# QoT-Driven Optical Control and Data Plane in Multi-Vendor Disaggregated Networks

**Giacomo Borraccini[1]*, Stefano Straullu[2], Alessio Giorgetti[3],**
**Rocco D'Ingillo[1], Davide Scano[4], Andrea D'Amico[1], Emanuele Virgillito[1],**
**Antonino Nespola[2], Nicola Sambo[4], Filippo Cugini[5], Vittorio Curri[1]**
[1] *Politecnico di Torino, Italy;* [2] *LINKS Foundation, Italy;* [3] *IEIIT-CNR, Pisa, Italy;*
[4] *Scuola Superiore Sant'Anna, Pisa, Italy;* [5] *CNIT, Pisa, Italy*
**giacomo.borraccini@polito.it*

**Abstract:** A novel disaggregated network architecture with independent PCE and optical control based on GNPy is proposed and experimentally validated over a network including two independent OLSs for total 1400 km, ROADM whiteboxes and pluggable transceivers.

## 1. Introduction

Disaggregated optical networks, vendor-neutral control and management, and multi-vendor inter-operability are attracting the interest from service providers and network operators [2] as a solution to the vendor lock-in and reduce capital expenditure [1]. The software from hardware decoupling is a specific example: the separation of control, management, and data planes have gained highly relevance in the last years. Together with the definition of vendor-neutral control and management of transponders/transceivers and ROADMs, disaggregation may enable operators to avoid the vendor-lock-in at the control plane level. In order to support vendor-neutral control and management, a lot of effort has been put in the definition of standardized data models shared by vendors and operators. YANG [3,4] has been identified as the data modeling language of choice to interface with the control and management system and is supported by the NETCONF protocol, standardized by Internet Engineering Task Force (IETF) [5]. Several consortia and projects, such as OpenConfig, [6] OpenROADM, [7] and Telecom Infra Project (TIP) [8] – including major operators, service providers, and vendors – are working to define vendor-neutral and disaggregated networks. Another aspect within control – in particular for lightpath (LP) provisioning (and maintenance as well) – is the quality of transmission (QoT) estimation. Coherent technology allowed optical transmission over transparent LPs impairing the transmission as additive white and Gaussian noise (AWGN) channels. Consequently, the figure of merit associated to the QoT is the generalized signal to noise ratio (GSNR) [9], defined as the ratio between the power of the channel under test and the sum of the accumulated amplified spontaneous emission (ASE) noise due to in-line amplifiers and non-linear interference (NLI) impairment arising from fiber propagation. Within the TIP [8], the GNPy [10] has been developed as an open-source and vendor-agnostic QoT estimator implementing the AWGN abstraction of LPs.

In this work, we propose and validate a disaggregated network architecture based on open transponders hosting pluggable transceivers and ROADM whiteboxes managed by a QoT-aware ONOS controller, interfaced using the NETCONF protocol [11,12]. ONOS relies on GNPy for QoT estimation, while OpenConfig vendor-neutral YANG data models are adopted for the control of pluggables and ROADMs from multiple vendors. The two ROADM-to-ROADM optical line system (OLS) are controlled by independent autonomous optical line controllers, relying on GNPy for GSNR estimation [13]. For the first time, the disaggregated control of packet-optical boxes and OLS is demonstrated for a propagation distance up to 1400 km.

## 2. Network Architecture

The innovative network architecture demonstrated in this experimental proof-of-concept is based on the independence between the amplifiers' control plane of each OLS and the data plane. The considered network system is composed by transceiver and ROADM whiteboxes, which allow to expose the current status and to set the working mode. The main actor operating in an open and disaggregated network context is a unique optical network controller which communicates with each device through an open protocol, defining the routing strategy at the data plane and orchestrating the operations of transceivers and ROADMs. Each line can be managed individually and autonomously by a specific line controller, choosing the most appropriate transmission strategy through the setting of the amplifiers' working point. A dedicated physical layer description is associated to the corresponding line providing information on each fiber span properties, amplifiers' characterizations and installed fiber features. The connection that allows closing the feedback loop between the network controller and the various line controllers is represented by a software computational block which estimates the QoT of each line starting from the

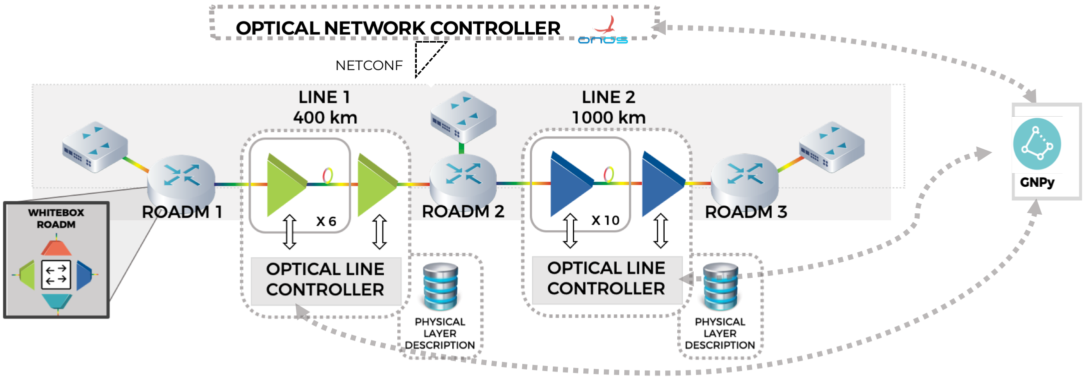


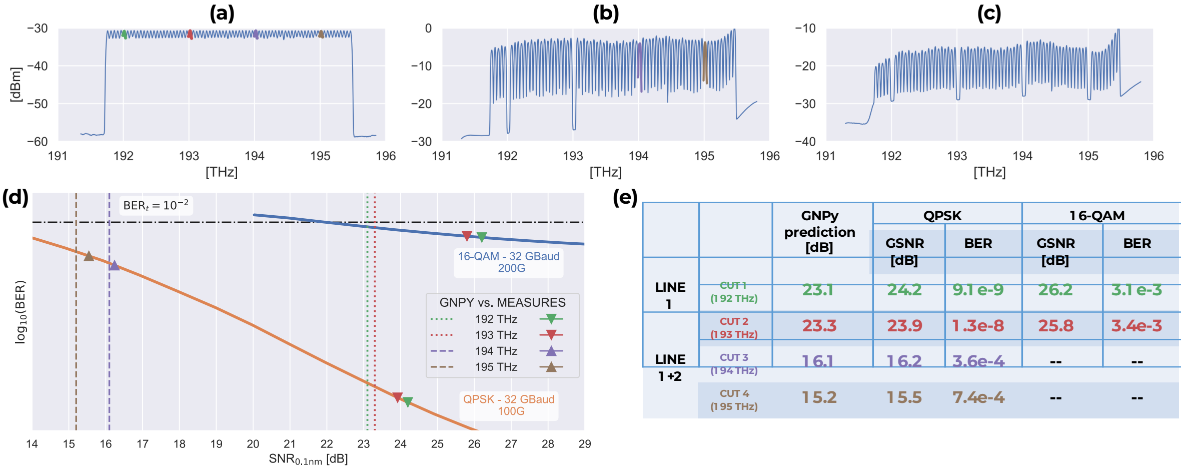
Fig. 1. Developed QoT-driven optical control framework on a two lines and three ROADMs network.

physical layer description and the configuration of the amplifiers, thus providing directions to the data plane for routing. Taking a cue from the network architecture scheme depicted in Fig. 1, GNPy interfaces with each optical line controller, estimating the QoT given the optical line properties and settings. Starting from this information, ONOS optimizes the routing strategy and operates the modulation format deployment based on the transceivers' characterization. In order to have a full vendor-agnostic approach, GNPy requires the software abstraction of all the amplifier and transceiver models, together with the fiber spans' physical properties (such as length, attenuation profile, lumped losses, Raman efficiency and dispersion) involved in the optical transmission. Starting from the concept of network disaggregation and softwarization, the presented architecture allows to manage independently the physical layer and the data plane, operating in a modular and completely neutral way with respect to the available resources.

## 3. Experimental Implementation & Results

The experimental setup implements the optical network scheme depicted in Fig. 1. A C-band WDM comb centered at 193.5 THz and composed by 75 channels, 50-GHz spaced modulated at 32 GBaud each is propagated through the optical network under test. We define 4 channel under test (CUT), centered at 192, 193, 194 and 195 THz, respectively, generated by a Cassini AS7716-24SC [8], an open network packet-optical box built by Edgecore that can host line card slots to incorporate ACO/DCO optical ports based on coherent DSP and optical transceivers from leading optical technology partners. In our case, 4x CFP2-DCO coherent pluggables from Lumentum are used and programmed in order to generate 4 independent signals (DP-QPSK or DP-16-QAM modulated) and to detect and continuously monitor the related Bit Error Rate (BER), providing an updated average value every 15 seconds. A commercial programmable wave shaper filter (1000S from Finisar) is used to shape the output of an ASE noise source, generating 71 channels that, coupled with the 4 CUTs, assemble the 75 channels OLS spectral load with no loss of generality because of the large time constant characterizing the physical effects within EDFAs. Line 1 is composed by 6 spans, each based on a commercial EDFA operating in constant gain mode and followed by a standard single mode fiber (SMF) of 65 km nominal length. Similarly, line 2 is composed by 10 amplified SMF spans of about 100 km each. Three commercial ROADMs (from Lumentum) are used to emulate the networks nodes: ROADM 1 is configured to add the 75 channels and to route them at the line 1 input (Fig. 2-a); ROADM 2 drops two CUT (CUT 1 and CUT 2), so that their BER can be evaluated at the end of line 1. The 73 remaining channels are then propagated through line 2 (Fig. 2-b) and ROADM 3 finally drops CUT 3 and CUT 4 at the end of line 2 (Fig. 2-c). The software-defined network controller, ONOS, controls the ROADMs and the Cassini packet-optical boxes using the NETCONF protocol [12]. The drivers for controlling such devices were already available in the ONOS master code branch, but still significant extensions have been implemented for this deployment. Specifically, the OcNOS operating system installed on the Cassini boxes uses a YANG model not compliant with the OpenConfig model. So, the extended driver applies to the proprietary OcNOS YANG model and provides the following features: device and ports discovery, tuning of the laser frequency, modulation format and output power configuration and pre-FEC BER monitoring. Moreover, the ONOS CLI has been extended to allow the configuration of a single cross-connection on ROADM devices. For the purposes of the experiment, 75 intents are established in the network with explicit path and wavelength assignment: 4 of them are used the propagation of modulated traffic, the others for ASE noise propagation. To deal with the configuration of the noise intents, 2 emulated OpenConfig transponders are added in the network topology.

As preliminary steps to the experiment, a single amplifier of each EDFA model involved in the experiment undergoes a characterization process, which allows to map the effective gain and ASE noise generated by the corresponding settings. A back-to-back (B2B) characterization of the DCO modules hosted in the Cassini is carried



| | | GNPy prediction [dB] | QPSK | | 16-QAM | |
|---|---|---|---|---|---|---|
| | | | GSNR [dB] | BER | GSNR [dB] | BER |
| LINE 1 | CUT 1 (192 THz) | 23.1 | 24.2 | 9.1 e-9 | 26.2 | 3.1 e-3 |
| | CUT 2 (193 THz) | 23.3 | 23.9 | 1.3e-8 | 25.8 | 3.4e-3 |
| LINE 1+2 | CUT 3 (194 THz) | 16.1 | 16.2 | 3.6e-4 | -- | -- |
| | CUT 4 (195 THz) | 15.2 | 15.5 | 7.4e-4 | -- | -- |

Fig. 2. Propagating WDM comb at line 1 input after ROADM 1 (a), line 2 input after ROADM 2 (b), line 2 output after ROADM 3 (c). Comparison between GNPy predictions and experimental measurements, graphically (d) and in table (e).

out for each modulation format and different received power levels, deriving the corresponding BER vs. SNR characteristic curves. Once the experimental setup is established, the fiber spans of both the OLSs are characterized to abstract their physical layer properties [14]. The amplifiers' working point of both lines is individually optimized maximizing and flattening the GSNR at their output [13]. The proper operation of the presented proof-of-concept is experimentally verified measuring the real pre-FEC BER from the dropped modulated channels using the Cassini at each line terminal and translating them into the corresponding GSNR value by means of the previously obtained B2B characteristic curves. We performed the measurements on CUT 1 and 2 dropped by the ROADM 2 using both the DP-QPSK and DP-16-QAM modulation formats and on CUT 3 and 4 after the ROADM 3 only in DP-QPSK. The obtained results in terms of GNPy predictions and experimental measurements are reported both graphically and in table in Fig. 2-d and Fig. 2-e, respectively. GNPy estimations are in all the cases conservative with respect to the experimental values. Comparing them with respect to the DP-QPSK measurements, the deviation is within 1.1 dB. Focusing on the CUT 1 and 2, we observe a larger GNPy/measured-GSNR gap on DP-16-QAM with respect to DP-QPSK. Furthermore, the GSNR trend vs. CUT frequency between GNPy predictions and measurements is opposite with respect to both the measured modulation formats. The first aspect is related to a pejorative characterization of the amplifiers, since the transmission quality is not yet degraded by optical propagation after about 400 km. Given the almost flat prediction, the BER measurements reflect this statement, presenting values which are considerably similar. The opposite trend is instead related to the uncertainty associated to the measure and the fiber span characterizations. In any case, assuming a BER threshold of $10^{-2}$, GNPy prediction sustains and ensures the possibility to deploy modulated 16-QAM connections for both CUTs. Considering the case of CUT 3 and 4, GNPy prediction is extremely accurate with respect to the measurements obtained after about 1400 km of optical propagation.

## 4. Conclusions

The proposed network architecture with disaggregated and independent OLS control has been successfully validated, lightening ONOS operations while guaranteeing extremely accurate QoT assessment through GNPy.

## Acknowledgment

The authors wish to thank the Lumentum, Telecom Infra Project, Cisco, IP INfusion, Open Network Foundation for providing hardware and software. Partial support from the H2020 B5G-OPEN Project (Id: 101016663).

## References

1. E. Riccardi et al., "*An operator view on the introduction ofwhite boxes into optical networks*", JLT, 536, 15, 2018.
2. Facebook: https://code.facebook.com/an-open-approach-for-switching-routing-and-transport/
3. M. Bjorklund, "*YANG - a data modeling language for the network configuration protocol (NETCONF)*", IETF RFC 6020.
4. M. Dallaglio et al., "*Control and management of transponders with NETCONF and YANG*", JOCN, 9, 3, 2017.
5. R. Enns et al., "*Network configuration protocol (NETCONF)*", IETF RFC 6241, 2011.
6. OpenConfig: http://www.openconfig.net
7. Open ROADM: http://www.openroadm.org
8. Telecom Infra Project: https://telecominfraproject.com/
9. M. Filer et al., "*Multi-vendor experimental validation of an open source QoT estimator for ...*", JLT, 36, 15, 2018.
10. V. Curri, "*GNPy Model for Design of Open and Disaggregated Optical Networks*", Th1A.1, ECOC 2021
11. "*https://opennetworking.org/onos/*".
12. A. Giorgetti et al., "*Control of open and disaggregated transport networks using ...*", JOCN, 12, 2, 2020.
13. G. Borraccini et al., "*Cognitive and autonomous QoT-driven optical line controller*", JOCN, 13, 10, 2021.
14. G. Borraccini et al., "*Autonomous physical layer characterization in cognitive optical line systems*", OFC 2021.