Optical Amplified Line Self-Healing Using GNPy as a Service by the SDN Control

Original
Optical Amplified Line Self-Healing Using GNPy as a Service by the SDN Control / Ambrosone, Renato; D'Amico, Andrea; D'Ingillo, Rocco; Virgillito, Emanuele; Straullu, Stefano; Aquilino, Francesco; Curri, Vittorio. - ELETTRONICO. - (2024), pp. 1-4. (Intervento presentato al convegno 24th International Conference on Transparent Optical Networks (ICTON) tenutosi a Bari (Italy) nel 14-18 July 2024) [10.1109/icton62926.2024.10647520].

Availability:
This version is available at: 11583/2992157 since: 2024-09-03T13:00:56Z

Publisher:
IEEE

Published
DOI:10.1109/icton62926.2024.10647520

Optical Amplified Line Self-Healing Using GNPy as a Service by the SDN Control

Renato Ambrosone[1], Andrea D'Amico[2], Rocco D'Ingillo[1], Emanuele Virgillito[1], Stefano Straullu[3], Francesco Aquilino[3], Vittorio Curri[1]

[1]DET, Politecnico di Torino, Torino, Italy, renato.ambrosone@polito.it
[2]NEC Labs America, Princeton, USA.
[3]LINKS Foundation, Torino, Italy

Abstract: A control architecture for a partially disaggregated optical network is proposed using a GNPy-based digital twin for QoT estimation. The proposed implementation enables soft failure mitigation by autonomously adjusting the amplifier working points.

1. Introduction

The use of software defined networking (SDN) has been crucial to address increasing network traffic demands that significantly affect the physical layer (PHY) in the last decade. The consistent rise in connectivity requests, both from end-users and advanced applications, has posed significant challenges to the capacity and flexibility of traditional networks. Network operators are progressively recognizing the importance of the disaggregation of network elements, and are embracing multi-vendor solutions. Disaggregation allows the decoupling of hardware and software components, enabling network operators to select optimal solutions tailored for their specific requirements. Consequently, the adoption of a multi-vendor approach has emphasized the need for common data structures. By establishing shared data formats, network operators ensure that different vendors' hardware and software components can comprehend and process information uniformly. As a result, the network ecosystem becomes more adaptable, agile, and resilient, capable of accommodating diverse technologies and vendor solutions. Thus, many network operators have joined together in founding consortia to define common specifications (e.g. OpenConfig [2, 5], Open ROADM [3, 5]). Beside the advantages afforded to network control, the SDN approach enable real-time streaming telemetry from network devices [1]. This has made the presence of an optical network digital-twin (DT) possible, whose advantages have been widely discussed [6, 7].

In this paper, we demonstrate the potential of a DT implementation in a partially disaggregated network scenario [10], using the open-source GNPy library by the Telecom Infra Project (TIP) [4] as a digital model service. In the scope of an optical line system (OLS), the DT approach is established setting up an optical line controller (OLC), which is in charge of data collection and control [7], having direct access to OLS telemetry and settings along with the capability to send request to an as-a-service instance of GNPy; all the communications are implemented through representational state transfer (REST) interfaces. GNPy has already proven to be a powerful Quality-of-Transmission Estimator (QoT-E) [9]. In this work the OLC first uses GNPy functionalities to compute the optimal OLS working points (WP)s to be set in normal conditions. Then, a soft failure scenario is simulated by introducing arbitrary losses

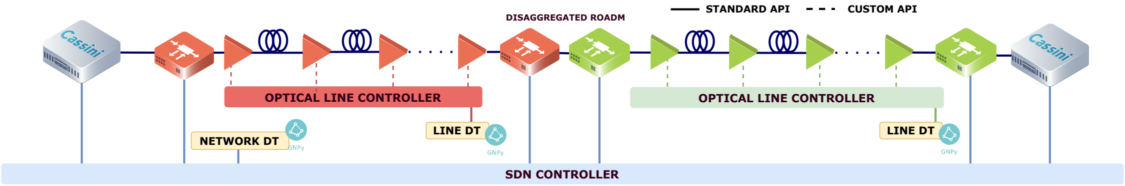


Fig. 1: Disaggregated optical network architecture with multi-vendor OLSs is described. Each OLS is controlled by an OLC with proprietary interfaces, instead, the ROADMs switching matrix and the transponder are handled by an SDN controller via standard interfaces ensuring compatibility between different vendor lines. In this scenario, each OLC can rely on a Line DT to properly retrieve the best parameters for the NEs in the line. The SDN controller exploits the network DT to properly select the transponders parameter and the lightpath.

979-8-3503-7732-3/24/$31.00 ©2024 IEEE

at the input of three fiber spans. This, will be mitigated exploiting the proposed control structure.

Both the SDN controller and the OLC detect the anomaly conditions and the OLC inquires again the GNPy instance for evaluating the new optimal WPs for a fast and automatized recovery.

2. Partially Disaggregated Control Architecture

Fig. 1 describes the proposed partially disaggregated architecture [11] in a multi-vendor framework. An OLS is defined as a series of fiber spans interconnected by in-line amplifiers (ILA)s. An optical multiplexer (MUX) is followed by a booster amplifier (BST) at the OLS input terminal, while an optical demultiplexer (DMX) is preceded by a preamplifier (PRE) at the OLS output terminal. In the scope of this study, the reconfigurable optical add-drop multiplexers (ROADMs) are assumed to be disaggregated: each switching degree may be from a different vendor, with the single-vendor restriction enforced only on the degrees at the specific OLS terminals.

The entire OLS is controlled by a single OLC that usually is a closed-vendor software implementation. Additionally, the amplifiers and the single degree switch are also handled by the OLC, including the WPs of the amplifiers and the MUX and DMX adjustable per-channel attenuations. Notably, the ROADM switching is out of the OLC scope, being handled by the centralized SDN controller. In Fig 1, each OLC interacts with a logical instance of GNPy, which can be implemented alongside the local controller, or externally, enabling the “QoT-E as a service” scenario that is capable of managing different lines.

The SDN controller provides a centralized view of the entire optical network gathering information from OLCs and uses this comprehensive awareness to make decisions about routing, modulation format feasibility, traffic engineering, and resource allocation when a traffic request arrives from an upper layer.

3. Experimental Setup and Software implementation

In this work, the optical testbed depicted in Fig.2 serves as PHY system. The amplified line consists of 10 commercial erbium-doped fiber amplifiers (EDFAs), (8 ILAs, 1 BST, and 1 PRE) interconnected with 9 spans of standard single mode fiber (SSMF) that have nominal lengths of 100 km. At the BST input, a C-band wavelength division multiplexing (WDM) comb is generated, consisting of 96 channels spaced 50 GHz apart, each modulated at a rate of 32 GBd. A commercial waveshaper filter is programmed to shape the output of an amplified spontaneous emission (ASE) noise source, producing 92 channels. The 4 channels under test (CUTs) are modulated by 4 commercial TRX CFP2-ACO/DCO coherent pluggables from Lumentum, plugged into two Cassini AS7716-24SC boxes provided by Edgecore, and added to the WDM comb through the MUX section of a commercial wavelength selective switch (WSS). The Cassini whitebox utilizes the OcNOS operating system developed by IP Infusion, that offers configuration and monitoring capabilities through NETCONF interfaces. At the end of the OLS, the 4 CUTs are dropped by the DMX section of a commercial WSS and provided to the receiver side of coherent modules. Both MUX and DMX sections are equipped with an optical channel monitoring system (OCM) as shown in Fig. 2. Bearing in mind the partially disaggregated approach, the OLC can be integrated within the software control architecture. Specifically, the OLC interacts with amplifiers through vendor-proprietary interfaces, which allow the operating values to be read

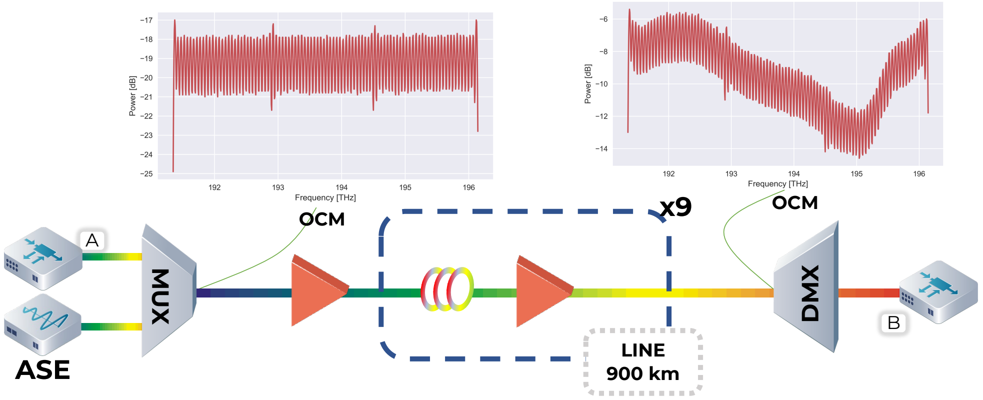
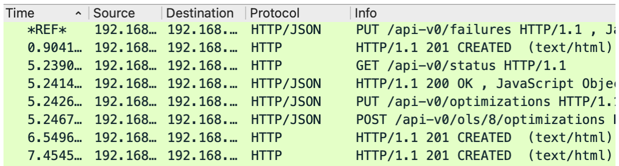
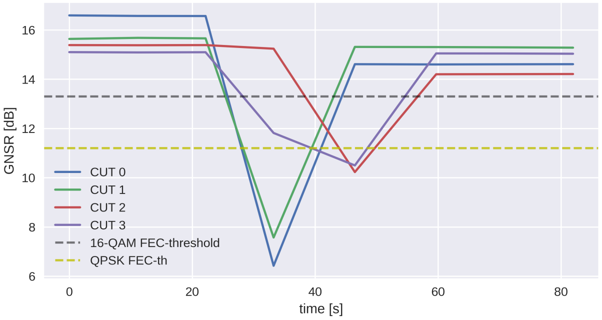


Fig. 2: OLS build in laboratory. This laboratory setup replicates a single-vendor OLS which is controlled using proprietary interfaces.



```
Time      ^ Source     Destination  Protocol    Info
   *REF*    192.168…   192.168.…    HTTP/JSON   PUT /api-v0/failures HTTP/1.1 , Ja
   0.9041…  192.168…   192.168.…    HTTP        HTTP/1.1 201 CREATED  (text/html)
   5.2390…  192.168…   192.168.…    HTTP        GET /api-v0/status HTTP/1.1
   5.2414…  192.168…   192.168.…    HTTP/JSON   HTTP/1.1 200 OK , JavaScript Obje
   5.2426…  192.168…   192.168.…    HTTP/JSON   PUT /api-v0/optimizations HTTP/1.
   5.2467…  192.168…   192.168.…    HTTP/JSON   POST /api-v0/ols/8/optimizations
   6.5496…  192.168…   192.168.…    HTTP        HTTP/1.1 201 CREATED  (text/html)
   7.4545…  192.168…   192.168.…    HTTP        HTTP/1.1 201 CREATED  (text/html)
```

(a) Wireshark traffic capture for the soft failure self-healing. All the messages exchanged by the control plane are shown, starting from the first ones which are used to simulate a failure on the line. Subsequently the network controller obtains the status of the line, which was requested because the controller itself noticed a reduction in terms of BER. This is followed by an optimization request to the OLC which will use the line-DT to obtain the new WPs given the change in the state of the lines.



(b) The continuous curves plotted in the figure show the evolution of the GSNR over time since the creation of the soft failure on the line, while the dashed curves show the FEC thresholds for the 16-QAM and QPSK modulation formats, respectively. From the evolution of these sharp drop in transmission quality is present as soon as the fault is added which brings all the CUTs below the threshold. Following the optimization obtained by the line-DT, the channels manage to return above the threshold, correctly maintaining a GSNR value lower than the previous one since the total loss is greater than the previous one due to the failure.

Fig. 3: Self-Healing experimental results

(input and output power) and set (gain and tilt). An automatized procedure has been implemented for real-time telemetry streaming both for the OLC, reading the EDFAs and OCMs telemetries, and the SDN controller, reading the bit error rate (BER) of the received channels. This data collection framework, along with the GNPy digital model service, enables the creation of a a specific line-DT, and a general network-DT.

In particular, the proposed line-DT implementation integrates GNPy and the OLS telemetry for an accurate emulation of the OLS transmission. Additionally, the line-DT includes various algorithms that leverage the accurate digital model for QoT estimation, planning and adaptive control. Representational state transfer (REST) interfaces have been created to enable communication between the SDN controller, the OLC and line-DT.

4. Results

In the proposed experiment, OLC and SDN software are configured according to the lab's topology, in fact, thanks to the provided description, the software are capable to create a control and telemetry session for all the involved devices. Exploiting the developed REST interfaces, the OLC shares topology information with the line-DT via POST request. Then, a probing phase is performed in the physical OLS; this stage guarantees a minimal set of measurements that allow the digital model tuning on the specific OLS. To perform this procedure, the OLC sets the amplifiers' WP according to the following iterations: *i)* BST gain from 14 dB up to 28 dB with 1 dB step. *ii)* PRE gain from 28 dB down to 14 dB with 1 dB step. *iii)* ILAs gain equal to the previous span loss. *iv)* Amplifiers' tilt values in order to counteract the total amount of accumulated tilt on the WDM comb at the end of the OLS, measured thanks to the DMX OCM.

The extent of the explored gain intervals is fixed by the overall OLS power budget given the MUX and DMX output powers and the fiber span losses. All the steps and the related telemetry measurement are performed in about 2 minutes, which results in about half an hour probing time. Finally, all the collected data are shared with the line-DT through a POST endpoint, which can exploit the measurements received to create a physical model of the OLS. At this point, the line-DT can simulate the behavior of the physical layer and this potential can be exploited to obtain the WPs of the amplifiers capable of ensuring the best GSNR value. These value are returned to the OLC which can push the WPs into the amplifiers.

The experiment continues testing the potentiality of the architecture in the mitigation of a soft failure. As shown in Fig.3a, a soft failure is emulated by artificially increasing the input loss of three fiber spans.

Via BER monitoring, the SDN controller detects a reduction in transmission performances and promptly reacts checking the status of all OLCs crossed by the specific lightpath. Simultaneously, the OLC locates the failure via EDFA real-time power monitoring and communicates the failure status to the SDN controller. Once the problem is reported, the SDN allows the OLC to interrogate the line-DT that provides new WPs values for the new OLS conditions. Then, the OLC sets the new WPs mitigating the effect of the fault. The evolution of the generalized signal-to-noise ratio (GSNR), obtained converting the BER measurements, is reported in Fig. 3b passing from original conditions to fault and mitigation. Assuming FEC thresholds of 3×10^{-2} for 16-QAM used in DCO and 1×10^{-3} for QPSK used in ACO [12], GSNR thresholds of 13.3 dB and 11.2 dB are obtained, respectively, as plotted in Fig. 3b. After the recovery, less than 2 dB of GSNR are lost in the CUTs fitting the margin design in optical networks.

5. Conclusion

A control architecture for partially disaggregated open optical network has been exploited and extended by the implementation of line-DT and network-DT. In this work, for the first time, the potential of GNPy as a line-DT is proved for a single line handled by vendor-specific OLC. The authors want to underline the need and benefits to continue towards the implementation of open and standard interfaces as well as the greater integration of those already existing in single vendor systems which can favor the integration of QoT-E systems such as those used in this work.

Acknowledgment

This work has been supported by the TIP and by the EU Horizon Europe research and innovation program, ALLEGRO Project, GA No. 101092766. The authors also wish to thank the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, partnership on “Telecommunications of the Future” (PE00000001 - program “RESTART”). Authors also wish to thanks IP Infusion.

References

1. F. Paolucci *et al.*, *Network telemetry streaming services in SDN-based disaggregated optical networks. JLT 2018*
2. *OpenConfig*, `http://www.openconfig.net`
3. *Open ROADM*, `http://www.openroadm.org`
4. *TIP* `https://telecominfraproject.com`
5. A. Sgambelluri *et al.*, *OpenConfig and OpenROADM automation of operational modes in disaggregated optical networks IEEE Access 2020*
6. G. Borraccini *et al.*, *Experimental demonstration of partially disaggregated optical network control using the physical layer digital twin. IEEE TNSM 2023*
7. R. Ambrosone, *et al.*, *Open Line Controller Architecture in Partially Disaggregated Optical Networks. PSC 2023.*
8. G. Borraccini *et al.*, *Disaggregated optical network orchestration based on the physical layer digital twin. OFC23.*
9. V. Curri, *GNPy model of the physical layer for open and disaggregated optical networking*, *JOCN 2022*
10. A. D’Amico *et al.*, *Enhancing Lightpath QoT Computation With Machine Learning in Partially Disaggregated Optical Networks IEEE OJCS 2021*,
11. *TIP OOPT MUST Optical Whitepaper Target Architecture: Disaggregated Open Optical Networks*.
12. Yu Rong Zhou *et al.*, *High Capacity Innovations Enabling Scalable Optical Transmission Networks*, *JLT*