Demonstration of GMPLS lightpaths diagnosis using an all-optical sampling-based Q-factor Monitor in a network testbed

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Abstract

An all-optical sampling-based Q-factor monitor applicable to multi-bitrated and formatted signals was successfully demonstrated in a network testbed. Quality of GMPLS lightpaths could be diagnosed correlating the actually measured BER.

Introduction

All-optical networking is one of the most attractive technologies for telecom operators to effectively increase the network capacity. However, there remains a concern in deploying such all-optical networks how to assess the quality of signals with multi-bitrates and formats which are transparently conveyed. The previously reported path computation-capable network management system (NMS) incorporated with the link-based optical signal noise ratio (OSNR) monitoring mechanism can effectively design and provision the quality-ensured lightpath in the generalized multi-protocol label switching (GMPLS)-controlled all-optical network [1], however, it is additionally required to assess the actual bit error ratio (BER) or the equivalent parameter along the lightpath with the consideration of commissioning and maintenance. Although we have so far investigated the compact and cost effective Q-factor monitor using the electro-absorption modulator (EAM)–based all-optical sampling technique [2], the applicability assuming the actual network environment must be completed before the deployment.

In this paper, we demonstrate the all-optical sampling-based Q-factor monitor applicable to multi-bitrated and formatted signals for the first time, and indicate the diagnosed results of GMPLS lightpaths, correlating the actually measured BER in the network testbed.

Architecture of the all-optical network with optical performance monitoring

Fig.1 shows the overall architecture of the all-optical network and the work flow of the operation and the maintenance. In the path designing and provisioning operations, the path computation-capable NMS can compute the optimum lightpath, provision it incorporating with link-based OSNR monitoring [3], and manage multiple lightpaths. Once the quality of the commissioned lightpath is influenced by a network failure or environmental change, the operator immediately starts to diagnose the lightpath and pinpoint a failure point or a root cause. By introducing the all-optical sampling-based Q-factor monitor (OS-QM), the signal quality degradation caused by various physical impairments such as a chromatic dispersion (CD) and differential group delay (DGD) can be detected in addition to OSNR degradation by link-based OSNR monitoring. For example, if 2km-length fiber is inserted into an existing fiber span for maintenance, the CD and DGD value might be varied leading to performance degradation, although the OSNR is not so changed. Therefore, OS-QMs attached to the optical switching nodes are used to accurately assess the quality of signals at the same level of SONET/SDH-based networks. Fig.2 shows the schematic diagram of OS-QM. The OS-QM consists of a wavelength selective switch (WSS), a single Mach Zehnder delay interferometers (MZDI) and an EAM-based optical sampling monitor (OSM), which can observe synchronized waveforms without clock recovery by off-line software processes. The WSS is used to select a wavelength and a fiber port at the optical nodes for the monitored lightpath according to the lightpath information managed by the NMS. After that, the MZDI is used to demodulate the selected phase shift keying (PSK) signal. Note that the value of the FSR of the MZDI should be set to 10 GHz, which is the least common value of multiple bitrates such as 10, 40 and 100 Gbps. The OSM measures the Q-factor of the signal from one of the outputs of the MZDI by amplitude histogram analysis [4]. For monitoring the on-off keying (OOK) signal,

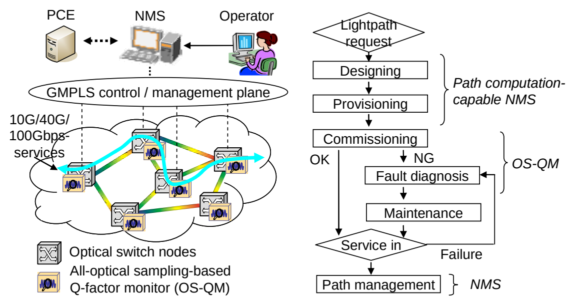

Fig.1 Architecture of all-optical network.

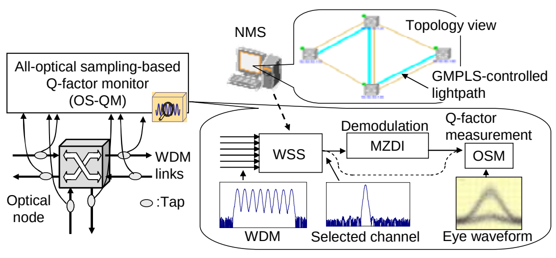

Fig.2 Schematic diagram of OS-QM.

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the MZDI is bypassed by an optical switch. Since the NMS manages the signal format used for the lightpath, it can control the optical switch so as to select either the PSK or the OOK signal on demand.

Demonstration and results

The testbed consisted of two GMPLS-controlled reconfigurable optical add/drop multiplexer (ROADM) nodes and two wavelength cross-connect (WXC) nodes based on the WSS connected by five physical links. The link 1, 4 and 5 were composed of two amplified spans with a length of 160 km, and the link 2 and 3 were composed of three amplified spans with a length of 240 km. The span loss of the link 1 and 4 was intentionally set to be higher than the ones of other links. To validate the operation of the OS-QM for GMPLS-based lightpaths, sixteen lightpaths between ROADM1 and 2 were provisioned considering the requirement of the end-to-end OSNR. Fig.3 shows the topology view as well as the established lightpaths indicated in the NMS. 10 and 40 Gbps-combined signals with multi-modulation formats are transmitted along these lightpaths. The commercially-available 10.7 Gbps-based non return-to-zero (NRZ)-OOK transponders and the 42.7 Gbps-based NRZ-differential PSK (DPSK) transmitter were used for a lightpath at 1550.92nm and for the one at 1551.72nm, respectively, while all other lightpaths were created using 42.7 Gbps RZ-DQPSK transmitters. Fig. 4 shows the optical spectrum measured at the tail-end of lightpaths and the end-to-end OSNR managed by the NMS.

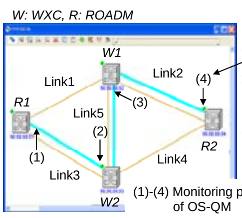

Fig. 3 Topology view.

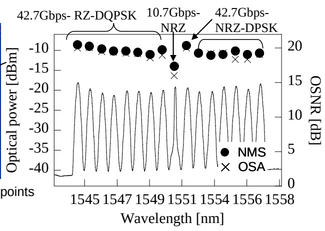

Fig. 4 Optical spectrum.

Fig. 5 shows the Q-factor ($Q^2\_{OS\text{-}QM}$) measured by the OS-QM at the monitoring points (1)-(4) (as shown in Fig. 3) along the lightpaths for the various signals. In addition, the Q-factors (Q^2_{BER}) obtained from the BER tester at the receiver is also plotted in Fig. 5 for comparison. The obtained eye diagrams after 640-km transmission using the OSM are also depicted in Fig. 5. The OS-QM could successfully assess the quality of the various signals at each distance. The $Q^2\_{OS\text{-}QM}$ is well correlated with the Q^2_{BER}. There was some discrepancy between the $Q^2\_{OS\text{-}QM}$ and the Q^2_{BER} as of the 10 Gbps NRZ signal because the bandwidth of OS-QM was much larger than that of the receiver. For the PSK signals, such discrepancy is mainly due to the difference of receiver types between the single receiver of OS-QM and double balanced one of PSK. Thus, this discrepancy could be calibrated after the measurement according to the bitrate and format.

Next, in order to verify the benefit of the OS-QM, we simulated the signal performance degradation by intentionally adding the CD of -40 ps/nm and the DGD of 15 ps between WXC2 and WXC1 assuming the environmental change after maintenance. Fig. 6 shows the difference of Q-factors (ΔQ^2) with and without the additional CD and DGD, measured by the OS-QM and the BER tester as for the 42.7 Gbps RZ-DQPSK signal. For comparison, the measured OSNR degradation (ΔOSNR) using the link-based OSNR monitoring technique was also described in Fig. 6. Although the quality degradations could not be observed by the OSNR monitoring, the degradation of around 1.5dB could be successfully diagnosed by using the OS-QM.

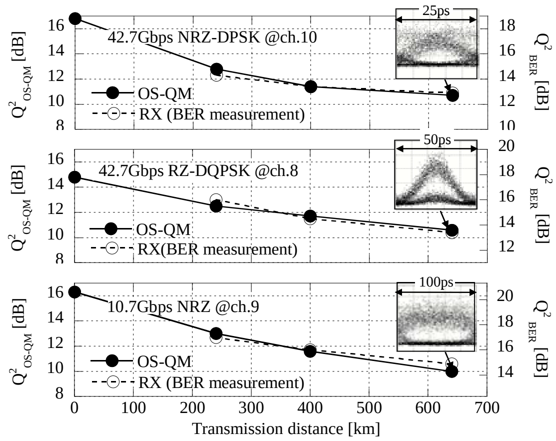

Fig.5 Quality assessment of lightpaths using OS-QM.

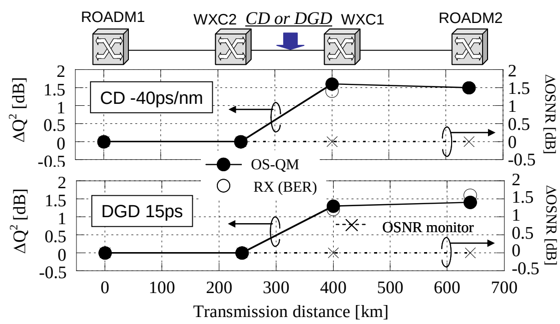

Fig.6 Diagnosis of degraded lightpath using OS-QM.

Conclusions

The all-optical sampling-based Q-factor monitor applicable to multi-bitrated and formatted signals was successfully demonstrated in the all-optical network testbed. Quality of GMPLS lightpaths and intentional degradation could be diagnosed correlating the actually measured BER as of 42.7 Gbps RZ-DPSK, 42.7 Gbps RZ-DQPSK and 10.7 Gbps NRZ signals. Through the verification of the effectiveness of the Q-factor monitoring in the testbed, we have a confidence of deploying and operating the all-optical networks in the actual network environment.

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