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Performance of Optical Node for Optical Burst Switching

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Abstract

Optical Burst Switching (OBS) is a switching paradigm that offers very high throughput with reasonable delay. In OBS, data is transported in the form of the optical burst of unknown length. Till date, the size of the burst can't be estimated in advance. Hence, in OBS deflection routing, contending burst is deflected to some other node and after some more slot, it will re-appear on the same node. This mechanism is known as deflection of burst. In our previous work, an estimation of burst is done and optical node architecture is used to store optical burst. The buffering of burst will reduce average latency as well as improve Burst Error Probability (BER). In this paper, the performance evaluation of the node architecture is presented under various conditions and it is shown that deflection routing along with buffering of contending burst provide very effective solution.

Keyword: Burst Loss Probability, Switch Architecture, OBS

1. Introduction

In recent years, demand for higher network bandwidth has become a major challenge for service providers due to increasing global popularity of the internet and the service it offers. The other challenge is to provide high capacities at low cost. From the past few years, optical data communication has been considered as the best solution to meet out the present bandwidth requirements of the users and for supporting future network services. This is possible because; theoretically a single piece of optical fiber has the ability to support bandwidth demand of up to 50 THz[1]. In addition to this, optical fibers are very cheap in cost and provide extremely low bit-error rates[1]. The optical fiber is less bulky than other transmission cables. Optical signals travel very long distances and are immune to electrical interferences. Furthermore, fiber cables are much more difficult to tap signal than copper wires, so optical fiber also provide security advantage[1]. All these factors are very promising and makes optical data networks the networks of the future.

In the optical data transmission, Optical Packet Switching (OPS) and OBS are two switching paradigm, which are heavily investigated in past. In OPS data transmission takes place in the forms of optical packets, which may or may not be of same duration. In OBS data transmission, the information is transmitted in the form of the burst of packets. These burst may contain one or several packets and the length of the burst is not fixed. The detailed discussion on OPS/OBS can be found in[1]. In this paper, OBS contention resolution scheme is discussed and as proposed in past. Buffering of contending burst can be a suitable option to reduce burst loss probability and duplication of packets in the networks.

2. Optical Burst Switching (OBS)

In Optical Burst Switching, control packet and burst are sending separately on different fiber links[2–5]. Over here, a control packet is sent at the beginning, following a burst of data without waiting for an acknowledgment for the connection establishment; this is called a one way reservation protocol. The main characteristic of OBS is to

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switch a whole burst of packet whose length can range from one to several packets to a session using one control packet and resulting in a lower control overhead per data unit. Out of band signaling is being used by OBS and the control packet and the data burst are loosely coupled in time. It means that they are separated at the source by an offset time, which is more than the total processing line of the control packet along the path. As a result, this eliminates the need for the data burst to be buffered at any subsequent intermediate node just to wait for the control packet to get processed in optical burst switched network.

The basic functions of an OBS network (Figure 1) are:

Collect IP packets from IP layer.
Aggregate these IP packets into OBS traffic (i.e., aggregating IP packets into bursts and generating Burst Header Cell (BHC)).
Transport OBS traffic to destination OBS node.
De-aggregate bursts into IP packets and deliver them back to IP layer.

2.1 Optical Burst Switched Networks

Within OBS, optical switches provide optical paths through each router, in which data can pass optically without any electronic processing. In order to obtain the switching information needed for switching and scheduling tasks, electronic processing of the header is required in each router node[6, 7]. To have an efficient processing of the header's routing and switching information, without disturbing the data transport, the header is removed from the data and sent in advance of the data part, on a separate control channel.

In OBS, the wavelength of a link used by the burst will be released as soon as the burst passes through the link, either by an explicit release packet or automatically according to the reservation made. This means that bursts from different sources to different destinations can effectively utilize the bandwidth of the same wavelength on a link in time-shared statistical multiplexed manner. If the control packet fails to reserve the wavelength at an intermediate node, the burst is not rerouted and it is dropped. OBS protocols are not all alike; some of them support a reliable burst transmission, which do have a negative acknowledgment that is sent back to the source node, which re-transmits the control packet and the burst after that. Other OBS protocols are unreliable and don't have such negative acknowledgment.

To avoid contention of control information, the channels inside in a fiber are divided in data channels and a few separate control channels (Figure 2). The Burst Header Packet (BHP) is sent in front of the Data Burst (DB) on a separate control channel. These control channels are grouped together in the Control Channel Group (CCG). The DB is scheduled on one of the data channels by a scheduler. All the different data channels form the Data Control Group (DCG) for a single fiber.

Circuit switching is good for smooth traffic and QoS guarantee due to a fixed bandwidth reservation. One of the problems with this kind of routing is that the path has to be kept reserved, even the traffic on the path is of bursty in nature. Further, a second problem is that, if a particular wavelength is reserved for an initial router, then that particular wavelength is not available for other subsequent router. Wavelength conversion is required to resolve this issue, which compromises some of the benefits of all optical transparent paths. The benefit of Packet switching is that it contains packets, which consist of header and

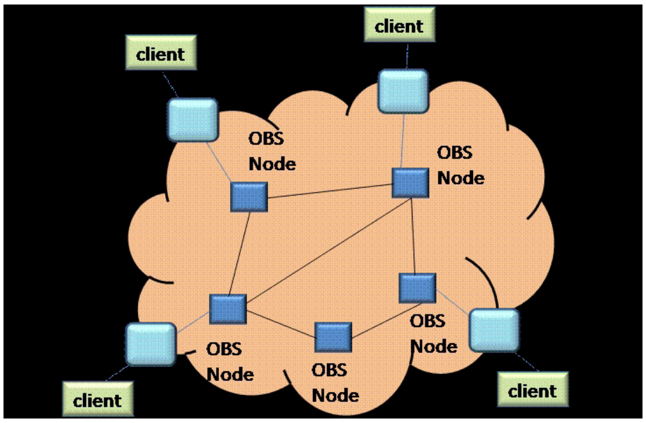

Figure 1. General layout of an OBS network architecture.

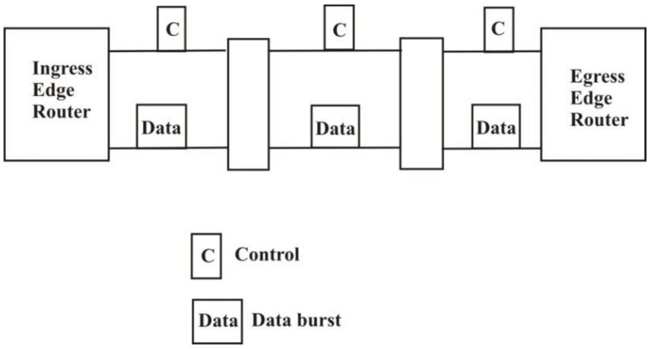

Figure 2. Transmission of Burst and control packet.

payload. The packet header (e.g. addresses) and a payload is sent without any circuit set up and we have static sharing of the link wavelengths among packets with different sources and destinations. Though, due to the store and forward mechanism, each node processes the header of the packet arriving at the node, where it has to be routed, and this makes the use of a buffer in each node necessary. OBS combines the benefits of optical circuit as well as packet switching. Unlike the circuit switched approach, it does not need to dedicate a wavelength for each end-to-end connection due to the fast release of the wavelength on a link, after the burst passes through it.

Also, unlike the packet switched approach, burst data does not need to be buffered or processed at the cross connect, since the OBS mechanism is a cut through one. In optical burst switching, offset time is the time between the burst header/control packets. The offset time, which is used in one-way reservation schemes, allows the network time to schedule the burst and set up resources prior to burst arrival is sent into the network. The offset time can be altered to allow the network time to configure based on the information carried in the burst header packet. By differing the offset time, different levels of quality of service can be provided.

2.1.1 Latency

Latency in a packet-switched network is measured either one-way (the time from the source sending a packet to the destination receiving it) or round-trip (the one-way latency from source to destination plus the one-way latency back to the source from the destination). Round-trip latency is mostly often quoted, as it can be measured from a single point. It should be noted that round trip latency excludes the amount of time that a destination system spends processing the packet. A service called ping is provided by many software platforms that can be used to measure round-trip latency. No packet processing is performed by Ping; it merely sends a response back when it receives a packet (i.e. performs a no-op), thus it is a relatively accurate way of latency measurement. Where precision is important, one-way latency for a link can be more strictly defined as the time from the start of packet transmission to the start of packet reception. The time duration from the start of packet reception to the end of packet reception is measured separately and called “transmission delay”. This definition of latency is not dependent of the link’s throughput and the size of the packet and is the absolute minimum delay possible with that link.

2.1.2 Deflection Routing

To mitigate the burst contention problem, researchers have proposed solutions based on deflection (or alternative) routing. All these methods allow re-routing contending bursts from primary to alternative routes. With these means, it alleviates congestion on bottleneck links and achieves dynamic load balancing in the network[8–11].

2.1.3 Optical Buffer

In telecommunications, an optical buffer is a device that is capable of temporarily storing light. Similar to a regular buffer, it is a medium of storage that enables to compensate for a difference in time of occurrence of events. More particularly, an optical buffer serves to store data that was transmitted optically. As light can’t be frozen, an optical buffer is made of optical fibers and generally, a lot bigger than a RAM chip of comparable capacity would be. A single fiber can be served as a buffer. However, generally, a set of more than one is used. A possibility is to opt for a certain length D for the smallest fiber and then let the second, third etc. have lengths 2D and 3D respectively. Another conventional example is to use a single loop, in which the data circulates for an uncertain number of times.

2.2 Burst Switching Variant

There are three variations of burst switching: Tell-And-Go (TAG), In-Band-Terminator (IBT) and Reserve-A-Fixed-Duration (RFD)[7]. In all three variations, bandwidth is reserved at the burst level and the most important point is that bursts are cut through intermediate nodes instead of being stored and forwarded.

2.2.1 Tell And Go (TAG)

In TAG, the source sends the control packet on a separate control channel to reserve bandwidth and set the switches along the path for a data burst that can be sent on the data channel without receiving an acknowledgment first. This means that the offset time T between the control and the burst packet is much smaller in comparison to the circuit set up time. After the burst is sent, another control signal is sent to release the bandwidth.

2.2.2 In-Band-Terminator (IBT)

In IBT, every storage burst has a header like in packet switching and also a special delimiter or terminator indicating the end of the burst. IBT isn't just like packet switching that has a store and forward mechanism, instead, IBT uses virtual cut through. In special, a source and the intermediate node can send the head of a burst even before the tail of the burst is received. This in turn means that the burst will encounter less delay and a smaller buffer size is needed at a node, exception of one case when the entire burst has to wait at a node because the wavelength at the link is not available.

2.2.3 Reserve Fixed Duration (RFD)

RFD is by some means similar to TAG, in the sense that the control packet is first sent to reserve bandwidth and set the switches, followed by the data burst after time offset T. In RFD, However, the bandwidth is reserved for a duration, which is specified by the control packet as a header of variable length packet, which contains the burst length. Although, this means that the burst will have a limited maximum size.

2.3 Just Enough Time Protocol (JET)

JET is a RFD scheme[12]. The source node having a burst of data to transmit sends initially a control packet on a signaling channel, which has a dedicated wavelength other than for the data to the destination node. At every node on the way, the control packet is processed in order to establish an all optical path for the data burst. Each node of the path chooses an appropriate wavelength on the outgoing link, reserves bandwidth on that link and sets up the optical switch, this is all done on the basis of the information carried by the control packet. In course of that time, the data burst wait for a time offset T, at the source node in the electronic domain. In JET, the intermediate network nodes work as follows:

The data which is coming from end stations is buffered according to its destination. After some time, the data is ready to send as an optical burst. A control signal (the burst header) is then sent to the next downstream node and after some time 'T offset (launch)' the burst is transmitted on the wavelength specified in the header.

T is the offset time delay between a header and its respective data. T is sufficient for the intermediate nodes to fulfill the arrival of a burst header on the control channel of a link, which signals a node to reserve a wavelength/time-slot for the soon-to-arrive data to be switched to an output link closer to the destination. Full wavelength translation capability at each link is needed, so that any burst can be routed to any free wavelength on the output link; hence the wavelength of a burst has local significance only. Then, the downstream node sends a new header to the next downstream node. At each hop, T offset is being reduced by the processing time (per-hop-offset) at each node. The prior notice provided by the header suffices that when the data-burst arrives at an intermediate node, the node is already set to route the signal from the input to output channel.

2.3.1 Disadvantages of Circuit Switching

(i) Inefficient utilization of resources.
(ii) Dependence on speed/protocol (Opaque).
(iii) Speed-limitations imposed by available electronic processing capabilities.

2.3.2 Disadvantages of Burst Switching

Faces two technological bottlenecks: Processing speed and buffering.

3. OBS Node Architecture

At an OBS node, no synchronization/alignment of bursts is necessary unless the switching fabric operates in a slotted manner. In addition, FDLs (Fiber Delay Lines) and wavelength converters can help in reducing burst loss[13]. Currently, it is a challenge to implement an OBS switching fabric with hundreds of ports operating at a switching speed, which is on the order of nanoseconds. Nevertheless, on-going research work has shown promise[6, 14, 15].

The OBS node switch architecture is shown in Figure 3. These nodes may be source/destination or intermediate nodes, while burst traversing through the network. In case of contention of the bursts, some burst will be either stored at the contending node or will be deflected to some other node in the network. The decision for the storage of burst or deflection of burst will be taken on the basis of size of the burst and will be discussed later in this paper.

The architecture (Figure 3) consists of both scheduling and switching sections comprises of AWG. The scheduling section is a $2N\times 2N$ AWG router, and while the switching section is a $N\times N$ AWG router. The upper N ports of the AWG router of the

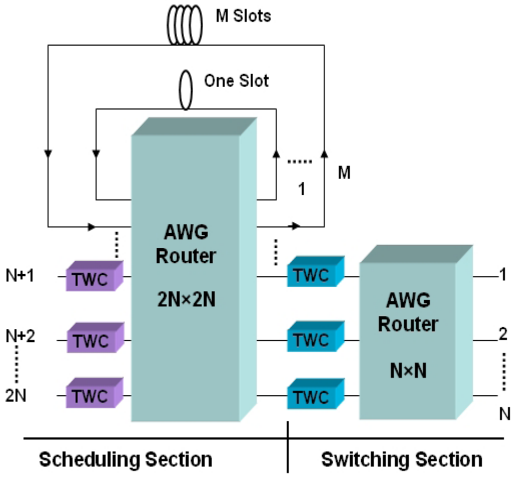

Figure 3. OBS Node Architecture.

scheduling section ranging from 1 to *N* connect to *N* buffer modules. The lower ports of the AWG acts as actual inputs/outputs port of the switch. The more description on the architecture can be found in[16, 17]. In nut shell, the contending packets (burst) are placed in the buffer by tuning their wavelengths appropriately such that they can be directed to correct buffer line (decision is made on the basis of delay required). In each module, only one burst per output port can be stored. The burst can be stored on any of the free wavelength available in particular module. Thus, at most *N* bursts can be stored for a particular output port in all the modules and in each module *N* wavelengths are used.

3.1 Effect of Burst Size on Drop Probability

The information arriving at the switch will be in the form of bursts and hence, the size of burst plays an important role on the designing of the OBS networks with respect to drop probability. Shorter the burst size, higher will be the number of BHCs for a constant throughput that might lead to congestion in control plan. BHCs will suffer from queuing delay before entering to the reservation unit. Due to this queuing delay, bursts might arrive before the switch is configured and hence, will be dropped. In worst case, it might create a situation, where a burst is arriving at an OBS node before the corresponding BHC has been processed. Obviously, this burst would be dropped because there is no reservation for it. In the next section, the probabilistic analysis is presented in the estimation of the burst size.

4. Probability Distribution of the Burst-Release Time

Under the assumption of Poissonian packet arrival, the assembly time *t* for *L*-sized burst follows a Gamma distribution with *L*-1 degree of freedom and parameter λ[18]. The Probability Density Function (PDF) for such assembly tune is given by

$$\text{PDF } L-1, \lambda = \frac{\lambda^{L-1} t^{L-2}}{L-1!} e^{-\lambda t} \quad ; t \geq 0$$

with mean $E\,t = \frac{L-1}{\lambda}$ and standard deviation $Std\ t = \frac{\overline{L-1}}{\lambda^2}$

As proposed in[18], the BCP is released after the first packet arrival with information and *L*, t_0 the probability to actually have *L*-1 additional packet arrivals before release t_0 time is given by:

$$\text{P}\,t < t_0 = {}_{0}^{t_0} \frac{\lambda^{L-1} t^{L-2}}{L-1!} e^{-\lambda t} dt = \frac{\gamma_{inc} L-1, \lambda t_0}{L-1!}$$

where γ_{inc} refers to the incomplete gamma function. It is worth noticing here that such probability depends not only on the choice of t_0 but also on the value of *L*. Clearly, it is easier to complete L_1 packet within time [0, t_0] than $L_2 > L_1$ within the same amount of time. This effect is shown in Table 1.

From Table 1, it is expected that for low value of λ, the probability of generation of large burst is very less. As the value of λ increases, the probability of generation of large burst increases. Hence, with the variation in the value of λ, the size of the burst can vary from very small to a large value with some definite probability. As discussed above, probability of generation of smaller burst is larger, in comparison to the probability of generation of larger size burst, thus smaller sizes burst will be more frequently generated.

5. Simulation and Result

In the previous section, a relation between probability and expected burst length is developed. In this section, simulation methodology is discussed. In the bursty traffic, arrivals are correlated i.e., packets arrive in the form of bursts. It is characterized by the offered load (ρ) and Burst Length (*BL*)[19]. Each burst of packets is equally likely to be destined to any of the output with probability *1/N*.

Table 1. Burst length vs CDF

L(Burst length)	CDF		
	$\lambda = 4$ $t_0 = 4$	$\lambda = 5$ $t_0 = 4$	$\lambda = 0.8$ $t_0 = 3$
3	0.99998	0.9999	0.4302
4	0.99990	0.9999	0.2212
5	0.9995	0.9999	0.0958
6	0.9986	0.9999	0.0356
7	0.9959	0.9997	0.0115
8	0.9900	0.9992	0.0016
9	0.9780	0.9979	
10	0.9567	0.9950	
11	0.9226	0.9891	
12	0.8730	0.9786	
13	0.8068	0.9609	
14	0.7254	0.9338	
15	0.6324	0.8951	
16	0.5332	0.8434	
17	0.4340	0.7789	
18	0.3406	0.7029	
19	0.2576	0.6185	
20	0.1624	0.5297	

This also implies that if a packet arrives on input *i* and destined for the output *j* in the current slot, then there is small but finite probability, that in the next slot packet arrives for the same destination. Thus, in the time domain traffic, each input is composed of burst of packets destined for the same output. Time correlation of the traffic on each input is specified by the Markov chain model (Figure 4).

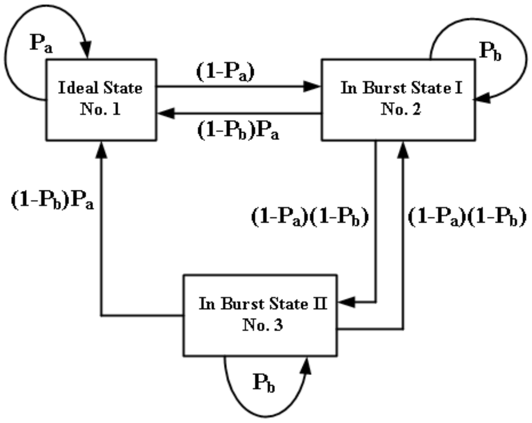

Figure 4. Bursty Traffic model.

This bursty traffic model consists of three stages:

i. Idle state
ii. Burst I state
iii. Burst II state

The system will be in idle state, if no packet arrives in current slot. With probability (P_a), if no packet arrives in the next slot, the burst will remain in the idle slot. Thus, with probability (1-P_a), a new burst will start and system will go in the burst state I. Now considering that, new burst will arrive for the same destination with probability (P_b). The burst can terminate in two ways:

A new burst start for another destination with probability (1-P$_a$) (1-P$_b$), By going to idle state with probability (P$_a$) (1-P$_b$).

The steady state distribution of the Markov chain can be expressed as:

$$\pi P = \pi$$

where, π is row vector; $\pi = \left[\pi_1\ \pi_2\ \pi_3\right]^T$ and P is transition matrix.

$$\begin{bmatrix} P_a & (1-P_b)P_a & (1-P_a)P_b \\ (1-P_a) & P_b & (1-P_a)(1-P_b)_b \\ 0 & (1-P_a)(1-P_b) & P_b \end{bmatrix} \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{bmatrix} = \begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \end{bmatrix}$$

with $\sum^{n} \pi_i = 1$

By solving the above two equations, we get the steady distributions as

$$\pi_1 = \frac{p_a(1-P_b)}{1-P_aP_b}$$

$$\pi_2 = \frac{(1-P_a)}{(1-P_aP_b)(2-P_a)}$$

$$\pi_3 = \frac{(1-P_a)^2}{(1-P_aP_b)(2-P_a)}$$

The average link utilization can be obtained as

$$\rho = 1 - \pi_1 = \frac{(1-P_a)}{(1-P_aP_b)}$$

The probability of a particular burst having *K* packets is

$$\Pr(K) = (1-P_b)(P_b)^{K-1} \quad K \geq 1$$

Thus, the average burst length can be obtained as

$$BL = \sum_{K=1}^{\infty} K.\Pr(K) = \frac{1}{1-P_b}$$

The value of Burst Length (BL) is obtained from Table 1, and Monte Carlo simulation is performed by varying different switching parameters and obtained results are discussed below.

In Figure 5, Burst loss probability is plotted vs. load by considering the Burst length of four, while assuming 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 from 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 from 4, 8 and 16. The burst loss probability is very high (0.30~0.35) for zero buffering and high load as shown in the Figure 5. Hence, burst needs to be deflected in order to avoid a large loss. Due to deflection of such a large number of burst, the network may become congested and, hence deflection alone may not serve a practical solution.

In Figure 6, burst loss probability vs. load is shown. Here, 4x4 switch and the burst length of 4 packets is considered while varying the buffering capacity of 4, 8 and 16 packets. The effect of buffer on burst loss probability can be clearly visualized by comparing the Figures 5 and 6. It is also observed that with the increase in the buffer size, the burst loss probability improves. At the load of 0.6, the bursts loss probability is 0.2 without any buffering as shown in Figure 5, whereas it is 0.01 with buffering capacity of 16 (shown in Figure 6). Thus, burst loss improves by a factor of 20.

In Figure 7, burst loss probability vs. load is plotted. Here, buffering capacity of 4 burst and the burst length

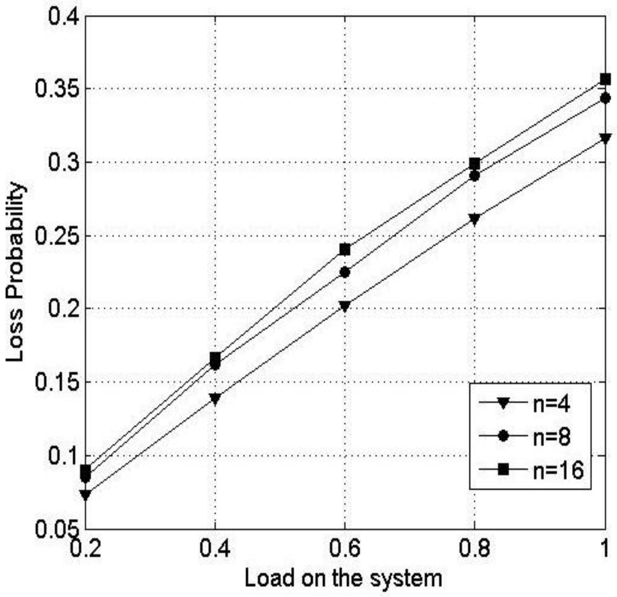

Figure 5. The burst loss probability vs. load with buffering of zero burst, and Burst Length of four while varying the number of nodes.

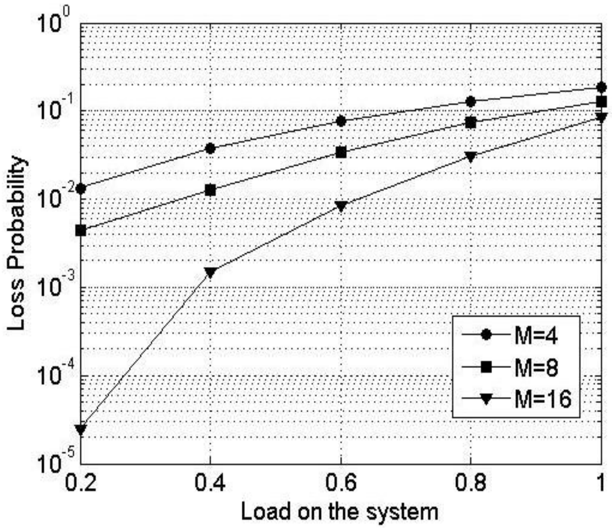

Figure 6. The burst loss probability vs. load for a burst length of 4, switch size of 4 and variable buffering capacity 4, 8 and 16.

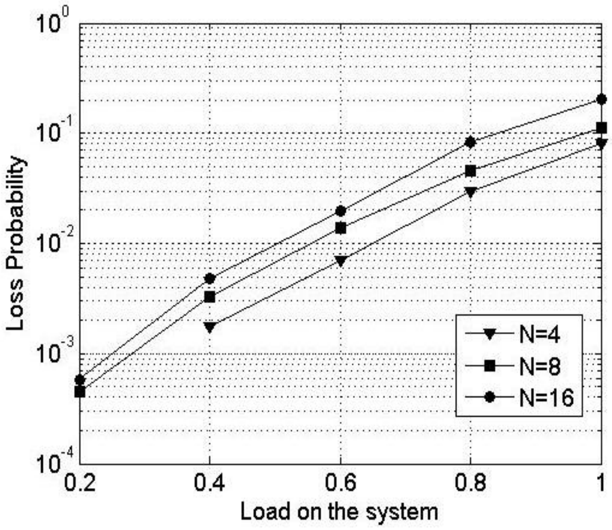

Figure 7. The burst loss probability vs. load with buffering of 4 burst, burst length of four while varying the number of nodes.

of 4 packets is considered for a variable switch size of 4, 8 and 16. Figures 5 and 7 are very similar with different burst loss probability. This is obvious results, because as the buffer space increases, the burst loss probability improves and the improvement is of 10~20 folds. This figure also signifies that the size of the buffer has to be increased to get a particular burst loss probability, if the number of inputs increases.

In Figure 8, burst loss probability vs. load is plotted. Here, 4x4 switch and the buffering capacity of 4 packets is considered for a variable burst length of 2, 4 and 8. The effect of burst size on burst loss probability can be clearly visualized. It is also observed that the burst loss probability increases with the increase in burst size. At the load of 0.6, the burst loss probability is 0.02386, 0.07421 and 0.1186 for a burst length of 2, 4 and 8 respectively.

Hence, in nutshell, following conclusions may be inferred:

i) Deflection routing alone is not a good solution due to very high burst loss probability.
ii) The buffering of burst at the contending node improves the burst loss probability.
iii) The burst loss probability increases with the increase in burst size for a fixed buffer capacity.
iv) The increase in buffering capacity improves the Burst loss probability.
v) If very large size burst arrives (more than the buffering capacity) then, these burst can be deflected to avoid loss of data.

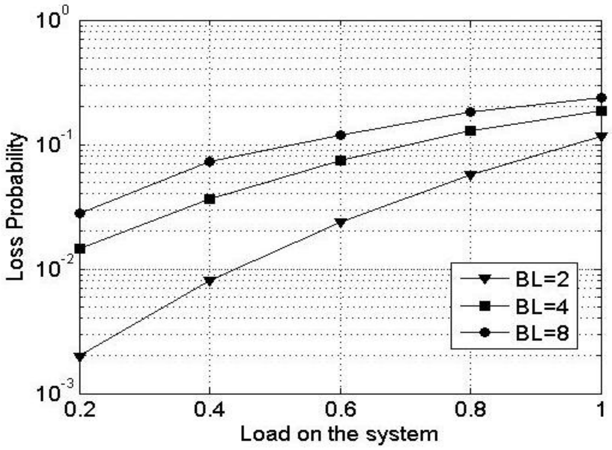

Figure 8. The burst loss probability vs. load with buffering of 4 burst, switch size of 4, with a varying burst length of 2, 4 and 8.

vi) In contention, the burst should be buffered for smaller size of burst, whereas deflection routing for larger size burst can be considered.
vii) Hence, in conjunction of both buffering and deflection of burst provide more realistic and effective solution.

6. Conclusion

In this article, 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 idea of optical burst switching is discussed. Different OBS variations were described in addition to the just enough time protocol was investigated. OBS is a very promising switching technique, that will most likely to be adopted in the future. In investigation, the contention of the burst is done in this work, and it has been found that the storing of the contending burst is a good and viable option and it reduces the burst loss probability. Finally this paper, conclude that the buffering of burst along with the deflection routing provide a very robust solution.

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