Softwarized Optical Transport QoT in Production Optical Network: a Brownfield Validation

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Abstract *We compare measured QoT on production network to GNPy predictions, showing an excellent accuracy for 40 channels on two paths. Transmission exceeds 2000 km on mixed-fiber hybrid amplified links. Non-conservative prediction is observed only in 23% of cases and the inaccuracy is limited to 0.3 dB.*

Introduction

The need for ultra large capacity data transport is a firm request of modern society, driven by the implementation of cloud services, data center interconnect and 5G broadband Internet access. For the Internet access, data transport is largely going to rely on wireless technologies, while the whole networking segment will be based on optical networks enabled by multi-band optical coherent technologies for data transport. Besides the increase in demand, data traffic is modifying its nature by increasing variations over the day-time[1], demanding for service-dependent traffic management, consequent network virtualization and slicing down to the physical layer[2]. These needs have been emphasized by the global COVID-19 emergency that is advancing the need for low-latency, high/quality telepresence Internet applications[3]. Consequently, operators aim to implement the software-defined networking (SDN) paradigm down to the optical physical layer, in order to maximize the hardware capabilities and to manage optical data transport as a network virtualized function[4],[5]. The key challenge is the need to include non-linear physical considerations into networking. Packets can easily be routed through an arbitrary sequence of switches and routers without alteration. Unlike packets, the quality of a lightpath through an optical network deteriorates depending on physical characteristics of fiber, amplifiers and lightpath switches. Without considering quality degradation a lightpath could still exist, but would not be able to carry any useful data[6].

Modeling physics for optical coherent technologies is fully compatible with such an approach: Lightpaths (LP) within a transparent network practically impair Quality-of-Transmission (QoT) as an additive Gaussian noise channel[7]–[10]. Thus, QoT is fully characterized by the LP signal-to-noise ratio (SNR) that is commonly identified as generalized-SNR (GSNR)[11]–[14] The GSNR includes both the amount of ASE noise introduced by the optical amplifiers (P_{ASE}) and the amount of nonlinear interference (NLI) generated by self- and cross-channel nonlinear crosstalk triggered by the Kerr effect and mitigated by the chromatic dispersion (P_{NLI}). Being both disturbances well characterized as dual-polarization additive Gaussian random processes[15]. The GSNR is so:

$$GSNR = \frac{P_{CUT}}{P_{ASE} + P_{NLI}} = \frac{1}{\frac{1}{OSNR} + \frac{1}{SNR_{NL}}},$$

where P_{CUT} is the power of the channel under test (CUT) and OSNR is the optical signal to noise ratio detectable by spectrum analyzers.

Consequently, the SDN implementation down to the optical transport can be summarized by a QoT-Estimator (QoT-E) that takes as inputs the network topology, the network status from the network controller and the LP route, and returns the LP GSNR[14]. This is the approach of the open-source project GNPy[16] by the consortium Telecom Infra project (TIP)[17]. GNPy has been extensively tested in green-field scenarios, displaying a capability to predict the GSNR with excellent accuracy, also in case of autonomous inputs from a network controller[13],[18]. In this work, for the first time, we test GNPy on a traffic carrying production network and show that GNPy can predict the GSNR with an excellent accuracy also under so called "brownfield conditions". The GSNR overestimation error stays below 0.3 dB and confirms that SDN can be applied down to the WDM optical transport, by a QoT-E application program interface (API) with standardized input data models.

Tab. 1: Fiber parameters.

Fiber type	α dB/km	D ps/nm/km	γ 1/W/km
NDSF	0.222	3.8	1.45
ELEAF	0.2	4	1.41
TWRS	0.24	6	1.84

The brownfield scenario

We analyze the network portion of the Microsoft core network[19] depicted in Fig. 1, which includes further details on the physical layer. It is a 3-node mixed-fiber network covering a distance exceeding 2000 km operated on the C-band and spectrally loaded with 40 wavelengths on the 50 GHz WDM grid. Transmission infrastructure includes mixed-fiber type: NDSF, ELEAF and TWRS; whose parameters are shown in Tab. 1. The length of fiber spans ranges from 48 km to 115 km. Most of the amplifiers are Hybrid Raman-EDFA, with few pure-EDFA amplification sites. ROADM nodes are used every $\sim$600 km to equalize the power per channel. Three colorless mux/demux locations – named node A, node B and node C – are used to add/drop channels. The network is operated by flex-format transceivers working at the symbol-rate of 34.16 GBaud and supporting dual-polarization QPSK, 8-QAM and 16-QAM, corresponding to data rates of 100, 150 and 200 Gbps, respectively. Signals are root raised cosine shaped with a roll-off of 0.2.

We focus on analyzing transmission on two paths identified by dashed lines in Fig. 1: A to B (red line) covering a distance of $\sim$1900 km, and A to C (blue line) with a reach of $\sim$2150 km. Over these paths, the selected modulation format is 8-QAM and the number of operating channels is 40. Ten channels in the spectral range from 191.35 THz to 191.6875 THz are deployed over the A-B path, while the thirty channels between 191.8125 THz and 193 THz pass node B, so covering the A to C path. Fig. 3 displays results and shows the exact spectral placement of the deployed channels.

Analysis and Results

The analysis is focused on verifying the capability of GNPy to evaluate the GSNR for each channel on the two considered paths. To this purpose, the deployed transceivers are first characterized in back-to-back (b2b) to obtain the pre-FEC BER vs. OSNR trans-characteristics. Such a curve is then used to convert the BER values read from in-field transceivers to the corresponding GSNR to be compared to the GNPy predictions. Fig. 2 depicts such a process. In a next step, the state of the network is probed by querying the Microsoft SDN line system monitoring tool which is based on representational state transfer (REST)[20] protocol. This allowed to collect data for the JSON data structure required as GNPy input, i.e., fiber parameters and lengths, amplifiers gain and noise figures and spectral loads and power levels.

GNPy performs QoT-E with a spatial and spectrally disaggregated approach: For each passed network elements, impairments on each channel under test is evaluated as loss/gain, filtering penalties, amount of ASE noise and NLI[14]. To this purpose, fiber spans are abstracted as lossy elements introducing some amount of NLI and ASE noise, in case of Raman pumping. The frequency-resolved loss/gain is evaluated by the considering loss coefficient – possibly frequency resolved – and the SRS effects – crosstalk and gain, if pumps are used. The frequency-resolved NLI is evaluated using the generalized GN-model[21]–[23] implemented with a spectrally disaggregated approach, so considering only the self- and cross-channel contributions which limits the computational time to a few seconds on a standard PC. GNPy also delivers additional metrics for each investigated lightpath, as the accumulated chromatic dispersion, PMD and latency, that are not used within this analysis.

In Fig. 3, results are presented as measured (triangles) and predicted (solid lines) GSNR for all the CUTs on the two analyzed paths. It can be observed that GNPy predictions are always very accurate with a very limited error that is most of the time conservative, i.e., GNPy predicts a GSNR that is slightly smaller that the accumulated GSNR. On the shortest path (A-B), the estimation is always conservative and very accurate, while for the A-C paths some ripples can be observed, also letting the actual GSNR being slightly lower than the predicted figure. Also, some outliers can be noted on the spectral borders of the two channel sets. To give a quantitative assessment on the accuracy of GNPy, we evaluate the prediction error as $\epsilon_{pred} = GSNR_{pred} - GSNR_{meas}$ in dB units and plot its distribution in Fig. 4. It can be noted that errors are in the range from -0.3 dB to +1.2 dB. It means that *a posteriori* we found that in the analyzed scenario the GSNR QoT-E predicted by GNPy can be fully trusted with only 0.3 dB of required GSNR margin. Analyzing percentages, Only 23%

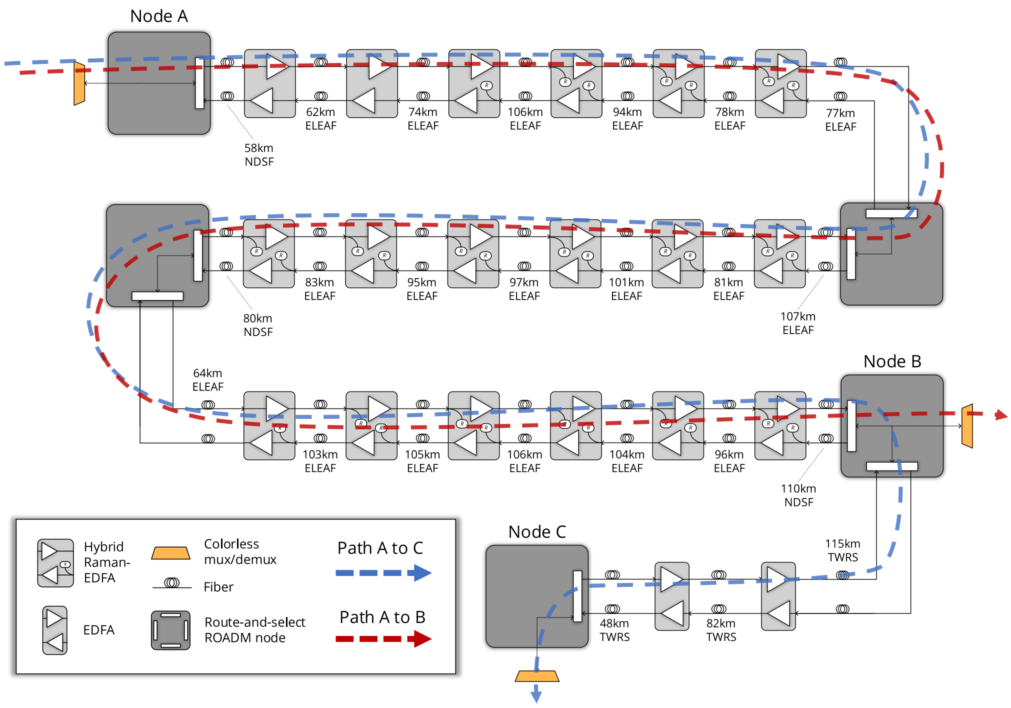

Fig. 1: Layout of the analyzed network portion. Fiber types and lengths are described as well as amplifiers' type. Red and blue dashed lines show the two analyzed paths.

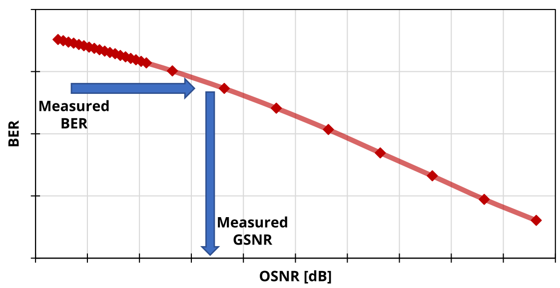

Fig. 2: Back-to-back pre-FEC BER vs. OSNR trans-characteristics and its use (blue arrows) in converting the measured BER into the corresponding GSNR.

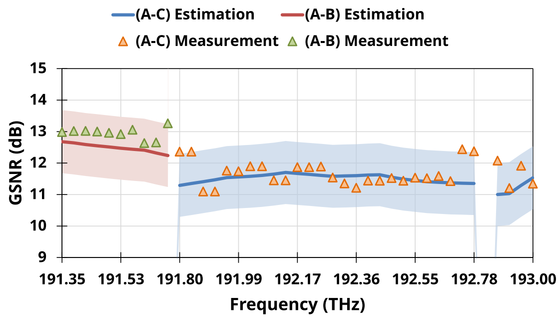

Fig. 3: Measured (triangles) and predicted (solid lines) for the set of channels over the two analyzed paths. $\pm$ 1 dB confidence intervals are shown as colored background.

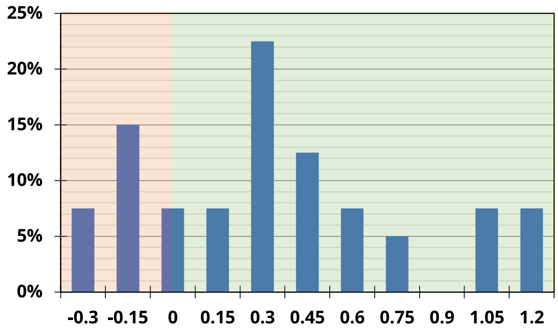

Fig. 4: Distribution of the error ϵ_{pred} for all analyzed CUTs. Negative error means non-conservative prediction.

of cases are non-conservative predictions. Analyzing Fig. 3 further, we can hypothesize that negative errors are likely caused by amplifier ripples that are not fully described in the network status provided as GNPy input. Positive errors extend up to 1.25 dB, but only few outliers exceed 1 dB, and these are located on the spectral borders (see Fig. 3) where the description of network elements could be less accurate.

Conclusions

In this work, for the first time, we have tested the capability to predict QoT as GSNR for a given lightpath over a network carrying production traffic. We collected the pre-FEC BER measured in-field converted as GSNR by the b2b BER vs. OSNR trans-characteristics over two paths on a mixed-fiber hybrid-amplified production network exceeding 2000 km reach. We compared the measured GSNR to the GNPy calculation getting a prediction error that only in 23% of cases is non-conservative with a GSNR over-estimation limited to 0.3 dB. In conclusion, the GNPy QoT-E has proven its accuracy in a production network demonstrating the feasibility of software virtualization of optical data transport for open optical network planning, control and management.

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