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In-band OSNR Monitoring System based on Link-by-link Estimation for Reconfigurable Transparent Optical Networks

Jun Haeng Lee, Noboru Yoshikane, Takehiro Tsuritani, and Tomohiro Otani
KDDI R&D Laboratories Inc., 2-1-15 Ohara, Fujimino-Shi, Saitama 356-8502, Japan
TEL: +81-49-278-7857, FAX: +81-49-278-7811, E-mail: jh-lee@kddilabs.jp

Abstract
A cost-effective optical performance monitoring system, based on link-by-link OSNR estimation, has been proposed for a reconfigurable transparent optical network. In-band OSNR monitoring was successfully demonstrated at 42.7 Gb/s RZ-DQPSK signals, reflecting the transmission performance.

1. Introduction

Optical performance monitoring (OPM) is an essential part of a transparent optical network for the efficient operation and maintenance of the network [1]. In particular, the channel power, wavelength, and optical signal-to-noise ratio (OSNR) of wavelength-division-multiplexed (WDM) signals are the basic parameters to be monitored for providing the quality of service (QoS) of the network. To date, several reliable and cost-effective techniques have been commercialized for the monitoring of channel power and wavelength [2]. However, it still seems difficult to monitor OSNR without a substantial increase in network cost, although several techniques capable of monitoring the in-band OSNR accurately have been proposed [3].

In this paper, we propose a cost-effective method, which can monitor the in-band OSNR in the reconfigurable transparent optical network by simply measuring the total input power to every optical amplifier (OA) and the power of each channel at intermediate optical nodes. We also demonstrated the OPM system, implemented by using the proposed OSNR monitoring technique in a reconfigurable transparent optical network testbed with 4 nodes. The element management system (EMS) indicated the monitored end-to-end OSNR appropriately, reflecting the transmission performance.

2. Principle of the proposed technique

In the proposed technique, the link OSNR of each link (composing a lightpath) is monitored separately instead of measuring the OSNR of an optical signal directly. Subsequently, the end-to-end OSNR is estimated by using the link OSNRs as $OSNR_{end\text{-}to\text{-}end} = 1/\Sigma_i(1/OSNR_{link,i})$, where $OSNR_{link,i}$ is the link OSNR of the i-th link. Fig. 1 shows the schematic diagram of the proposed technique for monitoring the link OSNR of a link between two optical nodes. To monitor the link OSNR, we measure the channel power at the input and output of the link and the total power at the input of every OA in the link. By using the channel power information obtained at the input and output of the link, the channel power differences in the wavelength band of the link are calculated. Subsequently, the distribution of channel power at the input of each OA is estimated by using these channel power differences, assuming that all OAs have equivalent gain tilt. This is a reasonable assumption in most cases, where the optical link is composed of the same type of OAs from a single vendor. The link OSNR is estimated as $OSNR_{link}=1/\Sigma_j(1/OSNR_{OA,j})$, where $OSNR_{OA}$ is the OSNR of an optical signal at the OA output when the input OSNR of the signal is infinite. $OSNR_{OA}$ is estimated from the measured total input power and the channel power distribution by using the relation as $OSNR_{OA}(\text{dB}) = P_{in}(\text{dB})+\alpha$, where P_{in} is the input channel power and α is a constant related to the characteristics of the OA [4]. Since the proposed technique utilizes the signal powers only for the OSNR estimation, it is not sensitive to the spectral filtering caused by network nodes or other impairments, such as polarization effects or nonlinearities. The basic idea of the OSNR estimation based on the operating conditions of OAs has been reported previously [5]. However, it was required to monitor the channel powers at every OA and allocate polarization modulators at the transmitter side, which could substantially increase the network cost. We solved this issue by monitoring the channel power at the input and output of the link only and measuring the total input power (instead of the channel power) at other OAs.

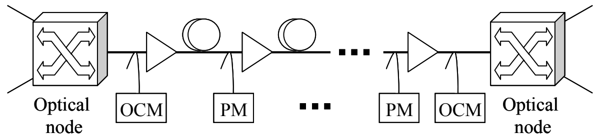

Fig. 1. Schematic diagram of the proposed OSNR monitoring technique.

3. Experimental setup

Fig. 2 shows the experimental setup of a reconfigurable all-optical network testbed (with 4 nodes) and the proposed OPM system. At Node1, the outputs of 32 DFB lasers operating at 1538.19 nm ~ 1563.05 nm (100-GHz ITU grid) were multiplexed and modulated at 21.3 GS/s with return-to-zero differential quadrature phase shift keying (RZ-DQPSK) format (equivalent to 42.7 Gb/s). After tapping and decomposing the modulated signals into 3 wavelength groups by using a wavelength selective switch (WSS1), one group (channel 13 ~ 22) was sent to an add port of Node2 while another group (channel 23 ~ 32) was sent to one of Node3. The other portion of the modulated signals was launched to Link1, which consisted of four 80-km-long standard single mode fiber (SMF) spans. At the input of Erbium-doped fiber amplifier1 (EDFA1), 10 % of the optical signal was tapped and sent to an optical channel monitor (OCM) to monitor the channel information (the channel powers and wavelengths of the WDM signals). Since the resolution bandwidth of the OCM (0.062 nm) was much smaller than the signal bandwidth, the channel power was obtained by integrating the optical spectrum over 0.7 nm span. Node2 and Node3 were configured by a dynamic wavelength cross connect (WXC) using two WSSes. Two OCMs were used at the input and output of a WSS pair respectively. The channel information monitored by these OCMs was also used as feedback information for the dynamic equalization of WDM signals after add/drop operation. Ten wavelength channels (channels 13 ~ 22) were dropped at Node2, and the wavelength group from WSS1 was added at this node. At Node3, a further ten channels (channels 23 ~ 32) were replaced by another wavelength group from WSS1. Both Link2 and Link3 were composed of two 80-km-long SMF spans. All EDFAs, except the boost amplifiers (EDFA1, 6, and 9), were 2-stage amplifiers with a dispersion compensating module (DCM) inside. The amplifiers used for Link1 and Link2 were automatic gain-controlled (AGC) EDFAs from the same vendor while those in link3 were automatic power-controlled (APC) EDFAs from another vendor.

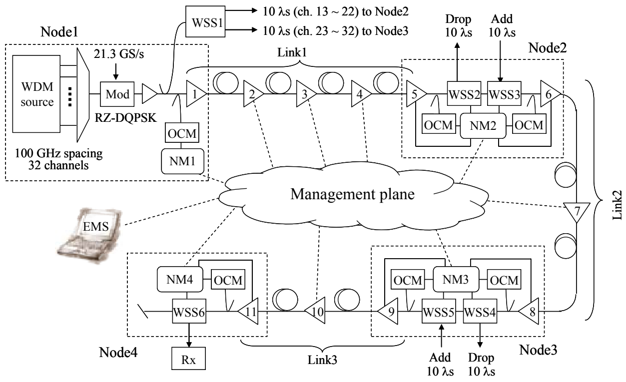

Fig. 2. Experimental setup for demonstration of OPM system.

In the proposed OPM system, the health of each link was monitored and managed by a node manager (NM) located in each node. For example, NM2 in Node2 was in charge of monitoring Link1. NM2 periodically retrieved the channel information of the Link1's input from NM1 in Node1 and the operating conditions of each EDFA in Link1 via the simple network management protocol (SNMP) through the management plane. In addition, the channel information of the Link1's output was obtained by a local OCM in Node2. Subsequently, NM2 calculated the link OSNR of each channel, based on these sets of information on a per second basis. Link2 and Link3 were monitored by NM3 and NM4, respectively. The EMS could retrieve the link OSNRs from every NM via SNMP through the management plane and calculate the end-to-end OSNR for each lightpath.

4. Results

Fig. 3(a) and (b) represent the optical spectra measured at the output of Link3 when RZ-DQPSK signals or unmodulated (continuous-wave) ones were transmitted, respectively. Although there were 3 wavelength groups with considerable OSNR difference, as shown in Fig. 3(b), it was impossible to differentiate these groups from Fig. 3(a) due to the broad signal spectrum when RZ-DQPSK signals were transmitted. For example, the OSNRs of channels 12 and 13 were almost same when observed from the optical spectrum in Fig. 3(a), whereas their true OSNRs (20 dB and 24 dB for channels 12 and 13, respectively) differed quite significantly from each other, as shown in Fig. 3(b). Fig. 4(a) represents OSNRs measured at the output of Link3. The OSNRs measured by the proposed OPM system agreed well (discrepancy < +/− 1 dB) with those measured by an optical spectrum analyzer (OSA) when cw signals were transmitted. Fig. 4(b) shows that the proposed OPM system could monitor OSNR degradation accurately when an additional loss (~ 4 dB) was simulated in the second span of Link1. The system was verified as tolerant of the operational condition. We also compared the Q-factors of the transmitted signals with those estimated from monitored OSNRs − the estimation of Q-factors was performed by referring the correlation between the OSNR and the Q-factor, measured in the back-to-back condition by loading optical noise only. As shown in table 1, the estimated Q-factor agreed well with the real Q-factor. In addition, there was considerable variation in performance between channels 12 and 13, as indicated in Figs. 3 and 4. The effect of optical fiber non-linearity is considered as one of the future items to be investigated.

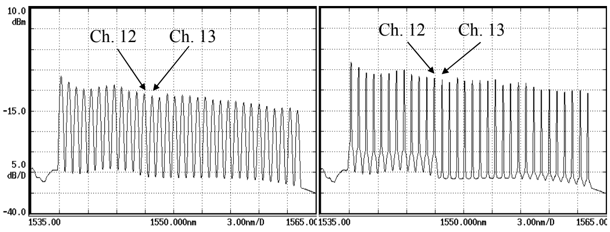

Fig. 3. Measured optical spectra at the output of Link3.

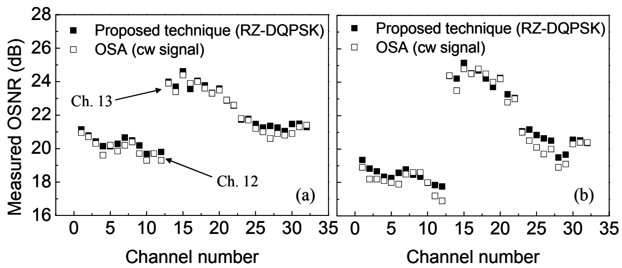

Fig. 4. OSNRs measured at the output of Link3. (a) without additional loss, (b) with additional loss (~ 4 dB) at the second span of Link1.

Table 1. Estimated and measured Q-factors of channels 12 & 13 after transmission. (I/Q: in-phase/quadrature data channel)

	Ch. 12 (I/Q)	Ch. 13 (I/Q)
Estimated Q-factor (dB)	14.3/14.4	18.0/17.8
Measured Q-factor (dB)	13.8/14.3	18.0/18.4

5. Conclusion

A cost-effective OPM system using commercial OCMs and power monitors was demonstrated in a reconfigurable transparent optical network testbed consisting of 4 nodes (including 2 WXC nodes). By using the proposed technique, we were able to successfully monitor the in-band OSNRs with an accuracy better than +/− 1 dB, even when 42.7 Gb/s RZ-DQPSK signals were transmitted up to three optical nodes (maximum transmission distance: 640 km).

Acknowledgement

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