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Enhancing Optical Burst Switching Networks Throughput at Low & High Traffic Loads

Mahmoud H. Odeh[1], Mohammed Mahmoud[1], and Moustafa H. Aly[1,2]
[1]Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt
[2]OSA Member
engmhodeh@gmail.com, drmmaly@aast.edu, drmosaly@gmail.com

***Abstract* — This paper presents a new burst-scheduling algorithm for variable size burst in optical burst switching (OBS) networks, which will improve the quality of service (QoS). This is done for burst control to avoid burst overlapping in the egress router of OBS network. The impact of the burst size ,fiber delay lines (FDL), inter-arrival time, burst loss rate (BLR), and minimum time gap required between two successive bursts (d) on throughput are studied.**

***Index Terms*— Optical burst switching (OBS), Quality of service (QoS), Fiber delay lines (FDL), Throughput (Th), Burst loss rate (BLR).**

I. INTRODUCTION

Nowadays, there is an increasing demand of transmission bandwidth as a result of the data traffic growth. An interesting solution to consider is the Wavelength Division Multiplexed (WDM) that permits to simultaneously transmit data on multiple wavelengths on a single fiber with high throughput. But currently, its capability is not completely exploited in a whole network due to the slowness of the nodes to receive process and send the data to the next node information. For this reason, it is necessary to research in new optical network solutions. The principal aim is to obtain networks that work totally in optical domain: eliminating the optical-electrical-optical (OEO) conversion and working directly in the optical domain. There are three types of switching paradigms for WDM. Optical Circuit Switching (OCS) that consists of setting up circuit connections lightpaths between source and destination pairs [1]. While the Optical Packet Switching (OPS) [2] the data is assembled in optical packets and a header is created with control information.

The data and its header are sent together in the same channel through the network. In each intermediate node (router), the control information is extracted and processed in the electrical domain whereas the data is buffered and switched in optical domain. The best benefit is its efficient bandwidth utilization: the transmission resources (i.e. wavelength) are not dedicatedly reserved and they are shared by traffic from many sources. A two-way reservation is needed to set up lightpaths. The principal advantage is that optical buffer (OEO conversion) is not needed at intermediate nodes and the main constraint is the fixed and limited number of wavelengths (channels) per fiber and the impossibility to fraction them OBS [3, 4] represents a balance between circuit and packet switching. It consists of the aggregation of multiple data packets into a burst, Figure 1. Then, this burst is transmitted without the need of any type of buffering at intermediate nodes. Thus, the OEO conversion is not necessary. In OBS, the control information is carried on a dedicated channel separately from the user data channels. OBS is generally based on one-way reservation protocol.

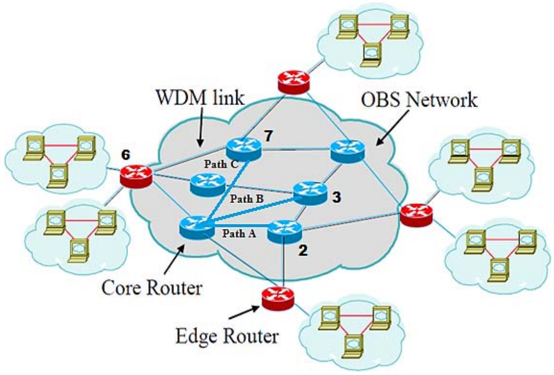

Figure 1. OBS router architecture [5]

A burst is a logical aggregation of Internet Protocol (IP) packets and it is transmitted entirely in the optical domain. IP packets destined to the same egress node are aggregated into a burst. A burst header packet (BH) or control packet (CP) for each data burst. The (CP) carries information of burst size and offset time of the corresponding burst is delivered leading the data burst by an offset time.

The burst traffic takes other statistical characteristics from those of the input packet traffic [4-6] due to assemble packets. The characteristics of the data traffic will be changed, i.e. from the packet size to burst size, and packet inter-arrival time to burst inter-arrival time. The assembly process from large independent packet traffic usually is Poisson traffic, and has an exponentially distributed inter-arrival time t_{in} with mean value μ. Also, the assembled burst traffic in the time based assembly algorithm has a fixed burst inter-arrival time and Gaussian- distributed burst lengths [4]. Actually, at low traffic loads, burst sizes B_{1i} (or B_{2j} or B_{3k}) $=B_{in}$ are relatively smaller or equal to the inter-arrival time t_{1i} (or t_{2j} or t_{3k}), Figure 2. But at higher traffic loads since after sending one burst from the assembly, t_{1i} (or t_{2j} or t_{3k}) $=t_{in}$ becomes smaller for the next burst to assemble when, B_{1i} (or B_{2j} or B_{3k}) $> t_{1i}$ (or t_{2j} or t_{3k}).

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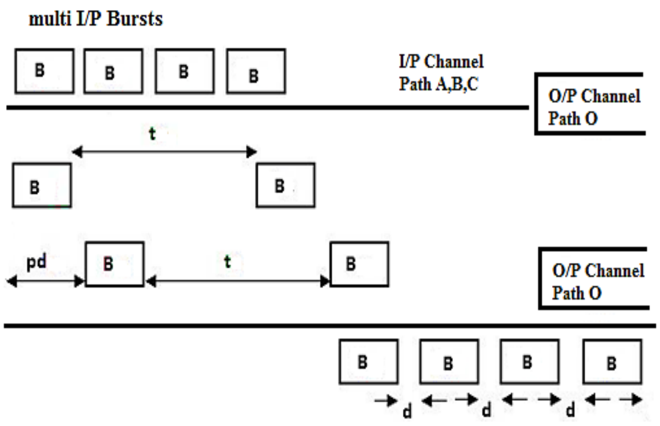

Figure 2. Multi input bursts of three channels (Path A, B and C) and channel one output channel (Path O of Figure 1).

In an OBS network, use (TAG) protocol having more than one OBS path passing a given link, burst overlaps may occur and in order to reduce the same, more delay is introduced in some bursts of the ingress node using limited fiber delay lines (FDLs). We used the offset-time to improve burst loss probability and hence the QoS performance [7]. The algorithms proposed in BORA [4], also, we show that without FDLs, if the total number of simultaneously arriving bursts exceeds the number of channels at the output port, burst loss is inevitable.

In this paper we first show the burst assembly process in both low and high traffic conditions and found out a relation of assembling times considering channel capacity, C, burst size in different channels, $B_{in,}$ in both low and large traffic conditions, this can reduce the lost packets. TAG is taken into consideration in the network analysis. It is shown that, with FDLs, the offset-time based system improves burst loss probability and hence the QoS performance. For an intermediate OBS node having many incoming links and one outgoing link with the condition of burst overlaps at lower traffic. We found a relation for the burst loss and the throughput depending on burst size Bin, inter-arrival time tin, and sizes of FDLs. It is shown that burst loss can be reduced using different sets of FDLs and with minimum usage of wavelengths. The improvements of throughput are shown for symmetric burst trends. There are priorities of channels because all the bursts or some bursts in one input channel can be passed to the output channel while controlling the others.

QoS is the service quality perceived by end users, so, it measures how good the offered network services are. The primary QoS metric of interest in an OBS network is the burst loss rate (BLR), which represents the congestion state of the network. Principally, in OBS networks, the burst is lost because of the failure on resource reservation, which means that there are a greater number of simultaneous reservation attempts than the number of available resources. Other possible causes of burst loss are the early arrival of data bursts with offset time and also due to simulation hazard. It is important to consider that, the dropped bursts have consumed and wasted network resources. So, it affects the network throughput. For this reason, it is necessary to search the manner to diminish the possibility of failure in reserving resources at intermediate OBS nodes. So our scope of work lies in optimizing the throughput of the total system and minimizing the loss as far as possible.

The rest of the paper is organized as follows: Section II presents the burst assembly and reservation process. In Section III, we assume the traffic load (ρ) in the lower and higher case. Analysis of systems with time delays are discussed in section IV. In Section V, we study the relation between throughput and loss rate. Output throughput without/with FDLs are explained in section VI and VII, respectively. In section VIII and IX, we discuss the different parameters affecting the throughput. Finally, we summarize our contributions and express the future work in section X.

II. BURST ASSEMBLY AND RESERVATION PROCESS

Burst assembly is the procedure of classification and aggregation of burst from various sources into optical bursts of variable length according to destination. There are assembly mechanisms [8]. There may be increased data loss and large delays both in low and heavy traffic loads. After a fixed time, all packets present in the buffer are assembled into a burst. The assembly algorithm is critical to the OBS network performance and its choice effect on the resulting OBS traffic statistic properties (burst length and inter-arrival time distribution). The optical burst is sent when a limit time $t=B/b_e$ is reached, B is the average burst length and $b_e=C/G$ is the mean input electrical bit rate. C is the output optical bit rate, known as the capacity of the fiber link and G is the rate gain factor, and the wavelength holding time $t_w=t/G$. The time-based assembly algorithm of low and heavy traffic loads [8] will be investigated having various burst reservation protocols [4, 7], in asynchronous transfer mode (ATM) in the existing protocols for OBS networks. In the distributed resource Reservation mechanism, resources can both be reserved using two-way resource reservation, labeled as tell-and-wait (TAW) and tell and-go (TAG).

In TAW, a CP is sent from the ingress node towards the egress node to reserve the bandwidth of one wavelength from source to destination. When the reservation is successful in the entire path, an acknowledgment message is sent back to the ingress node, which then starts transmitting the data burst. Otherwise, the node detecting resource shortage sends a negative acknowledgment message back to the source to release the reserved resources. The delay needed to data bursts by the resource reservation mechanism is a time elapsed between assembling a data burst and initiating its transmission at the ingress node after receiving the acknowledgment. It must be equal to or larger than the round trip time between the ingress and egress nodes. This is the major limitation of TAW, which may adversely affect the quality of real time delay sensitive traffic. The TAG shortens the delay imposed on data bursts by starting the burst transmission shortly after sending the CP to the core nodes along the routing path without waiting for an acknowledgment of a successful reservation. Any negative acknowledgment message will return to the source and retransmission after a back-off time.

III. TRAFFIC LOAD

Here we assume the traffic load (ρ) in the lower and higher the traffic load.

A) Low Traffic Load ($0 < \rho < 0.5$)

In the low traffic load, the new burst is starting to assemble after the previous burst is sent out, because the assembly queues will be empty after the first burst is sent out. In networks of packet transport, delays are due to queuing, propagation and processing. The processing time of a burst includes the time to schedule and transmit the burst. Therefore, the delay of the present burst will not be affected by the previous bursts because the traffic statistics only change within the assembly time period. Figure 3 shows the burst assembly queue length B versus assemble time T (time threshold) or delay in burst assembling. For equal data packet size of m units, the burst length B (packets/sec) having P_1 number of packets containing in the burst is equal mP_1 and the corresponding delay becomes T_1. Thus, in the low traffic load region, delay T increases with the increase of burst length B or its equivalent time.

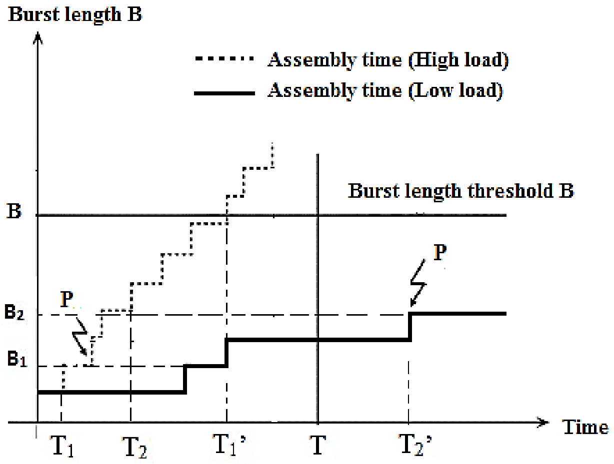

Figure 3. burst assembly process at high and low traffic loads [4].

For the relatively low traffic load $\rho_2 < \rho_1$, when they assemble time increases, burst lengths B also increases. Also; the higher values of assembling times as T_1' and T_2' for the same burst lengths B_1 and B_2, respectively, and the corresponding packet sizes of the traffic are P_1 and P_2 Thus, the delay T_L for burst assembling in the lower range of traffic load ρ can be assumed as

$$T_L = K_1 B (1-\rho)/C \qquad (1)$$

where k_1 is constant and B is burst sizes in k-bytes.

B) High Traffic Load ($0.5 < \rho < 1.0$)

In the heavy traffic load, the assembly queues will not be empty after the first burst is sent out, for which there is a delay of the packets, because the burst size becomes large and the burst interleaving time relatively less processing time. This leads to change the time to leave the following burst and the queuing process in the electronic buffer will further change the assembled burst traffic [4]. Thus, the delay T_H in assembling burst for higher traffic loads can be written as

$$T_H = 1/ (\mu/-\lambda) = 1/ \mu/\mu C- \rho) = K_2 B/C (K_3- \rho) S \qquad (2)$$

where 1/μ is the mean packet size in bits, C is the capacity in bps, λ is the mean flow in packets/sec. k_2 and k_3 are constants and the value of k_3 is near unity assuming the final form of T_H in Eq.2, S is the assignable lightpaths as servers.

IV. ANALYSIS OF SYSTEMS WITH TIME DELAYS

The use of TAG protocol in OBS network allows the use of many OBS paths passing the bursts in an egress node. We have introduced three input paths A, B, and C, coming from the core routers 2, 3, and 7, respectively. All bursts from all channels will pass in the output path O in OBS core router node number 6 connected by DWDM links, Figure 1. During the bursts out of the path, some burst may overlap depending on the burst sizes and inter-arrival time between the bursts.

Through Figure 2 we show the trend of bursts of three input channels of sizes B_{1i}, B_{2j} and B_{3k}, and inter-arrival time t_{1i}, t_{2j}, and t_{3k}, for the channel (CH-1), channel (CH-2), and channel (CH-3), respectively. pd_{12} and pd_{13} are the path differences between the first two bursts B_{11} and B_{21}, and B_{11} and B_{31}, respectively.

$$t_{1i} \geq B_{2j} + B_{3k} + 3d \qquad (3)$$

$$t_{2j} \geq B_{1i} + B_{3k} + 3d \qquad (4)$$

$$t_{3k} \geq B_{1i} + B_{2j} + 3d \qquad (5)$$

$$FDL_{12} = B_{11} + d - pd_{12} \qquad (6)$$

$$FDL_{13} = B_{11} + B_{21} + 2d - pd_{13} \qquad (7)$$

where d is the minimum time gap required between two successive bursts as a guard at the output path O, FDL_{12} and FDL_{13} are the required time delays of the fiber used for initial mismatch between $B_{11}$and B_{21}, and between B_{11} and B_{31}, respectively. FDL_S is a set of fiber delay lines or one fiber delay line known as the FDL_{max} having number of taps. For the requirement of no burst loss with the condition of Eqs.

(3-5), FDL_{max} is the maximum value of the delay lines put before the core routers for delaying the burst. Equations (6) and (7) show the relation between FDL and path difference, Pd, between the bursts, Pd_{12} and Pd_{13} are the path differences between the first two bursts B_{11} and B_{21}, and B_{11} and B_{31}, respectively. Through Eq. 6 the requirement of FDL_{12} will be lower if pd_{12} is set at higher values, so, if $Pd_{12} < B_{11} + d$, then we require FDL_{12}, and $FDL_{12}=0$ at $Pd_{12} = B_{11}+d$. Similarly, considering Eq.7, if $Pd_{13} < B_{11} + B_{21}+2d$, then we require FDL_{13}, and $FDL_{13} = 0$ at $Pd_{13}= B_{11} + B_{21}+2d$.

V. RELATION BETWEEN THROUGHPUT AND LOSS RATE

QoS is the service quality perceived by end users. It measures how good the offered network services are. The primary QoS metric of interest in an OBS network is the burst loss rate (BLR), which represents the congestion state of the network.

Formally, the burst loss rate is defined by

$$\mathrm{BLR} = \frac{\text{Number of lost bursts}}{\text{Number of total bursts}} \tag{8}$$

Principally, in OBS networks, the bursts are lost because of the failure on resource reservation, which means that there are a greater number of simultaneous reservation attempts than the number of available resources. Other possible causes of burst loss are the early arrival of data bursts by offset time. It is important to consider that, the dropped bursts have consumed and wasted network resources. So, it affects to network throughput. For this reason, it is necessary to search the manner to diminish the possibility of failure in reserving resources at intermediate OBS nodes .The relation between the BLR and the throughput, Th, is such that increasing values of Th corresponds to decreasing values of BLR, for the same traffic load [10].

In [9] calculated the relation between throughput, Th, and FDL_{max} for two values of the input burst number, at constant values of the burst size, inter-arrival time, path difference, and minimum time gap, to improve the throughput using FDLs. While In this paper, we found a relation between the throughput and FDL_{max} at three values of input, depending on different values of burst size and inter-arrival time, t. Different values of FDL_{max} describe the relation between throughputs, Th, burst sizes, B, inter arrival time, t, and burst loss rate, BLR. Through the results, we determined the best values for throughput, thus improve network performance and QoS.

VI. OUTPUT THROUGHPUT WITHOUT USING FDLS

The throughput, Th, can be expressed as [9]

$$\mathrm{Th} = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_c(p, n)}{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) + (3n - 1)(d + g_1)} \tag{9}$$

where n = the total number of bursts in each input channel (i,j,k), $g_1= (t_{1i} + t_{2j} + t_{3k}) - \{2\,(B_{1i} + B_{2j} + B_{3k}) + 9d\}$ and the condition $g_1 > 0$ is the additional time gap rather than required time gap occurs. Actually, $B_c(p,n) = 0$, when $g_1 \geq 0$ and no FDL_s are required in the egress node. Then, 3n is the number of bursts in the output channel and throughput becomes maximum when $g_1 = 0$ and it decreases with the increasing value of g_1. However, for $g_1 < 0$, $B_c(p,n)$ is finite and produces the trend of bursts which is blocked, p is the number of bursts passing in the output channel before one burst is blocked or controlled. Then, $B_c(p,n)$ can be expressed as

1. For p=3m; where m=1, 2, 3….

$$B_C(p, n) = \sum_{i=0}^{\infty}\begin{pmatrix} B_1\{[p/3] + 1 + i(p + 1)\} \\ +B_2\{[2p/3] + i(p + 1)\} \\ +B_3\{p + 1 + i(P + 1)\} \end{pmatrix} \tag{10}$$

2. For p=3m-1

$$B_C(p, n) = \sum_{i=0}^{\infty}(B_3\{[p/3] + 1 + i([p/3] + 1)\}) \tag{11}$$

3. For p=3m-2

$$B_C(p, n) = \sum_{i=0}^{\infty}\begin{pmatrix} B_1\{2[(p + 2)/3] + i(p + 1)\} \\ +B_2\{[(p + 2)/3] + i(p + 1)\} \\ +B_3\{p + 1 + i(P + 1)\} \end{pmatrix} \tag{12}$$

In Eqs. (10) and (12), the controlled bursts will occur in all the 3 input channels but in Eq. 11 the controlled bursts will occur in the third input channel only. It is seen from Eq. 9 that Th decreases for $g_1 <0$. However, Th can be increased by using a fiber delay line (FDL) in the egress nodes.

There are several proactive scheduling algorithms to reduce overlapping degree. In burst overlap reduction algorithm [11], it is required to reduce the total number of simultaneously arriving bursts at each port so that burst loss will be reduced. In an OBS network with the help of FDLs, the core network can delay bursts and the delay times can be controlled by switching the arrayed FDLs [9].

VII. OUTPUT THROUGHPUT USING FDLS

The throughput by using FDL can be expressed as

The expression of throughput, Th, for higher values of n and for p = 3n – 1, when burst loss/ controlled occurs in only third channel, can be written as

$$\mathrm{Th} = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_C(p)}{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_C(p) + \left\lfloor\frac{3n}{p+1}\right\rfloor \times G_3 + \left\{(3n-1) - 2\left\lfloor\frac{3n}{p+1}\right\rfloor\right\} d} \tag{13}$$

The Eqs. (14). For Th for higher values of n and for p = 3n / (3n-2), when burst loss/ controlled occurs in all the

$$\mathrm{Th} = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i}+B_{2j}+B_{3k}\right)-B_C(p)}{\sum_{i,j,k=1}^{n}\left(B_{1i}+B_{2j}+B_{3k}\right)-B_C(p)+\left\{\frac{1}{3}\left\lfloor\frac{3n}{p+1}\right\rfloor\right\}\times (G_1+G_2+G_3)+\left\{(3n-1)-2\left\lfloor\frac{3n}{p+1}\right\rfloor\right\}d} \tag{14}$$

$$G_1 = t + (Pd_{12} - Pd_{13}) - FDL_{max}$$
$$G_2 = Pd_{12} - FDL_{max} + B$$
$$G_3 = t + Pd_{12} - FDL_{max}$$

FDL_{max} is the maximum value of the delay lines put before the core routers for delaying the bursts [8].

VIII. THROUGHPUT ANALYSIS

This section discusses the different parameters affecting the throughput

A) Throughput and FDL_{max}

Figure 4 shows throughput, Th, versus FDL_{max} for three values of the burst size, B, (50, 70 and 100) µs, with the constant values of inter-arrival time t=130 µs, path difference pd_{12}=65 µs, pd_{13} =135µs and minimum time gap d=5 µs. It is clear that, the values of Th can be changed by B and FDL, Th increases with the size burst, B. At B=100 µs, Th is greater than at B=50, 70 µs.

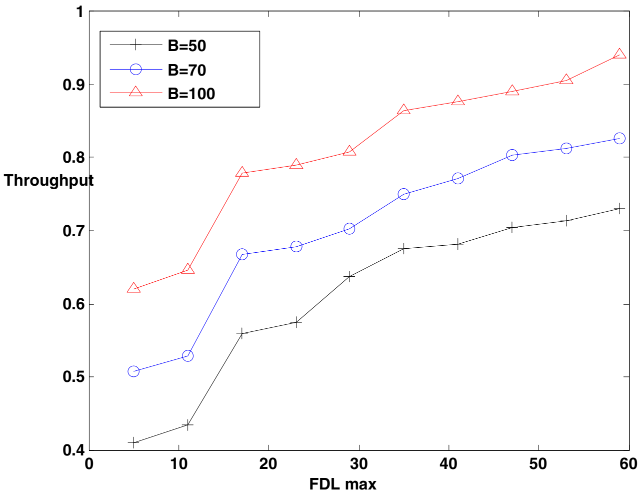

Figure 4. Throughput, Th, versus maximum values of fiber delay lines, FDL_{max}, for three values of burst size, B.

It is shown that the burst size, B, has a major impact on Th, at different values of FDL_{max}. The throughput increases FDL_{max}. The difference between higher and lower burst size B=50 µs and B=100 µs is 18% when using the average value of FDL_{max} =30 µs, thus the output throughput is increased.

B) Throughput and Burst Size

For an OBS network in burst transport system, the network throughput is proportional to the incoming traffic rate; the throughput can be improved by using appropriate burst values. [12].

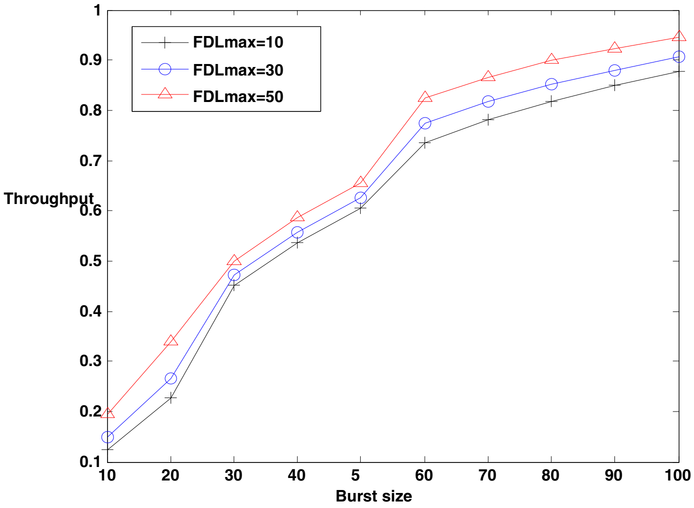

Figure 5. Throughput, Th, versus burst size, B, for three values of FDL_{max}

By introducing delay in the burst of the ingress node, the reduction of the burst overlaps improves the QoS performance. Using some constant values t=130 µs, pd_{12}=65 µs, pd_{13} =135µs and d=5 µs, Figure 5 show that, with limited fiber delay lines (FDLs). Throughput, Th, versus burst size, B, for three values of FDL_{max}, throughput increases with burst size. Actually, the increase of delay lines reduces the rate of burst loss. Thus, when the burst size increases, throughput also increases. At FDL=50 µs, the Th is greater than at FDL10, 30 µs, with increased burst size, B.

C) Throughput and Inter-Arrival Time

Through assembly algorithm, the burst size is related to inter-arrival time, larger burst size needs to increase inter-arrival time between burst. The analysis for output throughput depending on burst size, inter-arrival time, and sizes of fiber delay lines FDL is shown in Eqs. (3-5). So, throughput can be improved by increasing FDL. Figure 6 illustrates throughput, Th, versus inter-arrival time, t, with different values of FDL_{max}. As shown, Th increases with inter- arrival time, t, at B=80 µs pd_{12}= 65µs, pd_{13} =135µs and d=5 µs.

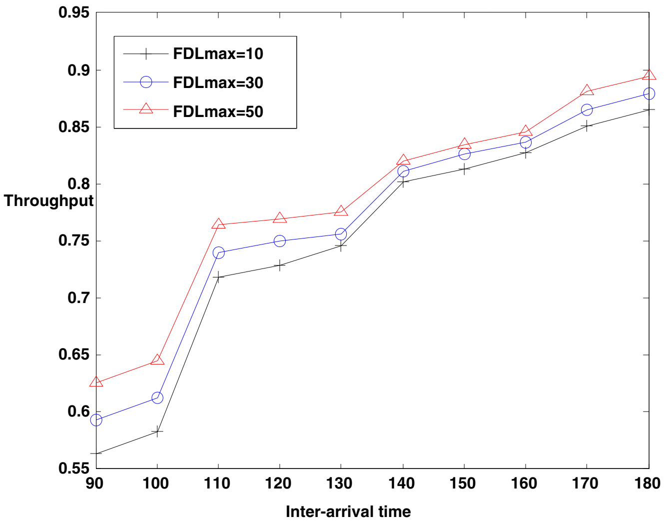

Figure 6. Throughput, Th, versus inter-arrival time, t, for three values of FDL_{max}.

It is noted that, the FDL has a large impact on Th, at different values of inter-arrival time, t. The difference between low and high output throughput is 7 % at t=100 µs. It is also shown that, the effect of FDL_{max} is decaying with the increase of inter- arrival time. We will need a minimum of FDL when the input inter-arrival time is large.

D) Throughput and Minimum Time Gap

In Figure 2, in output path O, d is the time gap between outputs bursts, the effect of change in the time gap by throughput is not relatively largely affected by different values of inter arrival- time, t, (90,130 and 150 µs) is used.

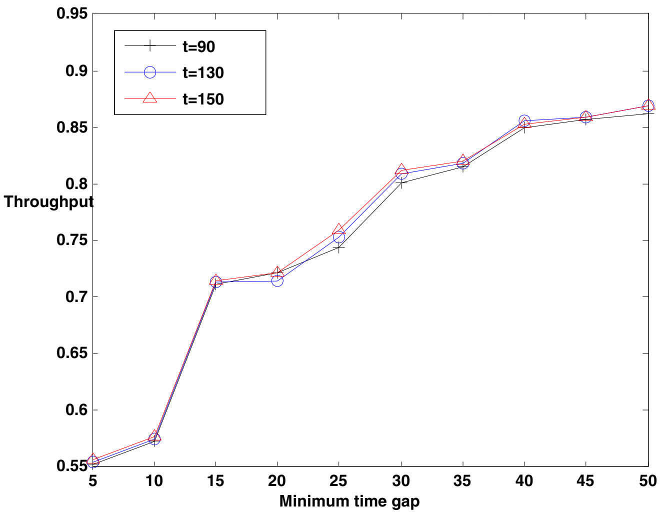

Figure 7. Throughput, Th, versus minimum time gap, d, for three values of inter-arrival time, t

This is described in Figure 7, where d is the minimum time gap required between two successive bursts as a guard at the output path, at B=80 µs, FDL_{max}=10 µs, pd_{12}= 65µs and pd_{13} =135µs. The minimum time gap is related to inter-arrival time.

IX. THROUGHPUT AND BURST LOSS RATE

Based on Eqs.(8,14), Figure 8 shows that, when BLR decreases, throughput, Th, increases, at constant input burst and different values of the burst size, B. We calculated BLR by the percentage of bursts that were lost from the total number of bursts at a specific burst size. Throughput, Th, is plotted versus burst loss rate, BLR, for different values of the burst size, B, (60, 80 and 100 µs).

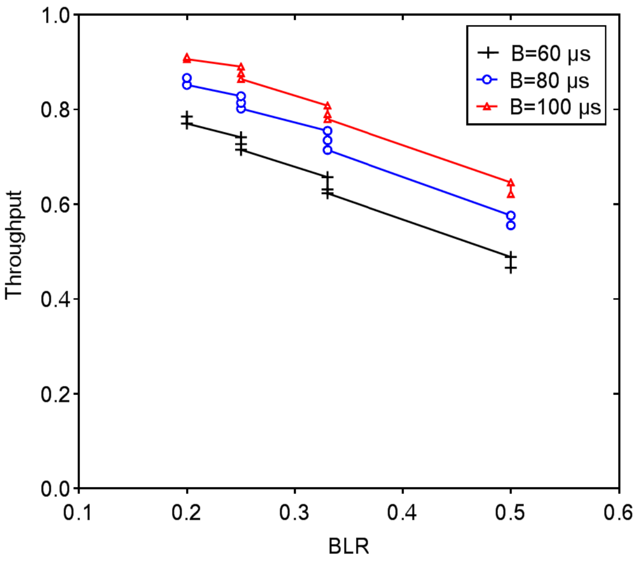

Figure 8. Throughput, Th, versus burst loss rate, BLR, for three values of burst size, B.

It is clear that, the effect of large burst size has more impact in the relation between BLR and Th. Throughput, Th, increases with the decrease of BLR. It is obvious that, the difference in Th between higher and lower burst size B=60 µs and B=100 µs, is 20% when BLR is 0.35.

X. CONCLUSION

In this paper, we have investigated the performance of an OBS network. The performance measure in terms of throughput is evaluated. The FDL_{max} has been used to avoid burst overlapping in the egress router of OBS network considering a TAG protocol at low and high traffic loads, in an intermediate node having three incoming links and one outgoing link in an egress node of optical domain. We found a relation for the throughput and FDL_{max} depending on burst size, inter arrival time, minimum time gap, d, and burst loss rate, BLR. The impact of the burst size and inter-arrival time on the throughput was studied. The difference between higher and lower burst size, B, µs, is mostly 18% when using the average value of FDL_{max}. The difference between low and high output throughput is 7 % at t=100 µs. Finally, the difference output, Th, between higher and lower burst size is 20% when the rate of loss BLR is 0.35. Results show that system performance improves with the increase of throughput using FDLs. Future work should extend the integrated analysis to OBS node architectures applying more than three routers such as five or seven core routers. Input from various sources are coming and are going through a channel, output is directed at specific lines depending upon their destination addresses. Our purpose here is to maximize the throughput of the channels, so; our future scope of work lies in optimizing the throughput of the total system and minimizing the losses as far as possible. Also, in order to get a broader view on performance, traffic models considering the burst assembly process could be included.

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