An Efficient Multiclass Mechanism for Optical Burst-Switching Networks

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***Abstract*— The novel applications require multiservice networks to guarantee quality of service (QoS). In this paper, we propose a multiclass admission control mechanism for providing QoS in optical burst-switched 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 evaluated its performance in different scenarios. Even when varying the offered load, the traffic amount of each service class, and the number of service classes, the proposed mechanism provides a lower blocking probability for the high-priority traffic in comparison with other similar admission control mechanisms.**

I. Introduction

The novel services, such as multimedia applications and computer grids, demand a large amount of bandwidth. In order to satisfy these new services, optical networks have been developed and wavelength-division multiplexing (WDM) has been considered as a major optical technology, due to its high capacity to transport data.

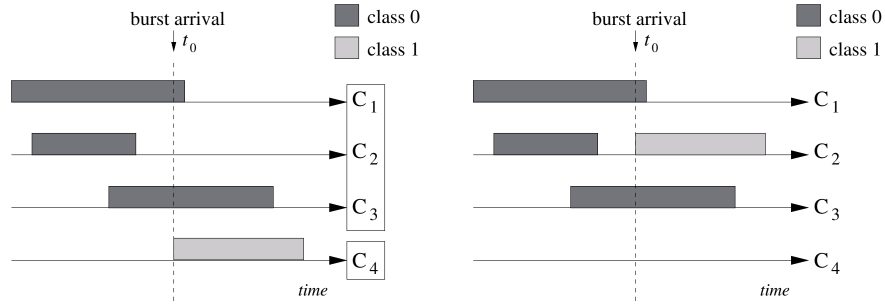
Nowadays, most WDM networks work with electronic switches equipped with optical interfaces, referred as OEO (optical interface - electronic switching - optical interface). These switches limit the data transport rate of WDM networks since the optical signal that arrives at an OEO switch is converted to an electronic signal. Although the optical transmission can reach the magnitude of terabits per second, the electronic switches currently operate with rates of few tens of gigabits per second. Therefore, to efficiently use the bandwidth offered by WDM networks, all-optical data transport techniques, including optical switching, are required. One of these techniques is optical burst switching (OBS) [1], [2].

In OBS networks, packets with the same destination address are first aggregated in bursts by the edge nodes of the network. 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. When the control packet arrives at an OBS switch that is in the source-destination path, it is converted and processed electronically. If possible, the OBS switch reserves the required resources for the burst. Otherwise, if there are no resources available, the burst is blocked. Most of the signaling protocols used in OBS networks do not require error messages or reservation acknowledgments from OBS switches. 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. Optical buffers are expensive and somewhat complex so not using them is an advantage.

In addition to bandwidth requirements, novel applications are also sensitive to quality of service (QoS) parameters, such as data loss and end-to-end delay. The best-effort service is not able to guarantee the required QoS of these emerging applications. It is necessary to develop multiservice networks [3]. Hence, quality-of-service support becomes essential in optical burst-switched networks.

Despite the bandwidth availability, only a few tens of wavelengths are available per optical link nowadays. Since a burst occupies one wavelength, or a fraction of this, 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 switching networks and, at most, are based on management of electronic buffers [4]. 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, to date, optical random access memories (RAMs) are not yet available and bursts can only be delayed by fiber delay lines (FDLs) [5]. Thus, it is necessary to develop specific QoS mechanisms for OBS networks.

In order to provide service differentiation, we propose a multiclass admission control mechanism for OBS networks. The proposed mechanism admits bursts of a given service class according to network load and a class-associated parameter. According to this parameter, referred as *load level*, it is possible to differentiate the burst blocking probability experienced by each service class. Based on the Erlang loss model, we develop an analytical model for the proposed mechanism. We analytically evaluate the performance of this mechanism and compare it to two other admission control mechanisms, considering the blocking probability experienced by the service classes. Several scenarios are tested by varying the offered load, the traffic amount of each service class and the number of service classes. In comparison with the other two mechanisms, the proposed mechanism always provides a



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

Fig. 1. An example of how static and dynamic mechanisms work.

lower blocking probability for the high-priority class bursts in all analyzed scenarios. Even when increasing the offered load, the amount of high-priority traffic, or the number of classes, the proposed mechanism is the only one that effectively differentiates the services.

The remainder of this paper is organized as follows. Section II presents related work concerning quality of service in OBS networks. The proposed admission control mechanism is introduced in Section III and its analytical model is developed in Section IV. Section V analyzes the performance of the proposed mechanism in comparison with the other mechanisms, based on their analytical models. Finally, Section VI concludes this paper and points out the next steps of this work.

II. Related Work

Quality of service support is a challenging issue in OBS networks. Several mechanisms [5], [6], [7], [8] have been proposed to address this point.

Yoo *et al.* [5] propose a modified version of the JET (Just-Enough Time) signaling protocol [1]. A different offset time is associated to each service class. The offset is the time interval between the control packet transmission and the burst transmission. The basic idea is to increase the offset time of the bursts belonging to high-priority classes. Hence, the nodes have more time to allocate the required resources and thus the burst blocking probability of a high-priority class is reduced. Nevertheless, since most high-priority bursts carry packets of time-sensitive media, such as voice and video, the offset time increase causes an increase in the end-to-end latency. Therefore, depending on the burst length and the isolation degree between service classes, the application quality can be degraded.

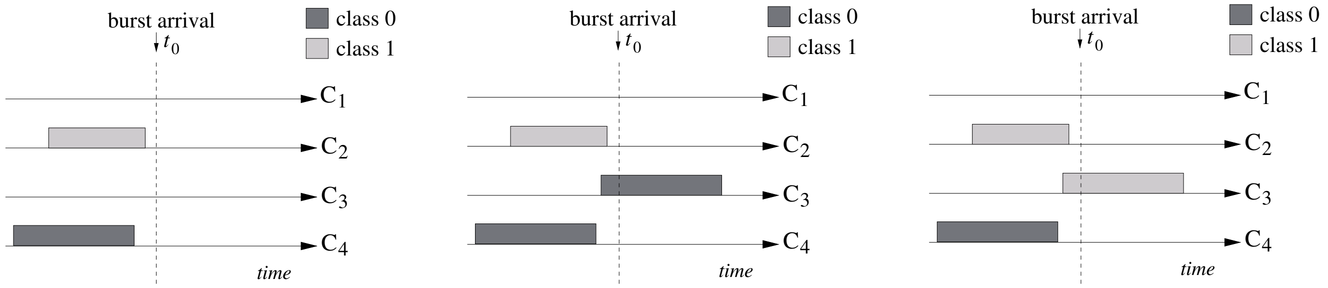
Zhang *et al.* [8] propose two admission control mechanisms: a static and a dynamic mechanism. Both are based on the number of wavelengths occupied by each service class. In the static mechanism, a fixed set of wavelengths W_i in a given link is reserved for bursts of a given service class i. In other words, if the first W_i wavelengths of a link are reserved for class i, burst of class i can only occupy the wavelengths $C_1, C_2, \ldots, C_{W_i}$. 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, given that the number of occupied wavelengths by bursts of class i is less than W_i. Fig. 1 shows an example of how these two 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, at most, three wavelengths ($W_0 = 3$). Then, when a burst of class 1 arrives at time t_0, it can occupy wavelengths C_2 or C_4.

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.* [8] 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. The performance of the static and dynamic mechanisms is analytically evaluated in Section V.

Wan *et al.* [6] also introduce an admission control mechanism based on the load of each service class. For a given class i, the maximum number of occupied wavelengths is within a predetermined quota. The inferior and superior bounds of this quota are derived from the amount of traffic and the QoS parameters of each service class. In order to implement this mechanism, Wan *et al.* propose a centralized architecture for OBS networks. In this mechanism, a central node determines when a burst is admitted. Altough practical, the proposed architecture introduces a single point of failure and increases the delay between the resource reservation and the burst transmission, once the edge nodes now have to wait for the resource reservation acknowledgment sent by the central node.

III. The Proposed Mechanism

In this section, we describe the proposed admission control mechanism. We assume that the network employs JET (*Just-*



(a) Bursts of both classes are admitted. (b) Only bursts of class 0 are admitted. (c) Only bursts of class 0 are admitted.

Fig. 2. Examples of how the proposed mechanism works.

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. Therefore, 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.

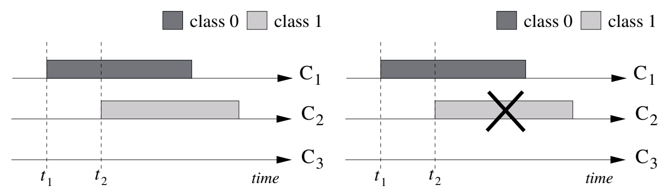
The proposed mechanism defines a parameter for each service class i, named load level, l_i. The load level must be configured at each node of the network and indicates the maximum number of wavelengths that bursts of a given class i may occupy. If we define W as the number of wavelengths in a given link, the inequality $0 < l_i \leq W$ always holds for every class i.

The load level is used by the proposed mechanism 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. 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 the burst blocking probability of class i is.

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. This is the key point of the proposed mechanism. 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. 2 shows three examples of how the proposed mechanism works for two service classes in one link with four wavelengths ($W = 4$). The high-priority class is class 0. Respectively, the load level of classes 0 and 1 are $l_0 = 4$ and $l_1 = 1$. In the situation illustrated by the Fig. 2(a), when a burst belonging to any class arrives at time t_0 it is admitted, once no wavelength is occupied. In Figs. 2(b) and 2(c) bursts belonging to class 1 are blocked, once one wavelength is occupied and the load level of class 1 is $l_1 = 1$.

In the previous example, class 1 bursts are admitted only when no 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. Figs. 3(a) and 3(b) show the differences between the proposed mechanism and the dynamic mechanism in a scenario with one link with three wavelengths ($W = 3$). We define $W_0 = 3$ and $W_1 = 1$, for the dynamic mechanism, and $l_0 = 3$ and $l_1 = 1$, for the proposed mechanism.



(a) Dynamic mechanism. (b) Proposed mechanism.

Fig. 3. The proposed mechanism vs. the dynamic mechanism.

In Figs. 3(a) and 3(b), a burst of class 0 arrives at instant t_1 and is allocated in wavelength C_1. After that, a burst belonging to class 1 arrives at t_2. In the dynamic mechanism, this burst can be allocated in wavelengths C_2 or C_3, once there are no wavelengths occupied by bursts of class 1 and $W_1 = 1$. On the other hand, the proposed mechanism blocks a burst of class 1 because one wavelength is already occupied by a burst of any class and $l_1 = 1$. In this example, the proposed mechanism does not block bursts of class 1 in only one situation: when the arrival time of a burst belonging to class 1 is equal to t_1. On the other hand, the dynamic mechanism blocks bursts of class 1 when one wavelength is already occupied by another burst of class 1, or when all wavelengths are occupied by bursts of class 0. Moreover, in comparison with the proposed mechanism, the static mechanism is also less aggressive with class 1 traffic, once this mechanism always reserves at least one wavelength for this class.

As shown in the previous example, the proposed mechanism privileges the high-priority class since it is more aggressive with low-priority classes. The probability that a burst belonging to class 0 finds a wavelength occupied by a burst of class 1 at an instant t is small since the proposed mechanism admits a lower number of bursts belonging to class 1. As a consequence, the contention for network resources is, at most of the time, between bursts of class 0. Thus, the burst-blocking probability of class 0 is almost exclusively a function of the amount of high-priority traffic and the main goal of the proposed mechanism is achieved: provides a lower blocking probability to the high-priority class, even it starves low-priority classes.

IV. The Analytical Model

In this section, we present the analytical model developed for the proposed mechanism based on the Erlang loss model [5], [7], [8]. 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 for the transmission.

A link is modeled as a *M/M/W/W* queue, where W is the link capacity in wavelengths. As shown in Fig. 4, each link can be represented as a continuous-time Markov chain. Each Markov chain state ω represents the number of occupied wavelengths ($\omega = 0, 1, 2, \ldots, W$).

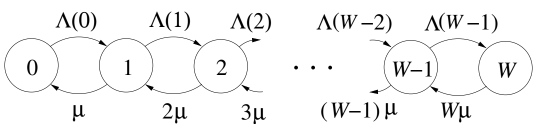


Fig. 4. The state diagram for the proposed mechanism.

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

$$\lambda_i(\omega) = \begin{cases} \lambda_i, & \text{if } \omega < l_i \\ 0, & \text{if } \omega \geq l_i \end{cases} \tag{1}$$

In other words, if the load level of class i satisfies the admission criterion, $\lambda_i(\omega)$ is given by λ_i. Otherwise $\lambda_i(\omega)$ is equal to zero.

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

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

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.

From the balance equations, derived from state diagram presented in Fig.4, 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

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

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,

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

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,

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

The effective load is the percentage of the offered load to the network which is admitted by the mechanism.

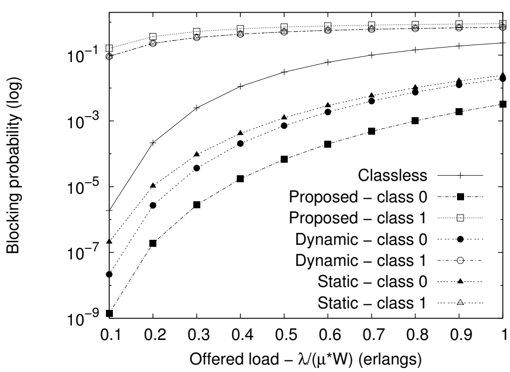
V. Results

In this section, we present the results from the performance analysis of the three admission control mechanisms. The analytical model of the proposed mechanism was validated through simulation [9] using the Tangram-II tool [10]. We also used this tool to analytically 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.* [8]. The analysis considers a scenario with a single node, which admits, or not, the offered bursts to a single link. The capacity of each wavelength is 1.0 Gb/s and the mean burst size is 128 kB for all service classes. In all analyzed scenarios, class 0 is the high-priority class. The performance of the three mechanisms is evaluated according to the load offered to the network, the traffic amount of each service class, and the number of service classes. The effectiveness of the proposed mechanism is also verified for a larger number of service classes [11].

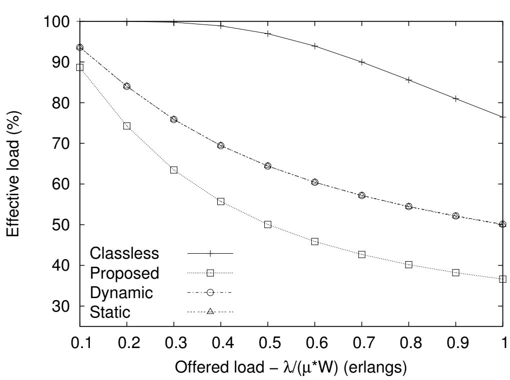
A. Performance for Two Service Classes

In this section, we consider two service classes, class 0 and class 1. The high-priority class is class 0. The link capacity in wavelengths is $W = 8$. For a coherent comparison, we assume, for the three mechanisms, the same value for the maximum number of wavelengths that bursts of class 1 may 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 e $l_0 - l_1$ for the proposed mechanism. We analyze three different scenarios varying the number of wavelengths that bursts of class 1 may occupy. In the more aggressive scenario, bursts belonging to class 1 can occupy up to 25% of the wavelengths in a given link. In the intermediary scenario, bursts of class 1 can occupy up to 50% of wavelengths. Finally, in the less aggressive scenario, bursts of class 1 can occupy up to 75% of the wavelengths. The performance of the three mechanisms is evaluated according to the offered load to the network and the traffic amount of each service class.

1) Impact of the Offered Load: In order to evaluate the impact of the offered load in the blocking probability experienced by each service class and in the effective load, the traffic amount of classes 0 and 1 is fixed. In this scenario, 30% of bursts belong to the high-priority, class 0, and 70% belong to class 1. We analyze three situations of aggressiveness to the low-priority class.



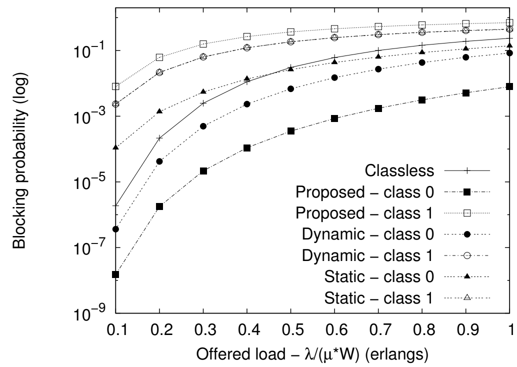
(a) Blocking probability.



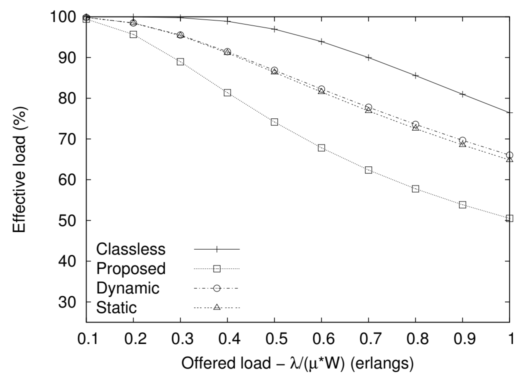
(b) Effective load.

Fig. 5. Impact of the offered load: more aggressive scenario.

In the more aggressive scenario, bursts of class 1 may occupy, at most, two wavelengths. Hence, $W_0 = 6$ and $W_1 = 2$ for the static mechanism , $W_0 = 8$ and $W_1 = 2$ for the dynamic mechanism , and $l_0 = 8$ and $l_1 = 2$ for the proposed mechanism. Figs. 5(a) and 5(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.

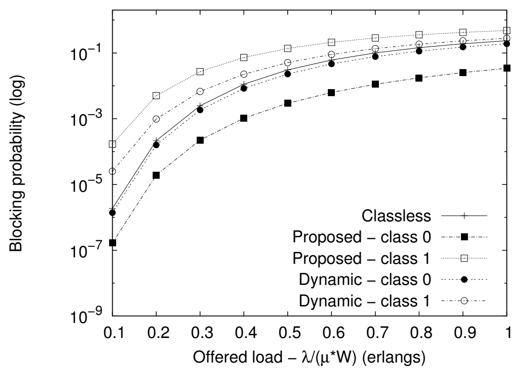


(b) Effective load.

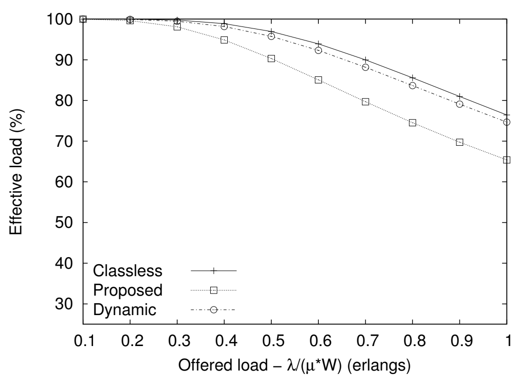
Fig. 6. Impact of the offered load: intermediary scenario.

It is possible to see 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 bursts belonging to class 1 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. 5(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 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.

Figs. 6(a) and 6(b) show the results for the intermediary scenario, where bursts of class 1 can occupy until four wavelengths. In this situation, we have $W_0 = 6$ and $W_1 = 4$ static mechanism, $W_0 = 8$ and $W_1 = 4$ for the dynamic, and $l_0 = 8$ and $l_1 = 4$ for the proposed mechanism. As in the more aggressive scenario, the proposed mechanism provides the lowest blocking probability for the class 0. For an offered load of 1.0 erlang, the blocking probability of class 0 provided by the proposed mechanism is ten times less than the one provided by the static or dynamic mechanisms. Furthermore, the effective load of the three mechanisms is greater than in the more aggressive scenario. This increase of the effective load ratifies the idea that a less aggressiveness to the class 1 results in a greater effective load.



(a) Blocking probability.

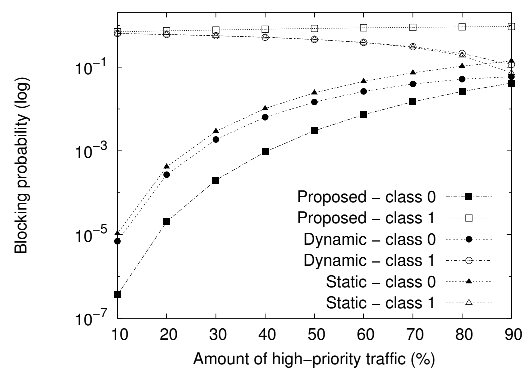


(b) Effective load.

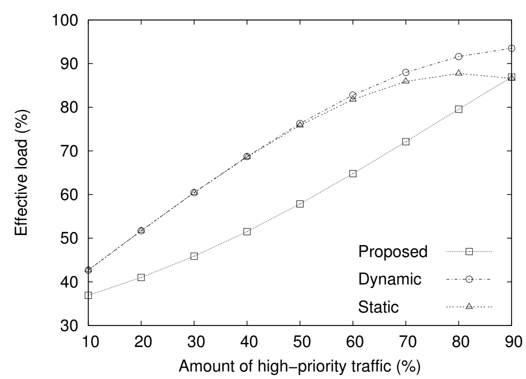
Fig. 7. Impact of the offered load: less aggressive scenario.

In the less aggressive scenario, where bursts of class 1 can occupy at most six wavelengths, we have $W_0 = 8$ and $W_1 = 6$ for the dynamic and $l_0 = 8$ and $l_1 = 6$ for the proposed mechanism. The performance of the static mechanism is not evaluated in this scenario, once the number of reserved wavelengths for class 1 would be greater than the one reserved for class 0. According to Figs. 7(a) and 6(b), as the offered load increases, the blocking probabilities of classes 0 and 1 tend to the blocking probability of the classless scenario. On the other hand, employing the proposed mechanism, the blocking probability experienced by class 0 is seven times less than the one provided for the class 1 in the highest load situation. Thus, for the dynamic mechanism, the service differentiation is degraded as the maximum number of wavelengths that bursts of class 1 may occupy increases. Moreover, in comparison with previous scenarios, the difference between the effective load provided by the dynamic and the one provided by the proposed mechanism is reduced. Then, we conclude that the proposed mechanism, in the less aggressive scenario, properly differentiates the services and provides an effective load only 10% inferior than the one of the classless scenario.

2) Impact of the Amount of Traffic of Each Service Class: The traffic amount of each service class also impacts in the performance of each mechanism. To analyze this impact in the blocking probability and in the effective load, the offered load is fixed at 0.6 erlangs. As in the Section V-A.1, we analyze three different scenarios varying the number of wavelengths that bursts of class 1 may occupy.



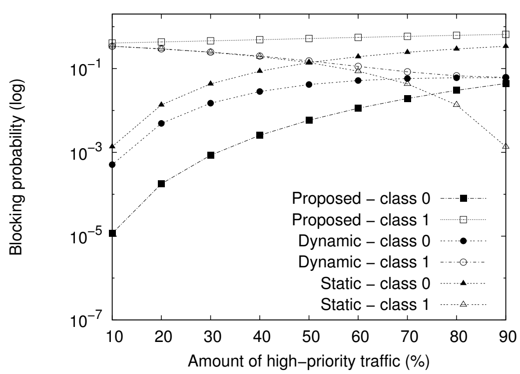
(a) Blocking probability.



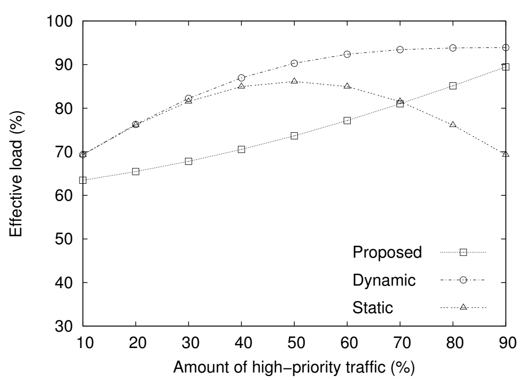
(b) Effective load.

Fig. 8. Impact of the amount of high-priority traffic: more aggressive scenario.

Figs. 8(a) and 8(b) show respectively the blocking probability and the effective load for the three mechanisms in the more aggressive scenario. According to Fig. 8(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. 5(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 load is the maximum. In this case, as shown in Fig. 5(b), the maximum effective load is 94% for an offered load of 0.6 erlangs. Fig. 8(b) shows that the dynamic mechanism provides the highest effective load, but beyond a point it does 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.



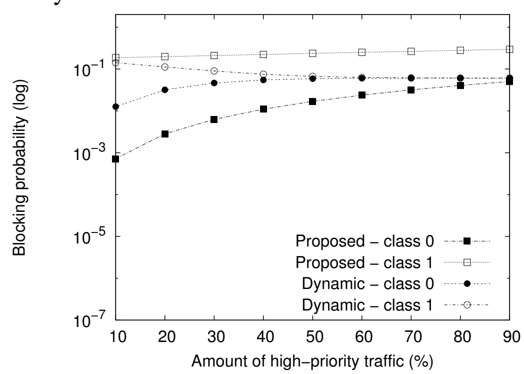
(a) Blocking probability.



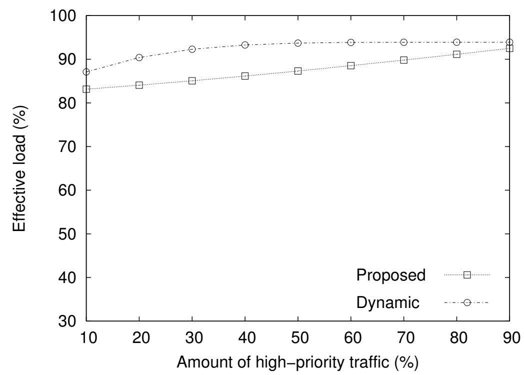
(b) Effective load.

Fig. 9. Impact of the amount of high-priority traffic: intermediary scenario.

Figs. 9(a) and 9(b) show the results for the intermediary scenario, where bursts of class 1 can occupy at most four wavelengths. It is possible to note that the behavior of the three mechanisms is similar to the behavior presented in the more aggressive scenario. Even when the amount of high-priority traffic increases, the proposed mechanism properly differentiates the blocking probability experienced by each service class. For the static mechanism, when the high-priority traffic reaches 50% of the total amount, the blocking probabilities of both classes are equal and the effective load is maximum, once half of the wavelengths is reserved for each class. In dynamic mechanism, the blocking probability of both classes and the effective load tend to the classless scenario, as the amount of high-priority class increases.



(a) Blocking probability.



(b) Effective load.

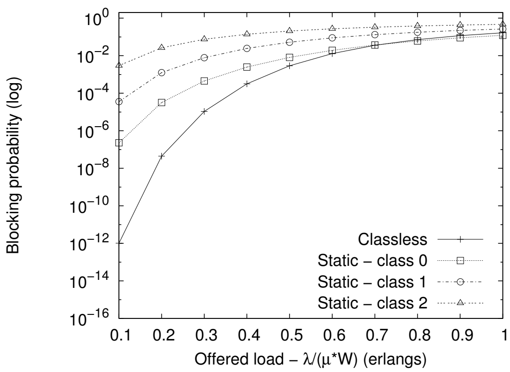
Fig. 10. Impact of the amount of high-priority traffic: less aggressive scenario.

In the less aggressive scenario, where bursts of class 1 can occupy at most six wavelengths, the performance of the static mechanism is not evaluated, once the number of reserved wavelengths for class 1 would be greater than the one reserved for class 0. As shown in Figs. 10(a) and 10(b), once again the proposed mechanism properly remains differentiating the services as the amount of high-priority traffic becomes larger. Furthermore, the effective load provided by the proposed mechanism tends to maximum value, when 90% of bursts belonging to class 0 and the offered load is equal to 0.6 erlangs. Then, we conclude that the proposed mechanism is the only one that effectively provides service differentiation, independently of the amount of traffic of class 0 and the load level of class 1.

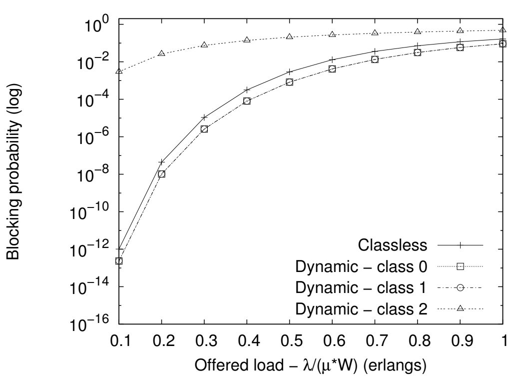
B. Performance for Three Service Classes

In this section, we evaluate the performance of the admission control mechanisms for three service classes - class 0, class 1, and class 2. Class 0 is the high-priority class. We assume that all service classes generate an equal amount of traffic ($\rho_0 = \rho_1 = \rho_2 = \ldots = \rho_{n-1} = \rho/n$). The performance of the three mechanisms is evaluated according to the offered load to the network. We consider two scenarios varying the maximum number of the wavelengths that bursts of the low-priority class may occupy.

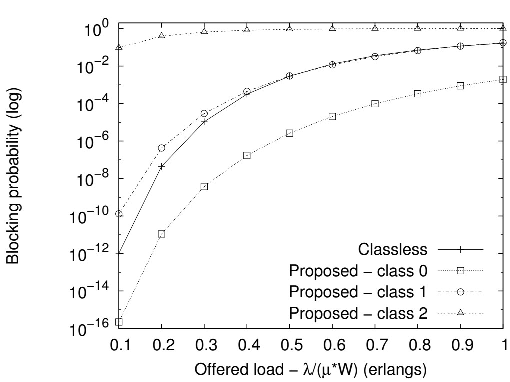
In the more aggressive scenario, we assume that the link capacity in wavelengths is $W = 18$ and that class 2 can occupy up to approximately 23% of the wavelengths. Thus, for the static mechanism $W_0 = 8$, $W_1 = 6$, and $W_2 = 4$, for the dynamic mechanism $W_0 = 18$, $W_1 = 14$, and $W_2 = 4$, and for the proposed mechanism $l_0 = 18$, $l_1 = 14$, and $l_2 = 4$.



(a) Static mechanism.



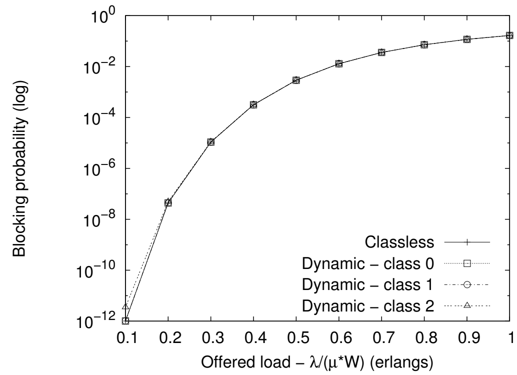
(b) Dynamic mechanism.



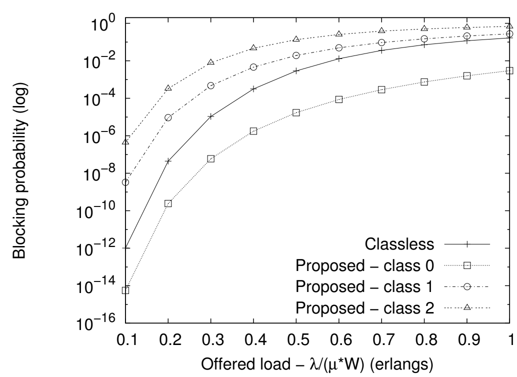
(c) Proposed mechanism.

Fig. 11. Performance for three service classes: more aggressive scenario.

As shown in Fig. 11(a), the static mechanism properly differentiates the services, but the blocking probability experienced by each one of the three classes is higher than the classless scenario. Fig. 11(b) shows that the dynamic mechanism does not properly differentiate the services. This is a consequence of the admission criterion of the dynamic mechanism which considers the occupation of each service class individually. Since all classes generate the same amount of bursts and W_1 is near to W_0, class 0 and class 1 experience almost the same blocking probability. On the other hand, according to Fig. 11(c), when the offered load increases the proposed mechanism effective differentiates the blocking probability experienced by every service class and also provides a lower blocking probability to the class 0.



(a) Dynamic mechanism.



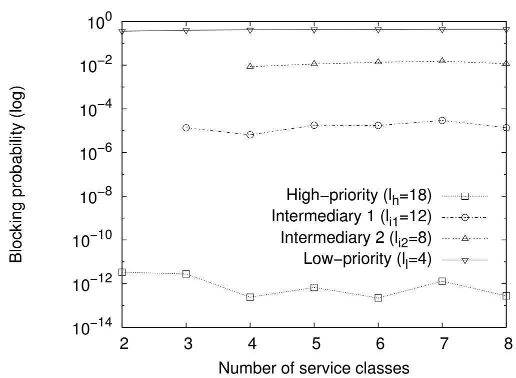
(b) Proposed mechanism.

Fig. 12. Performance for three service classes: less aggressive scenario.

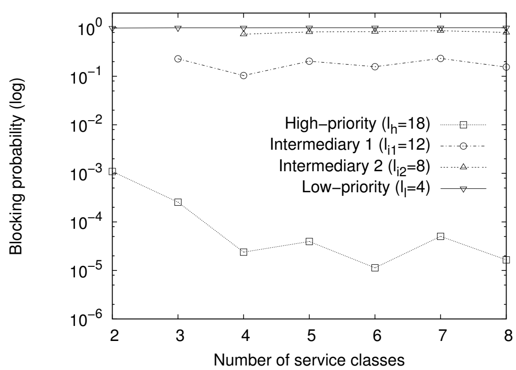
In the less aggressive scenario, we assume that class 2 can occupy up to approximately 67% of the wavelengths. Thus, for the dynamic mechanism $W_0 = 18$, $W_1 = 14$, and $W_2 = 12$, and for the proposed mechanism $l_0 = 18$, $l_1 = 14$, and $l_2 = 12$. In this situation, we do not analyze the static mechanism once the number of reserved wavelengths for the low-priority class would be greater than the one reserved for the high-priority class. Figs. 12(a) and 12(b) ratify the results previously discussed. The dynamic mechanism provides almost the same blocking probability for the three service classes. Then, we conclude that the dynamic mechanism is very dependent of the class-associated parameter W_i and the amount of traffic generated by each service class. On the other hand, the proposed mechanism properly differentiates the blocking probability of the three service classes even when the low-priority class has a higher load level. In this scenario, it is worth noting that the proposed mechanism stays providing a lower blocking probability for the high-priority class and does not starve the low-priority class, as the offered load increases.

C. The Effectiveness of the Proposed Mechanism

In order to determine the effectiveness of the proposed mechanism, we analytically evaluated its performance with a larger number of service classes ($n = 2, \ldots, 8$). In this situation, the link capacity in wavelengths is $W = 18$. In all analyzed scenarios, the load level of the high-priority class is $l_h = 18$ and the load level of the low-priority class is $l_l = 4$.



(a) Lower-load scenario.



(b) Higher-load scenario.

Fig. 13. The effectiveness of the proposed mechanism.

Figs. 13(a) and 13(b) show the blocking probability of four different service classes as a function of the number of classes. All service classes generate an equal amount of traffic. Two scenarios are considered: a lower-load scenario where the offered load is 0.2 erlangs, and a higher-load scenario where the offered load is 0.9 erlangs. As shown in Figs. 13(a) and 13(b), the higher the number of service classes, the better the service experienced by the high- priority class, class 0. It happens because the higher the number of classes, the lower the traffic generated by each service class. This better performance is paid by the starvation of the low-priority class. Nevertheless, the main goal of the proposed mechanism is achieved by providing a lower blocking probability to the high-priority class. It is worth noting that the aggressiveness to the low-priority class is determined by its load level. Thus, the starvation of the low-priority class can be reduced by increasing its load level. This is a choice of the network operator.

The up-and-down behavior of the blocking-probability curves presented in Figs. 13(a) and 13(b) is a consequence of how we add new service classes in the analysis. Suppose that we analyze a scenario with n service classes. Then, we add a new class i in the analysis. If the load level of the new class is closer to the load level of the high-priority class, the blocking probability of the high-priority class increases. On the other hand, if the load level of class i is closer to the load level of the low-priority class, the blocking probability of the high-priority class decreases.

VI. Conclusion

In this paper, we introduce a multiclass admission control mechanism for providing quality of service in optical burst-switched networks. The proposed mechanism admits bursts of a given service class according to network load and a class-associated parameter, named load level. An analytical model is derived for the proposed mechanism, and its performance is compared to the performance of the static and dynamic mechanisms. The blocking probability experienced by each service class, the offered load, and the number of service classes are used as performance metrics.

The service differentiation resulted from the static mechanism extremely depends on the amount of traffic generated by each service class. When we consider the more aggressive scenario with two service classes and the amount of high-priority traffic 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. Furthermore, when we consider a scenario with three service classes, the static mechanism differentiates the blocking probability of each class, but the blocking probability provided for the high-priority class is always higher than the one provided by the network without QoS support.

The performance of the dynamic mechanism is degraded as the gap between the parameter W_i of each class becomes smaller. In other words, the lower the aggressiveness to the low-priority class and the higher the number of service classes, the more susceptible is the dynamic mechanism to the increase of the offered load and to the amount of high-priority traffic. For example, in the less aggressive scenario for two service classes, 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 addition, when we consider three service classes and the gap between W_2 and W_0 is 30% of the capacity of the link, the blocking probability of all classes is almost the same.

The proposed mechanism effectively differentiates the services even when the offered load, the amount of high-priority traffic, and the number of classes increase. In comparison with the other two mechanisms, the proposed mechanism provides a lower blocking probability for the high-priority class bursts in all analyzed scenarios. The better differentiation is paid by a reduction in the effective load of the network and the starvation of the low priority-class in few situations. 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 the percentage of the high-priority traffic, the better the differentiation and the lower 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 performance analysis of the proposed mechanism in a multi-node topology, based on reduced load approximations, and the proposition of a feedback mechanism to guarantee absolute quality of service.

Acknowledgment

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