Concatenated GSNR Profiles for End-to-End Performance Estimations in Disaggregated Networks

Kaida Kaeval[1,3], Jani Myyry[2], Klaus Grobe[1], Helmut Grieβer[1], Gert Jervan[3]
[1] ADVA Optical Networking SE, Martinsried, Germany
[2] CSC - IT Center for Science Ltd., Espoo, Finland
[3] Tallinn University of Technology, Tallinn, Estonia
kkaeval@adva.com

Abstract: The performance of a wide-band optical spectrum service is computed using individual segment characterizations and compared to measured end-to-end performance. An accuracy of ±1.4 dB is achieved for live network routes up to 3116 km.

1. Introduction

Over the past years, Optical Spectrum as a Service (OSaaS) has gained traction among other high-capacity connectivity offerings and has been widely deployed in production networks [1,2]. Relying on open line systems (OLS), network operators can provide optical spectrum to customers who run traffic over it using their own DWDM terminals. Furthermore, this kind of transparent end-to-end connectivity is often realized by using spectrum infrastructure from multiple providers, creating a fully disaggregated networking scenario. This, however, requires a common service characterization method to be agreed between the providers and end users, in order to evaluate the end-to-end performance of the links before final purchase decisions and service handovers. In our recent work we proposed the GSNR profile as a reliable measure to estimate the individual link performance over the provided spectrum by using a channel probing method [3].

In this work, we investigate the channel probing method's ability to reliably estimate the performance of concatenated links when the GSNR profiles of the individual network segments are available. For this, two long-haul and one regional-haul link from the Funet production network are individually characterized and the estimation for the concatenated link performance is computed. Then, the links are transparently interconnected and the actual end-to-end performance of the merged link is captured by channel probing. Finally, the estimation accuracy is calculated.

2. Measurement set-up

Following the definitions in ITU-T Recommendation G.807 [4], we define an optical spectrum service as an optical media channel (MC) representing a transparent lightpath through an optical network on a predetermined frequency slot capable of carrying zero or more optical tributary signals (OTSi).

For this work, a 300-GHz media channel was provisioned in three non-overlapping network segments in Funet's long-haul Raman-enabled DWDM network. Two of the links featured a constant power adjustment algorithm on the OLS, equalizing the total power within the MC along the route, complicating the power spectral density based channel probing. The test set-up with spectral assignments is illustrated in Fig. 1. The optical user spectrum was added and dropped at a free terminal ROADM port using an 8:8 splitter/combiner module at the test site. To extend the transmission distance and to allow single-ended measurements from the test site, the spectral services were looped back in the far end ROADMs. To compensate for the insertion losses from the colorless access structures, signal

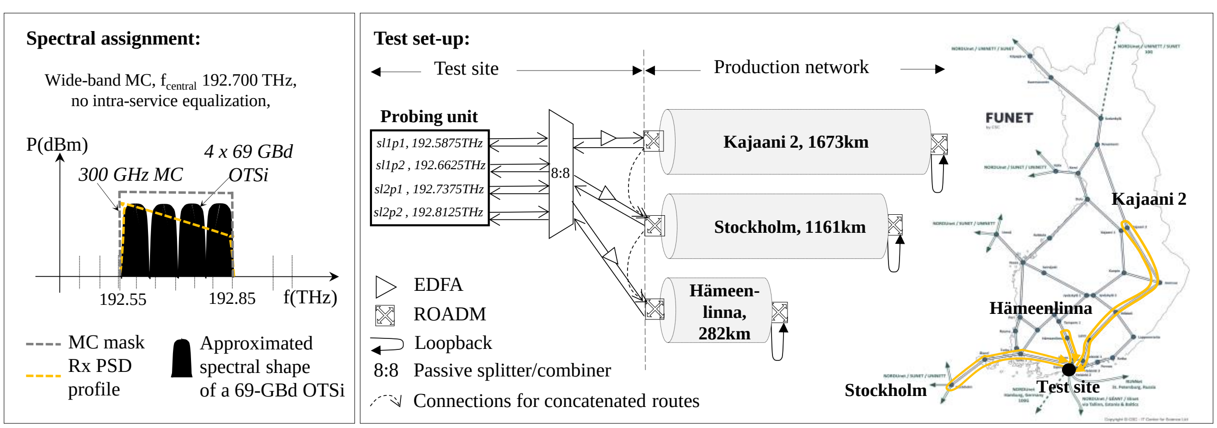

Fig. 1. Spectral assignment of the 300-GHz media channel and general test set-up

amplification after the 8:8 module was performed. Then the individual OTSi transmit powers to-the-line were equalized manually by adjusting the output powers of the probing unit. For concatenated route measurements, the add/drop structures were skipped and the signals were interconnected transparently to the next segment through physical patch-cords at the terminal ROADM C-ports. The received power spectral density (PSD) profile shows the tilt within the media channel, caused by the Raman gain spectrum.

Commercially available ADVA TeraFlex transceivers were used as probing units and two tests were performed per link: simultaneous probing with multiple probes and a single probe sweep with 12.5 GHz steps over the media channel bandwidth. For the multiple-probe scenario only 69-GBd DP-QPSK wide-band probing signals with 200-Gbit/s and a root raised cosine (RRC) spectral shape were used. For the case of a single-probe sweep, also 100-Gbit/s 31-GBd DP-QPSK or 200-Gbit/s 34-GBd DP-16QAM as a narrow-band probe configuration was used. To obtain comparable results from channel probing, a constant transmit power spectral density was maintained by adjusting the signal power at each symbol rate accordingly when switching between the configurations.

3. Results and interpretation

First, all routes were characterized by their GSNR profile. Fig. 2 shows the individual GSNR profiles along with receive power spectral densities for the multiple-probe and single-probe sweep results from three different network segments. The first route, Kajaani 2 with 1673 km, is the longest route characterized. The link features a power adjustment algorithm, that interferes with equal transmit power spectral density along the route, rising the power levels for narrow-band probes. This results in up to 3 dB higher power spectral density for narrow-band signals that causes them to operate slightly in non-linear regime at the peak side of the spectrum slot (192.55 THz). Unlike the Kajaani 2 link, the GSNR profiles of the 1161-km long Stockholm link follow the 1.8dB tilt of the received PSD and both probe configurations work in the linear regime over the full media channel bandwidth. Both of the longer links have a maximum deviation between the wide-band and narrow-band probe estimations below 0.6 dB for the estimated GSNR. The last link, Hämeenlinna with 282 km, has a high OSNR, not preferred for channel probing due to larger probing error due to saturation regimes of the probes [5]. The GSNR profiles recorded by the two probes used have a maximum of 2.0 dB deviation. The channel probing accuracy is further degraded by the enabled power adjustments on the link that is causing the up to 0.9 dB difference in received power spectral density.

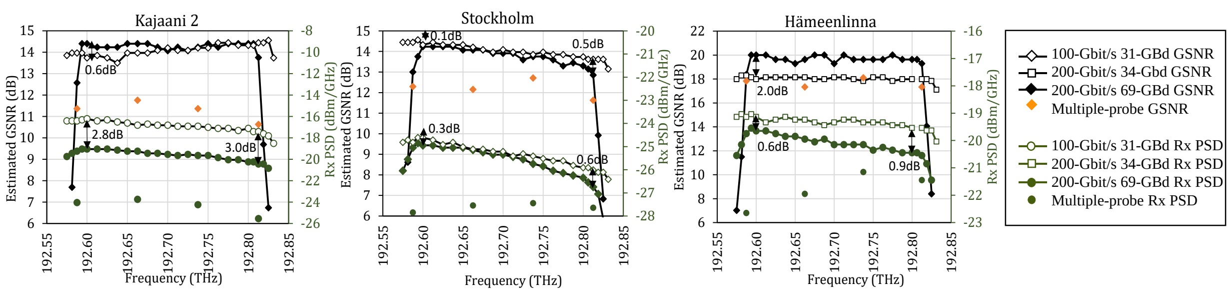

Fig. 2. Individual GSNR and Rx power spectral density profiles for the routes

The GSNR estimations for the concatenated routes are calculated according to

$$\frac{1}{GSNR_{TOT}} = \frac{1}{GSNR_1} + \frac{1}{GSNR_2} + \cdots \qquad (1).$$

First, two longer routes were concatenated, reproducing a service scenario with two independent core segment providers. The GSNR profile estimations and channel probing results for the concatenated segments are visualized in Fig.3 upper left. Then, the 260-km Hämeenlinna segment was added to the chain, illustrating the scenario with three service providers. The GSNR profile estimations and channel probing results with absolute values for the 3-provider scenario are presented in Fig.3 upper right. The bottom part of Fig. 3 presents the estimation error for both probes and multiple simultaneous probes for the two concatenated scenarios.

Within the effective service bandwidth, the GSNR values retrieved through direct channel probing on the concatenated link deviate from the individual segments` estimations by up to 1.4 dB. For most of the probing scenarios, the performance estimated by individual GSNR is underestimated by 0.4 to 1.4 dB compared to the real performance of the concatenated link. The only exception is the 100-Gbit/s 31-GBd DP-QPSK probe for the concatenated Kajaani 2 and Stockholm link, which was likely to overestimate the value due to the higher accumulated to-the-line launch power, contributing to higher nonlinear impact and hence, degrading the overall performance. Similar impact should be visible also on the 3-provider concatenated link, but here, all probe settings during the concatenated probing outperform the profile based estimations. The most probable cause for this is the biased GSNR profile estimated by the narrow-band probe setting for the shortest link, showing almost 2.0 dB degradation compared to wide-band probe setting and effectively lowering the estimated GSNR for the whole concatenated media channel.

Regardless of the generally lower values of the coarse GSNR profile provided by the multiple simultaneous probes, the estimation error is also less than ±1.4 dB between the estimations and measurements. Due to higher robustness against the power adjustments on the link, the estimations results are in better alignment with the valleys and peaks within the spectral slot. Probes working in the valley part of the spectrum report slightly higher estimation accuracy compared to probes working at the peak of the spectrum slot. This can be explained with higher accumulated to-the-line transmit powers that contribute to higher nonlinear penalty, which cannot be estimated with channel probing.

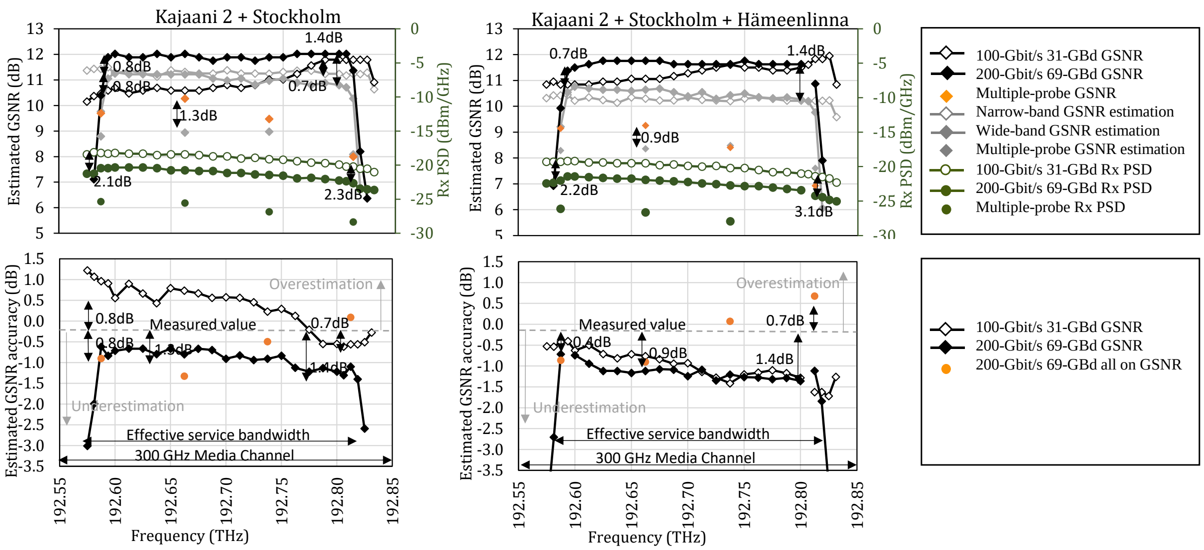

Fig. 3 Top: Comparisons of the estimations and channel probing results, Bottom: Estimation accuracy for different probes

In general, the accuracy of channel probing is very vulnerable to power adjustments at any point in the OLS, including the daily performance fluctuations on the link. In addition, the method is reliable only in linear operation within the effective bandwidth of the media channel. The primary method related error source is the poor alignment of the used probes with the available characterization curves. As the probing light transceiver characterization is often time- and resource-consuming task, readily available uncharacterized transceivers are often used as probes, which may lead to bias in the estimated GSNR profile. To avoid that, one single characterized probe, the golden transceiver, should be always used for the GSNR profile capture.

4. Conclusions

Optical Spectrum as a Service (OSaaS) has become an attractive service model for customers demanding high capacity, future proof network resources. For low-margin networking [6], reliable estimation for disaggregated networks is required. In black-box scenarios, where software-based QoT estimation tools [7] lack OLS-related input data, GSNR profiles can be used to calculate the expected end-to-end performance in multi-domain environments.

In this work, we have compared the GSNR estimations to end-to-end measurements for two- and three-provider scenarios with a maximum estimation error of ±1.4 dB. In service procurement scenarios where the OLS is treated as a black-box, this error magnitude can be justified as a rough estimation for long-haul links of 3000 km and more. Further accuracy improvements can be achieved by using characterized golden transceivers for the individual link characterizations and disabling any link power adjustments during the initial service characterization time.

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6. References

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