Comparative study of QoS mechanisms in OBS networks

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In this paper, we address the problem of Quality of Service (QoS) provisioning in Optical Burst Switching (OBS) networks. When examining the literature on OBS we can find several proposals of mechanisms dealing with QoS. As these mechanisms are evaluated in a specific node/network scenario each one, the results are usually not comparable. The aim of this work is to confront the performance of the most referenced QoS mechanisms in the same evaluation scenario consisting of a single isolated node.

1. Introduction

OBS is one of the potential solutions with more future in the optical networking panorama [1]. On the one hand, it efficiently exploits statistical multiplexing in the optical layer to overcome the wavelength switching inefficiency. On the other hand, it uses large data bursts to overcome the fast processing and switching requirements of the optical packet switching (OPS) currently only available at the laboratory. On the contrary to the OPS, the client packets are aggregated and assembled into bursts at the edge nodes of OBS network. Meanwhile, the control information is transmitted out-of-band by a control packet (CP) and sent with some offset prior to the burst in order to reserve resources (like wavelengths) on the transmission path for the incoming burst.

There are two distinct signaling architectures considered for OBS networks. The first one performs end-to-end resources reservation with acknowledgment in so called two-way reservation mode (WR-OBS) [2] while the other allocates resources on-the-fly a while before burst coming in a one-way reservation [1]. The problem of WR-OBS networks concerns the latency due to the connection establishment process [3], [4], therefore such architectures are considered mainly for the lower distance metro networks.

The one-way reservation model that can operate in large distance OBS networks performs according to the statistical multiplexing paradigm; hence it encounters the problem of burst contention inside the network. Indeed, when CP enters a node in order to make a reservation of an output fiber and wavelength for the associated incoming burst, it may happen that the requested resources are not available. The lack of optical memories complicates the contention resolution in optical networks. Nevertheless, several mechanisms using wavelength conversion, deflection routing and fiber delay line (FDL) buffering have been proposed to support this problem [5]. A similar difficulty appears when we try to preserve High Priority (HP) loss/delay sensitive traffic from the Low Priority (LP) regular data traffic. In this context, several mechanisms have been proposed for QoS provisioning in OBS networks [6]-[16].

Two basic models for QoS provisioning can be distinguished in OBS networks, namely relative QoS and absolute QoS. In the former, the performance of a class is defined with respect to the other classes, for instance it is guaranteed that loss probability of a burst belonging to HP class is lower than loss probability of a burst belonging to LP class. In the later, an absolute performance metric of quality as for example a maximal acceptable level of burst loses is defined for a class. The performance of given class in relative QoS model may depend on traffic characteristics of the other classes, whilst absolute QoS model aims at irrelative quality provisioning. On the other hand, absolute QoS model may require more complex implementations in order to achieve desired quality levels in wide range of traffic conditions while at the same time to preserve high output link utilization.

When studying the literature on QoS mechanisms in OBS network, one can find difficult to compare their performance since each mechanism is evaluated in a specific node/network scenario and the results usually are not comparable. Even carrying out such rating either over- or under-estimation of some mechanisms may happen. While the authors of [6] provide some comparative performance results of the mechanisms that provide the absolute QoS by means of intentional bursts dropping there are no such works regarding QoS mechanisms, which adopt the relative QoS. This paper aims at comparing contention resolution mechanisms that adopt such QoS model in OBS networks with the one-way reservation and that are frequently mentioned in literature.

2. QoS mechanisms

OBS networks based on the one-way reservation model need an additional support in order to preserve HP traffic from LP traffic during resource reservation process. Several components can contribute in QoS provisioning in such networks, as shown in Fig. 1. They are mainly related with control plane operations through the signaling and routing functions as well as data plane operations performed in both edge and core nodes.

Two mechanisms involving control plane features can provide service differentiation. On one hand, a hybrid signaling protocol [7] that consists of a co-operation of two-way and one-way resources reservation modes can support an absolute QoS. In such a scenario the establishment of end-to-end paths can provide guarantees such as no losses and negligible delay inside the network; while the unreserved resources can be used to transmit the best-effort bursts. On the other hand and similar to what proposed in OPS networks [8], the routing can be involved in supporting QoS. Indeed it may preserve the selection of overloaded parts of the network for loss-sensitive applications or minimize the path lengths for delay-sensitive ones.

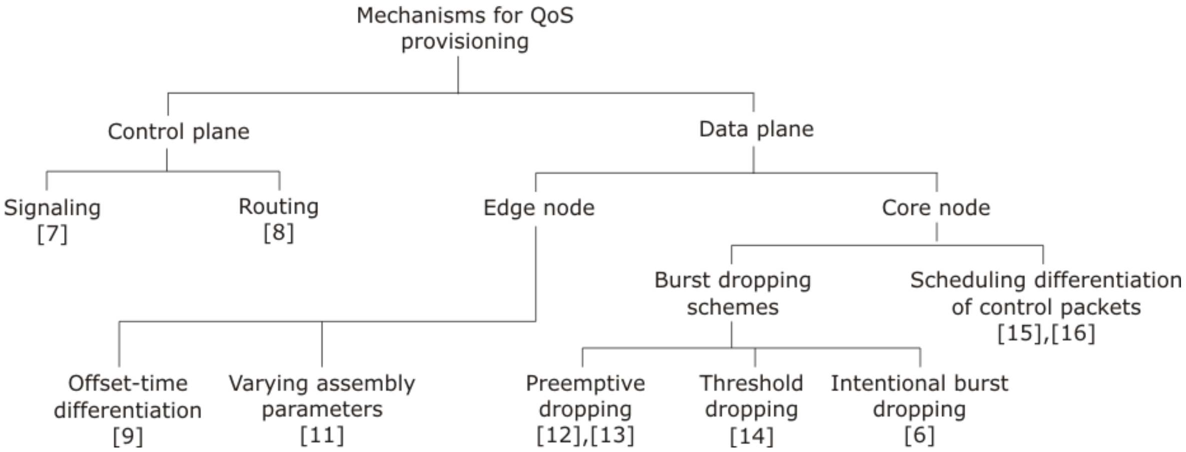

Figure 1: Categorizing different QoS methods in OBS networks.

Regarding the data plane, at first, edge nodes are responsible for the burst assembly phase where the incoming client packets are aggregated into bursts in the electronic buffers according to their class and destination. Then, QoS can be achieved by different ways as explained in the following classification.

- *Offset Time Differentiation* is one of the major QoS techniques [9]. The idea here is to assign an *extra offset-time* to high priority bursts, what results in an earlier reservation, in order to favors them while the resources reservation is done. The extra QoS offset has to be in the order of a few burst durations of lower priority bursts. The advantage of this technique is that it reduces the loss probability of high priority bursts whilst does not affect the overall performance. The main disadvantages are both sensitivity of the HP class to burst length characteristics of the LP class [10] and extended pre-transmission delay that may not be tolerated by some high priority applications.
- *Varying burst assembly parameters* like preset timers or burst sizes can help in minimization end-to-end delays and loss probabilities of high-priority bursts. For instance, in *Burst Length Differentiation* (BLD) technique HP bursts are aggregated with shorted assembly thresholds then LP bursts [11].

Other function of the edge nodes is traffic classification with assigning specific attributes (labels, priorities) to the bursts, which are carried by CPs, with the purpose of their further discrimination and processing in core nodes. Here, QoS provisioning takes place mainly in resolving the contention problem with an assistance of wavelength conversion, FDL buffering and deflection routing [5]. In particular, the following burst dropping schemes may be applied:

- *Preemptive* dropping, which in case of bursts conflict overwrites the resources reserved for the lower priority burst by the higher priority one; the preempted, low priority burst is discarded in such case. The preemption concerns either a whole burst unit [12] or can be partial in more efficient scheme with *burst segmentation* [13]. The drawback of the partial preemption is that it introduces additional complexity into the burst assembly process since it requires additional information about data segments in the burst to be carried and processed in core nodes.

- *Threshold dropping*, which provides more resources to higher priority bursts then to lower priority ones according to certain *threshold* parameter. When the resource occupation is above the threshold the lowest priority bursts are discarded while the higher bursts are accepted until there are some resources available. Likewise the OPS network, where some threshold based algorithms have been proposed to be used with both the wavelength assignment and the FDL buffering [14], similar solutions can be easily applied in OBS network.
- *Intentional bursts dropping*, which maintains the performance objectives of the higher priority bursts on certain levels by intentional dropping the lower priority bursts using active discard technique such as RED [6]. Intentional burst dropping may be classified as an absolute QoS technique.

Another group of mechanisms supporting QoS provisioning is based on the scheduling management of CPs that arrive to the control unit in core nodes. Indeed, by proper ordering of CPs some reservation requests can be serviced earlier what gives them more chances to encounter free transmission resources in the core node. Some of proposed techniques schedule CPs directly on base on their priorities [15] while the others apply a *fair packet queuing* algorithm, which regulates access to the reservation manager for different classes of services [16].

3. Evaluation scenario

The intention of this work is to evaluate the performance of selected QoS mechanisms that provide relative QoS in the same scenario of a single isolated node. The analysis concerns the efficiency in the contention resolution as well as the effectiveness in QoS differentiation. We focus on the mechanisms that use one-way reservation mode and are frequently mentioned in literature (see Section 2), in particular on:

- Offset-Time Differentiation (OTD),
- Burst Preemption (BP),
- Burst Dropping with Wavelength threshold (BD-W),
- Burst Dropping with Buffer threshold (BD-B),
- Burst Length Differentiation (BLD).

For the studied mechanisms, in the same scenario of a single isolated node we evaluate an effective Burst Loss Probability (BLP), which corresponds to amount of data (in *bytes*) lost among all the data transmitted. We set up an event-driven simulator that behaves like OBS node architecture with full connectivity and wavelength conversion, acting as an output queuing switch. It has 4x4 input/output ports and W=4 wavelengths per port, each one operating at 10 Gbps. We consider both buffer-less and buffered OBS scenarios. In the later, the OBS node uses a feed-forward FDL configuration with 4 delay lines. Provided delays are linearly increasing with a basic delay unit equal to the mean burst duration.

Two classes of traffic are considered, namely HP and LP class. The traffic is uniformly distributed between all input and output ports. The mean load per input channel (wavelength) is 0.8 Erlang. The percentage of HP bursts over the total traffic is 30%.

The burst length is Gaussian distributed with mean burst duration L=32 μs and standard deviation σ=15 μs. In further discussion we represent burst lengths in bytes and we neglect the guard bands. Therefore, mean burst duration corresponds to 40 Kbytes of data transmitted at 10Gbits rate. The burst inter-arrival times are Gaussian distributed with a mean that depends on the traffic load and σ=10 μs. We assume that the basic offset time is the same for all bursts in order to avoid the impact of variable-offsets on scheduling operation [17].

Regarding implementation issues the following conditions are assumed:

- For the scenarios with OTD, an extra offset time is equal to 4 mean burst lengths, which according to [9] provides fine isolation between HP and LP classes.
- BP uses a simple full preemptive scheme and each HP burst is allowed to pre-empt at most one LP burst in case there are no free wavelengths available. Moreover, in case all the wavelengths are busy and a HP burst finds some LP reservations that can be preempted, it preempts the LP burst, which dropping produces the minimal gap for the incoming HP burst.
- BD-W and BD-B access the wavelengths and the FDL buffer respectively according to a partial sharing approach [14]. In other words, only a fixed part of the resources is accessible for LP class while HP class can use the whole pool. In our implementation, the LP class has access to 50% of the most-indexed wavelengths in the BD-W and it has access to 50% of the shortest delay lines in BD-B mechanisms.
- Mean burst length is equal to 40 Kbytes and 10 Kbytes for LP and HP burst respectively if *BLD* technique is applied.

Scheduling algorithm applies the LAUC-VF scheme [18]. The algorithm search for the wavelength that minimizes the gap, which is produced on the time scale between newly and previously scheduled bursts. If FDL buffering is applied and a free wavelength can be found without using the buffer this min-gap policy is abandoned. This rule preserves us from using the buffer in case the output wavelength can be accessed directly. Finally, we assume that the searching is performed iteratively and it begins every time from the less-indexed wavelength and from the shortest FDL.

Among the considered QoS mechanisms, OTD, BP and BD-W can be used in both buffer-less and FDL-buffered scenarios, whilst application of BD-B mechanism is obviously limited to the nodes with buffering capabilities. Therefore, in evaluation of the buffer-less scenario we do not provide any results for BD-B mechanism.

Low number of wavelengths considered in the simulation scenario allows us to make a comparison of BLPHP results obtained in both buffer-less and FDL-buffered nodes. With more number of wavelengths and with FDL buffers applied the loss probabilities would be extremely low and would require long-time simulations in order to evaluate them, especially under low HP traffic loads. Nevertheless, for buffer-less scenario we provide some additional performance results presenting behavior of the mechanisms in systems with more number of wavelengths.

4. Results

4.1 Application of FDL and BLD capabilities

Fig. 2 presents performance results obtained for different QoS scenarios, namely with and without FDL buffers and BLD applied. In buffer-less case, we can observe that both OTD and BP offer the same performance for HP class, however BP conserves better from losses both LP and total traffic. It is due to the scheduling operation, which according to [17] may be deteriorated by varying of offset-times experienced in OTD mechanism.

We can observe that FDL buffers in general improve the performance. An additional application of BLD technique may further improve the loss performance of HP class when used together with other QoS techniques. Especially, it may be recommended in order to boost HP performance of BP, BD-W and BD-B mechanisms since it does not impact significantly the performance of LP class. On the other side, BLD should no be used with OTD because of sensitivity of OTD mechanism to scheduling operation that gets worsen if bursts of different lengths are scheduled [17].

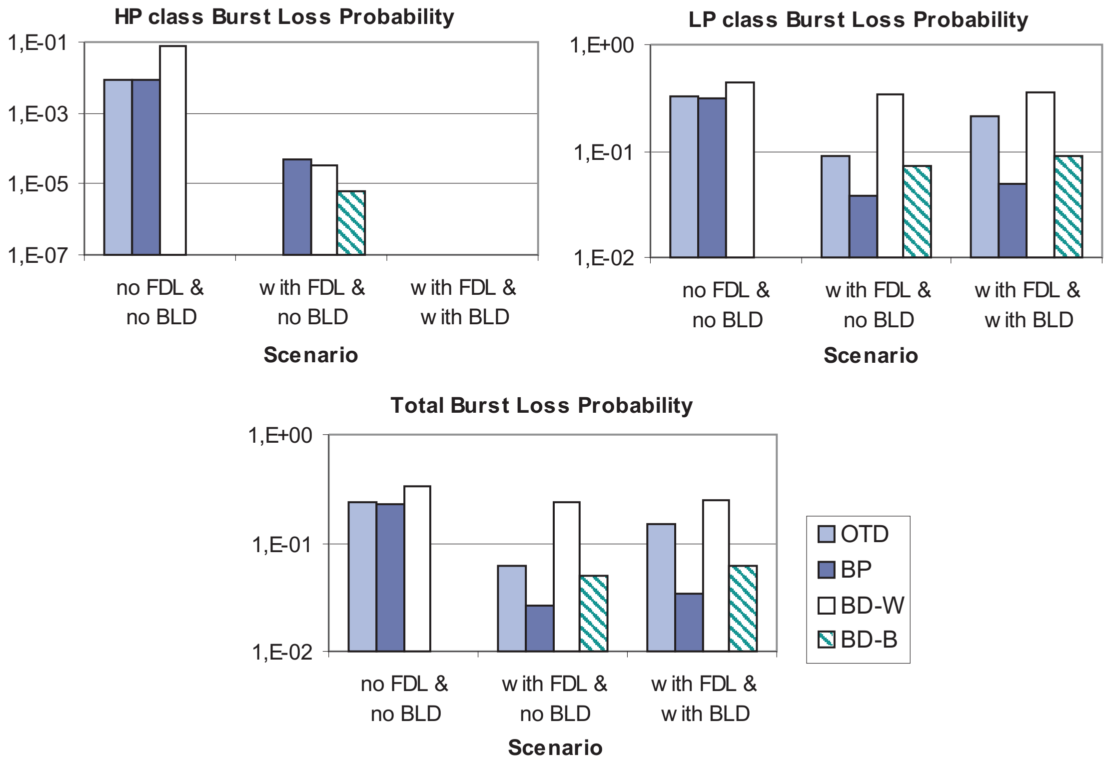

Figure 2: Comparison of QoS mechanisms in the scenarios with and without FDL buffers and BLD technique.

4.2 Wavelength dimensioning

In order to improve the effectiveness of QoS differentiation we can increase the number of wavelengths provided for the transmission of data bursts. As Fig. 3 shows, the improvement of HP class burst loss probability in both OTD and BP mechanisms in buffer-less scenario can be really high, like e.g. such of 3 orders of magnitude if we for instance the number of wavelengths from 8 to 16. BD-W has the worst performance results among all evaluated mechanisms and even application of more number of wavelengths does not improve them significantly. The reason for such behaviour is that BD-W mechanism has effectively less wavelengths available for burst transmissions on the output port then other mechanisms since it provide only 50% of wavelengths for LP class, Simultaneously, BD-W attempts to serve the same amount of the input traffic as the other mechanisms.

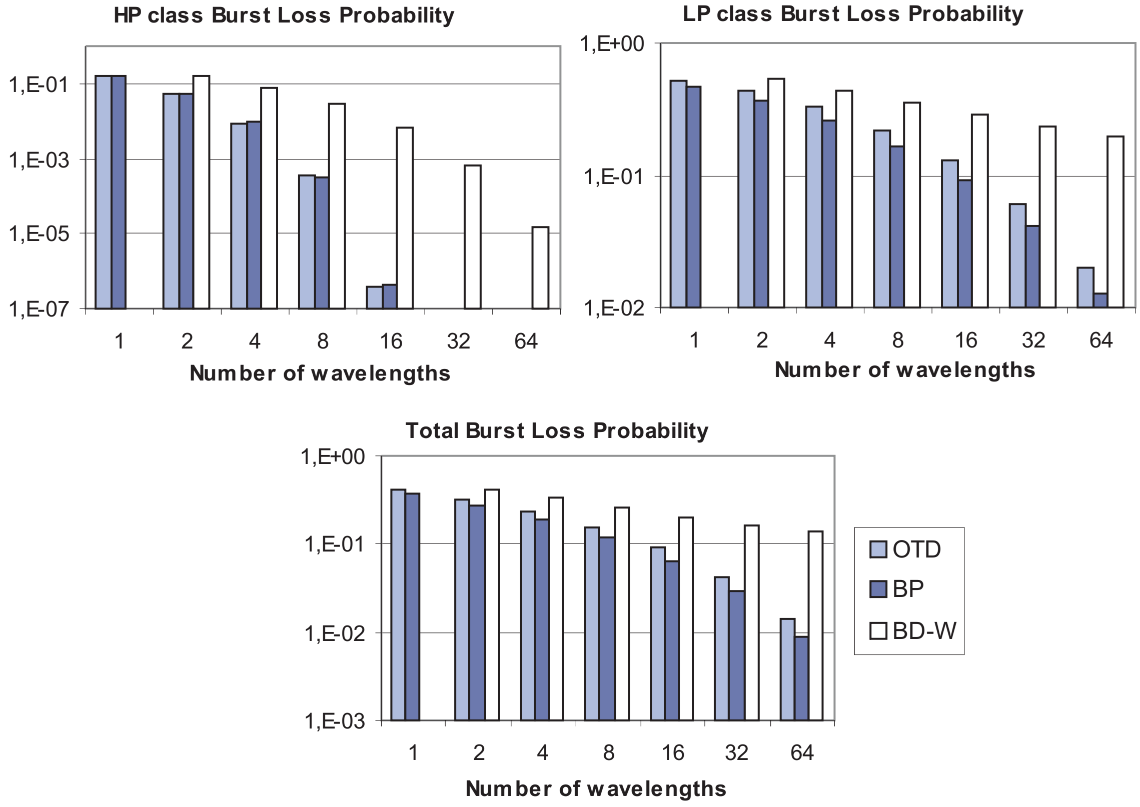

Figure 3: QoS and wavelength dimensioning in the scenario without FDL buffering.

5. Conclusion

In this paper we have evaluated and discussed performance results of the most addressed QoS mechanisms providing relative QoS differentiation. In particular, the burst preemption appears to be the most attractive mechanism since it concurrently offers a high-efficient resources utilization and very effective QoS differentiation. On the contrary, the offset time differentiation mechanism, which is frequently invoked in the literature, may be distinguished only for an offered effective class's isolation while its scheduling efficiency is deteriorated by variation of offset-times. The buffer threshold-based mechanism achieves fine performance; however it can be applied only in the networks with FDL buffering capabilities. Finally, the wavelength threshold-based mechanism offers the lowest performance and its application may be reasonable only in highly dimensioned networks where the wavelength threshold is following traffic changes.

Another conclusion from this work is that when FDL buffering is applied some of the mechanisms can be effectively used with burst length differentiation technique. Such combined scenario improves QoS performance in respect to the burst losses, whilst it only slightly affects LP class and overall burst loss performance. On the other hand, application of variable bursts-length technique should be avoided in the networks with offset-time differentiation mechanism since the overall loss performance can be seriously worsened in such scenario.

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