDL has to be put in the direction of every data channel in order to compensate for the processing and switching times. A signaling protocol developed based on this approach is called only *destination delay* (ODD) [10]. In the following we describe the burstification process in OBS networks in more details.

Several proposals have been proposed for making bursts out of small-size packets at OBS ingress nodes. The aggregation process can be performed based on different criteria. It is assumed that there is one assembly buffer per destination per QoS class at every ingress node to the OBS domain. The task of an assembly algorithm is to make a decision on when contents of an assembly buffer can be aggregated into a new burst. In general, burst assembly algorithms may be classified into three major categories, namely volume-based, time-based and hybrid algorithms. In a volume-based algorithm, which is most suited for best-effort traffic, a new burst will be generated as soon as the aggregate volume of packets in the buffer exceeds a predetermined threshold L_{Th}. However, in a time-based algorithm, which is appropriate for time-sensitive traffic, once a packet enters the buffer, a timer is set to T_{Th}, which should be determined taking into account the maximum delay that a packet can tolerate. Then, as soon as the timer expires, all packets in the buffer are aggregated to form a new burst. In this case, if length of the new burst is below a specific value, padding may be used. In a hybrid assembly algorithm, a buffer scheduler keeps track of both the aggregate volume of packets in the buffer and the time since the first packet has arrived. That is, a timer is set to T_{Th} once a packet arrives and finds the buffer empty, and length of the queue is compared against a volume threshold L_{Th} upon each new arrival. Then, a new burst will be generated either when timer expires or when volume threshold is exceeded. In other words, depending on the load intensity and chosen parameters a hybrid assembly algorithm may works as a time or volume based algorithm at any given time. In this work we only consider volume-based algorithm.

3. Contention Resolution in OBS/OPS Networks

As mentioned before, contention resolution in OBS/OPS networks is a challenging issue that has resulted in so many proposals. In general, contention may be resolved in three different domains, namely frequency, space, and time domains. In frequency domain the drop rate performance is improved by increasing the number of WDM channels, i.e., number of servers. This is achieved by employing wavelength converters. In the space domain, free links all over the network are utilized as a common buffering space. That is, when a data packet faces a contention in accessing a desired link in an intermediate switching node, it is forwarded to a free channel over an undesired link with the expectation that it will eventually get to its desired destination. This technique is referred to as *deflection routing* [9]. Some simulation results have shown that the performance of deflection routing depends on the distribution of the load over the network and under some situations it may even worsen the drop performance. Finally, contention may be resolved in time domain by delaying a contending packet using FDL buffers. Since the focus of this work is to analyze the dynamics of FDL buffers under assembled burst traffic, in the following we describe this way of contention resolution in more details.

To further reduce the loss rate in all-optical networks FDL buffers may be deployed. There are various proposals for FDL buffer's architectures that can be deployed for contention resolution. An FDL buffer may contain single or multiple delay lines; it can also be used either in a feed-forward or feedback configuration [5]. In the feed-forward configuration packets are switched from inputs to outputs via delay lines; however, in case of feedback configuration blocked packets are circulated back to the inputs of the switch. Also, in terms of reservation strategy, a packet that undergoes through the buffer may try to reserve the channel in two different ways [6]: in the *pre-reservation* scheme, it reserves the channel in advance and before entering the buffer; or alternatively, in the *post-reservation* scheme, it postpones the reservation process until it leaves the buffer. This implies that transmission of every packet that enters the buffer is guaranteed in the pre-reservation scheme. In this paper, we consider a multi-delay-line FDL buffer in feed-forward configuration with pre-reservation strategy.

When a new data burst arrives to a link equipped with FDL buffers, different situations may occur depending on the channel and buffer reservation strategy used. Channel scheduling algorithms for OBS networks can be classified into two major categories, namely *void-filling* (VF) and *non-void-filling* (NVF) algorithms [3]. In fact, voids may be created over the time horizon of a channel either because of different offset times between the bursts in JET reservation mechanism, or because of using FDL buffers. Accordingly, in a channel scheduling algorithm without VF voids created over the channel are not utilized, thus the scheduler only needs to maintain a time horizon for every channel, i.e., the time after which the channel has not been scheduled. In a VF scheduling algorithm, however, voids may be utilized if new arrivals are small enough to fit in the gaps between already scheduled bursts. Therefore, an algorithm with VF is more complicated than that without VF. In this study, both scheduling algorithms are examined. More specifically, we consider both VF and NVF variations of the two most common scheduling algorithms called *first fit* (FF) and *latest available unscheduled channel* (LAUC) [3].

4. Performance Evaluation

In this section, we investigate the impact of traffic aggregation, i.e., burstification process, on the loss performance of a core link which employs wavelength conversion and FDL buffering for contention resolution. The main objective is to analyze the dynamics of FDL buffers under assembled burst traffic.

4.1. Simulation Scenario

Fig. 1 shows the simulation scenario used for this investigation. We have considered a single output link at a core OBS node with W data channels, each operating at rate C *Gb/s*. The link receives burst traffic from N ingress nodes. Ingress nodes, denoted by *BAs*, receive IP packets and assemble them into bursts. It is assumed that packets arrive to the i^{th} burst assembler according to a Poisson process with rate λ_i, and that packets length is exponentially distributed with mean μ^{-1}. When fully loaded, each *BA* can deliver burst traffic of rate C_{low} *Mb/s*. It is also assumed that all *BAs* use volume-based assembly algorithm with threshold L_{Th}. Also, FDL buffer consists of a specific number of delay lines M, where the first delay line provides delay of D, the so-called *buffer granularity*, and the i^{th} delay line provides delay of $i \times D$, $1 \leq i \leq M$.

4.2. Numerical Results and Discussion

In order to evaluate impact of burst assembly on the loss performance we have used two different scenarios. The following settings are the same in both: IP packets' average length μ^{-1}= 500 *Bytes*, burst assembly threshold L_{Th}= 30 *Kbytes*, and number of delay lines M=4. Further, there are four *BA* categories; each includes a quarter of total *BAs*. All sources in the same category have the same IP packet arrival rate. Arrival rates of different *BA* categories are selected in such a way that the total offered load to the link is 0.8. Note that number of sources and their respective capacity for each scenario are selected so that when all *BAs* get fully loaded, the link receives load of 1. Table 1 lists values of other parameters used in different scenarios.

Table 1 Simulation Settings

	Scenario I	*Scenario II*
N	*64*	*128*
C_{low}	*155.52 Mb/s*	*622.08 Mb/s*
C	*2.5 Gb/s*	*10 Gb/s*
W	*4*	*8*

Simulation experiments are conducted using discrete-event simulator OMNET++ [11] by developing and incorporating additional required functionalities. The method of batch means has been used and the results are shown including 95% confidence intervals, if they are big enough to be visible. Figs. 2-5 depict data loss rate versus the buffer granularity D. Data loss rates are calculated as the number of bits lost over total number of bits generated. Also, to better understand the impact of burstification, the loss rates for different scenarios have been compared with those achieved when the link is fed with a traffic stream whose packet interarrival times and lengths are drawn from exponential distributions, denoted by *EXP*. Again, parameters of the exponential model are selected so that load of 0.8 is offered to the link and average packet length is set to be equal to 30500 *bytes*.

Fig. 2 shows the results for the loss rate when FF (NVF) and FF-VF scheduling algorithms are deployed. The results for traffic generated by

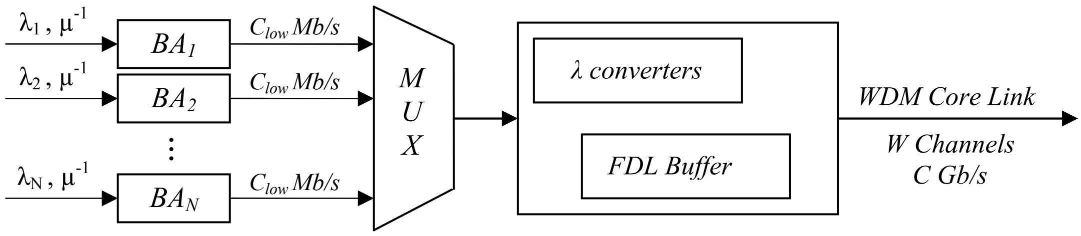

Fig. 1 Network Scenario used for simulation.

volume-based assemblers, denoted by *VB*, are shown and compared with those of the exponential model. Also, Fig. 3 shows the results for the same traffic scenarios when LAUC (NVF) and LAUC-VF scheduling algorithms are used. It is seen that LAUC algorithm achieves a better loss performance than FF, as expected. In fact, the superiority of LAUC algorithm over FF is that it uses the voids more wisely and thus achieves a better utilization of the link. Two other important conclusions that can be drawn from the results are as follows. First, there can be considerable differences between the loss rate of assembled burst traffic and that of exponential model. Second, in contrast to that for exponential model, in case of assembled traffic the loss rate is not a *monotone* function of the buffer granularity. That is, the loss rate decreases with *D* up to a minimum point and after that it starts increasing. Also, note that using different scheduling algorithms, this minimum loss rates occur at different values of *D*. Furthermore, referring to the curves, it is interesting to see that the drop rate curves of assembled burst traffic for VF and NVF bifurcate when *D* is equal to one, regardless of which scheduling algorithm has been used. However, for the exponential traffic such bifurcations occur at approximately *D* equal to 0.2. The reason is related to the statistical properties of the exponential distribution. That is, having packet lengths exponentially distributed, even very small voids are likely to be utilized. However, this is not the case for assembled burst traffic, because all bursts have almost the same length, which implies that voids could be utilized using VF only when their length is equal or greater than the average burst length. Moreover, it is observed that for assembled burst traffic increasing *D* beyond the point for which the minimum loss rate occurs, the loss rate constantly increases until it exceeds that of exponential model. This is because on one hand the average length of the gaps created over the channel increases, and on the other hand, these gaps can hardly be utilized due to the distribution of the packets length. Finally, when an NVF scheduling algorithm is used, the effectiveness of the buffer decreases sharply by increasing the buffer granularity and the loss rate asymptotically approaches that of a bufferless system.

Next, let us study the loss performance for traffic scenario II, as shown in Figs. 4 and 5. Taking into account the fact that number of servers (WDM channels) has been doubled in scenario II, it is expected that the loss performance get improved. From fig. 4 it is seen that when FF scheduling algorithm is used such does happen and the improvement factor at the point of minimum loss rate is around one order of magnitude. Also, in this case the system behaves almost the same as it does under scenario I, except that the value of *D* for which minimum loss occurs is shifted to 0.6.

Making use of LAUC algorithm for scenario II, as depicted in fig. 5, surprisingly results in a dramatic decrease in the loss rate for assembled burst traffic. That is, the drop rate decreases below 10^{-6} at D=1. However, this is not the case for the exponential traffic. More precisely, when number of servers is increased from 4 to 8, the drop rate of exponential traffic decreases by one order of magnitude, i.e., just similar to what happens when FF algorithm is used. Nevertheless, the amount of decrease for assembled burst traffic is about four orders of magnitude. In this case, it can be seen that at point *D=1*, the loss performance of aggregated traffic is as much as 4 orders of magnitude better than that of exponential traffic. Again, in scenario II, in comparison with scenario I, the optimum value of the buffer granularity is a little bit shifted to the right. Further, bifurcation between void-filling and non-void-filling algorithms occurs at the same value of *D* as it does in scenario I. Additionally, as soon as *D* goes beyond 1, the drop rate for aggregated traffic sharply increases so that at 1.3 it exceeds that of exponential case when VF is applied.

Finally, as it is observed from the figures, in both scenarios and regardless of the type of scheduling algorithm employed, when assembled burst traffic is used, there is almost no difference between VF and NVF algorithms up to the point where *D* is equal to 1. It is worth mentioning that this interval also includes the point at which the optimum value of loss is observed. On the other hand, it is known that VF algorithms are much more complicated than NVF

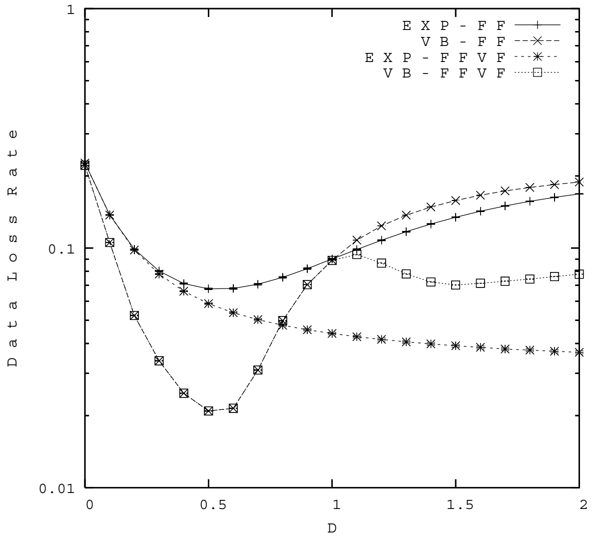

Fig. 2 Data loss rate vs. buffer granularity D (normalized to the average data burst length) for scenario I using FF scheduling algorithm.

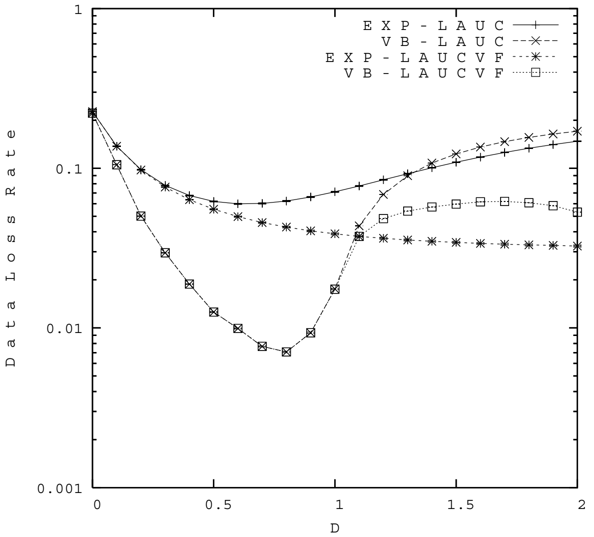

Fig. 3 Data loss rate vs. buffer granularity D (normalized to the average data burst length) for scenario I using LAUC scheduling algorithm.

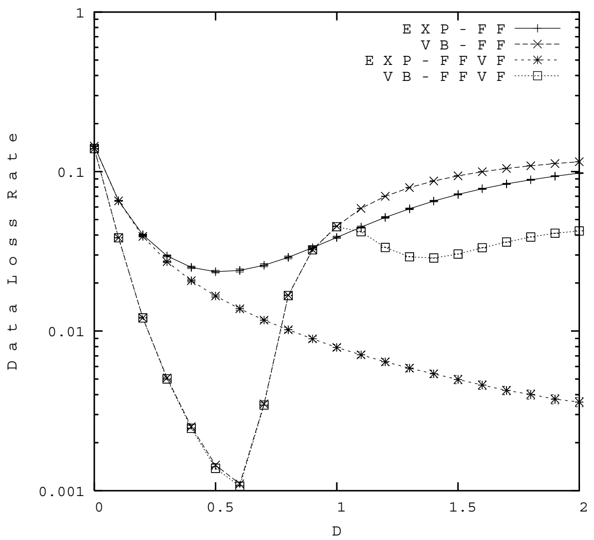

Fig. 4 Data loss rate vs. buffer granularity D (normalized to the average data burst length) for scenario II using FF scheduling algorithm.

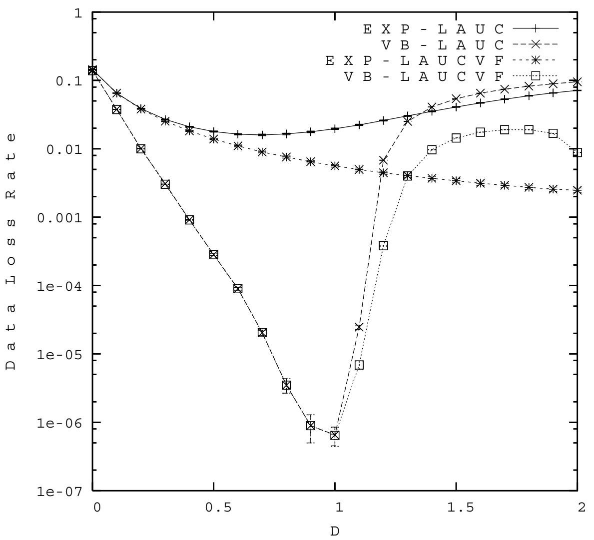

Fig. 5 Data loss rate vs. buffer granularity D (normalized to the average data burst length) for scenario II using LAUC scheduling algorithm.

ones and as a result, many efforts have to be put on implementing VF algorithms at the very high speeds of optical links. Accordingly, it is of great importance that if an FDL buffer is utilized properly so that the system is at its optimum working point, a simple NVF algorithm will achieve almost the same performance as a VF algorithm.

5. Conclusions and Future Works

In this paper, we have studied how traffic aggregation may influence the loss performance at core links, which make use of FDL buffers to resolve contentions, in an OBS network. Our focus is on traffic generated by the volume-based assembly algorithms. Next, the results have been compared with those obtained when a simple exponential model is used to generate burst traffic, as it is common in related literature. The simulation results revealed some important features that are not captured when impact of assembly process on traffic is ignored. Specifically, the following conclusions can be drawn for the settings used in this investigation. First, the loss rate of aggregated traffic can be as much as several orders of magnitude different from that of exponential model in a positive way. Second, in contrast to that of exponential model, the loss performance of aggregated traffic is not a monotone function of the buffer granularity D. Third, there is a value of the buffer granularity at which minimum loss rate occurs, and this value for assembled burst traffic is much smaller than that of the exponential model. Finally, when the buffer granularity is smaller than a specific value, there is no difference between the performance of VF and NVF scheduling algorithms. This specific value of D, for the assembly algorithm considered in this work, is much larger than that of exponentially modeled traffic. More interestingly, the values of the D that result in such a property include the point that gives the minimum loss rate. This result is of great practical importance.

In this work, we considered volume-based assembly algorithm. We are now working to extend the work to include other algorithms such as time-based and hybrid assemblers.

Acknowledgment

This work was supported in part by the European Commission within the Network of Excellence (NoE) e-Photon/ONe framework.

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