Modeling A Threshold Flow-Oriented Traffic Routing Technique In Optical Networks

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***Abstract*—Packet Discard (PD), Flow Discard (FD) and Early Flow Discard (EFD) techniques have been deployed for optimal channel utilization in optical networks. As the value of count increases in EFD scheme, the value of final packet-marking probability (pa) also increases. This increase in pa causes great deal of packet loss affecting the successful transmission of packets and flows at the destination node. In order to improve the quality of the transmitted traffic in optical networks, we propose a discarding technique for data transmission called Learning Automata-Like Early Flow Discard (LALEFD). This technique is founded on the principles of the operation of existing Learning Automata-Like Random Early Detection (LALRED) congestion avoidance mechanism that reduces the total loss of packets at the queue. Numerical results show that proposed discarding technique significantly improves packet and flow delivery ratio, loss rates as well as diverse delays. PD, FD and EFD schemes do not achieve such levels. Therefore, it is the most suitable approach to be deployed in optical networks for future optical flow-routing.**

***Index Terms*—Diverse, delay, Loss-Rate, technique.**

I. Introduction

Transmission Control Protocol (TCP) provides the services such as the cutting back on the transmission rate of flows whenever a congestion is encountered along the way of the packet flow. Such congestion at the router may be caused by too many sources trying to send an excessive amount of data with rate that is too high for the network to handle. Modeling and analysis of such TCP connections and other interaction with queues has been an active research area.

The transmission control protocol supports mechanisms such as slow start, congestion avoidance, fast retransmit and fast recovery to decrease the effect of packet loss. However, they are not very effective in curbing down congestion per second [2]. Thus, LALRED [2,6] congestion avoidance mechanism which maintains a low-average queue size, was proposed with the following advantages over Random Early Detection (RED)[3]:

- The number of packets lost at the gateway using LALRED is lower as compared to that using RED. LALRED reduces the packet drops at the gateway.
- The average queue size maintained when using LALRED is lower as compared to that using RED. The average queue size is proportional to the dropping probability at the gateway.
- Using LALRED, more packets are acknowledged to the sender.

Packet reordering causes service decay in performance, particularly for TCP due to constraints such as unnecessary retransmission of packets, inefficient estimation of round trip time and poor receiving capacity [1] . As a result, we believe that an alternative discarding scheme other than EFD, in bulk flow TCP routing is needed in optical network.

We observed that in RED algorithm [3, 11], the packets are to be marked or dropped before the queue gets full. In order to drop a packet it should be marked. When the average key queue size lies between the maximum and the minimum thresholds, packets are marked with a certain probability and these marked packets are not dropped. However, when the average queue size exceeds the maximum threshold, the packets are marked so that they can be dropped. Finally, it must be noted that as the value of count increases, the value of packets increases [2] as well.

A. Motivation

Information through optical networks has been extensively studied to provide high throughput and high capacity for Internet traffic. Optical packet switching network deploys buffering, wavelength conversion and multipath routing which are considered suitable. Thus, due to packet oriented routing and switching, the optical network can result in big numbers of packet-out-of -order and packet loss. This causes diverse delays in arriving upon end system, causing TCP flows that include those corrupted packets.

The tainted flows in optical network can augment the production of the Internet traffic and cause faulting in the higher layer protocol. The application of optical packet router considerably decreases good throughput than flow routers. Using optical flow with Variable size Early Flow Discard (VEFD) techniques, it is evident from the statistics that the optical packet routers contribute to a maximum loss of about 71.17%[1]. When the optical flow routing technique is used, the loss rate can be minimized to a larger extent of about 24.95% [1].

These percentage loss rates are still high for optimal utilization of bandwidth and channel capacity in optical network. Therefore there is need to model a threshold flow-oriented

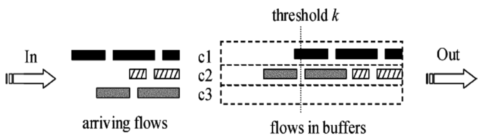

Fig. 1. Buffering flows in a wavelength converted OFR router with EFD[7].

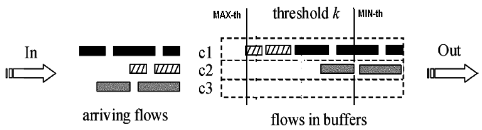

Fig. 2. Buffering flows in a wavelength converted OFR router with LALEFD.

traffic routing technique (EFD) in optical network to reduce the loss rate of Optical Packet Routers (OPR) and Optical Flow Routers (OFR).

Thus, in Section II, we had to review the existing literature on threshold flow-oriented traffic routing technique in optical networks to develop the model. Matlab with Wavelength Division Multiplexing (WDM) tool is used in the validation of the model and comparison of the (loss rates, diverse delays) in the model with Early Flow Discard as per LALRED, (LALEFD) and that of Early Flow Discard (EFD) technique as per RED is presented in Section III.

B. Wavelength Conversion

Wavelength Conversion (WC) is used to reduce the switching complexity as well as to improve the signal quality [7, 9]. With wavelength conversion, concurrent wavelength channels in a fiber are available to packets destined to the same output port. Figures 1 and 2 illustrate the wavelength conversions for OFR with three wavelength channel per fiber. Wavelength conversion has been widely studied for Optical Packet Switched Routers (OPSR), OFR with PD, FD, EFD. The use of optical buffers could be reduced largely by deploying wavelength converter under both short- and long-range dependent traffic [5, 7, 8, 9].

To assert the problems cited in PD and FD techniques [7], the early flow discarding technique introduces a parameter called threshhold value k. This threshold value is decided based on the buffer size.Every arrival of the flow is to be calculated for average queue size.The flow is then allowed only if it falls below the thresh hold value. Otherwise the incoming flow is studied for its importance and if it has control data or any other important data, it is allowed or simply discarded.

Therefore, in Figure 1 a threshold for the buffer occupancy will be set, beyond which no new flows can be accepted. Thus an arriving flow will seek a buffer space in the next available wavelength if the current one exceeds. The first flow is transmitted via wavelength c1 as in FD.

The buffer occupancy of wavelength c1 surpasses the threshold. The flow from the second wavelength is transmitted via wavelength c2. The one from the third wavelength is wavelength converted and stored in wavelength c2 since the buffer occupancy of c2 has not exceeded the threshold at that time. Wavelength c3 is reserved for the coming traffic. This scheme has the advantage of equal transmission opportunity for flows with different lengths.

With LALEFD, threshold values (MAX_{th} and MIN_{th}), buffer occupancy would be set. When it is past maximum threshold k, the new flow can be forced-drop. Therefore an arrival flow will search for a buffer space in the next available wavelength if the current one exceeds maximum threshold k. This scenario is described in Figure 2.

The first flow is transmitted via wavelength c1. After the occupancy of wavelength, c1 just exceeds the minimum threshold. The flow from the second wavelength is transmitted via wavelength c1 until the buffer occupancy reaches maximum threshold. Thus, the flow from the third wavelength is converted and transmitted via wavelength c2 since the buffer occupancy of c2 has not succeeded the minimum threshold at that time. The next incoming flow say n^{th} is wavelength converted and stored in wavelength c2. Wavelength c3 is reserved for the coming traffic $(n+1)^{th}$.

LALEFD technique has the advantage of equal transmission opportunity for flows with different wavelengths. Also the scheme intelligently chooses the randomly arriving packets to mark, drop, or not drop, based on the current average queue size in the network.

C. Contribution

This topic is of particular interest to all vendors and manufacturers interested in introducing it in the re-design of routers. Today, services that are considered prohibitively expensive, such as videoconferencing to the desktop (or home), electronic commerce and high-speed video imaging, will become commonplace because they will be technologically and economically feasible. In essence, optical-layer technology using the proposed discarding technique may improve the way we live even in a country having low quality of carrier for the country's backbone.

Thus, this paper will make the following contributions to the literature:

- By modeling the threshold value of optical flow routes with early flow discard, we propose a technique called LALEFD as per LALRED that yield smaller diverse delays compared to FD, and EFD when B is less than or equal to 70.
- The number of packets lost at the gateway with LALEFD is the lowest compared to PD, FD and EFD techniques. LALEFD reduces the packet drops at the gateway.
- The average queue size maintained with LALEFD is lowest as compared to PD, FD, and EFD techniques. The average queue size is proportional to the loss rate probability of packets at the gateway.
- With LALEFD, more flows are acknowledged to the sender since the loss rate probability is the smallest compared to PD, FD, and EFD schemes. Loss rates probability of packets is inversely proportional to the buffer size.

II. THE MODEL

A. Mathematical Model

We assume such a packet arrival process as a poison distribution λ'. A router model with first-in- first-out output buffering is considered. The transmission time of a packet is exponentially distributed with: mean $= \frac{1}{\mu}$ in time slot. Hence in terms of packets, the queue can be viewed as an M/M/1/B model, with arrival rate λ', service rate μ and buffer depth B in time slot. The number of packets per flow is a shortened geometric distribution with parameter *q*, having probability density function of zero above L. L is related to B and μ as $\frac{L}{\mu} \leq B$. The load on the queue is defined as [7, 10, 9]: $\rho = \frac{\lambda}{\mu}$, thus, in [14,7,9,5] we have;

$$\lambda = \lambda' \left[1 - q \cdot (1-q)^L\right] \tag{1}$$

If the number of wavelength in a fiber being n_m, the total packet arrival rate of fiber is

$$\Lambda = n_w \cdot \lambda \tag{2}$$

For a fiber channel with output buffering and wavelength conversion, the place of occupied buffer can be addressed as (*m*, *i*), where *m* is the index of the wavelength channel ($1 \leq m \leq n_w$) and *i* is the buffer being occupied for the particular wavelength channel ($0 \leq i \leq B$). When conducting the steady-state analysis of the buffer occupancy, [7] introduced a system mode parameter f, which indicates the wavelength channel is discarding traffic ($f = 1$) or not ($f = 0$). Therefore, for occupancy of the buffer that locates at wavelength channel m and buffer i, we can use (m, i, f) to express the state of the buffer.

B. Related Work

1) PD Technique: For OPR with PD, each arriving packet will be discarded only when it fails to find buffer space in all the n_w channels. Therefore, the queuing system only has one discarding status that is $(n_w, B, 1)$ as in [7,8,9]where the set of equations for the steady-state system is:

$$P_{n_w,B,1} + \sum_{m=1}^{n_w} \sum_{i=0}^{B} P_{m,i,o} = 1 \tag{3}$$

2) FD Technique: In the wavelength-converted OFR with FD, an arriving flow is discarded only after it fails to find buffers for the whole flow in all the wavelength channels. Therefore from the packets point of view, when the first packet of a flow arrives, the system will allocate the resources in the available wavelength channel with the lowest index to all the packets in the flow. Thus, as in press [7], at steady-state system, the equation is:

$$\sum_{m=1}^{n_w} \sum_{i=0}^{B} \sum_{f=0}^{1} P_{m,i,f} = 1 \tag{4}$$

The average of the total arriving-rate of new flows in all wavelengths of the fiber at time t is given as:

$$\Phi_{\text{ave}} = \frac{\sum_{h=1}^{n_w} h \cdot \lambda' \begin{pmatrix} n_w \\ h \end{pmatrix} \cdot q^h \cdot (1-q)^{n_w - h}}{n_w} \tag{5}$$

However, the parameters for equation (3) are found in[7].

3) EFD Technique: Similar to that of FD, the wavelength-converted OFR with EFD will discard an arriving flow.This happens only when it fails to find buffers for the whole flow in all the wavelength channels. However, the buffer in one wavelength channel will accept all flows till its occupancy exceeds a threshold. After that the buffer is not available to any arriving flows until the occupancy drops lower than the threshold. The state-transition-rate diagrams for these scenarios are shown in [5, 7, 9, 10, 8] and the equation at steady-state system is as follow:

$$\sum_{m=1}^{n_w} \sum_{i=1}^{B} \sum_{f=0}^{1} P_{m,i,f} = 1 \tag{6}$$

The rate of the arriving packet which is the head of a new flow with the number of packets less than L, is expressed as:

$$e = \Phi_{ave}[1 - (1-q)^L] \tag{7}$$

The rate of the next arrival, which is not the head of a new flow is given as:

$$d = \Lambda - e \tag{8}$$

C. The Model of OFR with LALEFD Technique

EFD based on RED avoids global synchronization by randomly choosing packets to be marked or dropped before the queue gets full.

Finally, it must be noted that as the value of count increases, the value of final packet-marking probability (pa) also increases. This increase in pa causes great deal of packet loss affecting the successful transmission of packets at the destination node wih EFD.

Therefore, the performance of LALRED is superior to that of RED by virtue of its low average queue size and its packet loss. LALEFD is pedestal on LALRED algorithm [2], and our main objective is to optimally utilize bandwidth and channel capacity in optical network. We can achieve these by minimizing the average queue size and reducing the packet loss at the queue. The LALEFD mechanism that we have proposed in this research, succeeds in achieving this. For large offered load, the drop probability is very close to that suffered by a smooth Poisson traffic in a Tail Drop router, which is given by the loss probability for the M/M/1/B queue.

1) How LALEFD Discarding Scheme Works: The parameter MIN_{th} must be correspondingly large to allow the link utilization to be maintained at an acceptably high level, if the typical traffic is busty. The MAX_{th} partly depends on the maximum average delay that can be allowed by the router. Figure 3 is the flow chart showing how LALEFD system works. The following four actions, based on the packet drop type, were advocated as in [2]:

- No-Drop is selected when the average queue size lies below the minimum threshold. When $i < k$ and $1 \leq m \leq n_w$, the flow will be accommodated in the buffer of the first wavelength.
- Minimum-Exceed action is chosen when the average queue size exceeds the minimum threshold or it transitions from an empty queue state to a nonempty queue state. Thus, if $i \geq k$ and $1 < m \leq n_w$, the flow will be accommodated in the buffer of the first or the next wavelength channel.
- Unforced-Drop is selected when the average queue size lies between the minimum threshold and the maximum threshold. For an unforced drop, the arriving packet is always dropped.
- Forced-Drop is chosen when the average queue size is above the maximum-threshold set for the queue or when the queue is full. So, when $i = B$ and $m = n_w$, the flow has to be discharged.

2) Steady-State Probability of Buffer Occupancy for OFR with LALEFD: The wavelength-converted OFR with LALEFD will discard an arrival flow when the average queue size lies between the minimum threshold and the maximum threshold, where the arrival packet is always dropped "unforced dropped". Forced dropped occurs when the average queue size is above the maximum-threshold set for the queue or when the queue is full. After that the buffer is not available to any arriving flows until the occupancy drops lower than the threshold. The state-transition-rate diagram is shown in Figure 4.

We can derive the average rate of the next arrival, which is the head of a new flow, with the number of packets less than or equal to L as:

$$D = \Phi_{ave} - e$$

$$D = \Phi_{ave}(1-q)^L \tag{9}$$

Thus, at steady-state system, as in Figure 4 we can derive the following set of equations:

$$\Lambda P_{1,0,0} = \mu P_{1,1,0}$$

$$e P_{1,0,1} = \mu P_{1,2,1}$$

$$\Lambda + m\mu P_{m,0,0} = m\mu P_{m,1,0} + e\sum_{i=k}^{B}\sum_{1=0}^{1} P_{m-1,i,1}$$

$$2 \leq m \leq n_w$$

$$(e + m\mu)P_{m,0,1} = m\mu P_{m,1,1}$$

$$2 \leq m \leq n_w$$

$$(\Lambda + m\mu)P_{m,i,0} = \Lambda P_{m,i-1,0} + m\mu P_{m,i+1,0} + eP_{m,i-1,1}$$

$$1 \leq m \leq n_w \quad and \quad 1 \leq i < k$$

$$(e + m\mu)P_{m,i,1} = m\mu P_{m,i+1,1}$$

$$1 \leq m \leq n_w \quad and \quad 1 \leq i < k$$

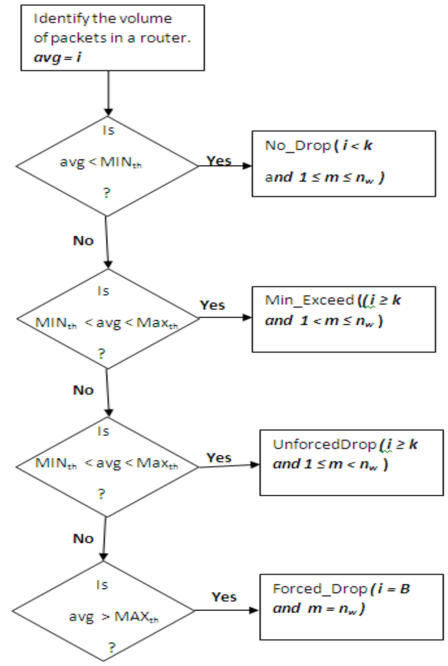

Fig. 3. Flow Chart showing how LALEFD Discarding Scheme works.

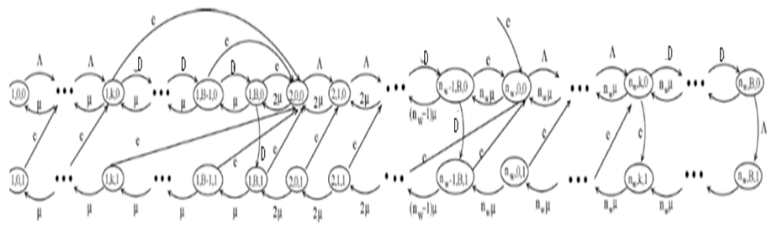

Fig. 4. State Transition Diagram for the Buffer Queue of a LALEFD Router with WC.

$$(e+m\mu+D)P_{m,k,0} = \Lambda P_{m,k-1,0} + m\mu P_{m,k+1,0} + eP_{m,k-1,1}$$

$$1 \leq m < n_w$$

$$(e + m\mu)P_{m,k,1} = m\mu P_{m,k+1,1}$$

$$1 \leq m < n_w$$

$$(e + m\mu + D)P_{m,i,0} = DP_{m,i-1,0} + m\mu P_{m,i+1,0}$$

$$1 \leq m < n_w \quad and \quad 1 < i < k$$

$$(e + m\mu)P_{m,i,1} = m\mu P_{m,i+1,1}$$

$$1 \leq m < n_w \quad and \quad k < i < B$$

$$(e + m\mu + D)P_{m,B,0} = DP_{m,B-1,0} + (m + 1)\mu P_{m+1,0,0}$$

$$1 \leq m < n_w$$

$$(e + m\mu)P_{m,B,1} = DP_{m,B,0} + (m + 1)\mu P_{m+1,0,1}$$

$$1 \leq m < n_w$$

$$(e+n_w\mu+D)P_{n_w,k,0} = \Lambda P_{n_w,k-1,0} + n_w\mu P_{n_w,k+1,0} + eP_{n_w,k-1,1}$$

$$n_w\mu P_{n_w,k,1} = n_w\mu P_{n_w,k+1,1} + eP_{n_w,k,0}$$

$$(e + n_w\mu + D)P_{n_w,i,0} = DP_{n_w,i-1,0} + n_w\mu P_{n_w,i+1,0}$$
$$k < i < B$$
$$n_w\mu P_{n_w,i,1} = eP_{n_w,i,0} + n_w\mu P_{n_w,i+1,1}$$
$$k < i < B$$
$$(\Lambda + n_w\mu)P_{n_w,B,0} = DP_{n_w,B-1,0}$$
$$n_w\mu P_{n_w,B,1} = \Lambda P_{n_w,B,0}$$

and

$$\sum_{m=1}^{n_w}\sum_{i=1}^{B}\sum_{f=0}^{1} P_{m,i,f} = 1 \tag{10}$$

D. Performance Metrics

The following performance metrices were used: buffer depth B, mean arival rate λ, service rate μ, the load on the queue ρ, c_i the rate of the arriving packet which is the head of a new flow with the number of packets less than (B - i).μ, the blocking probability and end-to-end delays among others.

1) Blocking Probability: Blocking probability is the ratio of the number of rejected requests to the total number of requests sent.Therefore, blocking probability is the proportion of the packet that is lost Π_B (Expected number lost per time unit divided by the expected number arriving per time unit).

$$\text{Blocking Probability } \Pi_B = \left[\frac{(1-\rho)\rho^B}{1-\rho^{B+1}}\right] \tag{11}$$

The loss rate is the arrival rate times the probability that the system is full. Thus,

$$\text{The Loss Rate (LR) } = \lambda \cdot \Pi_B$$
$$= \frac{\lambda^{B+1}}{\mu}\left(\frac{1-\rho}{1-\rho^{B+1}}\right) \tag{12}$$

The probability that the system is idle Π_0

$$\Pi_0 = \left(\frac{1-\rho}{1-\rho^{B+1}}\right) \tag{13}$$

Hence,

- Blocking probability for PD (Π_{PD}) will be:
$$\Pi_{PD} = \left[\frac{(1-\rho)\rho^B}{1-\rho^{B+1}}\right] \tag{14}$$
By substitution, LR of packets in OPR with PD is:
$$= \frac{\lambda^{B+1}}{\mu}\left(\frac{1-\rho}{1-\rho^{B+1}}\right) \tag{15}$$
- Blocking probability for FD (Π_{FD}) can be expressed as:
$$\Pi_{FD} = \left[\frac{(1-c_i)c_i{}^B}{1-c_i{}^{B+1}}\right] \tag{16}$$
Therefore, the LR of flows in OFR with FD is obtained as:
$$= \frac{c_i{}^{B+1}}{\mu}\left(\frac{1-c_i}{1-c_i{}^{B+1}}\right) \tag{17}$$
- The expression of blocking probability for EFD (Π_{EFD}) is:
$$\Pi_{EFD} = \left[\frac{(1-e)e^B}{1-e^{B+1}}\right] \tag{18}$$
Then, LR of flows in OFR with EFD is:
$$= \frac{e^{B+1}}{\mu}\left(\frac{1-e}{1-e^{B+1}}\right) \tag{19}$$
- Finally, blocking probability for LALEFD (Π_{LALEFD}) is obtained as:
$$\Pi_{LALEFD} = \left[\frac{(1-D)D^B}{1-D^{B+1}}\right] \tag{20}$$
The LR of flows in OFR with LALEFD can be derived as:
$$= \frac{D^{B+1}}{\mu}\left(\frac{1-D}{1-D^{B+1}}\right) \tag{21}$$

2) The End-To-End Delay in OFR: The end-to-end delay is averaged over all surviving data packets or flows from the sources to the destinations. Packets have to transverse many network devices and links; this travel adds up to the overall delay as in [4]. Let d_{ij} be the delay on the link (i, j) and $a_{i,j}$ be the proportion delay on the link (i, j) plus the processing delay at the node i (msec). Hence;

$$\text{Delay } d_{i,j} = \rho\left[\frac{(1 + B\rho^{B+1} - (B+1)\rho^B)}{\lambda(1-\rho)(1-\rho^B)}\right] + a_{i,j} \tag{22}$$

Therefore,

- The expression for the $d_{i,j}$ of packets on the link (i,j) in OPR with PD is:
$$d_{i,j-PD} = \rho\left[\frac{(1 + B\rho^{B+1} - (B+1)\rho^B)}{\lambda(1-\rho)(1-\rho^B)}\right] + a_{i,j} \tag{23}$$
- The $d_{i,j}$ of flows on the link (i,j) in OFR with FD is expressed as:
$$d_{i,j-FD} = c_i\left[\frac{(1 + Bc_i{}^{B+1} - (B+1)c_i{}^B)}{c_i(1-c_i)(1-c_i{}^B)}\right] + a_{i,j} \tag{24}$$
- The $d_{i,j}$ of flows on the link (i,j) in OFR with EFD is expressed as:
$$d_{i,j-EFD} = e\left[\frac{(1 + Be^{B+1} - (B+1)e^B)}{e(1-e)(1-e^B)}\right] + a_{i,j} \tag{25}$$
- However, the $d_{i,j}$ of flows on the link (i,j) in OFR with LALEFD is derived as:
$$\mathrm{d}_{i,jLALEFD} = D\left[\frac{(1 + BD^{B+1} - (B+1)D^B)}{D(1-D)(1-D^B)}\right] + a_{i,j} \tag{26}$$

III. Performance Evaluation

In this section, we evaluate the performance of the proposed discarding technique LALEFD in OFR and observe if the expected packet delay can be improved without increasing the packet loss too much.

The default parameters used are: packet size of 1500 bytes, 9.6 km lengths of fiber, signal propagation speed of 200, 000 kms^{-1} and data rates of 1 Gb/s [13] and, $a_(i,j) =$

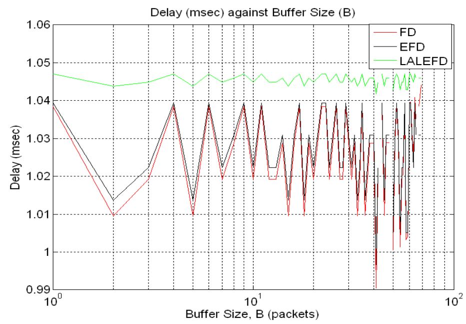

Fig. 5. Graph of Delay $d_{(i,j)}$ against Buffer Size(B) when L= 10, B=70.

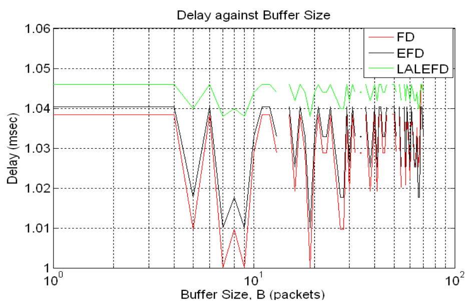

Fig. 6. Graph of Delay $d_{(i,j)}$ against Buffer Size(B) when L= 7, B=70.

$0.048msec$. Other parameters as used in [7, 10, 9] are $\mu = 1, n_w = 4$, $q = \frac{1}{5}$, B= 70 time slots and maximum number of packets allowed in a flow L is 10 unless stated. For simplicity, we are working at packets level.

A. Delays in OFR with FD, EFD and LALEFD

Here, we discuss the characteristics of these discarding schemes in terms of diverse delays by analyzing the results presented in Figures 5 and 6.

In Figure 5 when L=10, maximum buffer size 70, and the diverse delays between buffer size B = 1, 2, ... ,70 can be obtained. A mean diverse delay of 0.0028 for LALEFD, 0.0209 for EFD and for FD, the dissimilar delay has an average of 0.0222. Implying LALEFD has 86.6% lesser average diverge delay than EFD and 87.4% smaller average diverse delay than with FD. However, EFD has 5.9% lesser average diverse delay than FD.

In Figure 6, if L=7 and B=70 [10], the average diverse delays for LALEFD, EFD and FD are 0.0032, 0.0155, and 0.0188 respectively. This indicates 79.4% lesser diverse delay for LALEFD than EFD and LALEFD has 83% smaller varied delay than FD while EFD has 17.6% lesser diverse delay than FD.

The varied delays is much when buffer size is between 4-10 and 19-28 during busty traffic and congestion resulting to much loss of packets with FD and EFD unlike LALEFD where the diverse delay is minimal.

From Figures 5 and 6 , it is also clear that when L=10 and B=70; the values of diverse delays of LALEFD are very small compared to when L=7, and B=70. In addition to that, all the

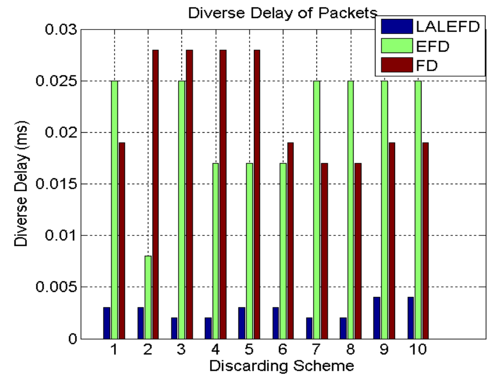

Fig. 7. The Diverse Delay of Packets with LALEFD, EFD and FD when L=10, and B =70.

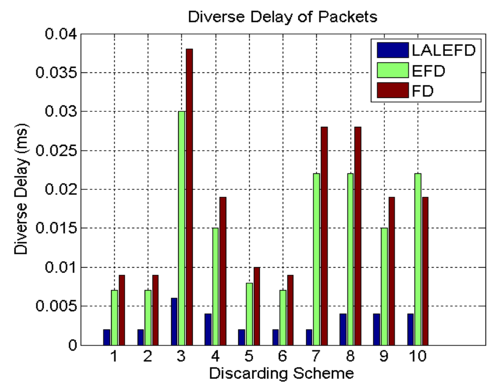

Fig. 8. The Diverse Delay of Packets with LALEFD, EFD and FD when L=7, and B =70.

diverse delays of OFR with LALEFD are less than 0.005 ms.

The random diverse delays of packets in OFR with FD, EFD and LALEFD are extracted from simulation results for ten samples as seen in Tables I and II. The observation indicates that, in terms of diverse delays, LALEFD is the most suitable discarding scheme compared to FD and EFD since the variation in delays is not significant.

Ten random samples of diverse delays of packet with FD, EFD and LALEFD when L=7, 10 and B=70 are presented in Figures 7 and 8. In both Figures 7 and 8, the diverse delay for LALEFD in average is less than 0.005 ms. At high congestion, the maximum diverse delay of packets with FD,EFD and LALEFD are 0.038 ms, 0.03 ms and 0.006 ms respectively.

Thus, when the value of packets increases, at high congestion, the diverse delay also increases. LALEFD performance is still superior over FD and EFD at peak load condition (busty traffic).

B. Loss Rate of Packets with PD, FD, EFD and LALEFD

Figures 9 and 10 compares the loss rates in different discarding techniques (PD, FD, EFD and LALEFD) at different buffer depths of 60 and 70 respectively.

In Figure 9, LALEFD, EFD, FD and PD provide maximum loss rates of $3.367*10^{-146}$, $4.168*10^{-90}$, $2.012*10^{-87}$ and

TABLE I
RANDOM DIVERSE DELAY OF PACKETS IN OFR WITH FD, EFD AND LALEFD

Scheme	1	2	3	4	5
Figure 7					
LALEFD	0.003	0.003	0.002	0.002	0.003
EFD	0.025	0.008	0.025	0.017	0.017
FD	0.019	0.028	0.028	0.028	0.028
Figure 8					
LALEFD	0.002	0.002	0.006	0.004	0.002
EFD	0.007	0.007	0.030	0.015	0.008
FD	0.009	0.009	0.038	0.019	0.010

TABLE II
RANDOM DIVERSE DELAY OF PACKETS IN OFR WITH FD, EFD AND LALEFD

Scheme	6	7	8	9	10
Figure 7					
LALEFD	0.003	0.002	0.002	0.004	0.004
EFD	0.017	0.025	0.025	0.025	0.025
FD	0.019	0.017	0.017	0.019	0.019
Figure 8					
LALEFD	0.002	0.002	0.004	0.004	0.004
EFD	0.007	0.022	0.022	0.015	0.022
FD	0.009	0.028	0.028	0.019	0.019

$2.801 * 10^{-2}$ respectively for peak load condition (busty traffic). In Figure 10, however, the maximum loss rate decreases in size as the buffer size increases.

The period where the congestion is being built-up are when the buffer sizes are between 0-1, 13-15, 25-28, 43-47 and 54-56 in fiber of $n_w = 4$ for all the discarding schemes. The discontinuity at these points showed the periods where no packets for PD and flows for FD, EFD and LALEFD are lost.

Increasing the size of the buffer will also increase the propagation delay of each flow which, in turn, increases the average congestion window size which makes the drop-rate to go down.

Numerical results indicate LALEFD out compete PD, FD and EFD discarding schemes. See the summary in Tables III and IV. The study also showed that for increase in buffer size (depth), the loss rates and diverse delay decreases consequently increasing good throughput.

Buffer utilization was much less against conventional packet discarding method. We observed that the loss rate of packets in OFR with LALEFD is almost zero (100% lesser than EFD or FD).

LALEFD, a novel flow routing method, has been proposed as an efficient technique to support Internet traffic in optical networks. Flow routing not only preserves the flexibility of packet switching approach but also prevents the packets from being out-of-order, thus improving the packet delivery performance and reducing the diverse delays in optical networks.

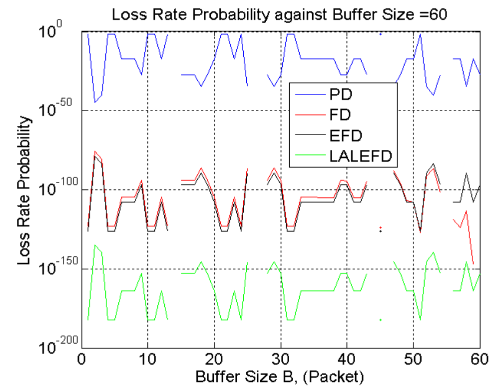

Fig. 9. Comparison of LR against B when Buffer Size is 60 for PD, and LALEFD Routers with WC, $\mu = 1, L = 10, n_w = 4, q = \frac{1}{5}$

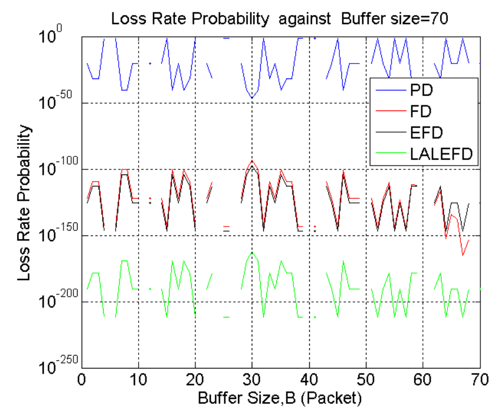

Fig. 10. Comparison of LR against B when Buffer Size is 70 for PD, and LALEFD Routers with WC, $\mu = 1, L = 10, n_w = 4, q = \frac{1}{5}$

TABLE III
LOSS RATE PROBABILITY OF PACKETS WITH LALEFD AND EFD.

LR	**LALEFD**	**EFD**
Figure 9		
Maximum	$3.367 * 10^{-146}$	$4.168 * 10^{-90}$
Average	$1.463 * 10^{-164}$	$1.84 * 10^{-108}$
Minimum	$6.353 * 10^{-183}$	$8.047 * 10^{-127}$
Figure 10		
Maximum	$4.782 * 10^{-170}$	$9.33 * 10^{-105}$
Average	$2.029 * 10^{-191}$	$4.022 * 10^{-126}$
Minimum	$8.604 * 10^{-213}$	$1.718 * 10^{-147}$

IV. CONCLUSION

A comprehensive analytical model comprising LALEFD, EFD, FD and PD have been studied to find the probability density functions such as loss rate of packets and diverse delay in OFR, with wavelength conversion and optical buffering. This is to improve the quality of the transmitted traffic in optical networks.

From the performance evaluation of these discarding techniques, numerical results showed that LALEFD provide the following advantages over PD, FD, and EFD:

- The loss rates of packets in OPR and OFR with PD, FD,

TABLE IV
LOSS RATE PROBABILITY OF PACKETS WITH PD AND FD.

LR	FD	PD
Figure 9		
Maximum	$2.012 * 10^{-87}$	0.02801
Average	$1.618 * 10^{-105}$	$5.976 * 10^{-18}$
Minimum	$7.47 * 10^{-124}$	$3.157 * 10^{-35}$
Figure 10		
Maximum	$2.112 * 10^{-101}$	0.02616
Average	$1.276 * 10^{-122}$	$7.251 * 10^{-21}$
Minimum	$5.088 * 10^{-144}$	$3.74 * 10^{-41}$

and EFD schemes are much greater than the LALEFD technique. The loss rate probability is inversely proportional to buffer size.

- The average diverse delay of packets in OFR with LALEFD is smallest compared to FD and EFD. Thus, variation in delays is not significant with LALEFD consequently; more packets are received at the gateways.
- PD ends up with largest percentage of corrupted and lost packets during congestion.

LALEFD is the most suitable approach for optical flow networks among the EFD, FD and PD for the future optical flow-routing networks.

Thus, In order to provide an application-friendly transmission environment for future Internet we observed the following:

- Wavelength conversion and optical buffering should be considered and on a bulk flow TCP with routing concepts.
- LALEFD can be the best to implement in optical networks.

However, the defect in LALEFD technique is the high value of the entire delay. To improve this, one needs to study how to minimize the entire delay while maintaining less amount of packet loss in OFR.

Currently, we are working on "Quality of Services on Internet Protocol using Optical Flow Routers with LALEFD". Areas of future work are:

- LALEFD technique in real time applications that uses UDP protocols,
- how loss of packets can be minimized while decreasing the entire delay in OFR with LALEFD and
- how LALEFD performs in environments characterized by nodes that are mobile.

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