Employing Fiber Loss Degradation Statistics in SLA based Margin Calculation Method for Optical Networks

Zhiqun Zhai[1], Liang Dou[2], Sai Chen[1], Huan Zhang[1], Chongjin Xie[3]
[1]*Alibaba Cloud, Alibaba Group, Hangzhou, China,* [2]*Alibaba Cloud, Alibaba Group, Beijing, China,*
[3] *Alibaba Cloud, Alibaba Group, New York, USA,*
zhaizhiqun.zzq@alibaba-inc.com

Abstract: We present a statistical analysis of fiber loss degradation with data from a live production network. A proper model is proposed to investigate system margins under typical scenarios with different operation conditions. © 2024 The Author(s)

1. Introduction

Margin allocation is necessary for system designers to maintain certain service level agreements (SLAs) of transport services in optical networks. By reducing the margin, network operators can increase network capacity that is usually translated into a CAPEX gain. The margins in an optical network are composed of three different parts: unallocated, design and system margins [1]. Numerous efforts have been made to reduce the unallocated margin and design margins by employing flexible transponders and enhancing the accuracy of quality of transmission (QoT) [2-4]. How to leverage the system margin is challenging due to its time-varying nature. Fiber loss degradation (FLD), either caused by environment changes or aging effects, is one major source needed to be covered by system margin. A commonly employed approach for calculating the required margin is to assume that the system can tolerate a constant fiber degradation, e.g., 3dB, and only one fiber span in the system experiences degradation. Obviously, this approach presents a uniform margin for all optical channels (OCHes) regardless of the number of spans they pass nor different SLA requirements.

In this paper, we conduct statistical analysis on FLD within different time intervals (15 minutes, 1 hour, 4 hours, and 1 day) using the monitored optical power from a live production network [5]. The probability function (*pdf*) of FLD is measured on 350 fibers with more than 25,000,000 valid data points for a 15-minute interval, equivalent to around 372 days. Thanks to the accurate QoT model with an error standard deviation of generalized signal to noise ratio (GSNR) estimation below 0.5dB [3-4], we further investigate the stochastic property of GSNR degradation with a simulation platform, where 100,000 random attenuation values of each fiber span are generated to emulate the *pdf* of FLD. The simulation results indicate that, when considering a reliability level of 99%, 1dB margin is sufficient for a single span OCH, which is a typical scenario in metro data center interconnect networks. While for an OCH in a 14-span system, which is more commonly encountered in long haul system, a margin of 4.5dB is required in order to maintain the same reliability level. Furthermore, we have proved that by reducing maintenance period, such as regularly adjusting the configurations, it is possible to decrease the margin required for the 14-span system from 4.5dB to 1.5dB, while still ensuring a 99% reliability.

2. Statistic of Fiber Loss Degradation

The real-time span loss is equal to the difference between the output power of the *A* device and the input power of the *Z* device, which are depicted as P_{out_A} and P_{in_z} in Fig. 1(a). Variable optical attenuator (VOA) is used to optimized the link condition, e.g., launch power and span loss, and its value is stored in the database once it is modified. By utilizing this information, the fiber loss can be calculated as follows:

$$loss = P_{out\_A} - VOA_A - P_{in\_Z} \tag{1}$$

Devices report their input power and output power every 15 minutes, including minimum (*min*), maximum (*max*), and average (*avg*) values, as the time sequences shown in Fig. 1(b). In a multi-span system, power drift in the upstream may lead to power fluctuations in all the following devices, and this condition is shown by the dotted boxes in Fig. 1(b). To avoid ambiguity in FLD calculation, we only consider the cases where the output power of device *A* within a 15-minute interval remains stable, e.g., the difference between the *max* and *min* of P_{out_A} is less than 0.2 dB, which is assumed as the accuracy of photo detector. So, the *max* and *min* values of fiber loss within a 15-minute interval can be expressed as:

$$loss_{max} = P_{out\_A\_avg} - VOA_A - P_{in\_Z\_min} \tag{2}$$

$$loss_{min} = P_{out\_A\_avg} - VOA_A - P_{in\_Z\_max} \tag{3}$$

where $P_{out\_A\_avg}$ represents the average output power of the device A, while $P_{in\_Z\_min}$ and $P_{in\_Z\_max}$ are the *min* and *max* input power of the device Z. Therefore, the fiber loss degradation can be obtained by:

$$FLD = loss_{max} - loss_{min} \tag{4}$$

We conduct statistical analysis on FLD over different intervals, such as 15 minutes, 1 hour, 4 hours, and 1 day. For the intervals larger than 15 minutes, we calculate the *max* and *min* values by examining *max* ($loss_{max}$) and *min* ($loss_{min}$) within that period. We collect data related with 350 fibers, resulting in a total of 25,000,000 valid data points for the 15-minute interval fiber loss. Fig. 1(c) illustrates the *pdf* of FLD under different time intervals. The majority of the distribution is within 0.5dB, corresponding to the photo detection errors. FLD larger than 0.5dB is regarded as related with fiber attenuation variation itself. As the interval increases, the probability of FLD exceeding 0.5 dB becomes higher, e.g., over 27.11% in 1-day interval comparing with less than 1.37% in 15-min interval.

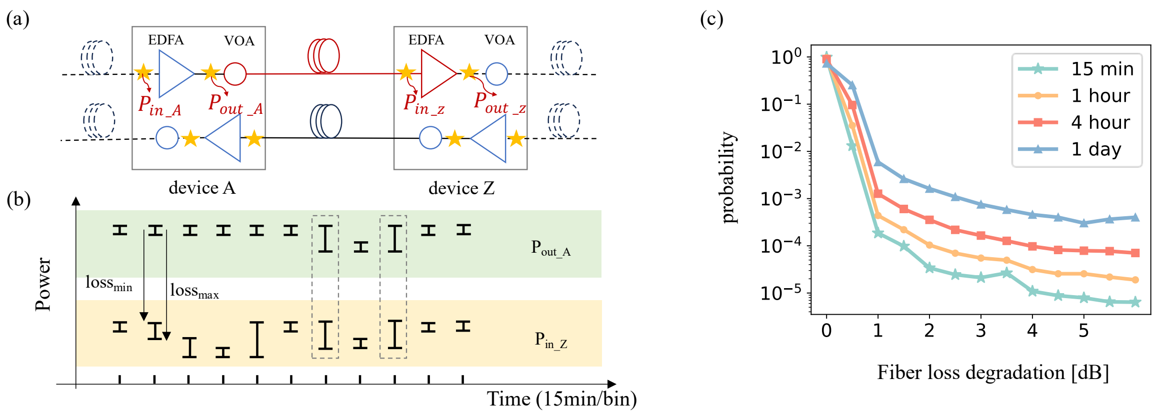

Fig.1 (a) Diagram used in statistic property calculation of FLD. (b) Illustration of the calculation of $loss_{max}$ and $loss_{min}$. The data in the dotted boxes are not included. (c) Distributions of FLD in different time intervals. EDFA: Erbium doped fiber amplifier. VOA: Variable optical attenuator.

3. Simulations and Discussions

To evaluate the distribution of OCH GSNR affected by stochastic property of FLD, we develop a transmission simulation platform, as shown in Fig. 2(a). Physical network is modeled and re-constructed in digital domain through resource manager, topology manager and device manager. The transfer function of active and passive components in devices are implemented in model layer. Device configurations are automated generated according to the pre-defined regulations at function layer and transmission performance is finally calculated in the network instance.

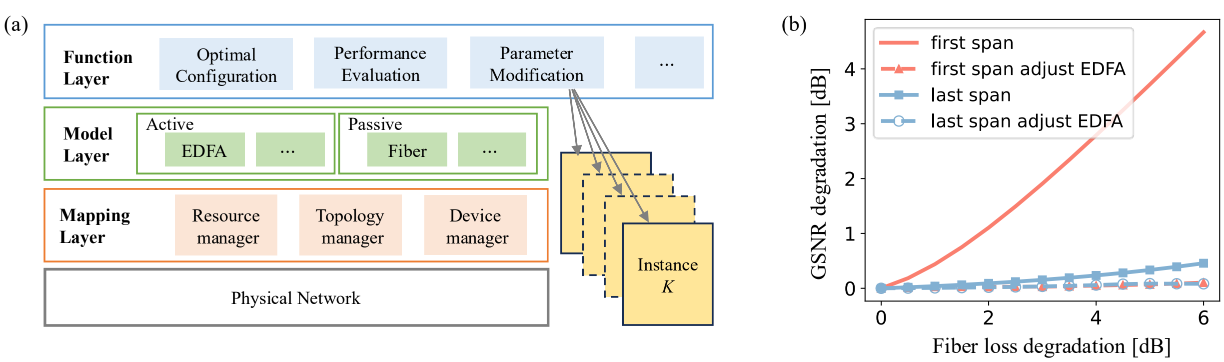

Fig.2 (a) The diagram of simulation platform to evaluation system performance. (b) The relationship between GSNR degradation and fiber loss degradation with an OMS of 14 spans.

We select four typical optical multiplex sections (OMSes) with 1, 4, 7 and 14 spans from a production network. The span length is roughly distributed from 50km to 90km, as shown in Table 1. It is assumed that each OMS is fully loaded by 48 channels in C-band with a channel spacing of 100 GHz, and the channel with center frequency of 192.4 THz is selected as the probe channel. First, we try to add additional loss on different positions of the OMS with 14 spans. As illustrated in Fig. 2(b), the impact of fiber degradation on GSNR is strongly dependent on the fiber index, and the first span is the farthest from the receiver and has a much bigger impact on system performance than the last span. Therefore, the GSNR degradation cannot be accurately calculated using a simple formula.

Table 1: Span lengths (km) in four different OMSes

OMS 1#	74km		**OMS 2#**	98km	78km	84km	
OMS 3#	82km	78km	107km	84km	62km	75km	68km
OMS 4#	60km	69.6km	53.6km	87.2km	79.5km	64.1km	80.2km
	69.4km	71.2km	71.7km	109.4km	98.8km	74.8km	60.4km

In order to evaluate the OCH GSNR degradation caused by FLD, we perform Monte Carlo simulation assuming that the fluctuation of each fiber is independently and identically distributed. In the function layer of simulation platform, parameter modification module configs 100,000 replica of network instances with random additional fiber loss values, which are generated according to FLD's statistical distributions, and GSNR is calculated in each replica, as shown in Fig. 2(a). By subtracting the base GSNR, we can obtain the distribution of GSNR degradation $\Delta GSNR$. Fig. 3(a) shows the distribution of the $\Delta GSNR$ within 1 days. It can be found that the GSNR degradation increases with increasing fiber span numbers, so that the system margin allocated should be different. To further illustrate such effect, an outage probability of $\Delta GSNR$ is defined as the probability that $\Delta GSNR$ is larger than the threshold, which is shown in Fig. 3(b). It can be found that to achieve 99% reliability, 1dB margin is sufficient for a single span OCH, while 4.5dB margin is required for the OCH passing through 14 spans. To achieve a low margin, certain strategies can be adopted to reduce the degradation of GSNR. As shown in Fig. 2(b), which depicts the simulation results of the 14 span OCH, the dashed line reported the results after adjusting the EDFA or VOA to compensate for the fiber loss degradation. It can be observed that for most of fiber loss degradation, compensation can be achieved without low additional cost. As depicted in Fig. 3(c), by reducing maintenance time, such as regularly adjusting the configurations, it is possible to decrease the margin required for the 14 spans from 4.5dB to 1dB, while still ensuring a 99% reliability.

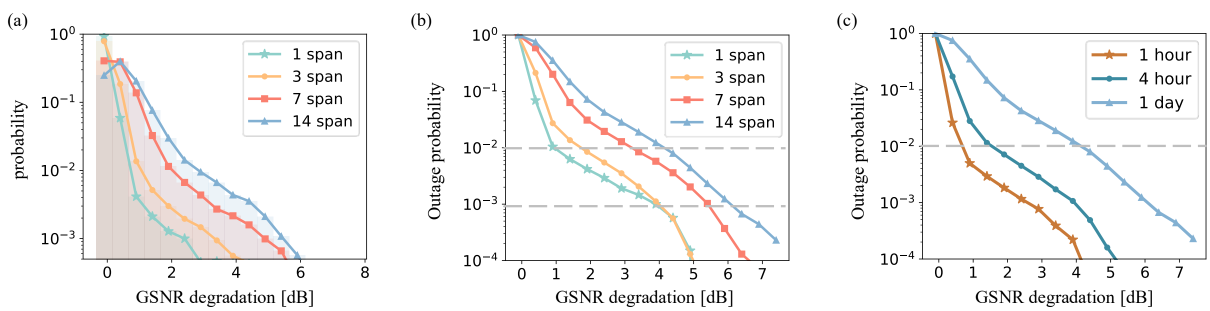

Fig.3 (a) Distribution of GSNR Degradation of the OCHes with different span numbers. (b) Outage probability of GSNR degradation. (c) Outage probability of GSNR with different maintenance periods.

4. Conclusion

The stochastic property of fiber loss degradation within different time intervals are statistically analyzed using more than 25,000,00 performance data from a live production network. The distribution of GSNR degradation is obtained with Monte Carlo simulation. It is found that OCH margin allocation is related with number of spans and required SLA level. Reducing maintenance period is an effective and practical way to further decrease the required margin.

[1] Y. Pointurier, "Design of Low-Margin Optical Networks," J. Opt. Commun. Netw. 1, A9-A17 (2017).
[2] L. Dou, B. Yan, J. Wu, J. Wu, Q. Chen, R. Lu, L. Wang, Z. Sun and C Xie, "Demonstration of Hitless Spectrum Optimization in a Flexgrid Disaggregated System," in 2022 European Conference on Optical Communication (ECOC), pp. Tu2.1.
[3] Y. He, Z. Zhai, L. Wang, Y. Yan, L. Dou, C. Xie, C. Lu and A. P. T. Lau, "Improved QoT Estimations Through Refined Signal Power Measurements in a Disaggregated and Partially-Loaded Live Production Network," in 2023 Optical Fiber Communications Conference and Exhibition (OFC), (2023), pp. Tu2F.5.
[4] Y. He, Z. Zhai, L. Wang, Y. Yan, L. Dou, C. Xie, C. Lu and A. P. T. Lau, "Improved QoT estimations through refined signal power measurements and data-driven parameter optimizations in a disaggregated and partially loaded live production network," J. Opt. Commun. Netw., 15, pp. 638-648 (2023).
[5] C. Xie, L. Wang, L. Dou, M. Xia, S. Chen, H. Zhang, Z. Sun, and J. Cheng, "Open and disaggregated optical transport networks for data center interconnects [Invited]," J. Opt. Commun. Netw. 12, C12–C22 (2020).