Using QoT-E for Open Line Controlling and Modulation Format Deployment: an Experimental Proof of Concept

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Abstract *We propose open line controlling and a modulation format setting based on GNPy GSNR evaluation, and test an experimental setup including an 8-span line equipped by commercial EDFAs, transporting two wavelengths from the open box Cassini. Excellent results are shown for GSNR flattening and prediction.*

Introduction

Network operators as well as public institutions have done, and are still doing, large CAPEX investments to install optical cables to support high-capacity data networks. Their aim is to fully exploit such infrastructure to fulfill the fast increasing data traffic demand and its modifications[1], recently enhanced by the global pandemic emergency[2]. Therefore, they are targeting the implementation of the open optical network (OON) paradigm to enable a full and flexible hardware exploitation and possible fiber sharing, as well as network virtualization and slicing down to the physical layer[3]. OON also permits a mix-and-match best-of-breed strategy with respect to vendor equipment, determining significant cost reduction. OON has been enabled by the introduction of coherent optical technologies for which optical transport can be simplified as transmission over transparent lightpaths (LP) impairing transmission as additive Gaussian channels. Consequently, the quality-of-transmission (QoT) can be summarized by the generalized signal to noise ratio (GSNR)[4],[5]

$$GSNR = \frac{P_{CUT}}{P_{ASE} + P_{NLI}} \,, \qquad (1)$$

where P_{CUT} is the power of the channel under test, P_{ASE} and P_{NLI} are the accumulated ASE noise from in-line amplifiers and NLI due to nonlinear fiber propagation, respectively. So, transmission optimization can be summarized as the maximization of the GSNR related to each optical line[6] and its flattening on the transmission bandwidth to get a uniform QoT for all wavelengths.

In this work, we propose to use of a QoT estimator (QoT-E) to predict the GSNR and to configure consequently the gain and tilt of amplifiers, executed from an open line controller. Then, we use the QoT-E to evaluate the available GSNR on a given LP, and consequently set the feasible modulation format for flex-rate transceivers. For QoT-E we use the GNPy open source library[7],[8] from the Telecom Infra Project[9] whose reliability has been extensively tested, including commercial multi-vendor equipment[10]. The results refer to an experimental setup exploiting an open coherent switch Edgecore Cassini[9] equipped with two CFP2-DCO modules by Lumentum, operating over an 8-span ITU-T G.652A fiber line, amplified by commercial EDFAs. We developed a Python open line controller interacting with GNPy that aims at maximizing and flattening the GSNR on the C-band by setting EDFA gain and tilt, then we require GNPy to set the feasible modulation format by comparing the GNPy-evaluated GSNR to the Cassini data models for each available modulation format. We tested and verified the experimental setup, showing excellent results for both GSNR flattening by the line-controller and modulation format setting. Four distances (2, 4, 6 and 8 spans) and two BER thresholds (10^{-3} and 10^{-2}) are tested. GSNR flattening is observed consistently within 1 dB, and GNPy predictions are always conservative and accurate within 1 dB, so enabling a reliable and potentially low-margin modulation format deployment. Results are expected to improve further with more accurate fiber loss characterization, that in this work has been considered as flat vs. frequency.

Controller Architecture & Experimental Setup

The experimental demonstration we are proposing relies on the network architecture description represented in Fig. 1, where the network controller operates the lines and LP deployment relying on the software abstraction of the optical

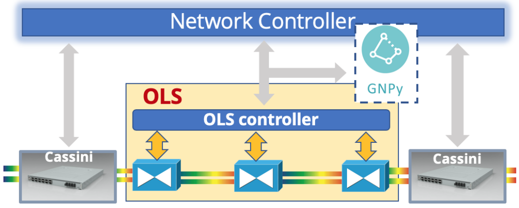

Fig. 1: Representation of the network architecture.

transport by GNPy. Starting from a generic optical fiber network, the focus is on the control of a single open line system (OLS) in order to optimize and flatten the GSNR to maximize transport capacity. For this purpose, an OLS controller has been developed to support and automatize the management of the optical amplifiers, autonomously setting their gain and tilt. The OLS controller collects information from the equipment and provides the line description to GNPy, so different gain and tilt values are autonomously and virtually tested targeting the GSNR maximization and flattening over the C-band. Then, the best gain and tilt for each amplifier are set and the line is ready to be operated. In particular, GNPy defines the OLS operations on the base of a physical layer description that takes into account the main characteristics of each fiber span – i.e. chromatic dispersion, effective area, Raman efficiency, loss and length – and an estimation of the connector losses. In this work, we provide a liberal description fiber for losses by considering flat loss coefficient, which is a rough approximation for ITU-T G.652A fiber. Therefore, we expect further improvements by considering a more accurate frequency-resolved loss description. Once the line is set to the target operational point, for each considered distance, the automatic modulation format deployment is implemented: GNPy is queried in order to get a GSNR evaluation on the base of the OLS setting, and channel spectral placement. Then, the GSNR value provided by GNPy is compared to the per-format GSNR requests obtained by the back-to-back flexible Cassini characterization as BER vs. OSNR, and supposing the BER threshold. We tested two possible BER thresholds: 10^{-3} and 10^{-2}.

Fig. 2(a) depicts the schematic block of the setup that we implemented in order to collect the experimental data set. The goal is to generate 80 channels, 50-GHz spaced, 32 GBaud each, assembled in a C-band WDM comb centered at 193.3 THz, and propagate it through an amplified optical line. The optical line is comprised of 8 spans, each based on an 80 km standard ITU-T G.652A fiber spool, and commercial EDFAs operating in constant gain mode, whose gain and tilt values are set by the OLS controller according to GNPy indications. Two modulated channels are tested (CUT 7 centered at 191.65 THz and CUT 73 centered at 194.95 THz), and the remaining C-band is filled with ASE-shaped channels. A commercial programmable wave shaper filter (1000S from Finisar) is used to shape the output of an ASE noise source, generating 78 channels that, coupled with the two channels under test, assemble the 80 channels optical line system spectral load (Fig. 2(c)), with no loss of generality because of the large time constant that characterizes the physical effects within EDFAs. The two CUTs are generated by the Edgecore Cassini AS7716-24SC[9]: an open transponder proposed by the TIP to enable network operators to easily extend and migrate existing metro and long-haul Dense WDM networks to add new 100G-200G capacities and extend inter-datacenter and Layer 3 services all in an open network platform. The Cassini can host up to 8 pluggable ACO or DCO transceivers. In this work, two flexible CFP2-DCO coherent modules from Lumentum[11] are used and programmed in order to generate two independent signals and to detect and continuously monitor the related BER and GSNR, providing an updated average value every 15 seconds. Available modulation formats and rates are summarized in Tab. 1.

	QPSK	8-QAM	16-QAM
Bit Rate [Gbps]	100	200	200
Baud Rate [GBaud]	32	42.667	32

Tab. 1: Lumentum CFP2-DCO modulation formats and rates.

Results

Firstly, for each modulation format summarized in Tab. 1, we evaluated the back-to-back performance of both CUTs computing the BER vs. OSNR curve, obtained measuring the noise loading at the receiver section through an Optical Spectrum Analyzer (OSA). Then, the line controller is run and EDFAs are set. So for each considered distance, GNPy is probed in order to get the GSNR prediction and set the feasible modulation format, according to the back-to-back characterization and BER threshold hypothesis. To verify the process worked properly, we experimentally measured the real BER and corresponding GSNR. BER measurements confirm the capability to reliably set the feasible modulation format for each distance and both CUTs. To measure

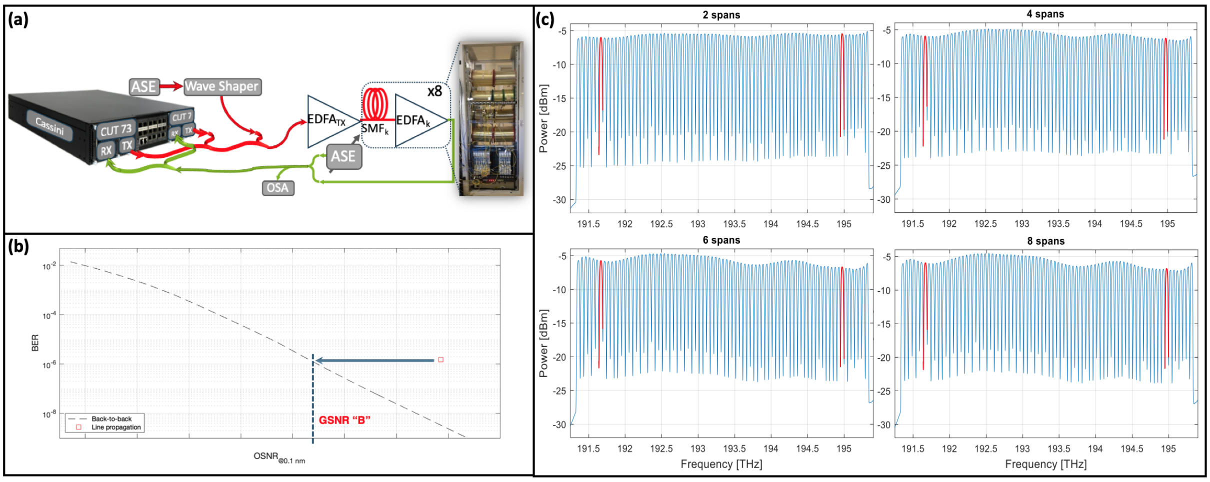

Fig. 2: (a) Experimental setup, (b) GSNR "B" evaluation method, (c) received WDM comb spectra for different line lengths.

	GNPy prediction			QPSK		8-QAM		16-QAM	
	CUT 7	CUT 73	Method	CUT 7	CUT 73	CUT 7	CUT 73	CUT 7	CUT 73
2 spans	22.1	22.1	A	25.4	26.0	**24.6**	**25.3**	**27.8**	**27.8**
			B	24.5	25.6	**25.1**	**26.3**	**27.2**	**26.3**
4 spans	20.5	20.6	A	**21.4**	**22.6**	21.2	21.8	**22.6**	**23.5**
			B	**20.7**	**21.7**	21.3	22.3	**21.8**	**22.3**
6 spans	19.1	19.1	A	**19.6**	**21.7**	**19.5**	**21.0**	19.9	21.7
			B	**18.9**	**20.8**	**19.7**	**21.3**	–	21.3
8 spans	18.8	18.8	A	**19.8**	**21.0**	**19.5**	**20.7**	19.9	21.2
			B	**19.0**	**20.3**	**19.7**	**21.0**	–	20.8

Tab. 2: GSNR values in 0.1 nm and dB. Blue numbers refer to 10^{-3} BER threshold, green ones to 10^{-2}.

the GSNR and quantitatively compare it to GNPy prediction we use two different methods: method A reads the value directly form the Cassini, while method B reads the measured BER from the Cassini and uses the back-to-back characterization to "translate" the BER value into the corresponding GSNR, as graphically explained in Fig. 2(b). Fig. 2(c) shows the received spectra at different distances. Results are summarized in Tab. 2. as GSNR values in 0.1 nm in dB units for the two CUTs at each distance. For all cases we measure less than 1 dB difference between the GSNR measured with the two methods, and method B always smaller then method A. GNPy predictions are always accurate and conservative, except for the case of 6-spans, CUT 7 for which only method B GSNR is 0.2 dB smaller than the predicted value. In any case, for all cases, the modulation format feasibility is correctly predicted by GNPy with large margin. From measurements, we observe that CUT 73 always behaves about 1 dB better than CUT 7, contrary to the line controller flattening setting and consequent GNPy predictions. This is caused by considering fiber loss as flat, which is a loose approach for fibers impaired by the water-peak absorption. In general, results are very good and show that optical lines can be effectively and reliably controlled by an open controller based on QoT-E also setting the feasible modulation format with excellent accuracy, even in case of loose description of fiber loss.

Conclusions

For the first time, to the best of our knowledge, we have experimentally shown a proof of concept of open line controlling and modulation format feasibility. We have developed a Python line controller that sets amplifiers' gain and tilt to maximize and flatten GSNR relying on GNPy for QoT-E and also for modulation format feasibility. We tested experimentally the method on an 8-span line loaded with two Lumentum CFP2-DCO channels with the Cassini open transponder and equipped with commercial EDFAs. GSNR flattening for line controlling and prediction for modulation format deployment displayed excellent accuracy and consistency within 1 dB. Results are expected to further improve by relying on a more accurate physical layer description, mainly for fiber loss.

Acknowledgements

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