Real-Time 179.2Tb/s Transmission using Commercial 400Gb/s Transceivers over 350 km Multicore Fiber

Lipeng Feng[1,*], Anxu Zhang[1], Hao Guo[2], Dongxiang Wang[2], Chuyu Peng[2], Yuyang Liu[1], Kai Lv[1], Hao Liu[1], Xiaoli Huo[1], Junjie Li[1]

[1]*China Telecom Research Institute, Beijing, China*
[2]*FiberHome Fujikura Optic Technology Co.,Ltd, Wu Han, China*
Author e-mail address: fenglp@chinatelecom.cn

Abstract: We firstly demonstrate the feasibility of 179.2 Tb/s transmissions over a 350 km 7-core fiber link while considering the splicing loss and link budget reservation for field deployment, using real-time 400Gb/s/carrier commercial transceivers.

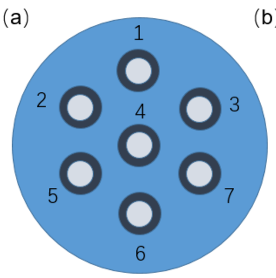
1. Introduction

Demand for higher capacity communication systems has been increasing due to the rising of data-hungry applications, such as the Internet of things (IoT), cloud computing, and short-form user video, which has enabled the global compound annual growth rate (CAGR) of IP traffic to reach 26% in the past five years [1]. As conventional single-mode fiber (SMF) systems are approaching theoretical capacity limitation, a space division multiplexing (SDM) system based on multi-core fiber (MCF) appears as a promising technology to meet this increasing demand in single optical fiber. Uncoupled core (UC-MCF) and coupled core (CC-MCF) are two potential candidates. In the past decade, many transmission experiments have been reported with the help of offline generated/received deceives [2-4] and real-time coherent receivers implemented on FPGAs [5-7]. Although the CC-MCF system has the advantage in the aspect of core density and low nonlinearities [8-10], it is indispensable to novel multiple input multiple output (MIMO) [11] technology. Compared with CC-MCF, UC-MCF is compatible with current transponders, which makes it a potential next step in SDM systems. Recently, the UC-MCF cables are successively deployed in Italy [12] and China, which indicates that industry and academics are making efforts to practical application. Tetsuya Hayashi et al. have verified that the installation does not significantly affect the attenuation and the crosstalk of the MCFs. Thus, to further promote the practical application, it is expected to present the performance of the commercial system through experiments. In 2017, a real-time quasi-full-duplex 400G/300G optical interconnection over 20 km MCFs has been achieved using commercial modules [13]. However, the data rate per wavelength per core is limited to 25 Gb/s.

In this paper, we experimentally investigate the transmission performance of a 400 Gb/s commercial system modulated by polarization-division-multiplexed 16-point quadrature-amplitude modulation (PDM-16QAM) with probabilistic constellation shaping (PCS) technology in 7-core fiber, transmitting 64 wavelength division multiplexed (WDM) signals ranging from 191.325THz to 196.125THz. A total distance of 350 km is reached by cascading different cores of a 50 km 7-core fiber and the long-term error-free performance is achieved with more than 2.88 dB OSNR margins. Besides, the splicing loss and 3 dB link budget are added to every span to simulate the actual situation of the field deployment. To the best of our knowledge, this is the first time to report the feasibility of 179.2 Tb/s transmission over 350 km MCF in a commercial system.

2. Multicore fiber and system setup

(a)



(b)

Ch.no	PMD (ps/√km)	Loss coefficient (dB/km)
1	0.048	0.183
2	0.036	0.188
3	0.032	0.185
4	0.135	0.183
5	0.025	0.183
6	0.023	0.187
7	0.050	0.187

(c)

Ch.no	1	2	3	4	5	6	7
1	-11.92	-83	-77	-83	X	X	-83
2	-79	-11.72	X	-78	-77	-80	-83
3	X	-83	-12.35	-79	-77	-78	-82
4	-80	-83	-80	-10.41	-80	-83	-82
5	-79	-78	-80	-81	-11.66	X	-80
6	-82	-81	X	-81	-82	-11.23	-78
7	-79	-80	X	X	X	-79	-11.21

Fig.1 (a) Cross section of the used MCF. (b) The PMD and loss coefficient of MCF. (c) Measured values of core loss and inter-core crosstalk.

The cladding and coating diameters of the used 7-core fiber are respectively 200 μm and 400 μm. Figure 1(a) shows the cross-section of the MCF. Seven 8-μm core diameter cores with trench are arranged in a hexagonal array with 62-μm core-to-core pitch. The measured cutoff wavelength for each core is about 1221 nm, and mode field diameters (MFD) at 1310 and 1550 nm are 8.3 μm and 9.3 μm, respectively. The polarization mode dispersion (PMD) and loss coefficient are shown in Fig. 1(b). In the experiment, the 50km MCF is spliced by two segments of MCF fiber, whose lengths are respectively 31 km and 19 km. The total loss and crosstalk of 7 cores at 1550 nm are measured by connecting the fan-in/fan-out (FIFO). Their values are displayed in diagonal and non-diagonal elements of Fig. 1(c), respectively, taking decibel [dB] as unit. For different cores, the loss differences mainly come from the splicing loss and the insertion loss of FIFO.

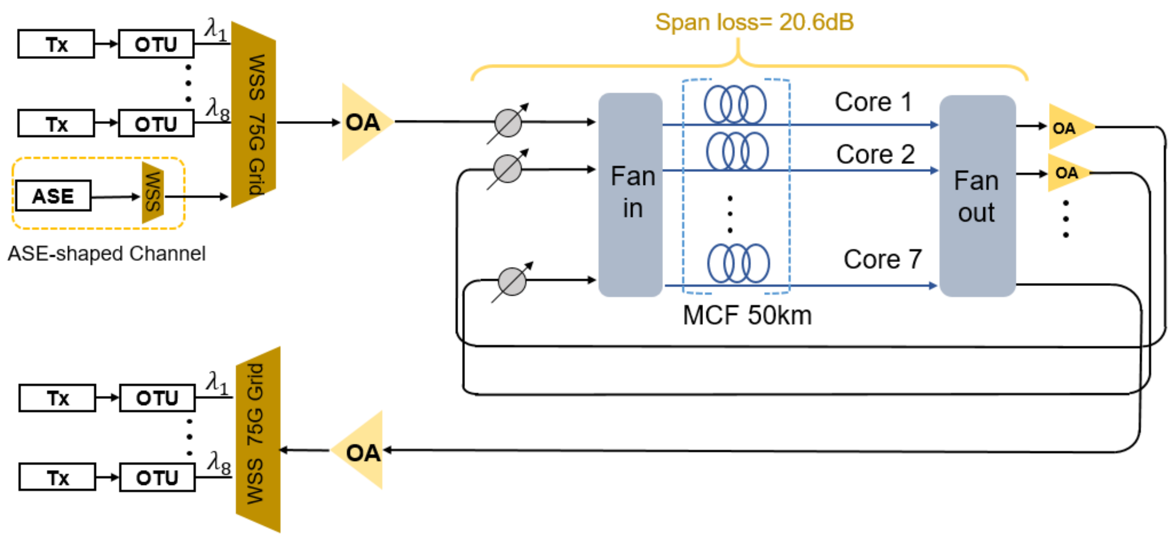


Fig. 2. Schematic diagram of the experimental transmission setup.

The experiment setup for the WDM transmission system is shown in Fig. 2. Eight 400 Gb/s coherent transceivers with 69-GBaud PCS-PDM-16QAM modulation format are employed to transmit testing signals. The wavelengths of testing channels are configured at the long, middle, and short regions of the extended C band (191.325THz to 196.125THz). They are combined with other 58 loading channels at a 75 GHz channel grid using a wavelength selective switch (WSS). The loading channels are emulated by a filtered ASE noise source. Their optical spectrums are shaped to be similar to the testing signals using another WSS. Then, 64 wavelengths are together injected into a 7-span transmission system. The 7 spans in the testbed are made up of individual cores, e.g., core1 is used as a transmission span 1, core2 is used as a transmission span 2, etc. For the transmission link, we use the co-propagation scheme to accumulate inter-core crosstalk after the transmission of all cores. The individual fiber core is connected to single-mode EDFAs and variable optical attenuators (VOAs) using the FIFO devices. In order to approach the loss of fiber link in the field trail as much as possible, we assume that a fusion point is introduced every 3 km and an average 0.35 dB splicing loss is introduced by each fusion point, originating from the experience value of field deployment. In addition, it is worth noting that each span needs about 3 dB loss margins for engineering link budget reservation. Thus, VOA is adjusted to increase every span loss to 20.6 dB for simulating the worst link situation.

3. Results and discussion

The optimum launch power is firstly investigated in this MCF system. The Pre-FEC BERs of the eight channels are measured with different launch powers at 0.5 dBm granularity. The average Pre-FEC BERs are calculated and depicted in Fig. 3, which shows that the minimum value is obtained at 3 dBm/channel. Then, the optical spectrum of the whole 64 channels with 75 GHz channel spacing at the receiver side is recorded by an optical spectrum analyzer under the optimum launch power, as shown in Fig. 4. It can be found that the system achieves a 4.8 THz working bandwidth.

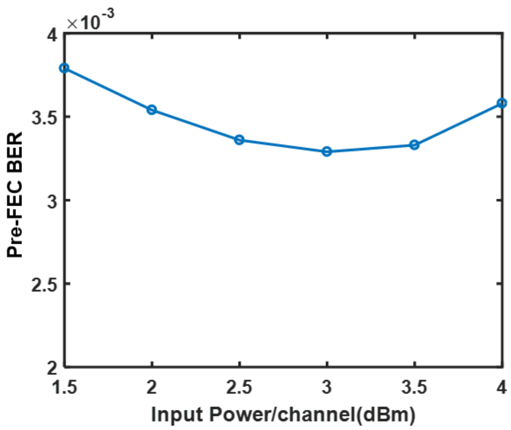


Fig. 3. The average Pre-FEC BER versus input power.

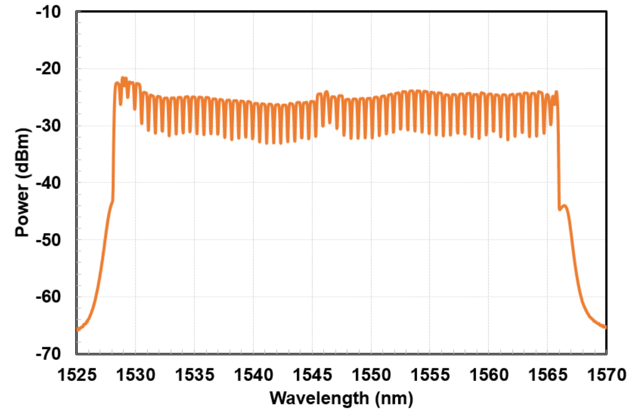


Fig. 4. The optical spectrum after 350 km transmission.

The transmission performance is demonstrated in terms of different wavelengths. Pre-FEC BERs of all channels are measured along the 48 THz working bandwidth range. During the whole testing, the power of the moved transceiver is set as the same as one of the local loading channels. From Fig. 5, it can be obtained that the flatness of Q-Factor for measured 64 channels is within 1 dB, and are beyond the FEC limit, which means all channels have almost the same performance from the short wavelength to the long wavelength range. Moreover, the received OSNRs at different wavelength regions are also measured. The measured results imply that the OSNR margins of the system are more than 2.88 dB. In Fig. 6, the long-term Pre-FEC BER tracing curve is shown, which is captured from the optical module by every 15 seconds at the 1565.581 nm wavelength. The whole curve shows a stable BER monitoring result over 24 hours. The inserter shows the print screen of 100GE BER test results.

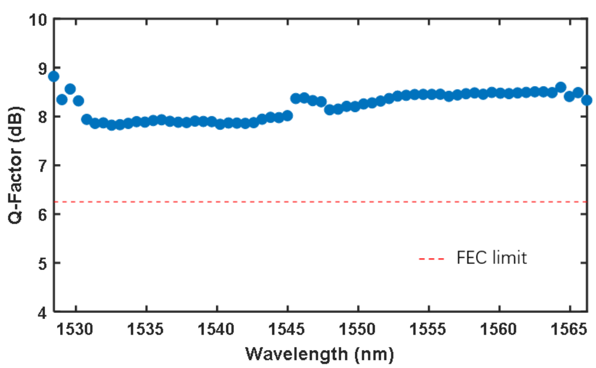


Fig. 5. Wavelength dependency of Q-factor after 350 km MCF transmission.

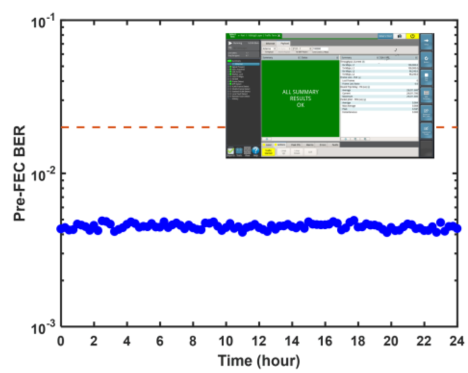


Fig. 6. Long-term pre-FEC monitoring.

4. Conclusion

In conclusion, we have demonstrated the feasibility of 179.2 transmissions over 350 km using commercially-available 7-core fiber and 400 Gb/s real-time transceivers. The 400 Gb/s signals with probabilistic shaping PDM-16QAM modulation format are fit in 75GHz grids with symbol rates of 69 GBaud. More than 2.88 dB OSNR margins are obtained with considering the splicing loss of 0.35 dB/splice and 3 dB link budget reservation at each span.

5. References

[1] Cisco Visual Networking Index: Forecast and Trends, 2017-2022.
[2] R. S. Luis et. al., in OFC2022, paper MB4.3.
[3] B. J. Puttuam et. al., in OFC2020, paper Th3H.5.
[4] B. J. Puttuam et. al., in OFC2021, paper F3B.3.
[5] M. Mazur et. al., in OFC2022, paper Th4A.1
[6] S. Beppu et. al., in OFC2021, paper F3B.4.
[7] M. Mazur et. al., in OFC2022. paper ThAB.8.
[8] T. Hayashi et. al., in OECC 2019, Workshop2.
[9] S. Beppu et. al., in OFC 2021, paper F3B.4
[10] Roland Ryf et. al., in OFC 2019, paper ThAB.3
[11] M. Arikawa et. al., in OFC 2021, paper W7D.2
[12] T. Hayashi et. al., in OECC 2019, paper PDP3
[13] Z. Feng et. al., in COL, 15(8), 080602(2017).