# Past and Future Prospects for Advanced Operation of Access Network Facilities

*Takashi Ebine*

**Abstract**

NTT is responsible for building and maintaining access network facilities, providing a variety of services ranging from fixed-line telephones using metal cables to data communications using optical fibers. In this context, we at NTT Access Network Service Systems Laboratories are researching and developing smart-engineering (design and construction) and smart-maintenance (maintenance and operation) technologies with the aim of operational innovation through digital transformation of such access network services. We are also taking on the challenge of creating new value in areas other than telecommunications by using assets at our communication facilities.

*Keywords: operational innovation, advanced operation, access network facilities*

## 1. Operational innovation in access network services

NTT is responsible for building and maintaining access network facilities and providing a variety of services ranging from fixed-line telephones using metal cables to data communications using optical fibers. Against this backdrop, especially in the fiber-to-the-home (FTTH) sector, which underwent a major transformation from metal to light, operational innovation has advanced significantly. As we move toward the coming Innovative Optical and Wireless Network (IOWN) era, we expect to see a significant transformation in services, along with a transformation in operational innovation.

In the early days of FTTH, Nippon Telegraph and Telephone Public Corporation was privatized against the backdrop of the deregulation of telecommunications in 1985, and in the 1990s, the construction of access network facilities underwent a major transformation due to the increase in the number of new telecommunications carriers and discussion on opening up NTT's optical-fiber network facilities to other telecommunications service providers. With the advent of competing services, such as asymmetric digital subscriber line, it was difficult to predict optical demand, and additional construction could occur, so it was a time when trial and error was repeated in the construction and maintenance of access network facilities. In such an era, the study of aerial-optical-drop fiber-cable-bundling technology, which started mainly from external factors, is an example of how operational sophistication could be achieved through the thorough use of existing facilities and space.

Although there were various challenges in the beginning toward implementing this technology, we verified and evaluated the reliability of the installation equipment and communications in response to long-term environmental changes. It is now the basic construction method for laying optical cables throughout Japan.

As we approach the IOWN era, NTT is preparing for technology accumulation and field deployment through research and development to address public demand for telecommunications infrastructure. We at NTT Access Network Service Systems Laboratories are advancing the operational sophistication of access network facilities from the perspective of operational innovation. This article presents two initiatives that have been or will be deployed in the field.

## 2. Upgrading facilities by digitizing the real world

One of the operational innovation initiatives that is being rolled out is the "Upgrading facilities by digitizing the real world" by using vehicles called mobile mapping systems (MMSs).

Digital Twin Computing, which digitizes and simulates the real world, is one of the components of IOWN. Outside facilities, such as utility poles, that support communication services will continue to require constant maintenance and operation. The inspection of outside facilities is carried out visually and with human experience and expertise, but further efficiency is required due to the shrinking workforce. We have been engaged in research and development of technology to automatically extract information on communication facilities from point-cloud data acquired from an MMS and quantify facility conditions such as deflection and thereby developed a structural-deterioration determination system that contributes to increasing the efficiency of inspection work.

The more flexible the pole, the more likely it is to have lateral cracks and be unsafe. By running an MMS to automatically extract utility poles with large deflections and visually inspect only those poles, it is possible to greatly reduce inspection work. Deflection can be calculated automatically by simply inputting point-cloud data into the system, which can also contribute to skill-lessness. To achieve remote and automated construction work, such as construction of columns, we are currently advancing technology for automatically recognizing facilities, heavy machinery, and the surrounding environment in real time from point-cloud data and pursuing the ultimate in accuracy to quantify the structural conditions of ultrathin objects such as cables (**Fig. 1**).

Point-cloud data has been used in various industries such as automated driving and surveying, and the accuracy of measurement equipment has been improved and their cost has decreased. However, the MMS used by each NTT Group company has different specifications, so processing and analysis software must be changed in accordance with the data acquired, which makes aggregation and deployment inefficient. In addition to automatic-recognition technology and facility-condition-quantification technology, facility requirements for acquiring point-cloud data inexpensively and with high precision from all communication facilities and the unification of MMS specifications of the NTT Group will be studied.

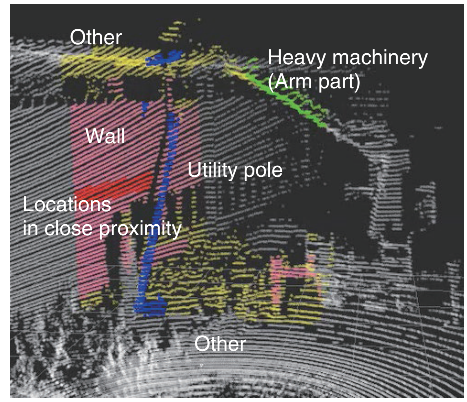


Fig. 1. Example results of real-time automatic recognition.

## 3. Research and development of concatenated loop topology for IOWN optical access networks

This section introduces two major activities for operational innovation. The first is the activity related to concatenated loop topology for optical access networks.

The star-type topology for the optical access network supporting FTTH services, which was designed to be economical, has been used. However, business demand from various service operators is expected to increase, including mobile-carrier demand such as Beyond fifth-generation mobile communications system (5G)/6G. Unlike FTTH, which has been used to address certain consumer demand by replacing metal cables with optical fiber cables, such business demand is uncertain in terms of the quantity and location, so problems such as inefficiency and inability to respond to highly reliable and flexible services are expected.

On the basis of this background, we established a concatenated loop topology for optical access networks that combines multiple cable loops in multiple stages and proposed a wiring method that optimizes higher reliability and high capability to accommodate optical demand with uncertainties for locations and quantity (**Fig. 2**). Loop topology has been considered a reliable and flexible wiring topology since the early days of FTTH, but this concatenated loop topology can improve reliability and flexibility not only near central offices but also in areas far from the central offices by using this multi-stage configuration. It can also select optical paths with a high degree of freedom. For optical access networks in the IOWN era, we are considering overlaying the current FTTH

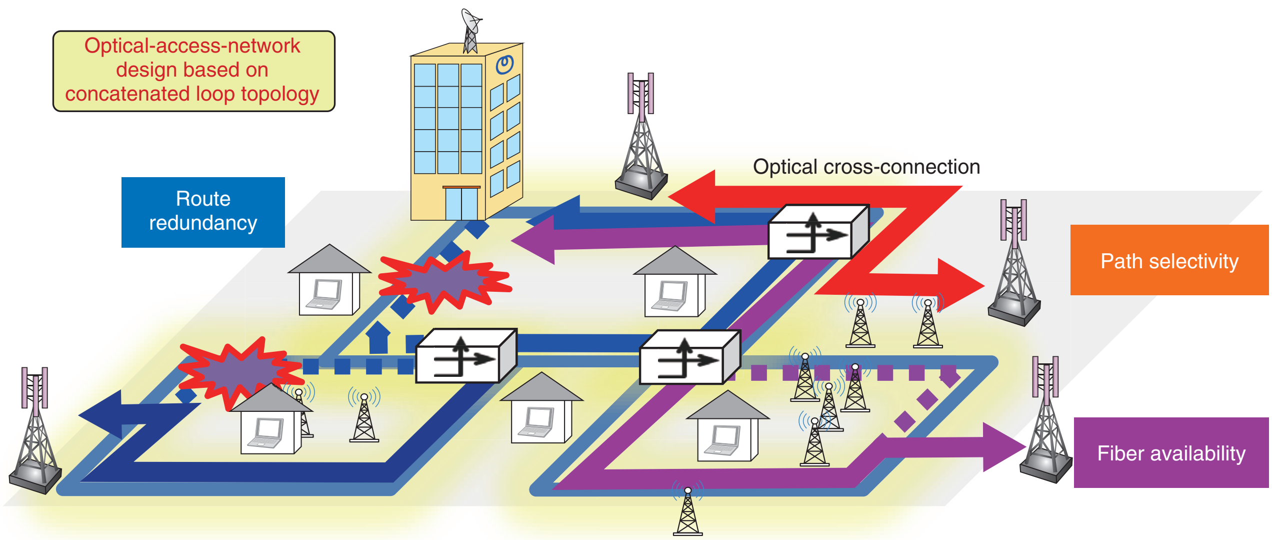


Fig. 2. Optical-access-network design based on concatenated loop topology.

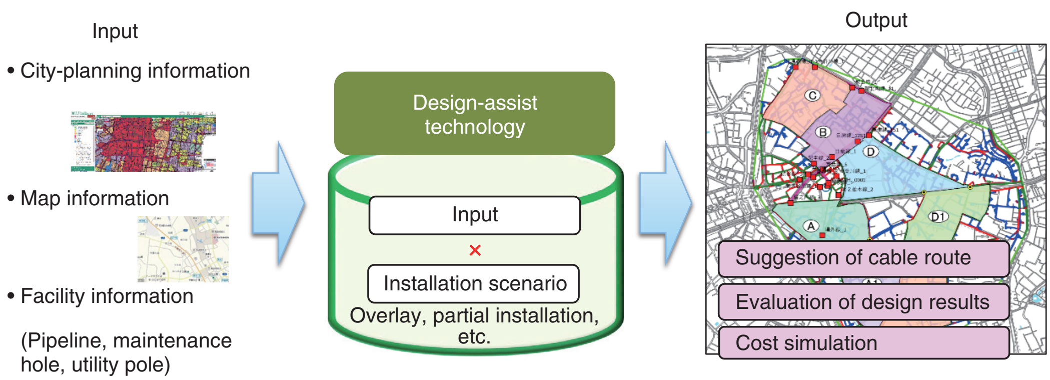


Fig. 3. Overview of design-assist technology.

network with a new layer of this concatenated loop topology.

However, to introduce new wiring methods, it is essential to estimate future demand and conduct simulations of capital investment and construction volume. This should enable the design of an optical access network on the basis of current equipment (i.e., availability of pipelines, utility poles, pull-up points, and optical cables). Manually carrying out such design requires an enormous amount of work, and the design quality varies depending on the designers' skills. Therefore, we are advancing research and development on design-assist technology for automatically generating appropriate cable-route proposals and assisting designers by inputting necessary information (**Fig. 3**). This technology is expected to make it easier to verify various deployment patterns in accordance with demand forecasts and area characteristics because it can significantly reduce the time for designing (about one to two days), which normally takes two weeks to one month by hand per area in a central office.

We will investigate the introduction of concatenated loop topology to green fields, such as smart cities, while aiming to deploy it in actual optical access networks. Operations and other aspects of this wiring method will be developed in parallel, and research and development will be promoted to implement

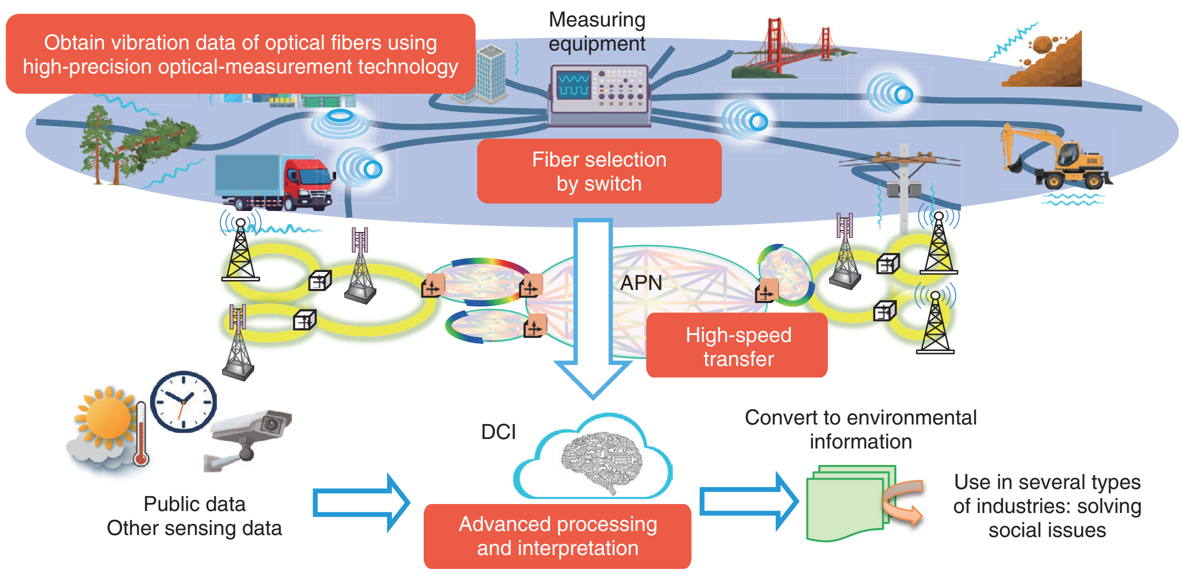


Fig. 4. Optical-fiber environmental monitoring.

IOWN along with related technology development.

## 4. Optical-fiber environmental monitoring using current communication cables and advanced optical-fiber sensing technology

The other operational innovation initiative that is expected to be developed is optical-fiber environmental monitoring.

By using current optical fiber cables for communications, which are the largest assets owned by the NTT Group, as sensors, we are advancing research and development on optical-fiber environmental monitoring with which vibrations generated by various events occurring around optical fiber cables are observed with our proprietary high-precision distributed acoustic sensing (DAS), and the resulting vibration data are analyzed and interpreted to identify events occurring around the cables (**Fig. 4**).

The technological requirements to achieve this include the ability to measure the distribution of vibration applied to an optical fiber with high precision, ability to process a large amount of measured data in real time to visualize the state of vibration, and ability to analyze and interpret the data to identify events. To improve the accuracy of vibration measurement, NTT's DAS is based on phase optical time-domain reflectometry (phase-OTDR) with frequency-division multiplexing (FDM) pulses. FDM phase-OTDR is used to observe more accurate phases of backscattered light and generate vibration waveforms with less noise than before by using FDM pulses and our unique noise-reduction algorithm. Although the processing of a large amount of data is a major issue, real-time data processing is possible due to the development of calculation algorithms and the use of field-programmable gate arrays. **Figure 5** shows example measurement results of vehicle traffic by FDM phase-OTDR using a communication optical fiber cable laid in an underground pipeline installed along an actual roadway. The horizontal axis shows the distance from the measuring device, and the vertical axis shows the elapsed time. The red and blue bars represent the measured amount of phase rotation of the optical signal and correspond to the amplitude of the vibration applied to the optical fiber. Therefore, a pair of red and blue lines indicates how one vehicle is traveling on the road. The number of pairs represents the number of vehicles. The slope of the line means the speed of the vehicle. This measurement can also be conducted in real time. The area around A in the figure, where the slope of the line increases, indicates that the traffic signal has turned red and vehicles have slowed down and stopped. This is expected to be applied to traffic-flow monitoring in smart cities and other areas. Vibration information obtained with such high precision is expected to be used to understand the surrounding conditions of optical fiber cables, and its use is progressing.

Optical-fiber environmental monitoring is also

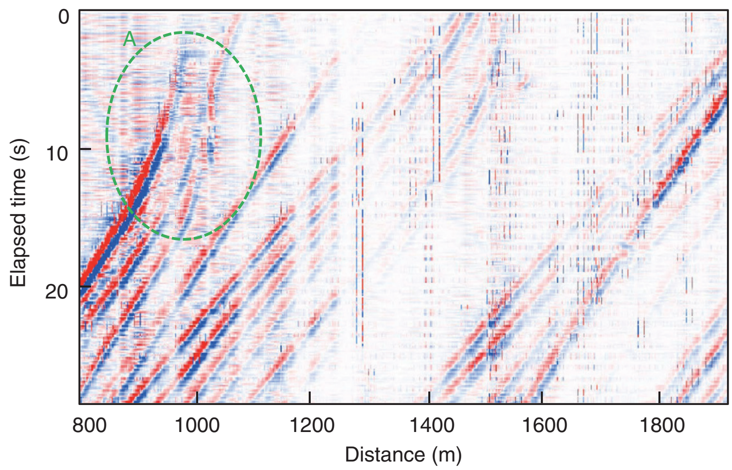


Fig. 5. Vehicle-traffic-measurement results with optical fiber cables laid in field.

aimed at achieving more advanced sensing by combining it with IOWN. We are considering the use of the fiber-path switching function of the All-Photonics Network (APN) to enable planar measurements by freely selecting the optical fibers to be sensed and the transfer of large amounts of measurement data by the high-speed transmission function of the APN. By using the abundant computing resources of the data-centric infrastructure (DCI) to analyze and interpret measurement data at high speeds, we expect to immediately generate environmental information. Discussions are currently focused on the configuration of the connection between the sensing device and switching function of the APN.

Optical-fiber environmental monitoring can provide new value to optical-fiber-cable networks as a sensing infrastructure. With the aim of expanding the application area, we will work on developing a method for measuring vibration with higher precision and over a wide area, accumulate knowledge and experiences to implement the method as a device, and develop systematization and use cases.

## 5. Direction of future initiatives

In the United States, companies, including Google, are focused on the road shoulder as a business opportunity and are competing for the rights to smart cities and autonomous driving. Innovation using current assets and technologies is occurring at the same time, and NTT believes that it is important to use space such as using the aerial-optical-drop fiber-cable-bundling technology, and effectively use current assets such as in optical-fiber environmental monitoring for innovation. With regard to the vast amount of assets held by NTT, such as utility poles and cables, we will continue to take on the challenge of creating new value, not only through the effective use of such assets but also in areas other than telecommunications, drawing on past good practices.

**Takashi Ebine**

Executive Research Engineer, Project Manager, Access Network Management Project, NTT Access Network Service Systems Laboratories.

He joined NTT in 1997 and has been engaged in the developmental research of access network facilities. He served in this position from July 2020 to June 2023 and is currently vice president, head of NTT Access Network Service Systems Laboratories.