Real-Time Demonstration of 500-Gbps/lambda and 600-Gbps/lambda WDM Transmission on Field-Installed Fibers

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Abstract: This paper describes recent technical challenges related to the real-time demonstration 500-Gbps/lambda and 600-Gbps/lambda in field experiments conducted on high-capacity optical transport networks. DSP-ASIC integrated real-time optical transponders are utilized.

1. Introduction

In response to the explosive increase in data communication traffic resulting from the proliferation of mobile traffic, movie data distribution services, and cloud computing, the NTT Group has recently developed a dual-carrier 400-Gbps wavelength division multiplexing (WDM) transmission system employing digital coherent optical communication [1]. The transmission capacity of optical communication systems has recently been increased significantly by the adoption of digital signal processing (DSP) and coherent transmission [2, 3]. Digital coherent technology has widely been applied to optical links, such as long-haul networks, metro networks, and short-reach networks, particularly data-center interconnects [2, 3]. Meeting the recent demand to support multiple applications, DSP must support multi-rate and multi-modulation formats. For example, DSP application specific integrated circuit (ASIC) can support 32-Gbaud based 100-Gbps quadrature phase shift keying (QPSK), 150-Gbps 8 quadrature amplitude modulation (QAM), and 200-Gbps 16QAM with polarization division multiplexing (PDM). In addition, to realize capacities of more than 400 Gbps/lambda, the modulation order must be higher than 16 with the symbol rate of about 64 Gbaud. A recent DSP-ASIC supports 400-Gbps 16QAM, 500-Gbps 32QAM, and 600-Gbps 64QAM [4, 5]. To increase the capacity per lambda with high spectral efficiency, we have to use high-order QAM signals. Figure 1 shows the bit per symbol of the modulation format versus required optical signal-to-noise ratio (OSNR). As shown in Fig. 1, high-order QAM signals require high OSNR. This drastically limits the transmission distance. Accordingly, we should consider techniques to improve the OSNR of the transmission links. To expand transmission distance of high-order QAM signals, which demands high OSNR and low fiber nonlinearity, a distributed Raman amplifier and large-core pure-silica-core fiber (PSCF) have been deployed in terrestrial links [1,6].

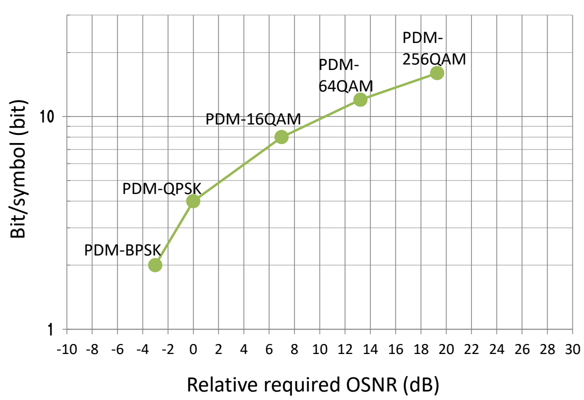

Fig. 1. OSNR requirements for high order modulation.

In this paper, we review recent technical challenges related to the real-time demonstration of 600-Gbps/lambda WDM transmission for regional networks [4] and 500-Gbps/lambda WDM transmission for long-haul networks [5] in field experiments. DSP-ASIC integrated real-time optical transponders and distributed Raman amplifiers are utilized. Moreover, PSCF is used for long-haul transmission.

2. 600-Gbps/lambda WDM transmission in regional network

Figure 2 (a) shows the setup for our field experiments that used NTT Group's terrestrial links in regional network. Our newly developed optical transponder consists of a DSP-ASIC based on 16-nm complementary metal-oxide-semiconductor (CMOS) technology [7]. In this experiment, a 600-Gbps/lambda 69-Gbaud PDM-64QAM signal was generated by the transponder. A 1574.54-nm channel (measured) and two adjacent 600-Gbps/lambda channels were multiplexed with 100 GHz channel spacing. In addition, six channels of 100-Gbps PDM-QPSK signals were also multiplexed to confirm the incremental upgradeability of the existing 100-Gbps system. The 100-Gbps signals were set with channel spacing of 150 GHz from the 600-Gbps signals. The OSNR of the transmitted signal was 39.3 dB. The transmission link had total length of 101.6 km and consisted of 4 spans of single mode fiber (SMF) and dispersion shifted fiber (DSF); span length was approximately 25 km. The loss coefficient of the installed fiber at 1574.54 nm ranged from 0.32 dB/km to 0.42 dB/km. The attenuation of each span was compensated by backward pumped Raman amplification. The OSNR value after transmission was 34.5 dB. At the receiver side, the measured signal was extracted from the coincident WDM signal by colorless coherent reception and demodulated in real-time. The signal quality was evaluated by its Q-margin, defined as the difference between measured Q-factor and Q-limit.

Figure 2(b) plots the Q-margin as a function of the fiber input power from -6 dBm/ch to -1dBm/ch and the received constellation of both polarizations for the cases of single channel and WDM channel transmission. With WDM transmission, the Q-margin was attained only with the fiber input power of -4 dBm/ch; the Q-margin degradation against single transmission was observed to be 0.3 dB. Simultaneously, we confirmed error free transmission by monitoring the quality of the 100-GbE signals with an Ethernet tester connected to six client ports of the transponder. Therefore, we successfully demonstrated 600-Gbps/lambda WDM transmission over 100 km of field-installed fiber in regional network as part of an existing 100-Gbps transmission system.

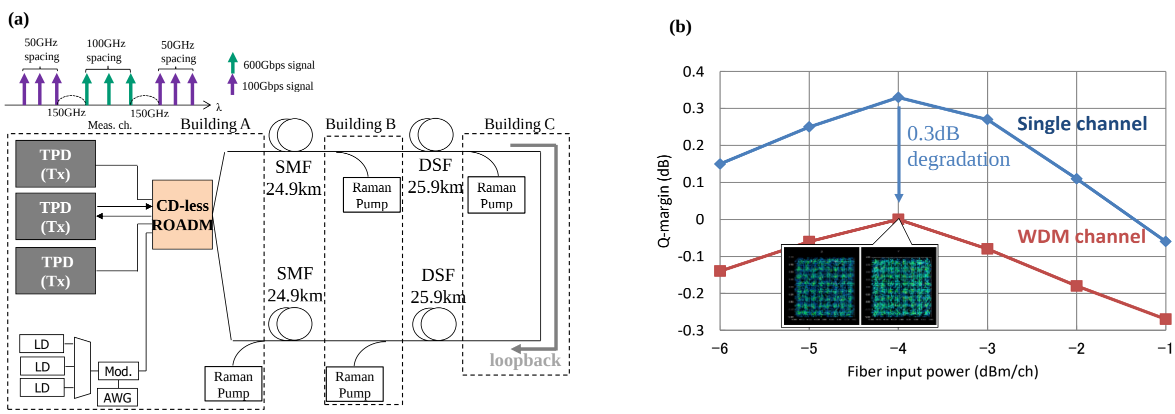

Fig. 2. (a) Field setup for 600-Gbps/lambda WDM trasnmission, (b) Experimental results.

3. 500-Gbps/lambda WDM transmission in long-haul network

Figure 3 (a) shows the setup for our field experiments that used NTT Group's terrestrial links in a long-haul network. The experimental equipment was placed at building A; building B was only for looping back the transmission lines. Our newly developed optical transponder consists of a DSP-ASIC based on 16-nm CMOS technology [7], a high-bandwidth coherent driver modulator (HB-CDM) based on indium phosphide (InP) technology [8], high-bandwidth intradyne coherent receiver (HB-ICR), and micro-integrable tunable laser assemblies (μITLAs) for signal and local oscillator (LO) sources. The measured signal was generated in the optical transponder; the electrical signals output from the DSP-ASIC were modulated by the InP-based HB-CDM in the optical frontend (FE) with the optical carrier output from a μITLA. The carrier frequency of the measured signal was set to 189.7 or 189.8 THz. The ten 100-GHz-spaced optical carriers with frequencies from 189.3 to 190.2 THz were multiplexed by an arrayed waveguide (AWG) and then modulated by a lithium niobate IQ modulator (LN-IQM) driven by electrical signals from a DSP-ASIC. The WDM signal was input into an 11-km SMF to decorrelate the signals. The measured and WDM signals were multiplexed by a wavelength selective switch (WSS). The WDM signal was input into field-deployed large-core PSCF (Aeff: 110 μm2) between buildings A and B (the PSCF is compliant with ITU-T G.654.E). In building B, the transmission lines were connected by patch fiber cables. The average optical loss of the transmission link was 20.7 dB per 112.2-km span (0.184 dB/km) at 1580 nm, which includes losses of the large-core PSCF, fusion splice points of the field-deployed fiber, cable termination frames (CTFs), and intra-building fibers. After WDM signal transmission over each 112.2-km span, the optical loss was compensated by hybrid EDFA and backward-distributed

Raman amplifier with pump lasers of 1460 and 1480 nm. The measured signal was then coherently detected by the ICR in the optical FE using the optical LO output from the µITLA. Finally, the received signal was equalized, demodulated, and decoded in the DSP-ASIC.

The net data-rate 1-Tbps (dual-carrier 500-Gbps/lambda 66-Gbaud PDM-32QAM) transmission performances at the center carrier frequencies of 189.7 and 189.8 THz of the WDM signals are shown in Fig. 3 (b). In these transmission experiments, the average fiber input power was 2.5 dBm/lambda, and the gain of the backward-distributed Raman amplifier was set to 11 dB for each 112-km span. We observed that the Q-margin exceeded zero as shown in Fig. 3 (b), which confirms that the error free by monitoring the quality of the 100-GbE signals with an Ethernet tester for each channel and transmission distance. Thus, we achieved 500-Gbps/lambda and dual-carrier 1-Tbps transmission over 1,122-km (10 spans × 112.2 km) of field-deployed large-core PSCF in a long-haul network.

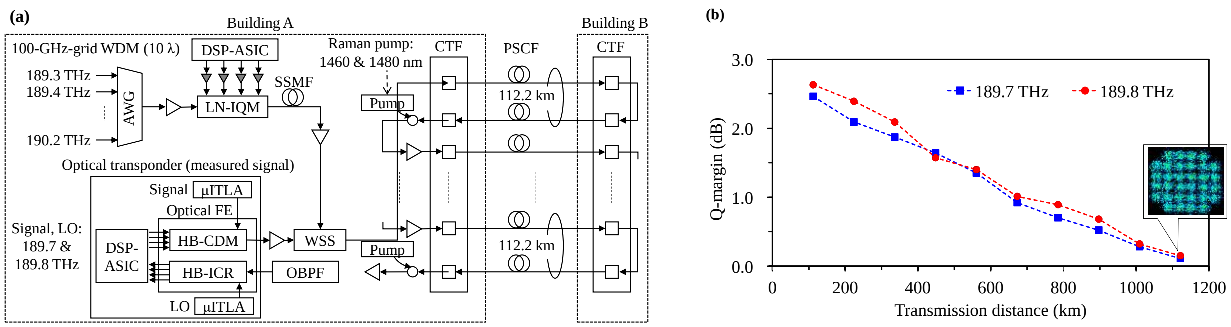

Fig. 3. (a) Field setup for 500-Gbps/lambda WDM trasnmission, (b) Experimental results.

4. Conclusion

We have demonstrated, on field-installed fiber, 600-Gbps/lambda WDM transmission for regional networks and 500-Gbps/lambda for long-haul networks. These performances are world beating results for the use of DSP-ASIC based on 16-nm CMOS technology and real-time optical transponders.

5. Acknowledgments

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6. References

[1] H. Maeda et al., "Field Trial of 400-Gbps Transmission Using Advanced Digital Coherent Technologies," J. Lightw. Technol., vol. 35, no. 12, pp. 2494–2499 (2017).
[2] S. Okamoto et al., "400 Gbit/s/ch Field Demonstration of Modulation Format Adaptation Based on Pilot-Aided OSNR Estimation Using Real-Time DSP," IEICE Trans. Commun., vol. E100-B, no. 10, pp. 1726–1733 (2017).
[3] Y. Loussouarn et al., "Multi-Rate Multi-Format CFP/CFP2 Digital Coherent Interfaces for Data Center Interconnects, Metro, and Long-Haul Optical Communications," J. Lightw. Technol., vol. 37, no. 2, pp. 538–547 (2018).
[4] H. Kawahara et al., "Real-time demonstration of 600Gbps/carrier WDM transmission and highly-survitable adaptive restoration on field installed fiber," OECC2019, TuB2-2.
[5] F. Hamaoka et al., "Dual-Carrier 1-Tb/s Transmission Over Field-Deployed Large-Core Pure=Silica-Core Fiber Link Using Real-Time Transponder," OECC2019, PDP.1.
[6] S. Shen et al., "G.654.E Fibre Deployment in Terrestrial Transport System," OFC2017, M3G.4, Los Angeles, CA, USA, Mar. 2017.
[7] O. Ishida et al., "Power Efficient DSP Implementation for 100G-and-Beyond Multi-Haul Coherent Fiber-Optic Communications," OFC2016, W3G.3.
[8] J. Ozaki et al., "Ultra-low Power Dissipation (<2.4 W) Coherent InP Modulator Module with CMOS Driver IC," ECOC2018, Mo3C.2.