Field Trial of Digital Twin-Assisted QoT Estimation in 400 Gb/s C+L Band Network with 470 km Transmission

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Abstract *We demonstrate the prediction accuracy of power spectrum evolution and QoT estimation for each channel in China Unicom's field trial of 400Gb/s C48+L48 WDM system. The feasibility of digital twin for application in optical network has been further confirmed.*

Introduction

Expanding per-fiber available transmission bandwidth is a straightforward solution to increase the capacity of current wavelength division multiplexing (WDM) networks [1]-[2]. The C+L band WDM system attracts telecom operators' increasing attentions with higher capacity, reusing the same fiber with C band WDM system. As the C+L WDM technology is gradually applied in the actual network, it is an urgent issue for telecom operators to consider how to smoothly upgrade the current C band to C+L band. That means we need a dynamic tool/technology to realize the precise performance prediction and network configuration optimization.

Digital twin (DT) is proposed to describe the real network numerically. With the aid of DT technology, it is possible to construct the mirror models of the physical network and accurately simulate the states and processes of transmission system [4]. These models are used to generate the optimization strategies that are then fed back to physical layer for a closed-loop management [5]. Gaussian Noise (GN) model is recognized as one of the most powerful tools for DT modeling and has been studied in previous works [6]-[7]. It has been successfully demonstrated in C+L band experimental platform. However, to best of our knowledge, it has not yet been proved in the field trial of C+L band system, deployed in the real telecom operator network.

In this study, we performed a field trial of a 400 Gb/s C48+L48 WDM system comprising 6 spans and evaluated the power evolution and quality of transmission (QoT). We employ an inter-channel stimulated Raman scattering (ISRS) GN model to estimate the QoT based on real data obtained from the network controller and compared it with the measurement outcomes. We demonstrated that the model can precisely predict the optical power spectrum evolution in frequency domain, and the discrepancy of optical signal-to-noise ratio (OSNR) and the generalized signal-to-noise ratio (GSNR) is less than 0.5 dB.

Field trial of architecture for 400 Gb/s C+L WDM system

The 400 Gb/s C48+L48 WDM field trial system is deployed in China Unicom's transmission network in Shandong province, as shown in Fig.1. The system consists of 6 spans of totally 470 km G.652 fiber, with 3 ROADM nodes, 3 Optical Line Amplifier (OLA) nodes and 1 Dynamic Gain Equalizer (DGE) node with no electrical regenerator node. Power equalization happens in each ROADM node, OLA node and DGE node by controlling the gain and tilt of optical amplifiers and the attenuation of the Variable Optical Attenuator (VOA) in Wavelength Selective Switches (WSS) cooperatively. This system is built in bi-direction and with 4 service-channels in C band, 2 service-channels in L-band modulated by PCS-PDM-16 quadrature amplitude modulation(QAM) with 86G baud rate and 100GHz channel spacing, and other channels are filled with amplified spontaneous emission (ASE) source. The ASE source is spectrally shaped by WSSs of ROADM in SLCW site to generate 100GHz WDM channels. Moreover, each of the filled channels is equipped with virtual network element in the controller to enable the auto power equalization.

In C+L WDM systems, the power evolution for each channel may fluctuate significantly and the QoT for each channel is generally non-uniform, which is mainly attributed to the non-flat gain profile and noise figure (NF) profile of erbium doped fiber amplifier (EDFA), SRS and

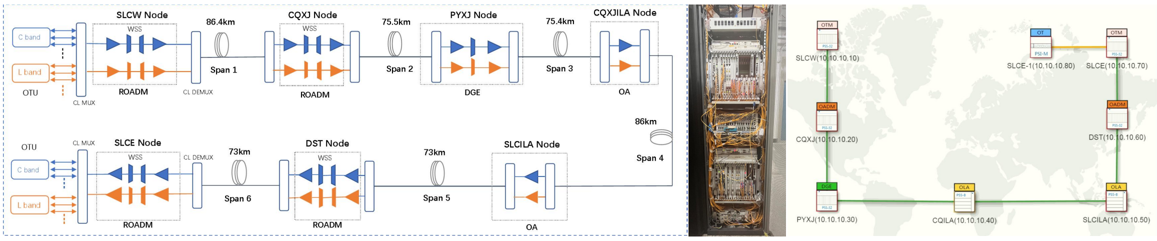


Fig. 1. Field trial of the 400Gb/s C+L WDM system, the topology in Nokia's controller and real equipment in SLCX node.

Kerr effect of fiber. In this field trial system, we collected the configuration and performance data from the network controller, as shown in Tab.1. The launch power values of each channel at the transmitter ranged from 4.5-8 dBm for C band and 4.5-6 dBm for L band. We measured the output power of each channel for both ROADM and OA nodes and also obtained it from optical channel monitor (OCM). At the receiver, the OSNR and bit error rate (BER) can also be obtained from the network controller.

Tab. 1: Parameters collected from Nokia's controller

Device	parameters
Transmitter	launch power for C band with 48-wavelength and L band with 48-wavelength
	central frequency, modulation format, signal rate
EDFA	output power of each channel for C+L band in the ROADM total output power for C+L band in the EDFA
	parameters of EDFA: gain tilt, gain, NF
ROADM/ DGE	output power of each channel for both C and L band
	VOA in WSS
Receiver	output power, OSNR, pre-FEC BER and Q value of each channel for both C and L band
Optical Fiber	fiber distance and attenuation

Multi-span model for C+L WDM system

As all major propagation impairments, i.e. ASE noise, and nonlinear interference (NLI) can be modeled as Gaussian disturbances, GSNR is used to assess the performance of each channel, as shown in Eq.1. It is the ratio between the power of the traffic signal P_{ch} divided by the sum of the powers of all noise sources, i.e. P_{ASE} and P_{NLI} . Further, ISRS GN model in closed-form [8] is induced to accelerate the calculation speed.

$$\mathrm{GSNR} = \frac{P_{ch}}{P_{ASE} + P_{NLI}} \qquad (1)$$

P_{ch}, P_{ASE}, and P_{NLI} stand for the power of channel, ASE noise, and NLI noise, respectively. In our simulation scheme, as to mirror the C+L band with multi-span transmission system, the ISRS GN model-based fiber model with the optimal nonlinear crosstalk calculation, adding the EDFA model, will be implemented, as shown in Fig.2. As only few WSSs are cascaded in this trial system which result in minor impact on the final results, filtering effects by WSSs are ignored in the simulation model.

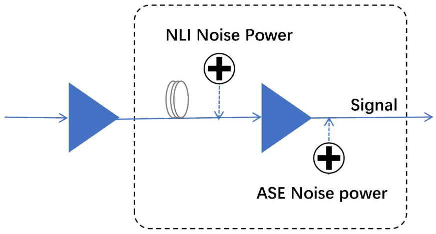
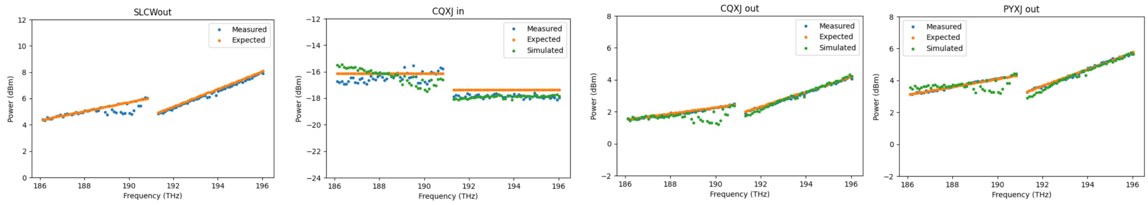


Fig. 2: .The transmission link model scheme

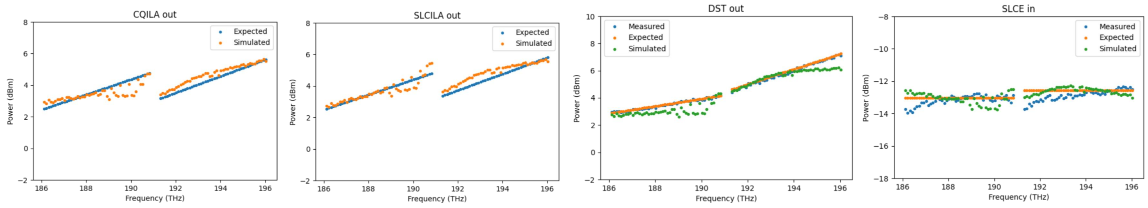
Simulation Results and Analysis

We obtained detailed characteristics and data on the trial system components including transmitters, ROADM, EDFA and fibers. With this rich data set we are able to model the C+L system behavior. Then, we run all the simulations with the same configurations of trial system, shown in in Tab.1. To demonstrate the accuracy of the transmission model, we compare the power spectrum evolution in each span and the QoT estimation utilizing GSNR metric.

The degradation of optical signal in the fiber will be accumulated with the transmission distance increase. When the degradation is up to a certain extent, the high BER at the receiver will lead to the service interrupted. For the traditional maintenance method, the degradation of signal can only be found when it causes the service alarm, and cannot be recognized in advanced before the failure occurs. Therefore, it is required urgently to track and predict the optical power spectrum evolution with the transmission distance increasing, to make sure the configuration can be adjusted beforehand. Therefore, we firstly simulate the C+L signal power spectrum evolution with multi-span transmission of EDFAs and fibers, as shown in Fig.3. It should be noted that as it was not equipped with OCM in the OLA nodes,

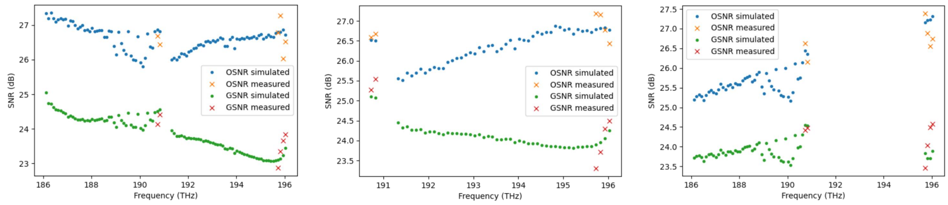


(a) Launch power before Span 1 (b) optical power after Span 1 (c) optical power before Span 2 (d) optical power before Span 3



(e) optical power after Span 4 (f) optical power after Span 5 (g) optical power before Span 6 (h) optical power before Span 6

Fig. 3. Power spectrum evolution for each span



(a) full C+L band (b) full C-band and 2 L-band channels (c) full L-band and 4 C-band channels

Fig. 4. Model simulation and measured results comparison: OSNR and GSNR of each channel at the receiver

i.e.CQILA and SLCILA, and it is difficult to measure each channel's output power at these nodes, we only used the total output power of EDFA for simulation. Therefore, the simulation values in these nodes can only be analyzed with the expected values which were calculated by Nokia's own algorithm. At the other nodes, the simulation values can be compared with the measured values which were read directly from the Nokia's controller. It is indicated in the Fig.3 that the maximum power evolution prediction errors by simulation for each channel are 1.53 dB comparing with measured values, and most simulation results fit quite well with the measured or the expected values, which means that the simulation scheme is suitable for the 400Gb/s C+L WDM system.

Further more, we simulate the QoT estimation using the OSNR and GSNR, as a function of wavelength in 3 scenarios, (a) full C+L band, (b) full C band and 2 L band channels, and (c) full L band and 2 C band channels, as depicted in Fig. 4. These three scenarios can exactly imitate the band-expanding during the actual network maintenance. When the C band system needs to be upgraded to L band, the ASE source-filled bands will be turned off first and then replaced with the planned service-bands. Therefore, it is essential to evaluate the feasibility of band-expanding scheme in advance to avoid the service interruption risk. In our simulations, we try to accurately predict the impact of expanding bands on the existing bands. Here we consider the two extreme situations, turning off the whole filled-L band signals and turning off the whole filled-C band signals, as shown in Fig.4.(b) and (c) respectively. It can be observed that for full C+L band, the prediction of GSNR and OSNR is very close to the measured value, with the prediction error of less than 0.5 dB. These trial results indicate that applicability of the model for the C+L WDM system.

Conclusions

In this paper, we demonstrate the accuracy of QoT estimation model by comparing power spectrum evolution and GSNR/OSNR of each channel in the field trial of 400 Gb/s C48+L48 WDM system. The prediction errors of optical power spectrum and GSNR are less than 1.53 dB and 0.5 dB, respectively, which validate the full availability of our model for the actual telecom operators' network. Based on these accurate DT models, we can realize the band-expanding and performance optimization strategies in the DT optical network which make the operation and maintenance more flexible and reliable.

Acknowledgments

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