A Model of Traffic Prediction based Admission Control in OBS Nodes

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***Abstract*— Scheduling is an operation that has a significant impact on the data forwarding performance of OBS nodes. In the case of service differentiation, the scheduling operation is also subject to additional controls from service differentiation supporting mechanisms in which an arriving burst can be admitted to be scheduled depending on its priority level and the availability of wavelengths. There are several proposed scheduling admission control models, but it is hypothesized that the traffic of arriving bursts is stable, the admission control is then performed, based on the amount of allocated wavelengths and the idle state of these wavelengths. However, arriving burst traffics in OBS networks usually fluctuate and accurate traffic forecasting will help allocate wavelengths more efficiently, increasing the scheduling efficiency in term of increasing bandwidth utilization and reducing burst loss. This paper proposes a model of traffic prediction based admission control, which includes a statistical method of forecasting the arriving burst rate for flexible wavelength allocation and a mechanism of prioritizing more resources for high-priority bursts. The simulation results have proved the efficiency of the proposed model in terms of the burst loss and the bandwidth utilization. A Markov chain based analysis model is also introduced to validate the proposed model.**

Keywords— OBS networks, admission control, service differentiation, wavelength re-allocation, Markov chain.

I. INTRODUCTION

Optical burst switching (OBS) [1] is considered as a promising technology for the next generation of optical Internet. In order to meet the rapid growth of Internet traffic and the ever-increasing deployment of multimedia services (such as VoIP, video on demand, cloud computing, etc.), OBS is chosen to better exploit the bandwidth of optical fibers, to create a flexible network infrastructure that can be configured at burst granurality and to handle the bursty traffic generated by multimedia services.

The typical architecture of an OBS network consists of core nodes connected to edge nodes in mesh (Fig. 1). Edge nodes that aggregate (assemble) electronic packets (such as IP packets, ATM cells, Ethernet frames ...) coming from access networks into larger carriers, are called bursts, which are primary transport units within OBS networks. Each edge node maintains the queues that correspond to destinations and priority classes. Once the (time or size) threshold is reached, the packets in the corresponding queue are assembled into a burst, which is sent into the core network. A burst control packet (BCP) is sent on a dedicated control channel to reserve the required resources and configure of switches at the intermediate nodes along a route from source to destination. The corresponding burst follows an offset time on an available data channel, which is switched all-optically at the intermediate nodes along its route.

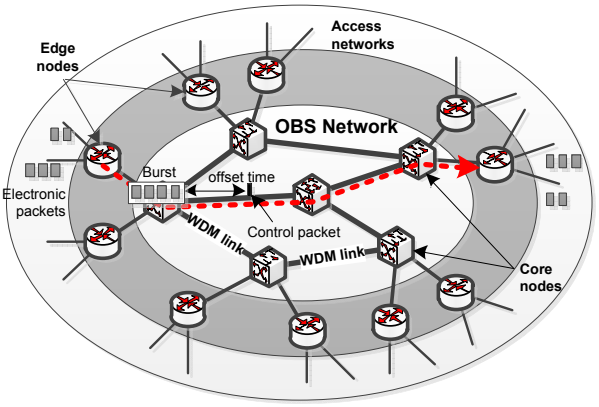


Fig. 1. A typical architecture of OBS networks.

Scheduling admission control (briefly, admission control) can be performed at edge nodes or core ones [2]. In the majority of proposed admission control models, low priority (LP) bursts are always more dropped to conserve resources for high priority (HP) bursts if a contention occurs. Scheduling is usually done sequentially in term of first come, first served, but in the case of service differentiation, scheduling of an arriving LP burst may cause blocking a HP burst that comes late. As shown in the example of Fig. 2a, if the LP burst arriving at the time point t_0 is scheduled, the HP burst arriving at the time point t_1 cannot be scheduled due to exhausted resources. Thus the LP burst must be actively dropped to conserve resources for the HP burst. In other words, the admission control is necessary to conserve more resources for HP bursts, while it limits resources to LP bursts.

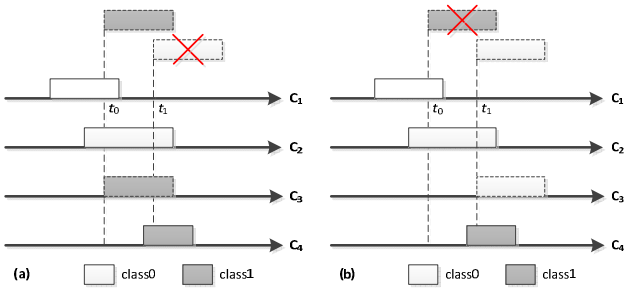


Fig. 2. An example of (b) actively dropping a LP burst to conserve resources for HP bursts, that is compared to (a) the model of first come, first served.

There are several proposed admission control models, including SWG (Static Wavelength Grouping), DWG (Dynamic Wavelength Grouping) [3] and LLAC (Load-Level Admission Control) [4]. However, these models assume that the traffic of arriving bursts is stable, the admission control is then performed based on the amount of

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allocated wavelengths and the idle state of these wavelengths. These models absolutely prioritize HP bursts, so their allocated resources could be not used up and wasted if the traffic of arriving HP bursts is low. These models do not take into account the fluctuation of arriving burst traffics for resource re-allocation. This article proposes a model of traffic prediction based admission control, which includes a statistical method of forecasting the arriving rate of bursts for flexible wavelength allocation and a mechanism of prioritizing more resources for HP bursts. A Markov chain based analysis model is also constructed to validate the proposed model and compare to simulation results.

The remainder of this paper is organized as follows: Section II briefly presents and analyzes the related works of admission control. Based on the drawbacks of the previous models, a model of traffic prediction based admission control is proposed in Section III, which includes a forecasting method for wavelength re-allocation and a HP burst prioritizing mechanism. In Section IV, a Markov chain based analysis model is constructed to validate our proposed model. The simulation results are compared in Section V and the conclusion is given in Section VI.

II. RELATED WORKS

The first proposals for the service differentiation supporting admission control are SWG and DWG [3]. Two classes of HP and LP are considered and the admission control is based on the number of wavelengths occupied by each priority class. Specifically, with an output link that have W available wavelengths, where W_i wavelengths are allocated to HP ($i = 0$) and LP ($i = 1$) bursts ($W_0 + W_1 = W$) and $\omega_i(t)$ are the number of wavelengths occupied by each priority class at the considered time point t, an arriving burst is admitted for scheduling if $\omega_i(t) < W_i$.

Although these two techniques have the same condition for scheduling admission, their wavelength allocation is different. With the SWG model, W_i wavelength is allocated physically for HP and LP bursts, while the DWG model admits an arriving burst to be scheduled on any available wavelength if the occupations do not exceed the allocated wavelengths of the corresponding priority class. As the example in Fig. 3a, with $W = 4$ and $W_0/W_1 = 1/3$, SWG will physically allocate three wavelengths C_1, C_2, and C_3 for HP bursts and the rest (C_4) for LP bursts. If a LP burst arrives at the time point t, it is only considered to be scheduled on C_4 though C_3 is idle. But with DWG (Fig. 3b), the LP burst can be scheduled on C_3 because the admission condition is guaranteed ($\omega_1(t) < W_1$ due to $\omega_1(t) = 0$ and $W_1 = 1$).

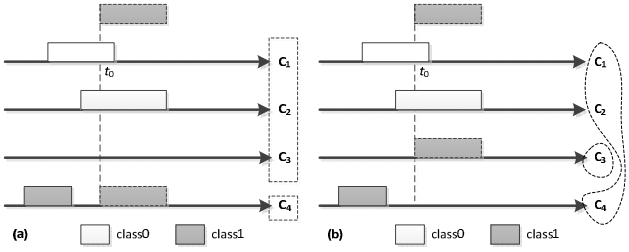


Fig. 3. Example of (a) SWG and (b) DWG admission control.

Both the SWG and DWG models need to keep the information of occupied wavelengths of each priority class, thus they require more memory. Moreover, the fixed wavelength allocation for priority classes makes bandwidth utilisation inflexible and ineffective. A proposal that has overcome these drawbacks is the LLAC method [4], in which only the information of all occupied wavelengths (ω) is memorized. Two load thresholds l_0 and l_1 are predefined for HP and LP classes, respectively. An arriving burst is admitted to be scheduled if all occupied wavelengths (ω) are less than its load threshold ($\omega < l_i$).

As the example shown in Fig. 4a, with two load thresholds $l_0 = 4$ and $l_1 = 1$ predefined for HP and LP, respectively, if a LP burst arrives at the time point t_0, it is scheduled because $\omega < l_1$ ($\omega = 0$). At the time point t_1, a HP burst arrives, it is scheduled because $\omega < l_0$ ($\omega = 1$). However, with the case in Fig. 4b, a HP burst arriving at the time point t_0 is scheduled because $\omega < l_0$ ($\omega = 0$), but a LP burst arriving at the time point t_1 is not scheduled because $\omega = l_1$ ($\omega = 1$). Similar to the case in Fig. 4c, a LP burst arriving at the time point t_0 is not scheduled because $\omega = l_1$ ($\omega = 1$), but a HP burst arriving at the time point t_1 is scheduled because $\omega < l_0$ ($\omega = 1$).

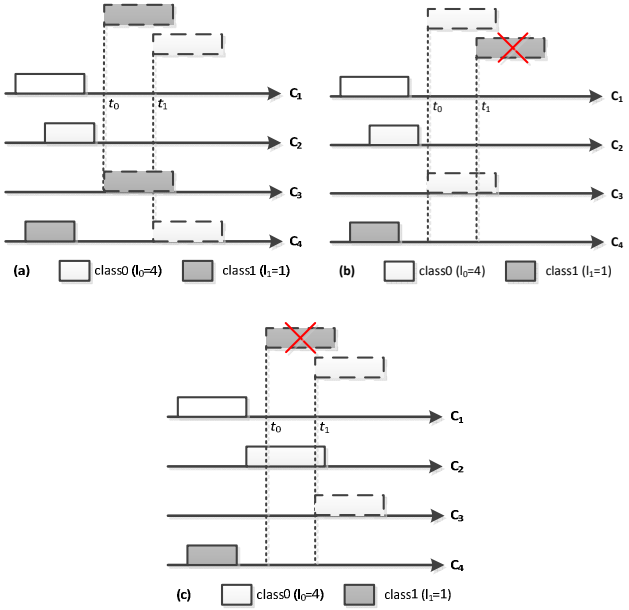


Fig. 4. Examples describing how LLAC works

An improvement of DWG is LDWG (Load-based Dynamic Wavelength Grouping) proposed in [5], where the wavelength allocation is based on the traffic load of each priority class. Specifically, a resource allocation factor is defined as

$$p_i = \frac{Load_of_class_i}{Total_load}.$$

So, if 60% HP traffic and 40% LP traffic arrive at an output link of W wavelengths, the wavelength allocation rate is $0.6W$ and $0.4W$ for HP and LP classes, respectively. In order to effectively utilize the allocated wavelengths and reduce burst loss, the authors in [5] also propose that HP bursts could use the surplus wavelengths allocated to the LP class and vice versa. However, the effectiveness of this proposal is only described through an example without a simulation-based evaluation.

In summary, the above admission control models consider the case in which the arriving burst traffic at the

output link is stable, the wavelength allocation is fixed. This is not appropriate for the reality because the arriving burst traffics are usually fluctuated, a periodical wavelength re-allocation that is varied adaptively according to the arriving rate of bursts will result in more efficient bandwidth utilisation and reduced burst loss. The next section of this article presents a model of traffic prediction based admission control that addresses the mentioned drawbacks.

III. TRAFFIC PREDICTION BASED ADMISSION CONTROL MODEL

The admission control can be performed at edge and core nodes. With the admission control model proposed in this article, the admission control takes place at the control plane when a BCP arrives and requires resources for scheduling its corresponding burst. An admission control algorithm is then called to seek and reserve resources on the wavelengths that are allocated to priority classes. The admission control model is deployed for each separated output link due to the state differentiation of arriving burst traffics and wavelengths.

A. Wavelength re-allocation based on the arriving burst rate

Considering an output link where arriving bursts are assumed to belong to one of two classes of HP and LP. There are W available wavelengths at the output link, where an arriving HP burst can be scheduled on one of W wavelengths, while a arriving LP burst is only scheduled on one of W_1 wavelengths, $W_1 < W$. This approach is intended to conserve more resources for HP bursts. Thus, the wavelength re-allocation is only made for the traffics of LP bursts, in which the allocated wavelengths (W_1) need to be increased if LP bursts arrive densely and HP bursts arrive sparsely. In other words, the amount of wavelengths allocated to LP bursts should be proportional to the arriving rate of LP bursts relative to the total rate of both priority classes as (1).

$$\frac{W_1}{W} = \frac{\lambda_1}{\lambda_0 + \lambda_1} \Rightarrow W_1 = W \frac{\lambda_1}{\lambda_0 + \lambda_1} \quad (1)$$

where $\lambda_{i\in\{0,1\}}$ are the rate of arriving HP (i = 0) and LP (i = 1) bursts.

To determine λ_0 and λ_1 for wavelength re-allocation, the TW-EWMA method [6] is used, which is based on the statistics of the rate in the past and the current arriving rate of bursts. Specifically, the rate of each priority class is

$$\lambda_i = (1-\alpha_i) \times \lambda_i^{avg} + \alpha_i \times \lambda_i^{cur} \quad (2)$$

where $\lambda_{i\in\{0,1\}}^{avg}$ and $\lambda_{i\in\{0,1\}}^{cur}$ are the average rate in the past and the current arriving rate of bursts, α_i is their weight.

In [6], α_i is chosen be equal to 0.3. However, as suggested in [7], α_i should be flexibly adjusted based on the current rate and the total rate of both priority classes as (3). This suggestion is reasonable because the coefficient α_i adjusted according to the latest state of arrival traffic will reflect accurately the variance trend of the next arrival traffic, that increases the accuracy of prediction.

$$\frac{1-\alpha_i}{\alpha_i} = \frac{\lambda_i^{avg}}{\lambda_i^{cur}} \Rightarrow \alpha_i = \frac{\lambda_i^{cur}}{\lambda_i^{cur} + \lambda_i^{avg}} \quad (3)$$

Another feature of the TW-EWMA method is that the observation window chosen for calculating $\lambda_{i\in\{0,1\}}^{cur}$ is discrete instead of being continuous to reduce the computational cost (Fig. 5). However, the window size has a significant impact on the forecasting accuracy and the computational cost: If the window is large, the forecasting is more accurate, but the computational cost is high, whereas if the window is small, the forecasting accuracy will decrease, but the computation cost is low [6]. Thus, a compromise between accuracy and cost should be studied to find an appropriate size for the observation window, but it is beyond the scope of this paper. For simplicity, the window size is selected by a half of wavelength re-allocation cycle.

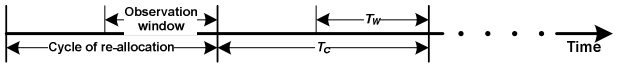


Fig. 5. The observation window is discrete, instead of being continuous as in TW-EWMA [6].

From the (1), (2) and (3), the amount of wavelengths (W1) allocated to LP bursts vary adaptively according to the fluctuation of arriving burst traffics.

B. Prioritizing more resources for high-priority bursts

Similar to LLAC, the proposed admission control for each arriving burst (*unscheduled burst*, *ub*) is performed, basing on a parameter ω defined as the total of overlaps of *ub* with the scheduled bursts of the same priority. Specifically, if the total of overlaps is less than the number of allocated wavelengths ($\omega < W$ for HP and $\omega < W_1$ for LP), the arriving burst (*ub)* is scheduled.

An absolute prioritizing mechanism for HP bursts is also proposed in this admission control model, in which a scheduled LP burst may be removed to transfer resources for an arriving HP burst. However, this approach also complicates the system because the core nodes must be able to generate a BCP that is sent back to its source to remove the previously-reserved resources at the nodes where the BCP have gone through.

The steps for transferring resources to HP bursts are as follows. When a HP burst arrives at an output link and no wavelength is found for scheduling it, the resource occupied by a scheduled LP burst is released to schedule the HP burst if:

- the HP burst overlaps with only one scheduled LP burst that will be released, and
- the BCP of this LP burst has not been sent to next nodes.

Otherwise, the HP burst is dropped.

In the case that a LP burst arrives and all resources are busy, this burst is dropped.

C. Algorithm of traffic prediction based admission control

For each arriving burst *ub*, where $ub = \{s_{ub}, e_{ub}, prio_{ub}\}$ is a triple of s_{ub}, e_{ub}, $prio_{ub}$ that are the start and end time, and the priority ($prio_{ub}$ = 0 for HP and $prio_{ub}$ = 1 for LP),

respectively, the algorithm of traffic prediction based admission control (TPAC) is described as follows.

Algorithm 1: ***TPAC algorithm***

Input: - W; // number of output wavelengths
- T_C; // the size of wavelength re-allocation cycle, e.g. $T_C = 10000$
- T_w; // the size of observation window, e.g. $T_w = T_C / 2$

Output:

Process

1 **while** *an burst ub arrives* **do**
2 ***iBFVF***(ub, W_1, W);
3 **if** (T_C *is reached*) **then**
4 λ_i^{cur} := the current rates of HP and LP classes arrived in the observation window;
5 // the weights of HP and LP classes as in (3)
$\alpha_i := \lambda_i^{cur} / (\lambda_i^{cur} + \lambda_i^{avg})$;
6 // the average rates of HP and LP bursts as in (2)
$\lambda_i^{avg} := (1-\alpha_i) \times \lambda_i^{avg} + \alpha_i \times \lambda_i^{cur}$;
7 // the wavelengths re-allocated for LP bursts as in (1)
$W_1 := W_0 \times \frac{\lambda_1^{avg}}{\lambda_0^{avg} + \lambda_1^{avg}}$;
8 **end if**
9 **end while**

Algorithm 2: ***iBFVF function***

Input: - ub; // the arriving burst $ub = \{s_{ub}, e_{ub}, prio_{ub}\}$
- W_1; // the wavelengths allocated for LP bursts
- W; // the available wavelengths of output link

Output: - *state*; // *state* = −1 if the scheduling is unsuccessful

Process

1 **if** ($prio_{ub}$ = 1) **then** // check if ub is admitted for scheduling
2 *overlap* := the total of overlaps of ub with the scheduled LP bursts;
3 **if** *overlap* ≥ W_1 **then return** −1;
4 **end if**
5 *best_channel* := ***BFVF***(ub, W); // call the BFVF algo. in [8]
6 **if** (*best_channel* = −1) ∧ ($prio_{ub}$ = 0) **then**
7 *best_burst* := ***Replace***(ub, W);
8 **return** *best_channel*;

iBFVF is a function improved from the BFVF algorithm that is the best algorithm of scheduling with void-filling [8]. The ***iBFVF*** function has three tasks: (1) check if ub could be admitted to be scheduled (Lines 1 to 4), (2) call the BFVF algorithm in [8] to schedule ub (Line 5), and (3) if task 2 fails (*best_channel* = −1) and ub is a HP burst ($prio_{ub}$ = 0), a LP burst will be removed to transfer resource for scheduling ub (Lines 6 to 7). The complexity of BFVF defined in [8] is O(Wlog(K)), where W is the total number of wavelengths at the output link and K is the average number of bursts scheduled per channel. Since the arriving and processing rate of bursts at each OBS core node are very fast, only the last two scheduled bursts are considered, therefore, the complexity of BFVF is reduced to O(W). The ***Replace*** function seeks in W wavelengths and selects the first wavelength on which a scheduled LP burst can be removed to transfer resources for scheduling ub, so its complexity is O(W). Because the ***iBFVF*** and ***Replace*** functions run separately, the complexity of the ***TPAC*** algorithm is O(W).

IV. Analysis Model

With the output link model of OBS nodes as considered in Section III, W wavelengths are used for scheduling n bursts that belong to the HP and LP classes. This link model is clearly equivalent to the queue system model in which W servers serve n clients. A two-dimensional Markov model as in [9] can therefore be used to analyze the efficiency (in terms of the blocking probability) for the admission control models.

Basing on the TPAC algorithm in Section III.3, the state transition diagram of the system can be described in Fig. 6, where:

- A state (i, j) corresponds to i LP bursts and j HP bursts that are scheduled on the output link;
- An arriving HP burst can be scheduled on one of W wavelengths, whereas an arriving LP burst is only admitted to schedule on one of W_1 wavelengths ($W_1 < W$);
- HP and LP bursts come at rates of λ_0 and λ_1, respectively, The service rate for these bursts is assumed to be equal and equals to μ, where 1/μ is the average length of incoming bursts;
- In state (i, j), $0 < i < W_1$, $0 < j < W$,
  - if a HP burst arrives and is admitted to schedule, the system transfers to state (i, $j + 1$);
  - if a LP burst arrives and is admitted to schedule, the system transfers to state ($i + 1$, j);
  - if a HP burst is served, the system transfers to state (i, $j - 1$); and
  - if a LP burst is served, the system transfers to state ($i - 1$, j).
- In state (i, j), $0 < i \le W_1$, $i + j = W$, if a HP burst arrives and all resources are occupied, a LP burst is dropped and the released resource is allocated to the HP burst, The system transfers to state ($i - 1$, $j + 1$).

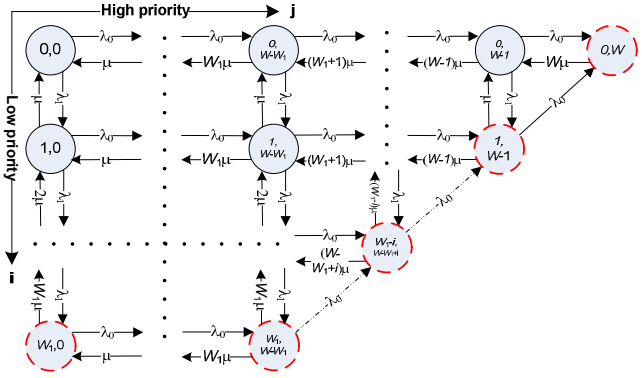


Fig. 6. State transition diagram of multi-dimensional model

Let $\pi_{i,j}$ be the steady state probability that the system is in state (i, j), according to the state transition diagram in Fig. 6, the following equilibrium equations are obtained:

$$(\lambda_0 + \lambda_1 + (i+j)\mu)\pi_{i,j} = \lambda_1\pi_{i-1,j} + \lambda_0\pi_{i,j-1} + (i+1)\mu\pi_{i+1,j} + (j+1)\mu\pi_{i,j+1} \quad (4)$$

for $0 \le i < W_1$, $0 \le j < W$, $0 \le i + j < W$;

$$(\lambda_0 + (i+j)\mu)\pi_{i,j} = \lambda_1\pi_{i-1,j} + \lambda_0\pi_{i,j-1} + (j+1)\mu\pi_{i,j+1} \quad (5)$$

for $i = W_1$, $1 \le j < W - i + 1$, $0 \le i + j < W$;

$$(\lambda_0 + (i+j)\mu)\pi_{i,j} = \lambda_1\pi_{i-1,j} + \lambda_0\pi_{i,j-1} \quad (6)$$

for $i = W_1$, $j = W - W_1$;

$$(\lambda_0 + (i+j)\mu)\pi_{i,j} = \lambda_1\pi_{i-1,j} + \lambda_0(\pi_{i,j-1} + \pi_{i+1,j-1}) \quad (7)$$

for $0 < i < W_1$, $0 < j < W$, $i + j = W$; and

$$j\mu\pi_{i,j} = \lambda_0(\pi_{i,j-1} + \pi_{i+1,j-1}) \quad (8)$$

for $i = 0, j = W$;.

Probability is $\pi_{i,j} = 0$, for $i, j < 0$.

In addition, the normalization condition is

$$\sum_{i,j} \pi_{i,j} = 1 \quad (9)$$

for $0 \le i \le W_1$, $0 \le j \le W$, $0 \le i + j \le W$.

Blocking will occur corresponding to the cases:

- A LP burst arrives and the number of wavelengths occupied by this priority class reaches the threshold ($i = W_1$, $i + j < W$), the burst is dropped;
- A LP burst arrives and the total number of wavelengths occupied by the HP and LP classes has reached the threshold ($i + j = W$), the burst is dropped, and
- A HP burst arrives and the number of wavelengths occupied by this priority class reaches the threshold ($j = W$), the burst is dropped;

Thus, the blocking probability equations of the HP and LP classes are:

$$P_1 = \sum_{j=0}^{W-W_1-1} \pi_{W_1,j} + \sum_{j=W-W_1}^{W} \pi_{W-j,j} \text{ and } P_0 = \pi_{0,W}. \quad (10)$$

The total probability of HP and LP classes is

$$P = \frac{a_0 P_0 + a_1 P_1}{a_0 + a_1} \quad (11)$$

The steady state probabilities $\pi_{i,j}$ are calculated basing on the Q matrix method as in [10].

V. Simulation and Analysis

The admission control of the SWG, DWG, LLAC and TPAC models are implemented in Network Simulator 2.28 with supporting of the package OBS-0.9a on a PC of 2.4 GHz Intel Core 2 and 2G RAM.

The simulation network is an NSFNET. Arriving packets, that belong to one of the two priority classes, have a Poisson distribution and their sizes are exponentially distributed in range of [500, 1000] bytes. The generated bursts also have the Poisson distribution and belong to one of these two classes. The effectiveness of these models is evaluated basing on two following criteria:

- The burst loss rate is calculated as the number of dropped bursts relative to the total arriving bursts, and
- The bandwidth utilization rate is calculated as the rate of the scheduled bursts relative to the allocated bandwidth.

Other simulation parameters include:

- Standardized loads range from 0.1 to 0.9;
- The rate of HP and LP loads in the network is 7:3;
- The number of wavelengths of output link (W) is 12;
- The wavelength re-allocation cycle (T_C) is 10ms, so the observation window size (T_W) is 5ms.

As depicted in Fig. 7, TPAC has the lowest burst loss rate for HP (Fig. 7a), LP (Fig. 7b) and both priority classes (Fig. 7c). This is because the wavelength allocation method of TPAC for HP class is similar to that of LLAC, so HP bursts always receive absolute priority. In addition, the mechanism of prioritizing more resources for HP bursts in the TPAC model also allows HP bursts to have more scheduling opportunities than LP bursts when a contention occur. Therefore, in some cases, the burst loss rate of TPAC is lower than that of LLAC. With LP class, due to the periodical wavelength re-allocation based on the arriving rate of LP bursts, LP bursts are allocated more resources to be scheduled. This reduces the LP burst loss rate of TPAC in comparison with that of the other models (Fig. 7b).

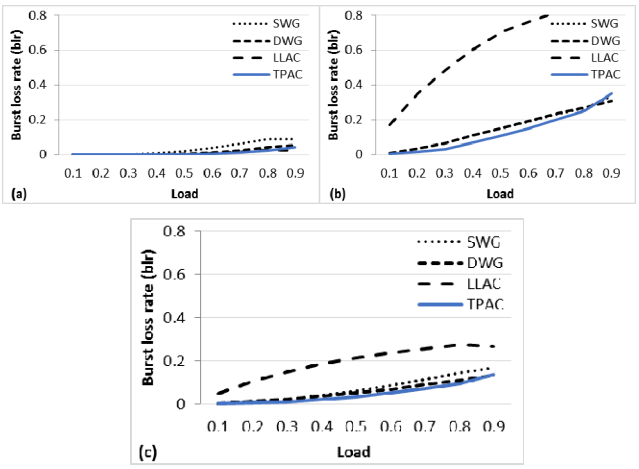


Fig. 7. Comparison of the burst loss rate of (a) HP class, (b) LP class and (c) both HP and LP classes in the SWG, DWG, LLAC and TPAC models.

Due to the reduced burst loss, TPAC has the highest bandwidth utilization rate for HP (Fig. 8a), LP (Fig. 8b), and both classes (Fig. 8c). The simulation results show that TPAC reduces 28% in burst loss and increases 16% in bandwidth utilization in comparison with those of LLAC. The reason for the difference between the high reduction in burst loss but a slight increase in bandwidth utilization is due to the fact that the rate of using the bandwidth of the links in OBS networks is only about 70% [11][12].

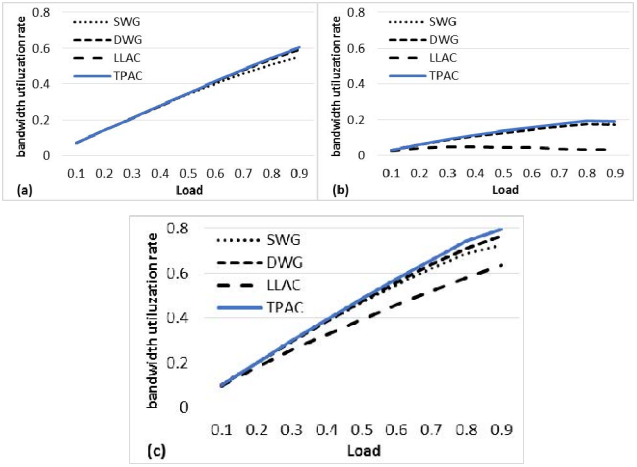


Fig. 8. Comparison of the bandwidth utilization rate of (a) HP class, (b) LP class and (c) both HP and LP classes in the SWG, DWG, LLAC and TPAC models.

With the same parameters as in the above simulation, Figure 9 shows that there is an approximation between the simulation results and the blocking probability of (11) that is drawn by Mathematica. In fact, it is almost impossible to achieve an equal because there are always the voids that are generated between the scheduled bursts on each wavelength. Figure 9 confirms the correctness of our proposed model.

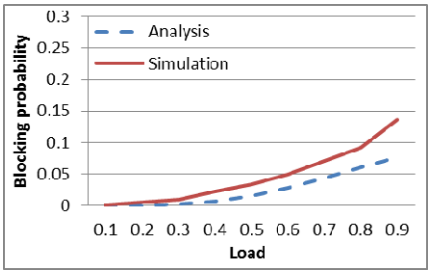


Fig. 9. Comparison on the burst blocking probability between analytical model and simulation.

VI. Conclusion

Admission control is an important operation that has a significant impact on the performance of OBS networks, especially in the case of service differentiation. In this paper, a model of traffic prediction based admission control has been proposed in which the wavelength re-allocation for LP bursts is flexibly adjusted depending on the rate of arriving HP and LP bursts. HP bursts are absolutely prioritized, so in addition to using any of the wavelengths on the output link, an additional mechanism of prioritizing more resources for HP bursts is also proposed for cases where there is a contention with scheduled LP bursts. Simulation results have also shown that the TPAC model is more efficient than the previous models in term of burst loss and bandwidth utilization. An analytical model based on Markov model is also built and it has confirmed the correctness of our proposed model.

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