A Feedback-based Hybrid OBS/OCS Architecture with Fast-Over-Slow Capability

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Abstract—**Dynamic bandwidth allocation in response to the bandwidth requirements of new emerging applications is an essential demand for future optical networks. Hybrid switching architectures combining the benefits of different switching technologies in a single node are key elements to support wavelength and sub-wavelength granularities. This paper proposes a novel feedback-based hybrid OBS/OCS node architecture that integrates slow (ms regime) and fast (ns regime) switching elements, aiming at flexible bandwidth allocation while reducing the related costs. Such a node utilizes the pre-transmission idle periods of slow elements in order to send those contending fast bursts, thus improving the overall network performance. The obtained simulation results illustrate significant improvement in terms of Burst Loss Rate (BLR), and lower related network costs when compared to previously proposed hybrid OBS/OCS node architectures.**

I. INTRODUCTION

The traffic growth in the Internet is explosive nowadays. Furthermore, this noteworthy growth trend will continue in the foreseeable future. By some estimates, it is expected that the volume of data growth associated to consumer broadband services will grow 60% per year, as a result of the spread and development of the new generation of applications, such as video streaming and new class of Internet services, which couple scientific instruments, distributed data archives, sensors and computing resources via optical networks [1]. Each application has its own traffic profile, resource usage pattern and requirements. Meanwhile, technology evolutions such as all optical regeneration, wavelength conversion or dispersion compensation could drive the application bandwidth requirements beyond the current state [2]. At present, optical networks rely on different switching techniques, such as Optical Circuit Switching (OCS) and Optical Burst Switching (OBS).

In OCS schemes, network resources are dedicated to a demand between two end-points by reserving one or more full wavelengths for relatively long holding times [3]. In fact, OCS networks provide a very coarse bandwidth granularity. On the one hand, OCS networks allow an efficient and QoS compliant data transmission for long-lived flows via ms regime fabrics (e.g., MEMS). On the other hand, since high port-count OCS elements are available, scalability concerns are solved. However, they offer poor bandwidth usage and reduced adaptation to bursty data traffic patterns.

In contrast, OBS ([4], [5]) has recently arisen as a promising technology able to realize a statistical multiplexing directly in the optical domain, thus increasing bandwidth efficiency. In particular, OBS granularity lies between those of Optical Packet Switching (OPS) and OCS providing better adaptation than OCS to the transmission of on-demand small sets of traffic, and presenting more relaxed technological requirements than OPS. However, absolute QoS guarantees are still an important challenge in OBS networks. Furthermore, from the economical point of view, a pure OBS network needs a high number of expensive switching elements (e.g., SOA-based).

Compared to these pure switching solutions, hybrid optical networks provide a promising trade-off in long-haul networks in terms of cost, capacity and dynamicity using a unified platform in response to the requirements of those applications in higher layers [6]. As a matter of fact, hybrid optical nodes could support heterogeneous types of applications in both wavelength and sub-wavelength switching granularities. Such functionalities are provided by means of different switching schemes, such as OCS and OBS in one single node, aiming to utilize the advantages of different technologies while avoiding their disadvantages, which improves the overall performance of the network in a flexible and cost effective way [7]. The smooth traffic flows with high QoS requirements (hereafter slow traffic) are carried by end-to-end circuits (millisecond switching regime), whereas burst data traffic (hereafter fast traffic) is supported on OBS (nanosecond switching regime).

This paper proposes a novel and cost-effective hybrid OBS/OCS node architecture, aiming to improve the overall performance of the existent alternatives in the literature. To enhance the performance, Tunable Wavelength Converters (TWC) are used to avoid traffic losses in case of contention by transferring traffic over free resources in the idle period of switching elements. Next, the role of an algorithm for TWC assignment regarding to the nodal degree of node in a network is highlighted. Finally, the performance of the architecture on a reference network is investigated and the relative total cost of the network is evaluated.

The remaining of this paper is organized as follows. Section II reviews the existing hybrid node architectures. The alternative proposed feedback-based hybrid architecture is illustrated in section III. In addition, sub-section III.A concentrates on the fast over slow capability and sub-section III.B illustrates the algorithm for TWCs assignment. A performance evaluation of the proposed OBS/OCS node by simulations in a 16-node reference network scenario is presented in section IV. Finally, section V concludes the paper.

II. Hybrid Node Architectures

This section reviews the hybrid nodal architectures previously proposed in the literature. In order to support different traffic granularities, the concept of Multi Granular Optical Cross Connects (MG-OXC) has been proposed. In general, MG-OXC nodes are switching fabrics that integrate two or more switching technologies in a single node. Many efforts have been done to extend the switching granularity through the combination of different switching technologies [8], [9]. Even though multi granular switching has been obtained in such nodes, design complexity and cost are still important challenges.

The authors in [10] proposed a generic optical switch that supports wavelength and sub-wavelength granularities. Such an OBS/OCS node architecture consists of two separate slow and fast switching parts. Fig.1 presents this architecture, which is named parallel as both parts of node work independently. Regarding the requirements of upcoming demands, a scheduling algorithm at the edge nodes of the network is introduced, which maps the incoming traffic into the appropriate parts of the hybrid node. The improvements of the hybrid switch over a wide range of traffic and switching parameters are obtained through simulation results. The work presented in [11] can be considered as complementary to the previous study; there the authors highlighted how the wavelength and sub-wavelength granularities can be supported using millisecond and nanosecond switching regimes, respectively, in an experimental hybrid OBS/OCS node prototype. Furthermore, an investigation on the attributes of available slow and fast technologies was done. Given the high port-count optical switches as a mature technology under production, and also their related low cost, optical MEMS have been indicated as the slow switching technology. Conversely, many fast switching technologies are still in the research stage. Thus, there has been no other possible option than SOA-based switches. In summary, the design, analysis, and demonstration of a multi-granular optical cross-connect has been presented and the feasibility of this architecture on an application-aware multi-bit-rate end-to-end OBS test-bed has been shown.

There are two notable characteristics in this basic architecture. First, the slow and fast parts of the architecture are completely isolated and there is no possibility to send traffic from one part to another (parallel hybrid node). The second point is the well defined concept of wavelength modularity, that is, identical wavelengths from different input fibers are switched in non-blocking switching fabrics. Each node consists of N input and M output fibers with total number of λ_w wavelengths per fiber. Indeed, the total number of wavelengths per fiber includes all the slow (λ_s, those switched by the slow switches), and the fast (λ_f, those switched by the fast switches) ones. After the demultiplexers, there are λ_s slow and λ_f fast switching elements, which are labeled from λ_1 to λ_s in the slow part and from λ_{s+1} to λ_w in the fast part. The number of input and output ports in each switching element are equal to the number of input and output fibers of the node, respectively. Finally, wavelengths are multiplexed on the output fibers before leaving the node. As it was mentioned, slow switching elements are millisecond switching technologies (e.g., Optical MEMS), while the fast elements are nanosecond fabrics (e.g., SOA-based switches). Two-way reservation mechanisms can be used to reserve the resources over the OCS network, while typical one-way Just In Time (JIT)-based reservation schemes could be used to control the resources in the OBS part [4].

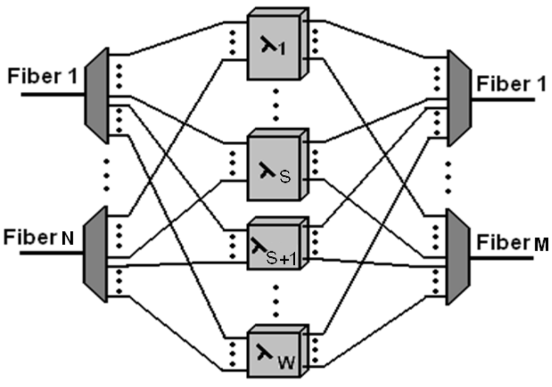

Fig. 1. Parallel hybrid OBS/OCS architecture

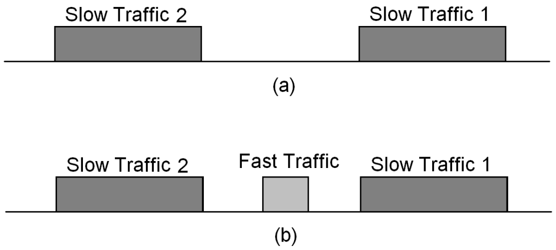

Fig. 2. (a) Consecutive slow traffic (b) fast over slow

The fundamental problem with the parallel hybrid OBS/OCS architecture is its poor bandwidth efficiency, especially under high traffic loads. In general, the switching resources of both parts are assigned to the traffic demands for the corresponding holding time. However, contentions can occur among bursts in one part of the switch (e.g. the fast one), while on the other part (e.g., the slow one) some idle resources might be found (idle period). As an example, Fig. 2.a represents the idle period of a slow resource between two transmissions of slow traffic demands. However, due to the lack of flexibility of the parallel architecture, there is no possibility to transfer contending traffic between any elements inside the parallel hybrid architecture. Hence, even if idle resources are available, there is no chance to use such resources to avoid traffic losses.

In order to improve the resource utilization, authors in [13] presented a Broadcast and Select (B&S) hybrid OBS/OCS architecture, as shown in Fig.3. Its realization requires equipping each of the N input fibers with λ_w full range TWCs. Looking

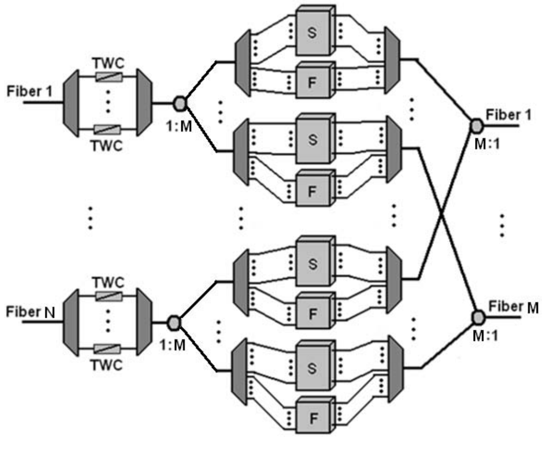

Fig. 3. Broadcast and select OBS/OCS hybrid architecture

at the literature, much work has undertaken the study of this kind of architectures ([14] and [12]). Assuming a $N \times M$ node, splitters divide each input signal into M equal parts. Note that amplifiers should be added at the input of each block to ensure the optical power level of the divided signals, which increases the cost of this structure compared to the parallel one. Next, similar to the former architecture, demultiplexed wavelengths are switched by individual devices. As illustrated in Fig. 3, each switching block of the B&S architecture consists of ON/OFF optical gate arrays. It is worth to mention that the B&S architecture is a high port-count architecture due to the splitting of the input signals into the number of outputs. Indeed, it is M times greater than the number of input ports in the parallel architecture which mentioned before.

In addition, in such nodes, TWCs are introduced at all wavelengths. Thus, each element at each block can be used by any traffic demand in that part, by configuring the devices on the fly in case of contention, thanks to the wavelength conversion capability at the inputs. Moreover, it is possible to use the configured slow switching elements during idle periods to transmit fast bursts. Assuming that the slow element will keep its state during the idle time after the transmission of a slow traffic demand, it is possible to transmit fast bursts with the same input port and directed to the same output port in case of contention. The concept of using a slow resource to transmit a fast traffic is referred as fast over slow in the rest of this work, and it is illustrated in Fig.2.b.

With the introduction of TWCs at each input of the node, the problem of bandwidth efficiency is solved. However, this architecture is not cost-effective due to the high port-count and the necessity for utilizing expensive devices, such as TWCs and amplifiers, at all input wavelengths. In addition, more energy consumption and worse signal to noise ratio is expected in this architecture, due to the existence of active devices. In this paper, we propose a more cost-effective hybrid OBS/OCS node describing a feedback-based architecture.The details of our proposal are described in the following section.

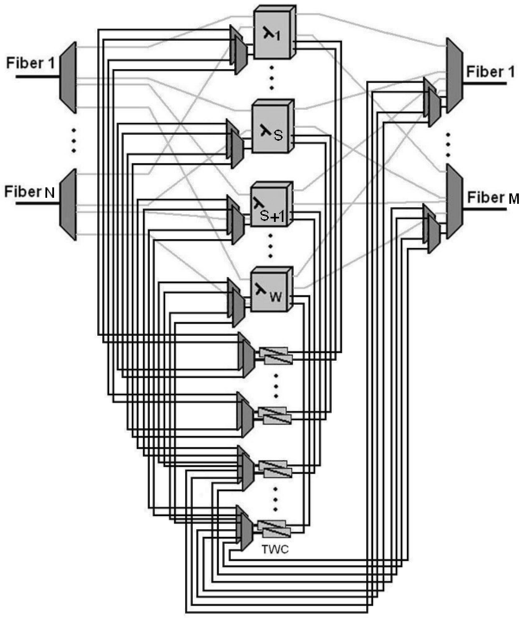

Fig. 4. Proposed feedback-based OBS/OCS hybrid architecture

III. FEEDBACK HYBRID OBS/OCS NODE ARCHITECTURE

In the design of the Feedback-based hybrid OBS/OCS (FB) node architecture, the main driver was cost reduction, while approaching the B&S architecture performance in terms of Burst Loss Rate (BLR). From the overview presented in the previous section, it is concluded that B&S based architectures are much more expensive than the parallel based architectures due to the high port-count and active devices required. As shown in Fig. 4, the fundamental structure of the FB architecture is similar to the parallel one. However, there are some additional ports in each switching element. These extra ports provide configurable routes to the conversion section of the architecture. In contrast to the B&S architecture, no TWC is placed per per input wavelength. In fact, to reduce the number of required TWCs, they are moved from the input to the feedback section. Thus, TWCs are shared between the same wavelengths arriving from different inputs. In this way, it is possible to reduce the related cost of the node while keeping the BLR in a reasonable level as will be demonstrated in next section. Furthermore, switching elements are non-blocking slow and fast fabrics as those used in the parallel architecture. Note, however, that there are some extra configurable routes to avoid burst drops. Hence, all free resources at one part are considered as a potential path to solve contention, due to the wavelength conversion capability at the feedback section. In addition, like to the B&S hybrid nodes, the slow resources could be used to perform fast over slow during their idle periods. However, this approach is quite different from the B&S one, as explained in the following subsection.

A. Fast over Slow Capability

As mentioned in section II, the fast over slow concept is referred to transferring some fast traffic over slow resources during its idle time. In order to provide this capability, in B&S hybrid architectures full range TWCs are inserted for all wavelengths in each input; otherwise, there is no possibility to deal with contention at the input without TWC. In the FB architecture, the conversion range of shared TWCs for slow wavelengths is λ_s-1, which is used to find a free resource in the slow part. Meanwhile, this range for fast part is λ_w-1, (i.e., (λ_f-1) is needed to find out a free resource at the fast part and the remaining are utilized to send fast traffic demands over slow idle resources). As shown in Fig. 4, resources are partitioned according to the number of outputs to make fast over slow connections. Therefore, the slow wavelengths could be used to transfer a traffic demand to a given destination. In fact, the reduced flexible number of TWCs due to their shared nature is the main advantage of the proposed FB architecture in front of the B&S one. This approach has a good potential to reduce the number of required TWCs significantly.

In case of contention, the first option for both types of traffic is to get a resource inside the corresponding part. For the fast traffic, if no available fast resource is found, an idle slow switching fabric, already configured to the desired output port, is searched. If there is a wavelength which is not in use for slow transmission, the TWC performs the wavelength conversion to the available wavelength and sends it to the appropriate slow switching element. In contrast to B&S architecture, there is no need to search for an already set-up connection in slow part to perform fast over slow. It is worth to mention that the resources in each part are dedicated to the offered traffic to that part. However, it is possible to have some collision between slow and fast over slow traffics. In such a case, pre-emption is applied for slow traffic to guarantee the resource availability. As a result, a requested slow resource carrying fast traffic will be released for the incoming slow traffic.

B. Algorithm for TWC Assignment

As mentioned in the previous section, wavelength partitioning related to the number of outputs is one of the important factors to perform fast over slow. For instance, assuming a node with M outputs and λ_s slow resources, there are λ_s/M slow resources dedicated to fast over slow to a given output port. If there are special QoS requirements for all the traffic departing from a specific output port, extra resources could be added.

Note that the slow switching fabrics in all intermediate B&S or FB nodes receive two different kinds of traffic. First, the slow traffic carried by the slow resources and, second, the fast traffic moved over slow wavelengths. The time gap between header and payload is not generally enough to configure the slow switching elements in latter kind of traffic. Hence, if a slow switching fabric is not already configured from the input to the desired output port, an incoming fast burst must be dropped. It shall be mentioned, though, that in the B&S architecture, the TWCs at the input ports to give the contenting burst the possibility to be moved again to any available resource in any part of the switch (even be moved again to the fast part of the switch). In contrast, in the FB nodes there is no direct access to the conversion section of architecture for the fast over slow bursts due to the required configuration time of slow fabrics and the place of TWCs at the architecture. However, to solve this it would be possible to find some already set connection at extra ports of slow fabrics to TWCs. In this case, the fast burst could be moved to any available resource in any part of the switch.

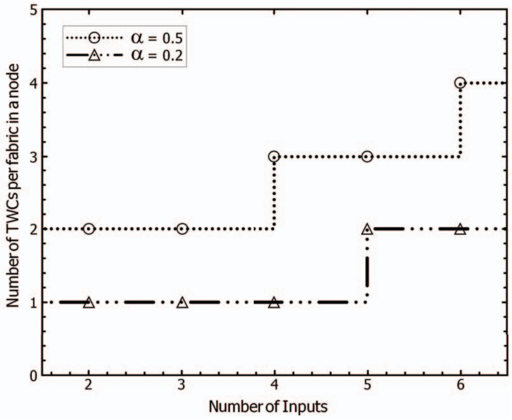

Fig. 5. Number of TWCs per fabric in a node for two given shared factors

Based on the discussion above, selecting the number of extra ports which are connected to the shared TWCs is an important issue. A node with higher offered load at a network needs more TWCs to solve contention efficiently, which means a greater sharing factor. The number of input links at a node is a good candidate to reflect the role of offered load in the equation. In fact, higher number of input links at a node generally means higher traffic offered to it. Considering $\alpha \leq 1$ as the sharing factor that shows how many inputs share a TWC at each element inside a node and N as the number of inputs, $f(\alpha, N)$ indicates the number of shared TWCs at each element inside the switch as follows:

$$f(\alpha, N) = \begin{cases} 1 & \text{if } \alpha = 0 \\ \lfloor \alpha \times N + 1 \rfloor & \text{if } 0 < \alpha < 1 \\ N & \text{if } \alpha = 1 \end{cases} \tag{1}$$

As seen in Eq.(1), if $\alpha = 1$ each switching fabric will have N TWCs. In contrast, the number of shared TWC at each fabric for $\alpha = 0$ is 1 to keep the feedback nature of architecture. Fig. 5 illustrates $f(\alpha, N)$ for two given shared factors as a function of number of input ports. For example, assuming a 3x3 FB node, with 10 wavelengths per incoming fiber, 2 TWCs would be equipped per switching element inside the node if a sharing factor equal to 0.5 would have been applied. This would finally result in 20 TWCs in the node.

IV. SIMULATION RESULTS

The performance of the proposed FB architecture has been evaluated through extensive discrete event simulation studies.

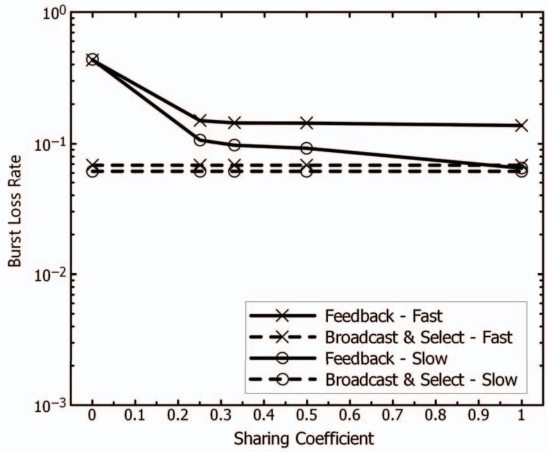

Fig. 6. Burst loss rate vs. sharing coefficient

To this goal, the EON core network composed of 16 nodes is used [15]. In addition, we assume 10 wavelength per fiber. Specifically, the burst loss rate performance and cost evaluation have been considered. The offered traffic is distributed at network uniformly, 70% of generated traffic is assumed to be slow traffic while the other 30% is fast traffic. 7 wavelengths per fiber are dedicated to slow traffic demands while the other 3 are used to carry fast traffic. The offset times between a control packet and the respective data are assumed to be controlled by source nodes, sufficiently provisioned to allow the configuration of appropriate switching fabric. The traffic generation implements a Poisson distribution with a varying average inter-arrival time to establish different loads. Data size follows an exponential distribution with average 5 ms for slow bursts and 250 μs for fast bursts. Un-weighted shortest path routing is used for finding routes in the network. In addition, a one way JIT-like reservation mechanism is used to support burst traffic in both parts. Pre-emption is applied for slow traffic. As a consequence, if a slow request arrives, the resource with fast traffic demand at slow part is unallocated and switch element configured for the upcoming slow demand. The confidence interval of 95% is applied at all runs.

The effect of the sharing factor on the BLR in the FB nodes is firstly investigated and compared to the BLR figures obtained by the B&S architecture. A fixed offered load of 0.5 Erlang per wavelength is used. The results for five different sharing coefficient values are shown in Fig. 6. Dash lines show the results of the network built of B&S nodes, which are quite equal due to the appropriate mapping of offered load and resources. By increasing the sharing factor, TWCs would be shared among fewer numbers of inputs. Therefore, the solid line will converge to the dash lines, which means total drops reduction. For α = 1, slow burst loss rate reaches the boundary of the B&S. Conversely, the fast burst loss rate is affected by the occupancy of slow resources in high loads. It is worth to mention that the BLR experienced by the slow traffic is always lower than in the case of the fast one. Indeed, this is related to the higher number of resources in the slow part, as any slow traffic burst has 6 possibilities to avoid a drop while this number is less than half in the fast part. In addition, the preemption guarantees the resource availability in the slow part, being the slow traffic insensible to the fast packets transmitted on slow resources. From now on, a α = 1/3 is chosen for the subsequent simulation studies, which makes a good trade-off between performance and cost in the proposed FB architecture.

In the next experiment, simulations are performed to evaluate the BLR in all architectures for different offered loads per wavelength using the α value previously selected. The slow and fast BLR figures are shown in Fig. 7 and 8, respectively. As illustrated in Fig.7, the BLR of the slow traffic in B&S and FB architectures is almost similar. Moreover, the BLR of the slow traffic when the FB architecture is used is reduced by almost one order of magnitude for low an medium loads compared to the parallel architecture. The same results for the fast traffic are depicted in Fig. 8. Indeed, the fast drop rate of parallel based-network is same as its slow curve. In addition, the BLR reduction for both FB and B&S architectures is quite similar to the previous results. However, this reduction is lower than the obtained one in the slow case. As mentioned, the return of fast traffic from a slow resource to the fast part of node in B&S is quite easy due to the place of TWCs, while it is almost impossible in the FB case. This effect leads to such a larger gap between curves.

Furthermore, we have evaluated the overall network cost depending on whether the B&S or the proposed FB architecture is deployed in the 16-node network under evaluation. Based on the sharing capability of the TWCs, the proposed FB architecture leads to lower overall costs with respect to the B&S architecture. In general, introducing TWCs in both architectures makes them more expensive than the parallel one. However, this additional cost drastically improves the QoS in the network. It is worth to mention that the port-count number and number of active elements are two other important parameters in cost increment. In contrast to the B&S, there is no need for signal amplification in the FB nodes which reduces the overall cost. Moreover, port-count number is lower in case of FB nodes. A parametric cost-benefit analysis for the B&S and FB nodes in the network under study shows a notable costs reduction using shared TWCs in the FB architecture, as shown in Fig.9. Such presented results are normalized to the total cost of the network provided that all nodes are B&S-like. As seen, the total network cost in terms of the required number of TWC is reduced by 50% when $\alpha = 1/3$ is applied. However, as obtained before in Figs. 7 and 8, BLR performance of network remain in a reasonable range. Furthermore, the proposed FB architecture allows a cost-effective node design by tuning the α parameter appropriately, so that the network QoS are meet at the lowest network cost. Indeed, such a cost-effective design is not allowed in the B&S architecture. Otherwise the B&S performance would be prevented in certain incoming wavelengths.

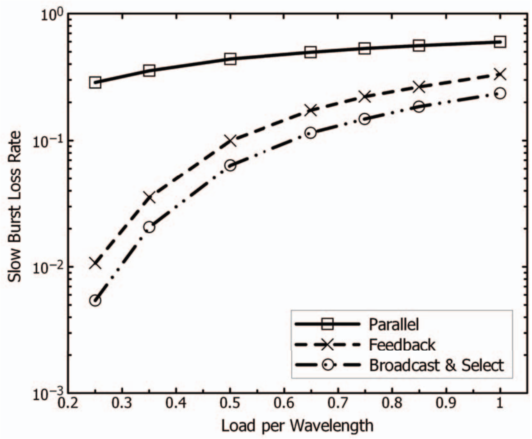

Fig. 7. Slow burst loss rate vs. load per wavelength

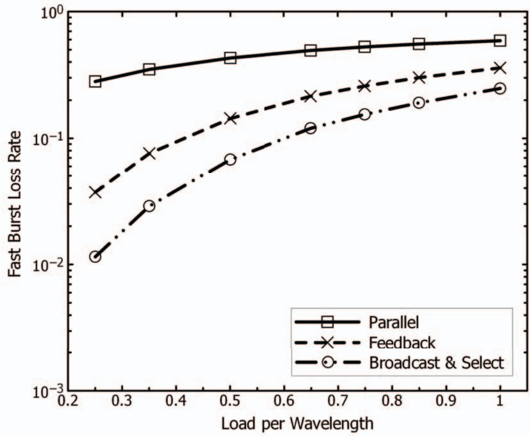

Fig. 8. Fast burst loss rate vs. load per wavelength

V. CONCLUSION

In this paper we presented a novel hybrid feedback-based OBS/OCS node architecture to support future all-optical transport networks in a cost effective way. Simulation results illustrated that the proposed feedback-based architecture outperforms the parallel architecture. Moreover, it provides similar BLR performance compared to the B&S architecture, while leading to a significant overall network cost reduction. In point of fact, as the FB architecture requires a lower number of active devices respect to the B&S architecture, it is expected to require lower energy consumption. Future work will be devoted to assess the energy consumption of the proposed FB architecture, comparing it to existent hybrid OBS/OCS node architectures such as the ones considered in this paper.

ACKNOWLEDGMENT

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 through the STRONGEST project under grant agreement n 247674. Moreover, the authors thank the support from the Spanish ministry through the project ENGINE (TEC2008-02634).

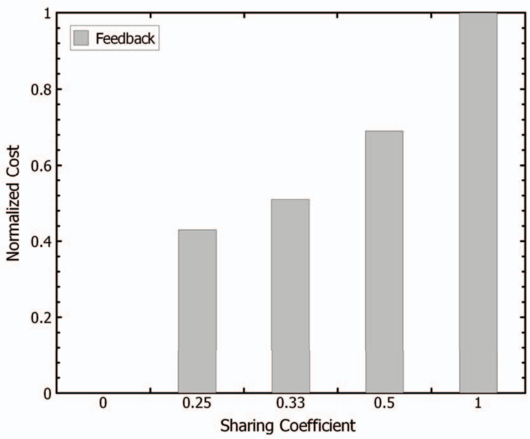

Fig. 9. Total cost of network

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