NEWS RELEASE

NTT
NIPPON TELEGRAPH AND TELEPHONE CORPORATION

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World Record 69-Terabit Capacity for Optical Transmission over a Single Optical Fiber

Nippon Telegraph and Telephone Corporation (NTT, Chiyoda Ward, Tokyo, President and CEO: Satoshi Miura) has successfully demonstrated an ultra-high-capacity optical transmission of 69.1 terabits per second (tera = one trillion) over a single 240 km-long optical fiber. (Figure 1) The 69.1 Tb/s transmission, based on the wavelength division multiplexing (WDM) of 432 wavelengths with a capacity of 171 Gb/s, is the highest ever reported in the optical transmission field, and is twice the previous record of 32 Tb/s. The technologies used in this experiment will be useful for constructing future high-capacity optical backbone networks.
This result was reported on March 25 as a post-deadline paper at the Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC 2010) held in the USA.

1. Background
Data traffic on optical networks is increasing rapidly because high-volume content such as a high definition images is now frequently transmitted over the Internet. NTT Network Innovation Laboratories (hereafter, NTT Labs) are researching and developing future optical backbone networks to cope with the rapidly increasing data traffic with which the data will be accommodated efficiently, and high-capacity, long-distance transmission will be realized. NTT Labs has already achieved a 13.5 Tb/s optical transmission over 7,000 km.

2. Technical points
There are three key technical points.
(1)Increased spectral efficiency using 16 QAM format
(2)Novel demodulation algorithm without using extra overhead signal
(3)Realization of ultra-wide band optical amplifier covering C and extended L bands
We used a 16 QAM format (*1), which enables us to realize an ultra-dense WDM with a wavelength spacing of 25 GHz, in the transmitter, and novel digital signal processing technology (*2) in the receiver. In the optical transmission section, we achieved low-noise, ultra-wideband amplification in the C and extended L bands (*3) and controlled the nonlinear effects inside the optical amplifiers.
With the 16 QAM format, the symbol rate (*4) is reduced to one-eighth of the transmission rate by combination with polarization division multiplexing (*5), so that the electric interface speed is reduced and the optical spectral band (*6) is narrowed. This leads to an increase in spectral efficiency to its highest reported value of 6.4 b/s/Hz in the 16 QAM format.

3. Future schedule
NTT Labs aim to realize high-capacity and long-distance optical transmission based on rates of over 100 Gb/s per wavelength and over 10 Tb/s per fiber, and to construct an optical backbone network that is superior in terms of economy and quality.

4. Details of technology

(1)Experimental setup
The 171 Gb/s signal per wavelength is generated by the combination of the 16 QAM format with polarization division multiplexing in the transmitter (Figure 2). The symbol rate is 21.4 Gbaud (one-eighth of 171 Gb/s). The 16 QAM signal is produced by combining two QPSK signals with an amplitude ratio of 2:1 in the QAM modulator. The bit rate of 171 Gb/s is that of the OTN ([*7]) frame, which includes the payload of 160 Gb/s, forward error correction and an overhead for management. 432 optical signals from 1527 to 1620 nm with a wavelength spacing of 25 GHz are multiplexed and a 69.1 Tb/s signal is generated.
Coherent detection and digital signal processing are used in the receiver (Figure 3). The receiver sensitivity for coherent detection is more than 3 dB higher than that with the conventional direct detection of an NRZ signal. A new algorithm without pilot-less processing ([*8]) was deployed to demodulate the 16 QAM signal. The signal processing can also equalize the wavelength distortion caused by chromatic dispersion and the polarization mode dispersion that occurs during an optical transmission.
We transmitted the 69.1 Tb/s signal over 240 km using ultra-wide band amplification technology with an amplification band of 10.8 THz (1.35 times wider than the conventional band), which was composed of a C band of 4.4 THz and an extended L band of 6.4 THz. We enhanced the signal-to-noise ratio by using distributed Raman amplification, and took measures to suppress the nonlinear effects that occurred owing to the increase in optical power inside the amplifiers. The Q values and optical spectrum after the 240 km transmission are shown in Figure 4. All the Q values measured for the 432 wavelengths were over the Q limit.

(2)Key devices
NTT Photonics Laboratories developed key components for this challenging experiment in cooperation with NTT Network Innovation Laboratories. These components are a QAM modulator, a tunable laser, and a dual polarization optical hybrid. The QAM modulator is a hybrid-integrated modulator composed of an LN lightwave circuit and a silica-based planar lightwave circuit (PLC). The 16 QAM signal is generated stably in the modulator. A tunable DFB laser with a narrow line width (100 to 200 kHz) is used as an optical source, and it can reduce the phase noise in coherent detection. The dual polarization optical hybrid for coherent detection is based on a PLC and is useful for compact implementation.

Title of paper
"69.1-Tb/s (432 x 171-Gb/s) C- and Extended L-Band Transmission over 240 km Using PDM-16-QAM Modulation and Digital Coherent Detection"

Terminology
*1: 16 QAM format
QAM is an abbreviation of quadrature amplitude modulation. QAM carries information about both the amplitude and phase of the signal, which has two

components each with a phase relation of 90 degrees (in-phase and quadrature-phase). One 16 QAM signal can transmit 4 bits.

*2: Digital signal processing technology
The technology whereby a received signal is converted to a digital signal, a distortion waveform is equalized electrically, and the phase of the original signal is determined. When the above process is performed after the signal has been received with coherent detection, it is called digital coherent signal processing.

*3: C and extended L band
Wavelengths with low propagation losses are used in optical communication. The C band is from 1530 to 1565 nm, and the L band is 1565 to 1625 nm. However the practical L band is determined by the characteristics of commercial amplifiers and is generally about 4 THz ranging from 1570 to 1600 nm. In the extended L band, this 4 THz band is extended to about 7 THz.

*4: Symbol rate
The speed per second when sending a code to a transmission line given in baud units. The symbol rate is one-fourth of the transmission bit rate when a 16 QAM signal is used.

*5: Polarization division multiplexing
A multiplexing scheme in which information is carried in two polarization components of the propagation light (x and y polarizations). This technique can double the capacity provided by a single polarization scheme.

*6: Optical spectral band
The width of the spectrum when an optical signal is measured in the frequency (or wavelength) domain. As the spectrum becomes narrower, the WDM that can be realized becomes denser.

*7: OTN
OTN is an abbreviation for optical transport network. The OTN has been standardized by ITU-T and offers a reliable optical network based on WDM systems.

*8: Pilot-less processing
A process whereby digital signal processing is carried out using only the received signal without any reference signals. It is called blind processing.

- Figure 1 Recent major high-capacity optical transmission experiments over 10 Tb/s
- Figure 2 Generation of 171 Gb/s signal using 16 QAM format and polarization division multiplexing
- Figure 3 Digital coherent signal processing in receiver
- Figure 4 Experimental results of 69.1 Tb/s, 240 km transmission

For further information, please contact:
NTT Science and Core Technology Laboratory Group
Public Relations Department
Tel: 046-240-5157
http://www.ntt.co.jp/sclab/contact.html