Performance Analysis of Delay in Optical Packet Switching Using Various Traffic Patterns

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Abstract— Quality of Service parameters are improved for development of optical packet switching technology. Delay is an important parameter in optical packet switching networks and it affects the performance of the network. In this paper, a mathematical model is presented to evaluate the delay rate. Delay rates are analyzed for fixed packet length and variable length packet for various traffic patterns viz. Non-uniform, Poisson and ON-OFF traffic models for various service classes using Reservation Bit technique. The results are compared with the existing port based First-Fit wavelength assignment algorithm. Here delay rates are reduced by 29% in our class based model than the port based model.

Keywords-component: Optical Packet Switching (OPS), RB (Reservation Bit algorithm), FF (First-Fit Wavelength assignment algorithm), Quality of Service (QoS), Packet Loss Rate (PLR), BER (Bit Error Rate), WDM (Wavelength Division Multiplexing).

1 Introduction

Due to the explosive growth of internet applications in recent years, data traffic has been exceeded the telephony traffic and bandwidth demands have been continuously increasing. It is also expected of the future networks to transport heterogeneous traffic services including multimedia and interactive applications necessitating bandwidth guarantees, minimum delay, less PLR, controlled jitter and etc. QoS provisioning seems therefore a mandatory task. Optical networks offer an extremely high traffic bandwidth capable of providing communication channels for several hundred nodes. Thus, the network traffic requires the network to evolve by increasing transmission capacity of optical fibers as well as switching capability. There are three switching schemes in optical networks namely optical circuit switching, optical burst switching (OBS) and optical packet switching (OPS). In the optical circuit switching, a dedicated end-to-end light path is established for each connection. Thus the transmission delay can be guaranteed and there is no virtually any loss, but less utilization of wavelength in this technique. In OBS, data is sent in bursts and a burst control message is sent ahead of each data burst to reserve a wavelength at each hop based on the expected arrival time of the data burst. In OPS, messages are transmitted in packets. At each switching node, the packet head is processed in the electrical domain for routing purpose and the packet data is kept in the optical domain. Wavelengths can be efficiently used in OPS [1]. Thus the optical packet switching has emerged as one of the most promising technologies for future telecommunication networks. OPS utilize very high bandwidth in the optical fiber using WDM. WDM offers an aggregate throughput of the order of terabits per second. WDM is widely becoming accepted as a technology for meeting growing bandwidth demands, and WDM systems are beginning to be deployed in both terrestrial and undersea communication links. Thus, WDM offers an excellent platform for carrying IP traffic. Consequently, OPS technology has many advantages, attract more intensive attention than ever. The next generation telecom infrastructure definitely comprise of optical networks with improved QoS.

In order to improve the performance of QoS in optical packet switching network, a detailed study has been made in this paper. The performance analysis of optical packet switching consists of two important issues namely packet loss and delay. Inorder to provide better QoS in optical packet switching, PLR and delay should be reduced. Packet loss and delay are not new issues in optical networks; however minimum loss and delay provide better QoS in Optical packet switching. In our earlier report the performance of 8B/10B code, Systematic code and Viterbi code in optical transmission in terms of Bit Error Rate has been analyzed. In the physical layer, transmission is done on bit by bit basis and Bit Error Rate has been reduced in the physical layer. When the bit errors in the physical layer are rectified, it will reduce the packet loss rates in the higher layers [2,3]. We have already reported that PLR has been...
reduced in non-uniform traffic pattern [4]. We have also implemented a RB algorithm for minimizing PLR in buffered non-uniform traffic pattern of optical packet switching mechanism [5].

In this paper we have analyzed the asynchronous OPS in terms of delay. Delay rate for fixed length packet and variable packet length has been studied for various traffic patterns viz. Non-uniform, Poisson and ON-OFF traffic models.

This paper has been organized as follows: Section II describes the architecture of asynchronous OPS. In section III, the analysis of delay rate is carried out for various traffic patterns in asynchronous OPS. In section IV, results along with discussions are presented and Section V deals with the conclusion and future work.

II. Description of Architecture

The architecture used in this paper is presented in [4,5]. It has been reproduced for the reference. The size of switch under consideration is \(N \times N\). The switch has \(F\) input fibers and \(F\) output fibers. By utilizing WDM, each fiber provides \(N\) wavelengths to transport data with a capacity of \(C\) bps. Buffers with the size of 5 are used in the OPS switch catering to each of the service classes. The switching process in OPS can take one of the two main forms. It can be synchronous (time slotted) with the fixed packet length or asynchronous (non-slotted) with variable packet lengths. In synchronous operation mode, all arriving packets have a fixed size and their arrival on each wavelength is synchronized on a time-slot basis, where a time slot is the time needed to transmit a single packet.

The operations of optical packet switching can be briefly described as follows: When a packet arrives at the switch, the packet header is extracted and processed electronically by the control module. While the header is processed, the packet payload is buffered in the optical domain using FDL processing buffers. Based on the destination, information extracted from the packet header and the control module decides to which output fiber/wavelength the packet is switched and configures the switch accordingly. Contention occurs when two or more packets are assigned to the same output port on the same wavelength at the same time [6 and 7]. The network has \(d\) service classes, ranging from service class 0 to service class \(d-1\). We assumed that the output on a single fiber/wavelength as the tagged fiber/wavelength. Delay is calculated for class \(i\) traffic at the tagged output fiber. Fig 1 shows a switch for packet arrivals to a tagged output fiber must originate from one of the FN input wavelengths.

III. Operating Principle

Operation of optical packet switch in a synchronous manner with fixed length of packets is explained in [5]. Here we assume that optical packet switch operates in an asynchronous manner with variable length of packets. Analysis of delay rate for variable packet sizes in asynchronous OPS using three types of traffic patterns viz. Non-uniform, Poisson and ON-OFF traffic models is presented in this paper. In contrast to [8], immaterial of packet size, allotted time slots remain the same and no shifting of time slot allocation is done.

In non-uniform traffic pattern all nodes are not to receive and send similar volumes of traffic [4, 9]. The number of packets arrived and transmitted of packets is not equal. There is an incoming packet for every slot. We assume that
each packet has equal probability of 1/N being addressed to any given output port and successive packets that arrive at the tagged output/wavelength are independent. Also, the packet arrival time at the input and transmission time to the output port are not equal. This is due to randomness of packet arrival. This increases the occupancy of the free slots. In Poisson traffic model, packet arrivals are random and are mutually independent. The Poisson distribution can be obtained for packet arrivals during an infinitesimal short period of time $t$, where $\lambda$ is called the arrival rate. Packet arrival at the output fiber is a single Poisson process with $\lambda$. In Poisson model, the number of arrivals in non-overlapping intervals is statistically independent. The arrival rate $\lambda$ is expressed as the average number of arrivals during a unit of time. The time distance between consecutive packet arrivals is exponentially distributed [10]. However Poisson arrival model is not an accurate model considering packet arrivals at the tagged output fiber/wavelength in OPS. The Poisson arrival model assumes an infinite number of sources, which is not the case in a real switch. When using a Poisson arrival model, there is the possibility of independency between the service time and the packet inter-arrival time [11].

Bursty traffic is also known as ON-OFF traffic model. Both the ON and OFF periods are distributed using exponential distribution with the mean $1/\mu$ and $1/\lambda$ respectively. It is an alternating process where an OFF period follows an ON period, and an ON period follows an OFF period. During ON periods, series of packets are transmitted from the source node and the time is called active periods. OFF periods are called passive periods and no packets are transmitted from the source. Active periods of a source are exponentially distributed with one specific mean value, and passive periods are exponentially distributed with another mean value. During an active period, packets are generated at regular periods. The most commonly used VOIP traffic model is based on a two-state on-off model of a single voice source. When a voice source is transmitted, it is in the ON state, and when the voice source is silent, it is in the OFF state; and the ON and OFF states appear alternatively. ON-OFF sources, each of which exhibits a phenomenon called the “Noah Effect” resulting in self similar aggregate traffic. The Noah Effect for an individual ON-OFF source model results in ON and OFF periods, i.e. “train lengths” and “intertrain distances” that can be very large without negligible probability [12 and 13]. The number of packet arrivals divides the timeslot and produces the time slice which is utilized for packet transmission. Hence the packet arrival rate is random, time slice is determined according to randomness of the packet arrival. ON and OFF periods are used with their own mean values and using the same mean values, various packets arrive and are transmitted during ON period and idling occurs during the OFF period. During ON period, packet is transmitted and there is no flow of packet during OFF period. In this model, FN independent state model generate packet arrivals at a tagged output fiber. In this paper, at every node there should be arrival(s) of different classes of packets. In ON-OFF model, ON periods and OFF periods occur at each node for different classes. When one class is in ON period, other classes may be in OFF period at that particular node and OFF period of one class is used by the other classes for transmitting packets. Also, other possibilities are (1) all classes may be in OFF period, (2) all classes may be in ON period and (3) some of the classes may be in ON period and rest may be in OFF period.

We assume that the switch is having buffers. In RB algorithm, the packets use the wavelength according to their service classes. If there is flow of packets into the ports with a specified service class, the incoming packets with assigned wavelengths occupy the ports as per the assigned service class. When the assigned wavelengths in one service class are occupied, it checks for 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 ports, the packets overflow. By introducing buffers, the packets that overflow are saved. When a free slot is not available for an incoming packet, instead of dropping that packet, it will be saved in the buffer which is provided in the switch. Before entering the buffer, a bit is added in the packet header for the purpose of reservation with respect to their service classes. Whenever free slots are available, the packets in the buffer occupy free slots. Buffered packets will have the priority over the incoming packets. In the FF algorithm, all wavelengths are numbered in a certain order, for example ascending order from 0 to W-1, where W is a number of wavelengths. When the deciding port attempts to assign a wavelength, it sequentially searches all wavelengths in an ascending order and assigns the first available wavelength [14]. In class based model, each node transmits the packets according to their classes. Buffers are placed in the port for every class. In port based model, wavelengths are placed in a sequential order. Irrespective of the class, the available wavelength is used by the incoming packets in a sequential order and buffers are only placed in each port.

FF algorithm is implemented in port based and packets are transmitted according to their wavelengths, whereas transmission of packets is class based in RB algorithm and packets are transmitted according to their service classes and wavelengths. Thus the drop rates of packets are reduced in optical networks resulting in improved QoS. The delay rate is found and analyzed in asynchronous OPS for various traffic patterns viz. Non-uniform, Poisson and ON-OFF traffic models for various service classes with packets of variable lengths. The delay rates for RB algorithm and FF algorithm are found and compared.

For fixed size packets and variable size packets in OPS, delay rate is encountered by implementing RB algorithm. The packet includes payload and header. Fig 2 shows the packet header. For fixed size packets, size considered is 512 bytes. For variable packet size, the range of packet size is in the
range of 512 bytes and 2k bytes. 20 bytes is included as header along with the payload invariably for any type of packets. Variable size packets are used in VoIP applications. In variable packet size, the size has been controlled by the application. Packet sizes of the range of 1024 to 2048 bytes show good efficiency in terms of bandwidth and reliability in Digital Video Broadcasting [15]. Packet size is measured using uniform min and max distribution. Packet size is chosen depending on the application.

<table>
<thead>
<tr>
<th>Source IP address</th>
<th>Destination IP address</th>
<th>Source Port</th>
<th>Destination Port</th>
<th>Packet Sequence no</th>
<th>Time Stamp</th>
<th>Flow id</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 bytes</td>
<td>4 bytes</td>
<td>2 bytes</td>
<td>2 bytes</td>
<td>2 bytes</td>
<td>4 bytes</td>
<td>2 bytes</td>
</tr>
</tbody>
</table>

Fig. 2 Structure of the packet header

When a packet is send from one node to other, the following delays occur: (1) transmission delay (time required to send all bits of packet into the wire), (2) propagation delay (the time taken by the packet to travel through the wire), (3) processing delay (the time taken to handle the packet in the network system), and (4) queuing delay (the time taken is buffering the packet before it can be sent). In most cases, the delay (2) and (4) are considered in simulations and measurements. The transmission delay (1) is usually small for fast links and small packets and is therefore not considered. Traditionally, the processing delay (3) has also been negligible [16]. In our measurements, we consider the delay (2) and (4). The mean delay for the above said traffic pattern is found using equation (1).

\[ T_D = T_{\text{Propagation}} + T_{\text{Queue}} \]  

Initially, we calculate the propagation delay that occurs when a packet travels from the source to the destination. Next, the queue delay experienced by a packet is calculated using equation (2). This delay is due to waiting period of the packet in the queue. A packet is in a queue, if a free wavelength is not available at that particular time slot.

\[ T_{\text{Queue}} = \frac{1}{N} \sum_{i=0}^{N} (T_i) \]  

where Ti is the transmission time of class i packets at particular time slice.

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.

IV. Results and Discussions

The delay values for the fixed length packets in slotted OPS using RB algorithm is studied and is also compared to the FF algorithm in our earlier paper [5]. In this paper, a detailed analysis is carried out to find delay in asynchronous OPS for variable length packet and is compared to FF algorithm.

We consider 240 packets for the simulation purpose. Delay for class i packets are calculated in the tagged fiber. Wavelength assigned is 16 and total time slot chosen is 10, hence this architecture can transmit 160 packets in a time slot. Buffers are used along with RB technique, 240 packets are chosen with an Erlang load of 1.5.
In service class 3, RB technique has 15 buffers, each service class has 5 buffers, but in FF algorithm, each port has 5 buffers and the total number of buffers is 20. 10.96ms, 10.88ms and 9.83ms are the delay values while employing FF algorithm and 7.55ms, 7.79ms and 7.91ms are the delay values while employing RB technique in asynchronous OPS using Non-Uniform, ON-OFF and Poisson traffic model respectively for Service class 3 and the same is shown in figs 3 and 4.

In Service class 4, both the techniques have 20 buffers. 10.94ms, 10.56ms and 10.18ms are the delay values while employing FF algorithm and 7.77ms, 8.01ms and 7.561ms are the delay values while employing RB technique in asynchronous OPS using Non-Uniform, ON-OFF and Poisson traffic model respectively for Service class 4 and
the same is shown in figs 5 and 6. From these it is seen that both the techniques have same amount of buffer. FF algorithm exhibits more delay, but delay is less in our approach.

While in service class 5, RB techniques have 25 buffers and FF algorithm need 20 buffers. 10.09ms, 10.88ms and 9.50ms are the delay values while employing FF algorithm and 7.1ms, 6.27ms and 6.48ms are the delay values while employing RB technique in asynchronous OPS using Non-Uniform, ON-OFF and Poisson traffic model respectively for Service class 5 and the same is shown in figs 7 and 8.

For all the service classes under consideration, buffers are more or less the same for RB technique and FF algorithm, whereas the delay rate is slightly higher in FF algorithm. The above statement is true when the class based transmission is compared with port based transmission.

Simulation results show that for all service classes under any type of traffic pattern, class based model produces 29% reduction of delay rate when compared to port based model and the same is shown in fig 9. In RB technique the buffered packets with respect to their classes will occupy the free slots of the corresponding service class wavelengths on First Come First Serve basis which reduces the waiting time in the buffer whereas in FF algorithm wavelength utilization is sequential, so buffered packets wait until they are serviced with the next sequential order of wavelengths. Thus delay rate is less in asynchronous OPS when RB technique is employed. The delays are improved much in our algorithm. This is due to the class based transmission.

Fig 10 shows the total number of transmitted bytes per slot. It is shown that more number of packets is transmitted in class based model for all traffic patterns under consideration when compared to port based model. Hence class based model produces lesser delay as well as more number of bytes transmission when RB technique is employed. It is also shown that non-uniform traffic pattern produces lesser delay when compared to ON-OFF and Poisson model.

V. Conclusion
The delay rates for the Non-uniform, Poisson and ON-OFF traffic models for various service classes are analyzed. Minimum delay has been achieved in all service classes under consideration by using reservation bit technique. It provides lesser delay for all service classes for fixed and variable length packets when compared to first-fit wavelength assignment algorithm. It is seen from our simulation, Poisson arrival model which is assumed in the analysis approximates a more realistic model wherein all input wavelengths are modelled as independent on/off processes with exponential holding time. Also we have presented a comparative study of reservation bit technique and first-fit wavelength assignment algorithm for synchronous and asynchronous OPS. It is concluded that in Optical packet switching reservation bit technique reduces delay; hence QoS is improved and at the same time Non-uniform traffic pattern result in better Quality of service compared to ON-OFF model and Poisson model. At the same time ON-OFF traffic pattern have better QoS when compared to Poisson process if OFF periods of one service classes are more efficiently utilized by other service classes.


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