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Nippon Telegraph and Telephone Corporation
NTT Communications Corporation

First Implementation of 100 and 40Gbps Ultra-High-Speed Plug-and-Play Optical Communications

-- Ultra-high-speed auto-configuration technology using digital coherent optical transmission in installed fiber environments --

Nippon Telegraph and Telephone Corporation (NTT, CEO: Satoshi Miura, Tokyo) and NTT Communications Corporation (NTT Com, CEO: Akira Arima, Tokyo), have conducted 100 and 40Gbps transmission tests in real field environments using existing installed optical fiber, and have demonstrated for the first time, plug-and-play functionality that greatly reduces the setup time previously required for configuring optical signals. This was achieved using a new technology developed by NTT which is able to auto-configure 100 and 40 Gbps ultra-high-speed signals.
This research result enables 100 and 40 Gbps ultra-high-speed signals to be configured easily and automatically, similarly to the 1 Gbps-class signals used for fiber-to-the-home (FTTH). It has been difficult to configure such signals immediately till now. This type of ultra-high-speed plug-and-play functionality, operating in 50 ms or less, will simplify network operations and maintenance and dramatically improve the speed of optical signal recovery when faults occur.

* Parts of this research use results from research commissioned by the Ministry of Internal Affairs and Communications (MIC) entitled “High-speed Optical Transport System Technologies” and by the National Institute of Information and Communications Technology (NICT) entitled “the Universal Link Project”

1. Research Background

With the recent rapid adoption of broadband access that is accompanying the spread of FTTH and smartphones, communications traffic continues to increase by about 20% per year. This is creating demand to further reduce costs and increase the capacity of the optical core network[*1], while maintaining its reliability as infrastructure for communications. In the past, NTT Com has always taken a leading role in introducing the latest optical communications technology and implementing an advanced core optical network to accommodate this level of increase in communications traffic and to provide highly reliable and economical broadband services to customers.
To provide even better broadband services, NTT has been advancing R&D on digital coherent technology[*2], an advanced technology able to increase the capacity of next-generation optical networks dramatically.
In the past, optical signals with ON and OFF corresponding to one and zero of the digital signal were sent over optical fiber for fiber-optic communications. However, to transmit an ultra-high-speed signal of 100 or 40 Gbps (equivalent to sending 2 h of high definition video in 2 s) using this method, the waveform distortion added to the optical signal during transmission through the optical fiber must be measured and the system configured to remove it. Performing such preliminary measurements requires several days, and configuring equipment to eliminate the distortion also takes time.
Digital coherent technology, which is a key next-generation technology for increasing capacity, is expected to help reduce configuration time and ensure stable operation in practical operating environments, further improving network operation and maintenance and enhancing the reliability of the core optical network.

2. Experiment Overview and Division of Roles

(1) Ultra-high-speed waveform distortion measurement using ultra-high-speed digital signal processing (DSP)[*3] and a known signal [NTT] (See Figure 1)

The newly developed technology is an application of digital coherent technology, which transmits an optical signal with lightwave characteristics (optical phase[*4] and polarization[*5]) corresponding to ones and zeros of the digital signal. It implements high-speed configuration for the ultra-high-speed signal by applying a new DSP function to the digital coherent technology. A DSP in the optical transmitter first introduces a known digital signal into the transmitted optical signal to measure waveform distortion beforehand, and this is transmitted as a digital coherent optical signal using lightwave characteristics. The receiver then receives optical signal, having been distorted by the unique transmission characteristics of the optical fiber, and it is digitized in real time, as-is, by the receiver DSP, making it available for high-speed digital signal processing. Specifically, the receiver DSP measures the waveform distortion added to the received optical signal directly and accurately by extracting the known signal from it, and later removes this measured waveform distortion from the received signal. The new technology measures the waveform distortion quickly and reduces configuration time to allow high-speed removal of the distortion. Both of these were difficult to implement with earlier optical communication methods using binary optical signals. NTT has successfully developed this DSP technology able to configure for 40 or 100 Gbps operation on a single wavelength automatically, within an extremely short time (50 ms or less), without human intervention.

(2) Construction of the field-test environment[*6] [NTT Com]

To apply DSP in a practical optical network, it must be able to handle any waveform distortion possible in the anticipated operating environments and must have adequate processing capability to respond quickly relative to changes in waveform distortion occurring in the optical fiber. In cooperation with NTT, NTT Com tested DSP circuit performance in this way for all manner of transmission environments, devised a procedure to verify the response characteristics, and built a field-test system spanning 580 km (with average transmission path polarization mode dispersion[*7] of 35.5 ps) using its own installed commercial fiber.

(3)Test result verification [NTT, NTT Com] (See Figures 2 , 3)

To study the state of optical signal communication, 11 wavelengths with 100 or 40 Gbps signals per wavelength were transmitted under over 1000 different artificially-created transmission conditions, in field tests spanning 580 km. The results confirmed extremely stable automatic configuration in all cases. Simulating various conditions provided evidence that the technology would be able to maintain the quality of the main signal under all conditions of installed fiber throughout Japan. Also, by measuring DSP configuration times, we confirmed that automatic configuration in 50 ms or less (excluding optical fiber propagation delay) was achieved, verifying DSP performance as designed in real operating environments.

3. Future Developments

In future high-capacity backbone networks, the network operation can be improved to handle various changes in traffic demand by instantaneously configuring the routing of ultra-high-speed optical signals. Also, this technology enables construction of highly reliable networks that can instantly configure alternate routings, for example, to recover from damage due to a large scale disaster. We are working to realize an economical network with both flexible operation and high reliability using this optical transmission technology.

*1: Optical core network

A broadband network using optical fiber and having a hierarchical structure consisting of access, metro, and core networks, in order of nearness to users. It is organized such that higher levels handle higher-volume, multiplexing aggregate information to achieve more economical and efficient transmission.

*2: Digital coherent technology

With digital coherent technology, the ones and zeros of a digital signal are mapped to states of optical signal properties (phase, frequency, polarization), as is done with radio-waves. At the receiver, the information signal on the optical wave is extracted as an electrical signal by mixing the weak received optical signal with a locally-generated optical signal. Then, the electrical information signal is digitized by an analog-to-digital converter, and any added noise or distortion is completely removed using high-speed digital signal processing to recover the original information signal. Compared to conventional intensity modulation methods, this achieves high-quality optical transmission with high receiver sensitivity and resistance to various types of distortion during transmission through fiber.

*3: Ultra-high-speed digital signal processing

With optical communication, generally the received signal after transmission by optical fiber is a continuous, analog, ultra-high-speed electrical signal with noise and waveform distortion added during transmission. With digital coherent technology, ultra-high-speed filtering and other complex signal processing is done to remove the undesirable noise and waveform distortion and obtain the original signal from this analog signal. To do this, the ultra-high-speed analog electrical signal is first converted to a digital signal that is easy to process using a computer. An ultra-high-speed digital signal that completely describes the received signal state can be generated using a sampling process, which reads the ultra-high-speed analog signal at fixed discrete time intervals, and a quantization process, which classifies the signal amplitudes read into many discrete levels. Specialized computer processing such as removing noise and waveform distortion from this ultra-high-speed digital signal, and the integrated circuits that accomplish such processing are called Digital Signal Processing and Processor respectively (both DSP). Using such circuits, high-quality signals can be reproduced in real time, which was difficult to achieve with conventional analog signal processing, and high-quality, highly reliable, ultra-fast optical communications with low delay can be realized.

*4: Phase

Light has wave properties similar to radio waves. The timing of the vibration of these waves is called the optical phase. Waves vibrate periodically, so phase can vary in a range of 0 to 360 degrees. Using this freedom, different optical phase values (e.g.: 0 and 180 degrees) can be made to correspond to 1 and 0 in a digital signal, and by detecting these phase differences, receivers with higher sensitivity than conventional on-off optical schemes can be created, able to transmit over longer distances and with higher capacity due to more efficient communications. This type of communication is called phase modulation and is commonly used in electrical communications.

*5: Polarization

As with radio waves, light vibrates along two independent directions (along X and Y axes). These independent axes are called the polarities. This property is often used for 3D movies to send different information to the right and left eyes, creating a 3D image effect. With earlier optical transmission, it was difficult for receivers to reliably detect two different directions of polarization, so only one of the polarization components could be used. With digital coherent technology, which uses DSP, two independent polarizations can be separated reliably at the receiver, so communication carrying independent information on each polarization direction is possible, increasing efficiency and capacity of transmission.

*6: Field-test environment

Central office and fiber-optic cable equipment, including commercial test equipment used to provide network services, is called a field environment. With installed fiber-optic cable, aspects such as polarization state and polarization mode dispersion change in complex ways due to temperature and maintenance work. This produces in environmental fluctuations that are difficult to reproduce in the laboratory. Digital coherent technology uses adaptive control to handle such environmental fluctuations, so testing in this sort of real operating environment is essential for a reliable implementation. A test environment that is the same as a real operating environment, as described above, is called a field test environment.

*7: Polarization mode dispersion

Optical fiber guides lightwave for transmission over long distances in a cylinder of quartz glass called the core, in the center of the fiber and finer than a human hair. Ideally, the cross-section of the core is a perfect circle, and ideal optical fiber has uniform characteristics that do not depend on the directions of the two independent phases. However, the propagation speed of the two phases changes slightly due to factors such as deviation from a perfect cylinder during manufacture, stress on the optical fiber during installation, or cable temperature. This propagation time difference is called the polarization mode dispersion, and it can change quickly depending on the environment. For ultra-high-speed optical communications of 40 Gbps or more, optical waveform distortion due to polarization mode dispersion becomes significant and can result in dramatically reduced transmission distances for conventional on/off modulation schemes. With digital coherent technology using DSP, the two polarization can be separated at the receiver, so waveform distortion due to polarization mode dispersion can be completely eliminated.

Attachment·Reference

- Figure 1 (a): Conventional optical transmission technology
- Figure 1 (b): Digital coherent transmission technology with new DSP function
- Figure 2: Field testing of the high-speed auto-configuration function using the DSP
- Figure 3: High-speed automatic configuration tests using DSP
- For Reference Technical Term: Digital Coherent Technology

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