Exploring Service Margins for Optical Spectrum Services

Kaida Kaeval(1,5), Frank Slyne(2), Sebastian Troia(3), Eoin Kenny(4), José Pedreño Manresa(1),
Sai Patri(1), Klaus Grobe(1), Daniel Kilper(2), Marco Ruffini(2), Gert Jervan(5)

(1) ADVA, kkaeval@adva.com
(2) Trinity College Dublin, SLYNEF@tcd.ie
(3) Politecnico di Milano, sebastian.troia@polimi.it
(4) HEAnet, eoin.kenny@heanet.ie
(5) TalTech, gert.jervan@taltech.ee

Abstract *Reliable operation of Optical Spectrum Services requires a good understanding of service margins. We investigate the Optical Spectrum Service margins under varying channel-load and Optical Signal To Noise Ratio (OSNR) conditions in the Open Ireland testbed and verify the findings in the HEAnet production network. ©2022 The Author(s).*

Introduction

Continuous research and development on automation and operation simplifications in disaggregated networks encourage network operators and service users to implement Optical Spectrum as a Service (OSaaS)[1],[2]. Identified by continuous access to the Open Line System (OLS) spectrum, OSaaS enables customers to freely select their operation margins depending on end application, perform signal pre-emphasis, and upgrade transponders as desired. Along with machine-learning techniques for performance estimation, OSaaS is of interest to increase the efficiency of using the spectral resources.

The achievable throughput of the OSaaS is defined by the performance over the specific spectral slot, and must be accurately determined. Information on OLS system components, channel load, OSNR of the route, and OSaaS service configuration is often sensitive to the service provider. This complicates the service performance and end-of-life margin calculations using the conventional methods, like open or proprietary Quality of Transmission (QoT) tools. As an alternative, the channel quality can be determined through channel probing measurements[3], which provide an estimate of a generalized signal to noise ratio (GSNR) QoT. This approach was shown to provide a full OSaaS characterization[4]. In this work, we investigate the margins required for this probe-based GSNR that would allow for direct neighbouring signals to get added after the initial service characterization. In addition, we examine the end-of-life scenario of gradual channel allocation onto OLS systems that are initially lightly populated. We use variable symbol-rate probing[5] over varied OSNR and channel-load conditions in TCD's Open Ireland beyond 5G testbed in the CONNECT research centre[6] and verify the lab results in a live production network from Ireland's National Research Network Operator HEAnet. Finally, recommendations for margin allocation are provided.

Test set-up

The set-up in the Open Ireland optical lab, shown in Fig. 1, utilizes a colourless add/drop with an 8:1 splitter/combiner (8PSM) and EDFA, two Lumentum reconfigurable optical add/drop multiplexers (ROADMs) with built-in boosters and pre-amplifiers, two 25 km fibre spools and two additional Lumentum ROADMs for amplified spontaneous emission (ASE) channel loading. Four different OSNR conditions were created by attenuating the power from the ROADM Tx port through the variable optical attenuator VOA-2.

A single 400-GHz wide optical media channel was configured for the OSaaS under test (CuT), and four carriers spaced 100 GHz apart were used inside the OSaaS, each configured to 200-Gbit/s DP-QPSK 69-GBd for OLS levelling.

For channel loading, continuous ASE noise was generated using the amplifiers in the Lumentum 1 and 2 ROADMs. Then, the ASE was shaped to 37.5 GHz bandwidth with 50 GHz spacing between each central frequency using the Wavelength Selective Switches (WSS) of ROADMs Lumentum 1 and 2. All pseudo channels for channel loading were levelled at the output of the second ROADM and enabled or disabled by VOA-1. Channel load conditions

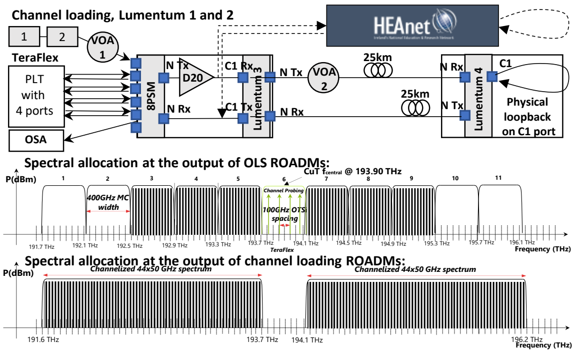

Fig. 1: Test setup in Open Ireland testbed

were varied by enabling 400-GHz wide OSaaS services within the ROADMs Lumentum 3 and 4.

For live network verification, the output power from the D20 amplifier was connected to the ROADM C-port at the entrance node in HEAnet's network. The connection to the short or long route was changed by switching the optical connection within an optical fibre switch that enables remote topology configuration (Polatis series 7000).

The Probing Light Transceivers (PLTs) were implemented using ADVA reconfigurable TeraFlex transceivers, providing 100 Gbit/s to 600 Gbit/s capacity per carrier by adjusting the modulation format and symbol rate. A total of seven PLT configurations were characterized and used to evaluate the QoT of the OSaaS under test. Constant PSD was maintained in the system by adjusting the Tx power of the PLT.

Results

The measurements from the TCD lab, presenting the GSNR values determined by comparing the received Q value to the back to back characterization curves of the transceiver are presented in Fig. 2. The y-axis presents absolute values for candidate GSNR estimations based on the measurements with different PLT configurations of a single transceiver. The four shaded areas present the OLS conditions after modifying the VOA-2 in the test set-up, leading to four received OSNR conditions as perceived by 200-Gbit/s DP-QPSK 69-GBd in …..I….. (i.e., single channel) load conditions: 30 dB, 27dB, 23dB, and 19dB, respectively. The x-axis presents nine symbols for channel load conditions, where each I and (.) stands for enabled or disabled ASE-loaded 400-GHz OSaaS service blocks from Fig. 1. Marker styles indicate different PLT configurations and the green dashed horizontal lines the required GSNR based on the transceiver specification documentation for the highest working verification signal, tested under specific VOA-2 settings. In Fig. 2, the minimum variation over all estimated GSNRs is at 14 dB GSNR, and the highest variation is observed near 21 dB GSNR. This also reveals that the two primary formats, 200-Gbit/s DP-QPSK and 200-Gbit/s DP-16QAM, recommended for channel probing in [3], are often the most extreme of the estimated GSNR values from symbol-rate variable probing. At high GSNR, high-symbol-rate signals are unreliable because a small change in Q leads to a large change in estimated GSNR, while the low-symbol-rate signals underestimate signal quality.

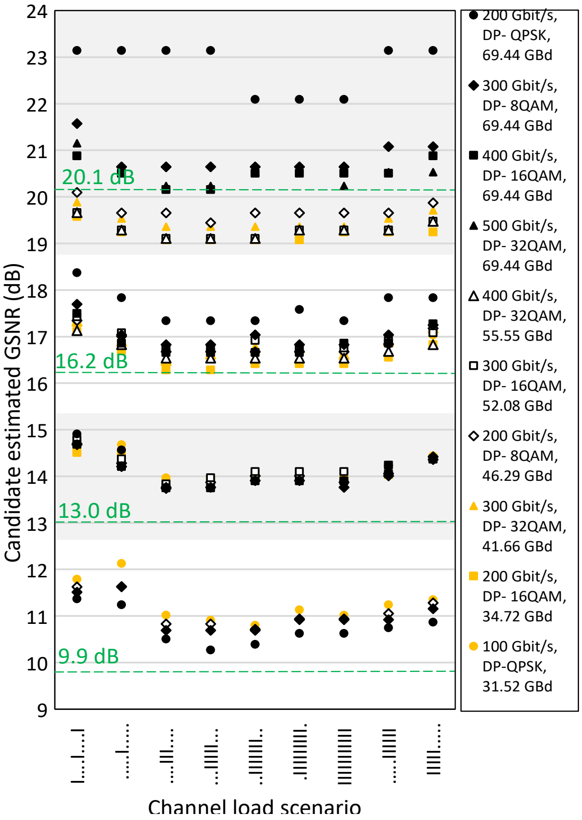

Fig. 2: Variable symbol-rate probing under nine different channel load and four different OLS conditions

Fig. 3 displays the GSNR estimation variance with the 200-Gbit/s DP-QPSK 69-GBd PLT configuration excluded. The x-axis presents OSNR conditions and the y-axis the deviation in estimated GSNR in dB. Different line styles represent different channel-load conditions. The variation in estimated GSNR is similar over different channel load conditions.

Margins for neighbouring channel impact must be estimated when providing OSaaS. For this purpose we focus on the 200 Gbit/s DP-QPSK 69-GBd signals, which showed the highest sensitivity to neighbouring channels. Fig. 4 top presents the GSNR degradation for the 200-Gbit/s DP-QPSK 69-GBd configuration for the channel under test over all nine channel-load scenarios. The x-axis presents the used channel scenario and the y-axis the GSNR degradation in dB. Line colors refer to different OSNR test scenarios. In general, the higher the spectrum allocation, the lower the impact from the addition of the direct neighbouring channels. For OSNR <27 dB, a 1.0 dB safety margin must be accounted for when operating the spectrum with 100 GHz channel spacing within the OSaaS.

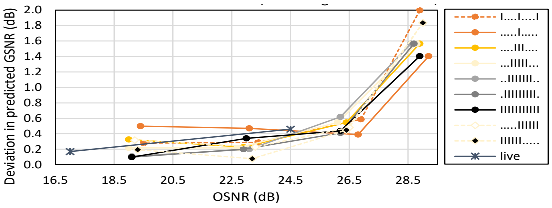

Fig. 3: GSNR deviations from symbol-rate variable probing, excluding results from 200-Gbit/s DP-QPSK 69-GBd configuration

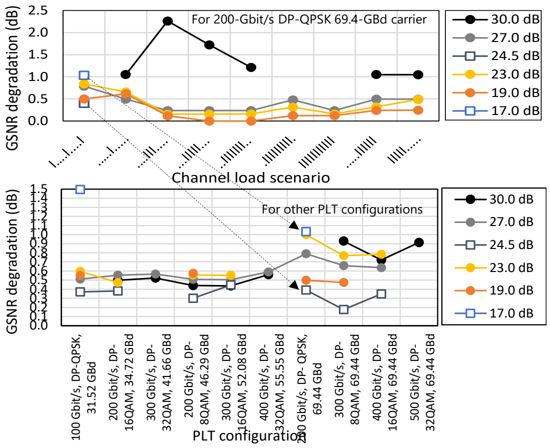

Fig. 4: GSNR degradation from enabling direct neighboring carriers within the OSaaS

Similar tests with direct neighboring channels were repeated for channel load scenario illustrated by (I….I….I), representing the lightly populated DWDM system. Symbol rate variable channel probing was then operated on a channel under test with a central frequency 193.95 THz. All other four channels within the 400-GHz OSaaS were equally distributed with 100-GHz spacing and configured as 200-Gbit/s, 69-GBd DP-QPSK. The x-axis presents the PLT configuration of the channel under test and the y-axis presents the degradation in dB relative to the no neighbours case. Line colors refer to different OSNR test-scenarios. Based on our results, PLT configurations up to 55.5 GBd experienced 0.5 dB of GSNR degradation from enabled direct neighboring channels while a variation in OSNR did not create a remarkable impact on these results. High-symbol-rate PLT configurations however had a much higher impact from neighboring channels where enabled, even though there was no spectral overlap due to 100 GHz spacing between the channels. The deviation between the two scenarios (neighbours on and off) was 0.47 to 1.0 dB, depending on the OSNR and used PLT modulation. This aligns well with the overestimation tendency of the high-symbol-rate PLT configurations in high OSNR scenarios, observed in Fig. 2.

Fig. 5 presents the margin requirements over the different channel load conditions presented on the x-axis. Line styles present the OSNR conditions. Based on the systematic lab study, up to 1.4 dB must be allocated in service margins to accommodate end-of-life channel loads, which allocated 88% of the spectrum in the lab OLS.

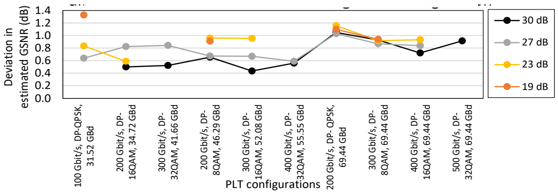

Fig. 5: EOL margin requirements

Testing was repeated on a long and short route on the HEAnet live network with 17.0 dB and 24.5 dB of OSNR and the results obtained were similar to the margins observed in the lab network. 17 dB and 24.5 dB OSNR test results from the live network are included in Fig. 3 and Fig. 4 which to illustrate the alignment between the lab and live network measurements.

The variation in GSNR-s estimated by different PLT configurations from variable symbol rate probing was 0.5 dB and 0.4 dB at 24.5 dB OSNR and 0.2 dB and 0.6 dB at 17.0 dB OSNR for the tested PLT signals at both ends of the live OLS spectrum. This aligns well with expected variations of 0.8 dB at 24.5 dB OSNR and 0.5 dB at 17.0 dB OSNR, considering the PLT measurement accuracy. On the other hand, the degradation from neighbouring channels did not align too well with the lab findings: the direct neighbour impact was up to 0.4 dB at 24.5 dB OSNR and 1.0 dB at 17.0 dB OSNR for 200-Gbit/s DP-QPSK 69-GBd test PLT configuration. However, much higher degradation was observed on one of the probes using a 100-Gbit/s DP-QPSK 31.5-GBd signal. The most probable cause for this was different probing units used for the live network and in the lab.

Conclusions

In this work, we investigate GSNR margins required to compensate for added channels within an OSaaS and also for the end of life margins required for OSaaS. Based on the systematic measurements in the Open Ireland CONNECT lab and HEAnet live network, on average, 1.0 dB GSNR margin is sufficient to cover degradation from enabling direct neighbouring carriers and an additional 1.4 dB margin allocation is required to compensate for the end-of-life channel load scenarios. Margin estimations from a live network deviated from estimations only within the measurement accuracy, except for one tested configuration on the longest live route. High symbol rate signals gave unreliable GSNR values at high OSNR and should therefore not be used for channel probing at OSNR > 27dB.

Acknowledgements

The work has been partially funded by the Bundesministerium für Bildung und Forschung (BMBF) under grant No. 16KIS1279K (AI-NET-PROTECT) and Science Foundation Ireland grants 18/RI/5721 (Open Ireland), 13/RC/2077_P2 (CONNECT) and NGI Atlantic (EU grant 871582).

References

[1] Colt, (2018), “Colt Spectrum brings cost effective Dark Fibre alternative to ultra-high bandwidth customers”, press release, 08/05/2018

[2] GEANT, (2021), “Moldovan and Ukrainian R&E communities benefit from new ‘spectrum’ link with GÉANT”, press release, 04/10/2021.

[3] E.R. Hartling, P. Pecci, P Mehta, D. Evans, V. Kamalov, M. Cantono, E. Mateo, F. Yaman, A. Pilipetskii, C. Mott, P. Lomas, P. Murphy, (2019), Subsea open cables: A practical perspective on the guidelines and gotchas. In: Sub Optic 2019, Apr 8th, Sub Optic Association Working Group.

[4] K. Kaeval, S.L. Jansen, F. Spinty, K. Grobe, H. Griesser, T. Fehenberger, M. Tikas, and G. Jervan, 2022. “Characterization of the optical spectrum as a service.” Journal of Optical Communications and Networking, 14(5), pp.398-410.

[5] K. Kaeval, H. Grießer, K. Grobe, J. -P. Elbers, M. Tikas and G. Jervan, “Channel Performance Estimations with Extended Channel Probing,” in Photonic Networks; 21th ITG-Symposium, 2020, pp. 1-5.

[6] Link available at www.openireland.eu