Performance Evaluation of Optical Burst in High Speed Backbone Networks

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Optical burst switching is a high-speed data transfer technology where, in place of isolated packets, a bunch of packets known as a burst is sent. However, this mechanism is simple in transmission and reception as bursts propagate on a dedicated path, but burst assembly is a complex problem, and till date, the optimum burst length for data transmission is not fixed. This is the main hurdle in the implementation of OBS. In this paper, a mathematical model is developed to obtain network traffic flow equations and packet/bust drop rates under with and without considering the buffers at various nodes of the switches. The burst length modelling is also detailed, and finally, Monte Carlo simulation is performed to obtain various results. The obtained results clearly reveal that the proposed mathematical model is well in agreement of simulation results.

Keywords: OBS, Burst length, load, burst drop rate

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1 Introduction

The OBS technique proved to be quite effective in addressing the switching of large amounts of data acquired by heterogeneous input lines at different time intervals. The OBS is composed of bursts of packets, thus very much different from optical packet switching (OPS) [1]. Packets are transferred in OPS, whereas bursts of packets are transmitted in OBS. If estimating total aggregated traffic prior to transmission is not possible, OBS, the proper reservation scheme cannot be applied. OBS is a combination of OPS and optical circuit switching (OCS).For the purpose of identifying the path in which data is transferred, connection-oriented circuits are developed in OCS.This is the reason why in OBS, dynamic provisioning using wavelength-based switching is used [2].A control packet is generated and sent prior by using a different reserved channel,and as soon as an adequate amount of data has been received at the sender's input lines, the data burst is released.An electronic controller is responsible for the electronic routing of control and data bursts. This electronic controller also decides the outgoing link and wavelength of the data burst [3].There will be a requirement for a wavelength-routed network for supporting OBS. This network permits a one-way virtual circuit architecture for processing a large quantity of data transmission over the optical switch with extremely low latency [4].

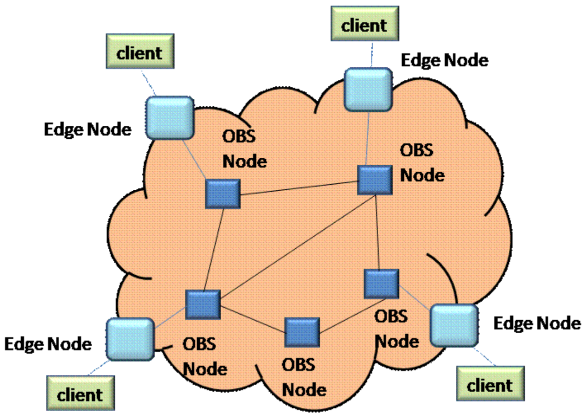

Fig. 1: Network cloud for Optical Burst Switching

Although just like other techniques, OBS too has certain drawbacks, such as the inability to estimate burst length. The variation in the burst length is quite wide. We may have a single packet or a group of several heterogeneous packets. Although we need just one control packet for the purpose of reservation and setup, the control overhead is kept to a minimum. As a result, OBS relies on out-of-band signaling, including optical bursts and control packets that are loosely connected. The data bursts arrive at varying times at the source node; therefore, the arrivals are divided by various arrival offsets. OBS faces a main problem as if the offset is higher, the control packet will be processed for a longer duration via the reserved route over the optical light path [5]. To reduce processing latency, data must be delayed at intermediate nodes, and then, till the arrival of the control packet, the optical burst has to wait.As soon as the control packet reaches, the wait time for bursts is over and they are unleashed on the wavelength-routed network [6]. Figure 1 illustrates the OBS nodes in the basic optical routing system Networks based on IP are supported by OBS over WDM via the interfacing of the network. Control programs are enabled to execute over client machines that coordinate the demands of high bandwidth for data by possible integration. As mentioned above, control packets can be routed with the help of WDM through the AWGR fabric on the basis of an allocated wavelength, from a source port to a destination port.Until the transfer is finished, the allotted wavelength is specifically reserved [7]. If we talk about a network based on IP, the reserved path among intermediate nodes is selected by a control packet [8]. When the packet is delivered to the destination port, on the basis of the destination IP address, WDM releases the reserved link [9]. The wavelength that was assigned is now released into the free wavelength pool.WDM changes the configuration of each intermediate optical switch in the reserved light path at the time of the given reservation [10]. As a result, in the routed network, each intermediate node is not obliged to examine the control packet's IP header, and they can instead target local forwarding to the neighboring optical router in the reserved path. Using WDM in optical routing, the light path may be selected by considering the minimum power required for correct reception of bits at the destination. Higher power may be required for correct reception of data if the shortest path is considered only in terms of distance, while a path of moderate distance having a comparatively lesser number of switches will be more efficient [11]. As a result, processing applications' end-to-end latency is considerably decreased, and IP layer losses are minimized. As soon as a burst passes through an intermediate node, the reservation's control information is immediately released, and the node's information is erased from the path.As a result, we have a free intermediate node that can now allocate the link bandwidth to those network nodes that are in a queue for transferring data. This makes it possible to make maximum use of the link and proper use of link throughput.

The burst assembly algorithm to reduce assembly delay was proposed in [11]. Awasthi et.al [12] proposed mechanism for the burst length estimation and relevant results are discussed. In [13], Shukla et.al further extended Awasthi et.al work and a closed form expression is derived for the estimation of burst lengths. For the next generation data center design for dual buffer OBS was proposed by Bhattacharya et., al [14] and simulation results are presented.

In this paper, a mathematical model is developed to obtain network traffic flow equations and packet/bust drop rates under with and without considering the buffer at various nodes of the switches. The burst length modelling is also detailed, and finally, Monte Carlo simulation is performed to obtain various results.

2 Mathematical Framework

Considering in a network each links has capacity 'C' and the overall queue length as 'Q'. The arrival rate is represented by '$\lambda(t)$', $L(t)$ represent the measure of traffic dropped and $\mu(t)$ represent the service rate at time t.

In the time interval $[t_1, t_2]$, the total arrival is described as [11]

$$L_{in}(t_1, t_2) = \int_{t_1}^{t_2} \lambda(x)\,dx \tag{1}$$

Similarly defining L_{out} is the transmitted traffic and given by

$$L_{out}(t_1, t_2) = \int_{t_1}^{t_2} \mu(x)\,dx \tag{2}$$

where $\mu(t)$ is the instantaneous service rate at time t. Queue length at time $t=(t_2-t_1)$ can be written as

$$Q(t)=L_{in}(t)-L_{out}(t) \tag{3}$$

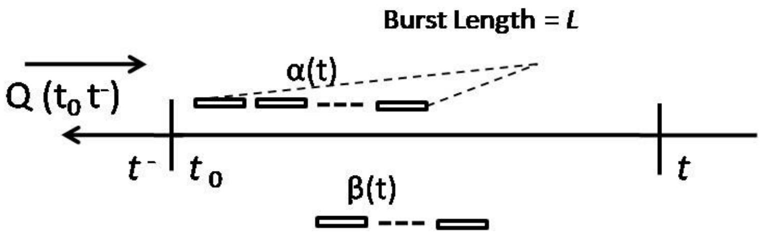

Fig 2: description of various parameters

The fraction of traffic dropped in the time interval [t_o, t], i.e.

$$P(t)=\frac{\int_{t^-}^{t}\left[\lambda(x)-\mu(x)\right]dx}{\int_{-}^{t}\lambda(x)dx} \tag{4}$$

or

$$P(t)=\frac{Q(t^- t_0)+\alpha(t-t_0)-\beta(t-t_0)}{L_{in}(t^- t_0)+\alpha(t-t_0)} \tag{5}$$

In networks where no buffer is used at the nodes the fraction of packet loss is given by equation 6. In the above equation previous queue length is given by $Q(t^- t_0)$ and in the time interval [t_o, t], the arriving traffic is given by $\alpha(t-t_0)$ and depart traffic is given by $\beta(t-t_0)$ and $L_{in}(t^- t_0)$ is the total traffic till time t_o. Initially, t_o is zero, setting this in above equation we get

$$P(t)=\frac{\alpha(t)-\beta(t)}{\alpha(t)}=1-\frac{\beta(t)}{\alpha(t)}=1-\rho_0 \tag{6}$$

where ρ_o is normalized throughput.
Further considering that buffer of size '*B*' is used, then the traffic loss probability can be written as

$$P(t)=\frac{Q(t^- t_0)+B+\alpha(t-t_0)-\beta(t-t_0)}{L_{in}(t^- t_0)+\alpha(t-t_0)} \tag{7}$$

Again, referring figure 2, let the packets which are accumulated in the time interval (t-t_o) to form burst are *L* and it is well known that the arrival of packets can be modeled as Poisson process and probability that a particular burst will have *L* packets will be given by [12]

$$P\left[\tau<\left(t-t_0\right)\right]=\int_0^{(t-t_0)}\frac{\lambda^L t^{L-1}}{(L-1)!}e^{-\lambda\tau}d\tau \quad (8)$$

or

$$P\left[\tau<\left(t-t_0\right)\right]=\frac{\gamma_{inc}\left[L,\lambda\left(t-t_0\right)\right]}{(L-1)!} \quad (9)$$

Where γ_{inc} refers to the incomplete gamma function. Let '*t*' is sufficiently large than the mean number of packets is a burst is given by

$$P\left[\tau<\infty\right]=\int_0^{\infty}\tau\frac{\lambda^L t^{L-1}}{(L-1)!}e^{-\lambda\tau}d\tau=\lambda t \quad (10)$$

The smaller size of bursts will increase delay, while with the larger size of the burst, in case of loss, huge data will be lost. In this paper, network traffic drop in terms of loss probability is plotted by considering various burst lengths and buffering at the contending nodes. It is found that a moderate size of the burst will be a good option with a reasonable amount of buffer for the storage of contending bursts. In the next section, the traffic loss probability is presented by considering the burst length $L = \lambda t$.

3 RESULTS

In the simulation for the bursty traffic generation, random arrival of packets is considered as detailed in [15], and length-based burst assembly mechanism is used.

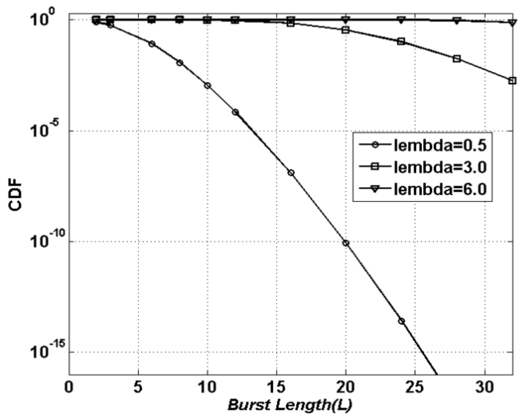

Fig. 3: Probability that $t<t_0$, w.r.t. burst length for t_0=4, and variable arrival rates

Figure 3, shows the cumulative distribution function (CDF), i.e., the probability of generation of a burst, vs. the burst length which varies from 2 to 30 packets at a fixed burst assembly time of '4'. For a low arrival rate of 0.5, the probability of generating a larger burst is essentially negligible, whereas for a burst duration of 20, the probability is 10^{-10}. As the arrival rates rise, the likelihood of greater bursts rises as well (3.0 and 6.0). A burst of length 12 is created with a probability of 1 with a lambda of 3.0. A burst of length 24 can be generated with the same chance as lambda 6.

Figure 4 shows the arrival rate vs. time with error bars for various burst lengths. When the arrival rate is low, such as 0.5, the assembly time for a 35-unit burst is 68 units, with an inaccuracy of 11.66 units. As a result, the prediction is inaccurate at lower arrival rates. Similar trends can be seen for L=4 and 20 at smaller loads. The assembly time would be 6.8 units with a 1.16 unit inaccuracy when the arrival rate is 5 for the formation of a burst of 35 packets. For a burst of 20 packets with the same arrival rates, the assembly time would be 3.8 units with an error of 0.87 units.

The assembly time is less than a unit for the burst of 4 packets, and the error time is negligible. In general, the graph shows that as the arrival rate increases, the assembly time decreases, and the associated error decreases as well. Because arrival rates are higher in bursty traffic, the aforementioned methodology can provide a very accurate estimate of burst length.

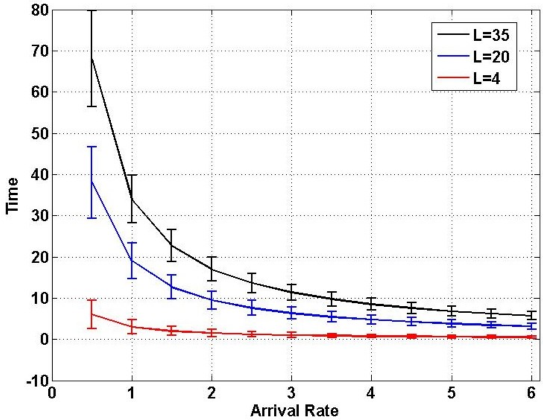

Fig. 4: Arrival rate vs. time for different burst lengths with error bars.

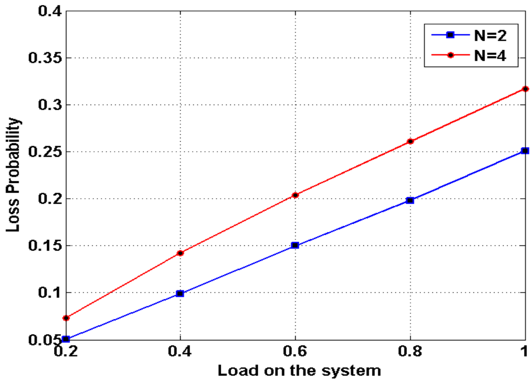

Fig. 5: Loss Probability verses Load for Zero buffer and varying number of inputs

In figure 5, for various values of *N*, the number of inputs, the loss probability versus load on the device is plotted, for the buffering of zero, i.e., no bursts were stored at the contending node, and in the event of contention, it was deflected to another node, from where it would return to the contending node and be served if the contention has been resolved [14].The bursty traffic model is used in the simulation. The switch sizes here range from 2 to 4. Since no buffering is assumed at each node, a significant number of bursts (32%) were deflected in this case. As a result, the previous suggestion that in the case of OBS contention, a deflection of burst is a very good viable alternative is incorrect for the following reasons:

1. Many dummy packets will be created in the networks as a result of the packet deflection.
2. The network would be quickly congested, which will increase the contention of bursts.
3. Because of the enhanced contention, the network's throughput drops, and the average latency may be extremely high.

In the next part of the work, the use of a buffer in case of contention of the bursts is detailed.
Figure 6 shows the loss probability versus device load for N=2 with buffering capacities of 4, 8, and 16 bursts. The simulation considers a burst with duration of four packets. As shown in the graph, the likelihood of a burst loss decreases as the buffer size grows. Thus, as per the required burst loss rate, the buffer can be enhanced to obtain a very low burst loss rate.

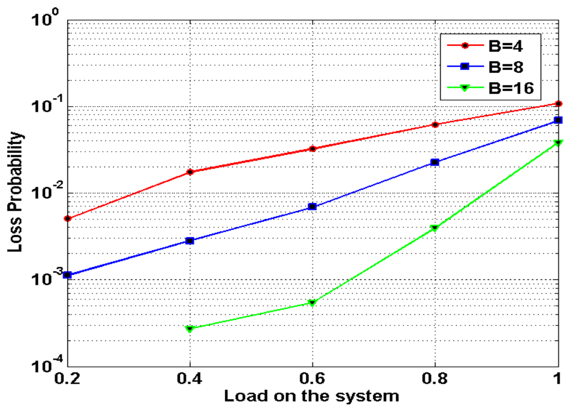

Fig. 6: Loss Probability verses. Load for different numbers of buffer for fixed burst length of 4

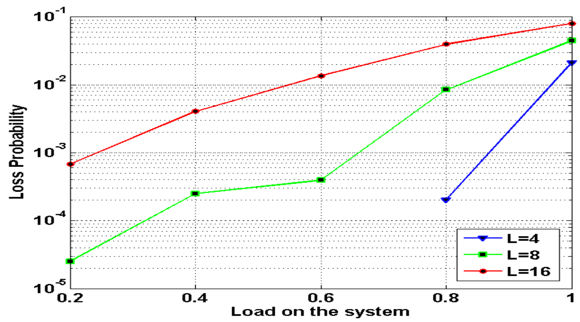

Fig. 7: Loss Probability verses. Load for fixed numbers of buffer 16, for a different burst length

Loss probability versus load on the device is plotted in figure 7, for N=2 and a buffering capability of 16 bursts. The burst duration is varied in the simulation. As can be seen in the graph, the likelihood of a burst failure increases as the burst duration increases. As a result, the burst length has an effect on the burst loss probability.Loss probability vs. device load is plotted in figure 8 for N=2 and buffering capacities of 8, 16, and 32 bursts. In the simulation the considered burst is of length 6. As a result, the likelihood of a burst failure increases as the burst duration increases. However, as the buffer size grows, the likelihood of a burst failure decreases.

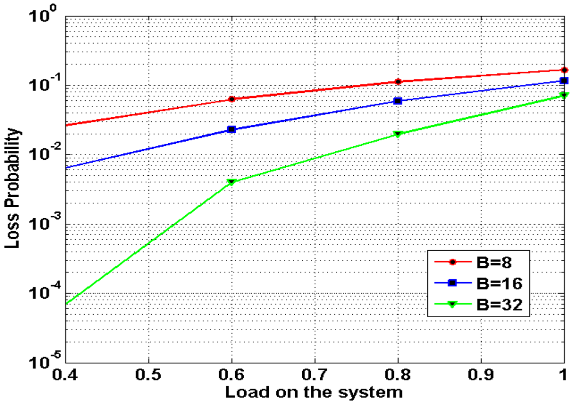

Fig. 8: Loss Probability verses. Load for a variable buffer for a fixed burst length of 6

Table 1: Comparison with other techniques

Reference	Method	Burst loss Probability
[12]	Without Buffer	0.35
[12]	Buffering	6E-04
[14]	Deflection Routing	2E-03
[14]	Buffering	5.2E-04
Proposed	Buffering	5.1E-04

In Table 1, a comparison with other work is presented. It is clear that without buffering, the burst loss probability is very high at 0.35, while with buffering of 16 packets it can be brought down to 6E-04s [12]. In the other notable state-of-the-art method, deflection is also considered, where the burst loss probability can be brought down to 2E-03, which is higher than that of the buffering (5.2E-04). In the proposed work, buffering is considered and it has been found that the burst loss probability is 5.1E-04, which is the lowest among the considered methods.

4 DISCUSSION

OBS is an important data transfer technology for high speed data transfer technology. The OBS technology is not mature enough due to the unavailability of tuneable wavelength converters and optimum burst length is still an open problem. The smaller size of bursts will increase delay while with larger size of the burst, in case of loss huge data will be lost. In this paper network traffic drop in term of loss probability is plotted by considering various burst lengths and buffering at the contending nodes. It is found that a moderate size of the burst will be a good option with reasonable amount of buffer for the storage of contending bursts.

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