Multilink Performance of the Load-Level-Based Admission Control Mechanism for OBS Networks

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***Abstract*— In this paper, we analyze the performance of the Load-Level-Based Admission Control mechanism (LLAC) for optical burst-switched networks in a multilink scenario. The goal of this mechanism is to differentiate the blocking probability of a given service class according to the network load and a class-associated parameter, called *load level*. For the proposed mechanism, we develop a multilink analytical model based on the reduced load approximation method, which provides a more accurate blocking probability estimation than a single-link model. With the multilink model, the performance of the load-level-based mechanism is even better than using a single-link model. For the analyzed scenarios, high-priority bursts experiences a blocking probability up to 60% lower than the one provided by the single-link model. The results also show that the load-level-based mechanism effectively differentiates the services in all analyzed scenarios, when compared to other similar mechanisms.**

I. Introduction

Optical burst switching (OBS) [1], [2] is an all-optical data transport technique proposed to ensure the efficient use of the bandwidth offered by wavelength-division multiplexing (WDM) networks. In OBS networks, packets with the same destination address are aggregated in bursts by edge nodes. Then, before the burst transmission, the aggregating edge node sends a control packet to establish an all-optical path in an out-of-band signaling channel. The network resources are only held for the burst switching and transmission time and core nodes do not need buffers to store and process bursts.

The quality-of-service (QoS) support is essential in OBS networks. Despite the bandwidth availability, the best-effort service is not able to guarantee the QoS required by new applications [3]. The main problem is that only a few tens of wavelengths are available per optical link nowadays. Once a burst occupies one wavelength, or a fraction of it, during the transmission, some bursts will be blocked depending on the load offered to the network. In addition, the existing QoS mechanisms are proposed for packet switched networks and, at most, are based on management of electronic buffers [4]. To employ these mechanisms in OBS networks, it is necessary to convert the optical signal to the electronic domain at each edge node, which limits the data transport rate. Moreover, to date, optical memories are not yet available and bursts can only be delayed by fiber delay lines (FDLs) [5]. Such factors lead to development of OBS-specific QoS mechanisms.

In a previous work [6], we proposed an admission control mechanism for providing service differentiation in OBS networks. The idea behind the Load-Level-based Admission Control Mechanism (LLAC) is to reserve a different amount of wavelengths in a link for each service class. The number of wavelengths that a class can occupy in a link is defined by a parameter called *load level*. Thus, LLAC differentiates the blocking probability experienced by a given class, admitting bursts according to the network load and the load level associated to this class. To evaluate the performance of LLAC, we considered a single-link model. The single-link model provides a satisfactory approximation for the blocking probability of each service class in a link, but it has some drawbacks. First, this model does not take into account the wastage of capacity caused by dropped bursts on the links they traverse before they are blocked. Second, the single-link model does not consider that the load offered to core nodes is reduced because of the blocking of bursts along source-destination path. For OBS networks, these two factors must be considered in the development of more realistic models.

In this paper, we derive a multilink analytical model for the load-level-based mechanism based on the reduced load fixed-point approximation for OBS networks [7]. The main goal of this paper is to analyze the performance of LLAC in a real network topology, using the developed multilink model. The load-level-based mechanism always performs well and, according to the results, its performance with the multilink model is even better than with the conventional single-link model. In addition, for all analyzed scenarios, LLAC provides a lower blocking probability for the high-priority class in comparison with other admission control mechanisms.

The remainder of the paper is organized as follows. In Section II, we discuss the works related to quality of service in OBS networks. The LLAC mechanism is presented in Section III. We then derive the multilink analytical model for LLAC in Section IV. After that, in Section V, we analyze the performance of the load-level-based mechanism in comparison with other similar mechanisms, based on their multilink models. Conclusions about this work are presented in Section VI.

II. Related Work

Several mechanisms [5], [8] have been proposed to address QoS support in OBS networks. One approach is to reserve a different number of wavelengths in a link for each service class. This is the idea of the admission control mechanisms for OBS networks. Zhang *et al.* [8] propose two admission control mechanisms: a static and a dynamic mechanism. Both are based on the number of wavelengths occupied by each service class. Let W_i be the number of wavelengths that a class i can occupy in a link, a burst of class i will be admitted if the following condition is satisfied,

$$\omega_i \text{ (\textit{number of occupied wavelengths by class } } i) < W_i. \quad (1)$$

Although these mechanisms have the same admission criterion, they differ in how the wavelengths are reserved for each class. The static mechanism reserves a fixed set of wavelengths W_i, in a given link, for bursts of a given service class i. On the other hand, the dynamic mechanism reserves a fixed number of wavelengths W_i, not a fixed set, for bursts of a given service class i. Thus, a burst belonging to class i can occupy any wavelength in a given link, because the admission criterion is satisfied. In addition, with the dynamic mechanism, high-priority bursts are admitted if there is at least one available wavelength. In other words, let h be the high-priority class, W_h is always equal to the link capacity. Therefore, there is no guarantee that the maximum number of wavelengths occupied by bursts belonging to a low-priority class i is W_i.

For the static and dynamic mechanisms, a node must keep track of the number of wavelengths occupied by bursts of each class to guarantee that the number of wavelengths occupied by bursts of a given class i does not exceed W_i. Consequently, every node must store a large number of states, which is not desirable. To reduce the number of states stored by nodes, we propose an admission control mechanism that does not require the knowledge of what service class occupies what wavelength in a given link and also benefits high-priority bursts.

III. The Load-Level-Based Mechanism

The Load-Level-based Admission Control mechanism (LLAC) assumes that the network employs a signaling protocol that does not require a positive acknowledgement for sending a burst, such as JET (Just-Enough Time) or JIT (Just-In Time) [1], implying that all OBS nodes must implement LLAC [6]. In addition, LLAC considers that each OBS node supports full wavelength conversion and a burst requires only one wavelength during its transmission.

The load-level-based mechanism defines a parameter for each service class i named load level, l_i. The load level must be configured at each node of the network and indicates the maximum number of wavelengths that bursts of a given class i can occupy. If we define W as the number of wavelengths in a given link, the inequality $0 < l_i \leq W$ always holds for every class i. The load level is used by LLAC to differentiate the burst blocking probability experienced by each service class. A burst belonging to a class i, which arrives at a node, at time t_0, is admitted if at t_0 the number of occupied wavelengths is less than the load level l_i, in other words,

$$\omega \text{ (\textit{number of occupied wavelengths}) } < l_i. \quad (2)$$

Otherwise, the burst is blocked without sending any error message back to the edge node. Therefore, the higher the load level of class i, the lower the burst blocking probability of class i. It is worth noting that the admission criterion of LLAC is based on the total number of occupied wavelengths, and not on the number of occupied wavelengths for bursts of class i, as occurs in static and dynamic mechanisms. This is the key point of LLAC, which leads to fewer states stored by nodes than in other mechanisms.

IV. The Multilink Analytical Model

The exact solution for blocking probabilities in OBS networks is an NP-complete problem [7]. Therefore, many studies employ a single-link model to calculate blocking probabilities in such networks. The single-link model provides an approximation for the network behavior. This model, however, does not consider that the load offered to core nodes is reduced because of the blocking of bursts along source-destination path. Thus, considering a single-link model to evaluate the performance of mechanisms developed for OBS networks cannot reflect the actual behavior of these mechanisms and also may lead to an overprovisioned network. In this section, we introduce a multilink model for the load-level-based admission control mechanism. The multilink model considers the reduced load fixed-point approximation for OBS networks, without service differentiation, developed by Rosberg *et al.* [7].

We consider a network N for developing the multilink model. Let L be the number of links in N, W be the capacity of a link in wavelengths, and R be the set of all possible routes in N. Each link v is unidirectional and a route r is an ordered set of links that connects a source node to a destination node. The network N also employs static routing. In addition, we consider the following assumptions.

- The arrival of bursts belonging to class i at route r is a Poisson process with rate $\lambda_{r,i}$.
- The burst transmission time is exponentially distributed with mean $1/\mu$ for all service classes, where μ represents the transmission rate of one wavelength.
- All the wavelengths in all of the L links of N have the same transmission rate μ.
- A burst that belongs to any service class requires the reservation of only one wavelength for its transmission until it reaches the destination or until it is blocked at one of the nodes of N.
- The number of service classes is n.

A link v is modeled as a *M/M/W/W* queue, where W is the link capacity in wavelengths. Each link can be represented as a continuous-time Markov chain and chain state ω represents the number of occupied wavelengths in a given time ($\omega = 0, 1, 2, \dots, W$).

After applying the admission criterion, the burst arrival rate of class i at link v, denoted by $\lambda_{i,v}(\omega)$, is a function of the number of occupied wavelengths in v. If the load level of class i satisfies the admission criterion of LLAC, bursts of this class are admitted. Otherwise, bursts of class i are blocked. Thus,

$$\lambda_{i,v}(\omega) = \begin{cases} \lambda_{i,v}, & \text{if } \omega < l_i \\ 0, & \text{if } \omega \geq l_i \end{cases}, \quad (3)$$

where the burst arrival rate of class i at an OBS node that admits bursts carried in link v, $\lambda_{i,v}$, is given by

$$\lambda_{i,v} = \sum_{r \in R, v \in r} \lambda_{i,r} \prod_{u=1}^{L} (1 - I(u, v, r).B_{i,u}(\rho_{i,u}, l_i, W)). \quad (4)$$

Equation 4 takes into account the reduced-load effect to determine the burst arrival rate of class i offered to link v. Let be $I(u,v,r)$ a binary variable. If the links $u,v \in r$ and link u strictly precedes, not necessarily immediately, link v along route r, then $I(u,v,r)$ equals one. $I(u,v,r)$ is equal to zero, for any another situation where links u and v do not satisfy the previously presented conditions. The blocking probability of bursts belonging to class i in link u is given by $B_{i,u}(\rho_{i,u}, l_i, W)$.

The total burst arrival rate offered to a link v, $\Lambda_v(\omega)$, is equal to the sum of the burst arrival rates of the n service classes at v, after verifying the LLAC admission criterion. Then, $\Lambda_v(\omega)$ is given by

$$\Lambda_v(\omega) = \sum_{i=0}^{n-1} \lambda_{i,v}(\omega), \quad \omega = 0, 1, 2, \ldots, W-1. \tag{5}$$

The rate $\Lambda_v(\omega)$ is a function of the number of occupied wavelengths, ω, because the arrival rate of each class i offered to link v depends on the LLAC admission criterion.

From the flow balance equations, derived from the Markov chain, we calculate the steady-state probabilities π_ω of each chain state ω. As the probability of a burst of class i be blocked at link v, $B_{i,v}$, is equal to the probability of the chain be in a state $\omega \geq l_i$, where l_i is the load level of class i in the time the burst arrives at v, we have

$$B_{i,v}(\rho_{i,v}, l_i, W) = \sum_{\omega=l_i}^{W} \pi_\omega = \sum_{\omega=l_i}^{W} \frac{\frac{1}{\omega!\mu^\omega} \prod_{k=0}^{\omega-1} \Lambda_v(k)}{1 + \sum_{j=1}^{W} \frac{1}{j!\mu^j} \prod_{k=0}^{j-1} \Lambda_v(k)}, \tag{6}$$

where $\rho_{i,v}$ is the load offered to link v for bursts of class i, which is given by $\rho_{i,v} = \lambda_{i,v}/\mu$.

Considering the blocking of a burst an independent event, which occurs from a link to other link along a route, the blocking probability of bursts belonging to class i in route r, $B_i(r)$, is given by

$$B_i(r) = 1 - \prod_{u \in r} (1 - B_{i,u}(\rho_{i,u}, l_i, W)) \tag{7}$$

and the blocking probability of an arbitrary burst that belongs to class i, B_i, satisfies

$$B_i = \frac{1}{\alpha_i} \sum_{r \in R} \lambda_{i,r}.B_i(r), \tag{8}$$

where $\alpha_i = \sum_{r \in R} \lambda_{i,r}$.

As we consider the reduced-load effect in the multilink model, there is no exact solution for blocking probability in a given link. An efficient method to calculate the blocking probability of bursts belonging to class i in a link employs a successive iteration procedure [7]. For this purpose, we define a vector $B_i = (B_{i,1}, B_{i,2}, B_{i,3}, \ldots, B_{i,L})$, which represents the blocking probability of bursts of class i in every link of the network. The iteration procedure begins when we assign an initial value for burst blocking probabilities of class i for every link of N, resulting in vector B_i^0. Then, at each iteration m, we solve the blocking probability of class i according to results of iteration $m-1$. To obtain the new vector of blocking probabilities B_i^m, we apply a transformation $T(B_i)$ defined by

$$T(B_i) = (T_{i,1}(B_i), T_{i,2}(B_i), T_{i,3}(B_i), \ldots, T_{i,L}(B_i)), \tag{9}$$

where $T_{i,u}(B_i) = B_{i,u}(\rho_{i,u}, l_i, W)$ and $B_i^m = T(B_i^{m-1})$. The iteration procedure is then repeated until B_i^m is sufficiently close to B_i^{m-1}. In all scenarios analyzed in this paper, no matter the initial vector, the successive iteration procedure always converged to a unique fixed point.

V. Results

In this section, we compare the proposed load-level based mechanism to the static and dynamic mechanisms. For the static and dynamic mechanisms, we extend the single-link models proposed by Zhang *et al.* [8] also based on reduced load approximation method. The multilink models for these two mechanisms are not presented for the sake of brevity. The analysis considers two service classes, where class 0 is the high-priority class. The number of wavelengths per link is $W = 16$ and the capacity of each wavelength is 1.0 Gb/s. The mean burst size is 128 kB for all service classes. The analysis is divided into two parts. First, we verify the accuracy of the multilink model developed for LLAC in comparison with the single-link model. After that, we evaluate the performance of the three mechanisms and the network without any QoS support, referred as classless, according to the load offered to the network and the aggressiveness against class 1.

A. Accuracy of the Multilink Model

In order to verify the accuracy of the developed multilink model, we consider a scenario in which the path from the source to the destination consists of a chain of nodes. The goal of this analysis is to show that the larger the length of the source-destination path is, the more essential a multilink model becomes to accurately estimate the burst-blocking probability. In the analysis, we compare the multilink model, based on reduced load approximation, to the single-link approximation, which does not consider that the blocking probability in a link is influenced by other links of the network. Considering the single-link approximation and a chain of nodes, the blocking probability of bursts from a given class i is estimated by

$$B_i = 1 - (1 - B_{i,v})^d, \tag{10}$$

where $B_{i,v}$ is the blocking probability of bursts belonging to class i in a single link v and d is the distance, or the number of links, from the source to the destination.

In this analysis, we apply the two approximation methods to the LLAC mechanism. We have $l_0 = 16$ for class 0 and $l_1 = 12$ for class 1. In addition, the load offered to the chain is 0.9 erlangs, 30% of bursts belong to class 0, and the distance between the source and the destination ranges from 1 to 7.

According to Fig. 1, the performance of the load-level-based mechanism with the multilink model is even better than using a single-link model. The results show that the larger the distance from the source to the destination, the greater the difference between the blocking probabilities estimated by each method. For a distance of 3 links, the blocking probability estimated to class 0 by the multilink model is 40% lower than the one estimated by the single-link model. This difference is equal to 25% for class 1. For a distance of 7 links, high-priority bursts experiences a blocking probability 60% lower than the one provided by the single-link model. For class 1, the difference of the estimations reaches 30%.

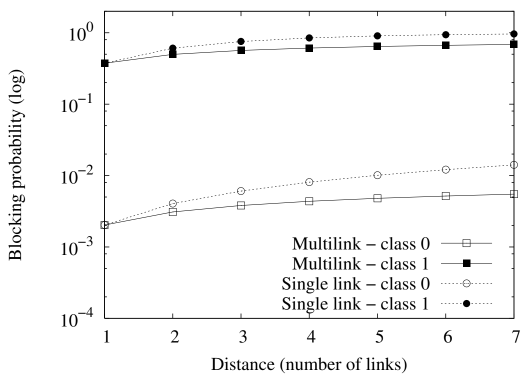


Fig. 1. Accuracy of single-link and multilink models.

B. *Impact of the Offered Load*

The NSFNET network, illustrated in Fig. 2, is used in ou analysis. This network is composed of 16 nodes and 50 unidirectional links. The weight assigned to each link is used in the shortest-path computation and represents the length of the links in units of 10 km.

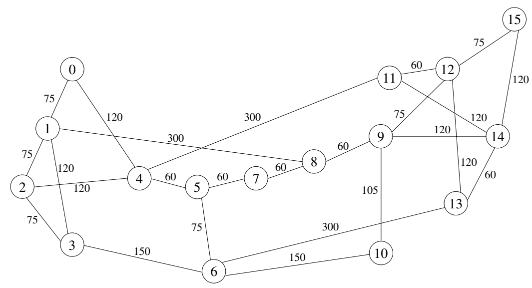


Fig. 2. The NSFNET network.

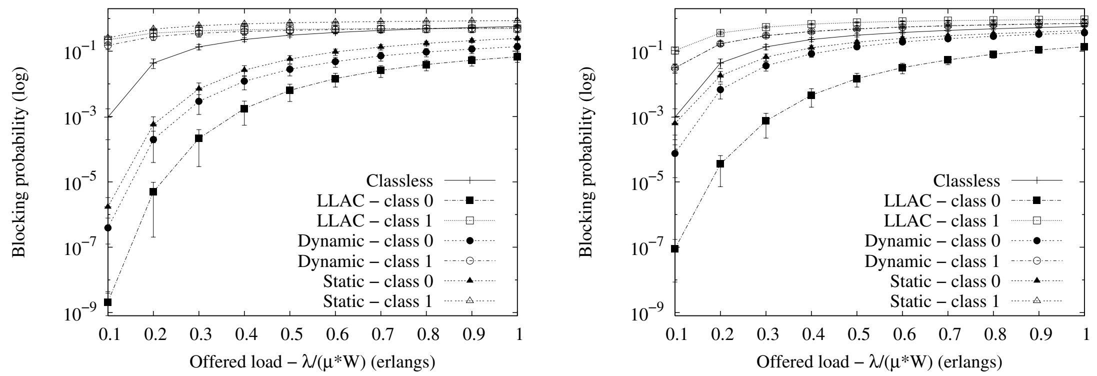
For each analysis run, we randomly choose 16 source-destination pairs. The same set of source-destination pairs chosen for a run is considered for all mechanisms. We define that each node can be the source of only one burst flow and thus we assure that all nodes of the network generates bursts. A source node generates bursts of both service classes. For every point of the curves presented in this section, we calculated the confidence interval for a 95% confidence level.

In order to evaluate the impact of the offered load in the blocking probability experienced by each service class, the traffic amount, per flow, of classes 0 and 1 is fixed. We consider that 30% of bursts belong to the high-priority class, class 0, and 70% belong to class 1. We also assume, for the three mechanisms, the same value for the maximum number of wavelengths that bursts of class 1 can occupy. As a consequence, the three mechanisms reserve the same number of wavelengths for high-priority class: W_0 for the static, $W_0 - W_1$ for the dynamic, and $l_0 - l_1$ for the load-level-based mechanism. We analyze two situations of aggressiveness against the low-priority class. For the more aggressive scenario, bursts of class 1 can occupy up to 25% of the wavelengths in each link of the network and for the less aggressive scenario, bursts of class 1 can occupy up to 50%.

For the more aggressive scenario, we have $l_0 = 16$ and $l_1 = 4$ for LLAC, $W_0 = 16$ and $W_1 = 4$ for the dynamic mechanism, and $W_0 = 12$ and $W_1 = 4$ for the static mechanism. As shown in Fig. 3(a), LLAC provides a lower blocking probability for high-priority bursts, as the offered load to the network increases. For an offered load of 0.6 erlangs, the blocking probability of class 0 provided by LLAC is about five times less than the one provided by the static or dynamic mechanisms. For the same offered load, the three mechanisms provide the same blocking probability to bursts of class 1. The better performance of the LLAC mechanism, in comparison with the other two mechanisms, is due to its admission criterion, which takes into account the total number of occupied wavelengths in a link instead of the number of wavelengths occupied by each service class in a link. Because of its criterion, LLAC becomes more aggressive with low-priority bursts and privileges high-priority bursts. With LLAC, the probability that a burst belonging to class 0 finds a wavelength occupied by a burst of class 1, at a time t, is small because this mechanism admits a lower number of bursts of class 1. As a consequence, the contention for network resources is, most of the time, between bursts of class 0.

Fig. 3(a) also shows that the higher the load offered to the network, the higher the blocking probability of each class, except in one situation. When the offered load ranges from 0.5 to 1 erlang, the blocking probability provided by LLAC to bursts of class 1 slowly decreases. The reduced-load effect along source-destination path explains this effect, once a fraction of bursts is blocked at each previous node in the source-destination path. Thus, nodes near to the source block more bursts of class 1 and, as a consequence, the load offered by this class to the following nodes is lower.

Considering the less aggressive scenario, we have for the LLAC mechanism $l_0 = 16$ and $l_1 = 8$, for the dynamic mechanism $W_0 = 16$ and $W_1 = 8$, and for the static mechanism $W_0 = W_1 = 8$. The LLAC mechanism, for this scenario, is the only one that effectively differentiates the blocking probability experienced by service classes. According to Fig. 3(b), as the offered load increases, the service differentiation provided by dynamic and static mechanisms is degraded. It is also worth mentioning that, for this scenario, the blocking probability provided by LLAC to bursts of class 1 does not decrease as the offered load increases. Since the aggressiveness against class 1 is lower, the number of low-priority bursts blocked by nodes near to the source is not enough to reduce the blocking probability of this class at the following nodes in the path until the destination. Such fact could not be observed, if a single-link model has been used.



(a) More aggressive scenario.

(b) Less aggressive scenario.

Fig. 3. Performance evaluation of the admission control mechanisms.

The previous results show that the number of wavelengths reserved for each class impacts the performance of the mechanisms. The larger the number of wavelengths reserved for a class, the lower the blocking probability experienced by this class. Thus, we evaluate the performance of LLAC and the dynamic mechanism as the aggressiveness against class 1 decreases. For both mechanisms, bursts of class 0 can occupy any available wavelength ($l_0 = W_0 = 16$). In addition, the load offered to the network is 0.2 erlangs, 30% of bursts belong to class 0, and the number of wavelengths that bursts of class 1 can occupy in a link, l_1 or W_1, ranges from 4 to 14.

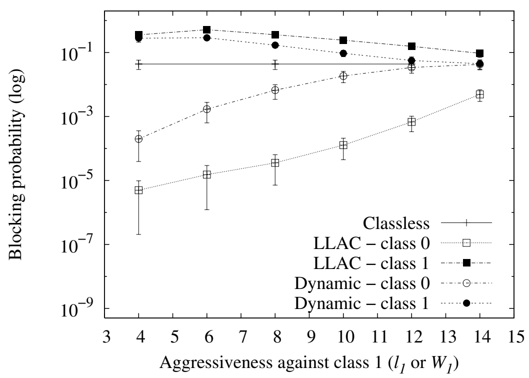


Fig. 4. Effectiveness of the admission control mechanisms.

As shown in Fig. 4, LLAC remains differentiating the blocking probability of each class as the load level of the class 1, l_1, increases. Even when $l_1 = 14$, just two units less than l_0, the two service classes experience different blocking probabilities. The blocking probability for class 0 is in order of 10^{-3} and for class 1 is in order of 10^{-1}. These results confirm that is possible to differentiate the blocking probability of each class using LLAC, without starving the low-priority traffic. The level of differentiation imposed to the services is a choice of the network operator. On the other hand, the service differentiation provided by the dynamic mechanism is degraded because $W_1 = 12$. For this scenario, the dynamic mechanism only differentiates the services, if the difference between the parameters W_0 and W_1 is larger than 4 units.

VI. Conclusion

In this paper, we derived a multilink analytical model for the load-level-based admission control mechanism (LLAC). The main goal is to evaluate the performance of LLAC in a real network topology, using the developed multilink model. The results show that the performance of the load-level-based mechanism using the multilink model is better than using a single-link model. For the analyzed scenarios, high-priority bursts experiences a blocking probability up to 60% lower than the one provided by the single-link model. In addition, the LLAC mechanism, compared to the static and dynamic mechanisms, provides a lower blocking probability to the high-priority bursts in all analyzed scenarios. Even when the offered load increases and/or the aggressiveness against the low-priority class decreases, LLAC effectively differentiates the blocking probability experienced by the service classes.

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