Cross-Layer Enabled Translucent Optical Network with Real-time Impairment Awareness

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***Abstract*—The existing dimensioning strategy for translucent, sub-wavelength switching architectures relies on over-provisioning, and consequently, overuse of costly, power-consuming optical-electrical-optical (O/E/O) regenerators. In addition, due to a variety of external phenomena, many physical layer impairments are time-varying, and hence, can strongly degrade network performance. In this work, we introduce a Cross-Layer Optical Network Element (CLONE) used for the dynamic management of physical layer impairments in the network. We investigate the impact of real-time impairment aware routing in a CLONE-enabled optical network with sub-wavelength switching. Simulation results show that the CLONE-enabled network architecture provides improvements in: (1) energy efficiency by optimizing the usage of regenerators, and (2) network performance in terms of the packet loss probability.**

I. Introduction

Ultra high-bandwidth, dense wavelength division multiplexing (DWDM)-powered optical transport networks (OTNs) are the prevailing communications infrastructure poised to support the delivery of emerging bandwidth-hungry applications and services such as video streaming/conferencing, high-definition TV, and video on demand, in a cost-effective, energy-efficient way. Moving forward, forecasts predicting traffic scenarios characterized by short-lived, small granularity flows, make it crucial for next-generation OTNs to engage highly agile optical transport technologies that include sub-wavelength switching [1]. By leveraging recent advances in nanosecond-range photonic devices such as fast tunable lasers and fast switching elements ([2], [3]), future OTNs supporting dynamic sub-wavelength switching can flexibly accommodate diverse traffic conditions with better efficiency [4].

At the same time, the rapid advances on relevant optical functions allowing for longer transmission distances, higher bit-rates, and more closely spaced wavelength channels, have dramatically increased the sensitivity to physical layer impairments (PLIs), which accumulate during the signal end-to-end transmission [5]. For this reason, translucent architectures have emerged as potential candidates to bridge the gap between the opaque and transparent networks, and therefore, to reduce costs and energy consumption in OTNs [6]. The existing dimensioning strategy for translucent architectures relies on the offline estimation of PLIs to strategically deploy a limited number of signal regenerators, which ensure that a target quality of transmission (QoT) network performance is met (see e.g., [7], [8]). However, such an approach results in both over-provisioning and overuse of regenerators due to inaccuracies in these estimations [9]. Furthermore, the lack of real-time access to physical layer performance metrics prevents the network from efficiently adapting to dynamically changing PLIs, and consequently, network performance can be adversely affected [5], [10]. Note that, in this paper, the term regenerator implicitly refers to electrical 3R regenerator, that is, the optical signal undergoes an optical-electrical-optical (O/E/O) conversion in order to be regenerated.

In this work, we show that the introduction of real-time impairment aware routing in a translucent, sub-wavelength switching network through the novel Cross-Layer Optical Network Element (CLONE) concept [11], leads not only to significant energy savings by optimizing the usage of regeneration resources, but also to network performance improvement as CLONE-enabled networks can effectively react to time-varying PLIs.

The remainder of this paper is structured as follows: Section II, provides a survey on recent work in PLI-aware OTNs and highlights the main contributions of this work. Section III, details the problem framework. Section IV, provides and discusses the simulation results. Finally, conclusions are given in Section V.

II. Related Work and Contributions

In order to meet a target QoT network performance, translucent architectures require a limited number of regenerators to be sparsely deployed across the network. This is done using a routing and regenerator placement (RRP) algorithm [7] in wavelength-routed networks, and a RRP and dimensioning (RRPD) algorithm [12] in sub-wavelength switching networks. Using a QoT estimator and a pre-specified minimum signal QoT performance (QoT_{th}), below which the signal is considered beyond the receiver's sensitivity, these algorithms can determine the impact that PLIs will have on the optical signal, and eventually, the feasibility of establishing a connection between two network points [13].

Such QoT models are based on two main methods, namely the numerical calculation of the optical signal to noise ratio (OSNR) [14], and the analytical or experimental evaluation of the Q-factor ([7], [15]); both these figure-of-merit have a direct relation to the signal bit-error-rate (BER) [16]. In this work, we assume the OSNR as the main signal QoT performance indicator, and hence, hereinafter we refer to QoT_{th} as OSNR_{th}.

The adverse effect that PLIs (e.g., amplified spontaneous emission noise (ASE), polarization dependent loss (PDL), chromatic dispersion (CD), polarization mode dispersion (PMD), cross-phase modulation (XPM), self-phase modulation (SPM) and four wave mixing (FWM)) have on DWDM systems due to fiber loss, dispersion and non-linearity, drives research to develop analytical models to accurately predict their impact [17]. However, these models are still not mature enough (in terms of both accuracy and computational efficiency), and hence, it is necessary to consider a penalty margin (m) (e.g., 2 dB extra) when determining an adequate OSNR_{th} [14]. Since a tight adjustment of m may cause a number of connections to be over-estimated (i.e., establishment of unfeasible connections), network operators wishing to guarantee stringent OSNR levels have to set higher m values; this in turn leads to a high number of under-estimations, and hence, to an over-provisioning of regenerators [9]. Under these circumstances, the lack of real-time feedback from the physical layer results in an overuse of costly, power-consuming regenerators. Moreover, a fixed penalty margin may still result in strong network performance degradation, as many PLIs are time-varying and can be affected by a wide range of higher-order time scale phenomena such as temperature variations, voltage drifts, component degradations and network maintenance activities [18], [19].

Therefore, in order to ensure efficient and robust operation in future dynamic OTNs, it is necessary to perform reliable and cost-effective optical performance monitoring (OPM), and, by this means, gain real-time access to the main physical layer parameters such as the OSNR and PMD [10]. In fact, this area has already received great attention in the context of wavelength-routed networks, where innovative proposals include, for example, real-time OPM coupled with path computation element (PCE)-based control planes (CP) to support dynamic management of either wavelength-switched optical networks (WSONs) [20] or the more recent elastic optical networks (EONs) [19].

However, no work as of yet has addressed the challenges of introducing real-time impairment awareness in a translucent, sub-wavelength switching scenario, which, due to its statistical multiplexing nature, requires dedicated OPM and CP solutions to optimize the use of the available (over-dimensioned) regenerators as well as to adapt to time-varying PLIs. To this end, in this paper we introduce the novel CLONE approach to support the dynamic management of PLIs. Assuming a pre-deployed translucent, sub-wavelength switching network, we perform a series of simulation experiments to compare the performance of the existing network approach (hereinafter referred to as STATIC network), where no real-time OPM is available, with that of a network of CLONEs using realistic time-varying PLI models. Through real-time access to OSNR measurements and a dynamic, distributed CP to efficiently disseminate this data, CLONEs optimize the use of regeneration devices, thus greatly improving energy efficiency. Moreover, we also show that the network of CLONES can dynamically adapt to time-varying PLIs and take decisions on-the-fly to re-route, drop or regenerate optical packet flows, resulting in improved network performance. Note that in this work we use the term *packet* generically to refer to the optical data unit of the sub-wavelength optical network (e.g., packets/bursts).

III. Problem framework

A. Notation

We use $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ to denote the graph of a sub-wavelength switching network; the set of nodes is denoted as $\mathcal{V}$, and the set of bidirectional links is denoted as $\mathcal{E}$. Let $f(s \rightarrow d)$, denote a packet flow between source s and destination d nodes, $s, d \in \mathcal{V}$. Adequately, let $\mathcal{V}_{x-d}$ denote the ordered set of nodes that define the path that $f(s \rightarrow d)$ has to follow from node x to d, $x, d \in \mathcal{V}$. Let also $\mathcal{R} \subseteq \mathcal{V}$ denote the subset of nodes that are equipped with a pool of regenerators. Finally, let $\mathcal{K}_{x-d}$ denote a set of pre-computed shortest-path routes from node x to d, $x \in \mathcal{V}_{s-d} \backslash \{d\}$.

B. RRPD and OSNR models

In [12], we presented several mixed integer linear programming (MILP)-based RRPD algorithms. To tackle RRPD, the routing and the regenerator placement and dimensioning (RPD) subproblems are solved sequentially so as to reduce complexity and improve network performance. Specifically, a source-based routing approach which minimizes congestion in bottleneck network links and a load-based RPD algorithm are used in this paper (see [12] for more details). To model the OSNR, we assume the method as described in [14] and [8]. To estimate the OSNR level for an optical path traversing k links (P_{osnr}), this model requires the OSNR contributions of both links (L_{osnr}) and nodes (N_{osnr}) on such path. Then, P_{osnr} can be computed as:

$$P_{osnr} = 1/(\sum_{i=1}^{k} \frac{1}{L_{osnr}^{i}} + \sum_{i=1}^{k} \frac{1}{N_{osnr}^{i}}), \tag{1}$$

Hence, once the routing problem is solved, all paths whose estimated P_{osnr} (in dB) is lower than OSNR_{th} are considered as input data for the RPD algorithm, as regeneration is required at some intermediate node. At this point, a translucent, sub-wavelength switching network can be dimensioned through the use of both the RRPD and OSNR models.

Regarding the OSNR model, it has been shown in [8] that a static value for both L_{osnr} and N_{osnr} can be estimated offline by performing an adequate system power budget and noise analysis. However, as mentioned in Section II, network operators have to add a penalty margin (m) on OSNR$_{th}$. Hence, the threshold is defined as OSNR$_{th}$ = OSNR$_{min}$ + m, where OSNR$_{min}$ represents the OSNR tolerance of the receiver and m accounts for OSNR penalties due to maximum tolerable PMD, residual CD, and all the other non-linearities. In addition, due to a range of higher order time-scale phenomena, both L_{osnr} and N_{osnr} are not static but time-varying contributions, making the penalty margin an even more critical parameter to deal with.

In this context, the lack of real-time OPM leads to a translucent infrastructure which is not able to dynamically adapt to changing PLI conditions even though it relies on an overuse of regeneration resources. As previously mentioned, we refer to this infrastructure as STATIC network.

To address these issues, we first propose to model both L_{osnr} and N_{osnr} as Gaussian random-variable functions. In the context of EONs, authors in [19] assume OSNR variations in a network link on the order of 1 dB every 30 seconds. Therefore, no abrupt/substantial changes in OSNR are expected at smaller time-scales (e.g., ms). For each node and link in the network, we denote such random function as $N(\mu[\text{dB}], \sigma[\text{dB}])$, where μ is the mean of the series and corresponds to the OSNR level estimated offline (link or node), and σ is a certain standard deviation. Under these conditions, we propose the CLONE concept to provide an efficient solution for the dynamic management of PLIs in the network.

In the next subsections, we first detail the main drawbacks of the STATIC network, and then, provide the features of the CLONE architecture.

C. The STATIC network

The RRPD algorithm disseminates both the routing and regeneration information to all network nodes so that they are able to determine, for each incoming flow of packets, the corresponding output port and whether such flow has to be regenerated. For instance, once RRPD determines that $f(s{\to}d)$ requires regeneration at some node $x \in \mathcal{V}_{s-d} \backslash \{s, d\}$, then $f(s{\to}d)$ will always be regenerated at x independently of the actual PLI conditions.

Therefore, due to the lack of real-time OSNR monitoring, the STATIC network approach exhibits the following operational issues:

- Packet flows which might not need regeneration as they have high OSNR (well above OSNR$_{th}$), are always regenerated in accordance to the RPD algorithm decision. Thus, they unnecessarily consume regeneration resources.
- Packet flows whose OSNR level has dropped below OSNR$_{th}$ cannot be detected, and therefore, continue their trip until the egress node consuming network resources. Note that these flows consume unnecessarily both regeneration (if RPD determined so) and capacity resources.
- Finally, since L_{osnr} and N_{osnr} are in fact time-varying functions, a certain route in the network can become unfeasible during any given time period. This issue cannot be detected either, leading to significant increases in packet loss.

D. The CLONE enabled network

The CLONE concept arises as a result of the ever growing traffic demand and rising challenges of controlling it, which dictate the need for the development of innovative architectures able to provide dynamic, intelligent interaction between network layers [21]. We envision the CLONE network model as a promising, integrated platform that leverages emerging physical layer technologies and systems to allow for introspective access to the optical layer. Hence, CLONE-enabled networks will facilitate the retrieval of real-time OPM measurements which can then be used to achieve greater energy efficiency and optimized network performance [22].

*1) **CLONE architecture**:* Figure 1, depicts a modular, generalized description of a CLONE. Featuring a bidirectional cross-layer signaling scheme between the data, OPM, and CP planes, the CLONE enables real-time physical layer measurements affect, for example, re-routing, dropping or regeneration decisions on a per packet flow basis. Furthermore, thanks to a distributed, high-speed field-programmable gate array (FPGA)-based optical CP, which allows CLONEs to communicate with each other, local OPM metrics can be efficiently disseminated across the network of CLONEs.

As to the OPM plane, we propose a dedicated OPM device per input port, embedded directly within the optical layer. OPM is performed over one of the channels carrying actual packet-rate data. Since future integrated OSNR monitors are expected to allow for ultra-fast measurements (e.g., hundreds of ns [11]), we envision OPM systems able to monitor ultra-fast, packet-rate channels. In fact, a proof-of-concept packet-rate OSNR monitor supporting 18 ms packet lengths has already been experimentally demonstrated [11]. Note that although in this work only OSNR is considered, we aim for OPM planes consisting of a set of sub-systems able to monitor a comprehensive range of PLIs such as OSNR, PMD and CD. In fact, PMD is also random and time-varying, and hence, PMD monitoring is crucial to manage highly reliable, ultra-high speed OTNs. For example, in [23], authors

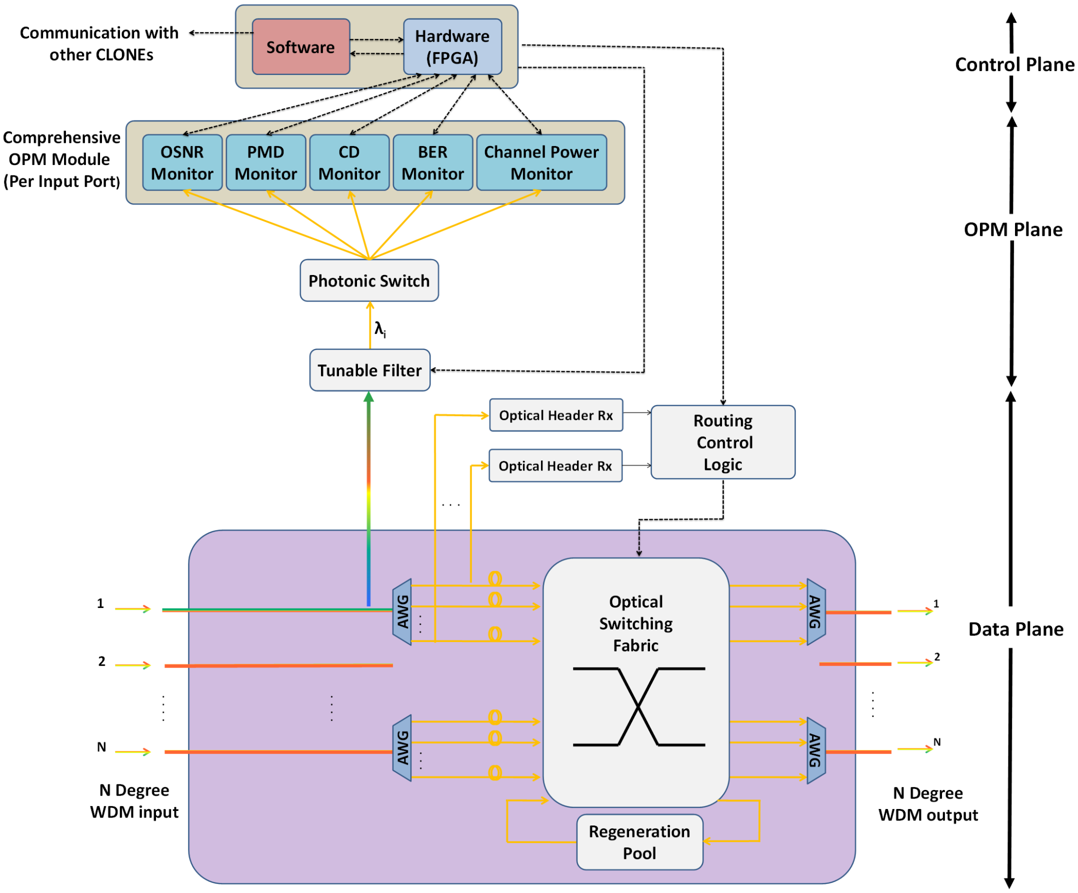

Fig. 1. Packet-switched CLONE: A system level description indicating the bidirectional information flow between the control, OPM and data planes.

experimentally investigate an OPM technique that extracts PMD-induced signal degradation from the sum including degradations induced by others (e.g., OSNR, CD and XPM) in high speed optical links.

Finally, at the data plane, we assume a translucent node architecture which is based on semiconductor optical amplifier technology and has a switching fabric configured as tune-and-select [8]. It must be noted, however, that regenerator pools are only available at selected CLONEs in the network, and that their location and size is determined by the RRPD algorithm.

*2) **Real-time impairment aware routing**:* This section details the real-time impairment aware routing algorithm that allows for the network of CLONEs to manage both regenerations and time-varying PLIs. The implemented algorithm relies on a distributed CP to efficiently disseminate the OSNR measurements, which allows it to compute the physical layer parameters L_{osnr} and N_{osnr}. Using the embedded OPM modules, these two attributes can be computed as explained in [14]. The algorithm is executed at source nodes $s \in \mathcal{V}$ and intermediate nodes $v \in \mathcal{R}$. Such nodes do not operate with full network information (i.e., each CLONE does not need to be aware of L_{osnr} and N_{osnr} for all nodes and links in the network) but they are restricted to the transparent region they belong to and the physical layer parameters of nodes and links therein. Specifically, CLONEs take forwarding/dropping decisions based on whether $f(s{\rightarrow}d)$ can reach the next regeneration node (or d) in its path. However, since packet flows may traverse a transparent region without undergoing regeneration, communication between nodes $v \in \mathcal{R}$, which delimit transparent regions, is needed to flood the OSNR history of each $f(s{\rightarrow}d)$. To this end, we use the term $OSNR_{s-d,i}$ to denote the OSNR value of $f(s{\rightarrow}d)$ at the last regeneration node or source i (i.e., i can either be s or a node $v \in \mathcal{R} : \mathcal{V}_{s-d} \ni v$). For example, in Fig. 2, $f(26{\rightarrow}6)$ following path $\mathcal{V}_{26-6} = \{26, 15, 25, 5, 6\}$, might not need regeneration at node 25, and hence, node 25 has to send $OSNR_{26-6,25}$ to node 5 so that node 5 can determine whether the flow can eventually reach 6.

As illustrated in Procedure 1, once the algorithm is executed at node $x \in \mathcal{V}_{s-d}$, it first computes the OSNR for $f(s{\rightarrow}d)$ at the next node in the path that is either a regeneration node or d (lines 1-2). Then, computes the OSNR level at such node and decides whether $f(s{\rightarrow}d)$ can be forwarded with or without regeneration. It is worth noticing that thanks to real-

Procedure 1 Real-time impairment aware routing algorithm

INPUT: Current node x, $f(s{\rightarrow}d)$, $OSNR_{s-d,i}$, $\mathcal{V}_{x-d}$
OUTPUT: Forwarding or dropping decision

$v^* \leftarrow$ next node $v \in \mathcal{V}_{x-d} : \{v \in \mathcal{R} \mid\mid v = d\}$;
$OSNR_{v^*} \leftarrow$ compute OSNR at v^*;
if $OSNR_{v^*} >$ OSNR$_{min}$ without regeneration **then**
  Forward $f(s{\rightarrow}d)$ and exit; /* Exit the algorithm */
else if $OSNR_{v^*} >$ OSNR$_{min}$ with regeneration **then**
  Regenerate and Forward $f(s{\rightarrow}d)$ and exit;
else
  for all route $k \in \mathcal{K}_{x-d}$ **do**
    Re-route $f(s \rightarrow d)$ through k and generate $\mathcal{V}^k_{x-d}$;
    $v^* \leftarrow$ next node $v \in \mathcal{V}^k_{x-d} : \{v \in \mathcal{R} || v = d\}$;
    Re-compute $OSNR_{v^*}$;
    if $OSNR_{v^*} >$ OSNR$_{min}$ without regeneration **then**
      Forward $f(s{\rightarrow}d)$ and exit;
    else if $OSNR_{v^*} >$ OSNR$_{min}$ with regeneration **then**
      Regenerate and Forward $f(s{\rightarrow}d)$ and exit;
    else
      Continue;
    end if
  end for
  Drop $f(s{\rightarrow}d)$;
end if

time impairment awareness the threshold for decision becomes OSNR$_{min}$. In case $f(s{\rightarrow}d)$ cannot be forwarded, a set of k shortest-paths from node x to d are evaluated. If all attempts fail, $f(s{\rightarrow}d)$ is temporarily dropped at node x. Note that in Procedure 1, if node $x = s$ and $x \in \mathcal{R}$, a regeneration will never be performed as the OSNR level is already at its maximum.

IV. Results and discussion

A. Simulation scenario

Simulations are performed considering a large-scale Pan-European backbone network topology known as Basic (shown in Fig. 2). We assume that network links are bidirectional each dimensioned with 32 wavelengths; the transmission bit-rate is set to 10 Gbps; the traffic is uniformly distributed between nodes; each node offers the same amount of traffic to the network; this offered traffic is normalized to the transmission bit-rate and expressed in Erlangs. Arrivals follow a Poisson process with a fixed packet size of 1 Mb (100 μs). Since we consider Poisson arrivals and a constant load, changing the packet size would imply either reducing or increasing inter-arrival times, and hence, the packet size does not have any impact on the packet loss probability (PLP) results obtained [24]. We consider 19 dB to be the OSNR receiver sensitivity (OSNR$_{min}$) and a penalty $m = 2$ dB, thus OSNR$_{th} = 21$ dB. RRPD dimensions the translucent network considering a network load of 10.72 Erlangs, and a target loss rate in the access to regenerator resources equal to B$^{QoT} = 10^{-3}$. As shown in Fig 2, such dimensioning results in a sparse placement of 456 signal regenerators. CLONE nodes $v \in \mathcal{R}$ monitor load at regenerator pools' access and can solve contentions at output ports using regeneration as long as target B$^{QoT} = 10^{-3}$ is met. A set of $|\mathcal{K}_{s-d}| = 3$ shortest-path routes $\forall\ s, d \in \mathcal{V}$ is pre-computed offline and available at each CLONE for re-routing purposes. Simulations are conducted on the JAVOBS sub-wavelength switching simulator [25].

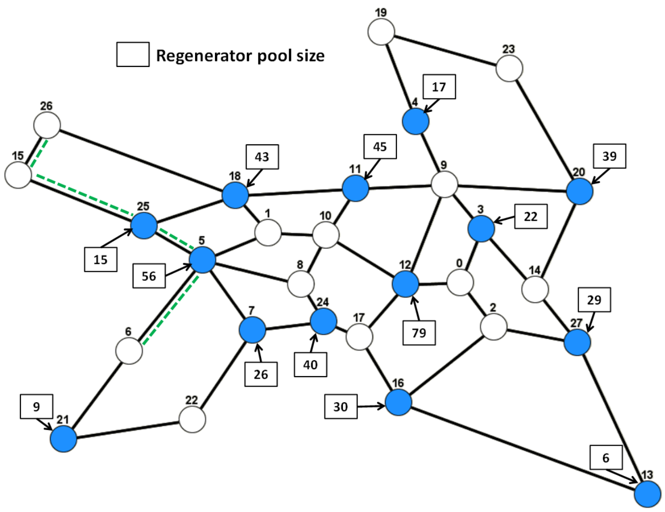

Fig. 2. Pan-European Basic topology with 28 nodes and 41 links [12]. Regenerator pools are sparsely deployed (blue nodes) and dimensioned according to the RRPD algorithm employed.

B. OSNR scenarios

We consider two different scenarios for σ:

- Scenario 1 ($Sc1$): σ is set to 0.8 dB. In this case, we have corroborated that no unexpected losses due to PLI impact occur in the network (i.e., margin m mitigates perfectly PLI impact). The objective of $Sc1$ is to exhibit the high energy-savings in terms of regenerator usage that can be achieved with the CLONE approach.
- Scenario 2 ($Sc2$): σ varies over time, and randomly can take either a very high/high value (1.8 dB, 1.4 dB), a medium value (1.1 dB) or remain the same (0.8 dB) with probability 0.1, 0.1, 0.3 and 0.5 respectively. The goal of $Sc2$ is to generate PLI situations which cause some routes to become unfeasible for a certain amount of time, and thus, force CLONEs to react and re-route packet flows temporarily.

We assume that every 2 seconds a new OSNR value is generated. However, in order to avoid abrupt variations and smooth the curve of the series, 20 points are interpolated between two consecutive Gaussian values. Hence, we assume that OPM modules report to the CP an OSNR measurement every 100 ms. Figure 3, shows two randomly selected L_{osnr} and N_{osnr} from the Basic topology under the two OSNR scenarios proposed. Although variations considering a large

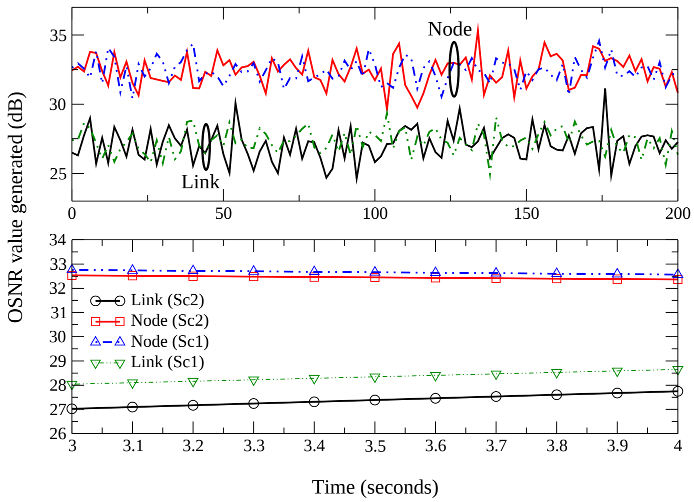

Fig. 3. OSNR randomly-generated series for both a link and a node in the Basic topology. Values over 200 seconds (top) and 1 second (bottom) highlight that no abrupt changes in OSNR are expected at the system sampling time-scale (i.e., 100 ms).

time window (200 seconds on the top) exhibit substantial variations in the OSNR contributions, a close view to the time-scale of the CLONE system (1 second on the bottom) shows that no abrupt changes are expected at the system monitoring time-scale (i.e., 100 ms). Besides, flow forwarding/dropping decisions are taken between regeneration nodes, and hence, the largest propagation delay through the CP equals that of the largest transparent segment in the network. For the network topology considered, the worst-case delay is on the order of 7 ms. Taking this value into account as well as the smooth OSNR curve exhibited by both links and nodes at the ms time-scale allows us to assume that CLONEs take their decisions based on updated OSNR measurements.

C. Results

In Figs. 4(a) and 4(b), the total PLP represents the sum of losses due to contention in network links and OSNR losses, which account for packets being lost at regenerator pools' access, packets that are dropped due to low ONSR (CLONE network) as well as packets whose OSNR at the destination node is beyond the receiver's sensitivity (STATIC network). In Fig. 4(a), it is possible to observe that under OSNR $Sc1$ the overall PLP (left y axis) is the same in both networks. This is because in this network scenario OSNR losses are negligible with respect to the contention ones, and hence, do not have a noticeable impact on the total PLP. However, Fig. 4(a), also exhibits the great optimization of regenerator resources that is achieved with the CLONE approach. Around two orders of magnitude difference in losses caused by contention at regenerator pools are achieved, which means that the CLONE network, using real-time impairment aware routing, only regenerates those flows that really need it. As a result of this efficient usage of regeneration resources, the CLONE network is able to provide, regardless of the load, a reduction of more than 60% in the average per packet number of regenerations (ppr) (right y axis).

On the other hand, in Fig. 4(b) ($Sc2$), where unexpected losses due to PLI can occur, we observe that in lightly loaded scenarios PLI-induced losses become significant, and as a result, there exists a strong degradation in terms of the overall PLP for the STATIC approach. The CLONE network, in contrast, is aware of such dynamic, time-varying PLIs, and is able to take decisions on-the-fly to either re-route or simply drop packets flows and, up to some extent, improve network performance. Note that this occurs within the typical operation range of sub-wavelength switching networks, that is, for overall PLP values of 10^{-3} and lower. Besides, the optimized management of regenerator resources is maintained as in Fig. 4(a).

Finally, in Figures 5(a) and 5(b), we show the amount of regenerators that can be turned off (i.e., that are not used) during network operation under both the STATIC and CLONE approaches. Due to the reduction of the traffic load sent to regenerator pools, the CLONE network can provide substantial energy savings as allows for a notable number of regeneration devices to be turned off during network operation.

V. Conclusions and Future Work

We show that a network of CLONEs can achieve both greater energy efficiency and dynamic adaptation to time-varying PLIs. We propose real-time impairment aware routing to minimize regenerator usage and to improve PLP due to the impact of time-varying PLIs. The performance of the CLONE network is compared against the STATIC approach which relies on offline estimations of the PLI impact. Our next goal is to extend the CLONE network model to a test-bed and experimentally validate the simulation results.

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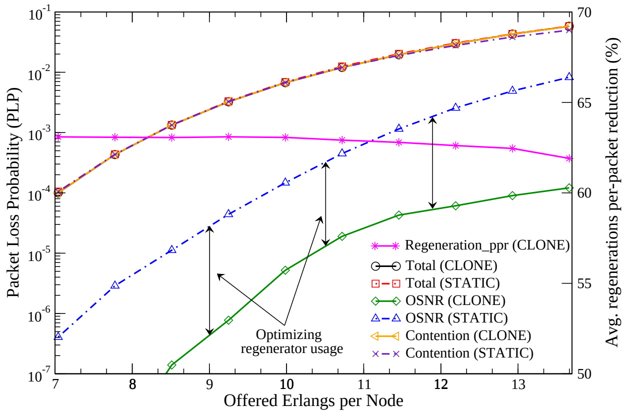
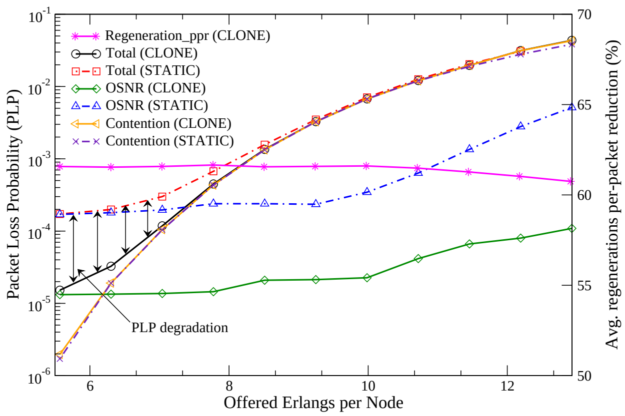
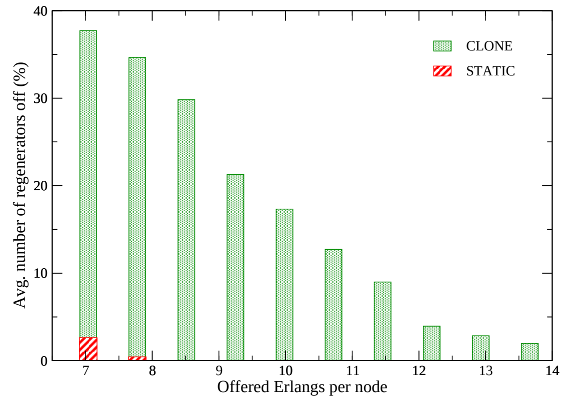


(a)

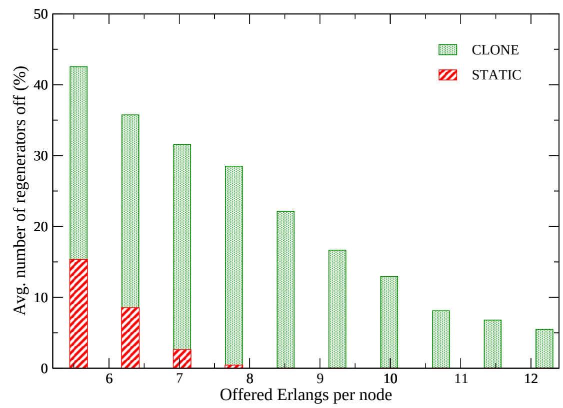


(b)

Fig. 4. Packet loss probability (left y axis) and average regenerations per-packet reduction (ppr) (right y axis) as a function of the offered load in the Basic topology for both the CLONE and STATIC networks under a) $Sc1$, and b) $Sc2$.



(a)



(b)

Fig. 5. Percentage of regeneration devices turned off during network operation as a function of the offered load in the Basic topology for both the CLONE and STATIC networks under a) $Sc1$, and b) $Sc2$.

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