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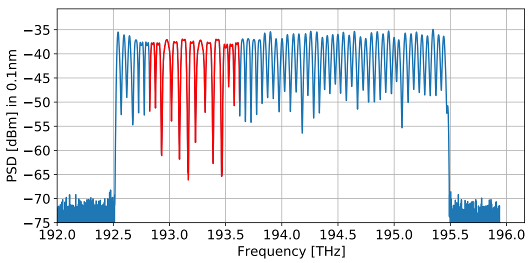
Abstract: We demonstrate accurate GSNR predictions for a flex-grid and flex-rate experimental transmission using an enhanced implementation of the open-source GNPy library for a 1600 km OLS, involving QPSK, 8-QAM and 16-QAM modulation formats.

1. Introduction

Network operators firmly request vendor-neutral solutions for network planning and management that fully and cost-effectively exploit optical network infrastructures in order to cope with continuously increasing internet traffic [1]. To pursue such an objective, groups such as the Telecom Infra Project (TIP) have formed, developing open hardware and software networking solutions alongside major industrial vendors and selected academic institutions. Within the TIP, the GNPy project targets the development of open-source software for the planning and management of optical networks; optical transport is abstracted using the generalized signal-to-noise ratio (GSNR) as a quality of transmission (QoT) parameter for transparent lightpaths deploying dual-polarization coherent optical technologies [2]. The GNPy software environment has been developed and extensively tested with excellent results in terms of accuracy and computational time for both greenfield and brownfield fixed-grid and fixed-rate scenarios [3].

To fully implement the elastic optical networking paradigm, extending transmission from fixed-rate to flex-rate scenarios has gained interest; in this regime, carriers transmit signals with a variety of different symbol rates, presenting a more flexible and promising solution to capacity problems, allowing existing network transmission limits to be surpassed with minimal CAPEX impact [4, 5]. Following this mindset, GNPy has been enhanced to manage this novel wavelength division multiplexing (WDM) transport scenario by introducing a spectrally disaggregated approach in the evaluation of the nonlinear interference (NLI) disturbance that is caused by self- and cross-channel nonlinear crosstalk. In this work, for the first time, we experimentally test this enhanced version of GNPy in a flex-grid, flex-rate transmission scenario. These transmission experiments have been carried out at Orange laboratories on a multi-span amplified optical line that is spectrally loaded with 55 channels within the C-band, involving a mixture of quadrature-phase shift keying (QPSK), 8-QAM (quadrature amplitude modulation) and 16-QAM modulation formats, with symbol rates ranging from 28 to 44 GBaud. The accuracy of this GNPy implementation is assessed by translating the BER values measured by the commercial transceiver into corresponding GSNR values utilizing the transceiver back-to-back characterization.

(a)



(b)

Fig. 1: (a) Laboratory Setup, (b) Equalized optical spectrum as measured by the OSA at the input of the OLS; the spectral region of interest is highlighted in red.

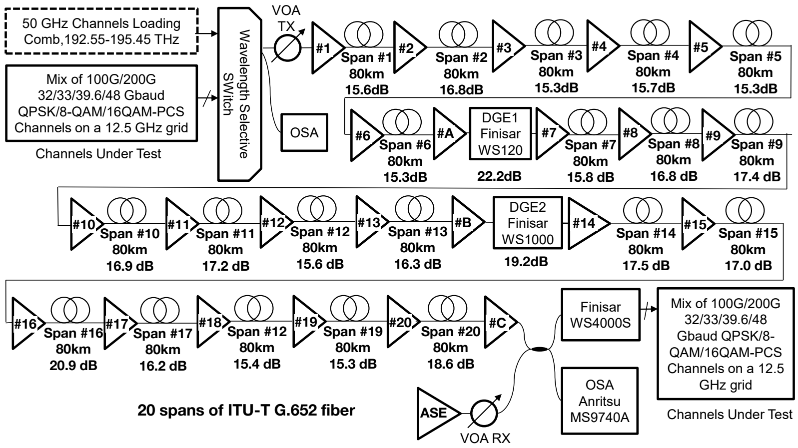


Fig. 2: A flow diagram showing the entire line used for transmission within this experiment.

2. Experimental Setup

The experiment performed in this work was carried out at Orange laboratories in Lannion, France, pictured in Fig. 1a. A detailed schematic of the OLS under investigation is given in Fig 2; the OLS consists of 20×80 km spans of ITU.T G.652 fiber that are characterized by mean losses of 16.6 dB. After each fiber span a JDSU WRA 200 erbium doped fiber amplifier (EDFA) is used to fully recover the fiber loss, operating in a constant gain mode. All EDFAs operate with a -1 dB tilt (expressed in dB per wavelength) in order to compensate for the SRS effect. As shown in Fig 2, after both the 6th and 13th spans, dynamic gain equalizers (DGEs) have been used to equalize the spectrum by compensating for both the amplification ripples and the residual tilt introduced by the SRS.

An example of the transmitted signal measured by a MS9740A Anritsu optical spectrum analyzer (OSA) is shown in Fig. 1b. A total of 55 channels have been considered within this experimental framework; these channels have been organized in a flexible WDM grid with a minimum division of 12.5 GHz located between 192.55 THz (1556.96 nm) and 195.45 THz (1533.86 nm) within the C-band. We designate a region of interest ranging from 192.85 THz (1554.53 nm) to 193.6 THz (1548.51 nm), containing 8 channels under test (CUTs) from four different industrial vendors, as described in Table 1. This sub-region is multiplexed by a wavelength selective switch (WSS), overlaid upon a loading comb consisting of 33 QPSK-modulated 100 Gbit/s channels mostly with a symbol rate of 28 Gbaud within a 50 GHz grid. These CUTs are transmitted with a bit rate of 200 Gbit/s, symbol rates of 39.6 Gbaud, and two modulation formats; 16-QAM with probabilistic constellation shaping (PCS) and QPSK.

In order to analyze the QoT of this experiment, the CUT signals are demultiplexed using a Finisar Wave-Shaper 4000S and received at the OLS termination. The GSNR measurement is performed with a noise loading procedure that changes the attenuation of a variable optical attenuator (VOA) in front of an amplified spontaneous emission (ASE) noise source. The resulting bit-error-ratio (BER) curve that is read from the transceiver card is then compared with the corresponding back-to-back BER curve, obtaining an estimation of the GSNR [3]. Additionally, at each CUT the OSNR was measured using the noise floor when the corresponding channel is turned off using the OSA. Using these GSNR estimations and OSNR measurements it is possible to evaluate $\mathrm{SNR}_{\mathrm{NL}}$ that is generated during transmission.

3. Results and Analysis

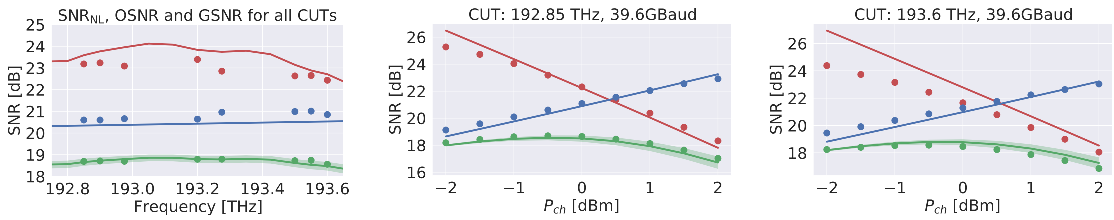
In order to analyze the GSNR responses of the OLS a series of experimental measurements were performed; the entire spectral load was transmitted at a flat power per channel, P_{ch}, ranging from -2 to 2 dBm in 0.5 dB intervals.

Table 1: A description of the spectral sub-region of interest. This region is subdivided in terms of the occupied frequency interval, Δf, the number of channels, N_{ch}, the symbol rate, R_s, and the modulation format, M.

Δf [THz]	192.85–192.975	193.05–193.125	193.2–193.275	193.35–193.45	193.5–193.6
N_{ch}	3	2	2	2	3
R_s [GBaud]	39.6	44	39.6	44	39.6
M	16-QAM PCS	8-QAM	QPSK	8-QAM	16-QAM PCS

To model these results, we performed simulations using an enhanced implementation of the GNPy engine. This enhancement upon the standard GNPy library has been performed in order to accommodate both flex-rate and flex-grid spectral formats, as well as the corrections described in [6, 7]. In order to provide the GNPy engine with a reasonable noise figure (NF) estimate we take the OSNR as measured at the OLS termination with a fixed launch power per channel of 1.5 dBm. In this power configuration, a GNPy transmission simulation of the entire line is then performed such that every amplifier produces the same amount of ASE, considering a unitary NF. In this way, we recover the evolution of the expected ASE noise profile; comparing this with the measured OSNR allows an accurate estimate of the true NF to be deduced. Another important parameter which is not known with full accuracy is the connector loss for each fiber span; we set a fixed value of 0.5 dB for all fibers.

In Fig. 3a we show the GSNR, OSNR and SNR_{NL} for all CUTs in the optimal input power configuration in terms of QoT (-0.5 dBm). These results show that the enhanced GNPy simulation provides a good estimation accuracy for both the linear and nonlinear impairments, giving an accurate final GNSR prediction, with a maximum deviation of 0.2 dB. In Fig. 3b and Fig. 3c we present the power sweep results for the two CUTs on the edge of the spectral region of interest. As with the optimal input power scenario, the GNPy GSNR predictions have a good level of accuracy along the entire power sweep, with a maximum error of 0.8 dB – this demonstrates that the enhanced GNPy implementation functions as a reliable QoT estimator for the system under investigation.



(a) (b) (c)

Fig. 3: (a) The measured and simulated SNR_{NL}, OSNR and GSNR values for all CUTs in the optimal input power per channel scenario (-0.5 dBm). (b), (c) Power sweeps for two selected channels. For all plots, the red, blue and green circles are the SNR_{NL}, OSNR and GSNR values as measured from the OSA at the line termination; the coloured lines show the respective simulated GNPy values. The shaded area surrounding the green solid lines represents the variation of the GSNR prediction varying the connector loss within a 0.5 dB range.

4. Conclusion

Within this work we present an enhanced implementation of the GNPy engine that is able to accurately model experimentally measured GSNR in a flex-grid, flex-rate transmission scenario. The performance of this implementation was tested using an experiment demonstrating that this model may be used as a reliable QoT estimator when utilizing the GSNR.

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