Field Learnings of Deploying Model Assisted Network Feedback Systems

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Abstract: Latent SNR margin in optical transport networks is investigated using performance monitoring SDN applications. An observed network can increase capacity by 13.8%, maintaining ≥1 dB of SNR margin at full fill without modifying any equipment.

1. Introduction

To achieve the greatest realizable capacity or the most robust performance on a bandwidth limited, amplified optical link, one core objective function is common – the system delivered signal-to-noise ratio (SNR) should be maximized. To maximize realizable capacity, the SNR should be maximized as shown by the Shannon-Hartley theorem. Furthermore, it is common to operate with some excess SNR margin to maintain error free communication even after future detrimental system events temporarily or permanently impact the SNR performance.

This paper investigates the amount of SNR margin available on deployed services in a live carrier network, and how that SNR margin is expected to change if operated at full fill, i.e. full spectral loading. We also investigate how much the SNR performance could be increased by fine tuning actuator targets to maximize SNR performance, and in combination with existing latent SNR margin, the amount of additional capacity that could be added into the system without changing any physical hardware, including the modems, while respecting a specified minimum SNR margin.

2. Performance Monitoring Gauges

In this study, data was extracted from a carrier network using two commercially deployed performance monitoring SDN applications. Both applications run in an SDN controller which communicates with the network hardware to set configuration data and retrieve measurements. A brief description of each application is given below.

2.1. *Channel Margin Gauge*

The first application utilized is a channel margin gauge (CMG) which monitors the SNR margin of each modem receiver in the network [1]. The SNR margin is defined as the operating receiver SNR relative to the required receiver SNR (RSNR), where the RSNR is the minimum SNR required for error free transmission. The CMG reports SNR margin data for all the modems in the network every 15 minutes.

2.2. *Photonic Performance Gauge*

The second application is a photonic performance gauge (PPG) which provides the line delivered SNR as a function of frequency, across each optical multiplex section (OMS) in the network. This application uses measurements fed into physical models to accurately determine the amplified spontaneous emission (ASE) and nonlinear SNR impairments across elements within an OMS. The application also models the control and optimization subroutines of hardware in each OMS and can therefore predict SNR performance at different spectral loading conditions based on predictions of how actuators would respond considering the various system control targets as shown in Fig 1 (a) and (b). These results are refreshed every 15 minutes, aligning with the results from the CMG.

PPG input data includes power spectral density, total power, fiber characterization data from OTDR and optical supervisory channels, erbium-doped fiber amplifier (EDFA) gain and tilt, Raman pump powers, plus provisioned information such as fiber types, objective function targets (e.g. power and shape targets for local controllers), as well as per-device factory calibration data. The PPG physical models primarily consist of wavelength dependent loss, Raman scattering, Rayleigh backscattering, and a modified Gaussian noise (GN) model derived from a GGN model [2, 3] for Kerr nonlinear interference (NLI) in fibers, EDFA gain models, and noise figure (NF) curve fitting models for EDFAs. The largest source of inaccuracy is uncertainty in exact fiber characteristics including unknown losses within the first several km of a fiber span. The observed error between the SNR determined using the PPG relative to the CMG of a selection of 31 channels is typically well below 0.5 dB, with a mean error of 0.018 dB as shown in Fig. 1 (c). These channels were selected based on availability of detailed factory calibration for the transponders in the field, with line rates from 200 to 400 Gbps and distances from 27 to 1565 km.

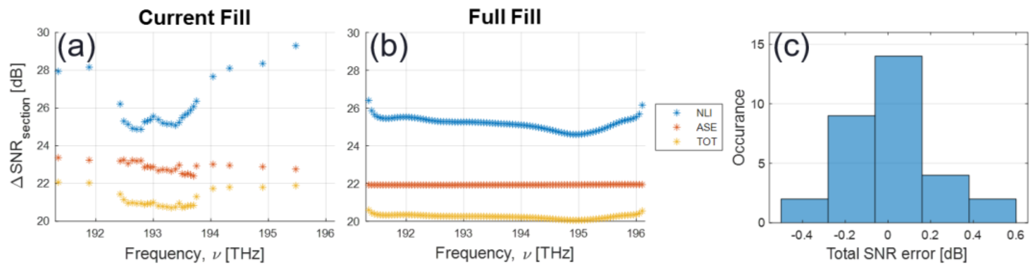

Fig 1. Incremental SNR calculations performed by PPG of an OMS showing nonlinear, ASE, and total SNR at a) current spectral fill loading and b) predicted full fill spectral loading conditions, and c) error between PPG calculated SNR and CMG output

3. Network Details

The network dataset contained a total of 210 bidirectional services carried across 55 bidirectional OMSs. A breakdown of some details for the services with CMG data is given below in Table 1. Although most modems monitored by the CMG are variable rate, in this network, all modems operated at 100 Gbps are fixed in capacity.

Table 1. Details of services currently operated

Line rate [Gbps]	Baud [GHz]	Number of services	Average distance [km]	Average number of amplifiers	Minimum SNR margin [dB]
100	35	105	666	6.9	2.3
200	56	27	1469	22.1	3.2
250	56	16	1062	15.9	2.6
300	56	51	885	10.2	1.4
400	56	11	70	2.0	1.9

4. Analysis and Results

The noise-to-signal ratio (NSR) in linear units measured at an optical modem receiver can be expressed as the summation of the various NSR impairments modified by the eye-closure, EC, for the modem at a given modulation format and is dominated by modem implementation penalties and the general SNR (GSNR) of the path comprised of ASE and nonlinear impairments from the optical add/drop multiplexers and OMSs [1]. This provides the relation between the SNR reported by the CMG to the per OMS SNRs reported by the PPG on each service in the network used in the analysis to generate Fig. 1(c):

$$NSR = EC \cdot \left(NSR_{Tx,imp} + NSR_{Rx,imp} + NSR_{add} + NSR_{drop} + \sum_k NSR_{OMS,k} + \cdots \right). \tag{1}$$

The received NSR under different state conditions (e.g. due to a change in channel loading, changing modulation format, or a performance change in the GSNR), can be re-written in terms of an initial state as simply

$$NSR_2 = \frac{EC_2}{EC_1} \cdot (NSR_1 + \Delta NSR_{1\to 2}), \tag{2}$$

where the 1 and 2 indicate initial state and new state respectively, and $\Delta NSR_{1\to 2}$ is the change in incremental NSR due to changes in the system conditions. The PPG calculates the NSR under current loading conditions as well as full fill, allowing us to remove the uncertainty in performance change due to channel loading by calculating the change in performance. On the current network, the average performance degradation on services by increasing to full fill loading is 0.21 dB, with the largest performance degradation of 1.60 dB.

Next, new actuator targets are determined which optimize the SNR performance of the photonic lines based on the actual deployed network conditions using a brute force search for optimal actuator conditions using a LOGO strategy [4] but considering all frequency dependencies. The brute force optimization is similar to [5, 6] which perform similar strategies across multiple bands using GNPy [7] as a simulation environment analogous to our PPG, however alternative methods exist or could be modified for our targets which solve the problem more efficiently [8].

Discrepancies between the planned and as deployed network are normal since the planning phase of any network includes data measured or estimated prior to deployment and a reasonable expectation of the performance of each hardware element based on a specification or factory distribution. This culminates in the planned control settings for the network being different than the optimal settings. In this work, we tune objective targets for local controllers primarily on EDFAs with known behavior including peak channel power targets, gain tilt, gain mode, and total output power offset settings (which adjusts EDFA pump ratios to improve NF). These are simple system input parameters that could be modified by a user, script, or an application in the future. The NSR we expect at full fill, after optimizing each OMS is again determined using Eqn. (2), where the change in total SNR performance due to the optimization on this network averages 0.35 dB, with a maximum improvement of 1.78 dB which more than cancels out the loading penalty on virtually all services. Most of this benefit is also present with current loading.

Combining the penalty of fully loading the network and the improvement of setting better system targets, we determine the optimized full-fill SNR, $SNR_{full,opt}$. The predicted margin without modifying the modulation format (line rate) or Baud on the variable transmission mode modems is plotted in Fig. 2(a) which is given by:

$$M_{full,opt}[\text{dB}] = SNR_{full,opt}[\text{dB}] - SNR_{current}[\text{dB}] + M_{current}[\text{dB}], \tag{3}$$

where $SNR_{current}$ is the current SNR performance and $M_{current}$ is the current SNR margin. Finally, to determine how much capacity can be extracted from the network, the RSNR of each transmission mode of each modem is considered with the amount of SNR which would be available at full fill, $SNR_{full,opt}$. The evaluation of $SNR_{full,opt}$ in this step needs to consider the perturbations due to changes in modulation format on eye closure and modem implementation noise, as per Eqn. (2) – in this analysis, most services used statistical data for these terms since only a small subset of the modems in this network had calibrated factory data available. Once the $SNR_{full,opt}$ is evaluated for the different higher rate modulation formats, a simple difference with their RSNRs in dB is performed to choose a suitable modulation format. The minimum margin in Table 1 is useful since it provides guidance on how much excess SNR margin the carrier network studied in this work would be comfortable operating their modems. Since we have modems operating down to 1.4 dB SNR margin and assuming some excess margin was available for change in channel fill, we chose a 1.0 dB margin constraint. The margin of the modems converted to their highest operating line rate with the 1.0 dB margin constraint is shown in Fig. 2(b). The change in distribution of line rates is shown in Fig. 2(c). The high margin tail in the distribution present in both Fig. 2(a) and Fig. 2(b) is due to 100 Gbps services which are not variable rate and therefore cannot be upgraded.

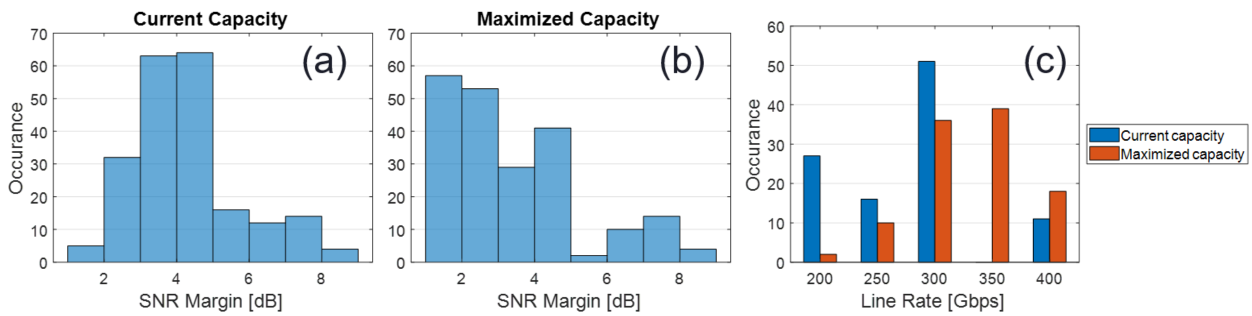

Fig. 2. SNR margin with full-fill, optimized photonic actuators at (a) current deployed line rates and (b) maximum line rates, and (c) Number of services operating at each line rate in current state and with increased capacity

5. Conclusion

Utilizing data from commercially deployed SDN monitoring applications on a carrier network, we showed that the network studied has margin that can be mined both from existing excess margin and untapped potential from better photonic actuator adjustment considering existing deployed conditions. The average capacity of the networks could be increased by 13.8% while maintaining a minimum margin of better than 1.0 dB at full channel loading, without any modification to the physical hardware or modifying Baud which would require channel regrooming.

6. References

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