Field experiment of 400-Gbps transmission in C+L-band over dispersion-shifted fiber

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Abstract: Dual-carrier 400-Gbps channels in C+L-band are transmitted over dispersion shifted fiber (DSF) in field for the first time. Distributed Raman amplification not accompanied by EDFA (all-Raman amplification) is used to suppress the nonlinear distortions, which strongly occur in the zero-dispersion region in C-band. The transmitted distance is 200 km and the maximum distance is expected to be 480 km, while the Raman pump power is lower than a safety level for commercial use. The field experiment demonstrates that all-Raman amplification is feasible for effective use of existing DSF links in regional optical networks.

Keywords: Raman amplifier, C+L-band transmission, field trial, dispersion shifted fiber, nonlinear effect

Classification: Fiber-Optic Transmission for Communications

References


1 Introduction

To cope with rapidly increasing data traffic, technologies for beyond-100 Gbps (B100G) transmission have been intensively developed. We recently reported on successful field trials of 400-Gbps transmission [1, 2]. As well as B100G, using multiple bands (e.g. C+L-bands) has attracted much attention as a solution to increase transmission capacity [3, 4]. However, in the case of dispersion-shifted fiber (DSF), which is used in backbone networks in Japan for historical reasons, the use of wavelengths around the zero-dispersion wavelength ($\lambda_{0}$) is usually avoided because nonlinear effects markedly lower the achievable distance [5]. This is an issue to be addressed for effective use of optical frequency resource with existing DSF links. The distributed Raman amplifier (DRA), which NTT has been commercially deploying in its national backbone network for more than 10 years, is a promising solution because its low-noise characteristic enables low-power transmission and accordingly low nonlinear distortions [6, 7].

In this paper, we report on the transmission of dual-carrier 400-Gbps channels using C+L-bands over 200-km of aged DSF in the field [8]. To the best of our knowledge, this is the first field trial of B100G transmission using C+L-bands over DSF. The C-band channels are chosen to overlap $\lambda_{0}$, so as to evaluate the worst case. We used DRAs that are not accompanied by erbium-doped fiber amplifiers (EDFAs) as repeaters to minimize the nonlinear distortion.

2 Experimental setup

Fig. 1(a) shows the configuration of the experiment. We used ten 20-km DSF links between two buildings. On the transmitter side, optical signals from C-band transmitters and those from L-band transmitters were multiplexed separately by using wavelength-selective switches (WSSs), amplified separately by using EDFAs, combined by using a C-band/L-band combiner, and launched to the transmission fiber. The signals of each band were comprised of a dual-carrier, dual-polarization (DP)-16QAM 400-Gbps channel for measurement and eight background channels modulated at 200-Gbps DP-16QAM, as shown in Fig. 1(b). The C-band channel wavelengths are ranged from 1544.128 nm (ch1) to 1547.715 nm (ch10) and the
L-band channels from 1572.476 nm (ch11) to 1576.196 nm (ch20) with 50 GHz spacing in ITU-T G.694 grid. The signals were amplified with a DRA unit after every single span. Each span loss was fully compensated by the DRA. The DRA unit consisted of a signal-pump coupler, a pump combiner, pump sources for the C-band (1425 and 1450 nm), and those for the L-band (1460 and 1480 nm). On the receiver side, the optical signal was demultiplexed into the C- and L-bands, amplified by using EDFAs, demultiplexed into channels by using the WSSs, and detected at the receivers.

The span losses of the fibers ranged from 5.4 to 6.3 dB. The average and the standard deviation of $\lambda_0$ were 1546.02 nm (between ch5 and ch6) and 2.2 nm, respectively. The pump power of each DRA was 380 mW in total, which is sufficiently lower than a safety level in our safety guideline. Our safety measures and guidelines on commercial DRA systems are discussed in a previous study [9].

3 Results and discussions

In the experiment, we focused on the performances of the C-band signals because the nonlinear distortions at the zero-dispersion region were of interest. The launch power was therefore optimized for ch5 (1545.720 nm), which is the closest to $\lambda_0$. Fig. 2(a) shows the Q-margins to the forward-error correction (FEC) limit of approximately 5.5 dB and the Q penalties after 200-km transmission at different
signal powers. The Q penalty is defined as the difference in Q-factors between back-to-back and after transmission at the same optical signal-to-noise ratio (OSNR). The Q-factors at $-19$ dBm/ch and $-13$ dBm/ch were worse than those in between because of a poorer OSNR and higher nonlinearity, respectively. Though the Q-factor of $-15$ dBm/ch was slightly better than that of $-17$ dBm/ch, we concluded that $-17$ dBm/ch is optimum for pursuing lower Q penalty. We used the same launch power for the L-band for simplicity, although the optimal power for the L-band would be higher.

We confirmed that the Q-margins were above the FEC limit for all of the channels after 200-km transmission, as shown in Fig. 2(b). Fig. 2(c) shows the optical spectrum after 200-km transmission. There was a slight tilt because we did not use gain equalizers.

![Graph showing Q-margin and Q penalty](image)

**Fig. 2.** (a) Variation of Q-margin and Q penalty for different launch powers (ch5), (b) Q-margins of all the channels after 200-km transmission, and (c) Spectra of DRA-repeated signals after 200-km transmission.

We then measured the Q-factors at intermediate spans by connecting the outputs of even-numbered DRAs directly to the C/L splitter on the receiver side at building A. For comparison, we also measured the signal performances up to
eight spans under the condition that the span loss is compensated by only EDFAs. This was done by replacing the DRAs with C-band and L-band EDFA pairs. In this case, the launch power was optimized to be $-12 \text{ dBm/ch}$. Fig. 3(a) shows the Q-penalty transition along the distance. In this comparison, we measured ch5 for the C-band, which is the closer to $\lambda_0$ of the two carriers of the 400 Gbps signal, to evaluate the worst case. We also measured ch15 as an L-band counterpart. The penalty of ch5 signal repeated with the DRAs was only 0.05 dB/span, while that repeated with the EDFAs was 0.17 dB/span. The nonlinear distortion was markedly suppressed thanks to the low-power transmission with the DRAs. The penalties for ch15 signal were low for both DRA and EDFA cases.

Fig. 3(b) shows the Q-margin transition of ch5 signal along the transmission distance. The Q margin of the DRA-repeated signal after 200-km transmission was 2.3 dB, while that of the EDFA-repeated signal after 160-km transmission was only 1.6 dB. The achievable distances of the DRA and EDFA cases were extrapolated to be 480 and 260 km, respectively.

![Graph](image)

**Fig. 3.** (a) Comparison in the Q penalties between C- and L-bands, (b) Comparison in the Q-margin of ch5 between DRA and EDFA repeaters.

The reason for the short reach of the EDFA case is not only the high nonlinearity but also that the noise characteristic of the EDFA is not designed for such a short span length. The gap between the EDFA and the DRA cases can be
reduced if a longer span length is used. The span length of the all-Raman transmission can exceed 20 km but is capped by the allowable maximum pump power. Further consideration is required to determine the practical limit.

We also evaluated the stability of the DRA-repeated C-band signal by measuring the Q-factor variation for 15.5 hours and it was as low as 0.22 dB.

4 Conclusion

In this article, we reported on the transmission of dual-carrier 400-Gbps channels in C+L-bands over 200-km DSF in the field under the condition that the C-band wavelengths fall on the zero-dispersion region. We used all-Raman amplification to minimize the nonlinear effects. The results showed that the Q penalty at the zero-dispersion region was 68% lower than that amplified using EDFAs, and the achievable transmission distance was expected to be 480 km. All-Raman amplification is an effective and feasible solution to optimize the use of existing DSF links.

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