Chapter 1

A PERFORMANCE OVERVIEW OF QUALITY OF SERVICE MECHANISMS IN OPTICAL BURST SWITCHING NETWORKS

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Abstract: This Chapter addresses the problem of quality of service (QoS) provisioning in optical burst switching (OBS) networks. OBS is a photonic network technology aiming at efficient transport of IP traffic. The lack of optical memories, however, makes the operation in such networks quite complicated, especially if one wants to guarantee a certain level of service quality. Indeed quality demanding applications such as, for instance, real-time voice and video transmissions, need for additional mechanisms so that to preserve them from low priority data traffic. In this context the burst blocking probability metric is perhaps of the highest importance in OBS networks. In this Chapter we present a general classification of QoS provisioning methods considered for OBS networks. We study several QoS scenarios that are based on the most referenced QoS mechanisms and we confront their performance in the same evaluation scenario consisting of a single isolated node. Among all the mechanisms analysed, the best overall performance is achieved with a burst preemptive mechanism. Since the preemptive mechanism produces the problem of resources overbooking in the network we address this issue as well.

Key words: optical burst switching; performance evaluation; quality of service.

1. INTRODUCTION

Optical burst switching (OBS)[1] is a promising solution for reducing the gap between switching and transmission speeds in future networks. The client packets are aggregated and assembled into optical data *bursts* in the edge nodes of an OBS network. A *burst control packet* is transmitted in a dedicated control channel and delivered with a small *offset time* prior to the data burst. In this way the electronic controller of an intermediate (core) node has enough time both to reserve a wavelength on its output link, usually for the duration time of the incoming burst, and to reconfigure dynamically the switching matrix. When the burst transmission is finished in a node the output wavelength is released for other connections. Such a temporary usage of wavelengths allows for higher resource utilization as well as for better adaptation to highly variable input traffic in comparison to optical circuit-switching networks. Moreover the aggregation of data packets helps to overcome the fast processing and switching requirements of optical packet switching (OPS) technology.

There are two distinct signalling architectures considered for OBS networks. The first one is based on a connection-oriented signalling protocol which performs end-to-end resources reservation with acknowledgment in so called *two-way reservation* mode[2]. The other exploits a connection-less signalling protocol which allocates the resources on-the-fly, a while before the burst arrival, in a *one-way reservation* mode[1]. Since the problem of the two-way reservation signalling concerns the latency due to the connection establishment process[3,4] such architectures are considered mostly for short-distant metropolitan networks.

The one-way reservation signalling that can operate effectively in large distance OBS networks performs according to a statistical multiplexing paradigm; hence it encounters the problem of burst contention inside the network. Indeed, when a burst control packet enters a node in order to perform the wavelength reservation for its data burst, it may happen that the requested resources are not available at the output link and the burst has to be dropped. The lack of optical random access memories complicates the resolution of burst contention in optical networks. To alleviate this problem several mechanisms based on wavelength conversion, deflection routing and fibre delay line (FDL) buffering[5] together with dedicated burst scheduling algorithms[6] have been proposed.

A similar difficulty appears when we try to preserve *high priority* (HP) loss/delay sensitive traffic from *low priority* (LP) regular data traffic. For non-real-time applications, such as data file transfers or e-mails, the loss of data burst is not so critical issue since adequate packet level protocols can provide retransmission capability to recover the dropped packets. However, the transmission of real-time information, for instance in voice, video, telemedicine applications, packets must arrive within a relatively narrow time window to be useful to reconstruct the multimedia signal. Retransmission in this case would add extensive delay to the reconstruction and would cause clipping or unintelligible speech as well as discontinuous picture. Here the loss of data burst means an unrecoverable loss of some information. Taking into account the foregoing, the burst loss probability is considered as the primary metric of interest in the context of quality of service (QoS) provisioning in OBS networks.

There are several techniques that enable QoS differentiation in OBS networks. The most addressed are based on *offset differentiation*,[7] *preemptive dropping*,[8,9] *threshold-based dropping*,[10,11] and *intentional dropping*[10] principle. All these techniques try to resolve the burst contention problem with an assumption that the bursts belonging to HP class are treated somehow better than LP bursts. As long as each QoS mechanism achieves it in a different way each one may offer different performance.

There can be found several works in the literature that provide a comparative performance analysis of selected QoS mechanisms. For instance Zhang[10] studies different QoS scenarios built on a wavelength threshold-based principle and an intentional dropping principle with the purpose of absolute quality guarantees. Vokkarane[9] compares the performance of different QoS schemes with a burst segmentation approach applied. Also, a comparative performance study of different optical packet-dropping techniques evaluated in an OPS network scenario is presented in[11].

In this Chapter we make an extension to these studies. In particular, we confront the performance of a frequently referenced offset time differentiation mechanism with two burst-dropping techniques, namely, with a preemptive dropping and a wavelength threshold-based dropping. All these mechanisms aim at the differentiation of burst loss probabilities in a connection-less OBS network.

The rest of the Chapter is organized as follows. In Section 2 we discuss some basic concepts of QoS provisioning in OBS networks. In Section 3 we present a general classification of QoS schemes considered for OBS networks. In Section 4 we study the performance of selected QoS mechanisms and highlight their pros and cons. In Section 5 we discuss the problem of resources overbooking that is inherent to a burst preemptive mechanism. Finally Section 6 concludes the Chapter.

2. BASIC CONCEPTS OF QOS IN OBS NETWORKS

2.1 QoS metrics

An effective QoS provisioning in OBS should engage both the definition of specific QoS classes to be given for higher level applications and the dedicated mechanisms for providing such classes. In general, each class can be characterized by a specific statistical traffic profile and has to satisfy distinct QoS requirements. In particular, the requirements concern to ensure a certain upper bounds on end-to-end delay, delay variation (also called the jitter) and burst loss probability.

The end-to-end delay arises mostly due to the propagation delay in fibre links, the introduced offset time, edge node processing (i.e., burst assembly) and optical FDL buffering. The first two values can be easily bounded by properly setting up the maximum hop distance allowed by a routing algorithm. Also, the delay produced in the edge node can be controlled by a proper setup of a timer-based burst assembly algorithm. Finally the optical buffering, which in fact has limited application in OBS, introduces relatively small delays. As long as there are many factors that have impact on the end-to-end data delay in an OBS network the problem of jitter is more complicated and needs for a special treatment. This topic, however, is out of the scope of this Chapter.

In a well-designed OBS network the data loss should arise only due to the resources (wavelength) unavailability in fibre links. The probability of burst blocking in a link depends on several factors, among others on implemented contention resolution mechanisms, burst traffic characteristics, network routing, traffic load offered to the network, and relative class load. Since the relation between these factors is usually very complex the control of burst losses may be quite awkward in a buffer-less OBS network.

2.2 Absolute vs. relative QoS guarantees

There can be distinguished two basic models of QoS provisioning in OBS networks, namely, a *relative* QoS model and an *absolute* QoS model. In the former the performance of a class is defined with respect to other classes; for instance, it is guaranteed that the loss probability of bursts belonging to HP class is lower than the loss probability of bursts belonging to LP class. In the latter an absolute performance metric of quality such as, for example, an acceptable level of burst losses is defined for a class. The performance of a given class in the relative QoS model usually depends on traffic characteristics of the other classes, whilst the absolute QoS model aims at irrelative quality provisioning. On the other hand the absolute QoS model requires more complex implementations in order to achieve desired levels of quality under a wide range of traffic conditions whilst at the same time to preserve high output link utilisation.

Providing the absolute QoS guarantees is desired by upper level applications. The lack of optical memories, however, makes the implementation of absolute QoS model very complicated in OBS networks, for instance, comparing to electrical data networks. For this reason most of QoS mechanisms considered for OBS networks basically offer relative QoS guarantees.

2.3 QoS in connection-oriented and connection-less OBS

The problem of QoS guarantees in connection-oriented OBS networks is similar to the one existing in dynamic wavelength-switched networks. In particular it concerns providing low establishment delays and low connection blocking probabilities, especially for HP connection requests. The establishment delay is a particularly critical problem in such networks. The reason is that the burst has to wait in an electrical buffer at the edge node until the connection establishment process terminates. This may produce the buffer overflow and, as a consequence, the data loss. After the connection is established, there is no data loss inside the network and the transmission delay is only due to the optical signal propagation delay. Notice, that in this case the connection-oriented OBS operation can provide absolute quality guarantees for the end-to-end connection.

On the contrary, the one-way reservation model needs for additional support in QoS provisioning in order to preserve HP traffic from LP traffic during both the resource reservation process and the burst transmission.

3. CATEGORIES OF QOS MECHANISMS

In this Section we provide a general classification of QoS mechanisms considered for OBS networks. In most cases, the same contention resolution-based QoS mechanisms can be applied in both OBS and OPS networks. Nevertheless, OBS possesses some additional features such as, for instance, the introduction of pre-retransmission offsets and the ability to operate with different signalling modes. These capabilities enable the implementation of other QoS schemes, which are proper only to OBS networks.

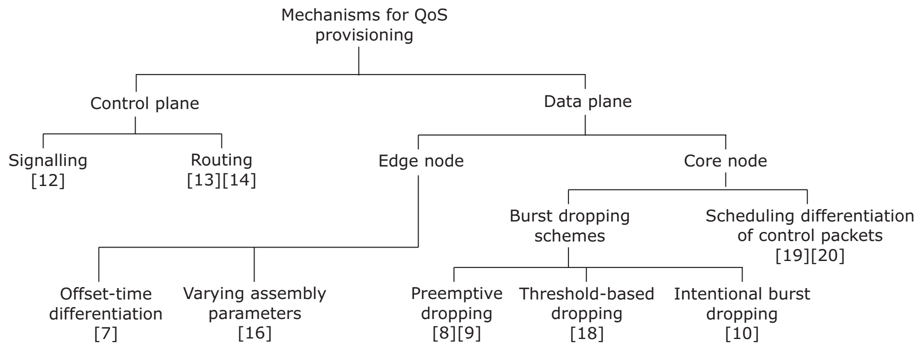

Figure 1-1. Categories of QoS mechanisms in OBS networks.

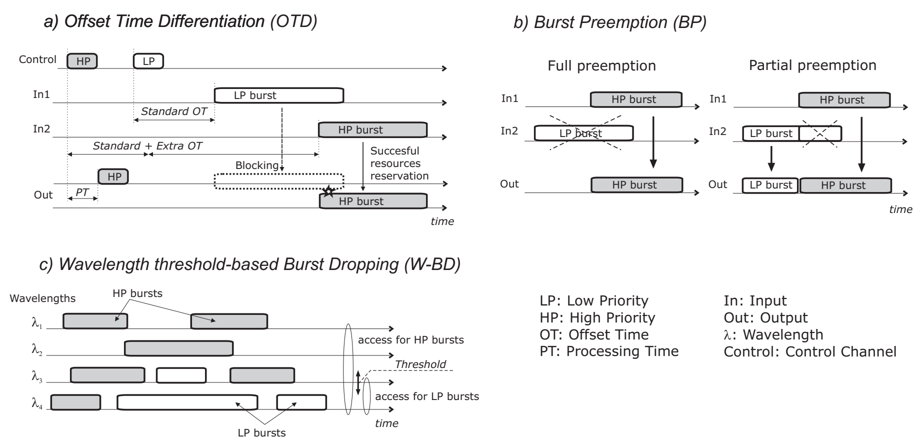

Figure 1-2. Selected QoS mechanisms.

In general several components can contribute to QoS provisioning in one-way reservation OBS networks (see Fig. 1-1). They are related with the control plane through signalling and routing functions and with the data plane through the functions performed in both edge and core nodes.

Two mechanisms involving the control plane operation can provide service differentiation. On one hand a hybrid signalling protocol that consists of a co-operation of two-way and one-way resources reservation modes[12] can support absolute QoS guarantees. In such a scenario the established end-to-end connections can provide the guarantees inside the network such as, no losses and negligible delays, whilst the unreserved resources can be used to transmit the best-effort data burst traffic.

On the other hand, QoS provisioning can be supported by the routing function in a similar way as in OPS networks[13,14]. In particular, a properly designed routing protocol may both minimize the length of routing path for delay-sensitive applications and preserve the selection of overloaded links for loss-sensitive applications, for instance, thanks to a deflection routing mechanism.

Regarding the data plane, at first, the edge node is responsible for the burst assembly process, when the incoming client packets are aggregated into data bursts in electronic buffers according to their class and destination. The solutions where bursts are unaware class assembled[9] present more drawbacks than benefits and they are not considered here. Then QoS can be achieved in the following ways:

- *Offset Time Differentiation*,[7] which is probably the most addressed QoS technique for OBS networks. The idea here is to assign an *extra* offset-time to high priority bursts, what results in an earlier reservation, in order to favour them while the resources reservation is performed (see Fig. 1-2a). The offset time differentiation mechanism allows achieving an absolute HP and LP class isolation, i.e., (almost) none HP class burst is blocked by an LP class burst. To have such a feature, however, the length of the extra offset time has to surpass several times the average LP burst duration[7]. The main advantage of this technique is its simplicity; it makes use only of the postponed transmission of HP bursts in the edge node and it does not require any differentiation mechanism in core nodes. The disadvantages are both the sensitivity of HP class to burst length characteristics[15] and extended pre-transmission delay, which may not be tolerated by some time-constrained applications. Another problem in conventional OBS networks is multiplication of effective burst classes due to the offset variation[15]. In order to limit its impact on QoS performance the transmission offset, which gives the margin for processing and switching operation in core nodes, should be small enough comparing to the extra offset.
- *Varying burst assembly parameters* such as, preset timers and burst lengths. In particular, the packets belonging to an HP class can be aggregated with shorter burst assembly periods than LP packets[16]. In this way the latency experienced by the HP traffic can be minimized. The designing of a burst assembly function is a delicate task since the resulting traffic characteristics may affect the overall network performance.

Another function of the edge node is traffic classification with assignation of specific attributes to the bursts such as, e.g., labels and priorities. These attributes are carried by the burst control packets with the purpose of their further discrimination and processing in core nodes.

First of all, QoS provisioning in core nodes takes place when resolving the burst contention problem and is achieved with an adequate burst drooping technique. The contention resolution usually is assisted by some mechanism(s) such as, wavelength conversion, FDL buffering, and deflection routing[5]. The following burst dropping techniques have been proposed for QoS differentiation in OBS networks:

- *Preemptive* dropping, which is another QoS technique, alongside with the offset time differentiation, widely addressed in the literature. In case of the burst conflict, the burst preemption mechanism overwrites the resources reserved for a lower priority burst by the higher priority one; the preempted, LP burst is discarded (see Fig. 1-2b). Several variations of this mechanism can be found in the literature and both relative[8] and absolute[17] QoS models are supported. In general the preemption can be either *full*[8] or *partial*[9]. The full preemption concerns the entire LP burst reservation, whilst the partial preemption overwrites only the overlapping part of the LP reservation. The partial preemption allows for more efficient resources utilization comparing to the full preemptive scheme. Its drawback, however, is the complexity of burst assembly process since this technique requires additional information about data segments in the burst to be carried and processed in core nodes. Also, the preemptive operation results in an excessive overhead in the data and control plane. Indeed in a conventional OBS network the burst control packet which belongs to a preempted LP burst may not be aware of the preemption and thus, it is transmitted through consecutive nodes occupying both processing and transmission resources.
- *Threshold-based dropping*, which provides more resources (e.g., wavelengths, buffers) to HP bursts than to LP ones according to certain *threshold* parameter (see Fig. 1-2c). If the resources occupancy is above the threshold, the LP bursts are discarded whilst the HP bursts can be still accepted. Likewise in OPS networks, where the threshold-based technique has been proposed to be used with wavelength assignment and FDL buffering algorithms[18], similar solutions can be easily applied in OBS networks[10].
- *Intentional bursts dropping*, which maintains the performance of HP bursts by intentional dropping of LP bursts. This objective can be achieved with the assistance of a burst discarding method such as, e.g., Random Early Detection (RED)[10]. Since the intentional burst dropping can be classified as a QoS mechanism with absolute quality guarantees, it inherits all the advantages and drawbacks of the absolute QoS model.

Table 1-1. Characteristics of QoS mechanisms in OBS.

Mechanism	QoS model	Supported QoS metric	Advantages	Disadvantages
Hybrid signalling	A	D / BL	- absolute end-to-end loss and delay guarantees for HP	- lower statistical multiplexing gain, inefficient usage of bandwidth (less resources available for LP traffic)
QoS routing	A (delays) / R (losses)	D / BL	- supports QoS guarantees on the network level	- controlling burst losses may be challenging (need for the network state information)
Offset time differentiation	R	BL	- simple, soft operation - no need for any differentiation mechanism in core nodes	- sensitivity of HP class to burst length characteristics - extended HP-class pre-transmission delay
Varying burst assembly parameters	A	D	- burst assembly parameters can be easily setup	- the resulting traffic characteristics may influence network performance
Preemptive dropping	R/A	BL	- can provide absolute QoS (with a probabilistic scheme) - improved link utilization (with partial preemption) - fine class isolation	- resources overbooking, increased control load (in case of successful preemption) - complexity of burst assembly process in case of partial preemption
Threshold-based dropping	R	BL	- can be easily implemented	- its efficiency depends on threshold adaptability to traffic changes
Intentional burst drooping	A	BL	- can provide absolute QoS	- the link utilization may suffer - complex implementation
Scheduling differentiation of burst control packets	R	BL	- priority queuing in electrical buffers is a feasible and well studied technique	- extended delay (need for longer queuing windows and so larger offset times to perform effectively)

Description: A – Absolute, R – Relative, D – Delay, BL – Burst Losses.

Another group of mechanisms which support QoS provisioning in core nodes makes use of a queuing and scheduling management of burst control packets that arrive to the node controller. Indeed, by proper ordering of burst control packets some reservation requests can be processed earlier; as a result they have more possibilities to encounter free transmission resources. Some of proposed burst control packet scheduling mechanisms are adapted from the well-studied electrical packet-switching networks. The burst control packets can be processed either directly on base on their priorities[19] or according to a *fair packet queuing* algorithm[20], which controls the access to the resource reservation manager for different classes of quality. A disadvantage of priority scheduling techniques in OBS networks is the increase of burst transmission delay. Indeed in order to operate effectively, the algorithm requires additional offset time in order to gather a number of burst control packets and schedule them according to their priorities.

In Table 1 we summarize the main features of discussed QoS mechanisms.

4. PERFORMANCE COMPARISON OF QOS MECHANISMS

In this Section we evaluate the performance of selected QoS mechanisms that aim at the provisioning of relative QoS guarantees. We focus on the mechanisms that implement a one-way reservation signalling protocol and are frequently mentioned in the literature (see Section 3 for more details), in particular:

1. Offset Time Differentiation (OTD),
2. Burst Preemption (BP), and
3. Wavelength threshold-based Burst Dropping (W-BD).

4.1 QoS scenario details

The QoS mechanisms are studied in a unified network scenario with a number of edge nodes and a single core node (see Fig. 1-3). Two classes of traffic are considered, namely, a high priority (HP) class and a low priority (LP) class. The edge nodes generate some HP class and LP class burst traffic pattern. The traffic is handled in the core node according to a given resources reservation and burst drooping policy. At the node output link we evaluate:

- the *burst loss probability* (BLP), for both HP class (BLP_{HP}) and LP class (BLP_{LP}) as well as for overall traffic, that corresponds to the amount of data burst traffic lost as a fraction of the data burst traffic offered, and
- the *throughput*, which represents the percentage of data traffic served with respect to overall data traffic offered to the core node.

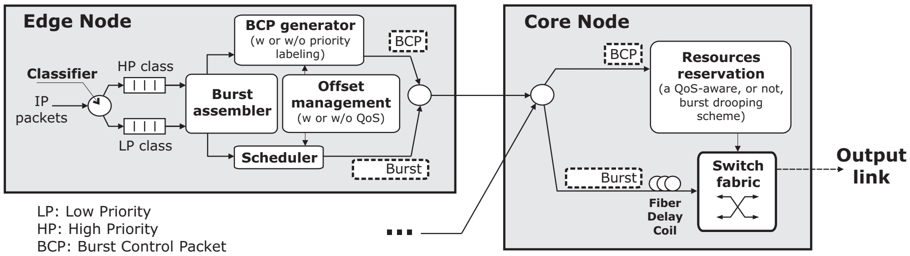

Figure 1-3. The QoS scenario under study.

We focus on a (nowadays) technologically feasible OBS core node[21, 22] of relatively low number of input ports and wavelengths, but with fast, sub-microsecond switching operation and short burst durations.

The burst scheduler implements a *latest available unused channel with void filling* (LAUC-VF) algorithm[6]. The algorithm searches for a wavelength that minimizes the time gap between currently and previously scheduled bursts. We assume that the searching procedure is performed according to a round-robin rule, i.e., it starts from the less-indexed wavelength each time.

The core node implements an *offset time-emulated* OBS architecture,[23] i.e., it comprises an additional fibre delay coil component which is responsible for the introduction of processing offset time. On the contrary to conventional OBS architectures, there is no additional offset, except an optional extra offset time for QoS purposes, introduced in the edge node between the burst control packet and the data burst. Thanks to this architecture we avoid the impact of variable offsets on scheduling performance[24] and thus we can gain a deeper insight into the mechanisms behaviour. Nonetheless, since the scheduling operation affects all the mechanisms equally we can expect that their relative performance will be also preserved in the conventional OBS.

The implementation of QoS mechanisms is the following:

- The duration of extra offset time assigned to HP bursts in the offset time differentiation mechanism is 4 times longer than an average LP burst duration. Such a setup allows achieving *quasi*-absolute class isolation[9].
- The burst preemption mechanism applies a simple full-preemptive scheme where each HP burst is allowed to preempt at most one LP burst if there are no free wavelengths available. The preemption concerns an LP burst that, when dropped, minimizes the gap produced between the preempting HP burst and the other burst reservations.
- The wavelength threshold-based burst dropping mechanism operates according to a *restricted* approach[11]. In particular, the threshold value specifies the maximum number of wavelengths that can be occupied

simultaneously by LP bursts. On the contrary, HP bursts are allowed to access the whole pool of wavelengths. The threshold selection problem is discussed in Subsection 4.3.1.

If either the burst preemption mechanism or the wavelength threshold-based burst dropping mechanism is applied, the edge node implements a traffic classification function that assigns appropriate priorities to the bursts.

4.2 Simulation scenario

The performance of QoS mechanisms is evaluated in an ad-hoc event-driven simulator. The simulator imitates an OBS core node with full connectivity, full wavelength conversion, and no FDL buffering. It has 4×4 input/output ports and 8 data wavelengths per port (if not specified differently), each one operating at $10Gbps$. The switching times are neglected in the analysis.

The traffic is uniformly distributed between all input and output ports. In most simulations the traffic load per input wavelength is $\rho = 0.8Erlang$ (each wavelength occupied in 80%) and the percentage of HP bursts over the overall burst traffic, also called HP class relative load α_{HP}, is equal to 30%.

If not specified differently, the burst inter-arrival times are normally distributed[25] with the mean that depends on the offered load and the standard deviation $\sigma = 5 \cdot 10^{-6}$. The burst durations are normally distributed[25] with the mean $L = 32\mu s$ and the standard deviation $\sigma = 2 \cdot 10^{-6}$. In further discussion we express the burst length in *bytes* and we neglect the guard bands; thus, the mean burst duration L corresponds to $40kbytes$ of data (at $10Gbps$ rate).

All the simulation results have 99% level of confidence.

4.3 Results and discussion

4.3.1 Threshold selection in W-BD mechanism

A critical designing issue for all threshold-based mechanisms is the setup of threshold parameter. If we assume independent exponentially distributed (i.e.d.) burst inter-arrival times and lengths,[27] the W-BD mechanism can be modelled as a queuing system[11]. We use such an analysis to assist the threshold selection process. In the discussion, we will also make use of the Erlang B-loss formula, which was shown to approximate well the link-level burst loss probabilities in OBS networks[26]:

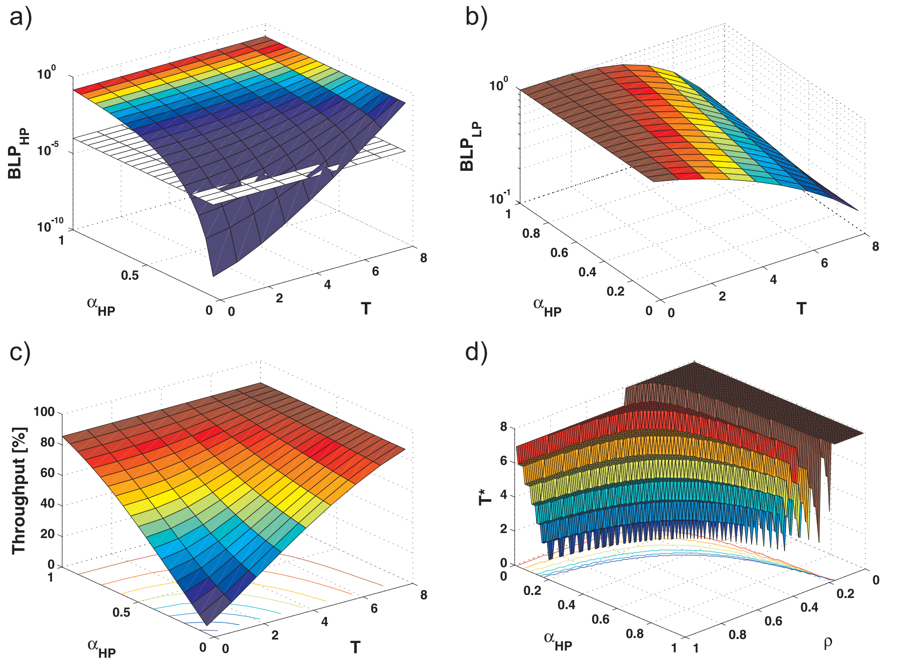

Figure 1-4. Performance of the wavelength threshold-based burst dropping mechanism (c = 8), a) HP class BLP, b) LP class BLP, c) throughput, d) threshold value guaranteeing $\mathrm{BLP_{HP}} \leq 10^{-4}$.

$$Erl(A,c) = \frac{A^c}{c!}\left[\sum_{i=0}^{c}\frac{A^i}{i!}\right]^{-1}, \tag{1}$$

where A is an offered traffic load and c is a number of wavelengths.

We consider the link has c = 16 wavelengths, the overall traffic load ρ is equal to 0.8, and T denotes the threshold parameter, i.e., the number of wavelength accessible to LP class bursts.

In Fig. 1-4a-c we present some analytical results of HP and LP class burst loss probabilities and the throughput. We can see that the performance of W-BD mechanism depends both on HP class relative load α_{HP} and on threshold T value. For given α_{HP}, the $\mathrm{BLP_{HP}}$ can be controlled by a proper selection of the threshold, however, at the cost of effective throughput. The lower bound on $\mathrm{BLP_{HP}}$ is obtained when $T = 0$ (i.e., the LP class traffic is not served) and equal to $b_1 = Erl(\alpha_{HP}\rho, c)$. The upper bound on $\mathrm{BLP_{HP}}$ is obtained for $T = c$ (i.e., no class differentiation) and equal to $b_2 = Erl(\rho, c)$.

Assume, there is same level of burst loss probability, denote it as $\mathrm{BLP}_{\mathrm{HP}}{}^{*}$, to be guaranteed for HP class. Then, if $\mathrm{BLP}_{\mathrm{HP}}{}^{*}$ is higher than b_1, we can find threshold T^* such that complies $\mathrm{BLP}_{\mathrm{HP}}(T^*) \leq \mathrm{BLP}_{\mathrm{HP}}{}^{*}$ and, at the same time, maximizes the throughput. In Fig. 1-4d we present the threshold values obtained for $\mathrm{BLP}_{\mathrm{HP}}{}^{*} = 10^{-4}$ and $c = 8$, as a function of offered traffic load.

4.3.2 Burst loss probability and throughput

In our implementation of QoS mechanisms, both OTD and BP mechanism can achieve absolute class isolation. In other words, the extra offset time we assign to the HP class in the OTD assures that the contention of an HP burst is only due to other HP burst reservations. If we assume i.e.d. burst inter-arrival times and independent and identically distributed (i.i.d.) burst lengths,[27] the burst loss probability of HP traffic class can be modelled with the Erlang loss formula and it equals to $Erl(\alpha_{HP}\rho, c)$. Similarly, the BP mechanism allows preempting any LP reservation by an HP burst and an HP burst is lost only if all the wavelength resources are occupied by other HP reservations. Thus again the loss probability of HP bursts is equal to $Erl(\alpha_{HP}\rho, c)$. Note that LP bursts are successfully transmitted either if there are free wavelength resources, not occupied by any earlier HP reservations (in case of the OTD), or the LP burst are not preempted by HP bursts (in case of the BP).

As we have already discussed, the W-BD mechanism achieves its topmost HP class performance if there is no threshold established ($T = 0$), i.e., only HP bursts are transmitted at the output port. In this case, the W-BD mechanism offers the same burst loss performance with respect to the HP class of traffic as the other two QoS mechanisms we study. However, the throughput of the W-BD mechanism is seriously deteriorated as long as none LP burst is served. In Fig. 1-4 we can see that by increasing the threshold value we can improve the throughput but still we achieve it at the cost of HP class performance.

In Fig. 1-5 we provide comparative performance results obtained in the simulation scenario (see Subsection 4.2 for more details). The evaluation is performed for $\rho = 0.8$ and $\alpha_{HP} = 30\%$, and different number of data wavelengths (c). We setup T, the threshold in W-BD mechanism, to be equal to 50% of c, so that the LP class bursts can access at most half of all the available wavelengths at the same time.

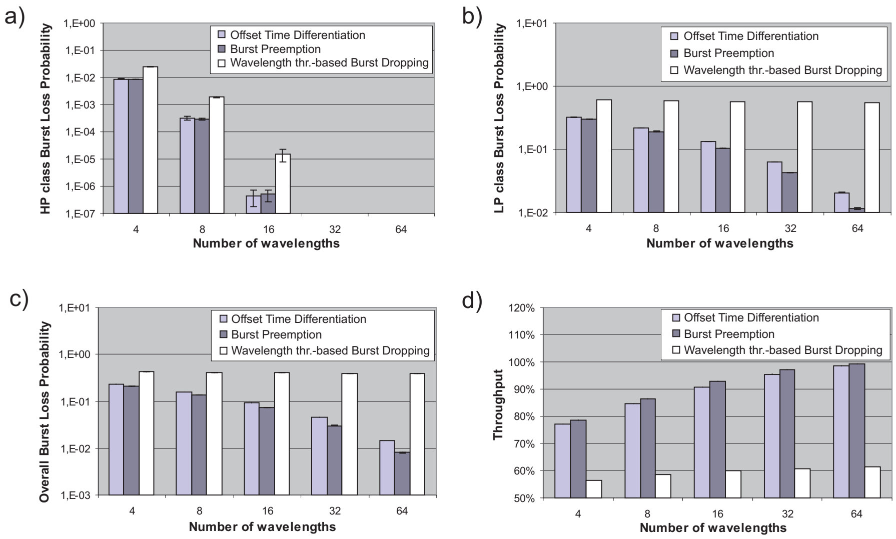

Figure 1-5. Performance of QoS mechanism vs. link dimensioning (ρ = 0.8, α_{HP} = 30%), a) HP class BLP, b) LP class BLP, c) overall BLP, d) effective data throughput.

In Fig. 1-5a we can see that by increasing the number of wavelengths in the output link we improve the effectiveness of QoS differentiation. The improvement of BLP_{HP} in both OTD and BP mechanism can be really high, for instance, as of *three* orders of magnitude when having 16 instead of 8 wavelengths. Also, we can see that W-BD mechanism offers the poorest HP class performance.

In Fig. 1-5b-d we present the results of BLP_{LP}, overall BLP, and the effective throughput. Although, the performance of both OTD mechanism and BP mechanism is very similar with respect to these metrics, still, the results are in the favour of BP mechanism; in the next Subsection we discuss this issue in more details.

We can also observe that the W-BD mechanism once again achieves very poor performance that hardly depends on available link resources. The reason is that this mechanism has effectively fewer wavelengths available at the output link than the other two mechanisms. Indeed, it provides only 50% of wavelengths for LP class, while it attempts to serve the same amount of input traffic. As a result, both the LP class performance and the throughput are seriously deteriorated.

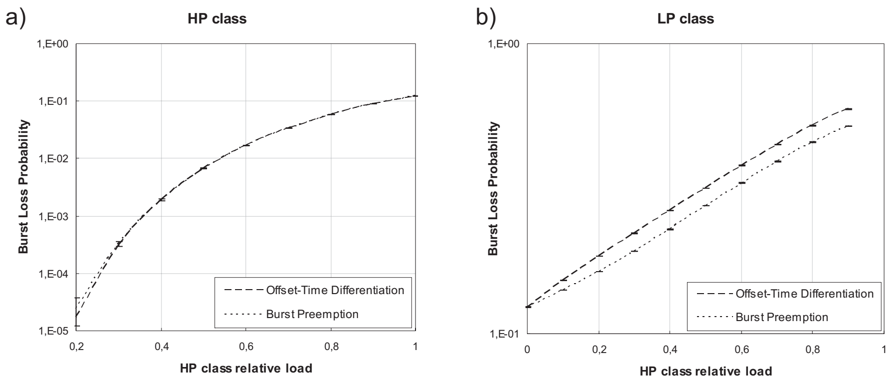

Figure 1-6. Burst loss probabilities vs. HP class relative load in OTD and BP mechanism ($\rho = 0.8$, $c = 8$), a) HP class, b) LP class.

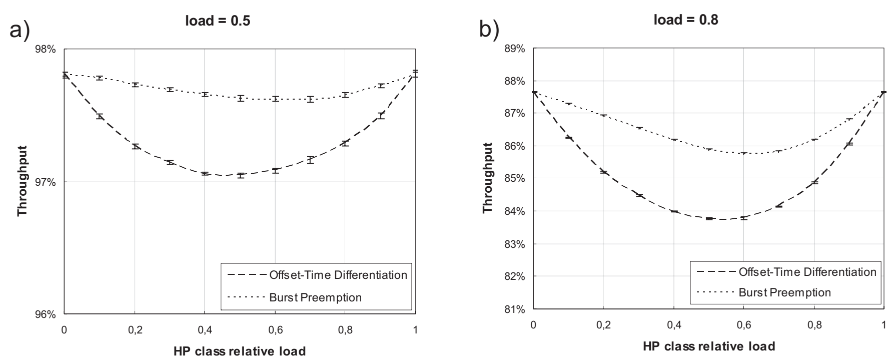

Figure 1-7. Effective throughout vs. HP class relative load in OTD and BP mechanism, with overall traffic load: a) $\rho = 0.5$, b) $\rho = 0.8$.

Although, the FDL buffering is not suitable for conventional OBS networks that operate with long data bursts, still, in OBS networks with short data burst transmission it may significantly help in the contention resolution and QoS provisioning problem. The application of FDL buffers should improve the utilization of link resources, and thus the node throughput, as well as it should decrease the loss probabilities of bursts belonging to each priority class.

4.3.3 Burst preemption vs. offset-time differentiation

The simulation results of BLP_{HP} shown in Fig. 1-5 and Fig. 1-6a confirm the correctness of arguments presented in the preceding Subsection. In particular, we can see that the HP class performance of OTD mechanism is much the same as of BP mechanism regardless of link dimensioning (Fig. 1-5a) and traffic conditions (Fig. 1-6a).

In Fig. 1-6b we can see that the LP traffic is handled more efficiently by the BP mechanism than by the OTD mechanism. It was shown[24] that the variation of offset times, which is inherent in the OTD mechanism, may have a negative impact on the scheduling performance in switching core nodes. Indeed, as Fig. 1-7 shows, the use of variable offsets makes worsen the effective data throughput in the OTD, especially, if the classes of traffic are equally loaded. Finally when comparing Fig. 1-7a and Fig. 1-7b, we can see that the deterioration of throughput is much more serious in highly loaded scenarios.

We can also observe some deterioration of throughput in the BP mechanism. It results from the preemptive operation which allows dropping an LP burst even if it has been partially transmitted at the output link. In such a case, the actual traffic load offered to the output link is increased and it comprises both entirely transmitted data bursts and the parts of preempted LP burst reservations. Since the probability of burst blocking increases accordingly the throughput decreases.

5. EFFECTIVE BURST PREEMPTION

As previously mentioned, the general drawback of burst preemptive mechanisms is possible waste of resources on the ongoing path in case of successful burst preemption. In conventional OBS networks, the burst control packet which belongs to a preempted LP data burst does not have any knowledge about the preemption. On the contrary, it continues its trip towards the destination node and consumes unnecessarily both the control-plane resources, when being processed in the node controllers, and data-plane resources, when reserving the wavelengths for its (preempted) data burst.

In order to assess such an overhead, we develop an approximate estimation of the preemption effect that is produced in a single node. In particular, we introduce a *preemption rate* (R) metric that expresses the number of preempted bursts over all the bursts (successfully) transmitted at the node output link.

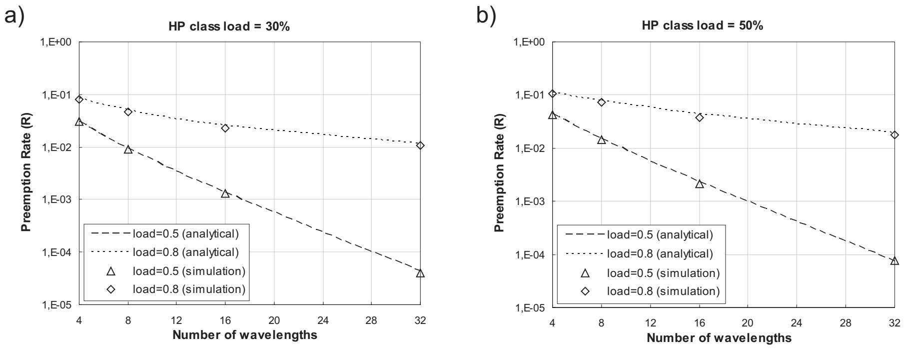

Figure 1-8. Preemption rate in an OBS node, with HP class relative load: a) α_{HP} = 30%, b) α_{HP} = 50%.

If we assume i.e.d. burst inter-arrival times and i.i.d. burst lengths, the preemption rate of a full burst preemption scheme can be calculated as (see Appendix A for a derivation):

$$R = \frac{\alpha_{HP}\left[Erl(\rho,c) - Erl(\alpha_{HP}\rho,c)\right]}{1 - Erl(\rho,c)}, \tag{2}$$

where ρ, α_{HP}, c are, respectively, the overall load, HP class relative load, the number of wavelengths in the link, and $Erl(\cdot)$ is given by (1).

The formula can be interpreted as following: the numerator represents the reduction of burst losses of the HP class after the application of the preemption mechanism whilst the denominator conditions it on those bursts that have been successfully transmitted.

In Fig. 1-8 we present analytical and simulation results of the preemption rate. As we can see, *R* increases if either the traffic load increases or the number of wavelengths in the link decreases. A small disparity between the analytical and the simulation results comes from the fact that the simulated bursts as stream-like arranged in the data channel (bursts do not overlap each other) and their arrivals are not more exponentially distributed (as we assumed in the analytical model).

R corresponds to the percentage of additional burst control packets that have to be processed at each node on their outgoing routing paths. These burst control packets are responsible for the wastage of both processing and transmission resources as long as their data bursts are not going to be transmitted anymore (they have been preempted). In large networks, of high number of nodes, the problem might be intensified since all the nodes undergo a similar effect. Such a study, however, is out of the scope of this work.

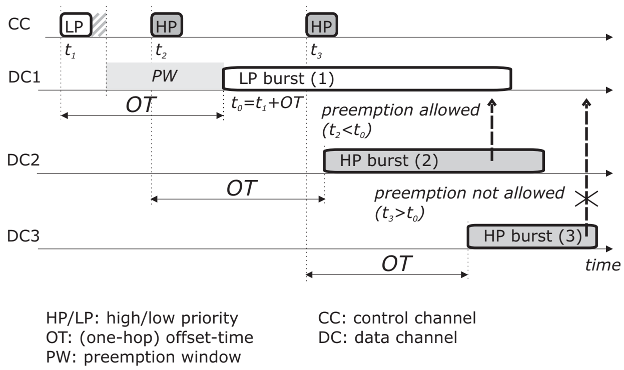

Figure 1-9. Preemption Window mechanism.

A particular attention should be paid to preemption-based routing mechanisms[28,29]. Such mechanisms assume that the bursts carried over alternative (duplicate) paths can be preempted by the bursts carried over primary paths. In such scenarios, the amount of preempted bursts might be really high as long as both ρ and α_{HP} are assumed to be high. As a consequence the useless burst reservations may decrease the effectiveness of preemption-based routing mechanisms.

The problem of the preemption-related overhead can be effectively avoided in OBS networks with a *preemption window* control mechanism[30] applied (see Fig. 1-9). The mechanism assumes that the offset time is enlarged by additional offset which defines a preemption window period. The preemption of an LP burst is allowed only during this period. A burst control packet, after its processing, has to wait in the switch controller until the preemption window expires. Then it is either sent towards the next node (if its data burst has not been preempted) or dropped (in case of successful preemption). After the burst control packet is sent the preemption of its burst is not allowed in the node. Thanks to these rules, there are no burst reservations in the ongoing nodes that belong to the preempted bursts.

6. CONCLUSIONS

In this Chapter we study the performance of the most addressed mechanisms providing relative QoS differentiation in OBS networks. We show that the burst preemptive mechanism can efficiently utilize transmission resources and, at the same time, it can offer highly effective QoS differentiation. The offset time differentiation mechanism is characterized by high HP class performance as well. Nevertheless, its scheduling efficiency, and thus the throughput, is deteriorated by the variation of offset-times. Finally, the wavelength threshold-based mechanism can be characterised by the poorest overall performance, which significantly depends on its wavelength threshold value. The application of this mechanism may be reasonable only for the links of a large number of wavelengths so that the threshold would be relatively high (in order to serve efficiently the LP traffic) and could adapt to traffic changes. Although, the evaluation of the performance of QoS mechanisms is obtained in a single node scenario, still, we can expect the mechanisms will behave similarly in a network scenario.

The high performance of burst preemption mechanism designates it to be a suitable mechanism for QoS differentiation in OBS. Although, in this study we concern on relative quality guarantees, still, the preemption mechanism can support absolute QoS guarantees[17] as well. A drawback of the preemption mechanism in conventional OBS networks is the waste of resources if the preemption occurs. Nonetheless, such a problem can be avoided in OBS networks with a preemption window mechanism applied.

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APPENDIX A. THE PREEMPTION RATE IN A BUFFER-LESS OBS NODE

Here we show how we derive the expression (2).

Let $n_{preempt}$ be the number of successful preemptions, $n_{lost\_HP}^{(np)}$ and $n_{lost\_HP}^{(p)}$ be, respectively, the number of HP bursts that are lost in a non-preemptive (without burst preemption) and a preemptive (with full burst preemption) scenario, n_{in_HP} be the number of incoming HP bursts, n_{in} be the total number of incoming bursts and n_{out} be the total number of bursts transmitted at the output link in a given time period.

Since each preemption means the acceptance of an HP burst instead of an LP burst, $n_{preempt}$ can be also interpreted as a difference between all the HP bursts that are lost in the non-preemptive scenario and the HP bursts that are lost in the preemptive scenario:

$$n_{preempt} = n_{lost\_HP}{}^{(np)} - n_{lost\_HP}{}^{(p)} \tag{A1}$$

Obviously:

$$n_{lost\_HP}{}^{(np)} = n_{in\_HP} \cdot B_{HP}{}^{(np)} \tag{A2}$$

$$n_{lost\_HP}{}^{(p)} = n_{in\_HP} \cdot B_{HP}{}^{(p)} \tag{A3}$$

where $B_{HP}{}^{(np)}$ and $B_{HP}{}^{(p)}$ are the HP burst loss probabilities in the non-preemptive and the preemptive scenario, respectively.

From (A1) – (A3) we have:

$$n_{preempt} = n_{in\_HP} \cdot (B_{HP}{}^{(np)} - B_{HP}{}^{(p)}) = \alpha_{HP} \cdot n_{in} \cdot (B_{HP}{}^{(np)} - B_{HP}{}^{(p)}) \tag{A4}$$

where α_{HP} is the HP class load ratio.

Than the preemption rate is equal to:

$$R = \frac{n_{preempt}}{n_{out}} = \frac{\alpha_{HP} \cdot n_{in} \cdot (B_{HP}{}^{(np)} - B_{HP}{}^{(p)})}{n_{in} \cdot (1 - B^{(p)})} \tag{A5}$$

Note, that the overall burst loss probability in the preemptive scenario ($B^{(p)}$) and the HP burst loss probabilities in the non-preemptive scenario ($B_{HP}{}^{(np)}$) are the same. Moreover $B_{HP}{}^{(p)}$ depends only on the HP class relative load (α_{HP}) due to absolute class isolation. Finally, assuming the exponentially distributed burst arrivals and lengths, we use (1) to calculate burst loss probabilities. Therefore, by the proper substitution in (A5) we obtain (2).

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