Translucent OBS network architectures with Dedicated and Shared wavelength converters

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Abstract—**The deployment of translucent optical networks is considered the most promising short term solution to decrease costs and energy consumption in optical backbone networks. Indeed, due to the technological maturity of translucent wavelength switched optical network (WSON) architectures, they have already caught close attention from the research community. Moreover, recent advances and enhancements in optical devices are now (re-)fostering research interest in sub-wavelength technologies like, among others, optical burst switching (OBS) and optical packet switching (OPS). Hence, in this paper, we evaluate and compare two novel node architectures for a translucent OBS (T-OBS) network. To be precise, we study nodes with both dedicated and shared wavelength converter resources (i.e., DWC and SWC). To this end, we consider the impact of the main physical layer impairments (PLIs) and make use of a routing and regenerator placement and dimensioning (RRPD) algorithm to minimize the number of optical-electrical-optical (O/E/O) regenerators deployed in the network whilst, at the same time, guaranteeing a target quality of transmission (QoT) network performance. The results presented prove the feasibility and the significant savings, in terms of the number of wavelength converters (WCs), that can be achieved by considering a network with shared wavelength converter resources.**

I. INTRODUCTION

Recent advances on main optical signal functions such as amplification, filtering and dispersion compensation are paving the way for the deployment of fully transparent optical transport networks (OTNs). However, such developments have also brought to light the severe impact that physical layer impairments (PLIs) have on the optical signal transmission. To avoid dealing with PLIs, research on OTNs has been mainly geared towards evaluating two particular network architectures, namely the opaque (i.e., using electrical 3R regeneration at each node) and transparent (i.e., optical 3R regeneration). Unfortunately, however, the high cost of optical-electrical-optical (O/E/O) devices on the one hand, and the lack of mature optical technology able to perform fully optical 3R regeneration on the other, prevent the deployment of these architectures. For this very reason, translucent OTNs have emerged as the ideal yet feasible candidate for bridging the gap between the opaque and transparent networks [1]. Indeed, due to the technological maturity of translucent Wavelength Switched Optical Networks (WSONs), they have recently received great attention from the research community [2]. However, the inflexibility and coarse granularity of WSONs motivates the development of sub-wavelength switching technology. Among the WDM solutions proposed, optical burst switching (OBS) has emerged as a competitive choice for the transport of highly dynamic data traffic in next-generation OTNs. For this reason, in [3], we presented a novel translucent OBS (T-OBS) network architecture in which core nodes switch incoming data bursts to their output ports either in an all-optical fashion or through O/E/O regenerators when signal regeneration is required. The T-OBS architecture proposed relies both on nodes having dedicated wavelength converters (DWC) (i.e., one WC per channel per input port) to reduce burst contention and on routing and regenerator placement and dimensioning (RRPD) strategies to perform a sparse placement of O/E/O regenerators. In [4], we extended this work to include a formulation of the RRPD problem which aims at minimizing the number of O/E/O regenerators required to meet a given target burst loss rate due to unacceptable optical signal levels. Consequently, the T-OBS network proposed provides an adequate trade-off between network construction cost (i.e., the number of O/E/O devices deployed is minimized) and service provisioning performance (i.e., proper end-to-end quality of transmission (QoT) must be ensured). To further improve this trade-off, in this paper, we evaluate a novel T-OBS network architecture built with nodes that have shared wavelength converter (SWC) resources. To demonstrate the feasibility of our proposal, we analyze and compare the impact of the main PLIs (i.e., amplified spontaneous emission (ASE) noise and splitting losses) on the T-OBS network considering both the DWC and SWC node architectures. Moreover, the performance of both T-OBS architectural variants is evaluated under the operation of an RRPD strategy through a series of simulation experiments. Results show that the SWC architecture is able to provide significant savings in the number of WCs at the cost of an affordable increase in O/E/O regenerators.

The remainder of this paper is organized as follows. In Section II, we briefly survey the previous work in translucent WSONs. In Section III, we give a complete description of both the DWC and SWC node architectures proposed. A power budget and noise analysis considering the optical signal to noise ratio (OSNR) as PLI constraint is presented in Section IV. In Section V, we evaluate and compare, by means of simulation, both T-OBS architectural variants considering several backbone network topologies. Finally, concluding remarks are made in Section VI.

II. RELATED WORK AND CONTRIBUTIONS

Due to the fact that WSONs rely on already mature technology, the study and evaluation of translucent WSONs

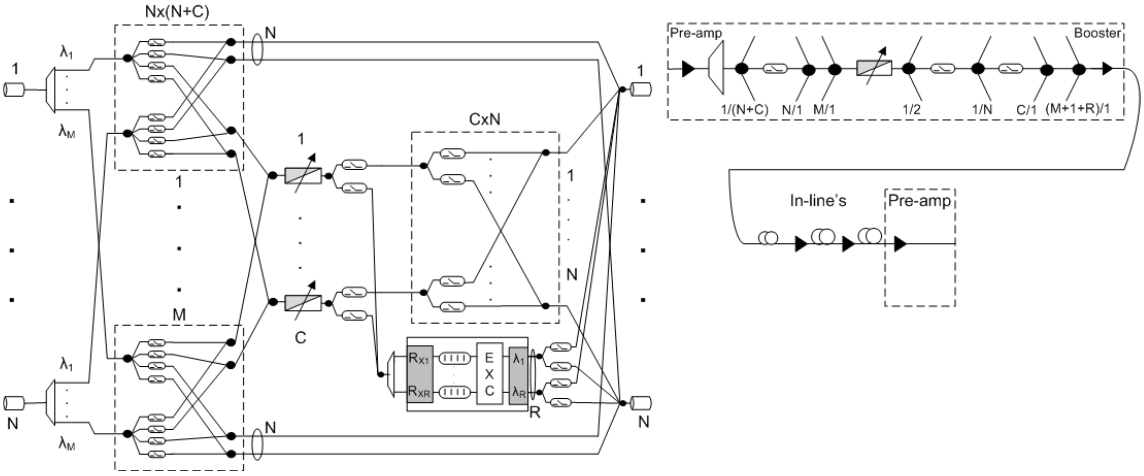

Fig. 1: T-OBS node architecture with SWC resources and signal path between two SPN T-OBS neighboring nodes.

have recently received increasing attention from the research community (e.g., [5], [6]). For a translucent optical network to work properly, a limited set of regenerators must be strategically deployed across the network for signal regeneration purposes [7]. This is a planning problem where a clear trade-off exists between network construction cost (i.e., O/E/O devices are expensive) and service provisioning performance (i.e., proper optical end-to-end QoT must be ensured). Therefore, both the routing and wavelength assignment (RWA) and the regenerator placement (RP) issues must be carefully engineered. However, both the RWA and the RP problems as well as their combination in the RRP problem are known to be $\mathcal{NP}$-complete [8], and hence, heuristic approaches are generally employed. For a recent compelling work on the joint RWA and regenerator allocation problem in translucent WSONs we refer the reader to [9] and also to its references. However, the inflexibility and coarse granularity of WSONs motivates the development of sub-wavelength switching technologies like OBS. In OBS, however, the majority of research has been mainly geared towards the opaque and transparent network scenarios. For this reason, in [3], we proposed a novel T-OBS network architecture which relies on nodes with DWC resources. Our aim in this paper is to further improve the cost-effectiveness of the T-OBS network architecture by evaluating the introduction of a node architecture with SWC resources. To this end, we evaluate the impact of the main PLIs on both architectures, and then, making use of an RRPD algorithm, compare the number of both O/E/O regenerators and WCs that both architectures require in order to ensure a proper QoT network performance.

III. T-OBS NODE ARCHITECTURES

A. Dedicated Wavelength Converters

DWC nodes are designed according to the well-known tune-and-select (TAS) architecture. TAS nodes rely on the promising semiconductor-optical-amplifier (SOA) technology for their basic switching modules, that is, high-speed optical switches and fixed-input/variable-output WCs. Besides, these nodes may also be equipped with a limited size pool of O/E/O regenerators according to the decision of an RRPD algorithm. These pools are strategically deployed across the network for signal regeneration purposes. For more details on this architecture and on the characteristic signal path between two TAS T-OBS core nodes we refer the reader to [3].

B. Shared Wavelength Converters

To model the T-OBS core node with SWC resources we consider the well-known shared-per-node (SPN) architecture [10]. Among all WC sharing schemes proposed in the literature, SPN represents the perfect sharing scheme in that it guarantees, for every incoming burst, a fair access to a shared pool of WCs. In Fig. 1, the T-OBS core node architecture with SWC resources is depicted together with the path that a signal follows between two SPN T-OBS neighboring nodes. The node consists of N input/output fibers carrying M wavelengths each; a pool of C perfectly shared variable-input/variable-output WCs and a limited number R of O/E/O regenerators. In a first switching stage, M space switching fabrics (each dedicated to a different channel) give access to the pool of WCs. At the output of each WC the signal is split into two branches in order to provide access either to the regenerator pool or to a second switching matrix which connects to the output ports of the node. Again, a fair access to the regenerator pool is guaranteed by this architecture.

IV. POWER BUDGET AND NOISE ANALYSIS

To quantify the optical signal degradation along an end-to-end optical path, in [3], we illustrated a model that captures the impact of the main PLIs on the optical signal transmission. This model makes use of the OSNR as the signal quality performance indicator to determine the contributions that both nodes and links on an optical end-to-end path have on the signal quality received at destination nodes [11]. Furthermore, in order to obtain the right node set-up, we perform a power budget and noise analysis considering performance parameter values obtained from datasheets of commercially available

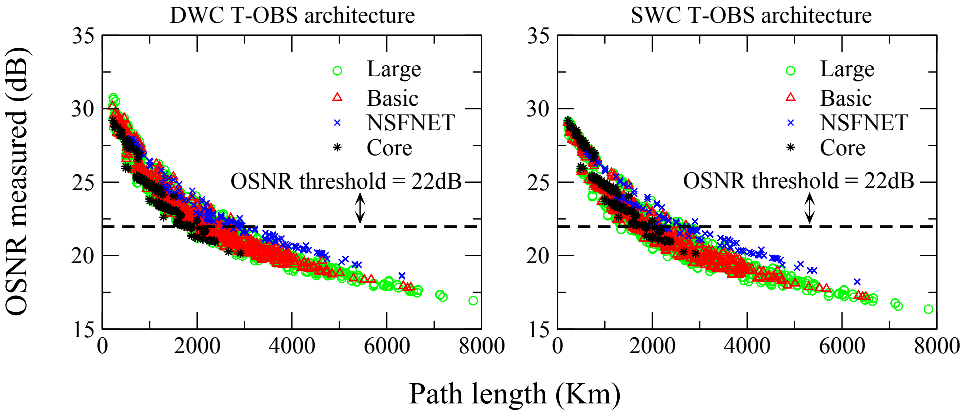

Fig. 2: OSNR evaluation considering the DWC and SWC T-OBS architectures.

devices (see e.g., [12]-[13]), or at most, lab trial devices [14]. To evaluate both the DWC and SWC architectures, the optical paths of four different topologies are considered: the Pan-European transport network in three different topology configurations, that is, Core, Basic and Large; and the NSFNET (US network) (for topology details readers are referred to [4] and to its references). We consider bidirectional links with 32 wavelengths each. Note that the OSNR level required for a transmission of $10Gbps$ per channel is $22dB$ [15]. The results provided in Fig. 2 show that, as expected, the SWC architecture has more paths not meeting the OSNR requirements (approximately 55% SWC vs. 43% DWC) owing to the differences in the components present in the signal path between two neighboring nodes.

V. PERFORMANCE EVALUATION

To analyze the performance of both architectures in terms of the overall burst loss probability (BLP), we consider the T-OBS network under the operation of our load-based RRPD algorithm which is based on mixed integer linear programming (MILP) formulations [4]. This algorithm is aimed at minimizing the number of O/E/O devices that are deployed in order to meet a given target loss rate (B^{QoT}) due to OSNR non-compliant bursts. The results considering DWC and SWC resources for the Core (load= 0.4, $B^{QoT} = 10^{-4}$) and Basic (load= 0.2, $B^{QoT} = 10^{-5}$) network topologies are provided, respectively, in Figs. 3 and 4. In the plots, the transparent (i.e., no O/E/O devices are available) and opaque (i.e., O/E/O at every WC is available [15]) cases are used as benchmark indicators (black and red curves, respectively). It is easy to observe that with the progressive and even deployment of regenerators in the network, the performance of the T-OBS network (green curve) reaches that of the opaque case: whilst OSNR-based losses are reduced (triangle markers), contention-based ones become predominant (circle markers). In the SWC case, the number of O/E/O devices increases due to the fact that a higher number of bursts in the network require regeneration at some point along their path. However, SWC achieves a significant reduction in the number of WCs (in the Basic network reduces WCs by 1046 units at the cost of deploying 83 more O/E/O regenerators (see Table I)). Note, however, that the BLP found when all regenerators required have been deployed slightly improves that of the opaque case. This is due to the differences in node architectures between the opaque and translucent networks: whilst the opaque network relies on in-line regenerators as in [15], our translucent architecture operates in the feed-back mode as shown in Fig. 1. It is also worth mentioning that the number C of WCs available at each node of the SWC network is tuned so that the performance of the translucent DWC case is met. Further results considering all the topologies are provided in Table I.

VI. CONCLUSIONS

We have presented a novel T-OBS network architecture with SWC resources and compared its performance with that of the network with DWCs. To this end, we have considered an OSNR model to capture the main PLIs and an RRPD algorithm both to perform a sparse placement of O/E/O regenerators and to ensure a proper QoT performance. The results obtained prove the viability of the SWC solution in terms of network performance and also show that SWC is able to provide significant savings in terms of the number of WCs required at the expense of a little increment in the number of O/E/O devices.

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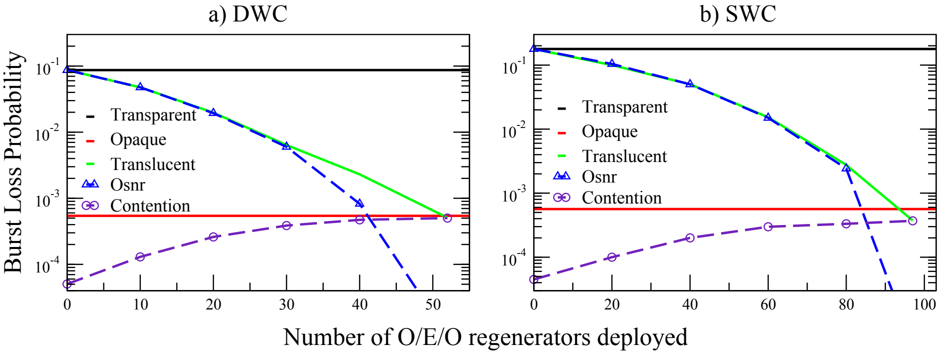

Fig. 3: T-OBS network performance under the DWC (a) and SWC (b) architectures in the Core network topology.

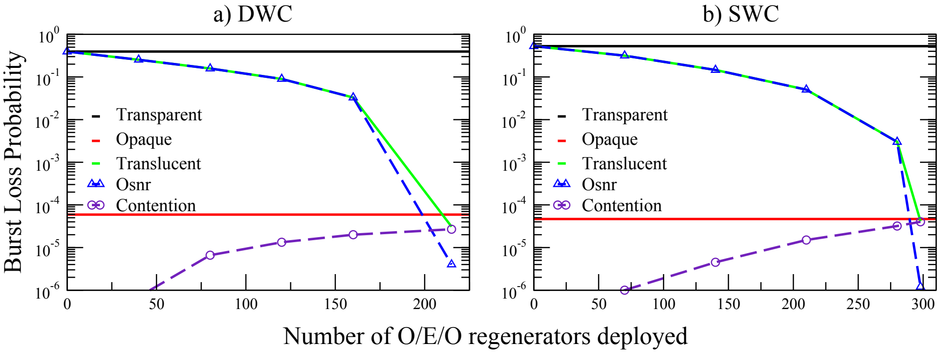

Fig. 4: T-OBS network performance under the DWC (a) and SWC (b) architectures in the Basic network topology.

Scenario			**# O/E/O**			**# WC**		
Network	Load	B^{QoT}	DWC	SWC	Diff.	DWC	SWC	Diff.
Core	0.4	10^{-4}	56	97	45	1472	954	-518
	0.8	10^{-2}	62	118	56	1472	1019	-453
Basic	0.2	10^{-5}	215	298	83	2624	1578	-1046
	0.4	10^{-2}	244	353	109	2624	1705	-919
Large	0.2	10^{-5}	367	471	104	3648	2085	-1563
	0.4	10^{-2}	428	573	145	3648	2460	-1188
Nsfnet	0.5	10^{-4}	215	292	77	1344	1016	-328
	0.6	10^{-3}	221	301	80	1344	1075	-269

TABLE I: Comparison of the hardware requirements of the DWC and SWC T-OBS architectures.

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