Effective Burst Preemption in OBS Network

Miroslaw Klinkowski*, Davide Careglio*, Daniel Morató† and Josep Solé-Pareta*
*Universitat Politécnica de Catalunya, Advanced Broadband Communication Centre - CCABA
Jordi Girona 1-3, 08034 Barcelona, Spain
Email: {mklinkow, careglio, pareta}@ac.upc.edu
† Public University of Navarra
Campus de Arrosada, 31006, Pamplona, Spain
Email: daniel.morato@unavarra.es

***Abstract*— Burst preemption is the most effective technique to provide Quality of Service (QoS) differentiation in Optical Burst Switching (OBS) networks. Nonetheless, in conventional OBS architectures, when preemption happens the control packet corresponding to the preempted burst continues its travel to the destination node reserving resources at each node of the path. Therefore, an additional signaling procedure should be carried out to release these unnecessary reservations. In this paper we present novel control architecture to efficiently apply burst preemption without the need of the signaling procedure. Analytical and simulation results prove the effectiveness of this proposal.**

I. Introduction

Optical Burst Switching was proposed in the late 1990s. It is a photonic network architecture directed towards efficient transport of IP traffic [1]. OBS uses statistical multiplexing providing fine switching granularity in the optical domain. In conventional OBS the packets from the access networks are aggregated and assembled into large burst units at the edge nodes. Meanwhile, the control information is transmitted out-of-band and delivered with some *offset-time* (OT) prior to the data burst in such a way that the intermediate nodes have enough time, both to process this information and to reconfigure the switching matrix.

Since OBS is based on statistical multiplexing, burst contention may arise at any core node. Indeed, when a control packet enters a node in order to make the reservation of a given output fiber and wavelength for the associated incoming burst, it may happen that the requested resource is unavailable because it is occupied by another burst. Wavelength conversion, deflection routing and fiber delay line (FDL) buffering have been proposed as contention resolution mechanisms in OBS networks [2].

Several strategies have been considered in literature to provide contention resolution with QoS provisioning in OBS networks [2], [3], [4]. The most effective solutions are the burst preemption (BP) techniques. In case of contention, BP allows the processing unit of the switch to overwrite a low priority (LP) reservation with a later arriving high priority (HP) one. Preemption concerns either whole burst units [5] (*full preemption*) or it allows for a partial preemption when a *burst segmentation* technique [6] is applied. Although partial preemption offers better performance characteristics it is at the cost of higher complexity since this technique involves additional information about the data bursts to be carried and processed in the core nodes.

The general drawback of preemption techniques in conventional OBS architectures is that in case of successful preemption either those resources are wasted or an additional signaling procedure should be carried out in order to inform downstream nodes about releasing the resources reserved for the preempted bursts.

In this paper we propose an OBS control architecture that overcomes this problem. The architecture assumes delaying the burst by means of an additional fiber span introduced in the input port of the core node as a substitution for the offset-time introduced by the edge node. This fiber is responsible for compensating both control data processing and switch configuration times. It also provides a preemption window in which preemption is allowed. The proposed preemption window mechanism expands windowed control techniques (like [7], [8]) to the burst preemption context achieving the performance of a classical burst preemption mechanism without the signaling complexity.

The rest of the paper is structured as follows. In section II, we describe the OBS control architecture for burst preemption with a preemption window mechanism. Section III provides an analytical model of the system with a single data channel. Section IV shows simulation results that validate the substantial improvement from conventional OBS architectures to the proposed one. Finally, section V concludes the paper.

II. Preemption Window Architecture

A. Control Architecture

For the burst preemption mechanism we consider the OBS architecture presented on Fig. 1 with additional *fiber span* (FS) inserted in the data path at the core node's input ports to emulate OT. In such architecture there is no OT setup by edge nodes. Control packet and burst travel simultaneously through the network. When both reach a core node the control packet goes directly to the switch control unit, whilst the burst is delayed in the FS by period OT (see Fig. 1). During this time the control packet is processed and the control unit can preempt its reservation by one with higher priority. The important rule of the mechanism is that the control packet, after its processing, is waiting for its burst in the memory of the control unit until the OT expires and then they are either sent

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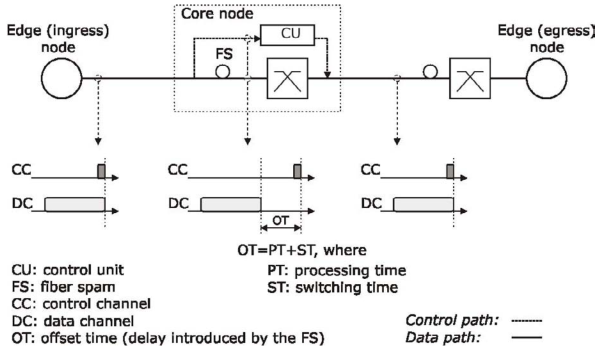

Fig. 1. OBS architecture for burst preemption mechanism

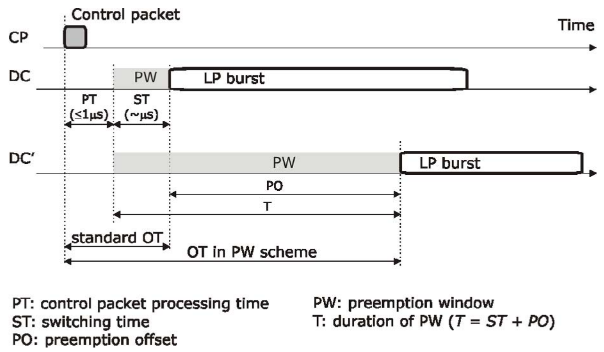

Fig. 2. The offset-time and preemption window

together to the next node (if the burst has not been preempted) or dropped (in case of successful preemption). After the control packet is sent and the burst is being transmitted, its preemption is not allowed in the node. Since the preemption can be done only in a time window (called further a *preemption window*) determined by a waiting time of a LP control packet (equal to T on Fig. 3), we further refer to this mechanism as a preemption window (PW) mechanism.

Fig. 3 shows an illustrative example of the PW mechanism. In the scenario on Fig. 3a and Fig. 3c the preemption of an LP burst can take place since the control packet of the HP burst arrives in the preemption window. The HP burst on Fig. 3b is not allowed to preempt the LP burst because its control packet arrives out of the preemption window. Finally, both HP and LP bursts on Fig. 3d can be transmitted since they do not collide.

B. *Offset-time and Preemption Window*

The OT in OBS networks is derived from both processing and switching times. The processing times have been reported as not exceeding 1μs [9]. The switching times should be also small comparing to burst durations for efficiency reasons and particularly for the transmission of shorter bursts, e.g. of tens of kB at 10Gbit/s rate, they should be in range of μs. Hence, since OT is quite small (a few μs) it impacts the preemption probability and there is a motivation to introduce an additional offset (the *preemption offset*) that enlarges the PW when the preemption of a low priority burst is allowed in a node.

An effective PW in which the preemption may occur is determined by switching time (ST) and preemption offset (PO) (see Fig. 2). ST is fixed and it depends on the switching technology. PO is also set but it can be adjusted in the node designing stage according to the performance requirements.

Both ST and PO, as well as the control packet processing time (PT) determine an offset-time to be compensated by means of the input FS. The sum of all offsets the burst experiences on its path through the network plus the propagation delay produces the total end-to-end burst delay. This delay is higher in comparison to conventional OBS networks by the sum of STs and POs.

C. *Implications*

The main advantage of the proposed preemptive mechanism is the lack of signaling overhead in case the preemption occurs. Indeed when the control packet reserves resources it already knows that its burst has reached the node. There is no pre-reservation on the ongoing path like in conventional OBS networks and so there is no need for releasing the resources. It should be pointed out that the PW mechanism can work with both full and partial burst preemption techniques.

Furthermore, the presented OBS architecture brings additional profit like dismissing the offset variations with the related unfairness problem in access to transmission resources [10]. Indeed, in conventional OBS networks, whilst the control packet travels through the network its OT decreases successively at each hop by the PT. Hence, according to the effect that has been exploited e.g. in *offset-time differentiation* mechanism [3], the bursts beginning the trip and so having higher OTs have more chances to reserve output wavelength than the bursts approaching the end with lower offsets. In the considered control architecture the burst and its control packet arrive at the same time and therefore the offset is constant for each pair of burst and control packet in the whole network, independently of the hop.

Another drawback of conventional OBS scenarios is the difficulty in providing alternative routing inside the network. In particular, the edge node should know the routing path prior to the control packet transmission in order to calculate and setup OT accurately. When allowing for alternative routing, the OT should be calculated for the worst case i.e. for the longest possible alternative path. This often can result in superfluous burst delay. In the considered OBS architecture the offset-time is introduced in each core node by means of the input FS. Therefore, the routing path can be created freely inside the network with any alternative routing algorithm.

Regarding the implementation issues, there is a need for only one FS per node input port which compensates the offset-times for all data channels simultaneously. The control channel should be extracted before that stage and brought to the switch control unit. An impairment of the optical data signal when using longer FSs should be taken into account and considered while designing the regeneration and amplification stages.

The proposed PW mechanism could be also provided in conventional OBS networks by increasing the OT introduced in the edge node by the sum of all the PW times required for all nodes on the routing path. A disadvantage of this solution is the additional complexity of the offset-times' management inside the network since the offsets should be precisely updated according to the waiting times the control packets experience in core nodes. Moreover, there still remains the problem of offset time variations, now even more serious and probably not acceptable because of the fairness objective.

Next section provides an analytical model of the preemption window mechanism for a single channel system.

III. Analytical Model

In this section, we analyze the blocking probabilities of the two classes of bursts, namely a high priority (HP) and a low priority (LP) class, in a single channel system when full-burst preemption mechanism with PW principle is applied.

Following the results in [11] we assume Poisson processes for the HP and LP burst arrivals with rates λ_{HP} and λ_{LP} respectively. The whole arrival rate to the core node will be $\lambda = \lambda_{HP}+\lambda_{LP}$. Lets denote the i.i.d. exponentially distributed random variables for the burst inter-arrival times as t_{HP} and t_{LP}.

Also, let l denote the burst duration, which follows an exponential distribution with mean value $1/\mu$. We assume the same distribution for both classes. However, in further analysis we use also l_{LP} in order to emphasize that we mean the duration of an LP burst.

A. Blocking Probability of LP bursts

In the considered system, an LP burst is lost either when it finds the system busy or due to the preemption of its reservation by an HP reservation. Therefore, the blocking probability of LP bursts $P_{B_{LP}}$ can be expressed as the sum of the probability P_{busy} to find a system busy and the probability $P_{preempt}$ that the LP is preempted by an HP burst after it is successful scheduled.

$$P_{B_{LP}} = P_{busy} + P_{preempt} \tag{1}$$

Regarding the first summand, the system could be approximated by an M/M/1/1 model. Then we can use Erlang's B formula for the loss probability, where $\rho = \lambda/\mu$ and the number of servers *c=1*:

$$P_{busy} = B(\rho, c) = \frac{\frac{\rho^c}{c!}}{\sum_{i=0}^{c} \frac{\rho^i}{i!}} = \frac{\lambda}{\lambda + \mu} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} \tag{2}$$

Now, the probability $P_{preempt}$ can be expressed as the product of two probabilities: the probability that an LP burst reservation is accepted by the system and the probability $P_{HPoverLP}$ that this reservation is further preempted by an HP reservation. Since the first factor is equal to the probability to find the system free P_{free}, we obtain:

$$P_{preempt} = P_{free} \cdot P_{HPoverLP} \tag{3}$$

where P_{free} is:

$$P_{free} = 1 - P_{busy} = \frac{\mu}{\lambda_{HP} + \lambda_{LP} + \mu} \tag{4}$$

According to the PW principle (see Section II), preemption of an LP burst reservation is allowed only if the LP burst transmission has not started yet. As it is shown on Fig. 3, we can discriminate two main cases, namely either the l_{LP} is greater or equal to the offset time *T* (Fig. 3a-b) or it is shorter (Fig. 3c-d).

1) For $l_{LP} \geq T$ we can further distinguish:
   - If the control packet of the HP burst arrives between the control packet of the LP burst and the LP burst (i.e. during an offset time *T* of the LP burst) (Fig. 3a), the LP burst is preempted and the HP burst is scheduled to be transmitted.
   - If the control packet of the HP burst arrives after starting the transmission of the LP burst (i.e. after expiring the offset time *T*) (Fig. 3b), the LP burst is transmitted and the HP burst is lost.

2) For $l_{LP} < T$we have:
   - If the control packet of the HP burst arrives before a time equal to the duration of the LP burst l_{LP} (Fig. 3c), the LP burst is preempted and the HP burst is scheduled to be transmitted.
   - If the control packet of the HP burst arrives after a time equal to the duration of the LP burst l_{LP} (Fig. 3d), both bursts are transmitted.

Taking into account the cases presented above, the probability $P_{HPoverLP}$ that an HP burst preempts an LP burst reservation can be calculated as the probability that the HP control packet arrives before the end of the *T* period and before a time equal to the duration of the LP burst. Since the HP arrival process is memory-less, we can write:

$$P_{HPoverLP} = P\{(t_{HP} < T) \cap (t_{HP} < l_{LP})\} \tag{5}$$

and further, with the total probability theorem applied:

$$P_{HPoverLP} = P\{(t_{HP} < T) \cap (t_{HP} < l_{LP})/l_{LP} < T\}\cdot$$
$$P\{l_{LP} < T\} + P\{(t_{HP} < T) \cap (t_{HP} < l_{LP})/l_{LP} > T\}\cdot$$
$$P\{l_{LP} > T\} \tag{6}$$

The second summand can be found easily. Starting with the conditional part and using the independence between t_{HP} and l_{LP}:

$$P\{(t_{HP} < T) \cap (t_{HP} < l_{LP})/l_{LP} > T\} =$$
$$= P\{(t_{HP} < T)/l_{LP} > T\} = P\{t_{HP} < T\} \tag{7}$$

We obtain:

$$P\{t_{HP} < T\} \cdot P\{l_{LP} > T\} = (1 - e^{-\lambda_{HP} T})e^{-\mu T} \tag{8}$$

For the first summand we have:

$$P\{(t_{HP} < T) \cap (t_{HP} < l_{LP})/l_{LP} < T\} \cdot P\{l_{LP} < T\} =$$

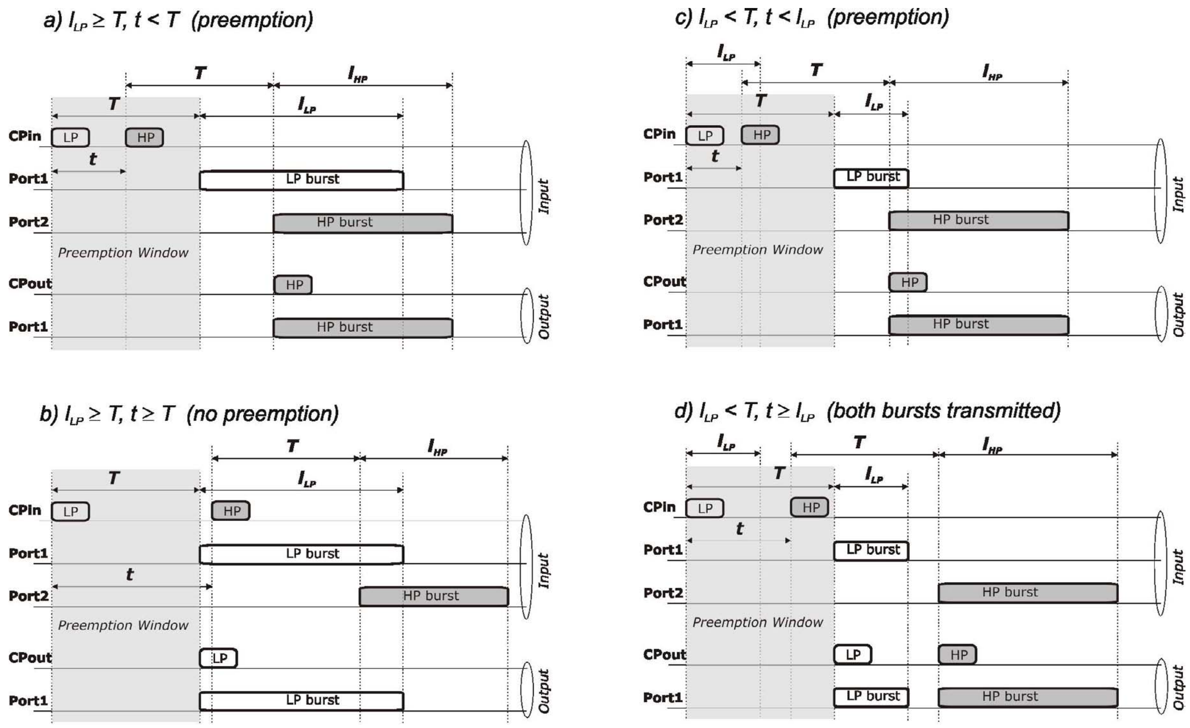

Fig. 3. Preemption window scheme (the processing times are neglected for simplicity); T is the duration of the Preemption Window, l_{LP} and l_{HP} are the durations of the LP and HP bursts respectively, t is the arrival time of the HP control packet

$$= P\{t_{HP} < l_{LP}/l_{LP} < T\} \cdot P\{l_{LP} < T\} =$$

$$= P\{(t_{HP} < l_{LP}) \cap (l_{LP} < T)\} =$$

$$= \int_0^T \int_0^y \lambda_{HP} e^{-\lambda_{HP} x} \mu e^{-\mu y} \, dx \, dy =$$

$$= 1 - e^{-\mu T} - \frac{\mu}{\lambda_{HP} + \mu}(1 - e^{-(\lambda_{HP}+\mu)T}) \tag{9}$$

Taking into account (6), (8) and (9) we obtain:

$$P_{HPoverLP} = \frac{\lambda_{HP}}{\lambda_{HP} + \mu}(1 - e^{-(\lambda_{HP}+\mu)T}) \tag{10}$$

Finally, the blocking probability of LP bursts is given by:

$$P_{B_{LP}} = P_{busy} + P_{free} \cdot P_{HPoverLP} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} +$$

$$+ \frac{\lambda_{HP} \cdot \mu}{(\lambda_{HP} + \mu)(\lambda_{HP} + \lambda_{LP} + \mu)} \cdot (1 - e^{-(\lambda_{HP}+\mu)T}) \tag{11}$$

B. Blocking Probability of HP burst

An HP burst is lost when it encounters the system occupied either by another HP burst or by an LP burst that is under transmission (preemption can not be performed in such case). This is equivalent to the set of events that the system is busy excluding all the events where an HP burst preempts an LP burst. Therefore, the blocking probability of an HP burst $P_{B_{HP}}$ can be expressed as the probability P_{busy} to find the system busy minus the probability to preempt an LP burst $P_{preempt}$ which frees the system and allows for the transmission of the HP burst. For the later a factor $\lambda_{LP}/\lambda_{HP}$ is enforced to take into account the different arrival rates.

Finally, we obtain:

$$P_{B_{HP}} = P_{busy} - \frac{\lambda_{LP}}{\lambda_{HP}} P_{preempt} =$$

$$= P_{busy} - \frac{\lambda_{LP}}{\lambda_{HP}} P_{free} \cdot P_{HPoverLP} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} -$$

$$+ \frac{\lambda_{LP} \cdot \mu}{(\lambda_{HP} + \mu)(\lambda_{HP} + \lambda_{LP} + \mu)} \cdot (1 - e^{-(\lambda_{HP}+\mu)T}) \tag{12}$$

C. Some inferences from the model

First, having $P_{B_{HP}}$ and $P_{B_{LP}}$ we can derive a total blocking probability $P_{B_{total}}$ that obviously is given by:

$$P_{B_{total}} = \frac{\lambda_{HP}}{\lambda_{HP} + \lambda_{LP}} P_{B_{HP}} + \frac{\lambda_{LP}}{\lambda_{HP} + \lambda_{LP}} P_{B_{LP}} =$$

$$= \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} = \frac{\lambda}{\lambda + \mu} \tag{13}$$

As we could expect, the obtained result conforms to the Erlang loss formula. Indeed, the PW mechanism does not impair the total blocking probability and even in the case of preemption, when a LP burst is replaced by a HP one, the number of lost bursts is preserved. Also, notice that the formula does not involve the T parameter as it is in case of $P_{B_{HP}}$ and $P_{B_{LP}}$ blocking probabilities.

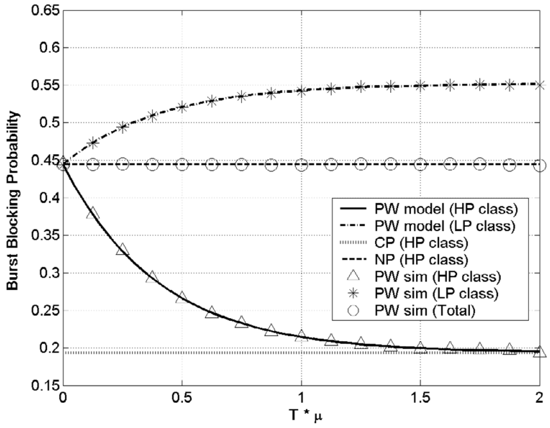

Fig. 4. Simulation vs. modeling results ($\rho = 0.8, \alpha = 0.3, \mu = 2$)

Now, let us look for the blocking probabilities at the boundary conditions. For $T = 0$, from (11) and (12) we obtain:

$$P_{B_{LP}} = P_{B_{HP}} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} \tag{14}$$

that is also equal to $P_{B_{total}}$. It is clear, because since $T = 0$ there is no preemption (NP) and the mechanism performs as a simple scheduling mechanism without QoS differentiation.

Now, let $T \to \infty$:

$$\lim_{T\to\infty} P_{B_{LP}} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} + \\ + \frac{\lambda_{HP} \cdot \mu}{(\lambda_{HP} + \mu)(\lambda_{HP} + \lambda_{LP} + \mu)} \tag{15}$$

and

$$\lim_{T\to\infty} P_{B_{HP}} = \frac{\lambda_{HP} + \lambda_{LP}}{\lambda_{HP} + \lambda_{LP} + \mu} - \\ + \frac{\lambda_{LP} \cdot \mu}{(\lambda_{HP} + \mu)(\lambda_{HP} + \lambda_{LP} + \mu)} = \frac{\lambda_{HP}}{\lambda_{HP} + \mu} \tag{16}$$

We see that with $T \to \infty$ both formulas exponentially approach their asymptotes defined by constant functions of λ_{HP}, λ_{LP} and μ parameters. In particular, the second asymptote for $P_{B_{HP}}$ could be also derived from the Erlang loss formula with only HP traffic taken into account. The explanation is that since $T \to \infty$ the lengths of the LP bursts are always less than T (see Fig. 3c and Fig. 3d) and therefore an HP burst can be blocked only by another HP burst. In this case, the mechanism behaves as a classical preemption procedure (CP) where an HP burst can always preempt an LP burst.

Fig. 4 presents the discussed model's characteristics, validating them by the mechanism's simulation (*PW sim*) results. Notice, that the x-axis on the graph is normalized by the mean burst duration ($1/\mu$) and α is the HP traffic ratio.

The PW model gives a glance on the mechanism's behavior in a single-wavelength system. To complete the study, in Section IV we provide some simulation results of PW mechanism in a multi-wavelength scenario.

IV. Multi-Wavelength Scenario

In a multi-wavelength scenario there is the problem of selecting the wavelength to be reserved for incoming burst. In our scenario, the scheduling algorithm applies the LAUC (*Latest Available Unused Channel*) mechanism [12]. In particular, if there are some wavelengths not occupied during the burst transmission the algorithm looks for one that minimizes the gap, which is produced on a time scale between the new and previously scheduled bursts. If all the wavelengths are busy and a HP burst finds some LP reservations that can be preempted, two solutions are possible. Namely, either the HP burst preempts the recently scheduled LP burst or it preempts the LP burst, which dropping produces the minimal gap for the incoming HP burst. In the study, we apply the later.

We use event-driven simulation to show the blocking probability performance of a full-burst preemptive mechanism with PW principle applied in the multi-wavelength system. Moreover, we look for an effective offset introduced by means of the input FS which is a tradeoff between offering high performance and minimizing the delay. We consider two classes of services, namely High Priority (HP) and Low Priority (LP).

A. Simulation scenario

We consider a general non-blocking OBS node architecture with wavelength conversion. The switch has 4x4 input/output ports and 8 wavelengths per port, each one operating at 10 Gbps. No FDL buffering is applied. The traffic is uniformly distributed between all input and output ports.

Regarding the burst length and the inter-arrival time (IAT) distributions we apply the ones studied in [11], [13]. In particular, the bursts length is Gaussian distributed with a mean equal to 40kbytes, which corresponds to mean burst duration equal to $32\mu s$ at 10Gbit/s rate. Minimum burst length is setup to 4kbytes while its maximum value is equal to 400kbytes. The burst IATs after the assembly process are also Gaussian distributed with a mean depending on the traffic load. The mean load per input channel (wavelength) and the HP traffic ratio are further denoted as ρ and α respectively.

B. Performance evaluation

Fig. 5 presents the PW-mechanism performance results obtained with the following conditions: $\rho = 0.8$ Erlang and $\alpha = 25\%$.

The first remark is that the PW mechanism behaves similar in the multi-wavelength system as in the previously modeled single-wavelength one. Furthermore, we can discern that for T between $1.5 \div 2$ of the mean burst duration ($1/\mu$), HP burst blocking probability stabilizes and it quickly approximates to the asymptote. This observation could serve us in order to find an upper limit of the effective offset in PW mechanism.

The transmission delay caused by the PW mechanism can be calculated as a sum of effective offset-times introduced in all core nodes lying on the routing path. Let us consider the mean burst duration equal to $32\mu s$, the effective preemption window between 1.5 and 2 of the mean burst duration, and the control packet processing time equal to $1\mu s$. For such system

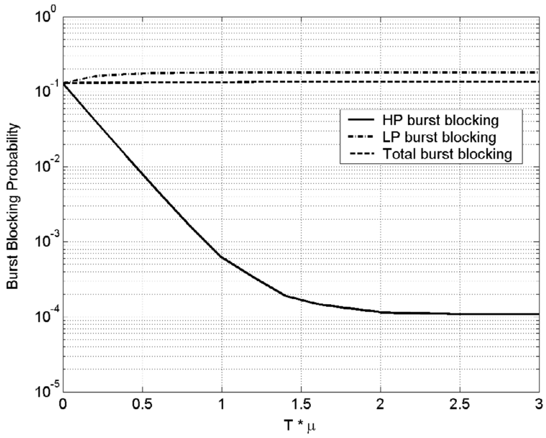

Fig. 5. Burst Blocking Probability as a function of the preemption window normalized by the mean burst duration

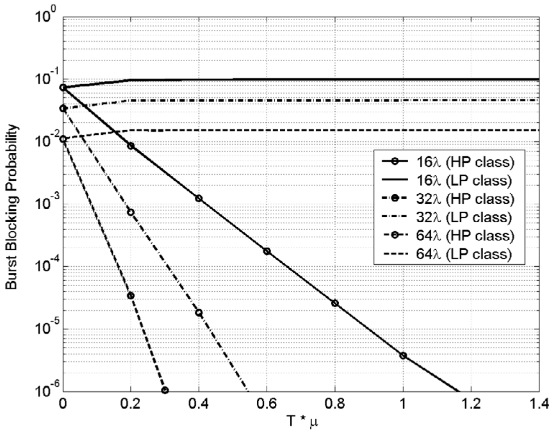

Fig. 6. Burst Blocking Probability as a function of the preemption window normalized by the mean burst duration and of the number of wavelengths ($\alpha = 25\%, \rho = 0.8$)

parameters we obtain the effective offset between 49 and $65\mu s$. We can easily estimate that even in a network with several core nodes lying on the routing path, the end-to-end burst transmission delay would be below $1ms$ which is very small in comparison to the QoS performance objectives (see e.g. [14]). Regarding implementation issues of the input FSs, such offset values seem acceptable and e.g. comparable delays are considered in FDL buffering. In particular, for the offset equal to $50\mu s$ a required FS length is about 10km. Notice, that there is a need for only one FS per node input port (see details in Section II).

As Fig. 6 shows, the effective PW guaranteeing low HP blocking probability (e.g. on the level of 10^{-6}) would be further reduced in the systems with more wavelengths.

In Fig. 7, we analyse the Blocking Probability as a function of the offered load and of the percentage of HP traffic load.

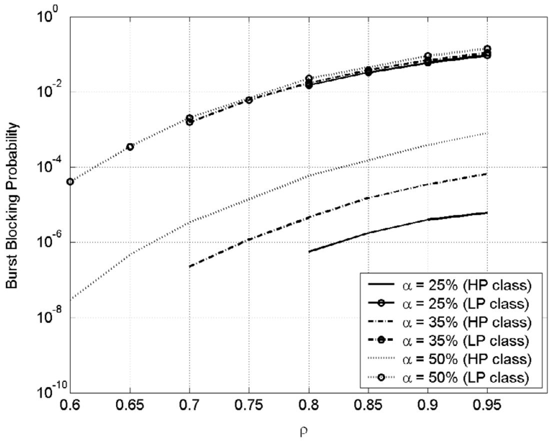

Fig. 7. Burst Blocking Probability as a function of the offered load (ρ) and HP traffic ratio (α); ($T * \mu = 0.3$, and 64 wavelengths).

The $T * \mu$ factor is fixed to 0.3 and 64 wavelengths are considered. In such system, we can observe that the PW mechanism achieves very low HP burst blocking probabilities with the input FS compensating the offset of the length of about 2km only. As in other OBS systems, the blocking probability of LP bursts is quite high, however it can be improved e.g. by applying output FDL buffering.

V. Conclusions

In this paper we proposed a dedicated architecture for burst preemption mechanisms in OBS networks. This architecture uses input fiber spans in core nodes in order both to emulate conventional offset-times and to introduce an additional preemption offset. The essential part of the proposed architecture is the preemption window mechanism. It allows for preemption of a low priority burst only in a specific preemption window period when the burst has not reached the output link. It is also responsible for transmitting the control packet and its burst simultaneously in such a way that there is no offset between them in a link.

Thanks to these rules there is no need for any signaling procedure to be carried out in order to release the resources on the outgoing path in case of successful burst preemption. Moreover, the considered OBS architecture does not experience the offset variations what dismisses related unfairness problems in resources reservation. Finally, it supports alternative routing.

Both modeling and simulation results show that even with a limited PW delay the PW mechanism can achieve the performance of a conventional preemptive scheme. Moreover, the obtained effective offset-time values show feasibility of their application. Furthermore, considered architecture can be used with any other preemptive technique in OBS networks, like e.g. with partial preemption. Finally, the delay introduced by the PW mechanism is relatively small.

Currently we are working on the analytical model of the mechanism for the multi-wavelength system.

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