Investigation of The Time-Offset-Based QoS Support with Optical Burst Switching in WDM Networks

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***Abstract*—IP over WDM networks have been receiving much attention as a promising approach to building the next generation Internet since it can reduce complexities and overheads associated with the ATM and SONET layers. Provision of quality of service (QoS) is one important topic in next generation Internet. Recently, An optical burst switching scheme to support basic QoS at the WDM layer, the offset-time-based QoS scheme, was proposed by Yoo, Qiao and Dixit (YQD scheme). In this paper, we propose a union bound method to estimate the loss probability for different priority service, which is an extension of the bounds given by Yoo, Qiao and Dixit. It is proved that the proposed union bound is tighter than that given by Yoo, Qiao and Dixit. Meanwhile, based on the conservation law, we also present a method to estimate the required maximum delay length of fiber delay lines (FDLs) if FDL buffers are employed in YQD scheme in IP over wavelength division multiplexing (WDM) networks. Some numerical results on the effect of fiber delay lines on the system performance and the required maximum delay length of FDLs for different service classes are presented.**

I. INTRODUCTION

There has been explosive growth in Internet Protocol (IP) traffic in the last few years. It has triggered a lot of research activities in devising new high speed transmission and switching technology. Wavelength division multiplexing (WDM) has emerged as a core transmission technology due to its capability of supporting a number of high speed (gigabit) channels in one single fiber. In order to efficiently use the bandwidth at WDM layer, it requires to develop the corresponding frameworks and protocols at higher layers.

Among them, IP over WDM networks have received much attention since it can reduce complexities and overheads associated with the ATM and SONET layers. Meanwhile, provision of quality of service (QoS) supports is another important issue in next generation Internet. This is because current IP provides only best effort service, but some critical and real time applications require a high QoS. (e.g. low delay, jitter and loss probability). Thus supporting QoS in IP over WDM networks is becoming an important research field.

There are some works focusing on the switching technologies [1]-[6]. Most of them think that optical burst switching is a promising paradigm since it combines the desirable feature of wavelength routing and optical packet switching. It features out of band control signal processing that eliminates buffering of data burst at intermediate nodes, while minimizing the setup time , and maximizing the cross-connect bandwidth efficiency. In [1] [4], they proposed an offset-time-based optical burst switching scheme which can use the extra offset time to isolate classes of traffic instead of the buffer. Meanwhile, if some fiber delay lines (FDLs) are employed, the system performance can be improved greatly. This kind of QoS support are implemented at WDM layer, which can be considered as a complement to QoS enhanced version of IP (IPv6). In [4], they only presented the upper and lower bounds on the burst loss probability in theory. However, the estimation of the maximum delay length of FDLs for different classes of traffic are based on simulation. If the product of the wavelength number per fiber and the FDL numbers is relatively larger, the simulation will take too much time to converge, especially for cases with low loss probability (e.g. less than 10^{-7}). In this paper, we investigate the QoS performance of YQD scheme and propose an union bound method to estimate the loss probability of traffic for different service classes. Comparing to the bounds of loss probability given in [4], the main difference in the proposed union bound is that it considers the factor of maximum delay length of FDLs. Furthermore, we also present a method to evaluate the required maximum delay length of FDLs based on the conservation law.

II. OPTICAL BURST SWITCHING AND OFFSET-TIME BASED QOS SCHEME

In this section, we shall review the offset-time-based QoS scheme given in [1][4].

In IP over WDM networks, IP routers connect to optical switching nodes (OSN). Inside the WDM backbone network, each OSN is interconnected with neighboring OSN through fiber links. Fig. 1 illustrates possible structure of an OSN. There are L incoming (and outgoing) fiber links, each of which has k wavelengths for carrying data burst

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and one additional wavelength for carrying control packet. Every control packet is processed by the electronic control module inside OSN, which generates appropriate control signals to set up the wavelength converters, FDL buffers and switching fabric. The optical switching fabric, which functions as an $Lk : Lk$ no blocking switch, switches each burst on an incoming wavelength as it arrives. The embedded FDL buffer is assumed as variable delay FDL buffers, each FDL buffer can provide a different maximum delay ranging from b to $(N-1)b$, where b is the delay that a single fiber delay element can provide.

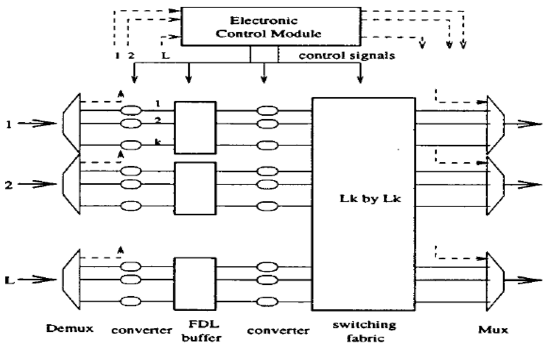

Fig. 1. structure of optical switching node.

Note that one physical FDL can be shared by all k wavelengths and creates k virtual FDLs.

The offset time based QoS scheme is as follows. At a source edge router, a 'base' offset time is predefined/calculated based on the total processing time to be encountered by a control packet on its way to the destination edge router. The basic idea is that the control packet will be sent first, but the corresponding data burst (e.g. several IP packets) will be buffered at the source edge router for this base offset time while the control packet is processed at each and every intermediate OSN. To establish an all optical path, the burst will cut through the preconfigured OSNs along the established path.

For a higher priority of bursts, an extra offset time is given. The control packet carries the value of the total offset time (sum of the extra offset time and the base offset time) along with other information such as destination address (or label), and the burst duration. As a result of processing the control packet at each intermediate OSN, a wavelength on the desired output link will be reserved using delayed reservation (DR), where reservation is made from the burst arrival time to the burst departure time. If no wavelength is available, the burst will be blocked and one FDL will be reserved using DR as well. Note that in OBS, since every wavelength reservation is made with known duration, the blocking time of the burst can easily determined. Based on the blocking time, the FDL with an appropriate length (delay time) will be reserved. If the blocking time is larger than the maximum delay time B, no FDLs will be reserved and the burst will be simply dropped without wasting any buffer capacity.

In [1][4], it has shown that if an appropriate extra offset time for each higher priority class to reserve the wavelengths and FDLs is given, higher priority class can be almost completely isolated from the lower priority classes in the sense of blocking probability. That is to say, it is almost true that the burst of higher priority will not be blocked by the bursts with lower priority.

III. UNION BOUNDS ON LOSS PROBABILITY

In this section, we shall analyze the blocking probability of two OBS protocols, namely, classless OBS and prioritized OBS. In classless OBS, no extra offset time is assigned to any burst except the base offset time (i.e., no priority, as in current IPs best effort service), whereas in prioritized OBS, a longer extra offset time will be assigned to a higher priority class. In order to distinguishes n classes where class i has higher priority (longer offset time) over class j if $i > j$.

Assume that class i arriving process of bursts belongs to the Possion distribution with average rate λ_i and an exponentially distributed service rate with an average $\mu_i = 1/L_i$, where L_i is the average length of the bursts of class i . Thus, the traffic intensity of class i is given by $\rho_i = \lambda_i/(\mu_i k) = \gamma_i/k$, where $\gamma_i = \lambda_i/\mu_i$, and the total traffic intensity is $\rho = \sum_{i=1}^{n} \rho_i$. The following model is similar to that used in [1]. We consider an OSN shown in Fig. 1, and focus on a given output link having k wavelengths and a single fiber FDL buffer containing N FDLs.

Let us first consider the bounds on loss probability in classless OBS. Assuming that the switch has an FDL buffer which can be roughly modeled as $M/M/k/D$ (where D is to be determined). Since the number of physical FDLs is N, the number of virtual FDLs is $d = Nk$. In order to simplify the analysis, we also assume that all the n classes have the same average burst length, that is, $L_i = L$. Let β denote the maximum length of FDLs in the FDL buffer. The probability of bursts having length larger than β is $1 - \exp(-\beta/L)$. Thus the average number of virtual FDLs which can be really occupied is $d(1 - \exp(-\beta/L))$. The average number of bursts in the switch (including those being transmitted and those being delayed) is $D = k + Nk(1 - \exp(-\beta/L))$. Because D may not be an integer, we replace it by D_1 and D_2, where D_1 is the largest integer less than D, and D_2 is the least integer greater than D. According to the $M/M/k/D_m$ model [7], the union bounds on the loss probability are, respectively,

$$pb_m = PB(k, \rho, D_m) = \frac{\gamma^{D_m}}{k^{D_m - k} k!} p_0, m = 1, 2, \qquad (1)$$

where $\gamma = \rho k$ and

$$p_0 = (\sum_{n=0}^{k-1} \frac{\gamma^n}{n!} + \sum_{n=k}^{D_m} \frac{\gamma^n}{k^{n-k}k!})^{-1}, m = 1, 2. \qquad (2)$$

It is easy to see that when there is no FDL buffer, i.e., $\beta = 0$, (1) is the same as the upper bound of loss probability given in [4]. When the maximum length of FDL buffer is very large, i.e., $\beta \to \infty$, then, $D_1 = D_2 = k + Nk$. In this case, the result in (1) is the same as the lower bound on the loss probability given in [4]. Thus, the union bounds can be considered as a general form of the bounds of loss probability given in [4].

We now consider the union bounds on the loss probability of class i in prioritized OBS. The method can follow that presented in [4].

It has been proved in [4] that when the traffic intensity is relatively high, i.e., $\rho \geq 0.8$, the conservation law holds, that is the overall performance (i.e. loss probability and throughput averaged over all classes) of the network stays the same regardless of the number of classes and the degree of isolations. In the following discussion, we assume that class i is completely isolated from class $i-1$. Let $\rho_{n-1,j}$ be the sum of the traffic intensity from class $(n-1)$ through class j, i.e., $\rho_{n-1,j} = \sum_{i=j}^{n-1} \rho_i$. By using the class isolation, we know that the traffic from lower priority classes (class $(j-1)$ through class 0) does not affect the loss probability of higher priority classes (class $(n-1)$ through class j). Thus, the union bounds on the loss probability of different classes can be calculated by the following iterative algorithm,

$$pb_m^{n-1} = PB(k, \rho_{n-1}, D_m), \qquad (3)$$

$$pb_m^{n-2} = \frac{PB(k, \rho_{n-1,n-2}, D_m) - c_{n-1} pb_m^{n-1}}{c_{n-2}}, \qquad (4)$$

$$pb_m^j = \frac{PB(k, \rho_{n-1,j}, D_m) - \sum_{i=j+1}^{n-1} c_i pb_m^i}{c_j}, \qquad (5)$$

for $j = n-2, n-3, ..., 1, 0$, where pb_m^j represents the union bound on the loss probability of class j with the average number of FDLs D_m, $c_j = \rho_j/\rho$ represents the ratio of the traffic intensity in class j over the total traffic intensity.

IV. MAXIMUM DELAY LENGTH OF FDLs

For the $M/M/k/H$ model, the average queue occupancy can be calculated by

$$Q_c(k, \rho, H) = \begin{cases} P_0 \frac{\rho \gamma^k}{k!(1-\rho)^2} R(\rho) & \text{if } \rho \neq 1 \\ \frac{H}{2} - k\frac{H}{H+1} & otherwise \end{cases}, \qquad (6)$$

where $\gamma = k\rho$, $R(\rho) = 1 - \rho^{H-k} - (H-k)\rho^{H-k}(1-\rho)$, and

$$P_0 = (\sum_{n=0}^{k-1} \frac{\gamma^n}{n!} + \sum_{n=k}^{H} \frac{\gamma^n}{k^{n-k}k!})^{-1}. \qquad (7)$$

In [4], some examples on the maximum delay length of the traffic with different priority were given by simulation. They did not present a theoretical method to estimate it. In this part, we also use the conservation law in order to investigate the maximum delay length of different priority service. The basic idea is that the overall average queue occupancy in the OSN stays the same regardless of the number of classes and the degree of isolation.

Let q_m^j represent the average queue occupancy of class j with average delay number of FDLs D_m. By using the class isolation, we know that the traffic from lower priority classes (class $(j-1)$ through class 0) does not affect the queue occupancy of higher priority classes (class $(n-1)$ through class j). Thus, the average queue occupancy of different classes can be calculated by the following iterative algorithm,

$$q_m^{n-1} = Q_c(k, \rho_{n-1}, D_m), \qquad (8)$$

$$q_m^{n-2} = \frac{Q_c(k, \rho_{n-1,n-2}, D_m) - c_{n-1} q_m^{n-1}}{c_{n-2}}, \qquad (9)$$

$$q_m^j = \frac{Q_c(k, \rho_{n-1,j}, D_m) - \sum_{i=j+1}^{n-1} c_i q_m^i}{c_j}. \qquad (10)$$

In fact, while using the $M/M/k/H$ model to calculate the average queue occupancy, it implicitly implies that every unit in the buffer with maximum buffer size H has the ability to storage one basic information unit. But in our discussed OBS scheme, the basic information unit is the information burst. It is reasonable to think that the average burst length is the size of the basic information unit. On the other hand, since the FDL buffer is not a real buffer as random access memory (RAM), it can only keep the optical burst a limited time, that is to say, it can only keep the optical burst as long as the period of time in which the optical signal travels through the maximum delay lines. In order to keep a reasonable probability on burst dropping, the required maximum length of FDLs should not be shorter than the maximum among all the average queue sizes on the prioritized service. Therefore, the required maximum delay length of FDLs should satisfies

$$B \geq \max_j \left\{ q_m^j, m = 1, 2 \right\}. \qquad (11)$$

In general, the lowest priority traffic will wait for much more time than others. Thus, q_m^0 is likely to be a lower bound of the required maximum delay length of FDLs .

It is worthy to note that in some cases, it may be important to estimate the values of q_m^j $(j = 0, 1, 2, ..., n-1)$.

Observing (10), we can easily obtain a simple way to estimate q_m^j, that is,

$$q_m^j < Q_c(k, \rho_{n-1,j}, D_m)/c_j \tag{12}$$

V. Numerical Results

In [4], they discussed the effect of different parameters on the systematic QoS performance such as the loss probability, the average queuing delay etc. It assumed that all classes generate an equal amount of traffic. In this paper, we consider a general case where the classes may have different amount of traffic. In the following simulation, we also assume that all the classes have equal mean burst length, all offset time differences are equal to $3L+B$, where B is the maximum delay length of FDLs.

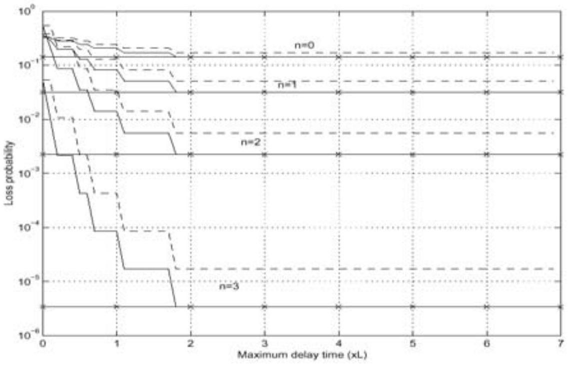

Fig. 2. comparison of the union bounds and the lower bounds given in [4]

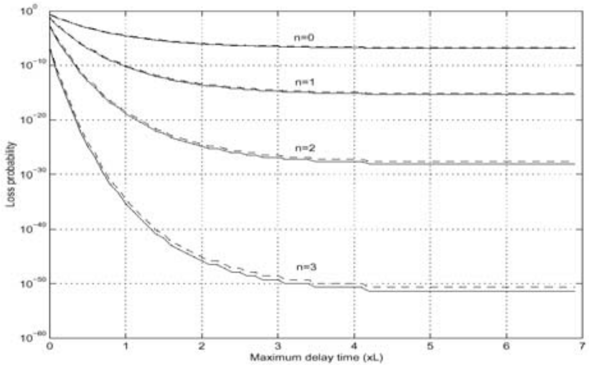

Fig. 3. Comparison of the two kinds of union bounds on the loss probability

A. Comparison of Bounds on Loss Probability

Comparing the union bounds (1) with that presented in [4] for the classless service, we know that the union bounds include the information on the maximum delay length of FDLs. Similar to the classless service, the union bounds for the prioritized classes service also include the information on the maximum delay length of FDLs. Fig.2 shows the results of the different bounds via the maximum delay time B. The parameters used are $n = 4, k = 2, N = 3$, $\rho = 0.8$, $\rho_1 = \rho_2 = \rho_3 = \rho_4 = 0.2$. (the same as that in Fig. 7 in [4]). The dashed lines denote the first kind of union bounds for all the four classes. The solid lines without any mark denote the second kind of union bounds for all the four classes. The solid lines with mark 'x' denote the lower bounds obtained in [4]. It is easy to see that when no FDLs is employed, the two kinds of union bounds are equal. When the maximum delay length of FDLs increases, the two kinds of union bounds decrease. Especially, as the maximum delay length of FDLs is large enough, the union bounds will not decrease any more, and keep the same values. Meanwhile, for each priority class, its second union bound converges to its lower bound obtained in [1]. The difference between the two kinds of union bounds is depended on the difference between D_1 and D_2. In Fig. 3, the parameters are selected as $n = 4, k = 16, N = 4$, $\rho = 0.8$, $\rho_1 = \rho_2 = \rho_3 = \rho_4 = 0.2$. It has been shown that as the product of the number of wavelengths in a single fiber and the number of FDL in the switch becomes relatively large ($Nk = 64$), the difference between the two kinds of union bounds will become relatively small.

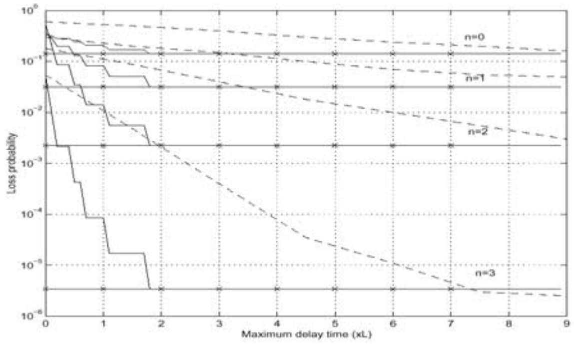

Fig. 4. Performance comparison on the simulation results the theoretical results

In Fig. 4, the same set of parameters as those used in Fig. 2 is adopted, where the dashed lines denote the simulation results, the solid lines denote the second kind of union bound, and the solid lines with mark 'x' denote the lower bound given in [4], respectively. It indicates that the second union bound provides a tighter bound than the lower bound presented in [4].

B. Evaluation of Maximum Delay Length of FDLs

In [4], it has shown that when FDL buffers are introduced into OBS switches, the loss probability can be improved considerably. When the FDL length is relatively short, it will result in higher dropping probability of bursts, especially for the lower priority services. When the FDL length is too long, it will increase the end to end latency (time delay). In this part, we shall investigate the required maximum delay length.

Recall that q_m^0 is the upper bound of the maximum delay length of FDL in general. From(12), we know that q_m^0 is upper bounded by $Q_c(k, \rho, D_m)/c_0$. Thus, it will be important to have a good knowledge on the property of function $Q_c(k, \rho, D_m)$. Fig. 5 shows the numerical results of $Q_c(k, \rho, D_m)$ for different N and k, where $n = 4$, $\rho = 0.8$, $\rho_1 = \rho_2 = \rho_3 = \rho_4 = 0.2$. It has been shown that for fixed traffic intensity ρ, when k is relatively larger (larger than 4), the values of $Q_c(k, \rho, D)$ (where $D = k + kN$) are mainly determined by k and nearly independent of parameter N. This result indicates that when WDM technique is adopted in OBS switch, and the wavelength number in each single fiber is relatively large, the maximum delay length of FDLs required is not depended on the number of FDLs in each OBS switch. This example in Fig. 5 also shows that $k \geq 4$, the required maximum delay length of FDLs needs not to be selected more than 10 times the average burst length regardless of the parameter N.

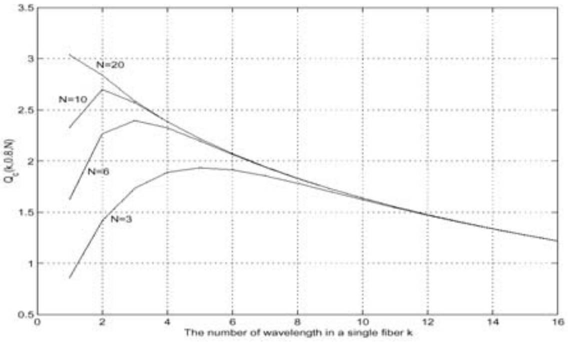

Fig. 5. Q_c function on different parameters k and N.

C. Variation of Amount of Traffic in Different classes

As an application, we discuss the effect of the variation of the amount of traffic in different classes on the system QoS performance. As an alternative, we shall use the second kind of union bound to discuss it. In fact, similar results can be obtained by using the first kind of union bound. In Fig.6, the set of parameters commonly used is $n = 4$, $\rho = 0.8, N = 4, k = 4$. Three different traffic intensity distributions are selected as following. In the first group (solid lines), $c_0 = c_1 = c_2 = c_3 = 0.25$. In the second group (dashed lines), $c_0 = c_1 = 0.3, c_2 = c_3 = 0.2$. In the third group (solid lines with mark '+'), $c_0 = c_1 = 0.2, c_2 = c_3 = 0.3$. The results in Fig. 6 have shown that the loss probability of the higher priority traffic is relatively sensitive to the variation of the amount of highest priority traffic, but the loss probability on the lowest priority traffic nearly keeps the same value. When the traffic intensity with higher priority increases, the corresponding loss probability of the higher priority service will increase.

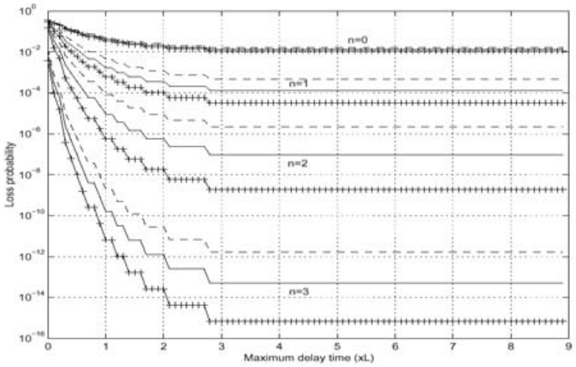

Fig. 6. Loss probabilities via variation of the amount of traffic in different classes.

VI. CONCLUSIONS

In this paper, we discussed the performance estimation of the offset-time-based QoS scheme given in [4], when applied to an optical burst switched WDM network with limited fiber lines (FDLs). We first proposed an union bound method to estimate the loss probability for different priority classes. Simulation results have shown that our union bound is tighter than the lower bound obtained in [4]. We also present a method to estimate the required maximum delay length of FDLs based on the reservation law. By using the proposed theory,we further discuss the affect of the variation of the amount of traffic in different classes on the QoS performance of different prioritized classes by using our union bound method.

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