200-km transmission of 100-Gbit/s 32-QAM Dual-Polarization Signals using a Digital Coherent Receiver

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Abstract *We demonstrate transmission of a 100-Gbit/s 32-QAM dual-polarization signal over a 200-km dispersion-managed fiber link using a digital coherent receiver. The receiver sensitivity of -20 dBm at BER = 10^{-3} is obtained after 200-km transmission.*

Introduction

The use of multilevel modulation formats is one of the most effective methods of increasing the bit rate in optical fiber transmission systems, while the symbol rate is maintained [1]. Quadrature amplitude modulation (QAM), where both of the in-phase and quadrature components of an optical carrier are modulated in a multilevel manner, is the best candidate among various modulation formats, because we can approach the Shannon's channel-capacity limit, minimizing the power penalty due to the increase in the level of modulation.

We have already demonstrated transmission of a 40-Gbit/s 16-QAM signal using a digital coherent receiver [2], and further increase in the multiplicity of QAM is highly expected in order to increase the bit rate. However, such increase in the multiplicity generally poses lower tolerance to laser phase noise and inter-symbol interference (ISI), and it has become crucial to examine the limit of the multiplicity in the 10-Gsymbol/s QAM system using coherent receivers.

In this paper, we extend the multiplicity of QAM up to 32 for the first time in the 10-Gsymbol/s coherent system, and demonstrate transmission of a 100-Gbit/s 32-QAM dual-polarization signal over a 200-km dispersion-managed fiber (DMF) link. Although laser phase noise, ISI, and polarization crosstalk begin to degrade the bit-error rate (BER) performance, we can still achieve the BER better than 2×10^{-3} by the offline measurement, which is the forward-error correction (FEC) threshold.

Experimental setup

Figure 1 shows the experimental setup for measuring the transmission performance of the 100-Gbit/s 32-QAM dual-polarization signal.

In the transmitter side, a continuous wave was generated from a distributed-feedback laser diode (DFB-LD). The wavelength of the DFB-LD was 1552 nm and its linewidth was about 150 kHz. An NRZ 50-Gbit/s 32-QAM signal was created by a lithium niobate optical IQ modulator (IQM). The IQM was driven by two streams of 6-level electrical signals generated from two independent ports of an arbitrary waveform generator (AWG). In order to eliminate the phase ambiguity of the received signal, 32-QAM signals were differentially encoded. Polarization multiplexing was performed with a combination of a polarization-beam splitter (PBS), a fiber delay for decorrelation, and a polarization-beam combiner (PBC). The 100-Gbit/s 32-QAM dual-polarization signal thus obtained was transmitted through a 200-km fiber link composed of five spans. Each span consisted of a 29-km single-mode fiber (SMF) and an 11-km dispersion-compensating fiber (DCF). The group-velocity-dispersion (GVD) value, loss coefficient, and nonlinear coefficient of the SMF were 21 ps/nm/km, 0.2 dB/km, and 0.8 /W/km, respectively. Those of the DCF were -56 ps/nm/km, 0.3 dB/km, and 3.0 /W/km, respectively. An erbium-doped fiber amplifier (EDFA) in each span compensated for the average loss of 11 dB due to 40-km transmission and optical-fiber splicing. The input power launched into SMF was fixed at 0 dBm. After 200-km transmission, a 2-km SMF was inserted to compensate for residual GVD.

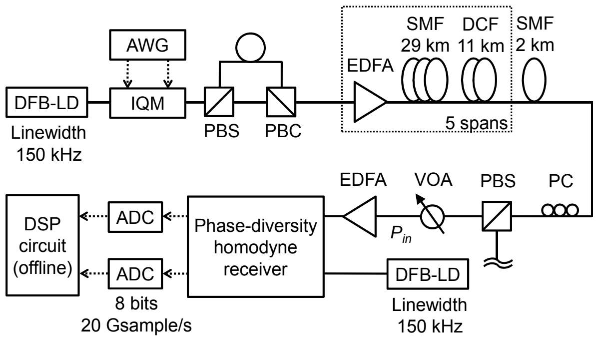

Fig. 1: Experimental setup for transmission of the 100-Gbit/s 32-QAM dual-polarization signal.

In front of the receiver, the signal was polarization-demultiplexed with a polarization controller (PC) and a PBS. Then, the received average power P_{in} was controlled by a variable optical attenuator (VOA). After that, the signal was pre-amplified by an EDFA, and detected by a phase-diversity homodyne receiver, where another DFB-LD having the same characteristics was used as a local oscillator (LO). The frequency mismatch between the transmitter and

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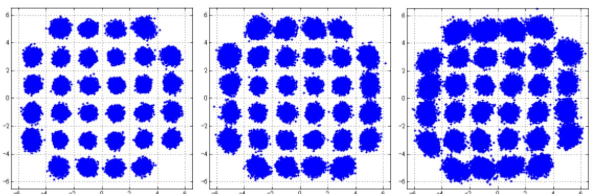
the LO was set below 10 MHz. The output from the receiver was asynchronously sampled at 20 Gsample/s by a 2-channel analog-to-digital converter (ADC) with 8-bit resolution. The digitized signals were processed offline by a digital signal-processing (DSP) circuit, which consists of clock recovery, fixed finite-impulse-response (FIR) filtering, decision-directed carrier-phase estimation, adaptive FIR filtering based on the least-mean square algorithm, and symbol decoding. The fixed FIR filter was designed to eliminate ISI due to imperfect IQ modulation. The step-size parameter in the decision-directed phase-locked loop was optimized so that BER deterioration due to phase noise of lasers was minimized [2]. The adaptive FIR filter with sixteen taps compensated for GVD slightly residual in the DMF system.

Experimental results

Figure 2(a) and (b) show the back-to-back constellation map of 50-Gbit/s 32-QAM single-polarization signals and the counterpart after 200-km transmission, respectively. Figure (c) shows the constellation map of 100-Gbit/s 32-QAM dual-polarization signals. The received average power P_{in} was -20 dBm in every case. In the single-polarization case, thirty-two states are clearly separated on the complex plane even after 200-km transmission. In contrast, the symbol alignment of dual-polarization signals is rather distorted due to polarization crosstalk.



(a) (b) (c)

Fig. 2: Examples of constellation maps of 32-QAM signals when P_{in} = -20 dBm, (a) single-polarization back-to-back, (b) single-polarization after 200-km transmission, and (c) dual-polarization after 200-km transmission.

In Fig. 3, crosses represent BERs of 100-Gbit/s 32-QAM dual-polarization signals after 200-km transmission measured as a function of the received average power P_{in}. As a reference, back-to-back BERs of 50-Gbit/s single-polarization signals and BERs after 200-km transmission are also shown by dots and rectangles, respectively.

Discussions

The solid and broken curves in Fig.3 represent the theoretical shot-noise limitation calculated based on computer simulations, where the linewidth of lasers used for the transmitter and the LO are 0 Hz and 150 kHz, respectively. From these theoretical curves, we find that the BER performance is degraded through laser phase noise and the power penalty at BER=10^{-4} is about 2.3 dB when the laser linewidth is 150 kHz.

Comparing the measured BER curves with the theoretical ones, we observe that the measured BER degradation from the theoretical limit is much larger than that stemming from the laser phase noise. The dominant cause of the degradation is ISI due to imperfect IQ modulation and band limitation of electrical devices used in the transmitter and the receiver. Such ISI remains even after the fixed FIR filter, and its effect on the BER performance becomes severer as the level of modulation increases. Moreover, the BER characteristics of dual-polarization signals are seriously degraded due to polarization crosstalk, which is overlapped with ISI. In spite of these harmful effects, the receiver sensitivity of the 100-Gbit/s 32-QAM dual-polarization signal after 200-km transmission is -20 dBm at BER = 10^{-3}, which is still lower than the FEC threshold.

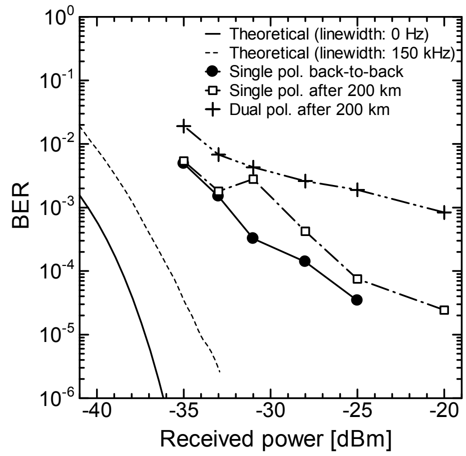


Fig. 3: BER characteristics of 32-QAM signals measured as a function of the received average power.

Conclusions

We have successfully demonstrated transmission of 100-Gbit/s 32-QAM dual-polarization signals over a 200-km DMF link using a digital coherent receiver. Although the BER is degraded due to laser phase noise, ISI, and polarization crosstalk, we can obtain the acceptable BER of 10^{-3} after 200-km transmission.

Acknowledgement

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References

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