Performance monitoring in transparent optical networks using self-monitoring optical-labels

J. Yang, M.Y. Jeon, J. Cao, Z. Pan and S.J.B. Yoo

A novel optical layer performance monitoring method in transparent optical-label switching networks is presented. It is based on the signal quality correlation between the data payload and the label, which allows monitoring of the data payload signal quality by monitoring the label bit error rates. Experimental results indicate effective estimations of payload data bit error rates over approximately a 15 dB dynamic range of signal-to-noise ratio.

Introduction: The conventional layered data communication network is evolving towards a simplified Internet protocol (IP) over wavelength-division-multiplexing (WDM) architecture. This simplification aims at reducing both the capital expenditure (CAPEX) and the operating expenditure (OPEX) of the network while enhancing its performance. Optical performance monitoring is one of the major hurdles in the deployment of transparent IP/WDM networks. Current transport networks have performance monitoring functions in the synchronous optical network (SONET) layer and asynchronous transfer mode (ATM) layer, while IP/WDM networks must achieve these functions in the optical layer. Moreover, in transparent optical networks the performance monitoring function must be independent of payload data format and data rate. Therefore, effective optical-layer performance monitoring is imperative for transparent IP/WDM networks. Several optical-layer performance monitoring methods have been reported, e.g., using optical signal histogram measurements [1] or Q-factor measurements [2] to estimate the signal bit error rate (BER), and using optical subcarrier tone for performance monitoring [3, 4]. In this Letter we present a new optical-layer performance monitoring method based on BER measurements of the subcarrier-multiplexed labels in optical-label switching networks [5]. This method provides an effective and simple way to estimate the payload data BERs in the presence of noise impairments. Each optical node can conduct performance monitoring by reading the label, without processing any bit of the payload data, thus ensuring the optical transparency of the payload data. This method is simple, efficient, and suitable for real-time on-line performance monitoring.

Experiment and results: The optical label switching router [5] transmits payload data in the baseband channel and label in the subcarrier channel. The 14 GHz subcarrier multiplexing places the label component and the data payload component within 14 GHz of each other in the frequency domain. Moreover, the label and the payload data travel the same path in the network. Therefore the label signal and the payload signal experience similar impairments in the network. This experiment emulates the situation in an optical-label switching network with noise impairments.

Fig. 1: Experimental setup for performance monitoring using subcarrier-multiplexed optical-labels

VOA: variable optical attenuator; BPF: bandpass filter; PG: pattern generator; LD: laser diode; SCM: subcarrier multiplexing; FBG: fibre Bragg grating

Fig. 1 shows the experiment setup for investigating the correlation between the label BER and the payload BER. The parallel pattern generator (PG) unit generates the 2.5 Gbit/s payload data and the 622 Mbit/s label signal, both of which are $2^{31} - 1$ pseudorandom bit sequences (PRBS). The label signal modulates the amplitude of the 14 GHz subcarrier. Then, the modulated subcarrier signal merges with the payload data signal to produce a composite signal, which in turn modulates the amplitude of the optical signal from the laser diode (LD). The wavelength of the laser diode is 1550.7 nm. The variable optical attenuator (VOA) and the erbium-doped fibre amplifier (EDFA) emulate the noise impairments in the transmission. Varying the attenuation level of the VOA may adjust the signal power injected into the EDFA, which subsequently changes the signal-to-noise ratio (SNR) at the receiver. The VOA attenuation range was 0–21 dB, which corresponded to changing the optical SNR at the receiver by approximately 21 dB. A fibre Bragg grating (FBG) with its peak reflection wavelength at 1550.7 nm reflects the payload signal and allows the sub-carrier label signal to pass through [5]. The bandpass filter (BPF) limits the total noise power introduced by the EDFA at the receiver. At each VOA attenuation level, the payload BER and the label BER are measured simultaneously.

Figs. 2a and b show the BER curves of the payload and label, respectively. The 3 dB bandwidth of the BPF and the FBG are 1 and 0.1 nm, respectively. As the FBG extracts the payload data, it determines the noise bandwidth of the payload data. On the other hand, the BPF dominates the noise bandwidth of the label signal. For the same amount of optical SNR degradation, Fig. 2 shows that the label signal suffers more power penalty than the payload data signal, primarily because the bandwidth of the BPF is 10 times that of the FBG allowing more noise to affect the label detection. For attenuation levels of 18 and 21 dB, error floors start to develop. The BER of the label is much more sensitive to the SNR degradation than the payload data channel, primarily due to the wider optical passband of the BPF providing a greater noise background.

Fig. 2 BER plots for payload channel and label channel

a Payload channel
b Label channel

Fig. 3 shows the payload-data BER against label BER at various VOA attenuation (SNR) levels. Each data point in Fig. 3 corresponds to a pair of payload-data and label BERs measured at the same power level. This Figure indicates the correlation between the payload-data BER and the label BER over the 21 dB SNR dynamic range. The correlation is particularly strong when the optical SNR degradation is small, i.e. when the VOA level is between 0–9 dB. In this case the label BER predicts the payload-data BER with excellent accuracy; the estimation error is less than one-third of one order of magnitude. When the optical SNR is highly degraded, the label BER overestimates
the payload-data BER, in which case the network can respond more sensitively to the network performance degradation. To increase the BER estimation accuracy in a wider SNR dynamic range, a narrower passband BPF or an additional optical filtering after the FBG can be introduced. This will improve the accuracy at the expense of the sensitivity. An alternate way is to compensate for the BER estimation error during the measured data processing. This method will not compromise sensitivity. In practical applications, the label channel BER can be monitored via error checking fields in the label such as bit-interleaved parity (BIP) check. Furthermore, dispersion causes phase difference between the two subcarrier sidebands. Although the work reported in this Letter only investigated the performance monitoring method to monitor signal degradations caused by noise, an extension of this method can also apply to dispersion monitoring by using a similar setup incorporating additional spectral filters differentiating the two sidebands of the optical label.

Fig. 3 Correlations between payload BER and label BER

Conclusion: An optical performance monitoring method exploiting the correlation between the BER of the label and that of the payload data has been demonstrated. The estimation of the payload-data BER requires only the label BER measurements, and it offers optical transparency of the payload data. Experimental results show that the label BER measurements provide sensitive network performance monitoring over a relatively wide 15 dB SNR dynamic range.

© IEE 2004

Electronics Letters online no: 20045769
doi: 10.1049/el:20045769

J. Yang, M.Y. Jeon, J. Cao, Z. Pan and S.J.B. Yoo (Department of Electrical and Computer Engineering, University of California, Davis, One Shields Ave, Davis, CA 95616, USA)

E-mail: jqyang@ucdavis.edu

References


ELECTRONICS LETTERS 14th October 2004 Vol. 40 No. 21