QoT-E Driven Optimized Amplifier Control in Disaggregated Optical Networks

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Abstract: We propose a vendor-agnostic framework exploiting QoT estimation to control EDFA settings targeting maximum GSNR average and flatness. We demonstrated its effectiveness by an experimental proof of concept exploiting open HW and SW by TIP.

1. Introduction

Internet traffic is envisioned to prosecute the geometrical growth over the next years with a further increase amid the *new normality* forced by the ongoing pandemic emergency [1]. To cope with such a scenario, network operators target the implementation of some disaggregation in their network infrastructure to implement SDN controlling that enables a better exploitation of available infrastructures [2]. The first step in this direction is the deployment of partly disaggregated optical networks for which ROADM-to-ROADM amplified optical lines may be independent WDM optical line systems (OLS)s from different vendors [3].

In transparent optical networks operated by coherent optical technologies, it has been extensively proven that the quality of transmission (QoT) is defined by the generalized SNR (GSNR), enabling a full physical layer abstraction by a graph weighted by the GSNR degradation induced by each network element or subsystem [4]. Mainly, GSNR degradation is caused by transparent propagation through OLSs, so a crucial role to maximize transmission capacity is the optimization operated by the OLS controller in setting the working point of amplifiers in order to minimize the impairment. Thus, in order to ensure a performative and equally distributed transmission over the entire spectrum, the target of the OLS controller can be mathematically formalized as the maximization of the GSNR average and flatness by properly defining the setting parameters of amplifiers, that generally are the gain and tilt values.

We exploit GNPy [5] as QoT estimator (QoT-E) and we propose an optimization method for amplifier control based on an evolutionary algorithm. We experimentally tested the proposed method on a full spectral load propagated through an 8–span line amplified by commercial EDFA used as black-boxes and carrying modulated channels from a Cassini box equipped with Lumentum pluggable transceivers and shaped noise. Results show an excellent efficiency of the proposed method that enables the definition of an optimal EDFA setting ensuring maximum average GSNR larger than 21 dB and residual tilt smaller than 0.1 dB/THz.

2. Amplifier Gain Optimization

Our investigation starts from a disaggregated optical network framework in which the operation of each node is under the supervision of an optical network controller (ONC). Contextually, each OLS between two adjacent nodes is supervised by an optical line controller (OLC) which in turn exchanges information with the ONC (Fig. 1). Based on the the ONC requests, the OLC is able to drive the amplifiers' operation providing for each of them the configuration of gain and tilt to correctly set the OLS working point. In this work, we provide an optimization framework that is able to define the optimal working point of the line in order to maximize the capacity using a given physical layer description of the OLS. The latter condition is achieved through the combination of a QoT-E

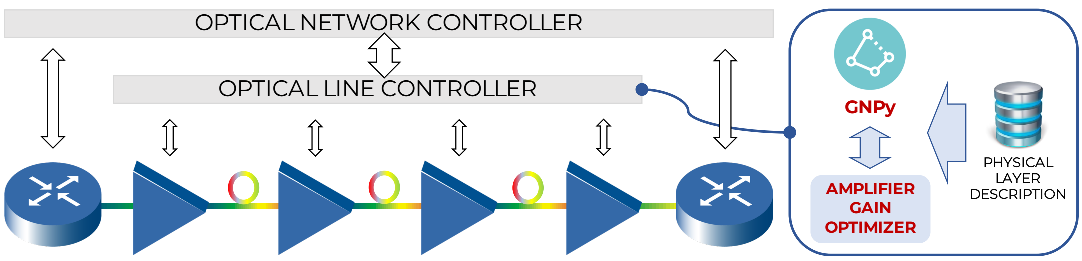

Fig. 1. Contextualization of the developed QoT-E driven optimized amplifier control strategy.

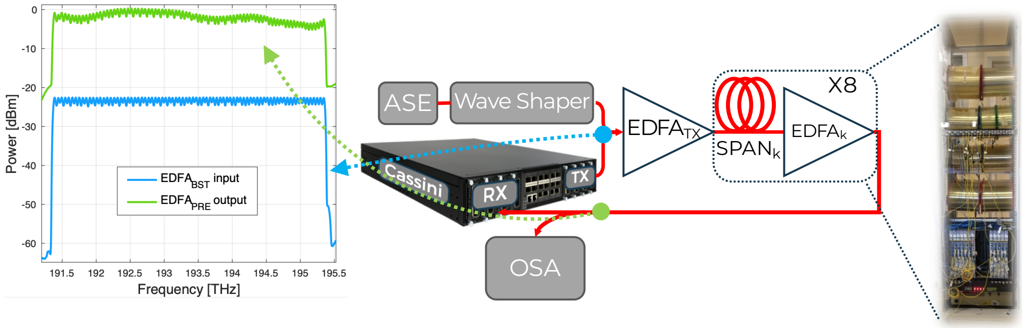

Fig. 2. Experimental setup and OSA measurements of the transmitted and received spectra.

and an optimization algorithm. The significant advantage of this control strategy is given by the agnostic approach with respect to the installed resources because the OLS operation is defined only once, after the physical layer description has been collected, without the use of power sweep procedures.

In this work, we use the already validated and open source Python library GNPy [6] as QoT-E and we propose as optimization algorithm a stochastic algorithm called covariance matrix adaptation evolutionary strategy [7] that results to be extremely effective in case of problem with highly nonlinear space and large problem dimension. Given the OLS physical layer description, GNPy allows to emulate the propagation of the input spectrum through the described OLS. In particular, the purpose of GNPy as QoT-E is to evaluate the GSNR at the output of the OLS for a given configuration of amplifiers. Regarding the optimization framework, its purpose is to define the amplifier configuration that maximally satisfies the ONC request. During the optimization process, the algorithm evaluates the status of the OLS for the generated population of the amplifier configurations. Every amplifier configuration consists of a couple of average gain G and tilt T values for each amplifier, including the booster and the pre-amplifier. So, the problem dimension is two times the number of amplifiers present in the OLS. Since our aim is to maximize the transmission system capacity, the objective function is built in order to have at the OLS output the GSNR profile with maximum average, maximally flat and minimally spread around its mean value. For this reason, the fitness of each generated configuration is evaluated as follows:

$$\max_{G_i,T_i} \left\{ \overline{\text{GSNR}}(G_i,T_i) - \sigma_{\text{GSNR}}(G_i,T_i) \right\} , \tag{1}$$

where i is the index related to the specific amplifier, $\overline{\text{GSNR}}(G_i,T_i)$ and $\sigma_{\text{GSNR}}(G_i,T_i)$ are the GSNR average and standard deviation for the given amplifier configuration, respectively, in dB units. Since all the terms of the presented objective function are positive, the achievement of the maximum GSNR is targeted taking the actual $\overline{\text{GSNR}}$ while the GSNR profile flatness is achieved considering the σ_{GSNR} with the minus sign as an additional penalty that mitigates the final fitness computation.

3. Experimental Setup and Results

Fig. 2 depicts the experimental setup that we have used to emulate the OLS under test, composed of a booster amplifier and 8 fibers spans, each approximately 80 km long, with a mixture of single mode fiber types, characterized by distinct physical parameters and followed by a commercial EDFA operating with distinct and constant gain and tilt values. A commercial programmable WaveShaper© (1000S from Finisar) is used to manipulate an ASE noise source output in order to generate a 80 channel WDM comb, centered at 193.35 THz with a WDM grid spacing of 50 GHz within the C-band, according to ITU-T specifications. We consider 9 independent channels under test (CUTs) over the 80 channels in order to have an equally distributed sampling of the spectrum; for these CUTs, the signal transmission is managed by a commercial AS7716-24SC Cassini device, along with a CFP2-DCO coherent module from Lumentum, configured in order to generate and detect a 32 GBaud, polarizaion-multiplexed quadrature phase shift keying (PM-QPSK) modulated signal. At the output of the OLS, we measure the BER in transmission for each CUT while 1% of power is split and provided to an optical spectrum analyzer (OSA) in order

Table 1. Optimal amplifier configuration found by the evolutionary algorithm.

	BST	AMP_1	AMP_2	AMP_3	AMP_4	AMP_5	AMP_6	AMP_7	PRE
G [dB]	19.9	17.6	19.5	17.0	19.7	19.7	17.1	19.5	16.7
T [dB]	1.5	1.5	1.4	1.4	0.3	0.4	-1.5	0.1	1.4

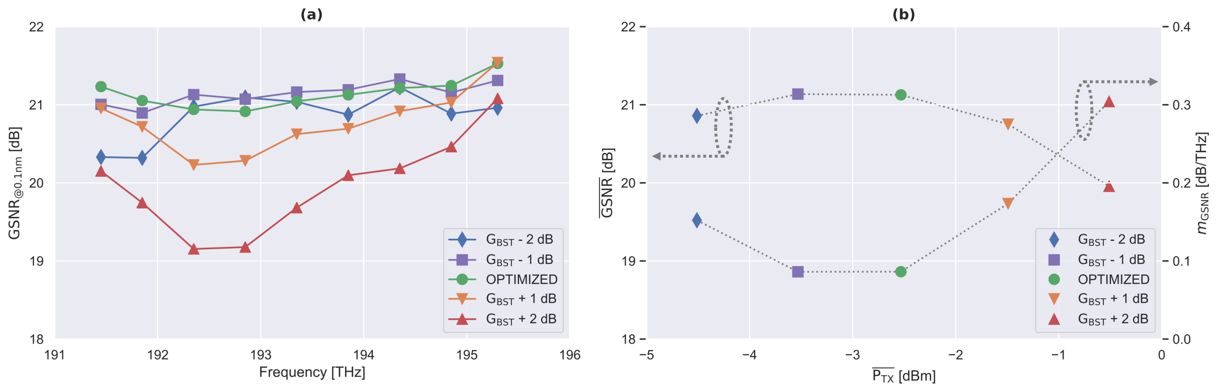

Fig. 3. Experimental results at optimal OLS configuration with $G_{\mathrm{BST}} = G_{\mathrm{BST,OPT}} \pm 2$ dB: (a) GSNR profiles, (b) GSNR aggregated metrics: average and linear regression coefficient.

to evaluate the CUT OSNR and the power levels of all 80 channels. An example spectrum power measurement performed using the OSA is shown in Fig. 2. From these quantities we obtain a quantitative estimation of the GSNR by inverting the BER vs. the OSNR curve obtained through a progressive back-to-back noise loading characterization [6]. The complete physical layer description of the presented setup has been produced characterizing each span in terms of fiber properties [8] and EDFA behaviours. In addition, the penalties related to the receiver site have been probed and adequately characterized in order to have a residual impairment that is comparable with measurement error. The optimization framework is set to determine the optimal amplifier configuration of 18 variables (9 gains, 9 tilts) where each average gain ranges from 14.5 dB to 20.0 dB and each tilt goes from -1.5 dB to 1.5 dB. The gain tilt is referred to the C-band in frequency ($\simeq$ 4 THz). Therefore, it is expressed in dB as the distance between the extremes of the applied gain profile.

Completed the optimization process, the final amplifier configuration is reported in Tab. 1. Given this parameter set, we perform five different experiments varying the average gain of the booster from -2 dB to + 2 dB with steps of 1 dB. With this power sweep approach, observing the characteristics of the GSNR profile, it is possible to experimentally demonstrate that the optimal working point evaluation is significantly effective. The five experiments are summarized in Fig. 3. Starting from the observation of the aggregated metrics in Fig. 3(b), it is possible to assert that the expected optimal configuration produces the best outcome in terms of maximum GSNR with the maximum flatness, with an average of about 21.1 dB and, given the linear regression of the profile vs. frequency, a coefficient of less that 0.1 dB/THz. It is possible to strengthen this thesis focusing on the experimental GSNR profiles in Fig. 3(a). Starting from booster gain values lower than the optimized one, it is evident that the blue and violet curves have a shape characteristic of the linear regime. On the other hand, going beyond the optimized booster gain level, the orange and the red profiles are clearly dominated by non-linearity.

4. Conclusions

We proposed a vendor-agnostic control procedure for optical amplified lines based on the maximization of GSNR average and flatness. Through an experimental proof-of-concept, we show the effectiveness of the proposed method using GNPy as QoT-E and a genetic algorithm for optimization. We show that the proposed framework enable to set an 8–span amplified line to operate at maximum average GSNR exceeding 21 dB and with a residual tilt lower than 0.1 dB/THz.

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