Optimal Offset-Time Decision for QoS in Optical Burst Switching Networks

Sungchang Kim, Jin-Seek Choi, Bin-Yeong Yoon, and Minho Kang

Abstract: **In this paper, we propose the optimal offset-time decision (OOD) algorithm which can effectively reduce the pre-transmission delay compared to the perfect isolation model, and can also be extended to general n priority classes while the target loss probability of each class is guaranteed for the variable offered load. In order to drive the OOD algorithm, we first analyze the loss probability of each priority class through class aggregation and iteration method; the analytic results obtained through the proposed algorithm are then validated with results garnered from extensive simulation tests.**

Index Terms: **Optical burst switching, optimal offset-time, QoS.**

I. INTRODUCTION

Optical network paradigms are changing rapidly as a result of the dramatic increase in Internet Protocol (IP) traffic and recent advances in optical network technologies. Up to now, three fundamental switching paradigms have been proposed in optical networks: 1) Optical circuit switching (OCS) [1] networks, 2) optical packet switching (OPS) [2] networks, and 3) optical burst switching (OBS) [3] networks. Taking into consideration network utilization, the OPS manifests the best performance since it can easily achieve a higher degree of statistical multiplexing gain, as well as most effectively exert traffic engineering. In contrast, although OCS results in poor utilization due to its dedicated use of wavelengths and slow reconfiguration time, the OCS network is much easier to implement than the OPS since while the former requires only slow (in ms order) switching components, the latter requires very fast (in ns or ps order) optical components. Furthermore, practical delivery of high bandwidth networking using OPS technology awaits the following key technological developments:

- High-speed optical random access memory to buffer optical packet, resolve output conflict, and alleviate congestion during bursty periods;
- Fast optical header recognition to forward optical packet;
- High-speed switching to commensurate with the high data rate of an optical fiber;
- Integration of the above functions by WDM and code division multiple access (CDMA).

The OBS, which coordinates itself between OCS and OPS, has been actively studied as a feasible solution of optical networking; advantages of OBS include high network resource utilization close to that of OPS, and the fact that OBS can be built with currently available optical technology, like OCS. Although, the OBS and OPS have similar characteristics such as statistical multiplexing gain, the difference between the two is that OBS boasts offset-time as its unique feature. In addition, the payload in the OBS is much larger than that in the OPS because of the burst assembly process, which is referred to as the data burst (DB). Note that the connection setup request message, which is called by the burst control packet (BCP), is transmitted separately from the DB. The advantage of offset-time, then, is to decouple the BCP from the DB in time, which makes it possible to eliminate the buffering requirement at the intermediate node, and also provides fast and transparent transmission. However, in order to implement a practical OBS network, there are many challenging problems to be solved: Burst offset-time decision, burst assembly mechanism [4], DB and BCP scheduling [5], protection and restoration mechanism [6], and a contention resolution scheme [7].

Furthermore, in order to support today's mission-critical Internet traffic (video on demand, VoIP, etc.), the OBS network must also support different traffic types based on their specific needs: This prompted researchers Yoo and Qiao to propose a novel Quality of Service (QoS) scheme [8] which uses extra-offset-time, called QoS offset-time. In terms of burst loss, the high priority class performs better than the low priority class as a result of the addition of QoS offset-time. This approach is very simple and efficient; however, there is no sophisticated decision mechanism in QoS offset-time. Yoo and Qiao only dealt with a perfect isolation case between subsequent classes which can be achieved if the QoS offset-time of high priority class is 3–5 times larger than the burst size of low priority class. In that case, there are two main drawbacks. First, there is a possibility of resource over-provisioning. For example, 50 percent isolation is enough for some applications to guarantee a required QoS. Second, the pre-transmission delay of high priority class is severe when we refer to the end-to-end delay in the optical domain. For example, the highest priority class has to go through $(n-1)t_{diff}$ longer pre-transmission delay compare to lowest priority class where t_{diff} is QoS offset-time difference between two adjacent classes and n is total number of service classes. The advantage of a reduced QoS offset-time to the high priority class is that it improves the burst loss of low priority class; that is, the optimal QoS offset-time decision may efficiently guarantee diverse QoS requirements.

With this background, we propose an optimal QoS offset-time decision algorithm which not only satisfies the diverse QoS requirements, but also reduces the pre-transmission delay. We assume that each priority class has different loss requirements,

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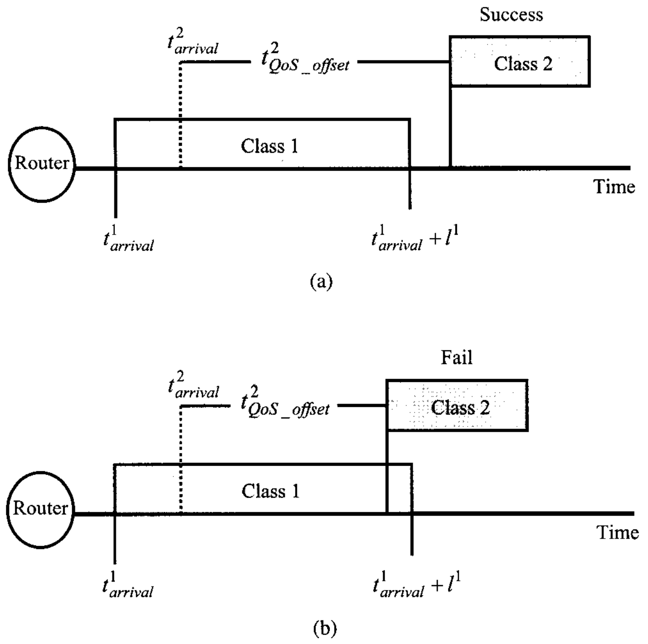

Fig. 1. Basic concept of QoS offset-time, where $t^1_{arrival}$ and $t^2_{arrival}$ represent the control packet arrival time of class 1 and 2 at intermediate node, and $t^2_{QoS\_offset}$ represents extra QoS offset-time in class 2, and l^1 indicates the burst length of class 1, respectively.

called target loss probability. Based on the target loss probability of each class, we can derive the optimal QoS offset-time between two adjacent classes in the case of general n classes.

The remainder of this paper is structured as follows. In Section II, we introduce the basic principle of an offset-time based QoS scheme, and analyze the blocking probabilities of prioritized multi-classes ($n > 2$) in Section III. In Section IV, we derive our proposed algorithm in detail. Section V presents results derived through simulation; and finally, in Section VI, we conclude the paper.

II. BASIC CONCEPT OF QOS OFFSET-TIME IN OBS NETWORK

In the QoS offset-time scheme, the OBS brings about two different offset-times: One is the basic offset-time that is required to make up the processing delay of the control packet in intermediate nodes; the second is QoS offset-time that is required to isolate traffic classes instead of buffer. For multiple QoS classes, different QoS offset-times will be assigned to each traffic class to provide differentiated QoS services.

As shown in Fig. 1(a), the high priority class 2 can be isolated from low priority class 1, if QoS offset-time, $t^2_{QoS\_offset}$ is greater than the burst length of priority class 1, l^1. However, the high priority class 2 can be blocked by the low priority class 1 if l^1 is greater than $t^2_{QoS\_offset}$ as shown in Fig. 1(b). Here, we were not concerned about basic offset-time which was independent of QoS performance. In [8], the authors assume that the high priority class can be perfectly isolated from low priority class if the QoS offset-time of the high class is 3–5 times larger than low class burst length. However, perfect isolation is impossible to achieve since the burst length is not fixed but variable. If we assume that burst length has exponential distribution, the assumption of perfect isolation greatly approximates the performance unless the QoS offset-time is infinite. In [9], the blocking probability is exactly evaluated for n classes. However, the evaluation model presents the approximation that the burst length of each class is bounded by a predefined maximum length. In usual cases, this truncated burst size model is not considered as a general OBS model. In [10], the authors propose an analytic model for arbitrary QoS offset-time which releases the approximation of perfect isolation in [8]. However, this paper only deals with the blocking probability of the two classes.

In the next section, the blocking probabilities of multi-classes are evaluated without the approximation of perfect isolation. The main focus is on analyzing blocking probabilities for general n class ($n > 2$) with exponentially distributed burst size and the Poisson arrival environment using the class aggregation and iteration method.

III. ANALYSIS OF BLOCKING PROBABILITIES FOR PRIORITIZED MULTI-CLASSES

In this section, we present an analysis of the blocking probabilities in Just-Enough-Time (JET) based OBS network that distinguishes n classes: assume that class n has the highest priority and class 1 has the lowest priority. Let's assume that the control packet of class m ($1 < m < n$) arrives at the Poisson stream with rate λ_m, and that the data burst length has exponential distribution. Let t_m^{burst} be the mean data burst transmission time of class m, and let ρ_m be an offered load which can be calculated simply by using $\lambda_m t_m^{burst}$. Based on this assumption, we can utilize the *Erlang B* formula for the blocking probability of the $M/G/k/k$ system: In this system, k represents the number of wavelengths used at each output port.

In order to evaluate the blocking probabilities for general n classes, we must first evaluate the three classes. For our analysis, we assume that the basic offset-time of each class is the same, which means that the basic offset-time does not affect class isolation; we may therefore assume that the basic offset-time of each class is 0. Furthermore, we define $\delta_{i|j}$ which indicates the QoS offset-time difference between class i and j ($i < j$).

The overall burst blocking probability P_{all} in multi-classes OBS node can be obtained by using the aforementioned *Erlang B* formula [11]

$$P_{all} = B(\rho_{all}, k) = \frac{(\rho_{all})^k/k!}{\Sigma_{i=0}^{k}(\rho_{all})^i/i!}. \tag{1}$$

In order to calculate the blocking probability of highest priority class , we consider the effective loads that affect the blocking probability. In Fig. 2(a), if we assume that the offset-time difference $\delta_{1|2}$ and $\delta_{2|3}$ are of an arbitrary small value, class 3 is not perfectly isolated from class 2 and 1. Therefore, P_3 can be represented by

$$P_3 = B(\rho_3 + Y_2(\delta_{2|3}) + Y_1(\delta_{1|3}), k) \tag{2}$$

where $Y_i(\delta_{i|j})$ is the effective loads of low priority class i affecting blocking probability of high priority class j and represented by

$$Y_i(\delta_{i|j}) = \rho_i(1 - P_i)(1 - R(\delta_{i|j})). \tag{3}$$

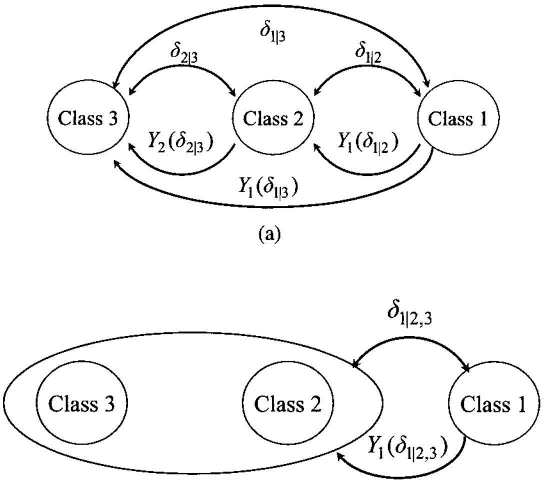

Fig. 2. (a) Relationship between two different classes according to offset-time differences and effective loads and (b) class aggregation model.

Within this equation, $\rho_i(1-P_i)$ represents the carried loads of class i and $(1-R(\delta_{i|j}))$ represents the probability of which data burst lengths in class i are larger than the offset-time difference $\delta_{i|j}$, where $R(\delta_{i|j})$ is the isolation rate between class i and j which can be represented by

$$R(\delta_{i|j}) = (1-\exp(-\delta_{i|j}/t_i^{burst})). \tag{4}$$

As a result of the memory-less property of exponential distribution in data burst lengths, the residual service time of class i data burst is the same regardless of the arrival time of class j data burst. Therefore, the approximation $Y_i(\delta_{i|j})$ is independent of class j arrival time.

We must now drive the blocking probability of class 2. In order to obtain P_2, we define the aggregated state which consists of class 3 and class 2 as shown in Fig. 2(b). The blocking probability of the aggregated state (consisting of mixed loads of class 3 and 2) can be represented by

$$P_{2,3} = B(\rho_{2,3} + Y_1(\delta_{1|2,3}), k) \tag{5}$$

where $\delta_{2,3}$ is the sum of the offered load from class 2 to class 3, which is defined $\rho_{m,n} = \sum_{i=m}^{n} \rho_i$ and $\delta_{1|2,3}$ is an arithmetic mean of offset-time differences between class 1 and aggregated class which consists of class 2 and 3, $\delta_{1|2,3} = (\delta_{1|2} + \delta_{1|3})/2$. Once we calculate $P_{2,3}$, the blocking probability of class 2 can be obtained by well known conservation law

$$\rho_{2,3} P_{2,3} = \rho_2 P_2 + \rho_3 P_3. \tag{6}$$

Once we obtain P_3 and P_2, the blocking probability P_1 is also calculated by conservation law. However, the blocking probability of each class is dependant on the other. For example, in order to calculate P_3 in (2), we have to know P_2 and P_1 in advance. Therefore, an iterative solution is required.

For zero order blocking probabilities, we assume that the P_3 and $P_{2,3}$ are completely isolated from lower priority classes such as $P_3^{(0)} = B(\rho_3, k)$ and $P_{2,3}^{(0)} = B(\rho_{2,3}, k)$; then we can obtain a zero order blocking probability of each class $P^{(0)}$ and effective loads $Y^{(0)}(\delta_{i|j})$. Next, first order blocking probabilities can be obtained when effective loads $Y^{(0)}(\delta_{i|j})$ values plug into (2) and (5). Iteration procedure continues until the blocking probability of each class converges at a certain level. In the case of general n class, the blocking probability of each class can be calculated by following lth iteration

$$P_n^{(l)} = B(\rho_n + \Sigma_{i=1}^{n-1} Y_i^{l-1}(\delta_{i|n})) \tag{7}$$

$$P_{m,m+1,\cdots,n}^{(l)} = B(\rho_{m,n} + \Sigma_{i=1}^{m-1} Y_i^{l-1}(\delta_{i|m,m+1,\cdots,n}), k) \tag{8}$$

$$\delta_{i|m,m+1,\cdots,n} = (\Sigma_{j=m}^{n} \delta_{i|j})/(n-m+1), (1<i<m<n) \tag{9}$$

$$P_m^{(l)} = (\rho_{m,n} P_{m,m+1,\cdots,n}^{l} - \rho_{m+1,n} P_{m+1,m+2,\cdots,n}^{l})/\rho_m \tag{10}$$

IV. OPTIMAL OFFSET-TIME DECISION ALGORITHM

In the previous section, we analyzed the blocking probabilities of general n classes by using the class aggregation and iteration method when the QoS offset-time is determined arbitrarily. However, in order for the QoS offset-time to support target blocking probability, the inversed formula of (1) must be used; however, the inversed transform of (1) can not be derived directly. As a solution to this problem, a heuristic method, in which the blocking probability is roughly estimated as an invertible equation form, can be used; the drawback is, however, that this heuristic equation shows large approximation for errors and high complexity. Thus, this section presents an optimal offset-time decision (OOD) algorithm which can be used in approximation of (1), and directly solves the resulting nonlinear equation. First, we derive the three classes and then extend the algorithm in the case of general n classes. The target blocking probability of class 3 and class 2 is given like P_3^{req}, P_2^{req}, and that class 1 is best effort service.

According to the previous analysis of blocking probabilities, target blocking probability of class 3 is given by $P_3^{req} = B(\rho_3 + Y(\delta_{2|3}) + Y(\delta_{1|3}), k)$. In order to calculate the $\delta_{2|3}$, we assume that the $\delta_{1|3}$ is large enough so that $Y(\delta_{1|3}$ can be negligible. Thus, the target blocking probability of class 3 can be approximated following the equation by using (1)

$$P_3^{req} = (A_3^k/k!)e^{-A_3} \tag{11}$$

where A_3 is $\rho_3 + Y(\delta_{2|3})$ and the denominator of (1) can be approximated exponential function $\Sigma_{i=0}^{k} x^i/i! \approx e^x$ if k is large so that the larger of wavelength number (k) on each link the higher accuracy of the analytical model can be achieved. From (11), we have the nonlinear equation $f(A_3) = k \ln A_3 - A_3 - \ln(P_3^{req} k!)$.

In order to solve this nonlinear equation, we use the Newton-Raphson method [12] which is represented as $A^{(x+1)} = A^{(x)} - (f(A^{(x)})/f'(A^{(x)}))$. Although the solution is more accurate if the iteration process is increased, for the low complexity and typical pattern, we chose only the first iteration value $A^{(1)}$ and set the initial value $A^{(0)} = \rho_3$. Thus,

$$A_3 = \rho_3 - \frac{\rho_3(k \ln \rho_3 - \rho_3 - \ln(P_3^{req} k!)}{k - \rho_3}. \tag{12}$$

Once obtained A_3, we can retrieve the isolation rate $R(\delta_{2|3})$ using (3), and finally the QoS offset-time $\delta_{2|3}$ can be derived by using (4)

$$R(\delta_{2|3}) = 1 + \frac{\rho_3 - A_3}{\rho_2(1 - P_2^{req})} \tag{13}$$

where

$$\delta_{2|3} = -t_2^{burst} \ln(1 - R(\delta_{2|3})). \tag{14}$$

Next, the $\delta_{1|2}$ is determined by using class aggregation method. As we derived in the previous section, the blocking probability of class 2 requires class aggregation state $P_{2,3}$ in (5). If we follow the same procedure from (11) to (14) with respect to $\delta_{1|2,3}$, we can obtain $\delta_{1|2}$ by the definition of $\delta_{1|2,3}$ which can be represented as $\delta_{1|2} = \delta_{1|2,3} - (\delta_{2|3}/2)$.

The formal description of the OOD algorithm which supports n priority classes is presented below. In Step 1, it first verifies the target blocking probability of class n through deciphering whether or not the target blocking probability can be guaranteed within a boundary. In that case, the lower bound of class n, $P_{n,Min}$, can be determined when class n is completely isolated from the lower priority classes. Since class n is of higher priority than class $n-1$, the upper bound of class n can not exceed the lower bound of class $n-1$, we assume that $P_{n,Max}$ is equal to $P_{n-1,Min}$. Lines 1 to 3 are used to get $\delta_{n-1|n}$ which was previously explained in (12), (13), and (14).

If Step 1 is successful, we can proceed to Step 2 which is the process of other classes for optimal offset-time decision. In Step 2, the processes have to be carried out sequentially from class $n-1$ to 2 since they are dependent on each other. For example in order to determine the $\delta_{m-1|m}$ $(1 < m < n)$, we must know, in advance, the optimal offset-time of higher priority classes such as $\delta_{m|m+1}, \cdots, \delta_{n-1|n}$. At line 5, OOD calculates the blocking probability of the aggregated class which can be easily obtained by (8). Next, lines 6, 7, and 8 follow the same procedure as lines 1, 2, and 3, but these are represented as an aggregated class case. Based on the offset-time of aggregated class $\delta_{m-1|m,\cdots,n}$ at line 8 which is defined arithmetically as the mean of offset-time difference from class $m-1$ to class m, class $m+1, \cdots$, and class n, we can finally obtain the optimal offset-time between class $m-1$ and class m, $\delta_{m-1|m}$. If the requested target blocking probability is out of bound, the OOD algorithm returns -1: This means that the target blocking probability can not be guaranteed with this priority class. If all of the processes are successful, the OOD algorithm returns optimal offset-time of all the classes.

Algorithm 1:

```
Begin {Optimal Offset-time Decision Algorithm}
Input: $P_n^{req}, P_{n-1}^{req}, \cdots, P_2^{req}$, Output: $\delta_{n-1|n}, \delta_{n-2|n-1}, \cdots, \delta_{1|2}$
Variable: $m$ = arbitrary class $(1 < m < n)$
Step 1:
if $(P_{n,Min} = B(\rho_n, k) \leq P_n^{req} \leq B(\rho_n + \rho_{n-1}, k) = P_{n,Max} = P_{n-1,Min})$
    1: $A_n = \rho_n - \frac{\rho_n(k \ln \rho_n - \rho_n - \ln(P_n^{req} k!))}{k - \rho_n}$, when $A_n^{(0)} = \rho_n$;
    2: $R(\delta_{n-1|n}) = 1 + \frac{\rho_n - A_n}{\rho_{n-1}(1 - P_{n-1}^{req})}$;
    3: $\delta_{n-1|n} = -t_{n-1}^{burst} \ln(1 - R(\delta_{n-1|n}))$;
    4: Go to Step 2
else
return $-1$/* Target blocking probability is out of bounds */
Step 2:
for $(m = n-1, m > 1, m--)${
if$(P_{m,Min} = B(\Sigma_{j=m}^{n} \rho_j, k) \leq P_m^{req} \leq B(\Sigma_{j=m-1}^{n} \rho_j, k) = P_{m,Max} = P_{m-1,Min})$
    5: Calculate the aggregated class $P_{m,m+1,..,n}^{req}$ using (8)
    6: $A_{m,m+1,..,n} = \rho_{m,n} - \frac{\rho_{m,n}(k \ln \rho_{m,n} - \rho_{m,n} - \ln(P_{m,m+1,..,n}^{req} k!))}{k - \rho_{m,n}}$,
       when $A_{m,m+1,..,n}^{(0)} = \rho_{m,n}$
    7: $R(\delta_{m-1|m,m+1,..,n}) = 1 + \frac{\rho_{m,n} - A_{m,m+1,..,n}}{\rho_{m-1}(1 - P_{m-1}^{req})}$
    8: $\delta_{m-1|m,m+1,..,n} = -t_{m-1}^{burst} \ln(1 - R(\delta_{m-1|m,m+1,..,n}))$
    9: $\delta_{m-1|m} = \delta_{m-1|m,m+1,..,n} - \frac{\Sigma_{j=1}^{n-m}(j\delta_{n-j|n+1-j})}{n-m+1}$ }
    else
return $-1$ /* Target blocking probability is out of bounds */
}
    10: return $\delta_{n-1|n}, \delta_{n-2|n-1}, .., \delta_{1|2}$
End {Optimal Offset-time Decision Algorithm}
```

V. SIMULATIONS AND RESULTS

In this section, we begin by presenting our analytical results driven by (7) and compare them with simulation results; we then show the effectiveness of the proposed OOD algorithm to guaranteeing QoS. The simulation model assumes that 16 wavelengths are used and each node has 8 × 8 ports, and that each port has a 10 Gbps transmission rate. The traffics are classified by three different priorities such as class 1, class 2, and class 3. Class 3 is the highest priority and class 1 is the lowest; the offered load of each class is equally distributed. All classes have the same average burst length t^{burst} which is exponentially distributed with an average value of 20 KB under the assumption that several tens of IP packets have been assembled into one burst. In addition, we assume that the offset-time differences between successive classes are not the same so that the isolation rate $R(\delta_{m-1|m})$ is variable between 0 and 1.

In Figs. 3 and 4, we show the blocking probabilities of each priority class versus the offered load. By comparing the blocking probabilities obtained from our analysis and simulation, our analytic results show that they are in agreement with those from the simulation, and that the iteration procedure may compensate the approximation error of class aggregation. Using this analytical model, we can obtain blocking probabilities of n classes in the case of not only perfect, but also partial, service isolation.

In Fig. 5, we show that the assumption of perfect isolation [6] is not valid even if QoS offset-time is three times lager than the mean burst length. As we decrease the QoS offset-time from $3t^{burst}$ to t^{burst}, the differences in performance between the partial and perfect isolation model are increased which are mainly caused by under-estimation of perfect isolation model.

Fig. 6 shows a graph of the QoS guaranteed region for priority classes where each line represents the lower bounds which are determined by the proposed OOD algorithm as a function of the offered loads. As can be observed from the algorithm, the lower bound of class 1, which is equal to upper bound of class 2, is the same as the classless case. Therefore, we can see that the both class 2 and class 3 take advantage of QoS offset-time to reduce their blocking probability. If the target blocking probabilities of class 2 and class 3 are placed within a bound at specific loads, both target blocking probabilities are guaranteed. However, the

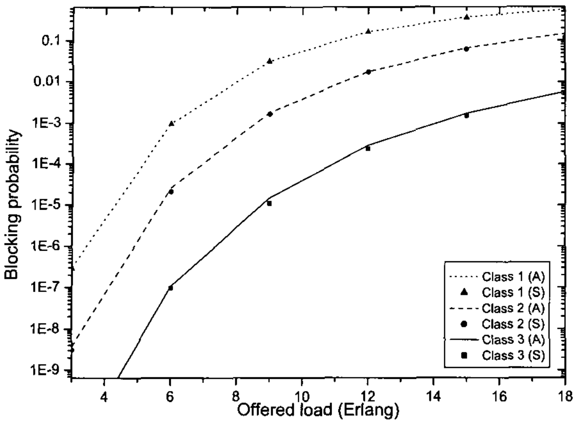

Fig. 3. Blocking probabilities of analysis and simulation results when the number of class is 3. QoS offset-time difference between adjacent classes is set to average burst length. (A) and (S) denote analysis and simulation, respectively.

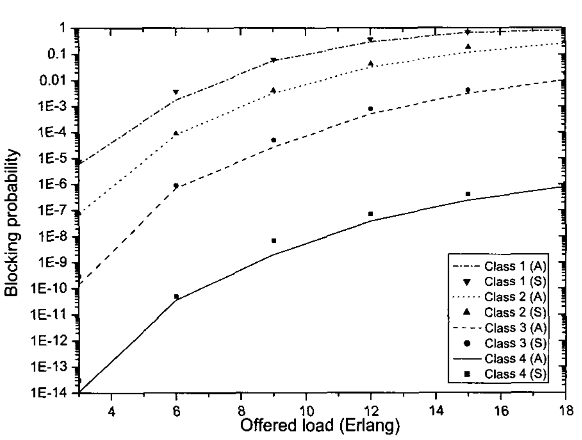

Fig. 4. Blocking probabilities of analysis and simulation results when the number of class is 4. QoS offset-time difference between adjacent classes is set to average burst length. (A) and (S) denote analysis and simulation, respectively

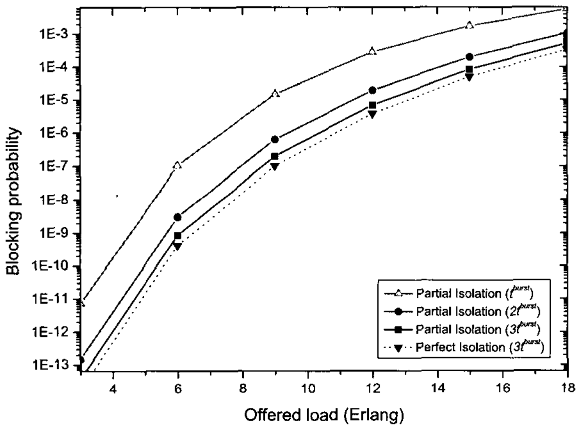

Fig. 5. Blocking probabilities of class 3 when the class 3 is isolated from low priority classes either partially or perfectly in the case of $\delta = t^{burst}$, $2t^{burst}$, and $3t^{burst}$.

price paid for the low blocking probability of class 2 and class 3 is that class 1, which supports best effort services, may have higher blocking probability.

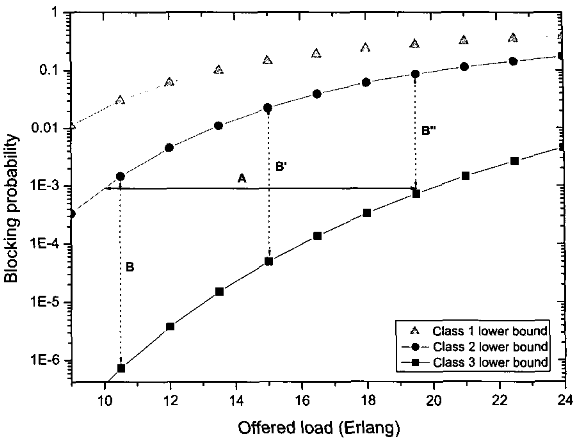

Fig. 6. QoS guaranteed region for priority classes where each line indicates the lower bounds of blocking probability for each class.

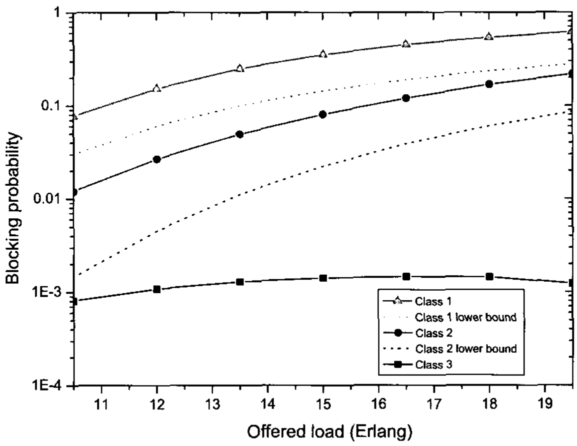

Fig. 7. Support of target blocking probabilities by optimal QoS offset-time.

Based on Fig. 6, we perform the two kinds of simulation: First, we examine whether or not our proposed OOD algorithm can really guarantee the target blocking probability along the solid line A. For this evaluation, we assume that class 3 requires the deterministic (absolute) QoS which is a necessary characteristic for multi-media applications; however, class 2 is sufficient enough to guarantee a relative QoS which is suitable for elastic applications such as file transfers. Second, we evaluate how much QoS offset-time is required to guarantee a target QoS which is shown in dotted line B, B$'$, and B$''$ at the specific loads.

Figs. 7 and 8 shows our findings for the first experiment which was previously discussed. Fig. 7 plots the blocking probabilities of each class by using OOD algorithm where we set the target blocking probability of class 3 for 10^{-3} and class 2 for mean value between the upper and lower bounds of class 2. As you can see, class 3 guarantees an absolute QoS in spite of an increasing load, while class 2 has been served relative QoS which varies according to the offered load. In Fig. 8, $\delta_{2|3}$ and $\delta_{1|2}$ are shown to support Fig. 7 which is driven by the OOD algorithm. In a scenario like this, $\delta_{1|2}$ is rather independent of the QoS offset-time. In contrast, $\delta_{2|3}$ increases sharply for increasing loads before they approach their lower bounds. Based on this

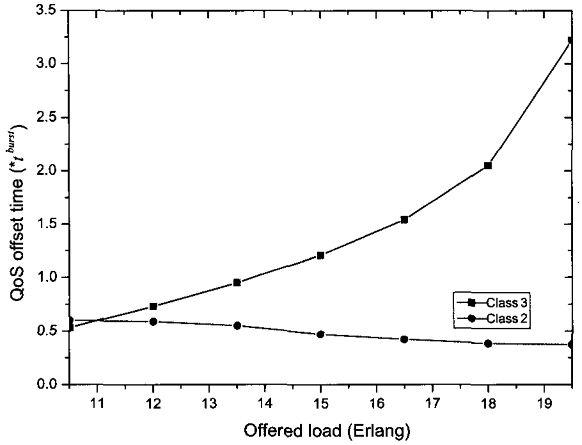

Fig. 8. Optimal QoS offset-time to guarantee for target blocking probabilities.

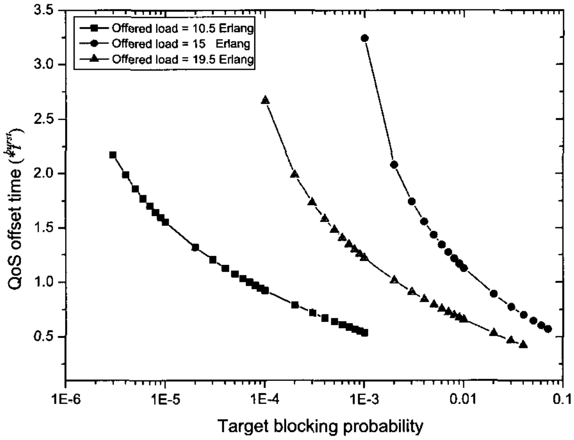

Fig. 9. Optimal QoS offset-time as a function of target blocking probability.

graph, we can infer that complete isolation is not necessary even though some specific classes require the absolute QoS; in other words, it can be guaranteed by using small QoS offset-time with the exception of those cases where the target QoS approaches lower boundaries.

Fig. 9 shows the optimal QoS offset-time variation as a function of target blocking probability. It is clear that small QoS offset-time is enough to support the target blocking probability when the offered load is low, so that the optimal QoS offset-time value can effectively reduce the delay compared to the perfect isolation case, while the target QoS is guaranteed.

VI. CONCLUSION

In this paper, we propose the Optimal Offset-time Decision algorithm which can effectively reduce the pre-transmission delay compared with the complete isolation model; it can also be extended to general n priority classes while the target blocking probability of each class is guaranteed for the variable offered load. In order to drive the OOD algorithm, we first evaluate the blocking probability of general n priority classes using the class aggregation model. We then use simulation to validate our analytic results that are shown to be in good agreement with our simulation results. Since this general n class analysis covers partial service isolation, we can precisely obtain the suitable isolation rate of each n class rather than the perfect isolation rate. From the various results obtained from the OOD algorithm, we prove that even small QoS offset-time, which does not completely isolate each priority class and keeps pre-transmission delay to a minimum, still guarantees both the absolute and relative QoS of the high priority classes. Moreover, the best effort class also takes advantage of lower blocking probability due to the small QoS offset-time of higher priority classes.

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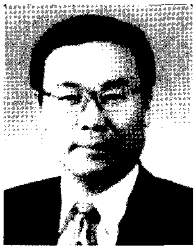

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