Experimental Validation of an Open Source Quality of Transmission Estimator for Open Optical Networks

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Abstract: We test the QoT-E of the GNPy library fed by data from the network controller against experimental measurements on mixed-fiber, Raman-amplified, multi-vendor scenarios on the full C-band: an excellent accuracy within 1 dB is shown. © 2020 The Author(s)

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1. Introduction

Operators are always willing to improve their network efficiency given the ever-increasing traffic and resource-constrained long-haul fiber. Furthermore, optical infrastructures based on coherent transmission technologies are indeed available for optimizations [1] aimed at exploiting the maximum available capacity of the deployed network [2]. An accurate quality of transmission (QoT) estimator (QoT-E) is fundamental to achieve this goal. Thus, open optical networks are challenging the status-quo by enabling operators to perform vendor-neutral analysis and planning, relying on quick network performance estimation. This way, operators and vendors alike are able to predict optical network performance and scrutinize results, both off- and on-line, in a trusted and comparable manner. Leveraging such capabilities within a software-define network (SDN) environment is instrumental for optimizing and automating the infrastructures' usage. The reference implementation is provided within the Telecom Infra Project (TIP) by the Physical Simulation Environment (PSE) working group [3, 4] as an open source code library by the name "GNPy" [5]. As depicted in Fig. 1, GNPy requires a description of the network status at layer-0, of the route under analysis and of the related spectral load, then it computes physical impairments along the path: GNPy acts as a QoT-E. The QoT-E delivers a quick evaluation of a commonly accepted, unique QoT parameter: the generalized signal-to-noise ratio (GSNR), which considers both the the accumulation of the Amplified Spontaneous Emission (ASE) noise and of the nonlinear interference (NLI) [6, 7].

This work documents the validation effort carried out over Microsoft's lab test-bed, evaluating the latest QoT-E version based on the generalized Gaussian noise model [8, 9] for the NLI calculation, and on accurate amplifier models for the analysis of the ASE noise. To this aim, the stimulated Raman scattering (SRS) is included by introducing a Raman solver [10] to accurately assess distributed Raman amplification. Furthermore, this is the first test based on data reported by the network controller or provided by the vendor without acquiring extra measurements from the field; contrary to what has been done in [6]. The presented results are obtained using GNPy as depicted in Fig. 1: network data are requested from the photonic controller and used to feed the QoT-E which is able to predict the GSNR within a matter of seconds[1]. To validate the GNPy predictions, GSNRs are compared to experimental bit-error-rate (BER) measurements by deriving the GSNR from BER.

The test-bed at Microsoft included mixed fiber and hybrid EDFA/Raman amplification enabling measurements for propagation distances from 400 up to 4000 km. Experiments where performed on full C-band spectral load using multi-vendor transceivers and different modulation formats. Excellent results where obtained with a prediction accuracy of better than 1 dB for more than 90% of the investigated cases, including challenging shorter

[1] One second per channel under test per fiber span, on a laptop with a dual core i7 CPU. Further reductions in computational time are already planned.

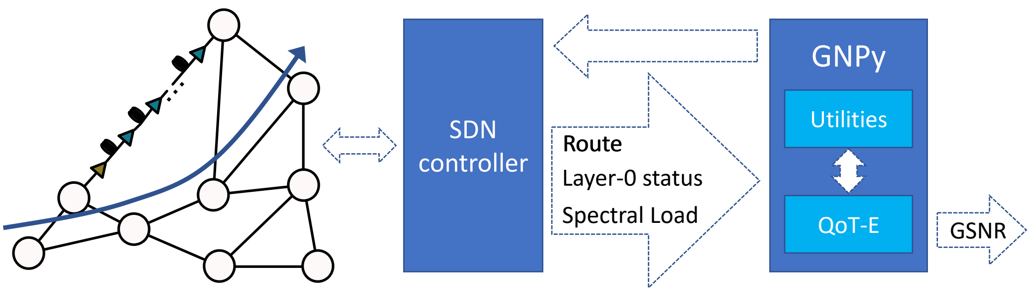

Fig. 1. Block diagram for the use of the GNPy library within a SDN environment.

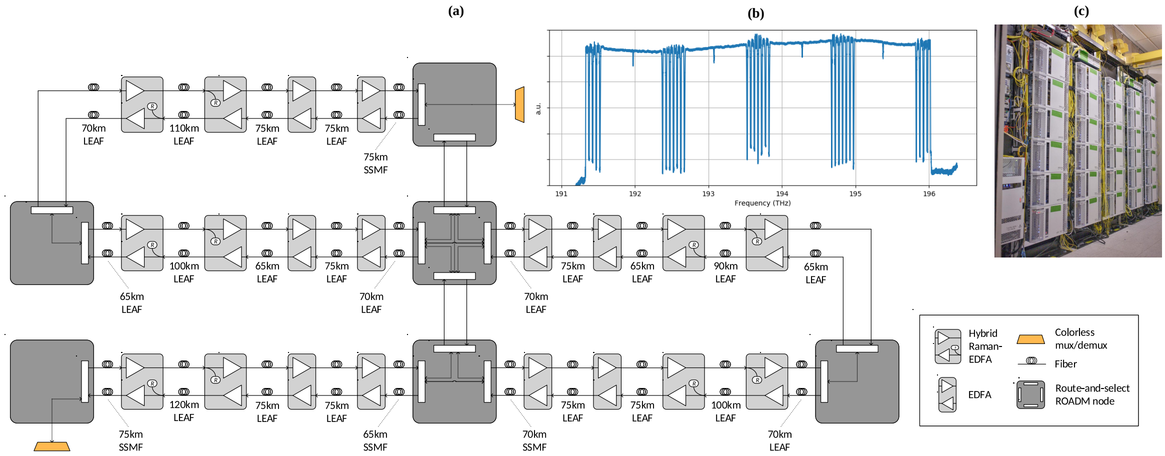

Fig. 2. (a) A scheme of the test-bed; (b) the transmitted spectrum; (c) A picture of the Microsoft test-bed used for the experimental validation.

distances in which measurement uncertainties lead to larger deviations from expected results. Shorter distances, in fact, have a low bit-error-rate (BER) which requires large time averages to be accurately measured and have a high GSNR which is more sensitive to small variations.

2. Experimental validation

The test-bed used for the experiments is shown in Figs. 2(a)(c): it emulates a commercial network with six ROADM nodes and five amplified optical segments. The longest bidirectional path in the network is 2000 km long. Each ROADM node is equipped with a booster amplifier and a pre-amplifier per node degree, and each line segment is roughly 400 km long. Each amplified line segment includes five fiber spans and four inline amplifiers (ILA): three Erbium Doped Fiber Amplifiers (EDFA) and one hybrid EDFA/Raman amplifier (HFA). Span lengths vary from 65 km up to 120 km, and the involved fiber types are G.652 standard single mode fiber (SSMF) and G.655 LEAF fiber. More details on the test-bed can be found in [6]. Commercial multi-vendor coherent transponders are used to generate a total of 26 channels under test (CUT) that are grouped into six media-channels (MC). Two MCs are comprised of four channels, and the remaining three MCs are made of six channels. The MCs are distributed within the 4.65 THz available bandwidth as follows: the two four-channel MCs are positioned at the edges of the spectrum, with one six-channel MC in the middle and the remaining two MCs are in the midpoints between the central MC and the external MCs. The rest of the spectrum is filled with properly shaped ASE noise [11] for a full C-band spectral load from 191.35 THz to 196 THz, as depicted in Fig. 2(b). The transponders support three modulation formats: PM-QPSK, PM-8QAM and PM-16QAM. The signals are root-raised cosine shaped with a roll-off of 0.2 and the symbol rate is 34.16 GBaud.

In order to estimate the GSNR from the QoT-E of GNPy, the state of the network was probed by querying it via Microsoft SDN line system monitoring tool, which is based on REST. In this way, information is collected on the configuration parameters, on the power levels measured by on-board photodiodes, and on the channel plan to populate the topology JSON file which is taken as input by the QoT-E. The required parameters include span losses, ILA gains and powers, Raman pumps, and lumped losses due to connectors and splices. In particular, connector losses of Raman amplifiers are critical to properly derive the actual power of the Raman pumps injected into the fiber. Another crucial parameter is the connector loss at each fiber input, as it defines the amount of power generating the NLI: we used a value of 0.75 dB as in [6, 7].

The GSNR values predicted by the QoT-E are compared to the measures ones. These are obtained by first characterizing the back-to-back (B2B) performance of each transponder as BER vs. OSNR. Then, the BER values of test-bed channels were obtained by querying the linecards, and the GSNR was derived by inverting the the BER vs. OSNR B2B characterization. Finally, errors are computed as the absolute value of the difference between the measurement and the QoT-E GSNR, in dB units. We tested different modulation formats and propagation distances: PM-QPSK at 2000 km and 4000 km, PM-8QAM at 400 km, 800 km, 1200 km, 1600 km and 2000 km and PM-16QAM at 400 km, 800 km and 1200 km, in both directions. The 4000 km path was obtained by looping back the signals over the 2000 km path.

Figs. 3(a)-(f) compare the measured GSNR (orange dots) to the GNPy prediction (blue line) for different modulation formats and for the shortest (Fig. 3(a)-(c)) and the longest distances in the network (Fig. 3(d)-(f)). The prediction demonstrates the tool's effectiveness at predicting the GSNR with excellent accuracy, and further, the ability to accurately capture the frequency variation of the GSNR. Observing the 400 km distances, in Fig. 3(b) and in Fig. 3(c), a larger inaccuracy is present in the middle of the band, then, increasing the distance this error

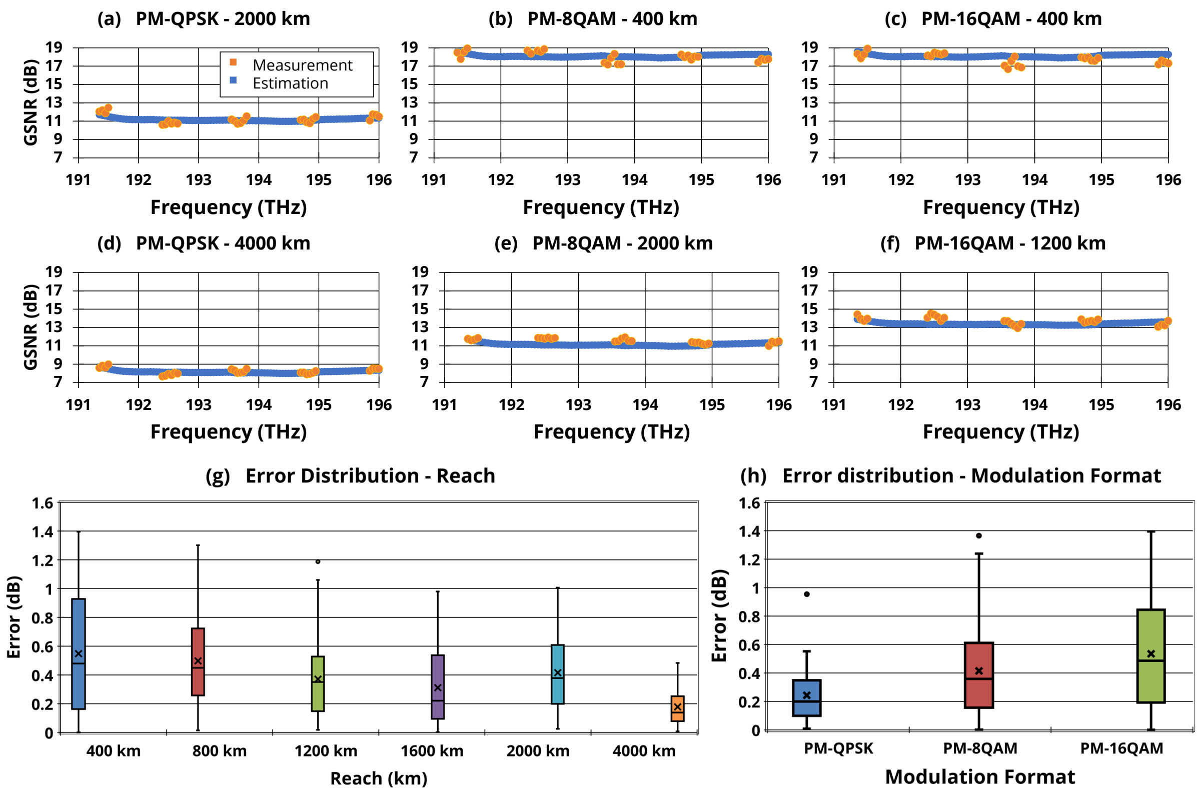

Fig. 3. GSNR estimated by GNPy (blue lines) and the actual GSNR (yellow dots) for PM-QPSK (a and d), PM-8QAM (b and e) and PM-16QAM (c and f) and for different reaches. Error distribution for each reach (g) and for each modulation format (h).

reduces since the overall GSNR reduction mitigates the uncertainty on both ASE noise and NLI. Measuring the GSNR at shorter distances is, in fact, more difficult since i) the BER is lower, then, less stable and ii) the GSNR is higher and therefore, more sensitive to small inaccuracies.

Fig. 3(g),(h) report the error distribution for different distances (Fig. 3(g)) and different modulation formats (Fig. 3(h)) as box-plots. Such statistics are based on a total of ∼500 samples of errors, in which, the largest value is at 400 km and it is 1.4 dB. Moreover, ∼80% of the estimations are within 1 dB of error at 400 km. This percentage grows to ∼92% at 800 km, then it reaches the 100% for larger distances. Furthermore, at 4000 km, all the errors are within 0.5 dB. Fig. 3(h) shows the error distribution per modulation format. The PM-QPSK is the modulation format presenting the lower error while PM-16QAM is the one affected by larger inaccuracy. This is related to the inaccuracies being larger at shorter distances and smaller at longer distances.

3. Conclusions

We shown the accuracy of the QoT-E of the open source GNPy library in predicting the GSNR for different modulation formats in a multi-vendor, full C-band, Raman amplified scenario. We used data programmatically obtained by the SDN controller and the accuracy of predictions against experimental measurements is within 1 dB for more than 90% of the cases, for distances from 400 km up to 4000 km.

References

1. V. Curri et al, "*Elastic all-optical networks: A new paradigm enabled by the physical layer. How to optimize network performances?,*" JLT , 35, p 1211, 2017.
2. T. Zhang et al, "*A WDM Network Controller With Real-Time Updates of the Physical Layer Abstraction.*", JLT, 37, pp. 4073-4080, 2019.
3. G. Grammel et al, "*Physical simulation environment of the telecommunications infrastructure project (TIP).*", OFC, pp. M1D-3, 2018.
4. J. Auge et al, "*Open optical network planning demonstration.*", OFC, pp. M3Z-9, 2019.
5. "*GNPy*", DOI: 10.5281/zenodo.3458320, https://github.com/Telecominfraproject/oopt-gnpy
6. M. Filer et al, "*Multi-vendor experimental validation of an open source QoT estimator for optical networks*", JLT, 36, p 3073, 2018.
7. A. Ferrari, et al. "*A Two-Layer Network Solution for Reliable and Efficient Host-to-Host Transfer of Big Data.*" ICTON, pp. 1-4, 2018.
8. M. Cantono et al, "*Physical layer performance of multi-band optical line systems using raman amplification.*", JOCN, 11, pp. A103-A110, 2019.
9. M. Cantono et al, "*On the interplay of nonlinear interference generation with stimulated Raman scattering for QoT estimation*", JLT, 36, pp.3131-3141, 2018.
10. J. Bromage "*Raman amplification for fiber communications systems.*" JLT, 22, p 79, 2004.
11. D. J. Elson, et al. "*Investigation of bandwidth loading in optical fibre transmission using amplified spontaneous emission noise*", Optics express, 25, pp. 19529-19537, 2017.