115.2 Tbit/s Transmission over 20 km SMF Using PDM 256-QAM signals in Ultra-Wideband System

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***Abstract*—We demonstrate the ultra-wideband transmission of 480, 50GHz spaced channels with PDM 256-QAM modulation over 20 km of SSMF. We achieved 115.2 Tbit/s transmission capacity by using artificial neural network to compensate fiber nonlinearity.**

Keywords—multi-band system, high-order modulation, fiber nonlinearity, WDM

I. Introduction

To deal with the rapid growth of data transmission traffic, it is necessary to increase the transmission capacity per optical fiber at the lowest possible cost. Most of the current optical networks are deployed in the C and L bands, studying and utilizing the available bands beyond the C and L bands is an effective way to increase the transmission capacity. The conventional C and L bands range from 1530 to 1625 nm, while the full band wavelength range from 1260 to 1675 nm [1], which greatly expands the bandwidth of the transmission channel. According to a assessment of G.652.D fiber transmission capacity implemented by Turin Polytechnic University in 2020, the theoretical transmission capacity of 50 km single fiber can reach 450 Tbit/s, and that of 600 km single fiber can reach 220 Tbit/s with the 365 nm bandwidth of O, E, S, C, and L bands is utilized [2]. Furthermore, the recent demonstrations also show that the transmission capacity of more than 100 Tbit/s can be achieved on the multi-band system by adopting advanced amplification technology and off-line digital signal processing (DSP) technology [3-8].

In this work, we extended the available wavebands to O, E, S, C, L and U band, and constructed a 6-band optical transmission system. We demonstrated 480-channel WDM transmission of 50 GHz spaced 15 GBaud polarization division multiplexed (PDM) 256-QAM signals on this system, and the total capacity can reach 115.2 Tbit/s by using artificial neural network technology to compensate the inter-channel nonlinear interference which is an important factor limiting communication capacity.

II. Experimental Setup

Fig. 1(a) shows the setup for 6-band WDM transmission system which is established on the VPI software. The transmitter uses O, E, S, C, L and U band continuous-wave (CW) lasers with a line width of 100 kHz for transmission. In each band, 80 optical carriers with 50 GHz spaced are generated from CW lasers. The wavelength of the measured signals is set to 1304.63 – 1327.43 nm in the O band, 1408.78 – 1435.41 nm in the E band, 1456.66 – 1485.15 nm in the S band, 1534.92 – 566.58 nm in the C band, 1571.09 – 1604.28 nm in the L band, and 1639.79 – 1675.98 nm in the U band. The optical carrier is modulated by the IQ modulator which is driven by an arbitrary waveform generator(AWG). The modulated 15 GBaud PDM 256-QAM signals of each band are amplified with semiconductor optical amplifier (SOA) in the O, E and U band, thulium-doped fiber amplifiers (TDFA) in the S band, and erbium-doped fiber amplifiers (EDFA) in the C and L band. The amplified 6-band signals are multiplexed using a multiplexer (MUX). After 20 km single-mode fiber (SMF) transmission, the WDM signal is de-multiplexed into each band using a de-multiplexer (DEMUX). The de-multiplexed signal of each band is again amplified by SOA, TDFA, and EDFA. After the amplification, the coherent receivers are used to detect the signals and the digitized signal is demodulated by off-line DSP as shown in Fig. 1(b) that includes dispersion compensation, polarization de-multiplexing, frequency offset estimation, and carrier

TABLE I. Parameters of Different Band

Parameter / Band	O-Band	E-Band	S-Band	C-Band	L-Band	U-Band
Bandwidth range (THz)	226-230	209-213	202-206	191.5-195.5	187-191	179-183
Number of channels	80	80	80	80	80	80
Nonlinear coefficient （1/W/km）	1.55	1.44	1.39	1.32	1.29	1.23

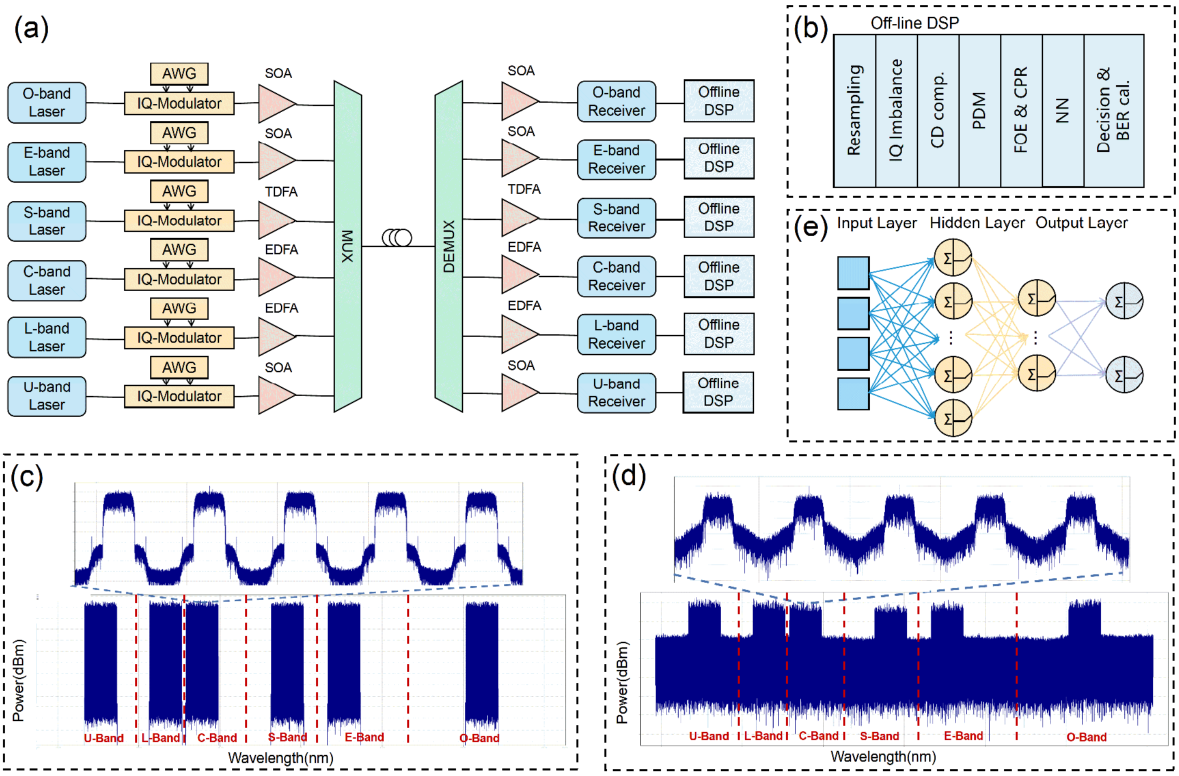

Fig. 1. (a) Experimental setup, (b) off-line DSP, (c) optical spectra before and (d) after transmission, (e) neural network structure diagram.

phase recovery. Then, a neural network is applied to compensate for the fiber nonlinearity. The signal after neural network equalization is decoded and the bit error ratio (BER) is calculated. Table 1 shows some parameters in each band, including bandwidth range, channel number and nonlinear coefficient.

Fig. 1 (c) and (d) show the spectrum diagram of the 6-band WDM system containing a total of 480 channels before and after 20km SMF transmission. For the better display, the spectrum of five channels in the C-band is amplified. Wavelength multiplexing leads to the dominance of inter-channel nonlinear interference in optical fiber nonlinearity, and the interference will intensify as the number of channels increases. Due to the influence of fiber nonlinearity, the signal has been seriously damaged and distorted, which undoubtedly limits the transmission distance and quality of the signal. To mitigate the fiber nonlinear interference, we use the neural network (NN) structure based on back propagation (BP) algorithm as shown in Fig. 1(e). We choose the in-phase (I) and quadrature (Q) components of X polarization and Y polarization as inputs. The hidden layer contains two layers and the neuron nodes of each layer are set to 300 and 10 respectively. We use the received symbols of WDM transmission system as input samples, and the transmitted symbols as target samples. The neural network learns the mapping relationship between the input samples and the target samples, and uses the relationship to train new data samples. Finally, the output layer outputs the trained samples.

III. Results and Discussion

Fig. 2 shows the change of BER characteristics with launch power at 1550nm wavelength in single-channel system and multi-band system with 20 channels multiplexing in each band respectively. In the single-channel system, the best BER performance (Log BER) can reach -4.063 when the launch power is - 2 dBm. While in the multi-band system, the best BER performance is -3.733 at the launch power of - 6 dBm. The BER performance in multi-band system is lower than that in single-channel system, which is caused by nonlinear crosstalk between channels in multi-band system.

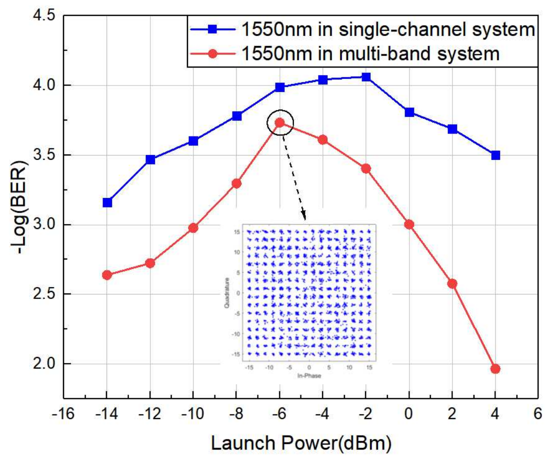

Fig. 2. BER versus launch power in single-channel system and multi-band system.

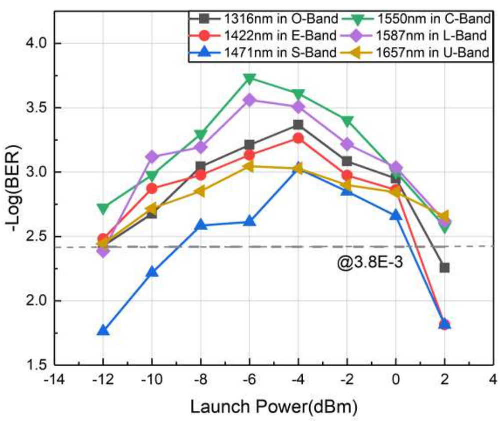

Fig. 3. BER versus launch power for different wavelength in multi-band system.

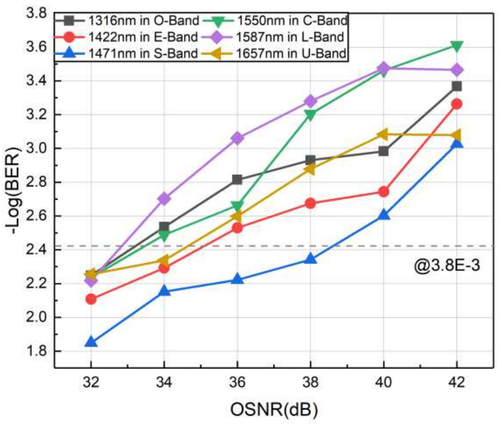

Fig. 4. BER versus OSNR for different wavelength in multi-band system.

Fig. 3 shows the BER performance versus launch power of each band in the multi-band system at the wavelength of 1316nm, 1422nm, 1471nm, 1550nm, 1587nm and 1657nm respectively. As the launch power increases, the BER performance also improves at first and reaches the optimal value at a certain launch power, then the BER performance becomes worse with the increase of launch power. This is because the increase of launch power leads to the intensification of fiber nonlinear effect, which brings damage to the signal. The signals in O, E and S band have the best BER performance when the launch power is - 4dBm,and the signals in C, L and U band have the best BER performance at the launch power of - 6dBm. Although the BER of each band can reach 3.8e-3, the BER of C and L band is significantly better than that of other bands, which is caused by the characteristic difference of different bands.

We also measured the BER of each band versus optical signal-to-noise ratio (OSNR) in the multi-band system at the launch power of -4 dBm as shown in Fig. 4. With the increase of OSNR, the BER of each channel is decreasing. The OSNR required for each band to reach 3.8e-3 is 33.17 dB, 35.12 dB, 38.70 dB, 33.45 dB, 32.85 dB and 34.70 dB respectively and the OSNR penalty due to differences between channels is 5.53dB. Significant differences in BER between bands can be observed, and in addition to characteristic differences of bands, amplifiers may also be the reason. Different amplifiers may vary slightly in gain and noise figure and this leads to differences in the quality of signals.

IV. Conclusion

We have successfully demonstrated the 480-channel WDM transmission of 50 GHz spaced 120 Gbit/s PDM 256-QAM signals over 20 km SMF in multi-band system contains O, E, S, C, L and U band. Using neural network structure compensate nonlinear interference between channels, we achieved a total capacity of 115.2 Tbit/s. This result paves the way for the available bandwidth of future transmission system to expand from the traditional C+L band to O, E, S, C, L and U band.

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