Performance evaluation of delay in optical packet switching using various traffic patterns

A. Kavitha[1,*], V. Rajamani[2] and P. Anandha Kumar[3]

[1]PSNA College of Engineering and Technology, Dindigul 624 622, India
[2]Indra Ganesan College of Engineering, Manikandam, Tiruchirappalli 620 012, India
[3]Department of Information Technology, Anna University, MIT Campus, Chennai 600 044, India

Delay is an important parameter in optical packet switching networks and it affects the performance of the network. In this communication, a mathematical analysis is carried out to evaluate the delay. Delay values are analysed for variable length packets for various traffic patterns, viz. non-uniform, Poisson and ON–OFF traffic patterns for various service classes using reservation bit algorithm. The results of the class-based models are compared with the existing port-based first-fit wavelength assignment algorithm. Delay values are reduced by 29% in the class-based model than in the port-based model. Furthermore, packet transmission rate in class-based model is higher by 15.4% than port-based model.

Keywords: Optical packet switching, reservation bit algorithm, traffic pattern, wavelength assignment.

OPTICAL packet switching (OPS) has emerged as one of the most promising technologies for future telecommunication networks. OPS utilizes very high bandwidth in the optical fibre using wavelength division multiplexing (WDM). The future networks are expected to transport heterogeneous traffic services, including multimedia and interactive applications necessitating bandwidth guarantees, minimum delay, less packet loss rate (PLR), controlled jitter, etc. Quality of service (QoS) provisioning therefore seems a mandatory task.

Packet loss and delay are not new issues in optical networks; however, minimum loss and delay provide better QoS in OPS. In order to improve the performance of QoS in the OPS network, a detailed analysis of delay is presented in this communication.

Figure 1 depicts the architecture of the OPS network, which comprises buffers.

The size of the switch under consideration is $F \times F$. The switch has F input fibres and F output fibres. Utilizing WDM, each fibre provides N wavelengths to transport data with a capacity of C bits per second (bps). Buffers with the size of five packets are used in the OPS switch catering to each of the service classes.

*For correspondence. (e-mail: kavivenkat99@gmail.com)

The operations of OPS 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 fibre delay line (FDL) processing buffers. The control module decides to which output the packet has to be switched. Contention occurs when two or more packets are assigned to the same output port on the same wavelength at the same time[1,2]. The network has d service classes ranging from service class 0 to service class $d - 1$. Delay is calculated in class i traffic at the tagged output fibre.

The reasons for selecting the architecture, size of the buffer, number of wavelengths and class-based transmission are given below:

Architecture: Future OPS networks will be different from today's WDM point–point architecture. However, optical networks lack optical random access memory. In order to provide an enhanced QoS in the existing optical networks, the architecture designed by Overby[3] is considered for our simulation purpose. This OPS architecture is suitable for using today's WDM concepts and also for class-based transmission.

Wavelength: In a timeslot, 16 wavelengths are assigned in our simulation. This is due to the following two reasons.

The first reason is window size. In order to increase the base capacity of the fibre, WDM uses different optical wavelengths on the fibre called 'windows'. Four, 8 and 16 WDM equipment will increase the capacity of each fibre strand by 4, 8 and 16 times respectively. Regarding the size of the window, we proceeded with the concept of 16 wavelengths.

The second reason is to create contention intentionally in the referred architecture. When 16 wavelengths are

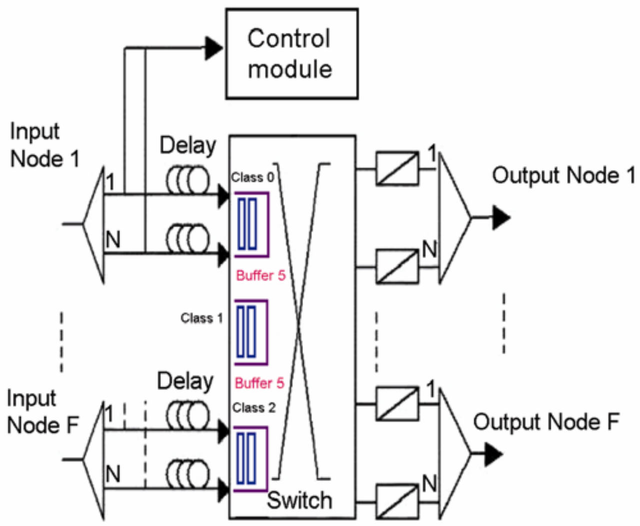

Figure 1. Architecture of the optical packet switching network with buffers.

assigned in one timeslot, four inputs can transmit 64 packets with an Erlang load of 1 and relative share of 0.25 in this architecture.

Buffer: Simulation results are taken for ten timeslots. During one timeslot, 16 wavelengths are assigned. Buffers with the size of five packets are placed to each service class. When three service classes are considered, there are three buffers with respect to each service class. Hence, 15 packets are stored in these buffers. This is nearly equal to the arrival of packets in one timeslot. Hence, buffers with the size of five packets are considered.

Service class: There are two types of transmission: (1) Flow-based transmission and (2) Class-based transmission.

In the flow-based transmission, a flow consists of the packets between two internet protocol (IP) sockets. To measure QoS in flow-based transmission, packets in one flow are different from packets in other flow[4].

In class-based transmission, there is no need to identify each flow. However, class-based transmission needs to identify packets based on their service class and consider that traffic to be in one category or in one service class for QoS treatment[4]. In class-based transmission, packets are differentiated based on service class information obtained from the packet headers. The term service class refers to a set of one or more types of traffic.

Class-based transmission is considered here for three different service classes, viz. service classes 3, 4 and 5. The types of service class under consideration are text, voice, File Transmission Protocol (FTP), audio and video.

In RB, the packets use the wavelengths according to their service class. If there is a flow of packets into the ports with a specified service class, the incoming packets with assigned wavelengths occupy the ports according to 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 wavelengths in these service classes. When the assigned wavelengths are completely occupied in all the ports, the packets will overflow. RB is implemented by introducing buffers. When a free wavelength 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 to the packet header for the purpose of reservation with respect to its service class. Whenever free wavelengths are available, the packets in the buffer occupy free wavelengths. Buffered packets will have priority over the incoming packets.

In FF, all wavelengths are numbered in a certain order, for example, ascending order from 0 to $W - 1$, where W is the 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[5].

In the class-based model, each node transmits the packets according to their service classes. Buffers are placed in the port for every class. In the port-based model, wavelengths are placed in a sequential order. Irrespective of the service class, the available wavelength is used by the incoming packets in a sequential order and buffers are only placed in each port.

FF is implemented in port-based models and packets are transmitted according to their port wavelengths, whereas transmission of packets is class-based in RB and packets are transmitted according to their service classes and wavelengths.

In non-uniform traffic pattern, each incoming packet has an equal probability of $1/N$ being addressed to any given output port and the successive packets that arrive at the tagged output/wavelength are independent. This is due to the randomness of packet arrival. The random nature of packet arrival increases the occupancy of the free wavelengths.

In Poisson traffic pattern, packet arrivals are random and mutually independent. The Poisson distribution has been obtained for packet arrivals during a short period of time λt, where λ is the arrival rate and is the average number of packet arrivals during a unit of time. The time interval between consecutive packet arrivals is exponentially distributed[6].

Bursty traffic is also known as ON–OFF traffic pattern. Both ON and OFF periods are distributed using exponential distribution. It is a process consisting of ON and OFF periods. During ON periods, a series of packets are transmitted from the source node and is known as active period. 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[7,8]. At every node, the arrival of different service classes of packets is considered. In ON–OFF traffic pattern, ON and OFF periods occur at each node for different service classes. The different possibilities of occurrence of service classes in the node are: (1) all service classes may be in OFF period, (2) all service classes may be in ON period and (3) some of the service classes may be in ON period and the rest may be in OFF period. The wavelength of one service class, which is in OFF period, is used by other service classes.

Analysis of delay for variable packet sizes in asynchronous OPS using three types of traffic pattern, viz. non-uniform, Poisson and ON–OFF traffic patterns is presented here. In contrast to Wen *et al.*[9], immaterial to packet size, allotted timeslots remain the same and no shifting of timeslot allocation is done.

The packet includes payload and header. Figure 2 shows the packet header. For variable packet size, the range is from 512 bytes to 2 kilo bytes. Twenty bytes is included as header along with the payload invariably for any type of packet. Variable size packets are used in VoIP applications. Here the size has been controlled by the application. Packet sizes in the range 1024–2048 bytes show good efficiency in terms of bandwidth and reliability in digital video broadcasting[10]. In any timeslot, the number of packet arrivals and size of the packet cannot be predicted. In order to find the packet size, uniform minimum and maximum distribution is used. This distribution is used for the observations that come from uniformly, exponentially and normally distributed populations[11].

When a packet is sent from one node to another, the following delays occur: (1) transmission delay, (2) propagation delay, (3) processing delay and (4) queuing delay. The transmission delay is usually small for fast links and for small packets, and is therefore not considered. Traditionally, the processing delay is also negligible[12]. In our measurements, we consider propagation delay and queuing delay. The average delay values for the traffic patterns under consideration are found using eq. (1).

$$T_{\mathrm{D}} = T_{\mathrm{Propogation}} + T_{\mathrm{Queue}}. \quad (1)$$

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 eq. (2). This delay is due to the waiting period of the packet in the queue. A packet is in a queue, if a free wavelength is not available at that particular timeslot.

$$T_{\mathrm{Queue}} = \frac{1}{N}\sum_{i=0}(T_i), \quad (2)$$

where T_i is the transmission time of class i packets at a particular timeslice. A timeslot is the time needed to transmit packet(s). Timeslot is divided into more number of timeslices and a timeslice is the time needed to transmit a single packet. The number of packet arrivals divides the timeslot produces the timeslice, which is utilized for packet transmission.

Summation of the waiting time in the buffer and the transmission time between source node and destination node through the switch are considered as delay and the same is found for the traffic patterns, viz. non-uniform, ON–OFF and Poisson traffic pattern.

The delay values for the fixed-length packets in slotted OPS using RB are studied and also compared to FF in our earlier publication[13]. Here, a detailed analysis is carried

Source IP address	Destination IP address	Source port number	Destination port number	Packet sequence number	Time stamp	Flow identifier
4 bytes	4 bytes	2 bytes	2 bytes	2 bytes	4 bytes	2 bytes

Figure 2. Structure of the packet header.

out to find the delay in asynchronous OPS for variable length packets. Delay is measured in buffered asynchronous OPS for service classes 3, 4 and 5 of various traffic patterns while employing RB and FF.

Delay in class *i* packets is measured in the tagged fibre. The wavelength assigned is 16 and total timeslot chosen is 10; hence this architecture can transmit 160 packets in a timeslot with an Erlang load of 1. For simulation purpose, 240 packets are chosen with an Erlang load of 1.5.

In FF, packets are transmitted with respect to their nodes and buffers are also placed with respect to their nodes. When packets arrive, the available wavelengths are placed in ascending order and therefore, all the incoming packets occupy the wavelengths one after another.

In RB, packets are transmitted with respect to their service classes and buffers are also placed with respect to their service classes. Packets of service classes 1, 2 and 3 occupy their corresponding assigned wavelengths and are transmitted in a parallel manner.

In service class 3, RB has 15 buffers, each service class has five buffers, but in FF, each port has five buffers and the total number of buffers is 20. Figures 3 and 4 show the delay values of asynchronous OPS for service class 3 while employing FF and RB respectively. It can be seen that 10.96, 10.88 and 9.83 ms are the delay values in FF, and 7.55, 7.79 and 7.91 ms are the delay values in RB using non-uniform, ON–OFF and Poisson traffic patterns respectively.

In non-uniform traffic pattern, packet arrival is in random. While employing FF in non-uniform traffic pattern, random nature of packet arrival utilizes the available wavelengths in a sequential manner. The average delay values in non-uniform traffic pattern are higher in some nodes and lesser in other nodes using FF. But in RB, if there is less number of packet arrivals in any service class; this will create free wavelengths of the same service class in that timeslot. These free wavelengths can be utilized by overflowing packets of other service classes.

In ON–OFF traffic pattern, in a timeslot, packets arrive with two state periods (ON and OFF). While employing FF in ON–OFF traffic pattern, when one node is in OFF period, the nodes which are in ON period transmit the packets in a sequential manner. Therefore, average delay values in ON–OFF traffic pattern are comparatively closer to the non-uniform traffic pattern using FF. Using RB, in ON period, service class packets are transmitted through the node, but in OFF period, service class packets are not transmitted from the corresponding node. OFF state of one node produces free wavelengths. Other nodes that are in ON period will utilize these free wavelengths. Therefore, almost equal amount of average delay occurs in all the nodes in ON–OFF traffic pattern using RB.

In Poisson traffic pattern, in a timeslot, nodes experience three types of packet arrival in a node. They are 'no packet arrival', 'less number of packet arrivals' and 'more numbers of packets'. Therefore, some nodes may transmit the

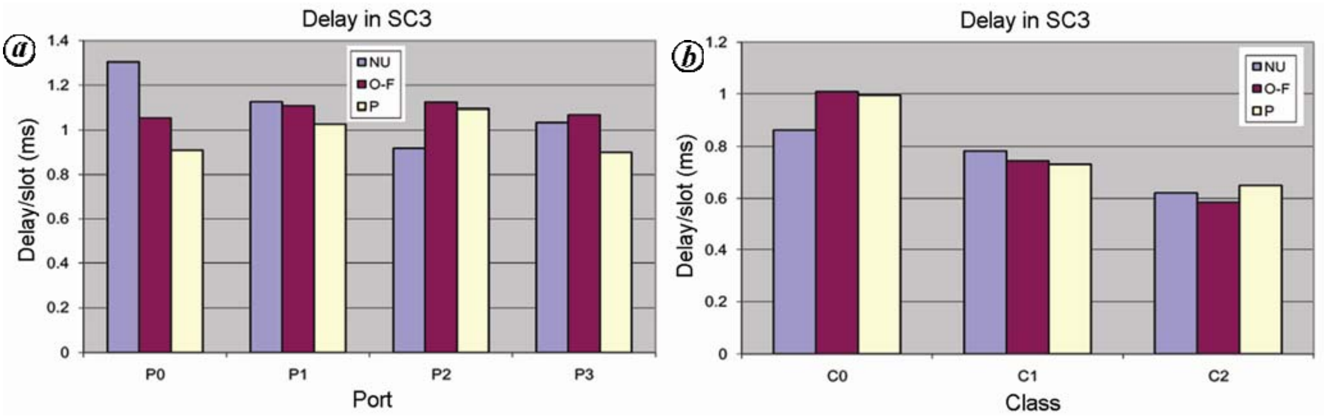

Figure 3. Delay rate for various traffic patterns for service class 3 using first-fit wavelength assignment algorithm (***a***) and reservation bit algorithm (***b***).

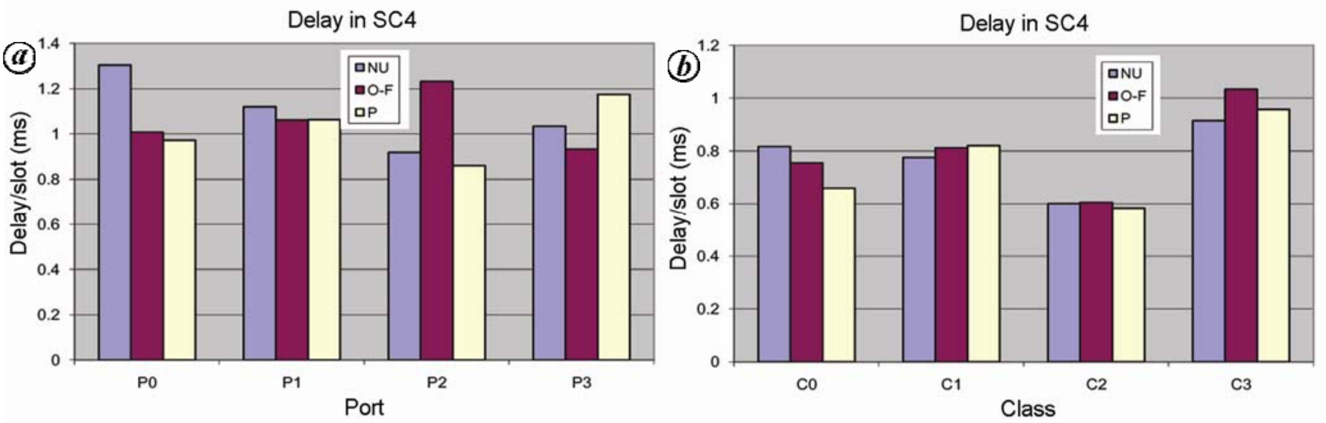

Figure 4. Delay rate for various traffic patterns for service class 4 using first-fit wavelength assignment algorithm (***a***) and reservation bit algorithm (***b***).

packets while others may not. The continuous transmission of packets in any node continuously utilizes the wavelengths sequentially. Therefore, with the implementation of FF in Poisson traffic pattern, wavelength-searching time is rather less and it also produces less propagation delay. Hence, average delay in this traffic pattern is less. Since the packets are transmitted with their own wavelengths in Poisson traffic pattern, it leads to small amount of average delay variation among service classes while implementing RB.

Using Figure 3, it has been analysed that FF exhibits higher delay when compared to RB. In FF, when one packet has arrived, it has to search the wavelength. Therefore, propagation delay is high. In addition, incoming packets and buffered packets will utilize the wavelengths in a sequential manner. Therefore, queue delay is also high. But, in RB, service class packets are transmitted in a parallel manner. Therefore, propagation delay is less. In addition, buffered packets have the first priority to occupy the wavelengths in RB. Therefore, queue delay is also less.

In service class 4, both the algorithms have 20 buffers. Figure 4 *a* and *b* shows the delay values of asynchronous OPS for service class 4 while employing FF and RB respectively. It shows that 10.94, 10.56 and 10.18 ms are the delay values in FF and 7.77, 8.01 and 7.561 ms are the delay values in RB using non-uniform, ON–OFF and Poisson traffic pattern respectively. Explanation of traffic patterns in Figure 4 *a* and *b* is similar to that of traffic patterns in Figure 3 *a* and *b*. Since in service class 4, four types of service class packet are transmitted in a parallel manner, propagation delay is less and hence delay is less in reservation bit algorithm when compared to Figure 3 *b*, as shown in Figure 4 *b*.

While in service class 5, RB has 25 buffers and FF needs 20 buffers. Figure 5 *a* and *b* shows the delay values of asynchronous OPS for service class 5 while employing FF and RB respectively. It shows that 10.09, 10.88 and 9.50 ms are the delay values in FF, and 7.1, 6.27 and 6.48 ms are the delay values in RB using non-uniform, ON–OFF and Poisson traffic pattern respectively. Explanation of traffic patterns in Figure 5 *a* and *b* is similar to that of Figure 3 *a* and *b*. Since in service class 5, five types of service class packet are transmitted in a parallel manner, propagation delay is less and hence delay is less

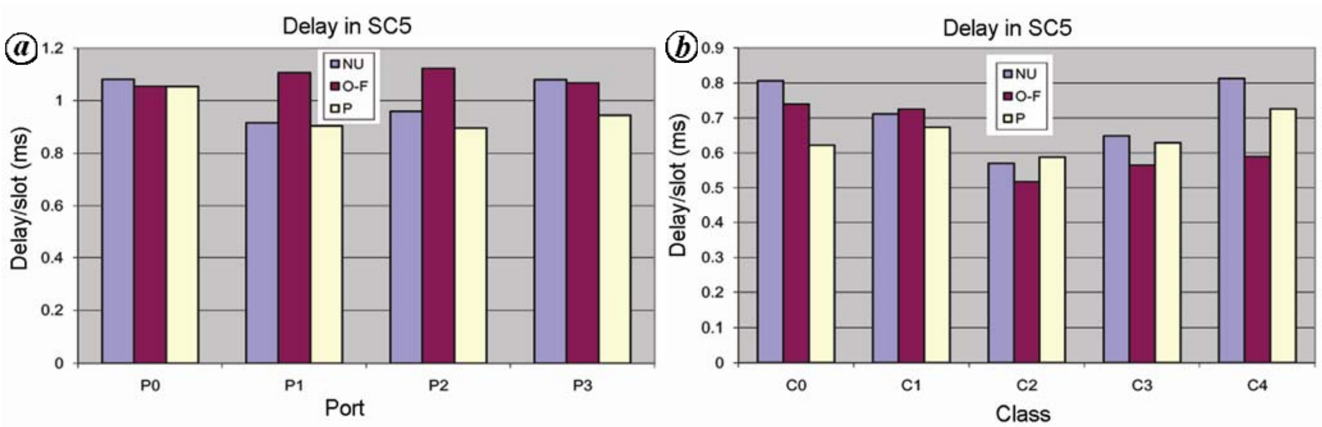

Figure 5. Delay rate for various traffic patterns for service class 5 using first-fit wavelength assignment algorithm (***a***) and reservation bit algorithm (***b***).

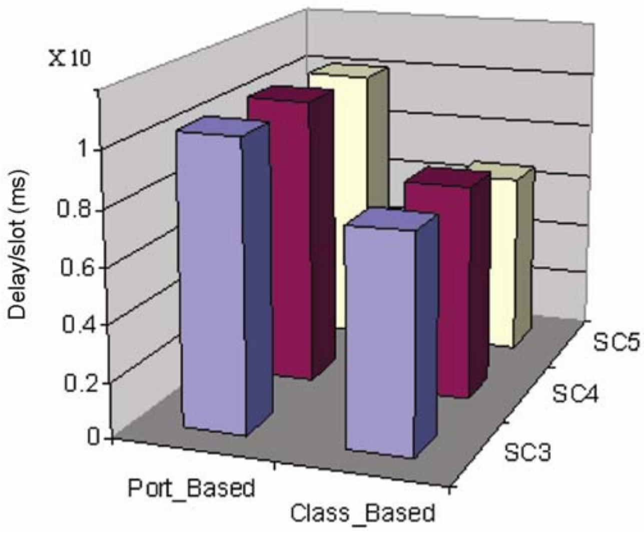

Figure 6. Delay rate comparison of various traffic patterns.

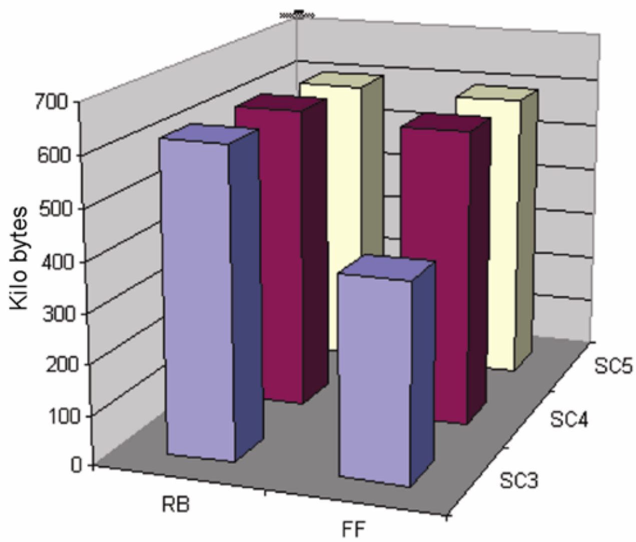

Figure 7. Comparison of data transmission.

in reservation bit algorithm when compared to Figure 3 *b*, as shown in Figure 5 *b*.

For all the service classes under consideration, buffers are more or less the same for RB and FF, whereas the delay values are slightly higher in FF. 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, the class-based model produces 29% reduction in delay rate when compared to port-based model (Figure 6). In RB, the buffered packets with respect to their service classes will occupy the free wavelengths of the corresponding service class wavelengths on a first come first serve basis, which reduces the waiting time in the buffer, while in FF, 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 is employed. The delay is reduced to a greater extent using our algorithm which improves the performance of QoS. This is due to the class-based transmission.

Figure 7 shows the total number of transmitted bytes per timeslot. It can be seen that more number of packets is transmitted in the class-based model for all service classes for all traffic patterns under consideration when compared to the port-based model. The packet transmission rate is higher by 15.4% in class-based model than port-based model. Also, class-based model produces lesser delay as well as more number of bytes being transmitted when RB is employed. Non-uniform traffic pattern produces lesser delay when compared to ON–OFF and Poisson traffic pattern.

The delay values for non-uniform, Poisson and ON–OFF traffic patterns for various service classes have been found and analysed. In addition, a comparative study of RB and FF for synchronous and asynchronous OPS is presented. RB provides lesser delay for all service classes for variable length packets when compared to FF. Delay values are reduced by 29% in class-based model than in port-based model. Furthermore, packet transmission rate is higher by 15.4% in class-based model than in port-based model. The drop rates of packets are reduced in

OPS networks while employing class-based model, resulting in improved QoS.

It is seen from the simulation results that the Poisson arrival model, which is assumed in the analysis, approximates a more practical model wherein all input wavelengths are modelled as independent ON–OFF processes. It is deduced that in OPS, RB reduces delay and thereby QoS is improved. At the same time, non-uniform traffic pattern results in better quality of service compared to ON–OFF and Poisson traffic patterns. Also, ON–OFF traffic pattern has better QoS when compared to Poisson traffic pattern, if OFF periods of one service class are more efficiently utilized by other service classes.

1. Øverby, H. and Stol, N., Evaluating and comparing two different service differentiation methods for OPS: the wavelength allocation algorithm and the preemptive drop policy. In Proceedings of 3rd International Conference on Networking, 2004, vol. 1, pp. 8–15.
2. Bjornstad, S., Stol, N. and Hjelme, D. R., A highly efficient optical packet switching node design supporting guaranteed service. *Proc. SPIE*, 2002, **4910**, 63–74.
3. Øverby, H., Packet loss rate differentiation in slotted optical packet switched networks. *IEEE Photon. Technol. Lett.*, 2005, **17**(11), 2469–2471.
4. Odom, W. and Cavanaugh, M. J., *IP Telephony Self-Study-Cisco QOS Exam Certification Guide*, CISCO Press, USA, 2005, 2nd edn.
5. Sun, X., Li, Y., Lambadaris, I. and Zhao, Y. Q., Performance analysis of first-fit wavelength assignment algorithm in optical networks. In IEEE Proceedings of the 7th International Conference on Telecommunications (ConTEL2003), 2003, vol. 2, pp. 403–409.
6. Yue, W., Takahashi, Y. and Tagaki, H., *Advances in Queueing Theory and Network Application*, 2009, Springer, ISBN: 978-0-387-09702-2, e-ISBN: 978-0-387-09703-9.
7. Kulikos, M. and Petersons, E., Remarks regarding queueing model and packet loss probability for the traffic with self-similar characteristics, networks. *Int. J. Electrical Comput. Engg.*, 2008, **3**(2), pp. 85–90.
8. Wong, E. W. M. and Zukerman, M., Bandwidth and buffer tradeoffs in optical packet switching. *J. Lightwave Technol.*, 2006, **24**(12), 4790–4798.
9. Wen, B., Shenai, R. and Sivalingam, K., Routing, wavelength and time-slot-assignment algorithms for wavelength-routed optical WDM/TDM networks. *J. Lightwave Technol.*, 2005, **23**(9), 2598–2609.
10. Vadakital, V. K. M., Hannuksela, M. M., Razaei, M. and Gabbouj, M., Optimal IP packet size for efficient data transmission in DVB-H. In Proceedings of the 7th Nordic IEEE Signal Processing Symposium, 2006, pp. 82–85.
11. Jance, J. and Thomopoulos, N., Min and max uniform extreme interval values and statistics. *J. Bus. Econ. Res.*, 2009, **7**(1).
12. Ramaswamy, R., Weng, N. and Wolf, T., Characterizing network processing delay. IEEE Proceedings of Global Telecommunications Conference (GLOBECOM'04), 2004, vol. 3, pp. 1629–1634.
13. Kavitha, A., Rajamani, V. and Anandhakumar, P., Performance analysis of slotted optical packet switching scheme in non-uniform traffic pattern using reservation bit technique. *INFOCOMP J. Comput. Sci.*, 2009, **8**(4), 71–78.

Received 3 August 2010; revised accepted 3 November 2011

A study on the factors affecting the morphology and electro-optical properties of polymer dispersed liquid crystal display

Farzana Ahmad[1], Jin Woo Lee[1], Y. J. Jeon[1,]* and M. Jamil[2]

[1]Liquid Crystal Research Center, Department of Chemistry, and
[2]Division of International Studies, University College, and
High Energy Physics Lab, Department of Physics, Konkuk University, Seoul 143-701, Korea

This communication deals with the study of polymer dispersed liquid crystal (PDLC) display fabricated by polymer-induced phase separation method. The effect of change in curing conditions (e.g. composition, UV power and temperature) on morphology and electro-optical properties of PDLCs was studied. In the studied PDLC film, liquid crystal (LC) dispersed in polymer matrix made droplet morphology. From our experimental findings, an increase in droplet size with increase in LC content (curing at low temperature and low UV power) has been observed. Further electro-optical properties developed by these morphologies are studied in detail.

Keywords: Droplet morphology, electro-optical properties, phase separation, polymer dispersed liquid crystal.

IN the last few decades polymer-dispersed liquid crystals (PDLCs), composed of micron-sized liquid crystal (LC) droplets (diameter from 10^{-8} up to 10^{-4} μm) embedded in a solid polymer matrix[1] have been the subject of intensive studies[2–13], because of both fundamental interest and potential applications in the field of smart windows, light shutter and active display devices[14–17]. These are subjects of interest due to the unique electro-optical properties of LC and ease of the fabrication process.

A PDLC film exhibits transparent and light-scattering states in electric field-on and field-off states respectively. In the field off-state, the PDLC film scatters light due to mismatch between the effective refractive index (n_{eff}) of the LC and the refractive index of the polymer (n_p). In the field-on state, LCs of positive anisotropy tend to align themselves with the directors parallel to the field direction. In such a state, the refractive index for incident light is equal to the ordinary refractive index (n_0), and if n_0 is matched with n_p, the films become transparent[18].

There are four distinct phase-separation methods for the preparations of PDLC films: polymerization-induced phase separation (PIPS), thermally induced phase separation (TIPS), reaction-induced phase separation (RIPS) and solvent evaporation-induced phase separation (SIPS)[19,20]. Morphologies, i.e. concentration, size and shape of LC

*For correspondence. (e-mail: yjjeon@konkuk.ac.kr)