Optical Labelling and Performance Monitoring in Coherent Optical Wavelength Division Multiplexing Networks

Chao Yang[1], Xiang Li[1], Ming Luo[1,3], Zhixue He[1], Haibo Li[1], Cai Li[1], and Shaohua Yu[1,2,3]

[1]*State Key Laboratory of Optical Communication Technologies and Networks, China Information Communication Technologies Group Corporation, Wuhan 430074, Hubei, China*

[2]*National Optoelectronics Innovation Center, Wuhan 430074, Hubei, China*

[3]*Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China*

yangchao@wri.com.cn

Abstract: We propose and experimentally demonstrate an optical labelling scheme in coherent optical WDM network to simultaneously recognize labels in each wavelength and monitor the OSNR using only one photodetector based on subcarrier index modulation technology.

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1. Introduction

Optical wavelength labelling technology can provide efficient and direct management for optical fiber connection and fault location in optical network, while on-line performance monitoring of different wavelength can be realized. It has played an important role in the flexible operation and maintenance of optical network to reduce the overall operating cost [1-2]. Generally, the optical label signal is generated independently, which contains the source and host addresses of the transmitted signal in each wavelength. The generation of optical label signal should have little effect on the performance of transmitted signal. Many methods have been proposed to generate the optical label signal, such as subcarrier multiplexing label [3], orthogonal modulation label [4], and optical time multiplexing label [5]. However, the main problem of these methods is that the label signal can be obtained only by filtering at the corresponding wavelength. Therefore the labels cannot be recognized at the intermediate nodes, which limit further application of these labels, such as routing and performance monitoring.

In this paper, we propose an optical labelling scheme based on subcarrier index modulation (SIM) technology. By allocating different frequency region to optical label signals at different wavelengths, simultaneous recognition of optical label signals at the intermediate nodes can be realized by using only one photodetector (PD) in wavelength division multiplexing (WDM) network. We conduct an experiment to verify the effectiveness of the proposed scheme by adding optical label signals to commercial available coherent optical 100-Gb/s module based on dual-polarization quadrature phase shift keying (DP-QPSK) signals. The experimental results show that the optical label signals can be successfully recovered after 1440-km standard single single-mode fiber (SSMF) transmission when the optical label signals are added on two wavelengths of 100-Gb/s DP-QPSK signals. The optical signal-to-noise ratio (OSNR) can also be monitored based on the power of subcarriers among the optical label signal with maximal estimated error of ± 0.6 dB.

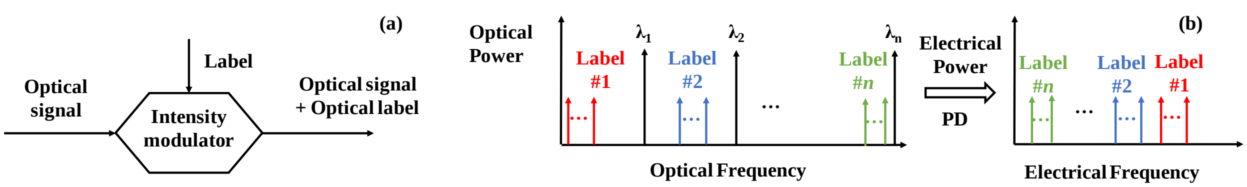

Fig.1 (a) Concept diagram of optical label signal generation (b) Frequency for the label signals

2. Principle

Figure1 shows the principle of optical label signal generation in WDM network. The optical label is loaded on the transmission signal by intensity modulator, as shown in Fig. 1(a). In SIM, the subcarrier is on if the binary symbol is “1” and subcarrier is off if the binary symbol is “0”. The frequency spacing between the optical label signals and transmission carrier of optical signal is different for different wavelengths. Fig. 1(b) describes the frequency allocations for different wavelengths based on SIM. In this scheme, all the optical label signals can be received by only one PD. After detection by PD, the electrical spectrum of the signal is also shown in Fig.1(b), where all the subcarriers are located at different frequency points in the electrical domain. It is noted that all the labels can be recovered by one fast Fourier transform (FFT) operation in digital domain, as all the optical labels are orthogonal to each other in optical domain. The bandwidth of the optical label signals is much smaller than that of the transmitted optical signal to mitigate the crosstalk. As indicated in Fig. 1(b), the SNR of recovered optical label signals can be calculated according to the power of subcarriers. Since the OSNR is linearly related to SNR [6], the OSNR in each wavelength can be obtained after finding the linear relationship between OSNR and SNR via linear programming.

3. Experimental Setup and Results

The experimental setup is illustrated in Fig. 2. For the generation of digital label signals, we consider the practical situation of 80 wavelengths in WDM network at C band with 50 GHz grid. For the frequency allocations among the electrical labels, we use IFFT operation at the transmitter side with IFFT size of 8192. Since intensity modulator is applied for cost-effective consideration, the used number of subcarriers should be 4096 for the 80 wavelengths. In order to avoid signal-to-signal beating noise in PD, the subcarriers with indexes from 1 to 50 are null. Then we allocate each wavelength with 50 subcarriers. Among the 50 subcarriers, 24 subcarriers are used to label the source and host addresses. Therefore, the maximal number of labeled address is 2^{12}. The rest subcarriers can be used to label other messages or calculation of noise power. The time-domain electrical label signal is also shown in the inset of Fig. 2. The analog label signals are then generated in an arbitrary waveform generator (AWG) operating at 4MSa/s, which is then loaded to a variable optical attenuator (VOA) to achieve intensity modulation. The bandwidth of the VOA is ~2MHz. The optical input to the VOA is the 100-Gb/s optical dual-polarization quadrature phase shift keying (DP-QPSK) signal, which is generated by commercial available coherent optical module. It is noted that the VOA is polarization insensitive. Therefore, the optical power of the DP-QPSK optical signal is adjusted by the electrical label signals. The electrical power of the electrical label signals should be optimized to minimize the power fluctuation of the DP-QPSK optical signal. For experimental verification, only two wavelengths of signals are used for transmission, which are combined by a wavelength-selective switch (WSS). The subcarrier indexes from 51 to 100 are allocated for VOA1 and subcarrier indexes from 101 to 150 are designed for VOA2. An amplified spontaneous emission (ASE) noise source is applied to emulate the optical signal in other wavelengths in the experimental demonstration. The transmission link consists of many SSMF spans without inline dispersion compensation. The length of each span is 80km, and the loss of each span can be fully compensated by a Raman fiber amplifier (RFA).

After fiber transmission, the received signal is divided into two parts. 99% power of the signal is used for the coherent detection of 100-Gb/s optical signal and 1% power of signal is used for label recognition and OSNR monitoring. The 1% power of signal is then injected into an avalanche photodetector (APD) to achieve optical-to-electrical conversion. The electrical signal is firstly passed through an electrical low pass filter, and then converted to digital signal by a digital storage oscilloscope (DSO) at 1-GSa/s for further off-line processing. The digital signal processing (DSP) includes resampling, FFT operation, overlap summation, label recognition and OSNR estimation. It is noted that since the optical label signals are send repeatedly, the insertion or removal of cyclic prefix and time synchronization process are not required in the DSP. Since the length of one optical label signal is 8192, the overlap addition means sum of multiple recovered optical label signals to reduce the effect of noise and enhance the SNR. The SNR is defined as the power of used subcarriers to the power of null subcarriers.

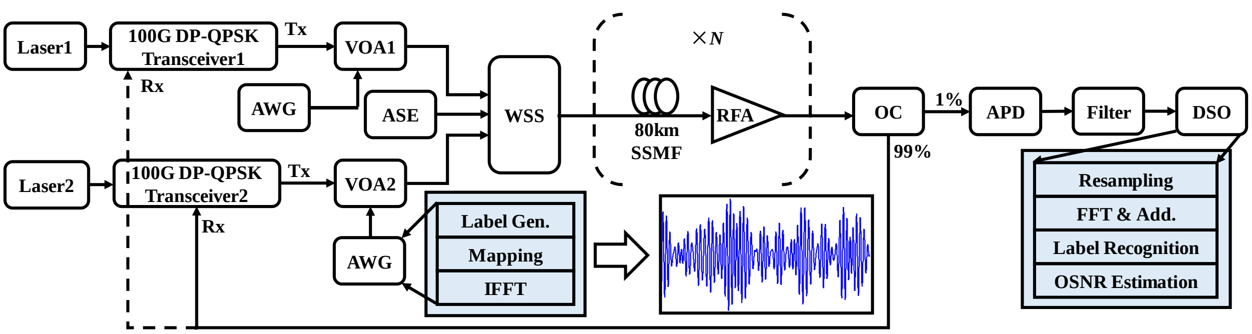

Fig.2 Experimental setup of optical labelling scheme for 100-Gb/s optical signal. AWG: arbitrary waveform generator; VOA: variable optical attenuator; RFA: Raman fiber amplifier; ASE: amplified spontaneous emission; OC: optical coupler; APD: avalanche photodetector; DSO: digital storage oscilloscope; FFT: (inverse) fast Fourier transform.

We first investigate the performances of the 100-Gb/s optical signal in the optical back-to-back (B2B) case. It is shown in Fig. 3 that the performances are affected by the peak-to-peak voltage (V_{pp}) of electrical label signal. Although higher value of V_{pp} can increase the SNR, the performance of 100-Gb/s optical signal is degraded if the power of electrical label signal is too large. In order to minimize the effect of electrical label signal, we choose the value of V_{pp} to be 0.05 V in the future study, which corresponding to BER lower than 10^{-10}. The inset (I) shows the waveform of recovered digital label signal when the ASE noise source is off. The 24-bit source and host addresses can be perfectly recovered. We also study the effectiveness of electrical filter and addition operation when the ASE noise source is on. The electrical low-pass filter with bandwidth of 10-MHz is used in our experimental demonstration to mitigate the noise. As shown in the inset (II) and (III), the SNR can be significantly enhanced when electrical low-pass filter is used at the receiver side. Similar trend can also be observed in the inset (IV) and (V). Better performance can be achieved when 200 digital label symbols are overlap added.

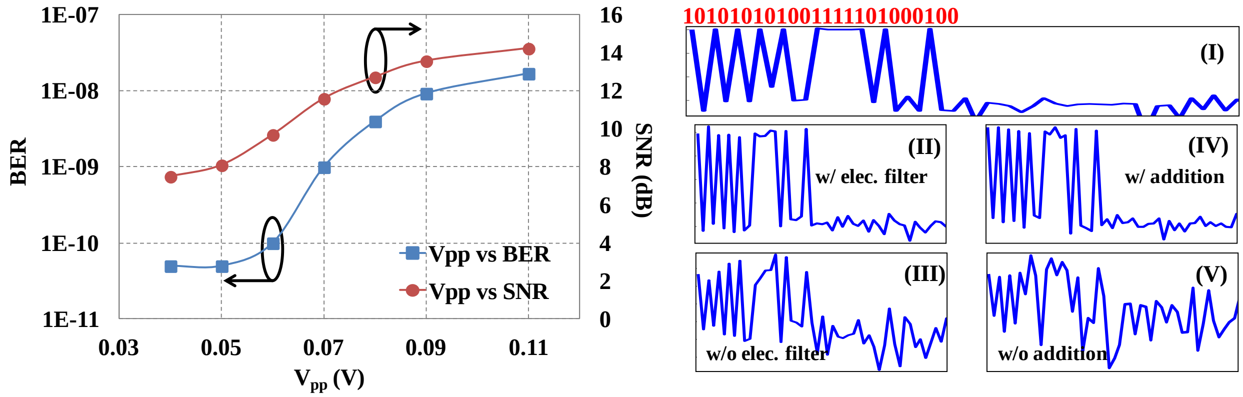

Fig. 3 The BER performance and SNR of recovered label signals versus peak-to-peak voltage. Inset: (I) recovered waveform of digital label signals with transmitted digital signals; recovered waveform of digital label signals with (II) and without (III) electrical low-pass filter; recovered waveform of digital label signals with (IV) and without (V) symbol overlap addition.

Then, we investigate the transmission performance of the optical label signals over SSMF transmission when the ASE noise source is off. Fig. 4 (a) shows the performances of SNR versus transmission distance of the two label signals. It can be seen that the two label signals have almost the same performance, which can achieve SNR of 8.4 dB after 1440-km SSMF transmission with 200 times overlap addition. The waveforms of the two recovered digital labels are also shown in the inset of Fig. 4(a). We also test the effects of channel spacing between the two lasers in the proposed scheme after 1440-km fiber transmission. It is shown in Fig. 4(b) there is no effect when the channel spacing between the two lasers is changing from 50 GHz to 1.8 THz. Therefore, the proposed scheme can be applied in the whole optical transmission band as long as the electrical label signals are not overlapped in the digital frequency domain. Finally, we measure the value of OSNR according to the calculated SNR at different transmission distance. It is noted that since the chromatic dispersion may have effect on the power of subcarriers, the parameters of linear programming for different transmission distance is different. As shown in Fig. 4(c), the maximal estimated errors of OSNR is ± 0.6 dB. Therefore, the proposed scheme may have the potential to be applied at the intermediate node for multiple wavelength OSNR measurement simultaneously.

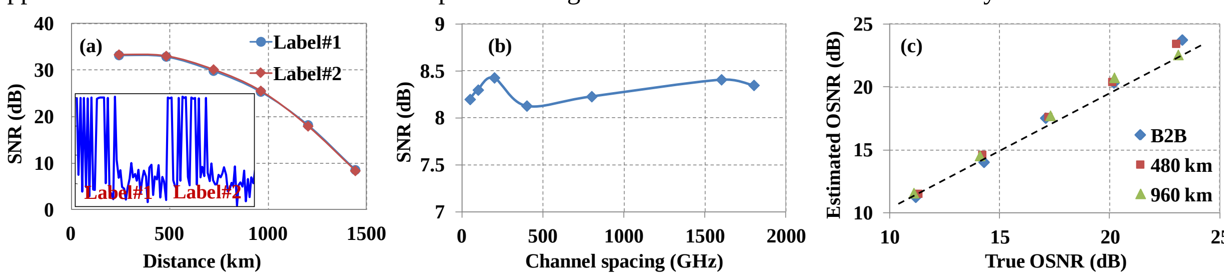

Fig. 4 (a) The SNR of two recovered digital label signals versus transmission distance; (b) The SNR of recovered digital label signals versus channel spacing between two lasers; (c) True versus estimated OSNRs for different transmission distance.

4. Conclusion

In this paper, we have proposed and experimentally demonstrated an optical labeling scheme based on subcarrier index modulation technology in practical fiber transmission system. By using multi-subcarrier label scheme, we have successfully achieved the reception of 2 label signals under the condition of using only one receiver for the data rate of 100Gbit/s DP-QPSK signals. Meanwhile, with the aid of the label signal the OSNR of the DP-QPSK signals can be effectively monitored.

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