Research and Development of Optical Fiber and Cable Technology

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Abstract

NTT Access Network Service Systems Laboratories has initiated the Access Media Project to further the research and development (R&D) of optical fiber and cable technologies for broadband network services. This article introduces the latest R&D in operations, administration, and management technologies that will be used to make the operation of a massive number of optical facilities more efficient. It also reviews next-generation optical fiber technologies to handle the explosive future growth of data traffic.

Keywords: optical fiber and cable, operations, administration, and management, next-generation optical fiber

1. Introduction

NTT has been involved in the development of optical fiber technology for over 40 years. This technology includes fiber manufacturing methods such as VAD (vapor-phase axial deposition), cabling and connection technology for use as communication equipment, and testing technology for network management. A commercial optical fiber network service was started in Japan in a trunk-line network in 1982, and the Japan longitudinal optical fiber network was completed in 1985. In access networks, the full-scale fiber-to-the-home (FTTH) service called B FLET'S began in 2001.

Optical fiber for trunk lines requires large capacity transmission and high reliability. Furthermore, economic efficiency and operability are very important for application to access networks.

NTT Access Network Service Systems Laboratories (AS Labs) has developed various optical components and systems to implement these commercial optical fiber services. In the recent decade, we have focused in particular on improving fiber and cable technologies for use in optical access networks to facilitate the deployment of the FTTH service. HAF (hole-assisted fiber) has holes around an optical fiber core and provides easy in-house DIY (do it yourself) capabilities based on ultralow bending loss characteristics due to the confinement effect of optical power distribution in the optical fiber core [1]. Ultrahigh-count and high-density optical fiber cable with a rollable ribbon structure achieves twice the density of conventional cable and improves accommodation in pipes because of its thinness [2]. In this article, we introduce the latest research and development (R&D) on optical fiber technology for access networks and for next-generation optical fiber networks.

2. Future direction of R&D of optical fiber and cable technology

Internet traffic is continuing to increase dramatically. The net increase in the number of FLET'S service users has stabilized in the last several years, although we are still managing a huge number of facilities for the optical fiber network. Also, due to the declining birth rate and aging population, the number of people available to work on the operation and maintenance of these facilities will certainly decrease. Thus, in the future, it will be essential to

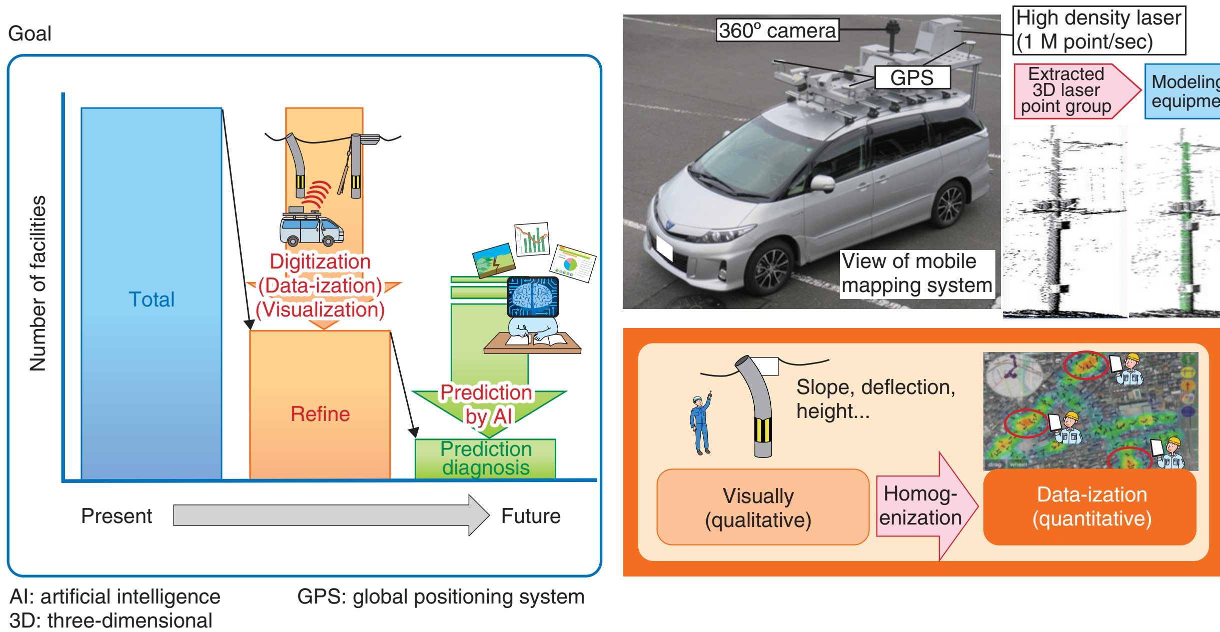

Fig. 1. Inspection technique for outdoor facilities.

deploy optical communication facilities that are more functional and efficient.

AS Labs is striving to achieve operational innovation and facility renovation, which respectively mean simple operation for managing the huge number of facilities and redeployment of network functions in the future. For operational innovation, we are working on improving the operations process so that it will require significantly less manpower by innovatively automating and improving the work flow for existing facilities. Namely, we are using (1) automation technology for equipment inspection work and (2) advanced sensing technology. We aim to implement planned maintenance work before spontaneous breakdowns occur.

In addition to the renovation of facilities, we plan to improve the efficiency of operations work and the fluidization of facility maintenance personnel by achieving greater efficiency of on-site work through (3) one-stop maintenance and (4) simple tasks, when constructing and renewing facilities. Furthermore, in order to support network traffic that continues to expand in the future, we are pursuing R&D aiming to realize (5) an innovative next-generation network represented by multi-core fiber/multi-mode fiber as an ultralarge capacity optical transmission technology.

3. Recent R&D topics

A lot of research is underway to find ways of improving facilities and their operation. The research being done on the five areas mentioned in section 2 is described here.

3.1 Inspection technique for outdoor facilities

I introduce here our inspection technique for outdoor facilities that enables efficient management of the huge number of these facilities. As shown in **Fig. 1**, this technique involves the use of technology that can automatically quantify the state of equipment during inspections and degradation diagnostic work currently underway at all outdoor facilities. In the future, less time and effort will be needed for facility maintenance because automatic diagnosis of damage and prediction of deterioration by artificial intelligence (AI) will reduce the number of unforeseen problems and free maintenance personnel from having to carry out unplanned work.

We will utilize as a feature of the technology a system called three-dimensional mobile mapping system (3D MMS), which carries out space measurement in 3D. This system operates with a GPS (global positioning system) antenna, 3D laser scanner, and a camera mounted on a car. The MMS collects 3D point cloud data, which will be stored in a facility

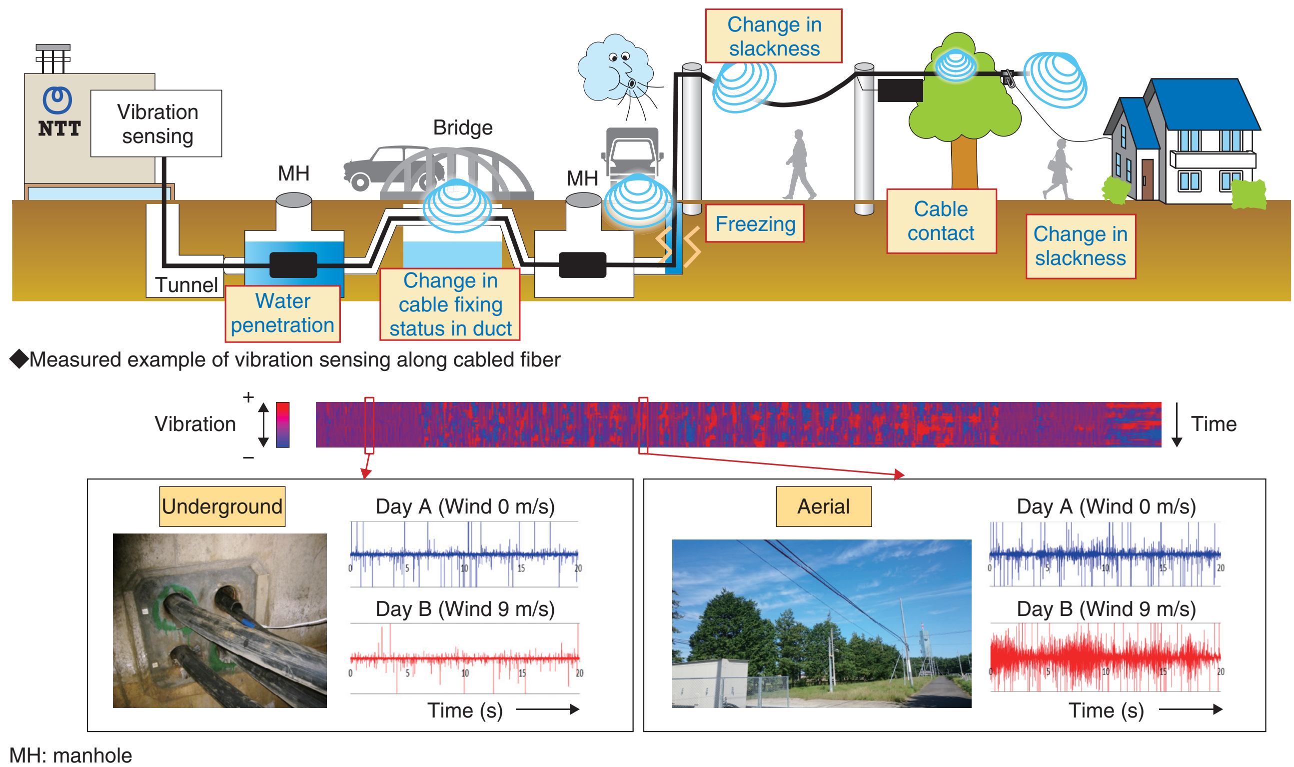

Fig. 2. Optical fiber cable sensing technology for visualizing outdoor equipment.

database. We will first collect point cloud data on equipment such as utility poles, cables, and branch lines. The system will then automatically analyze information such as the tilt and deflection of poles or the height of cables and then extract the facilities that need preferential inspection. The inspection targets will therefore be narrowed down, which will reduce the amount of work time needed for facility management. In the future, we will employ AI diagnosis using information on aging changes or environmental data around facilities to prevent facility faults before they occur. This will improve the reliability of the network and greatly contribute to streamlining facility maintenance operations.

3.2 Optical fiber cable sensing technology

We are also investigating optical fiber cable sensing technology for managing outside facilities by measuring an optical fiber installed as a sensor. In this work, the goal is to achieve the ability to remotely detect equipment abnormalities using acoustic/vibration remote sensing technology (**Fig. 2**). If this technology can be achieved, it will be possible to identify the location of faults or abnormal events such as water penetration into an optical closure, freezing, sagging, or points where cables have come into contact with objects (for example, trees), and we will be able to deal efficiently with the issue and prevent a communication breakdown before it occurs. Predicting failures and implementing plans to replace degenerate facilities will make it possible to minimize the impact on services and to streamline maintenance operations.

To realize facility state estimation, it is necessary to clarify the correlation between the state of deterioration of the facility and the measured result using a vibration or acoustic sensing technique. We will therefore try to elucidate the deterioration mechanism of network facilities in the future. However, since optical fiber is contained within a cable, and the cable has a secure coating, it is not easy to examine the external state of the optical fiber through such a structure. We plan to investigate various estimation techniques to find one that is accurate while also considering a combined approach with other measurement methods.

We are also working on ways to measure the deterioration of the optical fiber itself. In optical fibers

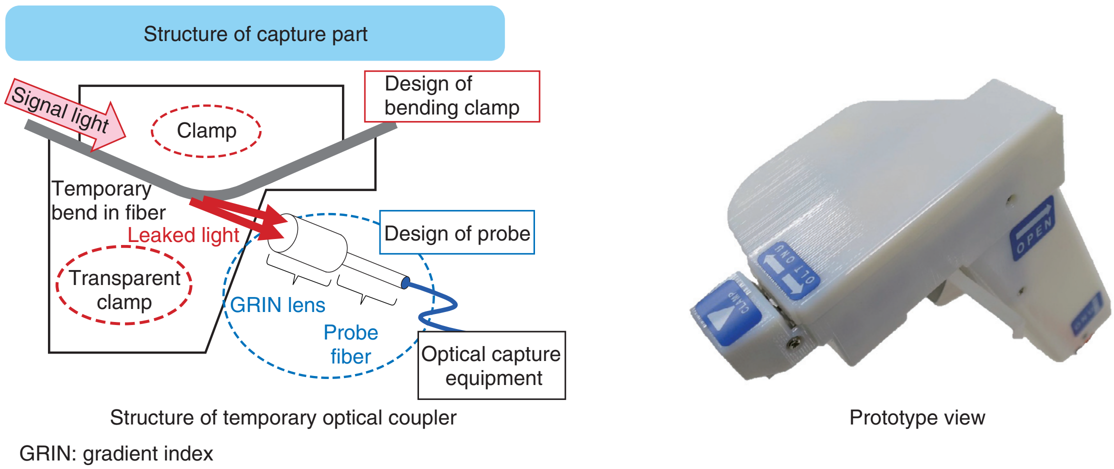

Fig. 3. Capturing MAC address of ONU signal using non-destructive fiber bending technique.

installed in the field, the loss characteristics may gradually increase due to freezing, side pressure, or other factors. The huge quantity of optical fiber already installed for FTTH services is expected to be used for a long time in the future. To efficiently maintain and operate the optical fiber network, it is necessary to be able to accurately measure the deterioration status of every optical fiber and to replace them as necessary.

At AS Labs, we are collaborating with NTT Communications to develop high-sensitivity technology to measure loss in the optical fiber network. The point of this technology is not to use optical pulses in the usual single-mode region wavelength (1260 nm~) but to use optical pulses in the multi-mode region wavelength (near 1050 nm) to measure loss in single-mode optical fiber. This generates back scattering light of a higher-order mode that is sensitive to loss and enables high-sensitivity loss measurement. Although it is now possible to measure loss with high sensitivity, we will continue to develop this technology in the future to predict the life expectancy of optical fiber and to predict deterioration of equipment.

3.3 MAC address capture technology

We are developing media access control (MAC) address capture technology that will achieve greater efficiency of service orders and maintenance operations. When information discrepancies occur between the facility database and the actual facility during service order and maintenance work, many adjustment operations have to be done at the construction site to check the usage status of the optical fiber line. It is possible to maintain an accurate facility database by checking the unique identification address (MAC address) that includes a signal from the optical network unit (ONU). Until now, if we had wanted to monitor the MAC address of an ONU, we would have had to install a monitoring point such as an optical coupler in the optical fiber network.

We are studying a temporary optical coupler that will make it possible to temporarily bend the optical fiber without cutting it, and to leak and input the optical communication signal (**Fig. 3**). This will enable us to capture a transmission signal from the ONU without interrupting services. By reflecting accurate information from such live optical fiber lines to the facility database, we will be able to carry out reliable construction work.

3.4 Fail-safe single-fiber cleaving technique

Here, I introduce a fail-safe single optical fiber cutter that enables connection work to be done on optical fibers without requiring special skills of the maintenance workers (**Fig. 4**). For optical fiber connection, it is necessary to vertically cut the end face of the optical fiber in order to precisely match the optical fiber cores that have a diameter of only about 10 μm. With conventional optical fiber cutters, skilled workers had to periodically carry out maintenance of cutters in order to maintain the optimum cutting conditions. With the fail-safe single-fiber optical fiber cutter, the blade structure has been changed from a metal blade to a plastic one with diamond abrasive grains, and we have also adopted a method that does not apply stress to the optical fiber at the time of cutting.

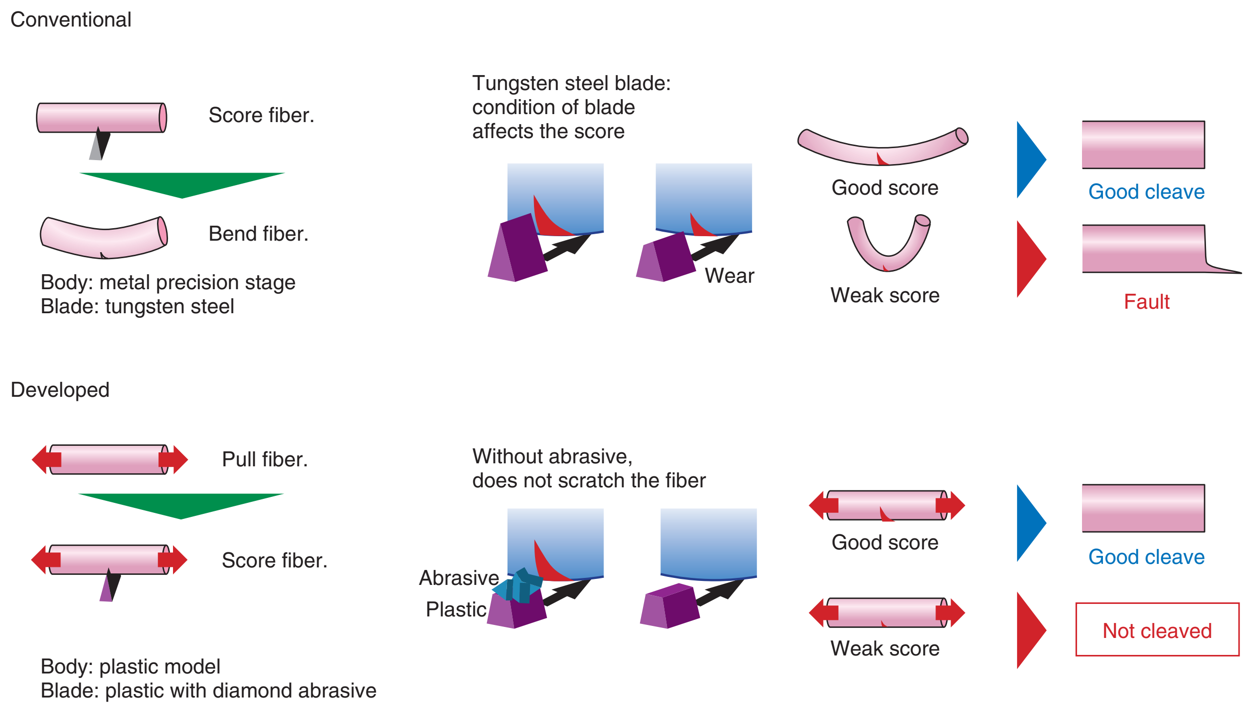

Fig. 4. Fail-safe single-fiber cleaving technique.

This means that if the cutter's condition has deteriorated and cutting cannot be performed normally, the cutter will not break the optical fiber. This prevents the occurrence of cutting failures due to insufficient maintenance of the cutter and improves the reliability of construction.

3.5 Next-generation ultrahigh speed and capacity fiber technology

Finally, I introduce ultralarge capacity fiber technology, which is a mid- and long-term effort to prepare for the explosive growth of future traffic. Until now, the transmission capacity per optical fiber has been dramatically increased by multiplicity and high signal density, for example, by applying TDM (time division multiplexing), WDM (wavelength division multiplexing), and digital coherent technology. However, as the number of multiplexed wavelengths increases, the signal power density per unit area of the optical fiber also inevitably increases, and as the power density of light increases, the occurrence of optical nonlinear effects in the optical fiber—thermal destruction phenomena (fiber fusing)—happens. Therefore, there is a limit to the optical power that can be input to optical fiber. In addition, due to the nonlinear effect, there is a trade-off relationship between the multi-valued level of the signal and the transmission distance, and it is subject to the transmission distance limitation. Therefore, the capacity limit is thought to be up to 100 Tbit/s per optical fiber line in the conventional technology.

Recently, space division multiplexing (SDM) has been attracting interest as a new method to overcome this capacity limit and deal with the future explosive increase in traffic. Various kinds of space multiplexing have been proposed, including multi-core fiber, in which there are multiple cores in a fiber, and multi-mode fiber, in which multiple modes are propagated in a core. In our project, we succeeded in conducting world-first mode-multiplexed transmission experiments and achieved the largest ever number of 114 channels through transmission of 19 cores × 6 modes with a multi-core structure optical fiber. With SDM technology, we will continuously challenge the utmost limits of transmission capacity of optical fiber with the outer diameter of 250-μm multi-core and muti-mode fiber, aiming to achieve ultrahigh density transmission. We will also work to make progress on the practical applications utilizing multi-core fiber with a standard clad outer diameter of 125 μm that is compatible with conventional manufacturing or peripheral (connection and cable) technology

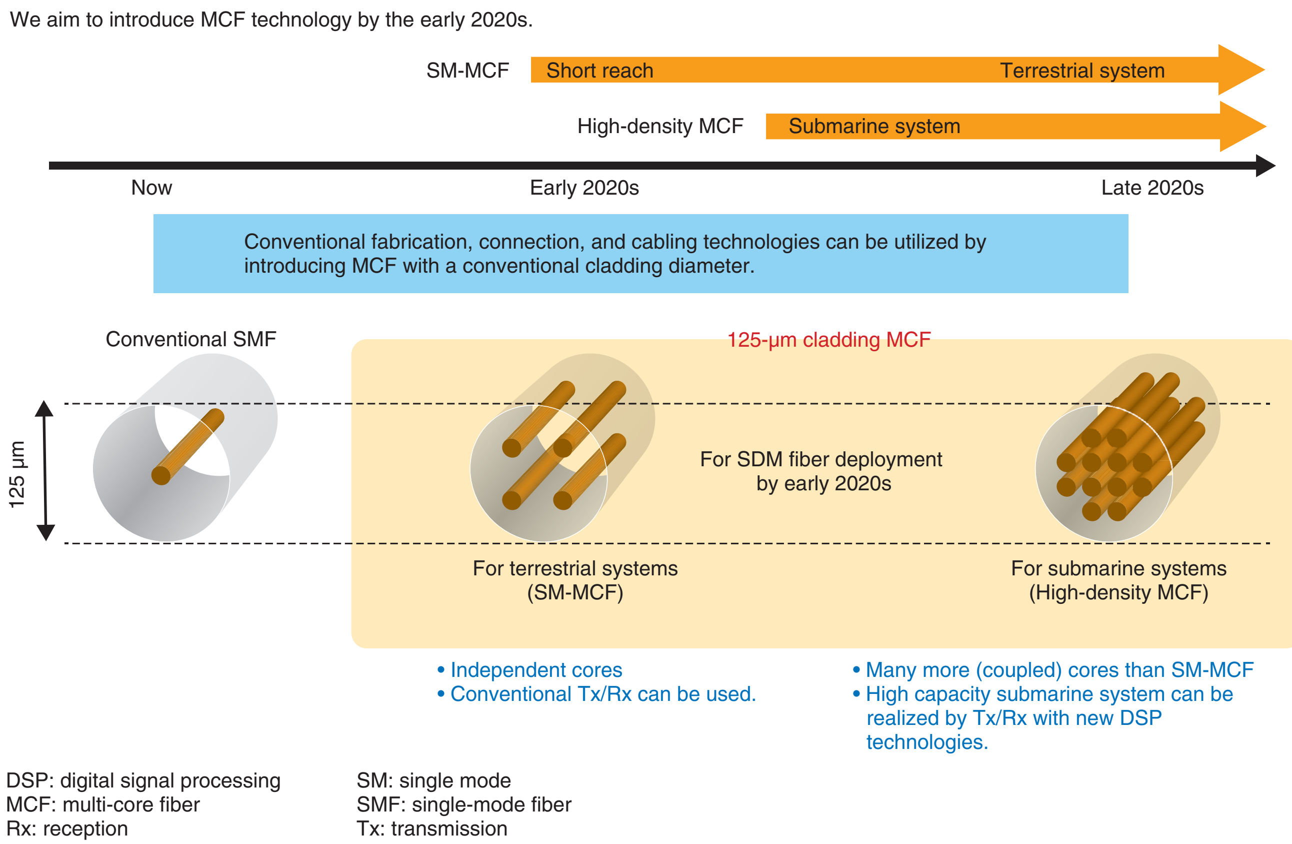

Fig. 5. SDM technology (multi-core and few-mode fibers).

(**Fig. 5**).

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■ **Author profile**

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He received a B.S. and Ph.D. in electrical and electronic engineering from Sophia University, Tokyo, in 1990 and 1995. He joined NTT in 1990, where he worked in the areas of computer vision and sensor fusion. After working at NTT-ME and NTT EAST, he joined NTT Access Network Service Systems Laboratories in 2017, where he has been researching and developing fiber optic cables and their peripheral technologies and access network maintenance and operation technology. He is a member of the Institute of Electronics, Information and Communication Engineers.