An Admission Control Mechanism for Providing Service Differentiation in Optical Burst-Switching Networks

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***Abstract*— In this paper, we propose a new admission control mechanism for providing QoS in optical burst-switching networks (OBS). The proposed mechanism admits bursts of a given service class according to network load and a class-associated parameter. Based on this parameter, referred as load level, it is possible to differentiate the burst blocking probability experienced by each service class. We also develop an analytical model for the proposed mechanism and validate this model through simulation. Different scenarios are tested by varying the offered load and the amount of traffic of each service class. The results show that the proposed mechanism properly differentiates the services in all analyzed scenarios and always provides a lower blocking probability for the high-priority class bursts in comparison with other similar admission control mechanisms.**

I. INTRODUCTION

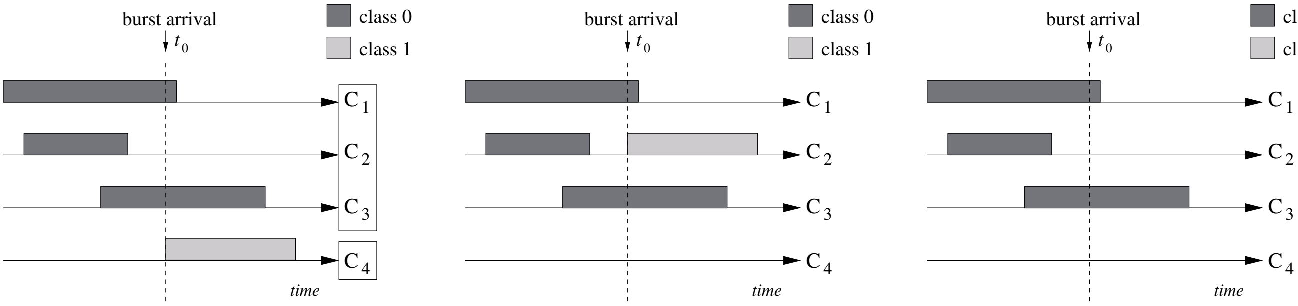
Wavelength-division multiplexing (WDM) is a high-capacity data transport technology. Nevertheless, to efficiently use the bandwidth offered by WDM networks, all-optical data transport techniques, including optical switching, are required. One of these techniques is the optical burst switching (OBS) [1], [2].

In OBS networks, packets with the same destination address are aggregated in bursts by the edge nodes of the network. Before the burst transmission, the aggregating edge node sends a control packet in an out-of-band signaling channel. When the control packet arrives at an OBS switch that is in source-destination path, it is converted and processed electronically. After that, the OBS switch reserves, if it is possible, the required resources for the burst. Otherwise, if there are not available resources, the burst is blocked. Most of the signaling protocols used in OBS networks do not require that an OBS switch sends an error message or a reservation acknowledgment to the edge node. The network resources are only held for the burst switching and transmission time. This is one of the main aspects that differs OBS from optical circuit switching. Optical burst switching also differs from optical packet switching since buffers are not needed to store and process bursts. The optical packet storage is expensive and complex.

Quality of service (QoS) support is an important issue in optical burst-switched networks (OBS). Currently, despite the bandwidth availability, a link has at most few tens of wavelengths. Once, a burst occupies one wavelength, or a fraction of this, during the transmission some bursts will be blocked depending on the offered load to the network. In addition, the existing QoS mechanisms are proposed for packet switching networks and, at most, are based on management of electronic buffers [3]. To use these mechanisms in optical burst-switched networks, it is necessary to convert the optical signal to the electronic domain at each intermediate node, which limits the data transport rate. Furthermore, optical random access memories (RAMs) are not yet available. Bursts can be only delayed using fiber delay lines (FDLs) nowadays [4]. Thus, it is necessary to develop specific QoS mechanisms for OBS networks.

Several mechanisms have been proposed for providing differentiated services in optical burst-switching networks [4], [5], [6], [7]. Zhang *et al.* [7] propose two admission control mechanisms: a static and a dynamic mechanism. Both are based on the number of wavelengths occupied by each service class. In the static mechanism, a fixed set of wavelengths W_i in a given link is reserved for bursts of a given service class i. In the dynamic mechanism, a fixed number of wavelengths W_i, not a fixed set, is reserved for bursts of a given service class i. Thus, a burst belonging to class i may occupy any wavelength in a given link, since the number of occupied wavelengths by bursts of class i is less than W_i. In these two mechanisms, a node must keep track of the number of wavelengths occupied by bursts of each service class to guarantee that the number of wavelengths occupied by bursts of a given class i does not exceed W_i. As consequence, every node must store a great number of states. Zhang *et al.* [7] also propose a modified dynamic mechanism. In this modified mechanism, bursts of high-priority class are always admitted when there is at least one available wavelength. Therefore, there is no guarantee that the maximum number of wavelengths occupied by bursts belonging to a low-priority class i is W_i. In the reminder of this paper, the modified dynamic mechanism is referred as dynamic mechanism.

In this paper, we propose an admission control mechanism for providing QoS in OBS networks. The proposed mechanism admits bursts of a given service class according to network load and a class-associated parameter. Based on this parameter, referred as *load level*, it is possible to differentiate the burst blocking probability experienced by each service class. We



(a) The static mechanism.
(b) The dynamic mechanism.
(c) The proposed mechanism.

Fig. 1. An example of how the admission control mechanisms work.

also develop an analytical model for the proposed mechanism, based on the Erlang loss model, and validate this model through simulation. Based on the analytical model, we evaluate the performance of the three mechanisms - static, dynamic, and the proposed mechanism - according to the blocking probability experienced by service classes. Different scenarios are tested by varying the offered load and the traffic amount of each service class. The results show that the proposed mechanism properly differentiates the services in all analyzed scenarios and always provides a lower blocking probability for the high-priority class bursts in comparison with the other two admission control mechanisms.

This paper is organized as follows. Section II describes the proposed admission control mechanism. The analytical model for the proposed mechanism is developed in Section III. Section IV analyzes the performance of the three admission control mechanisms based on their analytical models. Finally, Section V concludes this work and points out future research problems.

II. THE PROPOSED MECHANISM

In this section, we describe the proposed admission control mechanism. We assume that the network employs JET (*Just-Enough Time*) signaling protocol [1]. In addition, we consider that each OBS node supports full wavelength conversion and a burst requires only one wavelength during its transmission.

The use of JET implies that all network nodes must implement the proposed mechanism. In JET, a burst is sent after an offset time without waiting for an acknowledgment. Then, when a burst is sent, an edge node can not guarantee that the number of occupied wavelengths in each link of source-destination path is in accordance with the admission criterion. Just after receiving and analyzing the control packet, a node can determine if the number of occupied wavelengths is in accordance with the admission criterion at the instant of the burst arrival. Thus, to guarantee the service differentiation, the proposed mechanism should not be implemented only by the network edge nodes.

The proposed 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 may 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 proposed mechanism uses the load level to differentiate the burst blocking probability experienced for 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. Otherwise, the burst is blocked without sending any error message back to the edge node. Therefore, the higher the load level of class i is, the lower is the burst blocking probability of class i.

It is worth noting that the admission criterion of the proposed mechanism is based on the total number of occupied wavelengths, and not on the number of occupied wavelengths for bursts of class i. Therefore, in the proposed mechanism a node stores fewer states than in other mechanisms, such as the static or dynamic. The proposed mechanism only stores the load level of each service class and the total number of occupied wavelengths.

Fig 1 shows an example of how the three admission control mechanisms works for two service classes and one link with four wavelengths ($W = 4$). Class 0 is the high-priority class. In static mechanism, three wavelengths are reserved for class 0 bursts ($W_0 = 3$ with C_1, C_2, and C_3 reserved). Bursts of class 1 may occupy only one wavelength ($W_1 = 1$ with C_4 reserved). In the scenario shown in Fig 1(a), when burst belonging to class 1 arrives at time t_0, it can only occupy the wavelength C_4. Fig. 1(b) illustrates the dynamic mechanism operation. Class 1 bursts can occupy, at most, one wavelength ($W_1 = 1$) and class 0 bursts can occupy any wavelength if available. Then, when a burst of class 1 arrives at time t_0, it can occupy wavelengths C_2 or C_4. Finally, Fig. 1(c) illustrates the proposed mechanism operation. Respectively, the load level of classes 0 and 1 are $l_0 = 4$ and $l_1 = 1$. When a burst belonging to class 1 arrives at time t_0, it is blocked because two wavelengths are occupied by bursts of any class and the load level of class 1 is $l_1 = 1$. In this example, class 1 bursts are admitted by the proposed mechanism only when no one wavelength is occupied at its arrival time. It shows that the proposed mechanism is more aggressive with low-priority classes than the static and dynamic mechanisms.

III. THE ANALYTICAL MODEL

In this section, we present the analytical model developed for the proposed mechanism based on the Erlang loss model [4], [7], [6]. We assume that the burst link arrival is a Poisson process with rate λ and the burst size is exponentially distributed with mean $1/\mu$ for all service classes. In addition, a burst requires the reservation of only one wavelength.

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

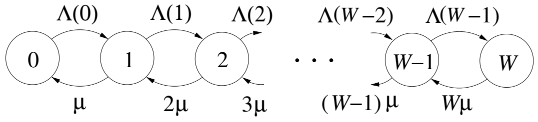


Fig. 2. The state diagram for the proposed mechanism.

Let be n the number of service classes, λ_i the arrival rate of bursts of the class i offered to a node, and $\lambda_i(\omega)$ the burst arrival rate of the class i offered to a link, after applying the proposed mechanism.

The total burst arrival rate, $\Lambda(\omega)$, can be expressed by the sum of the arrival rates of the n service classes after verifying the proposed mechanism admission criterion. Then,

$$\Lambda(\omega) = \sum_{i=0}^{n-1} \lambda_i(\omega), \quad \omega = 0, 1, 2, \ldots, W-1. \tag{1}$$

The rate $\Lambda(\omega)$ is a function of the number of occupied wavelengths, ω, because the arrival rate of each class i depends on the proposed mechanism admission criterion. According to this criterion, for admitting a burst of class i, the number of occupied wavelengths at the instant of the burst arrival must be less than the load level of class i, l_i. Thus, the burst arrival rate of each class i, after applying the admission criterion, is given by

$$\lambda_i(\omega) = \begin{cases} \lambda_i, & \text{if } \omega < l_i \\ 0, & \text{if } \omega \geq l_i \end{cases} \tag{2}$$

From the balance equations, derived from state diagram presented in Fig.2, it is possible to calculate the steady-state probabilities of each chain state ω. Thus,

$$\pi_\omega = \frac{1}{\omega! \mu^\omega} \prod_{k=0}^{\omega-1} \Lambda(k) \pi_0, \quad \omega = 1, 2, 3, \ldots, W \tag{3}$$

and

$$\pi_0 = \frac{1}{1 + \displaystyle\sum_{j=1}^{W} \frac{1}{j! \mu^j} \prod_{k=0}^{j-1} \Lambda(k)}. \tag{4}$$

From Eqs. 3 and 4, it is possible to determine the blocking probability of a service class i. The blocking probability of a burst of class i is given by the probability that the chain is in a state $\omega \geq l_i$, where l_i is the load level of class i. Therefore,

$$B_i(\rho_i, l_i, W) = \sum_{\omega=l_i}^{W} \pi_\omega = \sum_{\omega=l_i}^{W} \frac{\displaystyle\frac{1}{\omega! \mu^\omega} \prod_{k=0}^{\omega-1} \Lambda(k)}{1 + \displaystyle\sum_{j=1}^{W} \frac{1}{j! \mu^j} \prod_{k=0}^{j-1} \Lambda(k)}, \tag{5}$$

where the offered load to the network by bursts of class i is given by $\rho_i = \lambda_i / (\mu * W)$.

From Eq. 5 it is also possible to calculate the total effective load in a given link. Then,

$$T = \sum_{i=0}^{n-1} \rho_i . (1 - B_i(\rho_i, l_i, W)). \tag{6}$$

IV. RESULTS

The analytical model of the proposed mechanism is validated through simulation using the Tangram-II tool [8]. We also used this tool to compare the proposed mechanism with the static and dynamic mechanisms. For the static and dynamic mechanisms, we consider the analytical models proposed and validated by Zhang *et al.* [7]. The analysis and simulation consider a scenario with a single node, which admits, or not, the offered bursts to a single link. In this scenario, the link capacity in wavelengths is $W = 8$. The performance of the three mechanisms is evaluated for two service classes, class 0 and class 1. Class 0 is the high-priority class. The capacity of each wavelength is 1.0 Gb/s and the mean burst size is 128 kB for all service classes. Then, the mean service rate is $\mu = 1000$ bursts/s. For a coherent comparison, we consider, for the three mechanisms, the same value for the maximum number of wavelengths that bursts of class 1 may occupy. This value is the equal to 25% of the wavelengths in a given link. Thus, all mechanisms reserve the same number of wavelengths for class 0: W_0 for the static, $W_0 - W_1$ for the dynamic, and $l_0 - l_1$ for the proposed mechanism. The performance of the three mechanisms is evaluated according to the offered load to the network and the amount of traffic of each service class.

A. Analytical Model Validation

To validate the proposed model, we verify the burst blocking probability experienced by the two service classes varying the offered load to the network. We consider that 50% of bursts that arrives at the node belong to each service class. Also, we assume that the load levels of classes 0 and 1 are $l_0 = 8$ and $l_1 = 6$, respectively. Each point of the simulated curve was calculated with a confidence interval of 95% concerning samples mean. Fig. 3 shows the analytical and the simulated values that validates the model developed for the proposed mechanism.

B. Impact of the Offered Load

To evaluate the impact of the offered load in the blocking probability experienced by each service class, the amount of traffic of each class is fixed. In this scenario, 30% of bursts

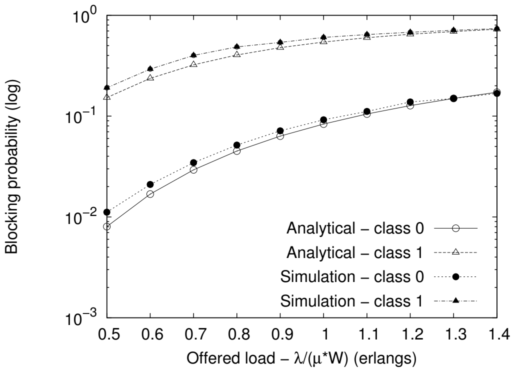
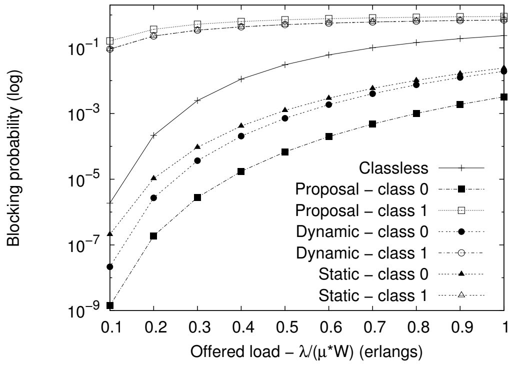
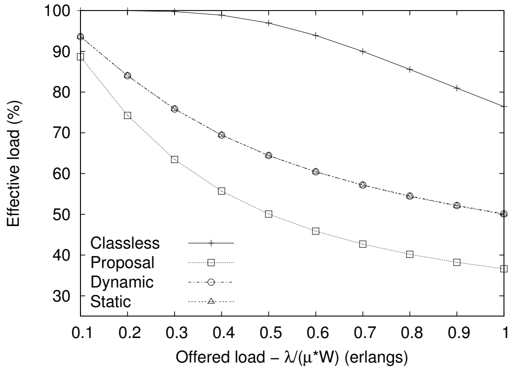


Fig. 3. Analytical and simulation results for blocking probability of classes 0 and 1 varying the offered load.

belong to the high-priority, class 0, and 70% belong to class 1. Furthermore, bursts of class 1 may occupy, at most, two wavelengths. Therefore, for the static mechanism $W_0 = 6$ and $W_1 = 2$, for the dynamic mechanism $W_0 = 8$ and $W_1 = 2$, and for the proposed mechanism $l_0 = 8$ and $l_1 = 2$. Figs. 4(a) and 4(b) show the burst blocking probability and the effective load for the three admission control mechanisms and for the network without QoS support, referred as classless network.



(a) Blocking probability.



(b) Effective load.

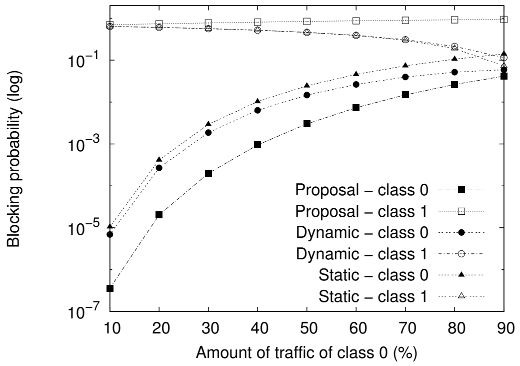
Fig. 4. Impact of the offered load.

It is possible to note that the proposed mechanism provides a lower blocking probability for class 0 bursts, as the offered load to the network increases. It is a consequence of the admission criterion used by the proposed mechanism that takes into account the total number of occupied wavelengths instead of the number of wavelengths occupied by each service class. Therefore, a small number of class 1 bursts is admitted. In other words, the probability that a burst belonging to class 0 arrives to a node at time t and finds a wavelength occupied by a burst of class 1 is reduced. Fig. 4(a) shows that, for an offered load of 1.0 erlang, the blocking probability of class 0 provided by the proposed mechanism is six times less than the one provided by the static or dynamic mechanisms. For the same offered load, the blocking probability of class 1 provided by the proposed mechanism is only 23% greater than the one provided by the static or dynamic mechanisms. The better differentiation obtained by the proposed mechanism is because it is more aggressive with the low-priority class, class 1. The better performance is paid by a reduced effective load of the network. When the offered load is 1.0 erlang, the effective load of the classless network is 76%, for the static and dynamic mechanisms it is 50% and for the proposed mechanism it is 36%. Thus, the effective load provided by each mechanism depends on the amount of traffic of each service class. The blocking probability of class 1 provided by the dynamic mechanism is greater than the one provided by the static mechanism, but, due to the scale, the curves are overlapped.

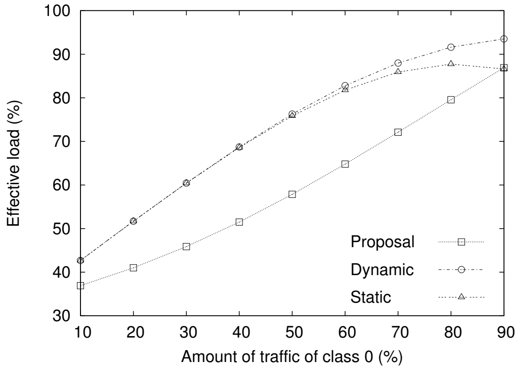
C. *Impact of the Amount of Traffic of Each Service Class*

The amount of traffic of each service class also impacts in the performance of the mechanisms. To analyze this impact in the blocking probability, the offered load is fixed at 0.6 erlangs. In addition, bursts of class 1 may occupy at most two wavelengths. Fig. 5(a) and 5(b) show the burst blocking probability and the effective load for the three admission control mechanisms.

According to Fig. 5(a), as the high-priority traffic increases, the proposed mechanism provides a lower blocking probability for class 0 bursts, resulting in a better differentiation for the service classes. Furthermore, the proposed mechanism is the only one that effectively remains differentiating the services. It is also important to note that when the class 0 traffic is greater than 85% the blocking probability provided by the static mechanism for class 0 bursts is greater than the blocking probability provided for class 1 bursts. Hence, the blocking probability of the high-priority class becomes greater than the blocking probability of the low-priority class. Therefore, the differentiation function provided by the static mechanism is highly dependent of the high-priority class traffic. For the dynamic mechanism, as the high-priority traffic increases, the burst blocking probabilities of both classes tends to be equal to 10^{-1}. Beyond this point the differentiation function is no more effective and the dynamic mechanism works like a classless network. As it can be observed in Fig. 4(a), the blocking probability value 10^{-1} is the same value of the classless network when the offered load is 0.6 erlangs. When the network does not support service differentiation the effective



(a) Blocking probability.



(b) Effective load.

Fig. 5. Impact of the amount of traffic of each service class.

load is the maximum. In this case, as shown in Fig. 4(b), the maximum effective load is 94% for an offered load of 0.6 erlangs. Fig. 5(b) shows that the dynamic mechanism provides the highest effective load, but beyond a point do not differentiate the traffic. It is also possible to note that the effective load provided by the static mechanism increases while the blocking probability of class 0 is the lowest. Therefore, when the blocking probability of class 1 is the lowest, the effective load decreases, because the most of offered bursts belongs to class 0. Finally, for the proposed mechanism, as the amount of class 0 bursts increases the effective load also increases. Nevertheless, the effective load provided by the proposed mechanism is less than the provided by the dynamic mechanism because almost all bursts belonging to class 1 are blocked.

V. CONCLUSION

In this paper, we propose an admission control mechanism for providing QoS in optical burst-switching networks. An analytical model is derived for the proposed mechanism, and its performance is evaluated and compared to the performance of the static and dynamic mechanisms.

The quality of service differentiation resulted from the static mechanism extremely depends on the amount of traffic of each service class. In the analyzed scenarios, when the amount of high-priority class bursts is equal to or greater than 80% of the total traffic, the blocking probability of the high-priority class becomes higher than the blocking probability of the low-priority class.

In dynamic mechanism, as the amount of high-priority traffic increases the mechanism degrades the service differentiation. When the amount of high-priority class bursts surpasses to 40% of the total traffic, the blocking probability of high-priority and low-priority classes are identical.

In all analyzed scenarios, the proposed mechanism effectively differentiates the services providing a lower blocking probability for the high-priority class bursts in comparison with other admission control mechanisms. The better differentiation is paid by a reduction in the effective load of the network. The performance of the proposed mechanism, when compared to the static or dynamic mechanisms, becomes better as the amount of high-priority bursts increases. The higher is the percentage of the high-priority traffic better is the differentiation and lower is the reduction of the effective load. A scenario with a higher percentage of bursts belonging to high-priority class is realistic. It is expected that the optical network traffic be mainly derived from voice and video applications providing high-priority bursts. Furthermore, the proposed mechanism requires fewer states than the other two mechanisms, which turns the optical switching task simpler and more efficient.

The next step of this work will be the analysis of the performance of the proposed mechanism in a multi-node topology and the proposition of a mechanism to support absolute quality of service.

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