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CONTENTION RESOLUTION IN OPTICAL BURST SWITCHES USING FIBER DELAY LINE BUFFERS

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Abstract

Optical burst switching (OBS) is a circuit switching paradigm that provides very high throughput with reasonable delay. In OBS, the data burst size is not uniform and can be of any length. As the size of the data burst cannot be estimated in advance, several burst assembly techniques have been proposed. In this work, an estimation of data burst is done in advance which enable us to store the data burst. In this process, buffering of the data burst reduces average latency as well as it helps to improve the burst loss probability (BLP). Finally, the investigation indicates that the deflection routing along-with buffering of contending bursts provide an effective solution by decreasing the loss probability nearly 100 times.

Keywords: Contention resolution, Markov chain model, Optical packet switch, Optical burst switch, Optical buffering.

1. Introduction

In recent years, we have witnessed tremendous increase in data transfer as a result of excessive bandwidth demand by the users, which in turn requires the evolution of high-speed data transmission technology. To fulfil these requirements, wavelength division multiplexing (WDM) technology is used, which provides more than one channel of gigabits capacity in a single fibre. In the current scenario, the network uses only a small fraction of the available bandwidth of the optical fiber. Thus, the ever growing demand for higher and higher bandwidth can be catered to by using fiber optic networks. Optical networks have two basic components: nodes and links (optical fiber), where switch is the main component of a node in optical network. Various switching techniques, such as optical circuit

Nomenclatures

$\hat{L}$	Burst size information in BCH
t_o	Burst release time information in BCH
T	Burst release time

Greek Symbols

λ	Arrival rate
γ_{inc}	Incomplete Gamma function

Abbreviations

BCH	Burst Control Header
BL	Burst Length Probability
BLP	Burst Loss Probability
FDL	Fiber Delay Line
O/E/O	Optical-to-Electronic-to-Optical
OBS	Optical Burst Switching
OCS	Optical Circuit Switching
OPS	Optical Packet Switch
SCDT	Separate Control Delayed Transmission
WDM	Wavelength Division Multiplexing

switching (OCS), optical packet switching (OPS), optical burst switching (OBS), etc. are present in the literature.

The OBS technology is a switching paradigm which combines the advantages of circuit switching (wavelength routing) and packet switching. In OCS, the entire path needs to be reserved by allocating a fixed (dedicated) wavelength channel on each link from the source to destination [1]. Hence, the utilization of bandwidth is very poor. Whereas, in OPS each packet is routed form the source to destination individually, thus improves the bandwidth utilization in comparison to OCS. However, an OPS system has various implementation issues like synchronisation, O/E/O conversion, lack of optical memory, non availability of high-speed optical logic gates, etc. In OBS, the data packets are aggregated before transmission on the edge node (ingress node), which is known as burst assembly. It can be achieved through various techniques, such as aggregation time based, burst length based, and hybrid assembly mechanisms [2]. Figure 1 shows the schematic diagram of OBS network.

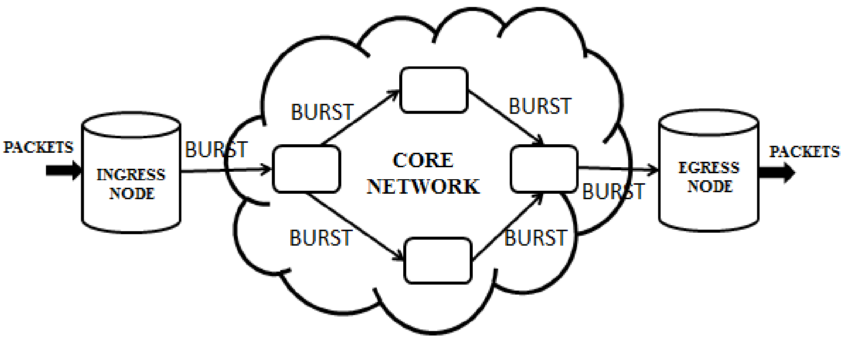

Fig. 1. Schematic diagram of OBS network.

After the burst assembly, the data burst and control packet is transmitted separately on different channels. This scheme of bandwidth reservation is known as separate control delayed transmission (SCDT), in which a control packet is first sent out on a control wavelength followed by the data burst after an offset time. The burst flow diagram is shown in Fig. 2. The offset time is required between the start of data burst transmission and corresponding control packet to compensate the delay caused due to the processing of control header and configuration of the switches at intermediate nodes from the source to destination. Thus, the offset time must be greater than the total processing delay of the control packet and much lesser than the round-trip propagation delay.

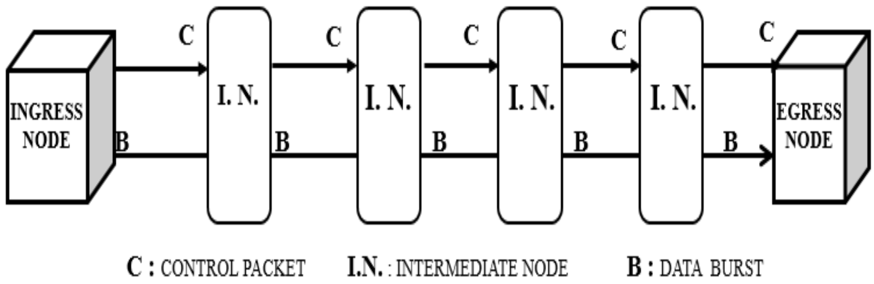

Fig. 2. Burst flow diagram.

If the offset time is sufficiently large, then the burst of data will be switched all-optically without being delayed at any intermediate node (‘cut-through’ manner). This SCDT scheme demands certain factors, based upon which OBS is functional, such as WDM technology, buffers, node architecture and technology, reservation protocol for resource allocation, etc. to be taken care of.

As in OBS technique, only the control packet goes through O/E/O conversion at the intermediate nodes, the overall latency, signalling overhead, and complexity is lesser than OPS and OCS [3 - 5]. The data burst is switched all-optically. Thus, the OBS is suitable for providing data transparency and it utilizes the capacity of the optical fiber more efficiently.

Though the OBS provides above advantages, it needs to overcome some of the challenges like optimal burst assembly mechanism, complexities in adaptive approaches, handling noise produced due to wavelength conversion, contention resolution due to long bursts, large delay due to deflection, etc.

Further, as only the control packet goes through O/E/O conversion at the intermediate nodes, it is vulnerable since it requires some processing time. If the intermediate node has invaders, they may copy the header and send it to the neighbouring nodes. Due to these malicious headers, the actual header is unable to reserve the resources. This threat is known as burst header flooding attack, where the fake burst control header (BCH) overflows the neighbouring node’s buffers. Moreover, one of the major problems in OBS is contention. As the data bursts contain huge amount of data, losses caused due to the contention affect the transmission of data severely and the network provider cannot afford it.

The rest of the paper is structured as follows: Section 2 reviews some of the previous works on OBS contention resolution schemes, identifying the problem which motivates us to carry out the work here. Section 3 shows the mathematical analysis for estimation of burst length and highlights the problems due to estimation. Section 4 discusses the analytical results and provides the solution to the problem of contention. Section 5 deals with the simulation scenario, which includes the comparisons of present scheme and proposed scheme. Finally, the conclusion has been drawn in Section 6.

2. Contention Resolution in OBS

In OBS, the data burst length is not fixed and thus increases the complexity. The contention occurs when more than one burst appear on a particular node for common output in a single time slot. Three different techniques to resolve the contention have been proposed in the literature, i.e., in wavelength domain, time domain, and space domain by using wavelength conversion technique, optical buffering, and deflection routing, respectively [6].

The contention in the wavelength domain can be resolved by converting the contending wavelengths to available free wavelengths and the following procedures might be adopted for the same: i) full range conversion, where any of the incoming wavelengths can be converted to any of the available wavelengths, ii) limited range conversion, where incoming wavelengths can be converted only to a few limited wavelengths out of all available wavelengths, and iii) sparse wavelength conversion, where it is possible only on few selected nodes of the network. The main drawback of this scheme is its cost which is very high.

In deflection routing, the contention is resolved by deflecting the contending bursts on alternate path [7]. This scheme does not require any extra hardware, decreases the burst loss probability, and increases the link utilization. However, the main drawback here is over congestion and recirculation of data bursts through the network. The deflected burst increases the congestion on new path and in case of higher traffic load, the data burst will keep deflecting from one path to another several times before reaching the destination. Further, the delivery of data bursts at the destination node might be out of order and thus proper sequencing of the received data bursts is required at the egress node.

In practice, optical buffers are not available and thus fiber delay lines (FDLs) are used as buffers for contention resolution [8]. Here, rather than storing the contending data bursts in the buffers, the contending bursts are delayed by fixed amount of time. This can be accomplished by reserving the wavelength first and then FDL reservation. Firstly, appropriate wavelength will be assigned by the scheduler. If the wavelength is unavailable, the data burst needs to wait for some minimum time. If this waiting time is less than the delay of FDL, then the burst will be sent to the FDL after checking the availability of the buffer space, else it will be dropped. Therefore, before sending the burst to the FDLs, we must know its length. The length of FDLs depends on the burst length, which is variable in case of OBS and thus the use of buffers is limited in case of OBS.

Burst segmentation is another technique to avoid the burst loss in similar scenarios. In this technique, when contention among two data bursts occurs, it divides the contending bursts in to segments and the segment which overlaps will be dropped from the system. The segmentation can be done in two different ways, i.e., segmenting the tail or segmenting the header. Controlling, retransmission, and synchronisation of data bursts are the main problems in this technique.

In this paper, an analysis has been carried out for proper estimation of the burst length. This enables us to fix the buffer size for the storage of contending data bursts. In this work, we have proposed a hybrid approach of contention resolution, which is the combination of buffering and deflection routing. In this approach, when the burst length is more than the FDL capacity, then the arriving burst will be deflected, otherwise it will be stored in the buffer at the contending node only.

Burst estimation will help in deciding the buffer size required for the storage of burst in case of contention. Also, due to burst estimation, we can send the BHP before full burst aggregation and by this the overall delay can be decreased as aggregation time is overlapped with the waiting time.

3. Burst Length Estimation

The traffic has been modelled as Poisson distribution, where the probability of arrival after time *t* can be calculated through its cumulative distribution function (cdf) as given below:

$$F(t) = P(T \leq t) = 1 - P(T > t) = 1 - P(X = 0) \tag{1}$$

Here, *X* is Poisson distribution with mean λ, which has parameter λt over the time interval $(0, t)$. Then the probability that *r* packets arrive to form the burst will be given by:

$$P(X = r) = \frac{e^{-\lambda t}(\lambda t)^r}{r!} \tag{2}$$

Thus, we have,

$$F(t) = 1 - \frac{(\lambda t)^0 e^{-\lambda t}}{0!} = 1 - e^{-\lambda t} \tag{3}$$

To find the probability density function (pdf) of *T*, we take the derivative of the cdf with respect to *t* and it is represented by [9, 10]:

$$f(t) = F'(t) = \lambda e^{-\lambda t} \tag{4}$$

We observe that if $X \approx Poisson(\lambda)$, the time until the first arrival is exponential with parameter λ .

3.1. Relation of Poisson and Gamma distribution:

If *X* is an event occurring in time is a Poisson process with parameter λ , then *X* has parameter λt 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*-) packets. We can compute the above as following:

$$F(t) = 1 - P(X \leq k-1) = 1 - \sum_{x=0}^{k-1} \frac{(\lambda t)^x e^{-\lambda t}}{x!} \tag{5}$$

Now, from the cdf given by Eq. (5), we can find the pdf of a continuous random variable *T*; which denotes the time required for *k* arrivals by calculating the derivative of Eq. (5) with respect to *t* and it will be represented by:

$$f(t) = F'(t) = e^{-\lambda t} \lambda \sum_{x=0}^{k-1} \frac{(\lambda t)^x}{x!} - e^{-\lambda t} \sum_{x=0}^{k-1} \frac{x(\lambda t)^{x-1} \lambda}{x!} \tag{6}$$

Therefore, we have,

$$f(t) = e^{-\lambda t} \lambda \frac{(\lambda t)^{k-1}}{(k-1)!} = \frac{t^{k-1} \lambda^k e^{-\lambda t}}{(k-1)!} \tag{7}$$

3.2. Burst–release time distribution:

If the arrival of bursts is Poisson distributed, then the assembly time *t* for an *L*-sized burst follows a Gamma distribution [11]. In order to find the pdf for such assembly, we have substituted $K = L$ in Eq. (7) and it is represented by:

$$\Gamma_t(L, \lambda) = \frac{\lambda^L t^{L-1} e^{-\lambda t}}{(L-1)!}, \ t \geq 0 \tag{8}$$

With mean $E[t] = \frac{L-1}{\lambda}$ and standard deviation $Std[t] = \sqrt{\frac{L-1}{\lambda^2}}$

As the BCH is released after the arrival of the first packet of data 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 arrive actually is given by:

$$P(t < t_0) = \int_0^{t_0} \frac{\lambda^L t^{L-1}}{(L-1)!} e^{-\lambda t} dt \tag{9}$$

$$P(t < t_0) = \frac{\gamma_{inc}(L, \lambda t_0)}{(L-1)!} \tag{10}$$

where, γ_{inc} refers to the incomplete gamma function.

In this scenario, where BCH is released after the arrival of first packet only, BCH can over-reserve the resources if the burst length provided by BCH is more than the actual buffer size. Moreover, 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 the burst is n, where $n < \hat{L}$. So, the BCH over-reserves the resources. Let $Y = \hat{L} - n$, where Y is a random variable which is representing the over-reservation at the intermediate node. The probability mass function of Y is given by:

P ($Y = p$) = P ($n = \hat{L} - p$ Poisson arrivals in $[0, t_0)$)

$$\mathrm{P}\left(Y = p\right) = \frac{\left(\lambda t_0\right)^{\hat{L}-p}}{\left(\hat{L}-p\right)!} e^{-\lambda t_0} \tag{11}$$

where, $0 \le n \le \hat{L} - 1$ and the random variable Y is Poisson (shifted) distributed. Now, the average over-reservation of the resources in terms of packets will be:

$$\mathrm{E}\left[Y\right] = \sum_{n=1}^{\hat{L}-1} \left(\hat{L}-n\right) \frac{\left(\lambda t_0\right)^{n-1}}{\left(n-1\right)!} e^{-\lambda t_0} \tag{12}$$

Case 2: Waiting time of burst

In this case, we have considered the scenario in which $\hat{L}^{\text{th}}$ packet, i.e., the last packet of the data burst arrives before the release time of the burst, i.e., last packet arrives at time $t < t_0$. Thus it forces to buffer the data burst for some time, let us assume Z. So, Z is a random variable that represents the waiting time in buffer, i.e., $Z = t_0 - t$. Then, it is evident that the pdf of Z is a shifted gamma distribution, which is given by:

$$f_Z(t) = \Gamma_{t_0 - t}(\hat{L}, \lambda)$$

$$f_Z\left(t\right) = \frac{\lambda^{\hat{L}} \left(t_o - t\right)^{\hat{L}-1}}{\left(\hat{L}-1\right)!} e^{-\lambda\left(t_o - t\right)}, \quad 0 \le t \le t_o \tag{13}$$

Therefore, the average waiting time can easily be obtained by:

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

$$= \int_0^{t_0} \left(t_o\right) \frac{\lambda^{\hat{L}} \left(t\right)^{\hat{L}-1}}{\left(\hat{L}-1\right)!} e^{-\lambda t} dt - \int_0^{t_0} \left(t\right) \frac{\lambda^{\hat{L}} \left(t\right)^{\hat{L}-1}}{\left(\hat{L}-1\right)!} e^{-\lambda t} dt$$

$$\mathrm{E}\left[t_o - t\right] = \frac{t_o}{\left(\hat{L}-1\right)!} \gamma_{\text{inc}}\left(\hat{L}, \lambda t_0\right) - \frac{1}{\lambda\left(\hat{L}-1\right)!} \gamma_{\text{inc}}\left(\hat{L}+1, \lambda t_0\right) \tag{14}$$

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

4. Analytical Results

In this section, the results have been generated by following the analysis done in Section 3 and the results are shown below under various conditions.

Figure 3 shows the burst release time distribution for different burst length L (3, 6, 9, 12, 15 and 18 packets). It is obvious from the result that as the burst length increases, the burst release time also increases for the same arrival rate (4 erlang). This happens as for the same arrival rate, the time in which greater number of packets will arrive is more; therefore, as the burst size increases, the time for forming the burst also increases. Therefore, as the burst size increases, for the same arrival rate the pdf becomes more and more flattened.

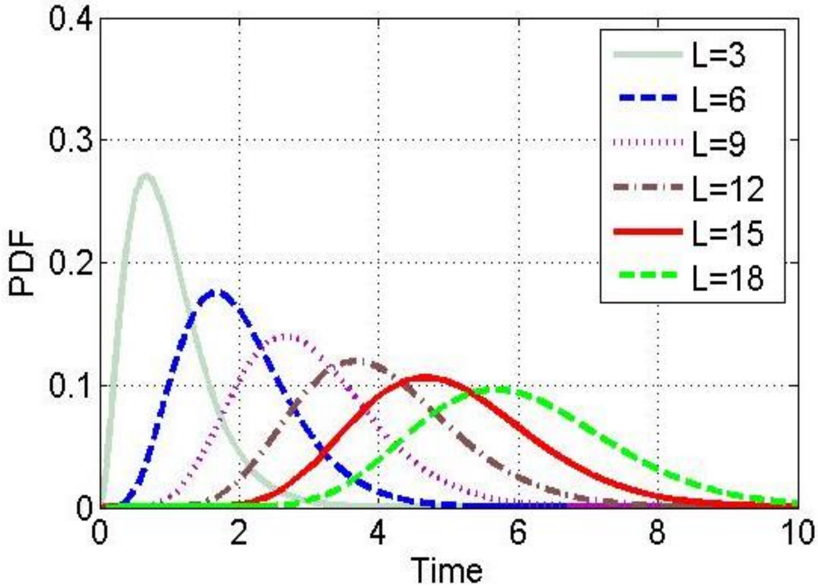

Fig. 3. Burst release time distribution for L = 3, 6, 9, 12, 15, and 18.

Figure 4 shows the probability of generation of bursts of different length, for different arrival rate and burst assembly time. For the burst length of L = 2 (keeping the packet arrival rate of 0.5 erlang), the probability of burst formation on or before 4 time unit is 0.6. The result indicates that with the increase in L, the probability of assembly decreases, e.g., at L = 4, the probability becomes 0.14. Finally, it converges to 0 for $L > 6$. Further, the result indicates that on keeping the packet arrival rate of 3 erlang, for smaller values of L, the probability of burst formation on or before 4 time unit is approximately 1. In this case too, as L increases, the probability decreases, e.g., at L = 8 the probability becomes 0.91, whereas, at L = 12 and L = 16, the probability is 0.4 and 0.15, respectively. Finally, it converges to 0 for $L > 18$. Similarly, while keeping the packet arrival rate to 6 erlang, the probability of burst formation on or before 12 time unit is approximately 1, whereas, at L = 16 and L = 20, the probability is 0.965 and 0.82, respectively. In this case also, as L increases, the probability decreases; however, the decrement becomes very small as λ is large. Here, the inter-arrival time between packets is small and hence probability of generation of data burst is large. Therefore, it is evident from the above discussion that the probability of burst formation on or before time t_0 decreases on increasing the burst length. This happens because when the rate of packet arrival is more, greater number of packets arrives within the same time period. Hence, burst formation with the larger length is more probable in comparison to lesser packet arrival rate.

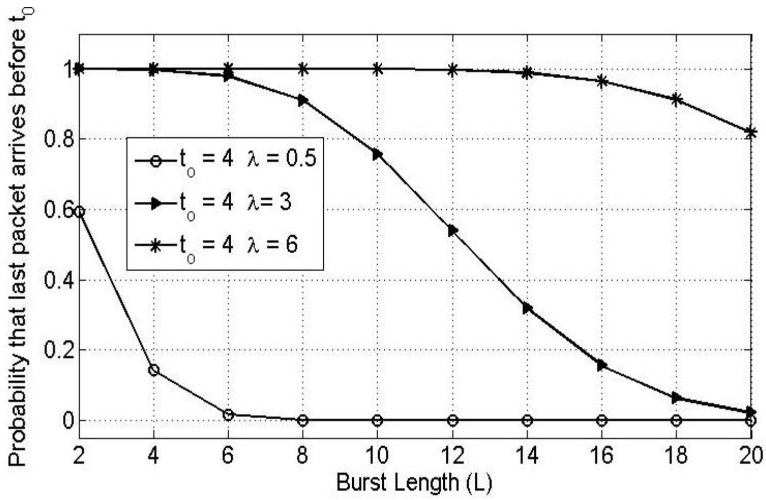

Fig. 4. Probability that $t < t_0$, with respect to burst length for $t_0 = 4$, in case of packet arrival rate of 0.5, 3, and 6 erlang.

Figure 5 shows that for L = 2 (keeping the packet arrival rate of 0.5 erlang and t_0 = 4 time unit), average over-reservation of the resources is approximately 0. As L increases, the average over-reservation of the resources increases linearly as evident from the result, e.g., at L = 4 it becomes 1, at L = 12 it becomes 9, and at L = 20 it becomes 17. Also, on keeping the packet arrival rate to 3 erlang, for smaller values of L, the average over-reservation of the resources is approximately 0.When L increases and becomes 10, the average over-reservation becomes 0.5 and at L = 14 it becomes 2. Similarly, for packet arrival rate of 6 erlang, the average over-reservation of the resources is approximately 0 till L = 14. In this case, when L increases, the average over-reservation of the resources increases but very slowly, e.g., at L = 16 it approximately becomes 0.05 and at L = 20 it becomes 0.35. Therefore, increase in L causes over-reservation; however, for higher values of packet arrival rate the increment is very small.

Figure 6 shows the average waiting time in the queue, before the release of data burst, with respect to the burst length. The result indicates that for L = 2 (keeping the packet arrival rate of 0.5 erlang and t_0 = 4 time unit), the average waiting time is approximately 1.1 time unit. As soon as L increases, the average waiting time decreases exponentially as at L = 4 it becomes 0.15 time unit. Further, it converges to zero for L > 6. The similar effect is observed on keeping the packet arrival rate of 3 erlang, where for L = 2, the average waiting time is approximately 3.5 time unit, for L = 12 it becomes 0.5 time unit, and it converges to zero when L = 18. Similarly, on keeping the packet arrival rate to 6 erlang, for L = 2, the average waiting time is approximately 3.5 time unit; whereas, as L increases, the average waiting time decreases but slowly in this case. For example, at L = 12 it becomes 2 time unit and at L = 20 it becomes 0.55 time unit. Therefore, increase in L causes decrement in average waiting time in the buffer and it is more for larger values of packet arrival rate for same L.

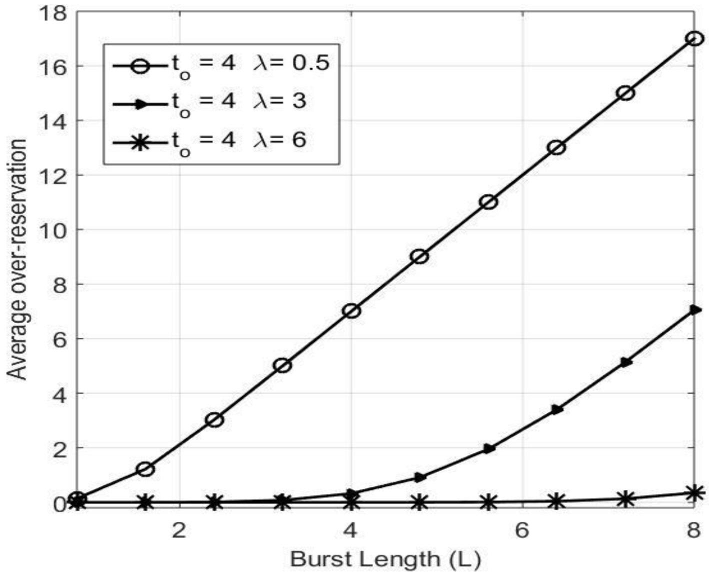

Fig. 5. Average over reservation of the resources with respect to burst length for $t_0 = 4$, in case of packet arrival rate of 0.5, 3, and 6 erlang.

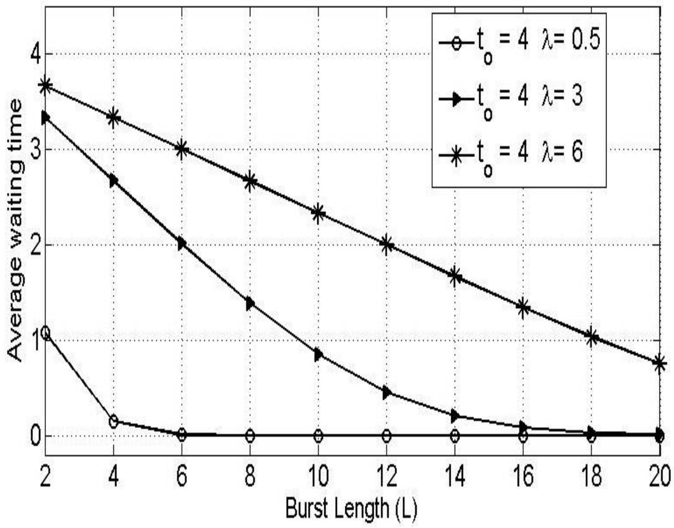

Fig. 6. Average waiting time in queue before release of burst with respect to burst length for $t_0 = 4$, for packet arrival rate of 0.5, 3, and 6 erlang.

Figure 7 indicates that for smaller values of λ (keeping the burst length constant, $L = 3$ packets), the probability of burst formation on or before 4 time unit is approximately 0. With the increase in λ, the probability increases very fast, e.g., the probability is 0.6 at $\lambda = 0.8$ and the probability reaches its maximum at $\lambda = 2$. Also, for the burst length of $L = 10$ packets, the probability of burst formation on or before 4 time unit for smaller values of λ is approximately 0. Like before, with the increase in λ, the probability increases, e.g., it becomes 0.11 at $\lambda = 1.6$

and 0.75 at λ = 3. In this case, the probability reaches its maximum at λ = 4.4. Similarly, on keeping the burst length to $L = 20$ packets, for smaller values of λ, the probability of burst formation on or before 4 time unit is approximately 0. In this case, the probability changes very slowly with the increase in λ, e.g., the probability is 0.1 at λ = 3.6 and it reaches to 0.52 at λ = 5. Therefore, it is evident from the result that as the packet arrival rate increases, the probability that L number of packets arrives on or before t_0 time increases, however, the rate of increment decrease as L increases.

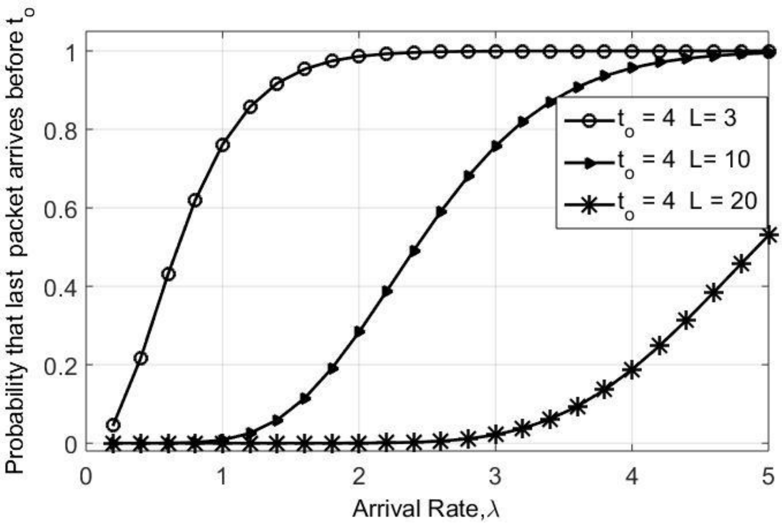

Fig. 7. Probability that $t < t_0$, with respect to the packet arrival rate for t_0 = 4 and L = 3, 10, and 20.

Figure 8 shows that for λ = 0.2 (keeping the length of burst $\hat{L}$ = 10 packets and t_0 = 4 time unit), the average over-reservation of the resources is approximately 8. With the increase in λ, the average over-reservation of the resources decreases. As at λ = 2.4, it is 1 and at λ = 3.4, it converges to zero. Similarly, the result shows that for λ = 0.2 (keeping the length of burst $\hat{L} = 20$ packets and t_0 = 4 time unit), the average over-reservation of the resources is approximately 18. When λ increases, the average over-reservation of the resources decreases, e.g., at λ = 2.8, it reaches to 8 and at λ = 5 it reaches to 1. However, in this case, the rate of decrement is smaller compared to the earlier case and also the initial value is very high compared to the case of smaller values of $\hat{L}$. Therefore, it can be concluded that increase in λ causes less over-reservation, which is beneficial, however, the rate of decrement decreases as the burst length increases.

Figure 9 shows the variation of average waiting time in the queue vs. λ. For λ = 0.2 (keeping the length of burst $\hat{L} = 3$ packets and t_0 = 4 time unit), the average waiting time is approximately 0 time unit. However, with the increase in λ, the average waiting time increases, e.g., at λ = 2 it becomes 2.5 time unit and at λ = 4 it becomes 3.25 time unit. Also, Fig. 9 shows that for λ = 0.2 (keeping the length of burst $\hat{L} = 10$ packets and t_0 = 4 time unit), the average waiting time is approximately 0 time unit, whereas, at λ = 3.2, it becomes 1 time unit and at λ = 5, it becomes 2 time unit. In this case, the increment is smaller than the earlier case. Similarly, the result indicates that for λ = 0.2 (keeping the length of burst $\hat{L} = 20$ packets and t_0 = 4 time unit), the average waiting time is 0 time unit. In this case, the average waiting time increases very slowly with the increase in λ, as till λ = 2.8, it is 0 time unit, at λ = 4.4, it becomes 0.14 time unit, and at λ = 5 it becomes 0.35 time unit. Therefore, the increase in λ causes increment in the average waiting time, however, the rate of increment decreases with the increase in the burst length.

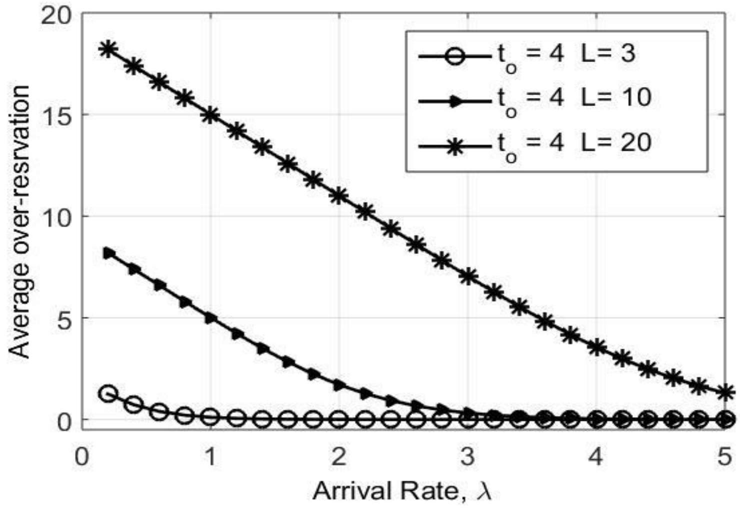

Fig. 8. Average over reservation of resources with respect to the packet arrival rate for t_0 = 4 and burst lengths of 3, 10, and 20.

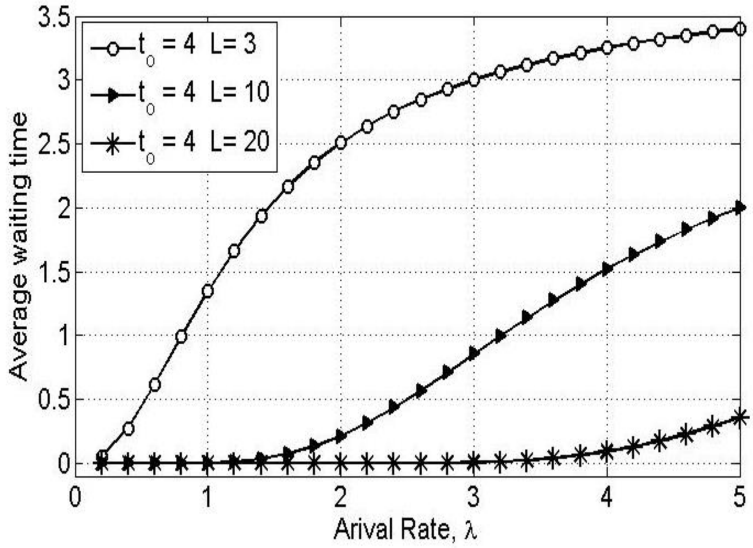

Fig. 9. Average waiting time in the queue before the release of data burst with respect to the packet arrival rate for t_0 = 4 and burst length of 3, 10, and 20.

Average waiting time is the average time required for the release of the data burst after its aggregation, as the last packet of the burst arrives before the release time of the burst. Therefore, if this is large then it will give an obvious delay to the network and degrades its performance. Over-reservation of the resources comes in the picture when the estimated length of the data burst is greater than the actual burst length. In this case, the early released BHP reserves more than required resources for the upcoming burst. So, over-reservation acts as the false unavailability of the resources which is actually available and can be utilized by others; hence over-reservation degrades the network performance.

5. Simulation Procedure and Results

The nature of the data traffic is bursty in real world. In this type of traffic, the arrival of data packets is correlated as it arrives in bursts. The characteristic parameters of the bursty data traffic are the offered load (ρ) and the burst length (*BL*) [11]. Each burst of packets is equally likely to be destined to any of the output with probability $1/N$, where, N is the number of all possible outputs. This also implies that if in the current time slot, a packet arrives on input i and destined to the output j, then there is a finite probability of arrival of packet for the same destination in the next time slot also. Thus, in the time domain, the traffic at each input is composed of burst of packets which has same destination.

The correlation (time) of the traffic on each input is characterized by the Markov chain model as shown in Fig. 10. This model assumes three stages, i.e., idle state, burst-I state, and burst-II state. If no packet arrives in the current time slot, then the system will remain in the first state named as idle state. Probability that no packet will arrive in the next time slot is P_a, then the burst will remain in the idle state. Thus, with the probability ($1-P_a$), a new burst will start and the system will go to the burst-I state. Now considering that with probability P_b, the new burst will arrive for the same destination. Therefore, the burst can be terminated in two ways [12]: i) probability that the next packet will start a new burst for some other destination is ($1-P_a$) ($1-P_b$), and ii) by going to the idle state with probability (P_a) ($1-P_b$). If the Markov chain distribution is in the steady state, then

$$\pi P = \pi \tag{15}$$

where, π is the row vector $\pi = \begin{bmatrix} \pi_1 & \pi_2 & \pi_3 \end{bmatrix}$ and P is the transition matrix, which is given by:

$$\begin{bmatrix} P_a & (1-P_a) & 0 \\ P_a(1-P_b) & P_b & (1-P_a)(1-P_b) \\ P_a(1-P_b) & (1-P_a)(1-P_b) & P_b \end{bmatrix} \tag{16}$$

with

$$\sum_{i=1}^{3} \pi_i = 1 \tag{17}$$

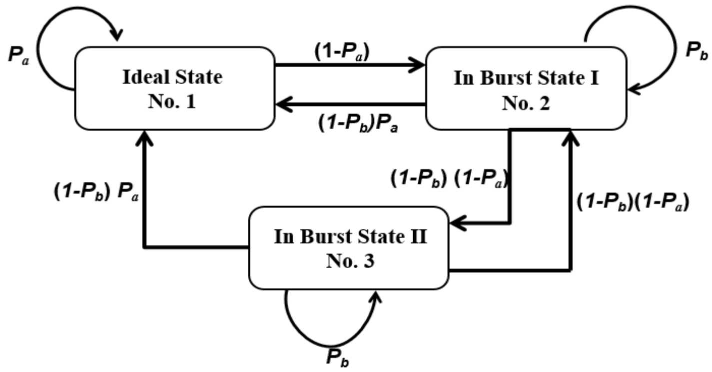

Fig. 10. Markov chain model for the bursty traffic.

By solving Eqs. (15) and (17), we get

$$\pi_1 = \frac{P_a(1-P_b)}{1-P_aP_b} \tag{18}$$

$$\pi_2 = \frac{(1-P_a)}{(1-P_aP_b)(2-P_a)} \tag{19}$$

$$\pi_3 = \frac{(1-P_a)^2}{(1-P_aP_b)(2-P_a)} \tag{20}$$

Now, we can say that the average link utilization will be:

$$\rho = 1-\pi_1 = \frac{(1-P_a)}{(1-P_aP_b)} \tag{21}$$

The probability that a particular burst has K packets is:

$$\Pr(K) = (1-P_b)(P_b)^{K-1} \qquad K \geq 1 \tag{22}$$

Now, the average length of the data burst will be given by:

$$BL = \sum_{K=1}^{\infty} K.\Pr(K) = \frac{1}{1-P_b} \tag{23}$$

Following the above mentioned Markov chain model, the simulation has been carried out for a switch with different dimension, along with different burst length and buffer sizes. The results shown below depict the effect of burst length and switch size on the loss probability and impact of buffer on the network performance.

Figure 11 shows the burst loss probability for varying switch sizes (of N = 4, 8, and 16), keeping the burst length = 4. In this case, when contention occurs, the bursts are deflected and they cannot be stored as the buffering has not been considered. We can observe from the result that the burst loss probability in this case is very high, e.g., for load 0.6 it is 0.2 and for load 1, the burst loss probability is 0.35 which is unacceptable in real life scenario. Further, as the switch size increases, the burst loss probability also increases. Therefore, some alternate contention resolution scheme is necessary, as the deflection routing alone is not enough to take care of the contention.

Figure 12 shows the loss probability in the system vs. traffic load, keeping the switch size and burst length constant at 8 and 4 respectively, while varying the buffer size (for B = 8, 16, 32, and 64). It is evident from Fig. 12 that as the system load increases, the loss probability also increases. At the moderate traffic load of 0.4, the loss probability is 10^{-4}, 3×10^{-3}, and 2×10^{-2} for B = 32, 16, and 8, respectively. On increasing the system load to 0.8, the loss probability becomes 1×10^{-3}, 10^{-2}, 4×10^{-2}, and 10^{-1} for B = 64, 32, 16, and 8, respectively. Finally, at the load 1, the loss probability reaches the value of 3×10^{-2}, 5×10^{-2}, 1×10^{-1}, and 2×10^{-1} for B = 64, 32, 16, and 8, respectively. These values show that at low loading condition, the increment in buffer size from 8 to 16 decreases the loss probability by 10 times. While at higher loading condition, this decrement is quite small, i.e., 2 times to be precise.

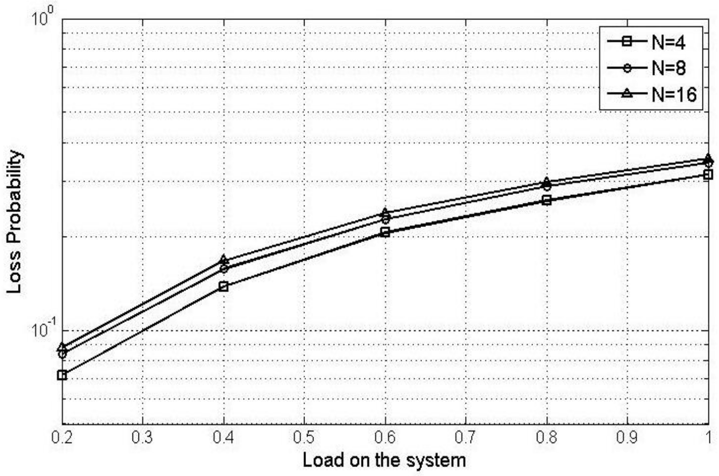

Fig. 11. The burst loss probability vs. traffic load with buffering of zero burst and burst length of four while varying the switch size.

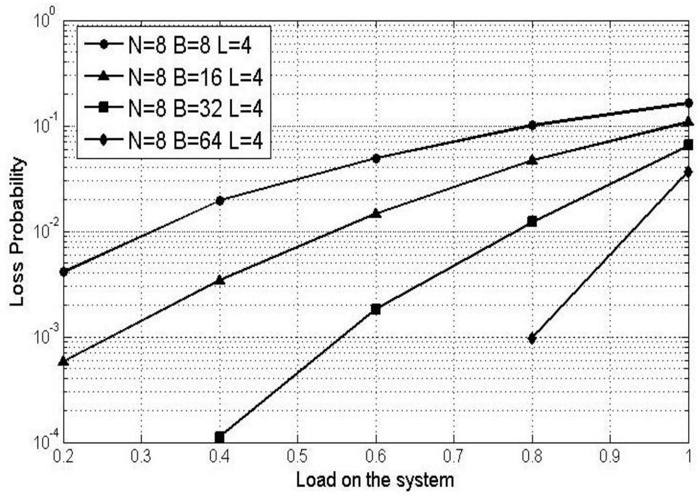

Fig. 12. Loss probability in the system vs. traffic load on the system, keeping switch size and burst length constant at 8 and 4 respectively; while varying the buffer size *B* = 8, 16, 32, and 64.

Figure 13 shows the burst loss probability in the system vs. traffic load, keeping the switch size and buffer size of 16 and 32 respectively, while varying the burst length (for L = 4, 8, and 16). The result indicates that the burst loss probability is low when the system load is less. As soon as the system load increases, the loss probability also increases. For example, at load = 0.4, the loss probability is 1.5×10^{-4}, 5×10^{-3}, and 2×10^{-2} for L = 4, 8, and 16, respectively. Finally, at traffic load of 1, the burst loss probability reaches the value of 6×10^{-2}, 10^{-1}, and 2×10^{-1}, respectively for L = 4, 8, and 16. The above result shows that the loss probability increases when burst length increases for constant buffer size. Furthermore, Figs.11 and 12 indicate that on increasing the switch size, the burst loss probability increases but slowly.

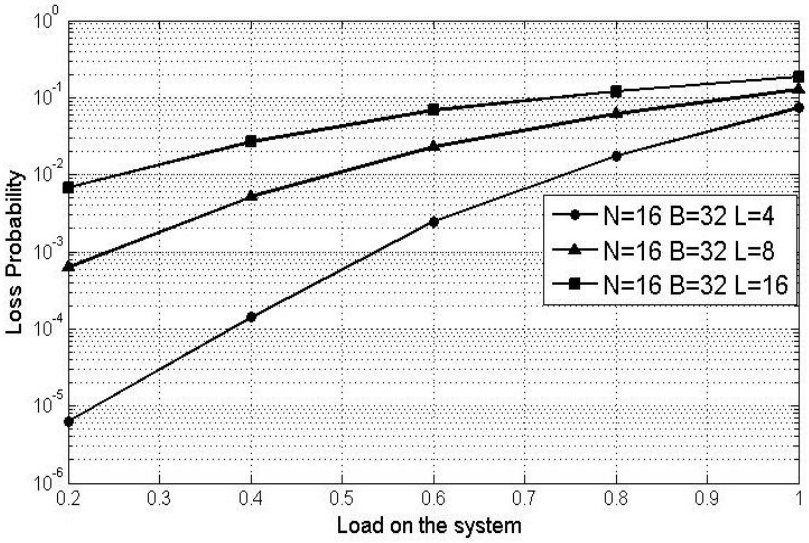

Fig. 13. Loss probability in the system vs. load, keeping switch size and buffer size 16 and 32 respectively, while varying the burst length L = 4, 8, and 16.

In case of the deflection routing along with buffering, if the length of the data burst is less than or equal to the average burst length at the time of the contention, then the contending burst will be stored in the buffer and hence do not hinder the network; as in case of deflection routing only, the contending burst is transferred to any other link and increase the load of that link. In our proposed technique, deflection routing is only applied when the data burst size is greater than the average burst size, whose probability is very less and hence does not affect others much. So, the overall burst loss probability of the network decreases. Also, on comparing Figs. 11 and 13, for traffic load of 0.6, the burst loss probability without buffer for burst length of 4 packet is 0.2, whereas, it decreases to 0.002 in case of buffering. Therefore, in this case, the buffering provides 100 times better performance in terms of the burst loss probability. On top of this, if the deflection routing is also incorporated, it will further improve the performance of the network and loss probability will be reduced. As the probability of getting a very large size bursts is very less, therefore, decrement in burst loss probability will remain around 100.

6. Conclusions

In this article, a novel switching paradigm called optical burst switching (OBS), as an efficient way to resolve the problem of congestion that the Internet is suffering from, has been discussed. The investigation encompasses the contention resolution of the data bursts and it has been found that by storing the contending bursts, we can achieve a fairy good and viable option of reducing the burst loss probability. From the simulation and analytical results shown in this paper, some of the important conclusions can be drawn as follows:

- When only deflection routing is used as the contention resolution scheme, the loss probability of the system is very high and thus requires some other technique to handle the issue.
- As buffering reduces the burst loss probability, it is a good alternative for contention resolution in OBS network.
- Burst loss probability increases on increasing the burst size, keeping the buffer size constant. Whereas, as the buffer size increases the burst loss probability decreases.
- Deflection of the data burst can be beneficial if the burst of larger size than the buffering capacity arrives.
- Therefore, in order to handle the contention of small and medium size bursts, buffering can be used as contention resolution scheme. Whereas, for the large size data bursts, deflection routing should be opted for.
- Hence, the combined mechanism of buffering and deflection routing of the data bursts provides more feasible solution in OBS networks.

Finally, this paper concludes that the buffering of data burst along with the deflection routing provides a very robust solution to the contention resolution problem, which is applicable for the future networks.

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