Study of 16 Tbit/s WDM transmission system derived from the CO-OFDM with PDM 16-QAM*

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In this paper，a wavelength division multiplexing (WDM) transmission system derived from the coherent optical orthogonal frequency division multiplexing (CO-OFDM) with polarization division multiplexing (PDM) and 16-order quadrature amplitude modulation (QAM) is studied. A simulation of 80-channel WDM transmission system with data rate of 200 Gbit/s is built, and the transmission performance of the system is analyzed. The simulation results show that the system Q value of the WDM channels at 16 Tbit/s with a spectral efficiency of 7.14 bit/s/Hz is potentially over 10.0 dB for a long haul transmission up to 1800 km in a standard single-mode fiber.

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Owing to the demand for extremely high capacity in communication, researchers have spurred intense effort on high spectral efficiency and high data rate for optical networks[1,2]. To increase the overall network capacity of wavelength division multiplexing (WDM) system, high spectral efficiency modulation formats with high per-channel bit rates are being proposed as significant solutions with great potentials[3]. Furthermore, various studies on coherent optical orthogonal frequency division multiplexing (CO-OFDM) have drawn special attention in spectral efficiency, receiver sensitivity and polarization or chromatic dispersion tolerance[4-10]. In addition, the incorporation of the 2×2 multiple-input multiple-output OFDM (MIMO-OFDM) also opened an interesting avenue for doubling spectral efficiency[11]. Thus, under a WDM system and using CO-OFDM with polarization division multiplexing (PDM), high order quadrature amplitude modulation (QAM) technology in optical fiber communication has been able to build higher speed rates, larger capacity and longer haul distance transmission via optical networks. Nevertheless, departing from its significant potential, WDM systems using CO-OFDM have been paid intense attention in the field of optical fiber communication in recent years[12-15]. However, there has been almost no report on the WDM transmission system using a CO-OFDM with PDM and high order QAM technology either in simulation or laboratory experiment.

In this paper, we study a WDM transmission system using the CO-OFDM with PDM and 16-order QAM technology in simulation, expecting to demonstrate the simulated outcome of a 200 Gbit/s×80-channel WDM transmission system with a nominal data rate of 16 Tbit/s.

In Fig.1, a schematic diagram of WDM transmission system is provided using the CO-OFDM with PDM. In the transmitter, a 25 Gbit/s data stream with a length of 2^{16}-1 of pseudo random sequence (PRS) is generated by a PRS generator, and divided into x- and y-polarization branches. Each of them is mapped onto 512 subcarriers with a QAM after serial-to-parallel (S/P) transform. The time domain signal is generated through using inverse fast Fourier transform (IFFT) with guard intervals applied as one quarter of the observation period. The time domain signals are then serialized and converted into analog signals by two digital-to-analog converters (DACs). The radio frequency (RF)-to-optical up-conversion is achieved by applying two Mach-Zehnder (MZ) optical modulators biased at zero output power, and the modulated optical signals are combined by a polarization beam combiner (PBC) for polarization multiplexing. The obtained signals after multiple WDM channels are launched into the optical link which is a standard single-mode fiber. The optical OFDM signals then after WDM channels are demultiplexed and fed into the optical-to-radio (OTR)

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down-converter, where the optical OFDM signal is converted to an RF OFDM signal. It is important to note that it contains the polarization diversity and coherent detection. At the receiver, the received signals are converted into digital form through two analog-to-digital converters (ADCs) and then re-arranged to be parallel. Following a fast Fourier transform (FFT), the channel estimation is conducted. At the last step, a QAM decoder is used to analyze the symbols obtained on each subcarrier to make the final decision and to recover the original signals.

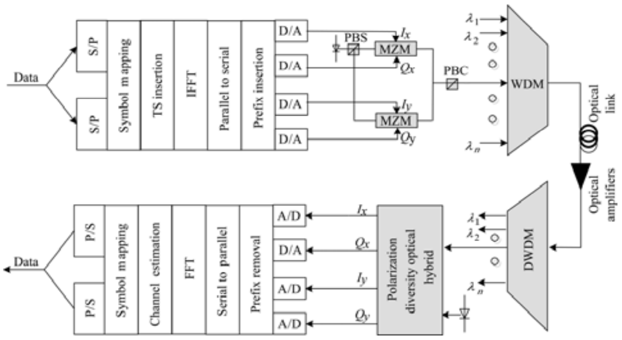

Fig.1 WDM system using CO-OFDM with PDM

The results show that WDM systems in combination with the coherent detection optical OFDM with PDM and 16-QAM technology can effectively take advantage of spectrum resource for a long haul transmission at 16 Tbit/s. Overall, this study reports a simulation analysis from the spectrum of the signal and the relationship between Q value and each WDM channel's optical power. Because the results from all of the 80 channels are similar, we only intend to demonstrate the simulated outcome of the first channel. The parameter settings are as follows: the OFDM parameters are 512 subcarriers, the IFFT point of each-way single is 1024, and there is a 16-QAM encoding for each subcarrier. Continuous wave (CW) laser frequencies are 193.05 THz, 193.1 THz, 193.15 THz and 197 THz, respectively, where the power is -5 dBm. WDM bandwidth is 50 GHz using Gaussian filter. It is useful to note that the fiber link using standard single-mode fiber has chromatic dispersion of 16 ps/(nm·km) and polarization-mode fiber has dispersion of 0.2 ps/km and loss of 0.2 dB/km. A nonlinear coefficient of $2.6\times10^{-20}\ m^2/W$ is applied to both modes. In the case for fiber with 100 km span, the loss is compensated by optical amplifier with gain of 15 dB and noise figure of 4 dB. The line widths of the transmitted and received lasers are assumed to be 150 kHz. Under the experimental condition, the part of photoelectric conversion is applied using coherent detection, each PIN photodiode detector sensitivity is set to be 1 A/W, and the dark current is 10 nA.

Fig.2 shows frequency spectrum of the first channel of WDM systems using CO-OFDM with PDM and 16-QAM. After calculation, the spectral efficiency of the system is obtained as 7.14 bit/s/Hz. It can be drawn that the WDM system using the CO-OFDM with PDM and 16-QAM presents a high spectral efficiency.

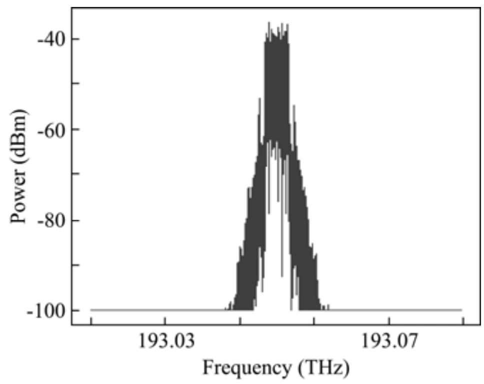

Fig.2 Frequency spectrum of the first channel of WDM system using CO-OFDM with PDM and 16-QAM

Fig.3 shows the system Q of the received data versus the optical launch power of the first channel of WDM system with different fiber lengths. In fact, Q is obtained without noise loading at the receiver. We then use the selected optical power to control the signal to noise ratio. From the results, we can see that when the optical power increases in a certain range, the system Q increases gradually. However, when the power increases to a certain extent, the Q value decreases, because the nonlinearity degrades the system performance. The optimal optical launch power of CO-OFDM with PDM system for each WDM channel varies from 12 dBm to 14 dBm.

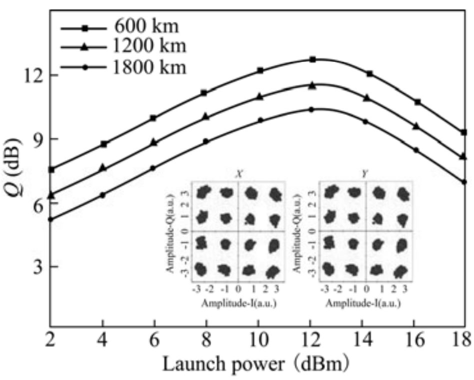

Fig.3 System Q versus the optical power of each WDM channel with different fiber lengths

The results in the insets of Fig.3 can also clearly demonstrate that the constellation of WDM system at the first channel using CO-OFDM with x- and y-polarization modes over 100 km transmission in one span has no compensation at the data rate of 16 Tbit/s, which shows successful transmission and reception. The simulation can prove that the WDM system using the coherent optical OFDM with PDM can achieve higher signal rate, better dispersion and more promising nonlinear tolerance.

By incorporating a CO-OFDM with PDM and 16-QAM technology into WDM systems, we successfully carry out a simulation. The results show that the system Q of the WDM channels at 16 Tbit/s is over 10.0 dB for a long transmission up to 1800 km in a standard single-mode fiber. Compared with the traditional optical WDM systems, we find that the WDM system using the CO-OFDM with PDM and 16-QAM technology can not only maximize the advantage of spectrum resources, but also effectively suppress dispersion and nonlinear effects in the fiber. In our future study of the system, we will focus on higher modulation and novel channel estimation algorithm to further improve the performance of the transmission system.

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