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Nippon Telegraph and Telephone Corporation

World Record for High-capacity Optical Fiber Transmission without Optical Dispersion Compensation
- Wireless technologies enhance optical fiber communication. 13.4 terabits (134 channels of high-definition digital movies) per second transmitted over 3,600 km -

Nippon Telegraph and Telephone Corporation (NTT, Chiyoda Ward, Tokyo, President and CEO: Satoshi Miura) has successfully demonstrated an ultra-high capacity optical transmission of 13.4 terabits per second (tera = one trillion) over a single 3,600 km-long optical fiber without optical dispersion compensation[*1]. The 13.4 Tb/s signal is multiplexing of 134 channels with a channel capacity of 100 Gb/s. The transmission distance of 3,600 km is the longest ever reported for an ultra-high-capacity transmission of over 10 Tb/s. The capacity-distance product (an important measure of transmission capability) of 48.2 Pb/s km (= 13.4 Tb/s x 3,600 km, Peta = thousand trillion) also exceeded the previous record (Figure 1). The technologies used in this experiment will be useful for constructing future high-capacity, long-distance optical backbone networks[*2].

This result will be reported on September 25 as a post-deadline paper[*3] at the European Conference on Optical Communication (ECOC) held in Brussels, Belgium, from September 21.

1. Background

The present optical backbone network has a transmission capacity of over 1 Tb/s based on the wavelength division multiplexing (WDM) of signals with a channel capacity of 40 Gb/s. Data traffic has roughly doubled every year owing to the rapid spread of broadband technology and the demand for rich content such as images in access networks. We must increase the capacity of the optical backbone network while maintaining its reliability as a communication infrastructure.

Optical amplifiers are currently used in optical transmission lines in backbone networks to amplify signals that have weakened as a result of transmission loss. Until now, if we wanted to transmit signals of 10 Tb/s or more at a channel line rate of 100 Gb/s over 1000 km, we had to reduce the span length between optical amplifiers and provide optical dispersion compensation for the distorted waveform in each optical amplifier. We need to eliminate the need for optical dispersion compensators to simplify the amplifier composition and extend the transmission distance without reducing the span length.

NTT has overcome this hurdle and succeeded in extending the transmission distance to 3,600 km without dispersion compensation by newly applying wireless technologies to the optical communication field.

2. Outline of experiment

NTT Network Innovation Laboratories applied the orthogonal frequency division multiplexing (OFDM[*4]) modulation format widely used in wireless communication to optical fiber communication to increase spectral efficiency, and also used a novel two-subcarrier optical OFDM signal in the transmitter.

Digital coherent technology, a wireless technology, was also applied to the receiver to compensate for the waveform distortion that occurred during the transmission process.

134 wavelengths with a line rate of 111 Gb/s were multiplexed with a 50 GHz spacing (the total signal band is 6.7 THz) and transmitted over 3,600 km without optical dispersion compensation using low noise optical amplifiers. The spectral efficiency was 2 bit/s/Hz.

With this experiment, NTT demonstrated for the first time that it is possible to transmit a 100 Gb/s class signal such as a 100 GbE signal over distances greater than 3,000 km transparently, even if the signal is multiplexed up to 10 Tb/s or more, by employing an OTN[*5] frame as used in optical backbone networks.

3. Core technologies

In the transmitter and the receiver we employed OFDM and digital signal processing technologies that are widely used in wireless networks, and we used low noise optical amplification technology in the transmission line.

(1) Application of wireless technology I: Digital coherent signal processing technology (Figure 2)

In the receiver we used coherent detection and digital signal processing technologies. The coherent detection sensitivity is approximately 2 dB higher than that of direct detection. The separation of the two subcarriers was accomplished in a digital signal processing block. The waveforms of high-speed optical signals deteriorate owing to chromatic dispersion (CD) and polarization mode dispersion (PMD) during propagation along an optical fiber. This effect is one of the main factors limiting the transmission distance. We compensated for the waveform degradation and succeeded in improving the performance. We undertook this signal processing in a computer after saving the waveform data of the received signal. The dispersion compensation was 3.6 times greater than with a conventional 100 Gb/s transmission (over 63,000 ps/nm corresponding to a 3,600 km single-mode fiber). In addition, a PMD of 70 ps or more was compensated for simultaneously in a 100 Gb/s transmission for the first time.

(2) Application of wireless technology II: OFDM modulation technology (Figure 3)

In the transmitter we generated one 111 Gb/s signal per channel (wavelength) by optical OFDM modulation using only two subcarriers. The baud rate of the OFDM signal can be reduced to 13.9 Gb/s (one-eighth of 111 Gb/s) with the aid of quadrature phase shift keying (QPSK[*6]) modulation and a polarization division multiplexing format. This enables us to reduce the electric interface speed of the digital signal processor and also the optical spectral band thus leading to an increase in spectral efficiency.

Here 111 Gb/s is thought to be the bit rate at which a 100 GbE signal is accommodated in an OTN frame including forward error correction bytes and management overhead bytes.

(3) Wide-band, low-noise optical amplifier: Extended L-band amplifier with distributed second-order Raman amplification technology

We amplified the signals of 134 channels with a 50 GHz spacing using a lumped amplifier and a distributed Raman amplifier. The former was a low-noise extended L-band amplifier whose amplification band (approximately 7 THz) was 1.7 times wider than that of a conventional L-band amplifier. The latter was a backward-pumped distributed Raman amplifier providing second-order Raman amplification. The span length was 80 km. It is very important to suppress signal-to-noise ratio (SNR) degradation if we are to transmit a 100 Gb/s signal over a long distance. This time we succeeded in extending the transmission distance by improving the received SNR with second-order Raman amplification technology.
Figure 4 show the results we obtained after a 3,600 km transmission, and all 134 channels were over the Q-limit, which means that all the channels could transmit signals under error free conditions in the OTN frame.

(4) Key devices

NTT Photonics Laboratories developed key components for this challenging experiment in cooperation with NTT Network Innovation Laboratories. These components are an OFDM modulator, a tunable laser, and a receiver component for coherent detection. The OFDM modulator is a hybrid integrated modulator composed of an LN lightwave circuit and a silica-based planar lightwave circuit (PLC[*7]). In the modulator, the two subcarriers from a two-subcarrier generator are separated, each carrier is modulated with the QPSK format, and they are then combined. A tunable DFB laser with a narrow line width (less than 1 MHz) is used as an optical source and it can reduce the phase noise in coherent detection. The 90-degree hybrid with a polarization diversity function for coherent detection is based on a PLC and is useful for compact implementation.

4. Future schedule

NTT aims to realize 100 Gb/s serial long-distance transmission technology and construct a high-capacity and long-distance optical backbone network that is superior in terms of economy and quality.

Terminology

*1: Optical dispersion compensation
When an optical signal propagates an optical fiber, pulse broadening occurs due to dispersion. This is because propagation speed is different depending on the wavelength. Optical dispersion compensation is to return the distorted signal to former waveform by adding reveres dispersion to the signal.

*2: Backbone network
Long-distance and high-capacity core telecommunication line used by carriers to connect Internet service providers or broadband access networks.

*3: Post deadline paper
A paper that is called for after the submission deadline for regular papers. Organizations compete to achieve the best performance as regards the latest optical

communication technologies. The submitted papers are reviewed at the conference and only the best are selected and reported.

*4: OFDM
Abbreviation of Orthogonal Frequency Division Multiplexing. A digital modulation format in commercial use in wireless networks. It is used to multiplex plural subcarriers in the frequency domain, and the frequency spacing between the subcarriers is set at the symbol duration. It enhances the spectral frequency because the frequency band of each subcarrier overlaps that of its adjacent subcarrier but each subcarrier is separated without interference in the receiver.

*5: OTN
Abbreviation of Optical Transport Network. The international standard for optical networks using WDM systems (ITU-T G.709 recommendation).

*6: QPSK
Abbreviation of Quadrature Phase Shift Keying. A modulation format where data are transmitted by using the phase of the carrier. It can handle double the information volume of the on-off keying format.

*7: PLC
Abbreviation of Planar Lightwave Circuit. A planar lightwave circuit is formed on fused silica that includes an optical waveguide. This technology can be used to integrate complex passive optical devices in small areas, and is also used to realize multiplexing and demultiplexing devices for WDM systems.

-Figure 1 Capacity-distance product in optical transmissions of over 10 Tb/s
-Figure 2 Digital coherent signal processing technology (receiver)
-Figure 3 OFDM modulation technology (transmitter)
-Figure 4 Experimental results of 13.4 Tb/s, 3,600 km transmission

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