Performance Analysis of Slotted Optical Packet Switching Scheme in Non-Uniform Traffic Pattern Using Reservation Bit Technique

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Abstract. Improvement in the performance of optical networks in terms of Quality of Service is achieved using an optical packet switching technique. Slotted optical packet switching mechanism employed in non-uniform traffic pattern is analyzed by using a novel Reservation Bit technique. Minimum packet loss is achieved by employing buffers in contrast to the use of buffer-less slotted optical packet switching in non-uniform traffic pattern. Performance of Reservation Bit algorithm is analyzed for different Service classes and is compared with First-Fit wavelength assignment algorithm. Also, delay rate for different traffic pattern is found and analyzed.

Keywords: Optical Packet Switching (OPS), Packet Loss Rate (PLR), Quality of Service (QoS), WDM (Wavelength Division Multiplexing), TDM (Time division Multiplexing), BER (Bit Error Rate).

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1 Introduction

Optical networks are high capacity telecommunication networks that use optical technologies. Since light has higher frequencies and shorter wavelengths, greater number of information bits can be transmitted in optical networks. Optical networks operate at a rate of terabits per second; hence they provide higher bandwidth [8]. Very high speed optical networks are required for establishing the next generation broadband data communication systems. It can transmit data in several gigabytes per second per fiber since it uses only one channel for each fiber to transfer data. Even though the bandwidth of fiber is high; such a type of optical system is inefficient in using the entire bandwidth. WDM, TDM or Hybrid TDM/WDM based optical networks are becoming the right choice for the next generation internet networks to transport high speed IP traffic [10]. QoS refers to control mechanisms that can provide different priority to different users or data flows or guarantee data flow in accordance with requests from the application programs. The important QoS parameters are packet loss rate, BER, bandwidth, delay, recovery time, jitter, reliability, response time, fault tolerance and etcetera.

This paper presents a novel and efficient algorithm to reduce the packet loss rate by employing reservation bit technique in the buffers incorporated in the switch and delay rate in different traffic patterns is found. It is seen that packet loss rate is reduced by introducing buffers in slotted OPS. The performance of the non uniform slotted OPS while using reservation bit algorithm is compared with that of the performance when first-fit wavelength assignment algorithm is used. Also, delay rate is found in different traffic patterns and is compared. The number and complexity of components included in the assigned buffer architecture must be kept to a minimum.

This paper has been organized as follows: Section 2 describes the architecture of slotted OPS. Section 3 introduces the reservation bit algorithm which is used in the buffer. In section 4, the packet loss characteristics are examined by using the algorithm presented in this paper and delay rate for various traffic patterns is also presented. In Section 5, results along with discussions are presented and Section 6 deals with the conclusion.

2 Description of the Architecture

Fig. 1 shows the architecture of the OPS network under consideration. A slotted optical packet switch is considered and Optical packet switching (OPS) as a future generation switching technique in optical communications is proposed. An optical packet is made up of a header and user data. In an optical packet switched network, when an optical packet arrives at a switch, the switch processes the optical packet in hybrid electro optical method: the optical packet header is processed electronically, while the packet payload remains in the optical domain.

The traffic is uniform if all arrival processes have the same arrival rate, and destinations are uniformly distributed over all output nodes. In non-uniform traffic pattern all nodes are not to receive and send similar volumes of traffic [1, 2]. Packet loss is the failure of one or more transmitted packets not reaching their destination [2]. Contention occurs when two or more packets are assigned to the same output port on the same wavelength at the same time [2, 4, 9].

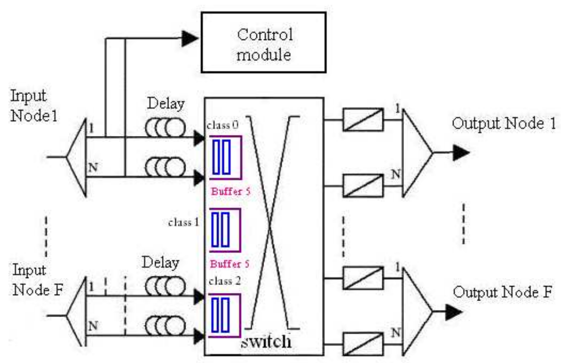

Figure 1: Architecture of the Optical Packet Switching Network

PLR is considered as one of the QoS parameters, which means that the service classes will be isolated based on different Packet Loss Rates.

The following assumptions have been made for the simulation:

- The switch has F number of input and F number of output fiber.
- In WDM mode, each fiber provides N wavelengths to transport data, each wavelength with a specified capacity c bps.
- N number of wavelength conversions takes place at each input node.
- C_i: Service Class (0 to $d-1$, where d is integer)
- P_i: PLR for class i traffic at output fiber, where $0 < i < d-1$.
- S_i: Relative share which is used to find the load in each class.
- ρ: Probability for packet arrival on an input wavelength, where $0 \leq \rho \leq 1$.
- A_k: Probability for k $(0 \leq k \leq FN)$ arrivals to the output fiber in a given time slots. The number of packets transmitted is k. A_k packets are distributed according to the Binomial process $P_p(k \mid n)$, where $n = FN$ is the number of input wavelengths and $p = \rho/FF$.
- There are two probabilities which are ρ and A_k, where ρ is the probability for packet arrival(s) at the input node and A_k is the probability for arrivals at the output fiber in a given time slot and it has been written as

$$\begin{aligned} A_k &= P_{\frac{\rho}{F}}(k \mid FN) \\ &= \binom{FN}{k} \left(\frac{\rho}{F}\right)^k \left(1 - \frac{\rho}{F}\right)^{FN-k} \end{aligned} \quad (1)$$

- The average number of packet arrivals in a time slot is $E[A_k] = FNp = \rho N$.
- If $k > N$, $k - N$ packets will be discarded. The average packet loss has been calculated using (2).

$$P_{av} = \frac{1}{\rho N} \sum_{k=N+1}^{FN} A_k (k - N) \quad (2)$$

- c_i is the number of packets in service Class i

$$\text{Total Number of Packets} = \sum_{i=0}^{d-1} c_i \quad (3)$$

- Relative share for uniform and non-uniform slotted OPS has been computed using

$$S_i = \frac{c_i}{\sum\limits_{i=0}^{d-1} c_i} \qquad (4)$$

3 Reservation Bit Algorithm

The reservation bit algorithm is written for slotted OPS wherein buffers are used to avoid overlapping of packets and the packet loss is reduced. This algorithm is designed and used to improve the QoS of the networks in terms of reduction in PLR.

The following assumptions are considered in this algorithm:

- Let j_i denote the number of class i packets that arrive in a time slot. The total number of packet arrivals to the fiber in a time slot is k. That is $j_0 + j_1 + \cdots + j_{d-1} = k$.
- In order to isolate the service classes, the parameter l_i $(0 \le l_i \le N)$ is introduced, which is the number of wavelengths reserved for Class i traffic in the case of contention in a time slot.
- For a service class i, if $j_i < l_i$ (the number of incoming packets are less than the wavelengths assigned), it will result $j_i - l_i$ free slots.
- For a service class i, if $j_i > l_i$ (the number of incoming packets are greater than the wavelengths assigned), it will result in $l_i - j_i$ overflow packets.

This algorithm is comprised of 10 steps as enumerated below.

Step 1: If the wavelengths assigned in the service classes of each time slot are greater than the number of packets arrived in that time,

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then
Go to Step 2.
else
Go to Step 3.
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Step 2: Find the value of free slots using the following formula:

$$\sum_{\text{ALl Service Class}} \text{If } (j_i < l_i) \text{ return } (j_i - l_i)$$

Go to Step 4.

Step 3: Find the value of packets that overflow using the following formula:

$$\sum_{\text{ALl Service Class}} \text{If } (j_i > l_i) \text{ return } (l_i - j_i)$$

Step 4: Packets that overflow may be assigned to free slots of other service classes. Free slots arise because of less utilization of wavelengths assigned to service classes.

Step 5: When overflow of packets is greater than the free slots, the free slots are occupied by overflowing packets and the remaining packets will be stored in the buffer with respect to their service classes.

Step 6: The packets in buffer are classified with respect to their service classes. The packets in the buffer have reservation bits.

Step 7: Whenever free slots arise in service classes, the packets in the buffers will be given the highest priority.

Step 8: If the number of free slots arising in one service class is equal to the number of packets in the buffer of the same service class, then the buffered packets will occupy the available free slots.

Step 9: If the number of free slots arising in one service class is less than the number of packets in the buffer of the same service class, then the buffered packets will occupy the available free slots on First Come First Serve basis.

Step 10: If the number of free slots arising in one service class is greater than the number of packets in the buffer for the same service class, buffered packets will take the highest priority, the remaining free slots will be occupied by the incoming packets.

Step 10.a: If the number of balance free slots is greater than the number of incoming packets, all the incoming packets will occupy the free slots.

Step 10.b: If the numbers of balance free slots is less than the number of incoming packets,

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then
Go to Step 4.
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Free slots will arise when the number of incoming packets is less than the wavelengths assigned. In a given situation where the incoming packets are more than the wavelengths assigned in that time slot, overflow of packets will occur. Overflowing packets will occupy free slots generated by the other nodes in the same service class [5, 9] Three buffers of the size of 5 are used in the OPS switch catering to all service classes. The mathematical expressions used to calculate PLR in Slotted OPS are in accordance with [2].

4 Operating Principle

The reservation bit algorithm is implemented by introducing buffers. When the traffic speed of the access link is slower than the backbone network, then the buffer contains 5 packets so as to have 80% link utilization [6].

If there is flow of packets into the nodes with a specified service class, the incoming packets with assigned wavelengths occupy the nodes as per the assigned service class. When the assigned wavelengths in one service class are occupied, it checks the free wavelengths of other service classes and the packets will occupy the free slots in the other service classes. When the assigned wavelengths are completely occupied in all the nodes, the packets overflow. By introducing buffers, the packets that overflow are saved. When the free slot is not available for the incoming packet, instead of dropping that packet, it will be saved by the buffer which is provided in the switch. Before entering the buffer, a bit is added to the packet header for the purpose of reservation with respect to their service class. Whenever free slots are available, the packets in the buffer occupy free slots. Buffered packets will have the highest priority over the incoming packets. The buffered packets with respect to their class will occupy the free slots of corresponding service class wavelengths on First Come First Serve basis.

Poisson arrival process is used in asynchronous optical packet switching. Packet arrival rate in slotted OPS for more than one class is found using multinomial distribution [3]. PLR is calculated using (5) and the multinomial distribution is computed using (6).

$$Pi = \frac{1}{\rho N S_i}\left[\sum_{j_0=0}^{K}\sum_{j_1=0}^{K=j_0}\cdots\sum_{j_{d-2}=0}^{K-\sum_{v=1}^{d-3}}\left[M \times \left(j_0,\ldots,j_{d-2},k-\sum_{v=0}^{d-2}j_v;S_0,S_1,\ldots,S_{d-1}\right) \times xL_{\text{lost}}\right]\right] \tag{5}$$

$$M\left(j_0,\ldots,j_{d-2},k-\sum_{v=0}^{d-2}j_v;S_0,S_1,\ldots,S_{d-1}\right) = \left(j_0,j_1,\ldots,j_{d-2},k-\sum\nolimits_{v=0}^{d-2}j_v\right)S_0^{j_0}S_1^{j_1}\cdots S_{d-1}^{j_{d-1}} \tag{6}$$

Non-uniform traffic pattern of slotted OPS is tested for service classes 3, 4 and 5. The following parameter values are considered in this paper. The number of input and/or output nodes is 4; total number of wavelengths assigned is 16. For service class 3, wavelengths assigned for the 0-th class is 4, wavelengths assigned for class1 is 5, wavelengths assigned for class2 is 7. For Service class 4, wavelengths assigned for the 0-th class is 4, wavelengths assigned for class1 is 4, wavelengths assigned for class2 is 5, wavelengths assigned for class3 is 3. For Service class 5, wavelengths assigned for the 0-th class is 3, wavelengths assigned for class1 is 3, wavelengths assigned for class2 is 5, wavelengths assigned for class3 is 3 and wavelengths assigned for class4 is 2.In uniform traffic pattern, packet arrival probability is 0.6. In non-uniform traffic pattern, packet arrival probability ρ has been calculated using (3).

$$\rho = \frac{\text{Number of packet arrival}}{FN} \tag{7}$$

The number of packets transmitted by using this architecture is given by,

$$\text{Number of transmitted packets} = FN(\text{Number of Slots}) \tag{8}$$

Number of time slots assumed in this paper is 10. The architecture used in this paper can transmit up to 640 packets. It may be noted that the total wavelengths used in this paper is 16.

In this paper, the service classes are considered with a buffer size of five. This is due to the following reasons:

- When we reduce the buffer size to less than five, PLR value will increase.
- Practically PLR may exist when the optical signal is transmitted over fiber. When the size of the buffer is increased to more than five, there may not be PLR as far as simulation is considered. Practically PLR may exist.

In the First-Fit wavelength assignment algorithm, all wavelengths are numbered in a certain order, for an example ascending order from 0 to W-1, where W is a number of wavelengths. When the deciding node attempts to assigned a wavelength, it sequentially searches all wavelengths in an ascending order and assigns the first available wavelength [12]. First-Fit wavelength assignment algorithm is port based and packets are transmitted according to their wavelengths, Whereas transmission of packets is class based in reservation bit algorithm and packets are transmitted according to their service classes and wavelengths. Thus the drop rates of packets are reduced resulting in improved QoS. Analysis of delay rate in slotted OPS using three types of traffic patterns viz. Non-uniform, Poisson [11] and ON-OFF traffic models [7] are presented in this paper. Summation of the waiting time in the buffer and the transmission time between source node and destination node through the switch is considered as delay and the same is found for the above said traffic patterns. The mean delay for the above said traffic pattern is found using (4).

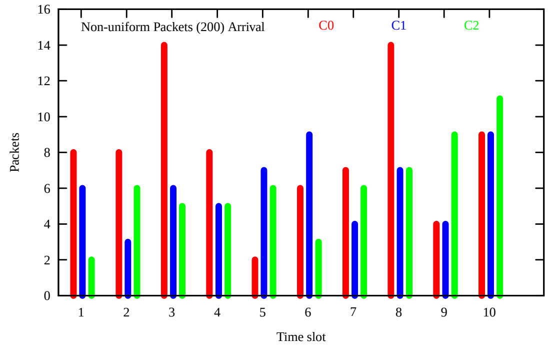
$$T = \sum_i \frac{\lambda_i}{\gamma} T_i \tag{9}$$

where T is the average network delay, λ_i is the average traffic on channel i, γ is the network throughput, and T_i is the average delay in passing through node i.

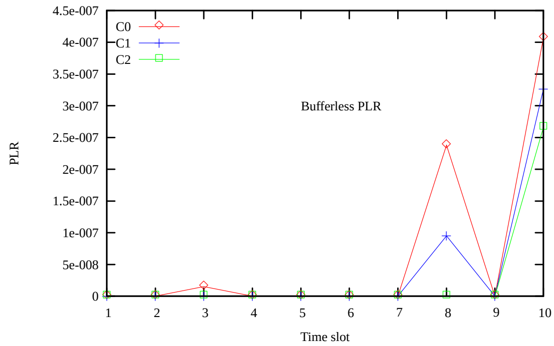
It is found that the delay in the buffer is less in non-uniform traffic pattern when compared to the rest. Moreover ON-OFF traffic pattern and non-uniform traffic pattern may produce the same delay. In ON-OFF traffic pattern, there is continuous flow of packets during on period and there is no flow of packets during off period. When one node is in on period, other nodes may be in off period in ON-OFF traffic pattern. So there may be continuous flow of packets in all time slots and at the same time there is the possibility of all nodes being in off period. When all nodes are in off period, there is no flow of packets and assigned wavelengths will not be used during that time slot(s). In Poisson traffic model, packet arrival is random and all nodes can transmit the packets during the same time slot(s). There is a possibility of certain flow of data during some time slots and occurrence of less number of packets during some slots. Moreover intervals between packet arrivals cannot be predicted. Even though packet arrival is random in non-uniform traffic pattern, the utilization of free wavelengths is high and delay rate is less and also PLR is less.

Table 1: Packet arrival rate for 200 packets

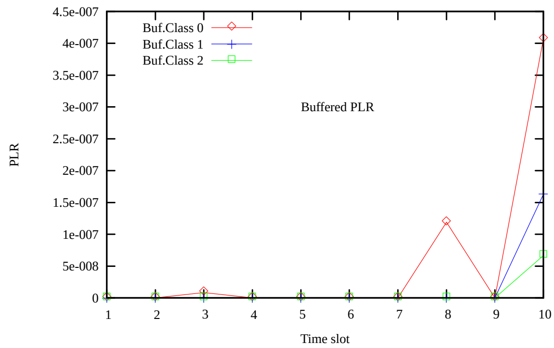
Time slots slots	Class 0 packets	Class 1 packets	Class 2 packets	Total packets
1	8	6	2	16
2	8	3	6	17
3	14	6	5	25
4	8	5	5	18
5	2	7	6	15
6	6	9	3	18
7	7	4	6	17
8	14	7	7	28
9	4	4	9	17
10	9	9	11	29
Total	80	61	59	200



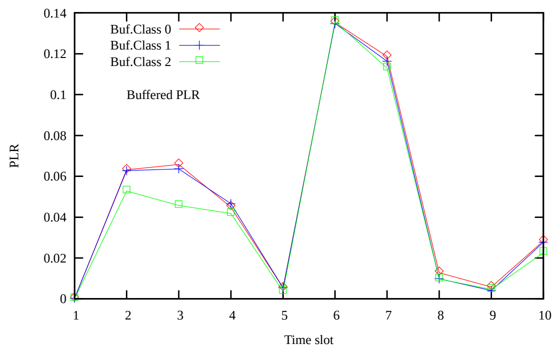
(a) OPS PLR arrival rate in non-uniform traffic pattern of 200 packets for service class3.



(b) PLR with time for buffereless OPS in non-uniform traffic pattern of 200 packets for service class 3.



(c) PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 200 packets for service class 3.



(d) PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 600 packets for service class 3.

Figure 2:

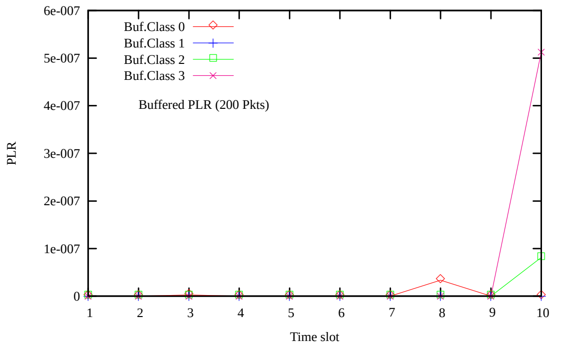


Figure 3: PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 200 packets for service class 4.

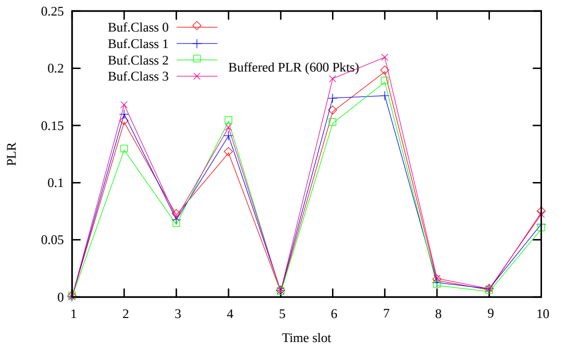


Figure 4: PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 600 packets for service class 4.

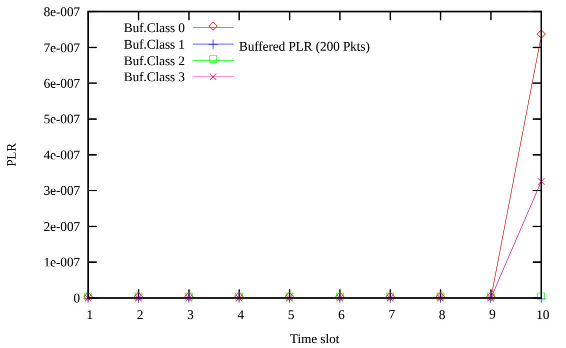


Figure 5: PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 200 packets for service class 5.

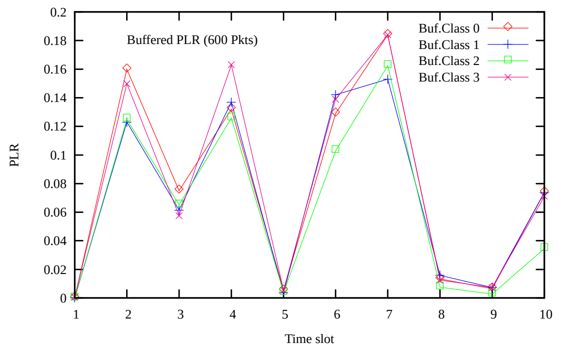


Figure 6: PLR graph for buffered Slotted OPS in non-uniform traffic pattern of 600 packets for service class5.

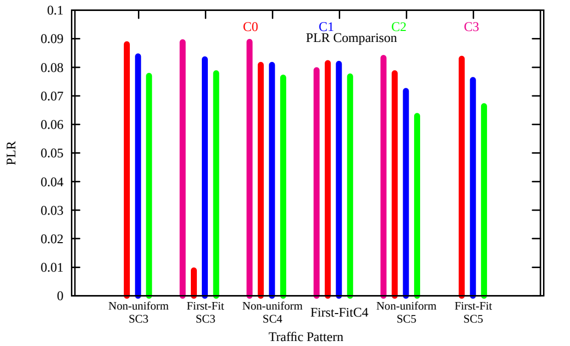


Figure 7: Comparison of PLR for buffered Slotted OPS in non-uniform traffic pattern using reservation bit technique and first-fit wavelength assignment algorithm for 600 packets.

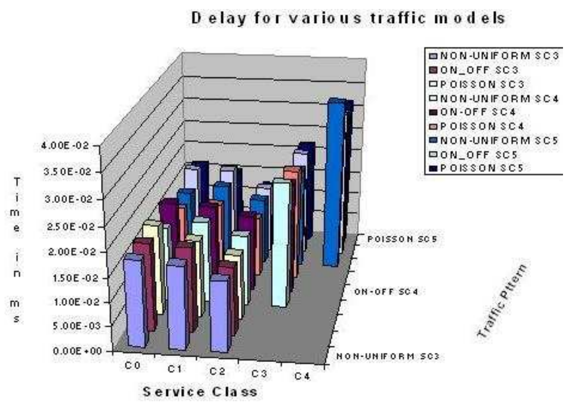


Figure 8: Comparison of Delay for Non-uniform, Poisson and ON-OFF traffic patterns for 200 packets.

5 Results and Discussions

The algorithm is tested for slotted OPS in the non-uniform traffic pattern for different data packets and different service classes.

Fig. 2(a) shows a bar chart for packet arrival with respect to ten time-slots for 3 service classes in non-uniform traffic pattern. The total number of packets arrived in all the time-slots and in all service classes is 200 and the same is shown in Fig. 2(a) and also in the Table 1. In Class 0, the packet arrival rate is very less in time-slots 5 and 9, less in time-slots 1, 2 ,4, 6 and 10, high in time slots 3 and 8. In Class 1, the packet arrival rate is very less in time-slots 2 and 9, less in time-slots 1, 3, 4, 5, 7 and 8, high in time-slots 6 and 10. In Class 2, the packet arrival rate is very less in time-slot 1, less in time slots 2, 3, 4, 5, 6, 7 and 8, high in time-slot 10. Hence the packet arrival is independent of time-slots as well as service classes.

The assigned wavelengths for different service classes are 16. If the free slots occur in one service class, it will be utilized by other service classes. In time-slot 1, the total number of packets arriving for 3 service classes is 16 and wavelengths assigned are 16. The incoming 16 packets utilize the assigned 16 wavelengths and so there is no packet loss. PLR for time-slot 1 is 0 and the same is shown in the Fig. 2(b). In time-slot 2, packet arrival is 17 and the assigned wavelengths are 16. Out of the 17 incoming packets, 16 packets utilize the assigned 16 wavelengths and the remaining 1 packet is dropped. There is a packet loss of 1. Thus PLR in time-slot 2 is above 0. Similarly in time-slot 9, packet arrival is 17 and the assigned wavelengths are 16. Out of the 17 incoming packets, 16 packets utilize the assigned 16 wavelengths and the remaining 1 packet is dropped. There is a packet loss of 1.In time-slot 10, packet arrival is 29 and the assigned wavelengths are 16.Out of the 29 incoming packets, 16 packets utilize the assigned 16 wavelengths and the remaining 13 packets are dropped.

For the time-slots 2, 7 and 9 the total packet arrival is same but the PLR differs because of the following reasons:

- In each time-slot there are 3 service classes. Though the total packet arrival with in a time-slot is same, the packets arrive at different times for different service classes.

- PLR is not uniform because of time of arrival of packets at each node is random. Each time slot is divided into hundred time periods and packets may arrive at any time period during the hundred time slots.

Inference of packet arrival in each of the three service classes and total number of packets in each time-slot for 200 packets in non-uniform traffic pattern has been referred from Table 1.

Fig. 2(c) shows a graph between PLR and time-slot for buffered optical switch with 200 packets. A buffer of size 5 for each service class is used. Free slots for one service class in a buffer cannot be used by another service class. If the incoming packets are more than the wavelengths assigned to all service classes, excess packets occur and these are stored in the buffer. If the excess packets are more than five, then those packets cannot be stored in the buffer and will be dropped. PLR is calculated using (6) for 3 service classes of non-uniform OPS with buffer for all the ten time-slots and are plotted in Fig. 2(c). Since the excess packets are stored in the buffers, PLR is less. Though the buffers are used, PLR cannot be predicted because the packets arrive randomly. PLR is less in buffered OPS when compare to PLR in buffer-less OPS. PLR for different time slots in buffer-less slotted OPS in non-uniform traffic pattern with 600 packets is also presented in Fig. 2(d).

In the same fashion the results are given for Service classes 4 and 5. Figs. 33, 4, 5 and 6 are plotted for 200 packets and 600 packets for service class 4 and 5 respectively. The explanation is similar to that of Fig. 2. Fig. 7 shows the comparison between PLR occurring in reservation bit algorithm and first-fit wavelength assignment algorithm. During service class 3, reservation bit technique has 15 buffers, each service class has 5 buffers, but in first-fit wavelength assignment algorithm, each node has 5 buffers and the total number of buffers is 20. Even though first-fit wavelength assignment algorithm has 20 buffers, reservation bit technique produces less PLR. At Service class 4, even though both the techniques have 20 buffers reservation bit technique produces less PLR. During service class 5, reservation bit techniques have 25 buffers and produces less PLR in comparison to first-fit wavelength assignment algorithm and the same is depicted in Fig. 7. The delay rate occurring in different traffic patterns is considered and is shown in Fig. 8. For all service classes delay rate is more or less the same for non-uniform and ON-OFF traffic patterns, whereas the delay rate is slightly higher in Poisson traffic pattern. The above statement is true when ON periods are more in ON-OFF traffic pattern and if the OFF periods are more the delay rate is less in non-uniform traffic pattern. Thus delay rate is less in non-uniform traffic pattern.

6 Conclusion

A novel Reservation Bit algorithm was implemented to minimize PLR in non-uniform traffic slotted OPS by employing buffers in the switch. Minimum PLR value is achieved by using buffers in the non-uniform traffic pattern. The improvement in QoS was achieved in terms of reduction in packet loss and is due to reservation of wavelengths for the packets. In non-uniform traffic pattern, packet loss in slotted optical packet switching using buffers is very much reduced compared to the buffer-less non-uniform traffic pattern. Analysis of the delay rate for traffic patterns under consideration is carried out and non-uniform traffic pattern results in improved QoS.

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