A Probabilistic Preemptive Scheme for Providing Service Differentiation in OBS Networks

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Abstract— **In this paper, we propose a Probabilistic Preemptive (PP) scheme for service differentiation in Optical Burst Switching (OBS) networks. By changing the preemptive probability, an OBS node can adjust the ratio of burst blocking probability between different traffic classes, while the overall blocking probability is not affected.**

I. INTRODUCTION

Optical burst switching (OBS) [1][2] is a promising solution for the next generation IP over wavelength-division multiplexing (WDM) networks. OBS combines the advantages of optical circuit switching and optical packet switching. OBS uses separate wavelengths to transmit control packets and data bursts. A control packet is sent out ahead of its corresponding data burst to reserve wavelength along the path of the burst. Then, the data burst can pass through switching nodes along its path optically without OEO (optical-electronic-optical) conversion.

In OBS networks, how the WDM layer supports differentiated service is an important issue. Supporting basic service differentiation at WDM layer can facilitate and complement a QoS-enhanced version of IP (e.g. IPv6). Among various QoS parameters, burst blocking probability is a critical one for service differentiation in OBS networks [3]. This is because it is desirable to have low blocking probability for high priority traffic, even when the overall load is heavy and the number of available wavelengths is limited. Thus, we need to find a suitable scheme to enhance OBS to support service differentiation. For this, there are a few challenges. First, the scheme should not degrade the overall performance, especially in terms of burst blocking probability. Second, the scheme needs to be simple to implement. Third, the scheme should avoid using optical buffer since optical buffer is not available yet. Fourth, the additional delay, if there is any, introduced by the scheme should not be too large.

To date, several OBS service differentiation schemes have been proposed in the literature. The extra offset-time-based scheme was introduced in [3]. In this scheme, the high priority class is given larger offset time. Having an extra offset time, the high priority class is able to reserve wavelength prior to the low priority class. Although this scheme can effectively achieve a good service differentiation by adjusting the extra offset time, it may introduce a significantly large extra offset time. In [4], it is shown that to achieve the best differentiation, the extra offset time has to be at least 4 to 5 times larger than the basic offset time. However, this may affect the end-to-end delay much. Another problem with this scheme is that it is particularly unfair to long bursts of low priority as discussed in [5]. The third problem with this scheme is the so-called near-far problem. Since the offset time is set according to path length as well as priority, there is a situation where two control packets may contain the same offset time but have different meanings. One is low priority burst with a large number of hops to travel, while the other is priority burst with extra offset time. In this case, the switching node could treat them equally. In an even worse situation, a switching node may see larger offset time of a low priority burst than that of a high priority burst. Consequently, the low priority burst may have higher chance to get a channel than the high priority burst if the offset-time-based scheme is adopted.

The segmentation-based scheme was studied in [6]. It assembles different priority segments into a burst at network ingress nodes. In each burst, packets are placed from the head to the tail of the burst in the order of decreasing priority. In case of contention, the segments having lower priority are either dropped or deflected whereas the remaining part of the burst can still be delivered to the destination node. However, this scheme encounters increased complexity for burst assembling at the destination node and burst scheduling at the intermediate switching node.

The intentional-dropping-based scheme was proposed in [5]. It implements a burst dropper at each switching node. The loss rate of each traffic class is maintained in a pre-defined proportion. A burst is dropped if the predefined loss rate of its class is violated, regardless of whether there is an idle channel. Intentional dropping gives more free periods of wavelengths to admit high priority bursts. The problem of this scheme is that it can cause excessive dropping, resulting in high dropping probability and low system utilization.

In this paper, we propose a novel scheme, called Probabilistic Preemptive scheme, for providing service differentiation in terms of burst blocking probability in OBS networks. This scheme is based on preemptive discipline. The difference is that we add a preemptive probability to the high priority class. Thus, high priority bursts can preempt low priority bursts in a probabilistic manner.

The rest is organized as follows. Section II describes the proposed scheme in detail. Section III analyzes the proposed scheme through multi-dimensional Markov chain. Explicit analytical results are given for a single channel system.

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Section IV presents simulation results to validate analytical results and study its ability in providing service differentiation. Finally, conclusions are made in Section V.

II. THE PROBABILISTIC PREEMPTIVE SCHEME

The main idea behind the Probabilistic Preemptive scheme is to add a probabilistic parameter to the existing preemptive scheme. This is similar to what has been used in our previous work [7][8][9], where the Probabilistic Priority discipline is designed for achieving service differentiation in electronic packet switching networks by adding a probabilistic parameter to the priority discipline. Nevertheless, the Probabilistic Preemptive scheme is different from the Probabilistic Priority discipline. First, the former has its root on preemption, which, however, is not allowed in the latter. Second, performance metrics for them is different. While the former focuses on burst drop or blocking differentiation, the latter is targeted for packet delay differentiation.

By changing the probabilistic parameter, the Probabilistic Preemptive scheme can achieve flexible blocking differentiation in OBS networks. With this scheme, when high priority bursts need wavelengths at a switching node but there is no room to accommodate them, wavelength reservation is re-examined. A high priority burst may preempt a low priority burst based on the probabilistic parameter to release the transmission period to the high priority burst. It is worth highlighting here that such preemption happens when the corresponding control packet for the high priority burst arrives. Since a control packet is sent out always before its corresponding data burst, each switching node has time to rearrange wavelength reservation even though there is no buffer available. Also note that the preemption is applied to the reserved transmission period not the real burst. Since the transmission period was initially reserved for the low priority burst, when it actually arrives to the node, it is dropped or blocked.

In this paper, we focus on the two-class case for simplicity. We classify bursts into two classes, namely class 1 and class 2. Class 1 is assumed to have high priority over class 2. For the high priority class, it is assigned a preemptive probability, p, with which it can preempt low priority class, i.e. class 2.

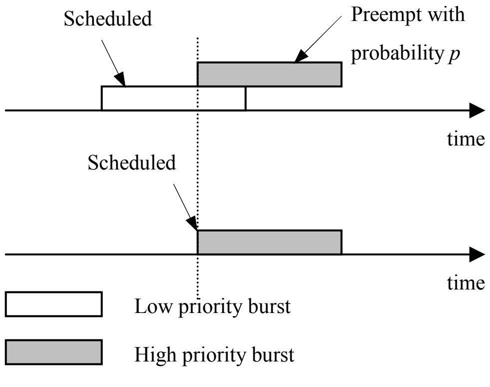


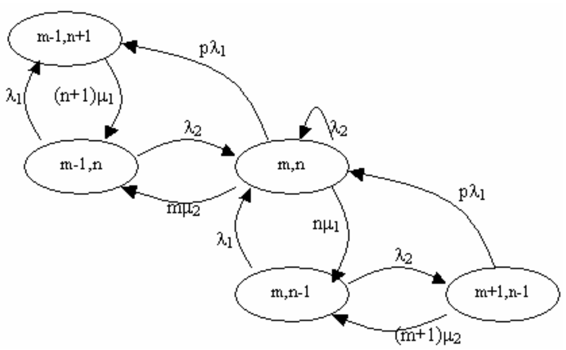
Figure 1. Probabilistic Preemptive scheme

A switching node keeps a linked list to track wavelength reservation information. Upon the arrival of a high priority class control packet, the switching node searches for a free period first. If the switching node cannot find a free period for that burst, it preempts a low priority burst based on the preemptive probability p as shown in Figure 1. If the preemption cannot be performed, i.e., all corresponding periods have been reserved for high priority bursts, the new coming high priority burst is simply dropped.

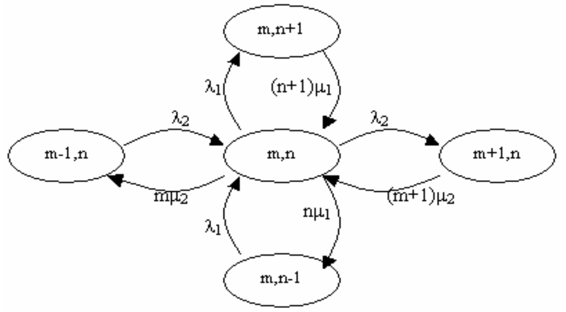
Clearly, the preemptive probability p affects the blocking probability for high priority class as well as for low priority class. Hence, we can ensure high priority class to have lower blocking probability than low priority class, since we can allocate more resource to high priority class by changing p. Similarly, we can adjust p to get different blocking probability ratio between these two classes, i.e., we can adjust the degree of blocking differentiation by changing p.

III. ANALYSIS

In this section, we analyze the blocking probability of the two classes. The analysis is based on the following assumptions. First, bursts of class i arrive according to a Poisson process with mean arrival rate λ_i. Note that such an assumption is adequate since it has been shown in [10][11] that Poisson arrival process can approximate real burst arrival after packet assembly very well. Second, service time of each class follows an exponential distribution with mean service rate μ_i. Third, all classes of traffic share k wavelengths and full wavelength conversion is assumed as for other schemes reviewed in the previous section.



(a) when m+n=k



(b) when 0 ≤m+n<k

Figure 2 State transition diagrams for state (m,n)

Figure 2 shows the state transition diagrams for a typical state (m,n), where the 2-tuple (m,n) represents a state in which m class 2 bursts and n class 1 bursts are in the system. $P_{m,n}$ is the probability that the system is in state (m,n). To get a general expression of balance equations, we simply set $P_{m,n}$ to 0 if either m<0 or n<0. Then, based on Figure 2, the balance equations for state (m,n) can be written as follows:

If $0 \le m+n < k$,

$$P_{m,n}(\lambda_1 + \lambda_2 + n\mu_1 + m\mu_2) - \lambda_1 P_{m,n-1} - \lambda_2 P_{m-1,n}$$
$$-(n+1)\mu_1 P_{m,n+1} - (m+1)\mu_2 P_{m+1,n} = 0 \qquad (1)$$

If m+n=k,

$$P_{m,n}(p\lambda_1 + n\mu_1 + m\mu_2) - \lambda_1 P_{m,n-1} - \lambda_2 P_{m-1,n}$$
$$-p\lambda_1 P_{m+1,n-1} = 0 \qquad (2)$$

In addition, we have

$$\sum_{\substack{m,n=0 \\ m+n \le k}}^{k} P_{m,n} = 1 \qquad (3)$$

To get the blocking probabilities of the two classes, we need to first derive the state probabilities $P_{m,n}$ by solving above equations. Then, we can obtain the blocking probabilities through proper equations. In the following subsection, we show how these can be done for a single channel system as an example.

A. The Single Channel Case

For a single channel system, its state transition diagram is shown in Figure 1, where it is assumed that the two classes have the same service rate μ.

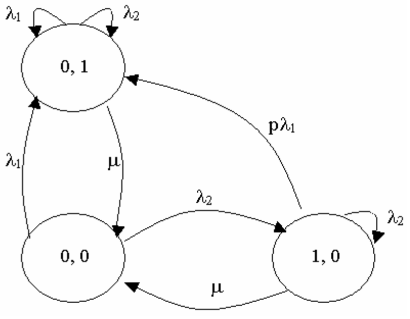


Figure 3. State transition diagram of a single-channel system with Probabilistic Preemption

The balance equations for the single channel system are re-written as followings based on equation (1) and (2):

$$\lambda_1 P_{00} + p\lambda_1 P_{10} = \mu P_{01} \qquad (4)$$
$$\lambda_2 P_{00} = \mu P_{10} + p\lambda_1 P_{10} \qquad (5)$$

Together with

$$P_{00} + P_{10} + P_{01} = 1 \qquad (6)$$

The state probabilities can be obtained as:

$$P_{00} = \frac{\mu}{\lambda_1 + \lambda_2 + \mu}$$

$$P_{10} = \frac{\lambda_2 \mu}{(\mu + p\lambda_1)(\lambda_1 + \lambda_2 + \mu)}$$

$$P_{01} = \frac{\lambda_1(p\lambda_1 + p\lambda_2 + \mu)}{(\mu + p\lambda_1)(\lambda_1 + \lambda_2 + \mu)}$$

Finally, the blocking probabilities p_i are calculated as:

1)For high priority class,

$$p_1 = P_{01} + (1-p)P_{10}$$

which, clearly, comprises two parts:

- The probability that a high priority burst arrives at state (0,1) and is dropped.
- The probability that a high priority burst arrives at state (1,0). However, the preemption cannot be performed due to probability (1-*p*) and hence the burst is dropped.

2) For low priority class,

$$p_2 = (P_{01} + P_{10}) + \frac{\lambda_1}{\lambda_2} p P_{10}$$

This result is derived based on the following. Consider a large time interval *T*. In this interval, there are $(\lambda_1+\lambda_2)T$ arrivals. For these arrivals, there are totally $(\lambda_1+\lambda_2)TP_{00}$ are transmitted successfully. Among those successfully transmitted bursts, $\lambda_1 T(1 - p_1)$ are high priority class 1 bursts and the remaining are low priority bursts. Hence, the blocking probability of low priority bursts in this interval is given by

$$1 - \frac{(\lambda_1 + \lambda_2)TP_{00} - \lambda_1 T(1-p_1)}{\lambda_2 T}$$

By applying equation (6) in the above form, the blocking probability of the low priority class is obtained. Intuitively, this probability can also be considered as consisting of two parts:

- The probability that a low priority burst arrives at either state (0,1) or state (1,0) and is dropped.
- The probability *p* that low priority bursts at state (1,0) are preempted by some high priority bursts. Here, there is a factor λ_1/λ_2 being enforced. It is to account that only this portion of class 2 bursts at state (1,0) can be possibly preempted by high priority bursts due to the arrival rate difference between the two classes.

3) The overall blocking probability is calculated as:

$$p_{overall} = \frac{\lambda_2 p_2 + \lambda_1 p_1}{\lambda_1 + \lambda_2} = \frac{\lambda_1 + \lambda_2}{\lambda_1 + \lambda_2 + \mu}$$

For the overall blocking probability, it is interesting to see that it has no relationship with the probability parameter *p* and hence does not change when *p* varies.

B. *Achievable Blocking Differentiation*

1) When p=1:

Based on the analysis in the previous subsection, it is easy to verify that, for the Probabilistic Preemptive scheme, the lowest p_1 occurs when the preemptive probability p is equal to one. This means high priority bursts always preempt low priority bursts whenever it is necessary to do so. In addition, this lowest p_1 can be calculated using Erlang loss formula as follows:

$$p_1 = \frac{(\lambda_1/\mu)^k/k!}{\sum_{n=0}^{k}(\lambda_1/\mu)^n/n!} \qquad (7)$$

which is also the lowest blocking probability for high priority class that any scheme can achieve. This implies that the proposed scheme has the ability to achieve the largest burst blocking differentiation.

2) When p=0:

For the worst case, high priority class bursts are not allowed to preempt low priority class bursts, i.e. there is no differentiation between the two classes. This can also be achieved by the proposed scheme if p is set to zero. For this case, the two classes have the same blocking probability, which can be calculated as below:

$$p_1 = p_2 = \frac{((\lambda_1+\lambda_2)/\mu)^k/k!}{\sum_{n=0}^{k}((\lambda_1+\lambda_2)/\mu)^n/n!} \qquad (8)$$

Hence, for high priority class, its burst blocking probability is bounded between (7) and (8). By adjusting the preemptive probability *p*, we can get any desired blocking probability for high priority class between these two bounds.

C. *Conformance to the Conservation Law*

The conservation law states that the sum of the blocking probabilities p_i encountered by a set of traffic classes, weighted by their shares of arrival rate λ_i, is independent of the scheduling discipline. In other words, $\Sigma(\lambda_i * p_i) = (\Sigma\lambda_i)*p_{overall}$, where $p_{overall}$ is the overall blocking probability of the system and is independent of the adopted scheduling scheme.

In [12], it has been conjectured that the conservation law holds for the extra offset-time-based scheme. The work in [12] verified through simulation that the overall performance, which is the burst blocking probability, of an extra offset-time based system stays the same regardless of the number of classes and the setting of extra delay to the offset-time.

For the Probabilistic Preemptive scheme, we also have the same conservation conjecture, which is the overall blocking probability of a Probabilistic Preemptive system stays the same regardless of the degree of service differentiation determined by the preemptive probability *p*. From the analysis of the single channel case, it can be easily verified that this conjecture holds. For multiple-channel cases, we shall verify such a conjecture through simulation in the next section.

IV. SIMULATION RESULTS

In this section, we use simulation to show that the proposed Probabilistic Preemptive scheme can support service differentiation in OBS networks. Here, a single switching node system without buffer is used for simulation. It is assumed that the switching node has full wavelength conversion capability. In addition, it has 8 wavelengths or channels in its output link to transmit data bursts and 1 channel to transmit control packets. It is also assumed that there is no loss of control packets. In the simulation, the same service rate μ is set for the two classes, while the arrival rate of class 2 is twice of that of class 1, i.e., $\lambda_2 = 2\lambda_1$.

A. *Impact of p on Burst Blocking Ratio*

Figure 4 shows the burst blocking ratio between the two classes against the preemptive probability *p*. The blocking ratio refers to the blocking probability of high priority class 1 divided by that of low priority class 2. In this figure, the high and low priority class loads are 0.2 and 0.4 respectively. Figure 4 shows that the blocking probability ratio decreases when *p* increases. The ratio equals to 1 when *p* is 0. This is the situation where preemption does not take place and the two classes have the same blocking probability. The maximum service differentiation occurs when *p* is 1, i.e., when the blocking ratio achieves the lowest value. At this situation, preemption will always be preformed whenever it is necessary. In addition, we can get the desired loss ratio by adjusting *p* to achieve required service differentiation.

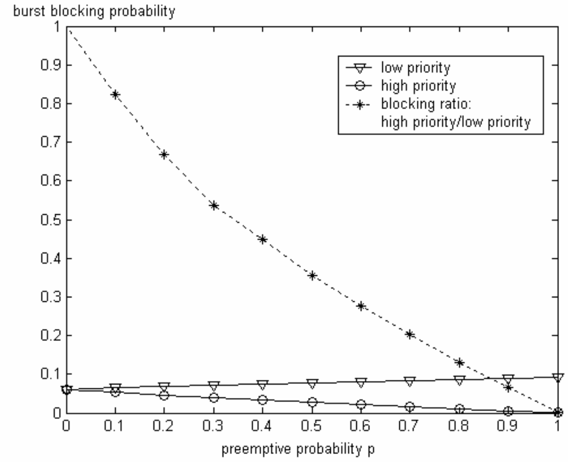


Figure 4. Preemptive probability p vs. blocking ratio

B. *Impact of p on Blocking Probabilities*

Figure 5 shows blocking probabilities against *p* for the 8-channels system. Here again, high priority class load is 0.2 and low priority class load is 0.4. It can be seen from this figure that the overall blocking probability stays the same regardless of the change of *p*. Hence, the proposed scheme can effectively achieve service differentiation, while maintain the overall performance. This also implies that the conjectured conservation law holds for the 8-channels system.

Figure 6 further shows the overall burst blocking probability against preemptive probability *p* for systems with some other number of channels with the same load condition. This figure illustrates the same phenomenon as shown in

Figure 5 in terms of the overall burst blocking probability against *p*. These simulation results validate the conformance of the Probabilistic Preemptive scheme to the conservation law.

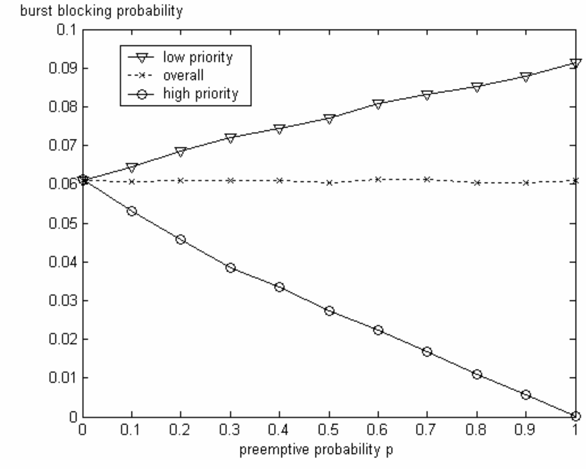


Figure 5. Preemptive probability p vs. blocking probabilities

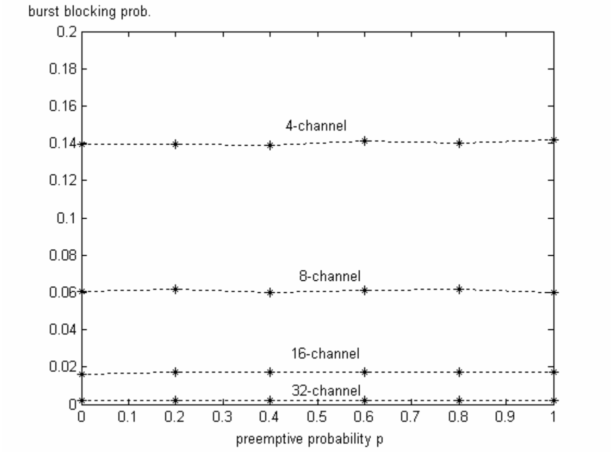


Figure 6. Preemptive probability p vs. overall blocking probability

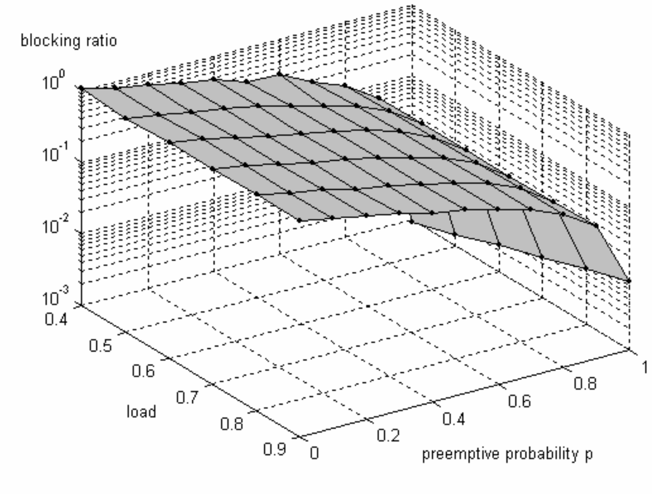


Figure 7. Blocking ratio vs. both load and preemptive probability p

C. *Impact of Load on Burst Blocking Ratio*

Figure 7 shows the impact of load as well as the preemptive probability *p* on burst blocking ratio between the two classes in the simulated system. Here, the blocking ratio again refers to the blocking probability of high priority class 1 divided by that of low priority class 2. It can be observed from the figure that, as load increases, the blocking ratio decreases. In addition, as *p* increases, the blocking ratio decreases due to more preemptions taking place. It is interesting to see that a desired blocking ratio can be maintained by adjusting *p* properly even when load condition changes. Clearly, the proposed Probabilistic Preemptive scheme is flexible for providing service differentiation in OBS networks.

V. CONCLUSIONS

In this paper, a simple and flexible scheme, called the Probabilistic Preemptive scheme, has been proposed to provide efficient support of service differentiation in OBS networks. The proposed scheme does not require the use of buffer at a switching node. Nor does it introduce additional delay. Analytical and simulation results have shown that the Probabilistic Preemptive scheme is effective in achieving adjustable service differentiation without degrading the overall performance in terms of blocking probability. Note that while the proposed scheme provides another option for achieving service differentiation in OBS networks, it does not exclude the integration with other schemes with the same purpose. In fact, all the three schemes reviewed in the introduction may be integrated with the Probabilistic Preemptive to achieve additional freedom in achieving service differentiation in OBS networks.

REFERENCES

[1] C. Qiao and M. Yoo, “Optical Burst switching (OBS)-A New Paradigm for An Optical Internet”, Journal of High Speed Networks, Vol. 8, pp.69-84, 1999.

[2] J.S. Turner, "Terabit burst switching", Journal of High Speed Networks, Vol. 8, No. 1, pp. 3-16, 1999.

[3] M. Yoo and C. Qiao, "A New OBS Protocol for Supporting QoS", in SPIE Proc. of Conf. All-optical Networking, Vol. 3531, pp. 396-405, Nov. 1998.

[4] M. Yoo and C. Qiao, "Supporting Multiple Classes of Services in IP over WDM Networks", IEEE GLOBECOM’1999.

[5] Y. Chen, M. Hamdi, and D.H.K. Tsang, "Proportional QoS over OBS networks", IEEE GLOBECOM 2001.

[6] V. Vokkarane, Q. Zhang , J. Jue, and B. Chen, "Generalized Burst Assembly and Scheduling techniques for QoS Support in Optical Burst-Switched Networks", IEEE GLOBECOM’2002.

[7] Y. Jiang, C. K. Tham and C. C. Ko, “A Probabilistic Priority Scheduling Discipline for Multi-Service Networks”, Computer Communications, Vol. 25, No. 13, pp. 1243 - 1254, 2002.

[8] Y. Jiang, C. K. Tham and C. C. Ko, “Delay Analysis of a Probabilistic Priority Discipline”, European Trans. On Telecommunications, Vol. 13, No. 6, pp. 563 - 577, 2002.

[9] C. K. Tham, Q. Yao and Y. Jiang, “Achieving Differentiated Services through Multi-Class Probabilistic Priority Scheduling”, Computer Networks, Vol. 40, No. 4, pp. 577 - 593, 2002.

[10] X. Yu, Y. Chen and C. Qiao, "Performance Evaluation of Optical Burst Switching with Assembled Burst Traffic Input." IEEE GLOBECOM’2002.

[11] M. Izal, J. Aracil. "On the influence of self similarity on Optical Burst Switching traffic" IEEE GLOBECOM’2002.

[12] M. Yoo, C. Qiao and S. Dixit, "QoS Performance in IP over WDM Networks", IEEE JSAC, Vol. 18, No. 10, pp. 2062-2071, Oct. 2000.