Throughput Analysis of Multi-input & single-output channels in Core Routers of Optical Burst Switching Networks

Jubin Hazra, Biswajit Das, Soumyanil Banerjee, Saptarshi Mallick,
and Alok K Das, Life Senior Member,IEEE
Institute of Engineering and Management, Kolkata-91, India, E-mail: alok_kumar_das@yahoo.com
Avranil Das,
ABA Systems, Kolkata-700 042, India, E-mail: avranildas@hotmail.com

Abstract **We describe here a new burst scheduling algorithm to avoid burst overlapping in the egress router of optical burst switching (OBS) network, and hence to improve the quality of service (QoS) in developing several optical networks to fulfill the increasing demand of Internet facilities. We consider TAG (tell-and-go) protocol where many lightpaths pass in a given link and burst overlap may occur. In an intermediate node having many incoming links and one outgoing link at lower traffic loads, we found the conditions for the burst controls, either passing of all bursts or blocking of some bursts in the egress nodes of optical domain. It is shown that in low traffic loads, burst blocking can be made zero but in higher traffic loads there is burst blocking, which can be reduced using different sets of fiber delay lines (FDLs) for which minimum usage of wavelengths can be achieved. The relation between number of burst blocking and the requirements of FDLs are shown. We used time-based assembly algorithm in an assembly node to build the burst at low and high traffic loads. The analysis for throughput depending on burst size, inter-arrival time, and sizes of fiber delay lines (FDLs), is made and improvement of throughput using FDLs is shown. Passing of bursts at the input channel and hence the priority of channels depending upon the burst size, intermediate gap between two successive bursts in the input channels, the arrival time for the first burst in the second & third input channels, and the FDL used in core nodes are shown.**

***Index Terms*—Optical burst transport (OBT), burst overlap and reduction, quality of service (QoS), fiber delay lines (FDLs), TAG (tell-and-go) protocol, Throughput(Th)**

1. Introduction

Advances in dense wavelength division multiplexing (DWDM) technology allow to study and to do intensive R&D activities in developing several optical networks to fulfill the increasing demand of traffic in Internet and communications. The technologies related to these, optical circuit switching (OCS), applicable to telephone networks, is relatively easy to implement but produces problem for fluctuating traffic and the dynamic links. The method optical packet switching (OPS) provides statistical multiplexing of bursty traffic of packets in which a buffer in electrical domain is required, but a buffer with logic in optical domain is too immature. On the other hand, optical burst switching (OBS) that combines the advantages of OCS and OPS is a promising switching technology to exploit the potential benefits of optical communication and has gained much attention in R&D activities [1]-[3]. Actually, OBS alleviates some of the optical problems of OPS and do less optical processing, also supports Internet protocol (IP) over WDM multiplexing (IP-over WDM) in future all optical telecommunications networks. An all optical network may have hundreds of wavelength channels with optical cross-connects (OXCs) in each egress node where IP edge routers with buffering capabilities are located at the perimeter of the network (Fig.1). Unlike OCS, it uses statistical multiplexing at burst level but no circuit setup delay. In the access networks, after assembling the packets in the electrical domain as burst of packets, OBS is not using permanent connections but sending the bursts with the burst header/label over lightpaths from senders to end users' optical networks. That label can be sent ahead of burst to allow enough time for the switching in routing. It can also be sent on a different control channel and processed electronically. The other one can be IP router or layer-2 switches are to be used to groom traffic in optical networks to connect optical links with high speed routers.

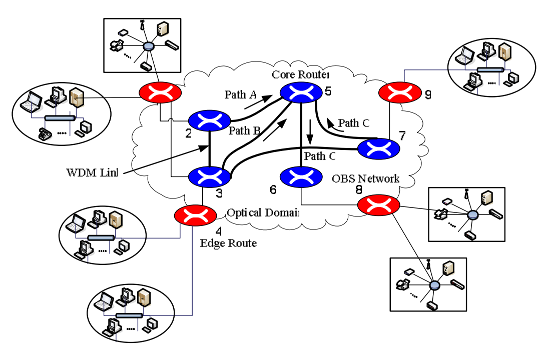

Fig. 1 OBS router architecture

An OBS network has many interconnected OBS nodes in which an ingress node assembles packets from local access networks (Fig.1), like Internet protocol (IP) packets, into bursts and send out a corresponding control packet (CP) or burst header

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(BH) for each data burst. The CP carries information of burst size and offset time about the corresponding burst and is delivered leading the data burst by an offset time.

Since multiple packets are assembled, the burst traffic will have other statistical characteristics from those of the input packet traffic [4]-[6]. The packets arriving at the assembly queue will have to wait in the electronic buffer and this buffering process changes the characteristics of the data traffic i.e. from packet size to burst size, and packet inter-arrival time to burst inter-arrival time. The packet traffic in a queue is an aggregated process from large independent packet traffic which is normally a Poisson traffic, and has an exponentially distributed inter-arrival time t_{in} with mean value μ. On the other hand, it is shown that the assembled burst traffic in 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} orB_{3k}) = B_{in} are relatively smaller or equal to inter-arrival time t_{1i} (or t_{2j} or t_{3k}) [Fig.3], but at higher traffic loads since after sending one burst from the assembly, t_{1i} (or t_{2j} or t_{3k}) = t_{in} becomes small for the next burst to assemble when B_{1i} (or B_{2j} or B_{3k}) > t_{1i} (or t_{3k} or t_{3k}).

For an OBS network other than ring with TAG (tell-and-go) protocol having more than one OBS path passing a given link, burst overlap may occur and in order to reduce the same, more delay is introduced in some bursts of the ingress node. Again, with limited fiber delay lines (FDLs), the offset-time based system can be used to improve burst loss probability and hence the QoS performance [7]. The algorithms proposed in BORA [4] shows that without FDLs, if the total number of simultaneously arriving bursts exceeds the number of channels at the output port burst loss is inevitable. However, we can reduce the overlapped bursts by delaying bursts using FDLs.

In this paper we first show the burst assembly process in both low and large traffic conditions and found out a relation of assemble times considering channel capacity C, burst size in different channels B_{in}. TAG is taken into consideration for the network analysis. It is shown that with fiber delay lines (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 condition of burst overlaps at lower traffic loads, we found a relation for the burst loss and the throughput depending on burst size B_{in}, inter-arrival time t_{in}, 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. Arrival of first burst of the input channel is taken variable in this study. Either all the bursts or some bursts in one input channel can be passed to the output channel while controlling the others, which shows the priority of channels. A mathematical model has been developed based on this which has been verified from the tables obtained from programming & also the corresponding graphs are shown.

2. *Burst Assembly Process and Traffic Load*

The long range dependency of the Internet traffic exists in traffic processes and there may be increased data loss and large delays both in low and heavy traffic loads, which degrades network performance and decreases network utilization. In access networks, the algorithm for data packet aggregation into burst will be timer based, and 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 mean input electrical bit rate. C is output optical bit rate, known as the capacity of the fiber link where G is rate gain factor, and the wavelength holding time $t_w = t / G$. We consider here time-based assembly algorithm of low and heavy traffic loads [8].

A. *Low traffic Load ($0 < \rho < \rho_L$)*

Actually, in the low traffic load, when one burst is sent out, the assembly queues are always empty and the next burst is started to create after the previous burst is sent out. In the network of packet transport, delays are due to queuing, propagation and transmission. A larger burst having multiple packets may have longer delays due to queuing at the node. In an assembly node, 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. Fig. 2(a) shows the burst assembly queue length B versus assemble time T or delay in burst assembling when the traffic load is ρ_1.For equal data packet size of ‘m’ units, the burst length B_1 (packets/sec) having P_n number of packets containing in the burst = mxP_n and the corresponding delay becomes T_1. For the larger burst length B_2 (packets/sec) having P_{n+k} number of packets containing in the burst = mxP_{n+k} and the corresponding delay will be T_2. Thus, in the lower traffic load region, delay T increases with the increase of burst length B or its equivalent time.

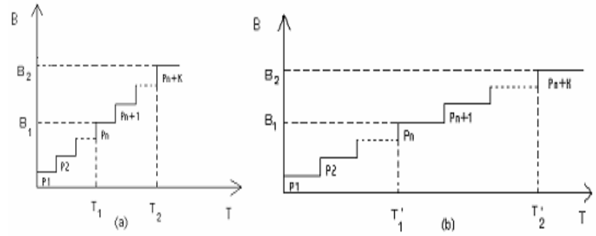

Fig.2 Burst assembly process (a) high, (b) low traffic loads

Again, for the relatively lower traffic load $\rho_2 < \rho_1$, assemble time or delay in burst assembling will automatically increase for the same burst lengths B_1 and B_2. Fig. 2(b) shows the higher values of assemble times as T_1' and T_2' for the same burst lengths B_1 and B_2, respectively, and the corresponding the packet sizes of the traffic are P_n and P_{n+k}. Thus, the delay T_L for burst assembling in the lower range of traffic load ρ may 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. Higher traffic Load ($\rho_H < \rho < 1.0$)

In the heavy traffic load, when one burst is sent out the assembly queues will not be empty for the next burst to assemble, for which there is delay of the packets . Here the burst size becomes large and its processing time is relatively large compared to the burst inter-leaving time. Thus the departure time of the following burst and the queuing process in the electronic buffer will further change the assembled burst traffic from Gaussian distributed to an almost constant rate process so long there are enough arriving packets in the buffer. Then the assembled traffic may become more like a constant rate and may be followed the similar queuing process of the standard queuing theory. Thus the delay T_H in assembling the burst for higher traffic loads can be written as

$$T_H \rightarrow 1/(\mu C-\lambda) \rightarrow 1/\mu C(1-\rho) = k_2 B/C(k_3-\rho)S \qquad (2)$$

where $1/\mu$ is the mean packet size in bits, C is the capacity in bps, λ is the mean flow in packets/sec. k_{2i} and k_3 are constants and the value of k_3 is near about unity assuming the final form of T_H in equation (2). S is the assignable lightpaths as servers.

3. Burst Reservation Process

Having various burst reservation protocols [4], [7], and in general there are two burst-level control mechanisms for asynchronous transfer mode (ATM) in the exiting protocols for OBS networks, namely tell-and-wait (TAW) and tell-and-go (TAG). In TAW, for one burst to transfer from an edge node, it first enquires to reserve the bandwidth of one wavelength from source to destination by sending a request. If all the links along the path becomes free to send the burst, the destination node will send acknowledgment ACK to the source to send out the burst immediately; otherwise, a negative acknowledgment (NAK) will be returned to the source and request for retransmission of the burst after a back-off-time and taking the previous bandwidth reservation. In TAG, the source transmits bursts without any bandwidth reservation in advance. An NAK is sent back to the source for any failure of reservation at intermediate node to initiate the retransmission after a back-off time. In comparison of two burst reservation protocols TAW is suitable over TAG when the propagation delay in the networks is negligible with respect to the burst length time. However, TAG performs better when the propagation delay is significant compared with the burst length.

4. Analysis of Throughput in Egress node with multi-inputs and one output channels

For an OBS network with TAG protocol, there may be more than one OBS path passing the bursts in an egress node. For simplicity we consider here three input paths A, B, and C, coming from the core routers 2, 3, and 7, respectively, and the bursts from all the channels will pass in the output path O in OBS core router node number 6 connected by DWDM links (Fig.1). In the optical domain there may be hundreds of DWDM channels in all the paths A, B, and C. In the output path all the input bursts coming from paths A, B, and C may pass or some bursts may overlap depending on the burst sizes, inter-arrival time between the bursts. Fig.3 shows 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. Now one can find out the condition of no burst loss at the one output channel O without FDLs as

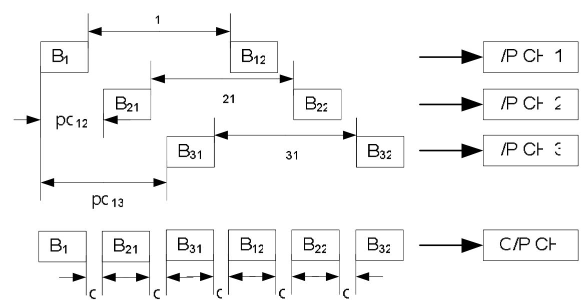

Fig.3. Input burst trends B_{1i} of channel 1, B_{2j} of channel 2, and B_{3k} of channel 3. Output channel (Path O of Fig.1) contains all the bursts of B_{1i}, B_{2j}, and B_{3k} or some of them.

$$t_{1i} \geq B_{2j} + B_{3k} + 3d \qquad (3)$$
$$t_{2j} \geq B_{1i} + B_{3k} + 3d \qquad (4)$$
$$t_{3k} \geq B_{1i} + B_{2j} + 3d \qquad (5)$$
$$FDL_{12} = B_{11} + d - pd_{12} \qquad (6)$$
$$FDL_{13} = B_{11} + B_{21} + 2d - pd_{13} \qquad (7)$$

where d is the minimum time gap required between two successive bursts as 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_{13}, respectively. FDLs is a set of fiber delay lines or one fiber delay line known as FDL_{max} having number of taps [8]. For the requirement of no burst loss with the condition of equations (3) - (5), the equation (6) shows that if $pd_{12} < B_{11} + d$, then we require FDL_{12}. Fig.4 shows the requirement of FDL_{12} versus pd_{12} for no burst blocking condition and it is clear that the requirement of FDL_{12} will be lower if pd_{12} is set at higher values, and $FDL_{12} = 0$ at $pd_{12} = B_{11} + d$. Similarly, considering (7), if $pd_{13} < B_{11} + B_{21} + 2d$, then we require FDL_{13}, and $FDL_{13} = 0$ at $pd_{13} = B_{11} + B_{21} + 2d$.

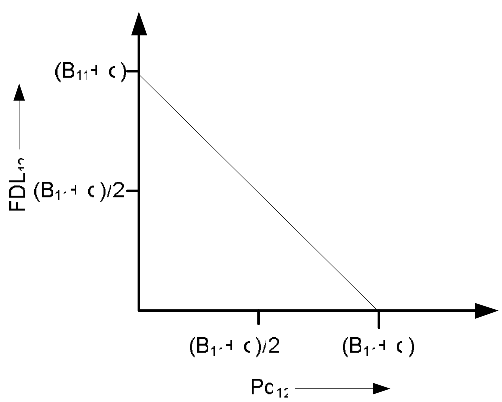

Fig. 4. Requirement of fiber delay line (FDL_{12}) vs. path difference (pd_{12}) between the bursts of CH1 & CH 2.

Throughput with or without requiring FDLs

The throughput (Th) can be expressed as

$$Th = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_c(p,n)}{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) + (3n-1)(d + g_1)} \qquad (6)$$

n = the total number of bursts in each input channel (i,j,k), $g_1 = (t_{1i} + t_{2j} + t_{3k}) - \{2(B_{1i} + B_{2j} + B_{3k}) + 9d\}$ can be obtained from equations (3) -(5) and the condition $g_1 > 0$ is the additional time gap other than required time gap occurs. Actually, $B_c(p,n) = 0$, when $g_1 \geq 0$ and no FDLs is 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 values of g_1. However, for $g_1 < 0$, the $B_c(p,n)$ is finite and for choosing higher values of p, FDLs will be required when (Th) will increase for which we need higher values of FDL_{max}. The number of bursts passing at the output channel before one burst is blocked, p, can be obtained from the input number of bursts. The number of burst blocking or burst loss decreases with the increase p or $FDL_{max.}$ For the symmetric trends having $B_{1i} = B_{2j} = B_{3k} = B = 80$ µm, and $t_{1i} = t_{2j} = t_{3k} = t = 70$ µm, and with the initial time delay between the bursts of two channels $pd_{12} = 75$ µm, Table 1 shows the variation of (Th) with p and the required FDL_{max} when 2n = 2000. p is the number of bursts passing at the output channel before one burst is blocked or controlled in the server of the electrical domain or in the router of the optical domain at egress node in order to avoid the loss of bursts. It can also be shown that the variation of (Th) becomes small even after increasing the number of input bursts n, when p and number of lost burst l will change accordingly. Then $B_c(p,n)$ can be expressed as

Case 1 (p=3k ; k=1,2,3….)

$$B_c(p,n) = \sum_{i=0}^{\infty}\begin{pmatrix} B_{1\{[p/3]+1+i(p+1)\}} \\ + B_{2\{[2p/3]+1+i(p+1)\}} \\ + B_{3\{p+1+i(p+1)\}} \end{pmatrix} \qquad (7)$$

Case 2 (p=3k-1; k=1,2,3….)

$$B_c(p,n) = \sum_{i=0}^{\infty}\left(B_{3\{[p/3]+1+i([p/3]+1)\}}\right) \qquad (8)$$

Case 3 (p=3k-1; k=1,2,3….)

$$B_c(p,n) = \sum_{i=0}^{\infty}\begin{pmatrix} B_{1\{2[(p+2)/3]+i(p+1)\}} + B_{2\{[(p+2)/3]+i(p+1)\}} \\ + B_{3\{p+1+i(p+1)\}} \end{pmatrix} \qquad (9)$$

It shows from (6) that (Th) decreases for $g_1 < 0$, however, (Th) can be increased by using fiber delay line (FDL) in the egress nodes. There are several proactive scheduling algorithms to reduce overlapping degree. In burst overlap reduction algorithm [4], it is required to reduce the total number of simultaneously arriving bursts at each port so that burst loss will be reduced. The larger the overlapping degree, it is expected that more an incoming burst will be dropped. 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 [7]. 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

$$Th = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_c(p)}{\sum_{i,j,k=1}^{n}\left(B_{1i} + B_{2j} + B_{3k}\right) - B_c(p) + \left[\frac{3n}{p+1}\right]\times G_3 + \left\{(3n-1) - 2\left[\frac{3n}{p+1}\right]\right\}d} \qquad (10)$$

$$Th = \frac{\sum_{i,j,k=1}^{n}\left(B_{1i}+B_{2j}+B_{3k}\right)-B_c(p)}{\sum_{i,j,k=1}^{n}\left(B_{1i}+B_{2j}+B_{3k}\right)-B_c(p)+\left\{\frac{1}{3}\left[\frac{3n}{p+1}\right]\right\}\times \left(G_1+G_2+G_3\right)+\left\{(3n-1)-2\left[\frac{3n}{p+1}\right]\right\}d} \quad (11)$$

The equation (11) for (Th) for higher values of n and for p = 3n/(3n-2), when burst loss/ controlled occurs in all the channels with

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

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

Table 1

Total no of bursts (2n)	No of pass bursts (p)	No of lost bursts (l)	(FDL max) [in µs]	Throughput (Th)
2000	1000	1000	5	0.551724
2000	1000	1000	10	0.571429
2000	1334	666	15	0.711372
2000	1334	666	20	0.727521
2000	1334	666	25	0.7442
2000	1500	500	30	0.8
2000	1500	500	35	0.813559
2000	1500	500	40	0.827586
2000	1600	400	45	0.85333
2000	1600	400	50	0.864865

Fig. 5 shows the simulated results of (Th) versus continuous values of $FDL_{max.}$ for two values of n, when a small variation of (Th) is observed for higher values of n.

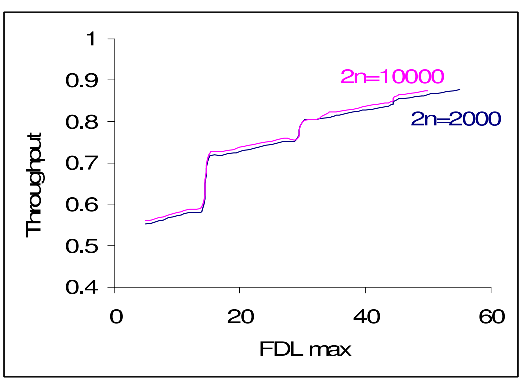

Fig 5. Throughput (Th) versus maximum values of fiber delay lines (FDL_{max}) for two values of input burst number.

5. Control of passing burst (p) and priority of input channel

For a multi-input and one output channel of a particular lightpath in a core router there will be need for the priority of input channels, which can be obtained by controlling the number of passing burst p. For a three inputs and one output node, p = 3 and p = 4 will execute uniform priority at the input channel. For p = 3, one burst will be blocked or controlled in the server of the electrical domain after passing 3 bursts from each input channel of the core router. For p = 4, one burst will be blocked or changed the lightpath at the core router after passing 4 bursts from each input channel. Again, p = 2 means the blocking of all the bursts in the third input channel and passing all the bursts from the first and second channels. Passing of all the bursts from the first and second channel, but after alternate passing of burst from the third channel occurs for p = 5.

Again p can be on line controlled by the parameters of burst size B, inter-arrival time t, and the fiber delay lines FDLs. Fig. 6 shows p versus FDL for two values of B with the constant values of t, pd_{12}, pd_{13}, and d =5 µs. Figure shows that the values of p can be changed by FDL and B. Fig. 7 shows p versus inter-arrival time t for different values of FDL with the constant values of B, pd_{12}, pd_{13} and d =5 µs. The solid lines represent the passing of bursts is repeated whereas the dotted lines are the non-repeated burst trends. Figure shows that the values of p can be changed by t, FDL, and B.

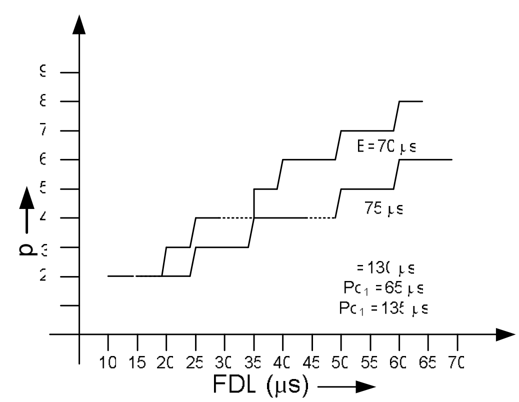

Fig 6. Passing of burst p in the input channels versus fiber delay lines (FDL) for two burst sizes B.

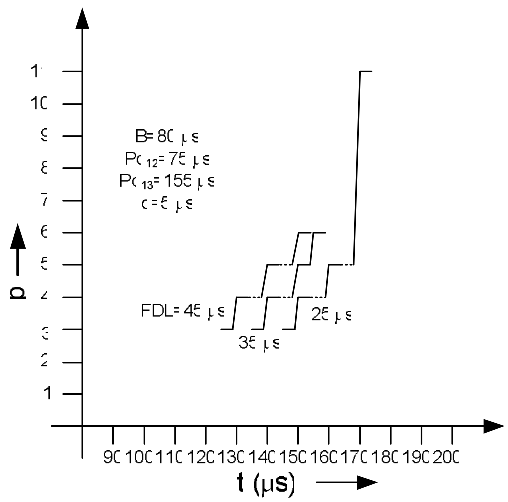

Fig7. Passing of burst p in the input channels versus inter-arrival time t for different values of fiber delay lines (FDL).

6. Conclusion

Here we have shown a burst scheduling algorithm to avoid burst overlapping in the egress router of optical burst switching (OBS) network considering a TAG (tell-and-go) protocol and at low traffic loads. In an intermediate node having three incoming links and one outgoing link in an egress node of optical domain, we found the conditions for the burst controls in an ingress node, either passing of all bursts or blocking of some bursts. We found a relation for the burst loss and the throughput depending on burst size B_{in}, inter-arrival time t_{in}, 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 analysis for throughput depending on burst size, inter-arrival time, and sizes of fiber delay lines (FDLs), is made and improvement of throughput using FDLs is shown. Control of passing of burst in the input channel and hence the priority of the channel depending on the parameters of burst size B, inter-arrival time t, and the fiber delay lines FDLs is shown.

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