FIELD TRIAL OF REAL-TIME SINGLE-CARRIER AND DUAL-CARRIER 400G TERRESTRIAL LONG-HAUL TRANSMISSION OVER G.654.E FIBER

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Abstract

The world's longest terrestrial G.654.E fiber link with a total length of 1539.6 km is performed. Error-free transmission of real-time single-carrier and dual-carrier 400G over 603-km and 1058.9-km G.654.E fiber with an OSNR margin of more than 5 dB are demonstrated, respectively.

1 Introduction

Traffic demand of optical transmission network has experienced dramatically growth over the past few decades due to the increasing high-speed internet services, such as high-definition video, big data, cloud computing, etc. To comply with this trend, coherent 400G technology is supposed to be applied in optical transmission network to overcome the channel capacity bottleneck. Furthermore, the transmission cost per bit also can be significantly reduced as the single-channel bit rate doubles or even quadruples. Currently, there are mainly two alternative schemes for coherent 400G system by using single carrier or dual carrier[1-4]. However, the optical signal-to-noise ratio (OSNR) tolerance of single-carrier and dual-carrier 400G are much higher than that of 100G, resulting in the limited unrepeated transmission distance. Compared with the conventional G.652.D fiber network, ultra-low-loss and large-effective-area fiber is capable of reducing fiber attenuation and increasing launch power, which has been deployed for transoceanic submarine transmission[5]. To fulfill the requirements of terrestrial optical transmission network, G.654.E fiber is subsequently introduced and specified by ITU-T. Recently, several transmission experiments and field trials are carried out based on G.654.E fiber for single-carrier and dual-carrier 400G[6-9]. However, the unrepeated transmission distance of single-carrier 400G is still less than 300 km, which cannot satisfy the backbone transmission.

In this paper, real-time single-carrier and dual-carrier coherent 400G transmission over 603-km and 1058.9-km G.654.E fiber are demonstrated in field trials. At the transmitter, 3 channels of dual-carrier 400G PM-16QAM and 4 channels of single-carrier 400G PM-16QAM with a total capacity of 2.8 Tb/s are generated. During 24-hours online test, error-free transmission of single-carrier and dual-carrier 400G with an OSNR margin of more than 5 dB is achieved. To verify the characteristics of the installed G.654.E fiber for terrestrial transmission, a 22-span 1539.6-km G.654.E fiber link is deployed, which is the longest terrestrial G.654.E link in the world at present. To the best of our knowledge, it's the first demonstration of single-carrier and dual-carrier 400G transmission over G.654.E fiber beyond 600 km and 1000 km with required ONSR margin in filed trail, respectively.

2 Experimental Setup

As shown in Fig. 1, the optical network topology is from BJ to NJ in China with a total length of 1539.6 km, which consists of 6 wavelength-add/drop nodes. The coherent optical signals can add/drop or pass-through in the nodes. The lengths of the deployed optical cable among these nodes are 136.5 km, 177 km, 290.4 km, 455 km, and 480.7 km, respectively. The numbers of corresponding spans are 2, 3, 4, 6, and 7, respectively. Among these 22 spans, the longest and the shortest span are 102 km and 30 km, respectively. To evaluate the transmission performance of the G.654.E fiber, G.652.D fibers are deployed in the same cable. Table 1 shows the typical parameters of the fibers.

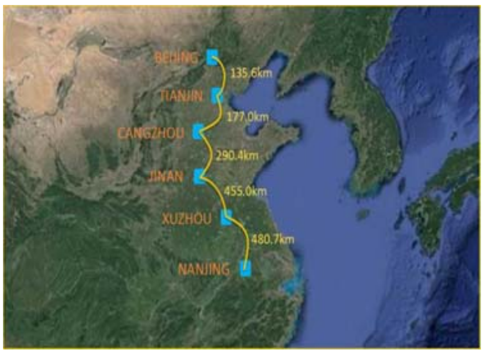

Fig. 1 Geographical view of the experimental optical network topology from BJ to NJ in China.

Table 1 Typical parameters of the G.654.E fiber and G.652.D fiber.

Fiber Type	Effective Area @1550nm	Attenuation @1550nm
G.654.E	110μm²	≤0.17 dB/km
G.652.D	80μm²	≤0.19 dB/km

Figure 2 shows the configuration of the coherent transmission system. 3 channels of dual-carrier 400G and 4 channels of single-carrier 400G are generated based on DP-16QAM modulation format at the transmitter in BJ(Node A). Here, the channel spacing of single-carrier and dual-carrier 400G are 75 GHz and 100GHz, respectively. The corresponding spectral efficiencies are 5.33 bit/s/Hz and 4 bit/s/Hz, respectively. The single-carrier and dual-carrier 400G signals are then multiplexed by wavelength selective switch (WSS). Figure 3 shows the optical spectrum of multiplexed single-carrier and dual-carrier 400G signals. The central wavelengths of the four single-carrier 400G signals are located at 195.2125 THz, 195.1375 THz, 195.0625 THz, and 194.9875 THz, respectively. Meanwhile, the three dual-carrier 400G signals are centered at 195.525 THz, 195.425 THz, and 195.325 THz, respectively. The multiplexed signals are subsequently amplified by an Erbium doped fiber amplifier (EDFA) and fed into the optical fiber. It is noted that the 400G signals can pass through the next add/drop nodes by WSS as the OSNR margin is still more than 5 dB.

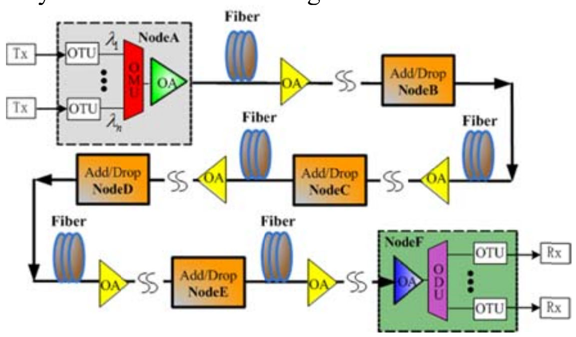

Fig. 2 Configuration of the single-carrier and dual-carrier 400G coherent transmission system in field trial.

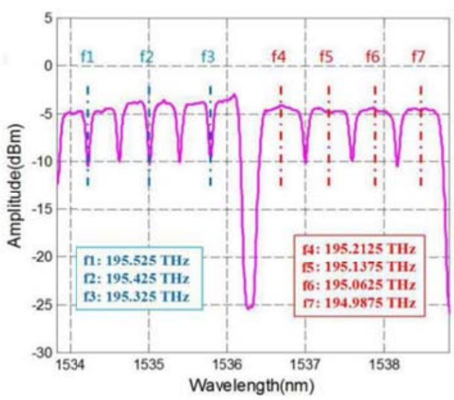

Fig. 3 Optical spectrum of the generated single-carrier and dual-carrier 400G signals.

3 Experimental Results

The installed 22-span 1539.6-km terrestrial G.654.E fiber link and G.652.D fiber link are bi-directional measured by an optical time domain reflectometer (OTDR) to verify the fiber characteristics. Figure 4 shows the attenuation distribution of the deployed 9011-Fkm G.654.E fiber and 6093-Fkm G.652.D fiber. The average loss coefficients of the deployed G.654.E fiber and G.652.D fiber are 0.169 dB/km and 0.186 dB/km, respectively, which are highly consistent with the requirements of the corresponding specification. The test results show that the macro-bending loss of the G.654.E fiber is below 0.05 dB (for R30mm×100 turns @1625nm), demonstrating that the G.654.E fiber can be applied under the complex terrestrial environment.

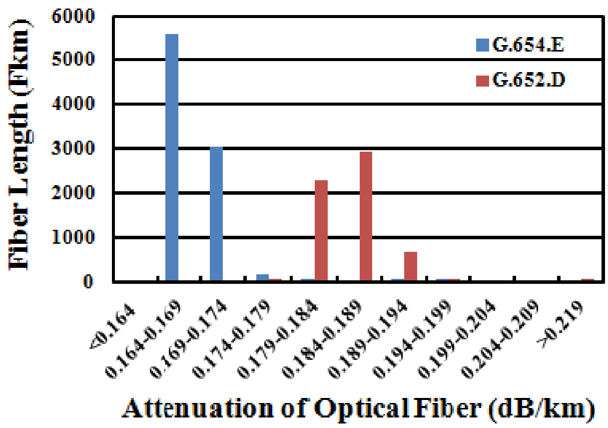

Fig. 4 Attenuation distribution of the deployed G.654.E fiber and G.652.D fiber.

The transmission performances of the single-carrier and dual-carrier 400G signals are further investigated. As is well known, the OSNR tolerance of the 400G coherent system is the most critical parameter for the unrepeated transmission. For the single-carrier and dual-carrier 400G DP-16QAM transceivers used in this field trial, strong FEC with 27% overhead is applied to improve the OSNR tolerance. As a result, single-carrier and dual-carrier 400G DP-16QAM with back-to-back OSNR tolerance of 20.2 dB and 15.4 dB are obtained, respectively.

Furthermore, the performances of the single-carrier and dual-carrier 400G signals after transmission over the G.654.E fiber link and the G.652.D fiber link are verified. The OSNR of the single-carrier and dual-carrier 400G DP-16QAM signals after transmission over different fiber links are shown in Fig. 5. For single-carrier 400G DP-16QAM signals, after 136.5-km G.652.D fiber link and 603-km G.654.E fiber link transmission, the average OSNR margin at the receivers are about 6.5 dB and 5.3 dB, respectively. For dual-carrier 400G DP-16QAM signals, the average OSNR margin after transmission over 603-km G.652.D fiber link and 1058.9-km G.654.E fiber link are about 5.4 dB and 5.2 dB, respectively. With 24-hours online test, error-free transmission performances of single-carrier and dual-carrier 400G with an OSNR margin of more than 5 dB are obtained. The results show that the unrepeated transmission distances of the single-carrier and dual-carrier 400G both can be significantly extended by using the G.654.E fiber instead of the G.652.D fiber. It is noted that extra attenuation of 0.06 dB/km are both applied in the G.654.E fiber link and G.652.D fiber link by placing optical attenuators at the end of each span to guarantee the system margin.

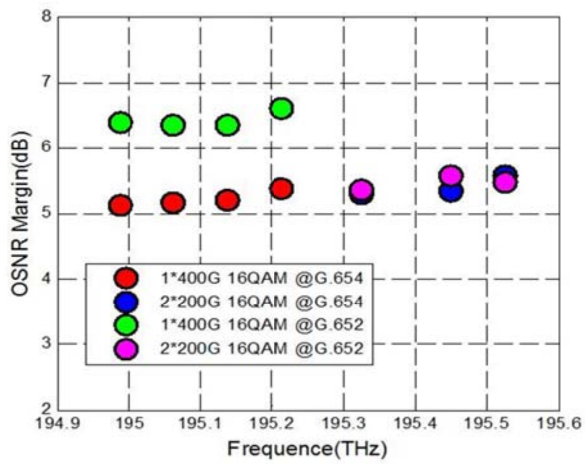

Fig. 5 OSNR margin of the single-carrier and dual-carrier 400G signals after transmission over the G.654.E fiber link and the G.652.D fiber link.

The nonlinerity performance of the G.654.E fiber is finally evaluated. Figure 6 shows the Q factor of the single-carrier and dual-carrier 400G DP-16QAM signals as a function of the launch power. It can be seen that the optical powers of the single-carrier and dual-carrier 400G signals before launching into the fiber link can be improved about 1.5 dB and 0.5 dB with the maximum Q factor, respectively, by using the G.654.E fiber instead of the G.652.D fiber. The results show that the G.654.E fiber is more robust to the optical power compared with the G.652.D fiber due to the larger effective area.

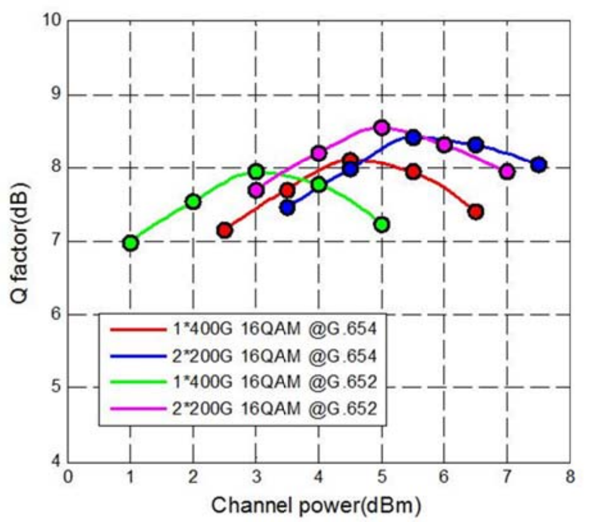

Fig. 6 Q factor versus optical power before launching into the G.654.E fiber link and the G.652.D fiber link for the single-carrier and dual-carrier 400G.

4 Conclusion

Error-free real-time single-carrier and dual-carrier coherent 400G transmission over 603-km and 1058.9-km deployed terrestrial G.654.E fiber link with an OSNR margin of more than 5 dB are performed through this field trial. The world's longest terrestrial G.654.E fiber link with a total length of 1539.6 km is also achieved to evaluate the fiber characteristics for terrestrial application. The results show that the transmission performances can be significantly improved by using the G.654.E fiber instead of the G.652.D fiber, such as the unrepeated transmission distance, launch power, etc.

5 Acknowledgements

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