SCWS Technique for QoS Support in Connection-Oriented Optical Packet Switching Network

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ABSTRACT
This paper considers an optical packet switching (OPS) network subject to asynchronous, variable-length packets and connection-oriented operation. The problem of providing QoS in such a scenario has been widely discussed and several solutions have been provided. They mainly suggest the use of some form of resources reservation on top of the contention resolution algorithm in order to isolate the higher priority traffic from the lower one. Recently we propose the novel technique called SCWS and evaluated it in a single node scenario. SCWS consists of implementing different contention resolution algorithms, each one specifically designed to cope with the requirements of a given priority traffic. In this paper we analyze the performance results when applying SCWS technique in a network scenario. Obtained results highlight the merits of such technique.
Keywords: optical packet switching, connection-oriented network, QoS provisioning, performance evaluation.

1. INTRODUCTION

Optical packet/burst switching (OPS/OBS) approaches are currently promises solutions for the next generation high-capacity Internet [1]. Both technologies are based on statistical multiplexing, and therefore packet/burst contentions may arise at each node. In order to make the statistical multiplexing more efficient and thus reduce the loss probability, contention resolution algorithms must be applied. They typically exploit space domain, by means of deflection routing, frequency domain, by means of wavelength multiplexing, and the time domain, by means of optical queuing using Fiber Delay Lines (FDL) [2]. In order to reduce the control complexity and improve the network performance, recent works suggest the integration of a connection-oriented path management protocol (for instance MPLS) on top of the contention resolution algorithm [3, 4].

In this paper we focus on this scenario and in particular we deal with the QoS provisioning problem. The technology limitation of the optical queuing motivates significant research efforts in recent years dealing with the design of simple contention resolution policies able to provide QoS differentiation. The impossibility of pre-emptying packets already buffered makes unfeasible the implementation of conventional fair queuing scheduling commonly used in electrical switches. At the same time, QoS schemes must be kept very simple to be effective in OPS/OBS where each node must be able to schedule tens of Tbit/s. The mechanisms proposed in literature use some form of resource reservation (either a buffer threshold or wavelength threshold), offset time or hybrid electrical/optical buffers. The limits of such mechanisms have been widely discussed (see for instance [5, 6]). Therefore to provide effective QoS, a novel generic technique called Service-Category-to-Wavelength Selection (SCWS) has been proposed in [6]. The aim of this paper is to apply this technique to an OPS network scenario and evaluate the resulting performance.

The rest of the paper is organized as follows. In Section 2 we provide brief descriptions of the connection-oriented OPS network scenario and the SCWS technique. Section 3 evaluates the application of SCWS in a network scenario. Section 4 concludes the paper.

2. NETWORK REFERENCE SCENARIO

In this connection-oriented OPS network, the tasks of the nodes are two-fold. On the connection side, the edge nodes are in charge of setting up and maintaining the Label Switched Paths (LSPs) throughout the network by means of a signaling protocol such as RSVP, as well as configuring the LSP forwarding table at each core node of the path by means of a Routing and Wavelength Assignment (RWA) scheme. This approach is similar to the ASON/GMPLS circuit switching solutions, but it achieves statistical multiplexing by sharing the wavelengths among several LSPs. Indeed, on the packet side, each node (either an edge or a core) is a generic non-blocking OPS node acting as an output queuing switch with full wavelength conversion capabilities and an optical buffer made by B FDLs. At the edge nodes, packets coming from the client networks are classified into a finite number

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of subsets such as the Forwarding Equivalent Classes (FECs) concept defined in the MPLS environment. Each FEC is identified by an additional label added to the variable-length packets. As packets belonging to the same FEC are identical from a forwarding point of view, they are transferred from source to destination along the LSP which corresponds to their label. This approach simplifies the tasks of the core nodes; in fact a simple label matching operation on the LSP forwarding table is required for each incoming packet, which speeds up the forwarding function compared with the connectionless OPS case and implicitly reflects the QoS requirements of the packets belonging to their LSPs. A contention resolution algorithm must be applied in case of packet contention. It is normally solved in time using the optical buffering; in case of heavy wavelength congestion (i.e. optical buffering is not sufficient to solve contention) the LSP is moved to another wavelength and the forwarding table is updated concordantly.

2.1 Service Category-to-Wavelength Selection technique

SCWS consists of implementing a set of K different contention resolution algorithms (usually referred as wavelength selection algorithms in connection-oriented environment), each one specifically designed to cope with the requirements of a given service category. When a packet belonging to an LSP with category i arrives at the node, the control unit executes the corresponding algorithm i to forward the packet which guarantees only the required services. In this paper we define a case study with two service categories:

- *Real Time* (RT) for interactive applications, which requires strict performance (very low Packet Loss Rate –PLR– and very short delay)
- *Best Effort* (BE) with no requirements

We hence use two different wavelength selection algorithms, which will be implemented in the control unit. The packets belonging to the BE service category is forwarded using the Minimum Gap Wavelength Selection (MGWS) algorithm [7]. In case of packet contention, it selects the queue with the smallest delay. If the wavelength is congested (i.e. no queues are available) it moves the LSP to the wavelength with the minimum gap, which is the shortest time between the end of the last packet routed to that wavelength and the beginning of the present one after delaying it, if needed. Regarding the RT packets, they will be forwarded by Sequence Keeping Wavelength Selection (SKWS) algorithm. It has been originally proposed in [8], and its aim is to achieve excellent level of PLR maximizing the resource utilization and throughput. It takes decisions controlling the delay in order to preserve the correct packet sequence belonging to the same LSP.

The integration between different algorithms is not trivial as shown in [6]. Indeed, the algorithm obtains Packet Loss Rate figures that are dependent of the FDL granularity D (being D the length unit of the FDLs), and, in general, they show the best results with different values of the D. A solution could be having two different FDL structures, each one reserved for a given category, but it can need very large buffers. As we proposed in [6], also here we design an ad-hoc FDL architecture based on non-degenerate delays [9] that decreases buffer requirements and achieves the perfect performance alignment between the algorithms. A detailed analysis is presented in the following section.

3. PERFORMANCE EVALUATION

In this section we present the performance evaluation. It is divided into two parts. Firstly we present the simulation results when the algorithms are evaluated independently. This part allows the design of the ad-hoc FDL architecture able to integrate the algorithms. Therefore we evaluate the resulting system.

3.1 Simulation scenario

The European Optical Network (EON) topology shown in Fig. 1 is considered. Each link transports 16 wavelengths at 2.5 Gbit/s.

Figure 1. European Optical Network topology.

Regarding the traffic pattern at the connection level, we consider that each wavelength is uniformly occupied by 3 LSPs. Shortest Path routing and Grouping wavelength assignment [10] are used. At the packet level, packet length follows an exponential distribution with a mean equal to 500 bytes and a Poisson distribution is used for the inter-arrival packets with a mean that provided a 0.8 offered load per each LSP.

3.2 Ad-hoc integrated FDL architecture design

We firstly analyze the performance of the MGWS and SWKW algorithms to find their optimum granularity. We consider a degenerate buffer with $B = 8$ in each node. In Fig. 2 we plot the PLR fixing the granularity (normalized to the average packet size) of MGWS algorithm to the value of $D = 0.4$ (Fig. 2*a*) and $D = 0.6$ (Fig. 2*b*), and varying the SKWS granularity, i.e. the x-axis values represents the ratio between granularities. For example, if the x-value indicates 2.0, it means that the SKWS granularity is twice as MGWS (e.g. 0.8 in Fig. 2*a*).

The first particularity to note from these figures is the opposite performance of the algorithms, which drives to a trade-off between PLR of high and low service category. This behavior can be easily explained with the fact that the algorithm with the higher granularity has more possibilities to forward a packet in the further delays, while the other algorithm with the lower granularity cannot reach such positions. Therefore, the lowest granularity class packets experiment very bad performance because of the reason aforementioned, and that bears to an emptier network where higher granularity algorithm packets never get lost.

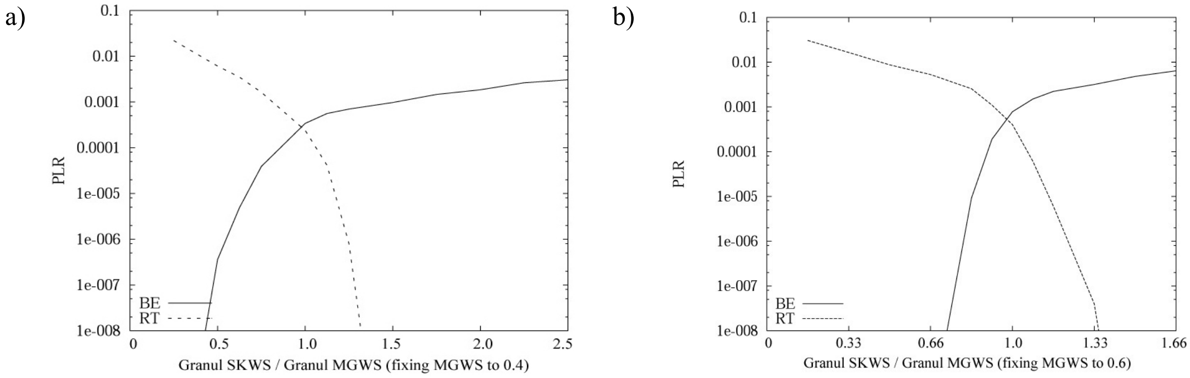

Figure 2. PLR as a function of the ratio between the granularity D of SKWS and MGWS, fixing a) D = 0.4 and b) D = 0.6 for MGWS.

To design the integrated FDL architecture, we have to select the granularity ratio achieving the desiderated performance and saving buffer requirements (i.e. there are common delays available for both categories). Interesting ratios are 1.5 and 2 as shown in Fig. 3*a* when two buffers of 8 delays are merged. For example selecting 2.0, we can set up two degenerate buffers: $\mathbf{Q}'$ with consecutive delays of D and length B' for the BE packets and $\mathbf{Q}''$ with consecutive delays of $2D$ and length B'' for RT packets. Then these buffers can be merged in a non degenerate buffer $\mathbf{Q} = \mathbf{Q}' \cup \mathbf{Q}''$, where the common delays are available for both service categories. Fig. 3*b* shows an example with $B' = B'' = 4$, and a resulting length $B = 6$ of buffer $\mathbf{Q}$ (instead of 8 if we had used two separated buffers).

a)

ratio	Num of FDLs
1	8
1.25	14
1.5	13
1.75	14
2	12

b)

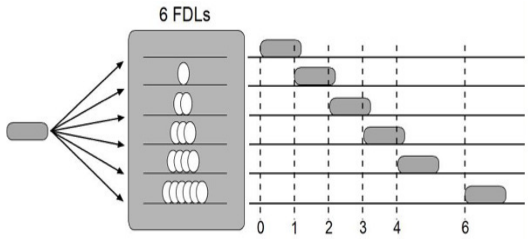

Figure 3. a) Number of required delays in the integrated buffer using different granularity ratio, b) Non-degenerate buffer configuration with 6 FDLs; BE packets can use delays {0,D,2D,3D}, while RT packets can use delays {0,2D,4D,6D}.

3.3 Simulation results

In this section we evaluate the performance of the EON network where each node uses an integrated buffer and the traffic consists of 50% of BE packets and 50% of RT packets.

Fig. 4 shows the PLR as a function of the normalized fiber granularity. In Fig. 4*a* the ratio is equal to 2 with a resulting length buffer of $B = 12$ delays while the ratio is 1.5 in Fig. 4*b* and the length is $B = 13$ (the original buffers have $B = 8$ delays). In the figures we include a secondary x-axis which indicates the granularity perceived by SKWS (2 and 1.5 times D in Fig. 4*a* and Fig. 4*b*, respectively). As expected, the performance of RT and BE categories are almost aligned and in particular RT obtains very low PLR.

Besides the PLR, we also consider other performance measures, which have been already proposed in [6]: the mean delay at the buffers (it does not include the propagation delay), the Forwarding Opacity (evaluated as the percentage of packets requiring a wavelength selection over the total number of packets), and the Out-of-sequence (OS) (evaluated as the percentage of packets delivered out-of-order at the destination over the total number of packets). Forwarding Opacity (FO) is an estimation of the overload of the node control function; in fact higher percentages indicate higher amount of times a node requires to move an LSP from one wavelength to another, which is the highest demanding task. Table 1 shows the results considering a ratio of 2 and $D = 0.3$. We highlight that required services are obtained: 1) the PLR isolation between RT and BE is five orders of magnitude, 2) RT packets obtain lower buffering delay than BE packets, 3) switching RT packets is more demanding than switching BE packets, and 4) RT packets are always delivered in correct order.

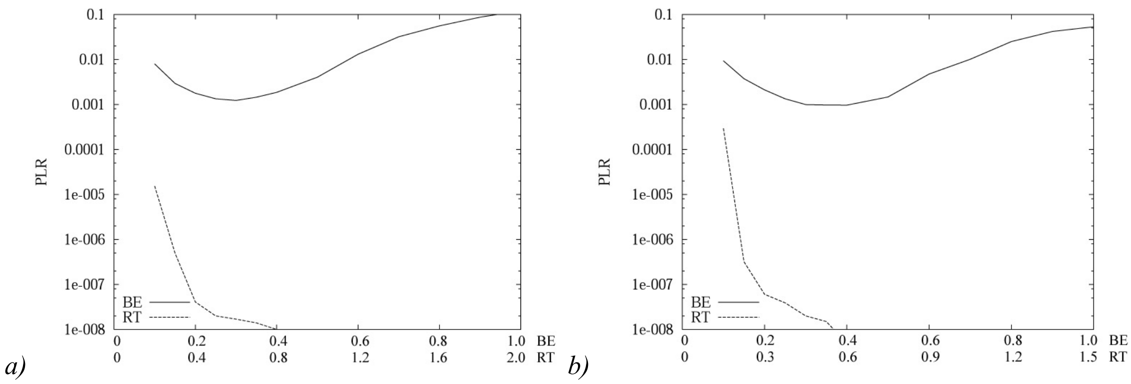

Figure 4. Packet Loss Rate packets as a function of the granularity by each category of traffic a) ratio equal to 2, and b) ratio equal to 1.5.

Table 1. PLR, delay, FO and OS with RT granularity equal to 0.6 and BE to 0.3 and an integrated buffer with B = 12.

	PLR	delay	F.O.	O.S
BE	$1.19\ 10^{-3}$	$2.23\mu s$	16.1%	4.4%
RT	$2.10\ 10^{-8}$	$1.41\mu s$	64.7%	0%

Table 2. PLR, delay, FO and OS with RT granularity equal to 0.6 and BE to 0.3 and an integrated buffer with B = 10.

	PLR	delay	F.O.	O.S
BE	$1.23\ 10^{-3}$	$2.20\mu s$	17.3%	4.1%
RT	$2.90\ 10^{-7}$	$1.20\mu s$	65.2%	0%

Once we have tested the network performance with this buffer configuration, we have tried to get similar results by using smaller buffers. We have reduced the number of FDLs assigned to the RT buffer (SKWS) to 6 (RT performance was so good that should not be a problem to reduce its buffer), which drives to an integrated buffer of $B = 10$ delays. Therefore we can compare the results obtained with the reduced buffer architecture (Table 2) with the ones obtained previously (Table 1).

4. CONCLUSIONS

In this paper we have considered an optical network integrating connection-oriented mechanisms and OPS technologies. In such a scenario we have applied the SCWS (Service Category-to-Wavelength Selection) technique to provide QoS. A case study with two different service categories has been carried out. The obtained results highlight that this technique, up to now only tested at node level also performs correctly in a whole network environment.

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