Flexible and Transparent Optical Labelling in Coherent Optical Wavelength Division Multiplexing Networks

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Abstract: Multichannel 10-Kb/s optical labelling signal added on the 100-Gbit/s DP-QPSK signals is experimentally demonstrated after 600-km SSMF transmission. By down sampling and low pass filtering, we successfully recovered the multichannel labels using only one photodetector.
OCIS codes: (060.4080) Modulation; (060.2330) Fiber optics communications

1. Introduction

With the rapid development of optical fiber communication system, higher requirements are put forward for the reliability and stability of the system. In order to ensure the normal operation and maintenance of optical network, on-line performance monitoring and network management information transmission are essential. Optical wavelength labelling technology can play an important role under such requirements, which have little effect on the performance of transmitted signal [1-2]. Recently demonstrated optical labelling techniques have been mainly based on subcarrier multiplexing label [3], frequency-shift keying (FSK) modulation label [4], and optical time multiplexing label [5]. Our previous work proposed an optical labelling scheme based on subcarrier index modulation (SIM) technology, which can detect different wavelengths labels by using only one photodetector (PD) in wavelength division multiplexing (WDM) network [6]. However, it is difficult to flexibly adjust the transmission signal rate and realize transparent transmission, which will limit the application of subcarrier index modulation technology in practice.

In this paper, we propose a new optical labelling scheme for more flexible and transparent transmission of label information. By digital down sampling of the oversampling data which is detected by using one PD in WDM network, and low pass filtering for different carrier frequency labeled signals respectively, we can effectively recover all the optical labelling signals. All optical labelling signals are generated independently in the system. Moreover, the proposed scheme is insensitive to the transmission rate and format of labelling signals. In the environment of commercial coherent optical 100-Gb/s dual-polarization quadrature phase shift keying (DP-QPSK) module signals transmission, we experimentally evaluate the performance of the scheme. The experimental results indicated that the labelling signals have little effect on the transmission signal and it can be successfully transmitted together with 100-Gb/s DP-QPSK signal over 600-km standard single single-mode fiber (SSMF) with only 1.9dB penalty.

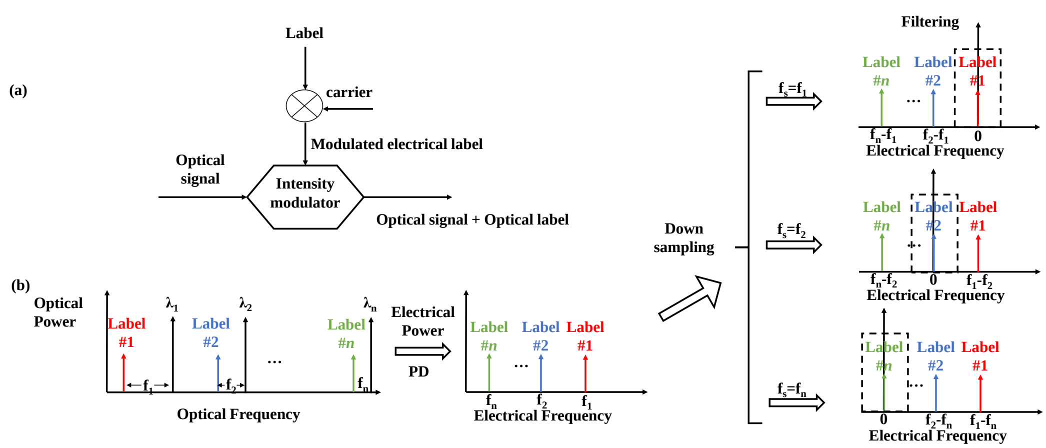

Fig.1 (a) Concept diagram of optical label signal generation (b) Process for the label signals recovery

2. Principle

Figure 1 shows the principle of label signal generation and reception in the proposed method. Firstly, the electrical label signals for different wavelengths are modulated to electrical carriers at different frequencies. Then, the modulated electrical labels are loaded onto the transmission signal by intensity modulator. As shown in Fig. 1(a), The proposed scheme can support signal transmission in different formats and is not sensitive to transmission rate.

Figure 1(b) depicts the change of labelling signal spectrum in the process of signal recovery. We can see that the frequency intervals between the carrier frequency of the labelling signal and its corresponding optical carrier signal are f_1, f_2 ,⋯, f_n respectively in the optical domain. After all the optical label signals are detected by one PD, as shown in the Fig. 1(b), the carrier frequency of the labelling signal are f_1, f_2 ,⋯, f_n respectively in the electric domain. In order to demodulate all labelling signals, we adopt a multi-channel parallel processing scheme to down sample the sampled data at f_1, f_2 ,⋯, f_n sampling rates respectively. As described in Fig. 1(b), the spectrum of the labelling signals move at the frequencies of f_1, f_2 ,⋯, f_n respectively, and the desired labelling signal is moved to the base frequency. Therefore, the signal can be easily recovered through a simple low-pass filter. It is noted that in order to avoid signal aliasing, the bandwidth of the single labelling signal and all labelling signals must be designed within a reasonable range.

3. Experimental Setup and Results

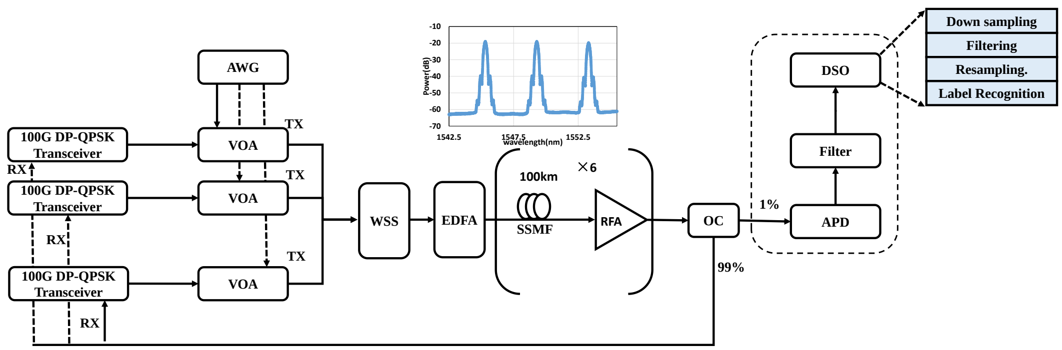

Fig.2 Experimental setup of optical labelling scheme for 100-Gb/s optical signal. AWG: arbitrary waveform generator; VOA: variable optical attenuator; RFA: Raman fiber amplifier; ASE: amplified spontaneous emission; OC: optical coupler; APD: avalanche photodetector; DSO: digital storage oscilloscope;

The experimental setup for the SSMF transmission of labelling signals based on the proposed scheme is shown in Fig. 2. Three 100-Gb/S DP-QPSK transmission signals are used with the wavelengths of 1545.4-nm, 1549.4-nnm, and 1553.4-nm to verify the effectiveness of the proposed scheme. The modulated labelling signal is generated in an arbitrary waveform generator (AWG). First, a pseudo random binary sequence (PRBS) with length of 4096 is first mapped to binary phase shift keying (BPSK) format for the labelling signal. Then, the electrical carrier signals of the labelling signals are loaded digitally with frequencies of 200-KHz, 250-KHz, and 300-KHz, respectively. As the rate of the labelling signals is only 10-Kb/s, there is no aliasing between the signals. The modulated labelling signals are then sent to an AWG running at 10-MSa/s, which then drive a variable optical attenuator (VOA) to achieve intensity modulation. The bandwidth of the VOA is about 2 MHz. The optical input of the VOA is the 100-Gb/s DP-QPSK signal, which is generated by commercial available coherent optical module. After the labelling signals is loaded to the transmission signal, the three wavelengths of signals are combined by a wavelength-selective switch (WSS). The modulated optical signal is then amplified by an erbium doped fiber amplifier (EDFA), which is used to control the launch power. The transmission link consists of 6 SSMF spans without inline dispersion compensation. The length of each span is 100km, 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 recovery. 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 to eliminate noise caused by beat of 100-Gb/s DP-QPSK signals, and then converted to digital signal by a digital storage oscilloscope (DSO) at 10-MSa/s for further off-line processing. The maximum length of the labelling signal is limited due to the lowest AWG sampling rate. For accurate evaluation, we use signal-to-noise ratio (SNR) instead of bit error rate (BER) to describe the quality of the recovered signal, which is defined as:

$$SNR_{dB} = 10 \cdot log_{10} \frac{S^2}{\left(S_R - S\right)^2} \quad (1)$$

where S_R is the recovered signal, and S is the transmitted labelling signal.

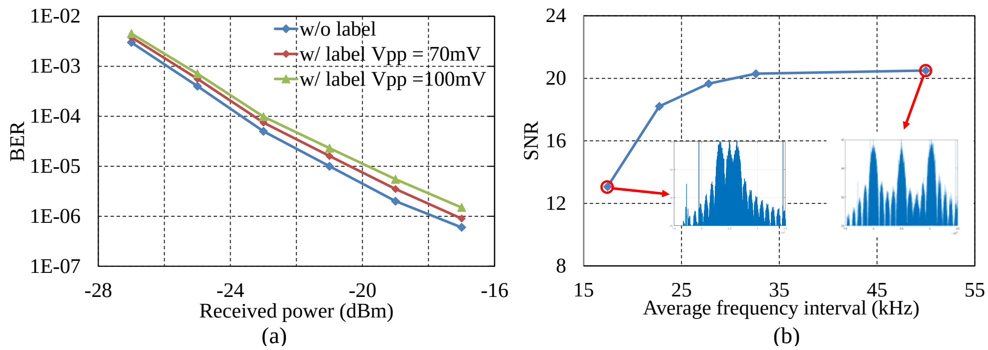

Fig. 3 (a) Receiver sensitivity measured at back to back (B2B) for the 100-Gb/s DP-QPSK signal with and without optical labels. (b) SNR of the recovered labelling signals versus average frequency interval between labelling signals.

We first investigate the effects of optical label signal on system performance. Figure 3(a) shows the measured curve of BER versus OSNR of the 100Gbit/s DP-QPSK signals with and without optical labels. It is observed that the performance is degraded with the increase of modulation depth of optical label signal. When the peak-to-peak voltage (Vpp) of the electrical label signal are 70mV and 100mV, the corresponding performance penalties are 0.4 dB and 0.8 dB, respectively. Thus, achieved penalties by using the proposed scheme are within 1 dB. Then, the effects of frequency interval between labels are also studied. Figure 3(b) depicts the relationship between SNR of the recovered labelling signals and frequency interval. Since the frequency interval of the measured signal to high-frequency carrier and low-frequency carrier are not consistent, we take the average value of the interval as the measurement parameter. It is observed that the performance of recovery labelling signal degrades with the reduction of the average frequency interval.

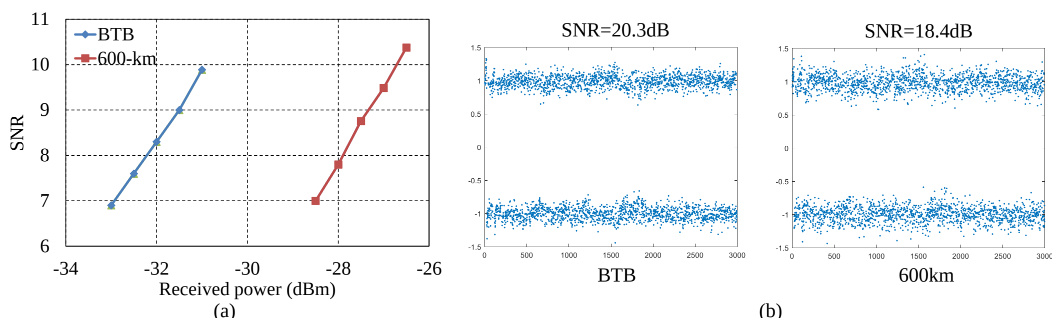

Fig. 4 (a) The SNR of recovered labelling signals versus received power for 600-km transmission; (b) The recovered label signals

Finally, we study the transmission performance of the optical label signals. Figure 4 (a) shows the performance of the recovered optical label signals in 600-km transmission under the condition of 70mV Vpp. It is shown in Fig. 4 (a) that the SNR of the label signal decreases as well as the receiving sensitivity of the 100Gb/s DP-QPSK signal with the transmission in the optical fiber. An approximate linear relationship between SNR and receiving sensitivity is verified by experiments, which can be applied to the performance monitoring of transmission signal. At the same time, as Fig. 4 (b) depicts that the SNR of the label signal decline from 20.3dB to 18.4dB after 600-km SSMF transmission, with only 1.9dB penalty.

4. Conclusion

We have experimentally demonstrated an optical labelling system in coherent optical WDM link. The proposed method can transmit label information flexibly and transparently with a real-time 100-Gb/s transmission system. By using digital signal processing techniques such as down sampling and low-pass filtering, multi optical label signals can be recovered via only one PD. In the actual transmission verification, the transmission penalty for 600-km SSMF is only 1.9dB.

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