# Straight-Line 1,073-km Transmission of 640-Gbit/s Dual-Polarization QPSK Signals on a Single Carrier

Chao ZHANG, Yojiro MORI, Masatoshi USUI, Koji IGARASHI, Kazuhiro KATOH, and Kazuro KIKUCHI
Department of Electrical Engineering and Information Systems, University of Tokyo,
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan, chao@ginjo.t.u-tokyo.ac.jp

**Abstract** *We demonstrate 1,073-km transmission of 640-Gbit/s dual-polarization QPSK signals using a digital coherent receiver with the time-division demultiplexing function. The bit rate-distance product is the highest among those reported in single-carrier coherent transmission systems.*

.

## Introduction

The digital coherent receiver, which employs a phase-diversity optical homodyne receiver and digital signal processing (DSP), can demodulate any multilevel coded optical signals without relying upon an optical phase-locked loop. Moreover, the receiver benefits from post-compensation in the digital domain, such as chromatic dispersion (CD) compensation [1], polarization-mode dispersion (PMD) compensation [2], and self-phase modulation (SPM) compensation [3].

In coherent transmission systems, the quadrature phase-shift keying (QPSK) format has been studied most intensively. For the moment, 2,550-km transmission of 25-Gsymbol/s dual-polarization QPSK wavelength-division multiplexing (WDM) channels has been demonstrated [4]. On the other hand, 6,400-km transmission of 10.7-Gsymbol/s dual-polarization QPSK signals is also reported [5].

However, the maximum symbol rate that such a digital coherent receiver can process is strictly limited by the processing speed of analog-to-digital converters (ADCs) and digital signal processors (DSPs). In order to overcome this limitation, we have proposed a digital coherent receiver having the time-division demultiplexing function and solved this problem [6]. Using the proposed receiver, we have made a proof-of-concept experiment in a back-to-back system and then demonstrated straight-line 1,073-km transmission of an 80-Gsymbol/s QPSK signal [7], confirming its applicability to long-haul transmission systems.

In this paper, we have raised the symbol rate up to 160 Gsymbol/s and employed polarization multiplexing: The combination of the QPSK modulation format, sixteen optical time-division multiplexing (OTDM), and polarization multiplexing enables the aggregate bit rate as high as 640 Gbit/s on a single optical carrier. Such a high bit rate on a single carrier is demonstrated with the digital coherent receiver, for the first time to our knowledge, in an ultra long-haul transmission system >1,000 km. The bit rate–distance product of this system reaches 640 Tbit/s-km.

## Principle of time-division demultiplexing

For time-division demultiplexing, the local oscillator (LO) light is pulsed at the base-clock rate of the 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 [8, 9] and extract the tributary, on which the LO pulse train is overlapped in the time domain. The tributary is digitized and processed in the digital domain. In this manner, we can obtain any one of the tributaries of the TDM signal. The extinction ratio and pulse width of the LO pulse has to be set up precisely in order to suppress inter-channel crosstalk.

## Experimental setup

The experimental setup for 1,073-km transmission of a 640-Gbit/s dual-polarization QPSK signal is illustrated in Figure 1. A 10-GHz optical pulse train with 2-ps pulse width at the wavelength of 1,556 nm was generated by an optical pulse source driven by a 10-GHz clock (CLK). Then, an arbitrary waveform generator (AWG) drove an optical IQ modulator (IQM) to generate a 10-Gsymbol/s QPSK signal. The signal was time-division multiplexed by sixteen times with an optical delay-line multiplexer (OMUX), and polarization multiplexing further doubled the bit rate.

The signal was incident on a 1,073-km-long transmission link. A 10-GHz clock was transmitted at the wavelength of 1,550 nm. The transmission link had 25 spans where each span consisted of a 29-km single-mode fiber (SMF) and an 11-km dispersion-compensating fiber (DCF). A 73-km-long SMF was inserted to counteract over-compensation of the transmission link. The averaged CD value of the SMF and the DCF were 20 ps/nm/km and -58 ps/nm/km, respectively.

At the receiver side, the polarization controller (PC) and the succeeding polarization beam splitter (PBS) were used for polarization demutiplexing of the signal. The electrical 10-GHz clock was O/E converted 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 IQ data of each tributary channel were sampled at a rate of 20 Gsample/s by a 2-channel ADC with 8-bit resolution. Offline DSP was executed for intermediate frequency cancellation, suppression of inter-symbol interference that stems from electrical filters, and phase-noise estimation.

### Experimental results

The constellation maps of one tributary of a 640-Gbit/s dual-polarization QPSK signal are illustrated in Figure 2. Their launched power was -2 dBm per polarization. We can observe that four states of QPSK signals are clearly separated even after 1,073-km transmission. Figure 3 shows bit-error rates (BERs) measured as a function of launched power per polarization of the signals ($P_{in}$). The circles and diamonds represent BERs of horizontal polarization and vertical polarization, respectively. The BER after 1,073-km transmission was under the ultra forward-error correction (FEC) threshold when launched power was above -5 dBm.

### Conclusion

We have successfully demonstrated 1,073-km transmission of a 640-Gbit/s dual-polarization QPSK signal with the digital coherent receiver having the time-division demultiplexing function. We obtained the BER under the FEC threshold when launched power was above -5 dBm. These results clearly show the possibility of ultrafast communication in ultra long-haul coherent transmission systems.

### Acknowledgement

This work was supported in part by Strategic Information and Communications R&D Promotion Programme of Ministry of Internal Affairs and Communications, Japan.

### References

1. S. Tsukamoto *et al*., IEEE Photon. Technol. Lett., **18**, 1016-1018 (2006).
2. S. J. Savory, Opt. Express, **16**, 804-817 (2008).
3. K. Kikuchi, Opt. Express, **16**, 889-896 (2008).
4. G. Charlet *et al*., J. Lightwave Technol., **27**, 153-157 (2009).
5. S. J. Savory *et al*., Opt. Express, **15**, 2120-2126 (2007).
6. C. Zhang et al., J. Lightwave Technol., **27**, 224-232 (2009).
7. C. Zhang *et al*., to be presented at ECOC'09 (2009).
8. F. Ito, Electron. Lett., **32**, 14-15 (1996).
9. C.R. Doerr *et al*., J. Lightwave Technol., **23**, 178-186 (2005).

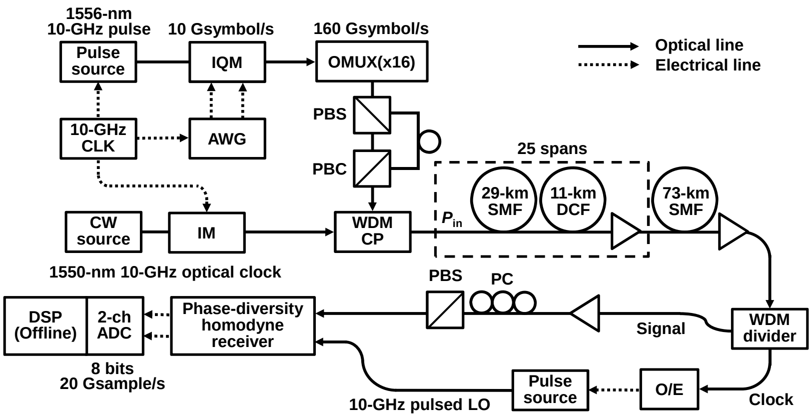
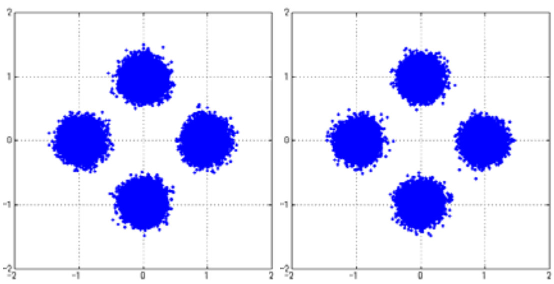



*Figure 1: Experimental setup for 1,073-km transmission of a 640-Gbit/s QPSK signal with the digital coherent receiver having the time-division demultiplexing function.*



(a) (b)

*Figure 2: Measured constellation maps of a tributary demultiplexed from a 640-Gbit/s QPSK signal when launched power per polarization is -2 dBm. (a): horizontal polarization and (b): vertical polarization.*

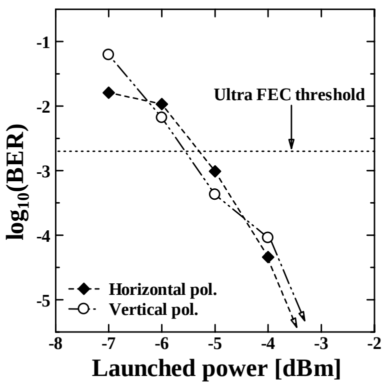



*Figure 3: BER characteristics of one tributary of a 640-Gbit/s QPSK signal after 1,073-km transmission against the launched power per polarization of signal.*