Transmission of 160-Gbit/s QPSK Signals on a Single Carrier over 1,000 km using Digital Coherent Receivers

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Abstract *We demonstrate 1,000-km transmission of a 160-Gbit/s QPSK signal, using a digital coherent receiver with the time-division demultiplexing function, and confirm the applicability of such a receiver to long-haul transmission systems for the first time.*

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Introduction

The digital coherent receiver can demodulate any multilevel-coded signals without optical phase synchronization. Moreover, the receiver benefits from post compensation in the digital domain, such as chromatic dispersion (CD) compensation [1] and polarization-mode dispersion compensation [2].

Both the symbol rate and the transmission distance have increased steadily in recent coherent system experiments. For the moment, Nelson *et al.* have reported 800-km transmission of an 11.5-Gsymbol/s dual-polarization quadrature phase-shift keying (QPSK) signal per carrier in the real-time mode of operation of the digital coherent receiver [3]. On the other hand, 2,550-km transmission of 25-Gsymbol/s dual-polarization QPSK wavelength-division multiplexing (WDM) channels has been demonstrated in the offline experiment [4].

However, the maximum symbol rate that such a digital coherent receiver can process is strictly limited by the performance of electronic circuits such as analog-to-digital converters (ADCs) and digital signal processors (DSPs). This limitation can be overcome by employing a local oscillator (LO) pulsed at a subharmonic frequency of the symbol rate in order to time-division demultiplex the signal in an optoelectric manner [5]. We have demodulated a 1.28-Tbit/s dual-polarization 16-ary quadrature amplitude modulated (16-QAM) signal in a back-to-back experiment with the proposed digital coherent receiver [6].

To shift such receiver to the practical stage, we need to assess its performance in long-distance transmission systems. In this paper, we demonstrate 1,000-km transmission of an 80-Gsymbol/s QPSK signal, and confirm its applicability to long-haul transmission systems for the first time.

Principle of time-division demultiplexing

For time-division demultiplexing, the LO in the phase-diversity homodyne receiver must be pulsed at the base-clock rate of the time-division multiplexed (TDM) signal. Since the homodyne output contains only the beat between the incoming signal and the LO pulse train, we can take the linear correlation between them [7, 8] and extract the tributary, on which the LO pulse train is overlapped. The LO pulse train thus samples one of the tributaries of the signal in an optoelectric manner.

Experimental setup

The experimental setup for 1,000-km transmission of a 160-Gbit/s QPSK signal is illustrated in Fig.1. A 10-GHz optical pulse train with 2-ps pulse width at the wavelength of 1556 nm was generated by an optical pulse source driven by a 10-GHz clock (CLK) [9]. Then, an arbitrary waveform generator (AWG) drove a lithium niobate optical IQ modulator (IQM) to generate a 10-Gsymbol/s QPSK signal. The signal was time-division multiplexed by eight times with an optical delay-line multiplexer (OMUX). A 10-GHz clock was supplied by an intensity-modulated optical signal at another wavelength at 1550 nm.

The signal and clock were coupled by an optical coupler (CP) and incident on a 1,073-km-long transmission line with the launched power of -5 dBm. The transmission line had 25 spans where each span consisted of a 29-km single-mode fiber (SMF) and an 11-km dispersion-compensating fiber (DCF). The average CD value of the SMF and the DCF are 21 ps/nm/km and -58 ps/nm/km, respectively. A 73-km-long SMF was inserted to counteract over-compensation of the transmission link.

At the receiver side, the signal and the clock were separated by a WDM divider. The electrical 10-GHz clock was detected by a photodetector and drove the pulse source which generated a 10-GHz LO pulse train. The signal and the LO were incident on a phase-diversity homodyne receiver. The received power (P_{in}) was controlled by a variable optical attenuator (VOA). The IQ data were sampled at 20 Gsample/s by a 2-channel 8-bit ADC. The DSP, which was executed offline, consisted of clock recovery, finite-impulse response (FIR) filtering for inter-symbol interference suppression, carrier-phase estimation for phase-noise cancelling, and symbol decoding. In this way, we could demodulate any one of the eight tributaries of the TDM signal.

Experimental results

The constellation map of a 160-Gbit/s QPSK signal measured in a back-to-back case and that after

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1,000-km transmission are shown in Fig. 2(a) and (b), respectively. Each received power is -30 dBm. Figure 3 illustrates bit-error rate (BER) characteristics of demodulated signals. Rectangles show BERs of 160-Gbit/s QPSK signals after 1,000-km transmission and triangles are those of the 160-Gbit/s QPSK signals measured in a back-to-back case. The dashed curve represents the theoretical shot-noise-limited BER characteristics. The BER after 1,000-km transmission was under the forward-error correction (FEC) threshold when the received power is -30 dBm. The deterioration of the BER after transmission is due to residual CD.

Conclusion

We have successfully demonstrated 1,000-km transmission of a 160-Gbit/s QPSK signal with the digital coherent receiver having the time-division demultiplexing function. We obtained the BER under the FEC threshold when the received power was -30 dBm. From these results, we confirm that such digital coherent receiver can work in the long-haul transmission system.

Acknowledgement

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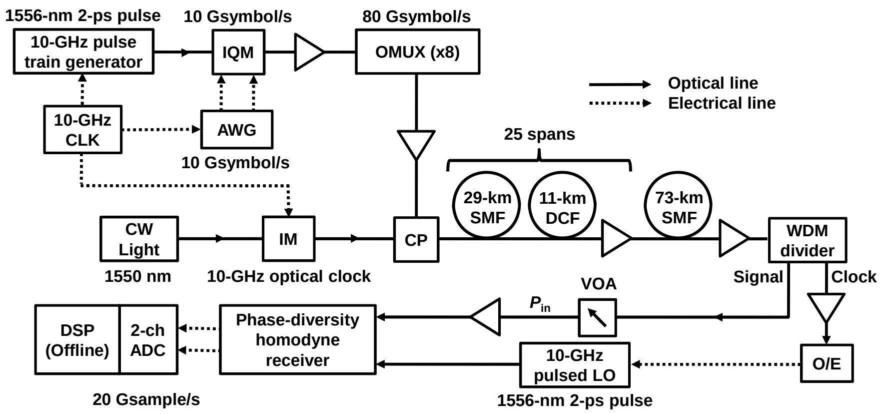
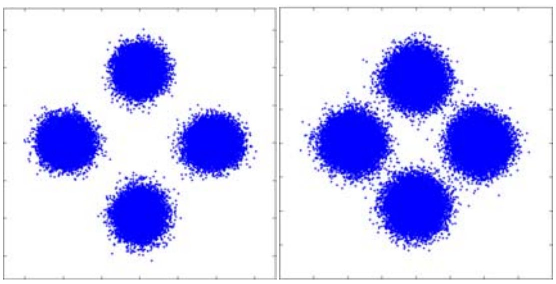


Fig. 1: Experimental setup for 1,073-km transmission of a 160-Gbit/s QPSK signal with the digital coherent receiver having the time-division demultiplexing function.



(a) (b)

Fig 2: Measured constellation maps of a tributary demultiplexed from a 160-Gbit/s QPSK signal. (a) is the constellation map when P_{in}= -30 dBm (error free for 100k symbols) measured in a back-to-back case, and (b) is the constellation map when P_{in}= -30 dBm at BER=$10^{-3.8}$ after 1,000-km transmission.

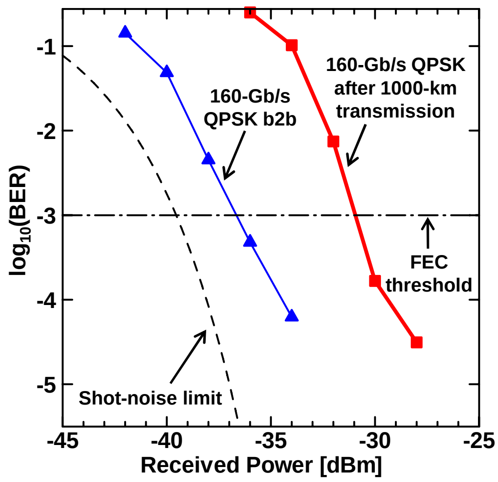


Fig. 3: BER characteristics of one tributary of a 160-Gbit/s QPSK signal after 1,000-km transmission. BERs of 160-Gbit/s QPSK measured in a back-to-back case and shot-noise-limited BERs of a 160-Gbit/s QPSK signal are shown as references.