Transoceanic-class Ultra-long-haul Transmission Technologies with High-speed Optical Signals

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1. Introduction

It is a great honor for me to have been named an IEICE fellow for my contributions to the research on ultra-long-haul high-speed optical transmission technologies for transoceanic submarine cable systems. In around 20 years of my research on ultra-long-haul transmission, the capacity transmitted in an optical fiber has increased by more than three thousand as shown in Fig. 1. These achievements could not be made without many people’s support. I express my deepest thanks for all of them.

In this article, I summarize my main research activities on ultra-long-haul high-speed optical transmission technologies.

2. 40 Gbit/s optical soliton transmission

Optical soliton utilizing the nonlinearity and the chromatic dispersion of optical fibers was considered as a possible high-speed optical transmission technology because of its ability to maintain the signal pulse shape over long distances [1]. In high-speed optical soliton transmission, Gordon-Haus timing jitter [2] is the most serious constraint and various solutions had been proposed. In 1995, as a simple and practical solution we proposed the dispersion-managed soliton transmission scheme [3], where the chromatic dispersion accumulated in the transmission line is periodically compensated as shown in Fig. 3, and demonstrated 40 Gbit/s transmission over 10000 km without any active transmission control. At that time, the bit rate in the commercial submarine cable systems was 5 Gbit/s and the bit rate in transoceanic distance transmission was successfully increased eight times. The effectiveness of the proposed scheme was well recognized through this demonstration, which has stimulated the many theoretical and experimental studies worldwide.

Fig. 2 Conventional Soliton

Fig. 3 Dispersion-managed Soliton

3. 40 Gbit/s-based wavelength-division-multiplexing transmission

After the study on single-channel transmission, we tried to expand the capacity of wavelength division multiplexing (WDM) systems based on the dispersion-managed concept. To increase the spectral efficiency in WDM systems, the pre-filtering scheme was introduced. By optimizing the pre-filtering and dispersion management for 40 Gbit/s ultra-long-haul transmission as shown in Fig. 4 and Fig. 5, the spectral efficiency was successfully increased to 0.8 bit/s/Hz and 2.56 Tbit/s WDM transmission over 8200 km with 64 channels of 40 Gbit/s Return-to-Zero Differential Phase Shift Keying (RZ-DPSK) signals was demonstrated in 2003 [5]. The achieved spectral efficiency was more than three times higher than the previous spectral efficiency record in transoceanic distance transmission with the conventional optical amplifiers. This is the first demonstration showing the feasibility of multi-terabit transmission with the conventional optical amplifiers, which opened a new era of WDM transmission with high-speed signals.
4. 100 Gbit/s transmission using advanced modulation formats

To increase the signal bit rate to higher than 100 Gbit/s, we focused on the advanced modulation formats which can relax the required bandwidth of the electrical and optical components. After the first demonstration of 100 Gbit/s transmission using Differential Quadrature Phase Shift Keying (DQPSK) in 2006 [6], our group proposed optical Orthogonal Frequency Division Multiplexing (OFDM) and demonstrated several high-speed long-haul transmission, including 20 Gbit/s transmission over 4160 km [7] and 40 Gbit/s-based WDM transmission over 4160 km in 2007 [8] and 100 Gbit/s-based WDM transmission over 1000 km in 2008 [9].

5. High-capacity optical fiber transmission using space division multiplexing

In order to break the capacity limit of the conventional single-mode fiber of around 100 Tbit/s, a new multiplexing scheme using "space" dimension, namely space division multiplexing (SDM), was proposed by Extreme Advanced Transmission Technologies (EXAT) Initiative [10], which was organized by NICT (the National Institute of Information and Communications Technology) in 2008 and shifted to IEICE technical committee in 2010. I have been a member of the committee since its establishment and currently serve as the chair of IEICE EXAT technical committee.

We demonstrated the first transoceanic distance transmission using 7-core fiber in 28.8 Tbit/s transmission over 6160 km in 2012 [11], where the transmission distance was more than doubled from the previous record of Multi-core fiber (MCF) transmission. After this demonstration, the fiber capacity was further expanded to 140.7 Tbit/s in 2013 by introducing more spectrally efficient scheme with duobinary pulse shaping and maximum likelihood sequence estimation [12]. The obtained capacity-distance product in 140.7 Tbit/s transmission over 7326 km was 1.03 Exabit/s·km and it is the first demonstration with the capacity-distance product of larger than 1 Exabit/s·km.

These demonstrations indicate that the MCF transmission will be one of promising technologies for future high capacity ultra-long-haul transmission systems.
6. Conclusion

My main research activities on ultra-long-haul high-speed optical transmission technologies are reviewed. The fiber capacity has increased by more than three thousand in last two decades. Since the data traffic in communication systems has been continuously increasing and the demands will be enlarged furthermore in the “new normal” era, a further capacity expansion in ultra-long-haul transmission systems is expected by introducing some innovative technologies. I hope to continue to contribute to the progress of such technologies by interacting with many people through IEICE activities.

7. References


