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# Buffering of Fixed Length Burst in Optical Burst Switching Networks

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## ABSTRACT

Optical burst switching is a hot area of research. OBS can be considered as variant of optical circuit switching. In OBS information is transmitted in form of bunch of packets. However in each burst number of packets may differ in number. Therefore, in OBS first control packet is sent to reserve advance path, thereafter same path is followed by burst. As burst length is not known, therefore contending burst cannot be stored instead deflection routing is used. To alleviate this problem, this paper discusses a method which proves an estimate of burst length for a particular load and assembly time, thus enable the possibility of storing of burst. Mathematical analysis is presented and results are shown using graphs and finally simulation results are presented for the buffering of burst in terms of burst loss probability.

**Keywords:** *OBS, burst length, control packet and buffering.*

## 1. INTRODUCTION

Optical burst Switching (OBS) is a switching paradigm, which can provide very high speed data transmission [1]. The concept of OBS is not new; however, due to the complexity of the OBS, research in this area is very challenging. In OBS, it is assumed that the information is transmitted in the form of bursts of packets, and a single burst may be of any length. As the burst length is not fixed, it is very difficult to design a system with such a large variations (minimum of 2 and maximum of some thousands of packets) of the burst length [2]. Therefore, in the available literature, it is assumed that at any node either burst will be served or it will be deflected to some other node in case of contention. It must be remembered that in case of OPS, packets can be dropped at switch input, but in OBS as the burst lengths may be very large in terms of number of packets and therefore, dropping them will lead to large loss of data. However, due to the deflection of bursts, a large number of bursts simultaneously can exist in the network and may become bottleneck for the network.

## 2. BURST ASSEMBLY MECHANISM

*A. Fixed Time based*

The Fixed-Time-based assembly algorithm [3] uses a fixed assembly time as the primary criteria, and based on this time T is fixed for burst formation and it requires each burst size to be larger than a minimum length.

Considering a fixed assembly time window *T* and a minimum burst length of *b* packets. generally, $b < \lambda T$ , where $\lambda$ is the average traffic arrival rate.

Defining parameters $p_i(t)$ as data arrived in time *t*. It is also notable that initially at *t*=0, $p_i(0) = 0$ .)

**1.** When first packet arrives in an empty burst assembly queue, time counter starts or set as $t = 0$, which increases with time;

2. When $t = T$

**if** $p_i(t) \geq b$ **then**

send all the collected data $p_i(t)$ for Burst *i* immediately;

**else**

increase the data size until it gets a size of *b* with padding and send the data out as Burst *i* immediately;

**end if**

4. Increase the burst index *i* and go to step 1;

*B. Fixed Length based*

Fixed Length burst assembly algorithm uses the maximum assembly time as the primary criteria because it depends on the burst size. To reduce delay, it also allows a burst to be sent out as soon as the burst length reaches or exceeds a given maximum burst length. The detail of this algorithm is given as follows.

Set a maximum burst length *B* and a minimum burst length *b* as well as a maximum assembly time window *T*. Normally, $b < \lambda T < B$ .

We also denote the data accumulated in the $i^{th}$ burst at time *t* as $p_i(t)$ . Here, $p_i(0)$ may not equal to zero because of the possible leftover packets from the previous burst $i - 1$ if it was longer than B packets.

If the buffer is nonempty or when a new packet arrives, initiate timer t=0 which increases with time;

**if** $p_i(t) \geq B$ **then**

go step 2;

**end if**

**if** $t \geq T$ **then**

**if** $p_i(t) < b$ **then**

increase the data size to *b* with padding and send the data out as Burst *i* immediately;

**else if** $p_i(t) \leq B$ **then**

send out the data as burst *i* immediately;

**end if**

increase *i*;

**end if**

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2. **while** total data size in the assembly buffer is larger than B **do**
subtract a burst of length B from the buffer and send it out as burst *i* immediately, increase *i*;
**end while**
4. go to step 1;

Note that if the maximum assembly time *T* in is very small relative to the maximum burst size *B*, the assembled burst's length will never reach *B*. In such a case, in this way this length based method becomes equivalent to a fixed timer based. In other words timer based assembly algorithm can be considered as a special case of length based algorithm if $\lambda T << B$. However, B may be small relative to T both the Algorithms will be treated separately.

**Analysis of Assembled Traffic**

Packets arrive at an OBS assembly node in the form of multiplexed traffic from many independent sources. Previous studies have shown that such packets arriving in a short time period will become independent as the number of sources increases, and in fact, such multiplexed traffic will approach Poisson traffic [3-10]. Normally the assembly time period can be treated as short time period where Poisson traffic is used to model the input packet traffic.

For an assembly node with infinite link capacity, the transmission time of a packet is negligibly small and accordingly each arrival packet can be treated as a point in the time axis. In other words, *Simple Poisson Point* process [11-13] can be used to model the input traffic in the infinite link speed scenario, which assumes that:

(1) no packet arrives at exactly the same time;
(2) all packet arrivals are independent.

Suppose all the packets have a size equal to a constant *q*, and the inter-arrival time $\tau$ of these packets follows an exponential distribution [13]:

$$f(\tau) = \lambda e^{-\lambda\tau} \quad (1)$$

For Algorithm I (Fixed-Time-Min-Length burst assembly), the burst inter-arrival time $\tau_i$ of the assembled traffic is equal to the time window *T*, i.e a fixed constant and thus we will focus on the burst size distribution for now.

The burst size denoted by variable $L$ depends on the number of packets variable p*i* arrived in the fixed time window *T*. The probability that there are *L* packet arrivals within time T is [6]:

$$P\{p_i = L\}$$
$$= P\{L \text{ packet arrive in time interval} T\}$$
$$= \frac{(\lambda T)^{L-1} e^{-\lambda T}}{(L-1)!} \quad (2)$$

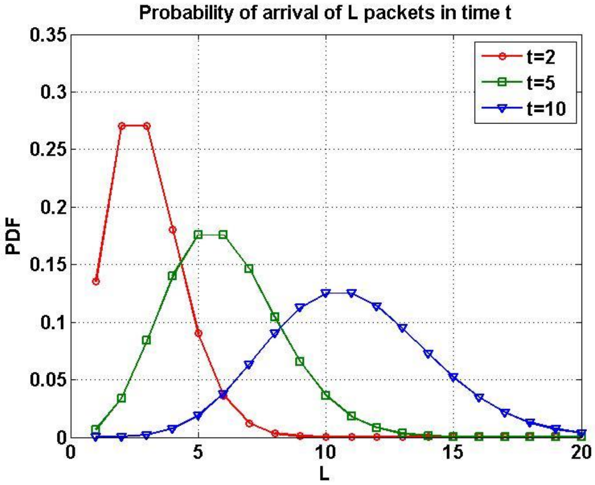


**Figure 1: Probability Distribution vs. Burst Length for different values of time**

In figure 1, PDF vs. burst length (L) is shown, for different values of t. For all the values of t curve follow the same trends. As the time increases, the chances of generating comparatively larger burst increases. But it is also noticeable that for larger values of t, PDFs peak value decreases.

## 3 EARLY RELEASE OF CONTROL PACKET AND BURST LENGTH ESTIMATION

Typically, the BCP is generated and transmitted straight after the data burst is assembled at the border node, since it must know the exact burst size and release time to inform the intermediate nodes' scheduler, under Just-Enough- Time (JET) scheduling. Hence, in addition to the delay suffered by the data packets during the burst assembly process, the packets suffer an extra delay given by the offset-time between the BCP and the data burst.

In certain situations, such delay may be excessive. To alleviate such long delay, this work proposes a mechanism to overlap the burst-assembly delay and the offset delay suffered by the data packets.

Essentially, after the first packet has arrived at the burst assembler, our algorithm

Generates and sends off the BCP to the next hop in the path. Such early BCP carries out a given burst-release time (which is equal to the offset time) and a rough estimation of the final size of the optical burst.

*A. Burst Length Estimation*

In general the packet arrival in network can be modelled as Poisson process. If *X* is represents an event occurring in time is a Poisson process with parameter λ, then *X* has parameter $\lambda t$ over the time interval (0, *t*). Now, the arrival of $k^{th}$ packet after times *t* can also be interpreted as that in time *t* or less, less than *k* packets have been arrived. So, the probability of arrival of $k^{th}$ packet after time *t* from now is same as the probability of arrival of less than or equal to $(k\text{-}1)^{th}$ packets from now. We can compute the above using:

Therefore, we have

$$f(t) = e^{-\lambda t} \lambda \frac{(\lambda t)^{k-1}}{(k-1)!} = \frac{t^{k-1} \lambda^k e^{-\lambda t}}{(k-1)!} \quad (3)$$

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The pdf obtained in eqn.3 in known as incomplete gamma distribution.

**Burst –Release time distribution:**

As the BCH is released after the arrival of first packet of burst with the information of burst release time ($t_0$) and Burst length ($L$), the probability that in time $t_0$ from the release of BCH next $L$-1 packets arrives actually, is given by equation (4) [14]:

$$P(t<t_0)=\int_0^{t_0}\frac{\lambda^L t^{L-1}}{(L-1)!}e^{-\lambda t}dt$$

$$P(t<t_0)=\frac{\gamma_{inc}(L,\lambda t_0)}{(L-1)!} \qquad (4)$$

Where, $\gamma_{inc}$ refers to the incomplete gamma function.

In this scenario where Burst Control Header (BCH) released after the arrival of first packet only then BCH can over-reserve the resource if burst length provided by BCH is more than actual buffer size and if the last packet of burst arrives before the release time of burst then the burst have to wait.

**Case 1: Actual burst size is less than $\hat{L}$**

In this section we have considered the first case in which the BCH reserves the resources for $\hat{L}$-sized optical burst, but the actual size of burst is $p$, where $p<\hat{L}$.

So BCH over-reserves the resources. Let $Y=\hat{L}-p$, then $Y$ is a random variable which is representing the over reservation at the intermediate node.

Now, the over reservation (average) of resources in terms of packets will be given in eq. (5):

$$\mathrm{E}[Y]=\sum_{p=1}^{\hat{L}-1}\left(\hat{L}-p\right)\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0} \qquad (5)$$

Here, $p$ is random variable therefore its pdf will be used.

The asymptotic value of over reservation can be found using the relation assuming $\hat{L}\to\infty$

$$\mathrm{E}[Y]=\sum_{p=1}^{\infty}\left(\hat{L}-p\right)\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}$$

$$\mathrm{E}[Y]=\sum_{p=1}^{\infty}\hat{L}\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}-\sum_{p=1}^{\infty}p\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}$$

$$\mathrm{E}[Y]=\hat{L}\left(1+\frac{\lambda t_0}{1!}+\frac{(\lambda t_0)^2}{2!}+\ldots+\ldots\right)e^{-\lambda t_0}$$

$$-\sum_{p=1}^{\infty}p\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}$$

$$\mathrm{E}[Y]=\hat{L}e^{-\lambda t_0}e^{\lambda t_0}-\sum_{p=1}^{\infty}p\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}$$

$$\mathrm{E}[Y]=\hat{L}-\sum_{p=1}^{\infty}p\frac{(\lambda t_0)^{p-1}}{(p-1)!}e^{-\lambda t_0}$$

$$\mathrm{E}[Y]=\hat{L}-1-\lambda t_0 \qquad (6)$$

**Case 2: Waiting time of Burst**

In this case we have considered the scenario in which $\hat{L}$ th packet i.e., last packet of the burst arrives before the release time of burst i.e., last packet arrives at time $t<t_0$. Thus it forces to buffer the data burst for some time $Z$. So, $Z$ is a random variable that represents the waiting time in buffer i.e. $Z=t_0-t$. The average waiting time can easily be obtained and represented in eqn. (7) :

$$\mathrm{E}[t_o-t]=\int_0^{t_0}(t_o-t)\frac{\lambda^{\hat{L}}(t)^{\hat{L}-1}}{\left(\hat{L}-1\right)!}e^{-\lambda t}dt \qquad (7)$$

The asymptotic value of average waiting time can be found using assuming $t_0\to\infty$

Using Gamma function definition

$$\Gamma(n)=\int_0^{\infty}e^{-x}x^{n-1}dx$$

$$\Gamma(n)=(n-1)!$$

$$\mathrm{E}[t_o-t]=\frac{t_o}{\left(\hat{L}-1\right)!}\left(\hat{L}-1\right)!-\frac{\left(\hat{L}\right)!}{\lambda\left(\hat{L}-1\right)!}=t_0-\frac{\hat{L}}{\lambda} \qquad (8)$$

with minimum value of zero.

On the basis of above mentioned estimates, the obtained results for the typical values are detailed in the next section

## 4. RESULTS

In this section, the analytical results have been generated for the analysis done and these results are shown in graphs under various conditions.

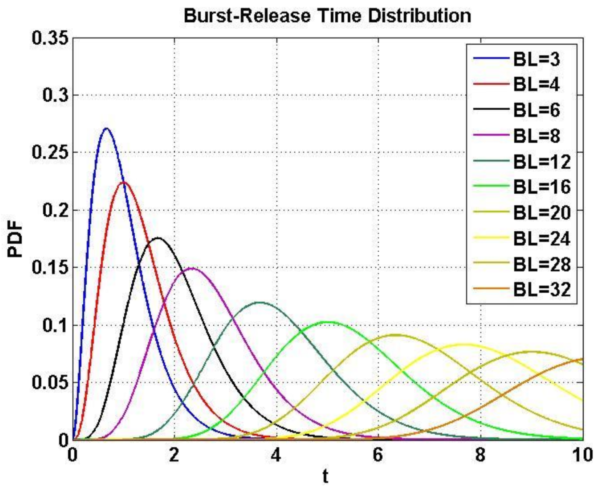


**Figure 2 Burst release time distribution for various burst lengths**

Figure 2, shows Burst release time distribution for different burst length ($L$). It is obvious form the result that as the burst length increases, the burst release time also increases for same arrival rate. As for same arrival rate the time in which greater number of packets will arrive is more so as burst size increases the time for forming burst also increases and hence as burst size increases then for same arrival rate pdf becomes more and more flattened.

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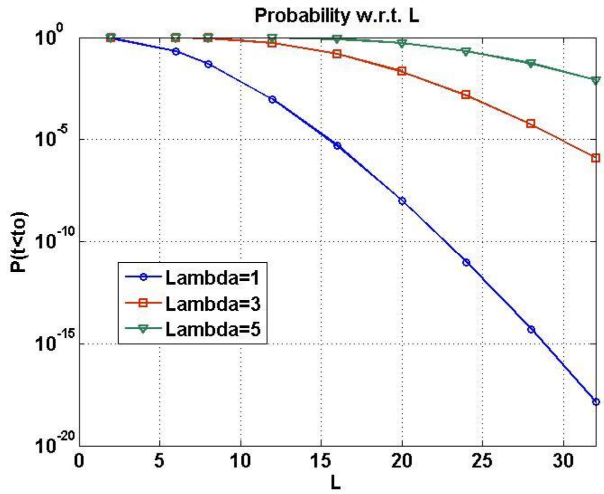


**Figure 3 Probability that $t<t_0$, w.r.t. burst length for $t_0$=4, in case of packet arrival rate of 1, 3, and 5.**

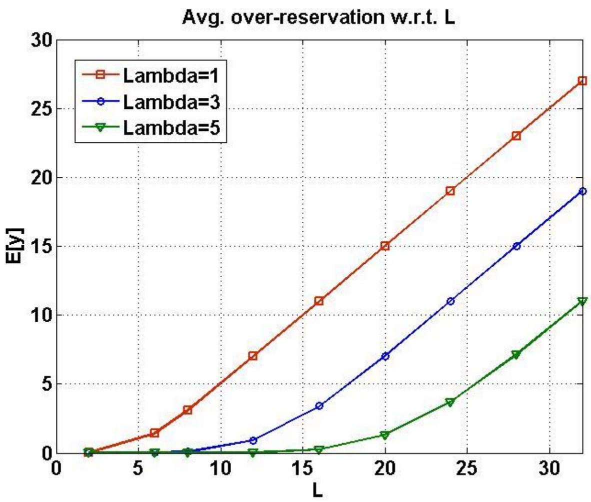


**Figure 4 Average over reservation vs. Burst length for packet arrival rate of 1, 3 and 5 for $t_0$=4**

In figure 3, probability of generation burst of different lengths at different arrival rates at fixed burst assembly time '4' is shown. For low arrival rate of 1 the probability of generation is generation of larger size burst is nearly zero as for the burst length of 20, the probability is $10^{-8}$. As the arrival rates increase (1 and 5) the probability of generation of larger bursts also increases. For lambda equals 3, burst of length 12 is generated with probability 1. Similarly for lambda 5, burst of length 20 can be generated with unity probability.

In figure 4, average over reservation is plotted vs. Burst length at different arrival rates. For lesser arrival rates, over reservation is very large, and this result is obvious as for lower value of burst generation time, burst of larger size will not be framed. However for larger arrival rates average over reservation is less. For lambda equals 5.0 till burst length of 15 over reservation is zero. Using asymptotic value, $\hat{L} - \lambda t_0 - 1$ till $\hat{L}$ of 21, over-reservation is zero. For arrival rate (λ) equals 5, $t_0$ equals 4 and for $\hat{L}$ is 20, and then over-reservation from figure 4 is 2, which is very close to the value obtained exact analysis. For other values difference in the results is not much.

In figure 5, average over reservation is plotted vs. Burst length at different arrival rates while considering $t_0$ equals 6. For lambda equals 5.0 till burst length of 24 over reservation is zero. Using asymptotic value, $\hat{L} - \lambda t_0 - 1$ for arrival rate (λ) equals 5, $t_0$ equals 6 the over-reservation is zero for burst length of 31 and from graph over-reservation is nearly 3, which is very close to the value obtained exact analysis.

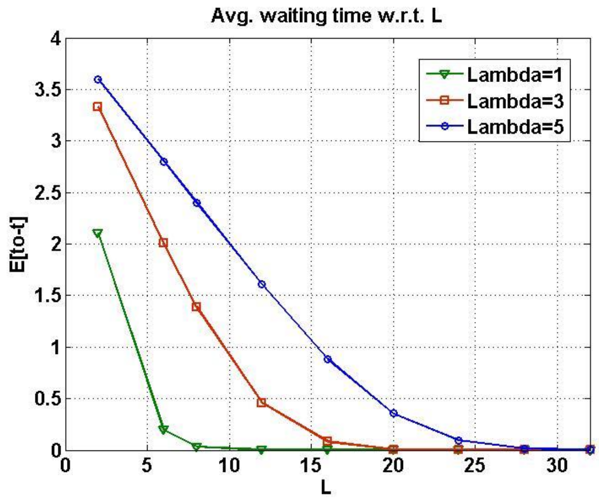


**Figure 5 Average waiting time vs. Burst length for packet arrival rate of 1, 3, and 5 for $t_0$=4**

From figure 3 and 5, it is clear that if one increases then other decreases. Therefore both cannot be minimized simultaneously. Therefore an optimal value should be selected. It has been found that, if $\hat{L} = \lambda t_0$, then both over-reservation and average waiting time can be minimized.

**V. Network Analysis**

Finally the generated burst will propagate in the networks. In the network, two more parameters need to be considered in the analysis:

1. Number of input and output links at each node,
2. Distance between the nodes though which data propagates form source to destination.

For analysis three bio-graphs are considered as shown below:

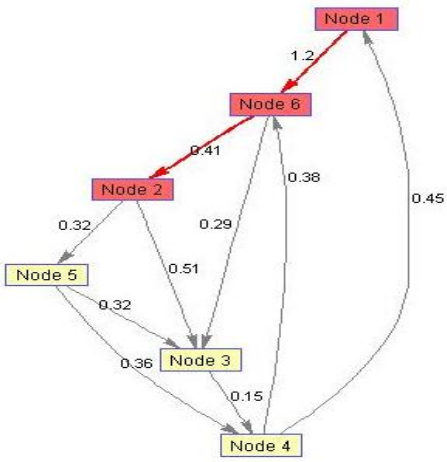


**Figure 6 Bio-Graph 1**

For example we have considered 6 nodes and 11 edges network. Distances among different nodes are shown in bio-graphs. Considering source node as 1 and destination node as

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2, the shortest path is 1-6-2 and distance is 1.61 units. In case of deflection routing path is 2-4-4-1-6-2, thus travelled distance is 2.72 unit.

In general, distances among adjacent nodes in optical core networks are in some hundreds to some thousands of kilometers. Considering 1unit=1000km.

Therefore, travelled distance in bio-graph in case of direct hopping is 1610 km and in case of deflection routing is 2720 km.

The total delay suffered by burst in case of deflection routing is

$$T_{DEF} = T_{BA} + T_{PD}^{DH} + T_{PD}^{DR} \quad (9)$$

The total delay suffered by burst in case of buffering of burst is

$$T_{BUF} = T_{BA} + T_{PD}^{DH} + T_{BB} \quad (10)$$

Considering the speed of light in fiber as $2\times10^8$ m/s, then propagation delay time in direct hopping ($T_{PD}^{DH}$) is 8.05 ms and propagation delay time in deflection routing is ($T_{PD}^{DR}$) 16.60 ms. The burst assembly time ($T_{BA}$) varies from 10 ms to some 100 seconds depending on arrival rates. However in high speed networks, it varies from 10 ms to 40 ms.

Let burst assembly time as 40 ms. Then total delay suffered by burst in case of deflection routing is (40+ 8.05+16.60)=51.65ms.

Considering that a packet consists of $10^5$ bits which is equivalent to $\frac{10^5}{10\times10^9} = 10\mu s$, and burst having 4 packets thus equivalent delay is $40\mu s$. Moreover the length of fiber delay lines is equal to burst length, and considering buffering of 8 bursts then total delay is $320\mu s$ or 0.42ms. Thus, buffering time is negligibly small.

$$T = T_{BA} + T_{PD}^{DH} + T_{BB}$$

Total delay suffered by burst in case of deflection routing is (40+ 8.05+0.42)=48.82 ms. Thus buffering of contending burst is a good idea in comparison to deflection routing.

### A. Results

In figure 7, loss probability vs. load on the system is plotted for various values of *N* i.e., number of inputs. the buffering of zero, i.e., at the contending node no burst will be stored, and in case of contention it will be deflected to some other node, form where it will come back again to the contending node and if contention is resolved it will be served. In the simulation the bursty traffic model is considered. Here, the switch sizes are varied from 2 to 6. Here, as no buffering is assumed at each node, therefore at the load of one, a large number of bursts ~ 42% will be deflected. In the load on interest 04 to 0.8, minimum number of deflected packets varies from 10 to 20 percent. Therefore as suggested previously that in case of OBS contention the defection of burst is a very good viable option is not correct due to the following reasons:

1. The deflection of packet will generate many dummy packets in the networks.
2. The network will easily be congested, and therefore further enhances the contention of bursts.
6. Due to the alleviated contention the throughput of the network decreases and the average latency can be very huge.

In the next part of the work, use of buffer in case of contention of the bursts is detailed.

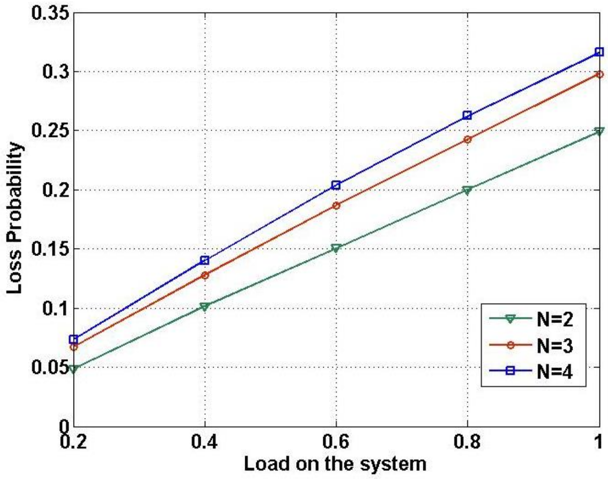


**Figure 7: Loss Probability vs. Load for different numbers of inputs and outputs without buffer**

In figure 7, loss probability vs. load on the system is plotted for various values of *N* i.e., number of inputs. the buffering of zero, i.e., at the contending node no burst will be stored, and in case of contention it will be deflected to some other node, form where it will come back again to the contending node and if contention is resolved it will be served. In the simulation the bursty traffic model is considered. Here, the switch size is varied form 2 and 4. Here, as no buffering is assumed at each node, therefore a large number of bursts ~ 32% will be deflected. Therefore as suggested previously that in case of OBS contention the defection of burst is a very good viable option is not correct.

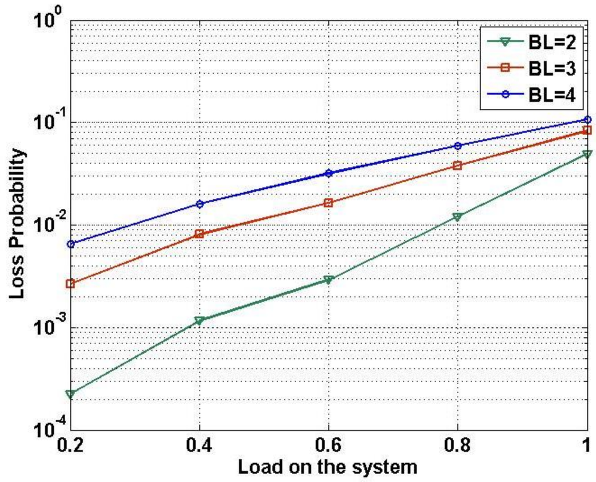


**Figure 8: Loss Probability vs. Load for numbers of inputs and outputs as 2 and with buffering of 4 bursts**

In figure 8, loss probability vs. load on the system is plotted for *N*=2, while assuming the buffering capacity of 4 bursts. In the simulation considered burst is of length 2, 4 and 6. Comparing with results in figure 7, using a small buffer a significant reduction in burst loss is possible. For *N*=2, burst loss decreases by 47%.

## 5. CONCLUSIONS

In this work, a novel paradigm called the optical burst switching (OBS) as an efficient way to resolve the problem of congestion that the Internet is suffering from is discussed. The major issue in the OBS is the estimation of the burst length before it arrives to the destination nodes. Due to this uncertainty, the deflection routing was assumed to be only feasible option for the contention resolution of the bursts. In this work, we have discussed that the arrival of very large burst is very rare event; hence network cannot be designed on the basis of very large bursts. The theoretical analysis and simulation results are presented to validate our hypothesis. Finally, we conclude that the storage of burst at the contending node for smaller and average size burst along-with the deflection of the larger size burst is the more suitable option rather than deflect all the contending bursts.

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