R&D of Innovative Optical Transmission Line Technologies

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Abstract

NTT Access Network Service Systems Laboratories is promoting research and development (R&D) on optical transmission line technologies necessary for the sustainable development of communications networks. In addition to R&D on such technologies for achieving efficient and sophisticated optical access networks, in 2019 we started R&D on innovative optical transmission line facilities toward implementation of the All-Photonics Network, which is one of the three key elements of the Innovative Optical and Wireless Network (IOWN) advocated by NTT. This article, which is based on a workshop lecture video-streamed on the Tsukuba Forum 2020 ONLINE website in October/November 2020, outlines the latest developments and future perspectives of optical transmission line technologies.

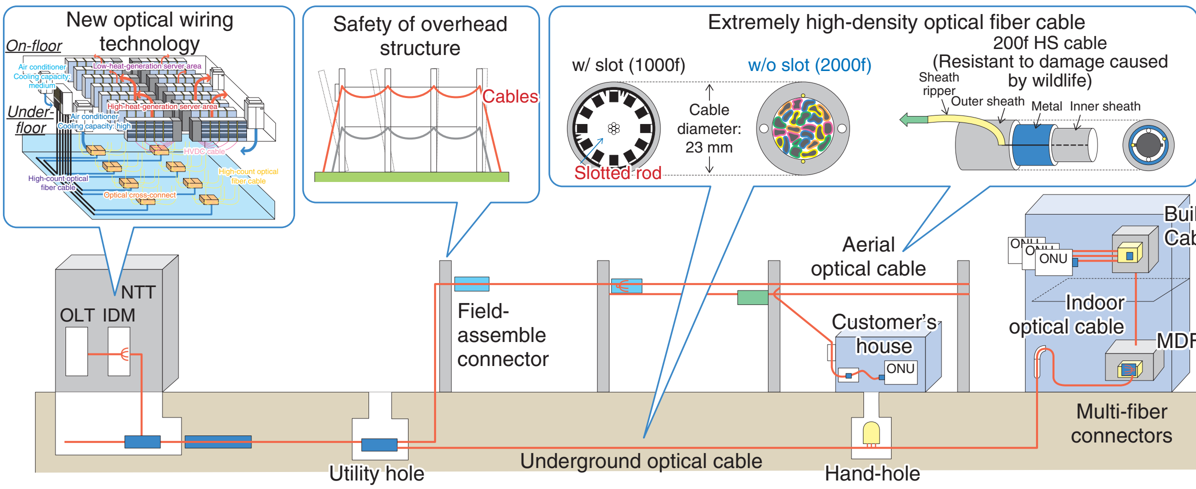
Keywords: optical transmission line, optical fibers and cables, IOWN

1. Promotion of efficient and sophisticated optical access networks

NTT Access Network Service Systems Laboratories has been leading the research and development (R&D) of optical transmission line technologies from fundamental research to practical application development toward sustainable development of telecommunication network services by economizing and upgrading optical access networks. **Figure 1** shows the technologies that make up an optical access network. An optical access network is composed of many products and technologies such as optical fiber cables, optical connectors, and overhead structures. We developed and installed various products and technologies to deploy efficient and sophisticated optical transmission line facilities, e.g., for simplified installation, and intelligent maintenance technologies. This article introduces our recent developments in optical transmission line technologies.

High-density and high-count optical fiber cables have been receiving increasing attention for installing a large number of optical fibers in a restricted space. NTT has proposed and developed an extremely high-density optical fiber cable by using the rollable ribbon and slot-less optical cable structure. By optimizing this cable structure, we developed the world's highest-density optical fiber cable, which is equipped with 2000 fibers with the same cable diameter as a conventional 1000-fiber cable. We have also developed a thin, high-density, high-strength (HS) optical fiber cable that is resistant to damage by wildlife. By applying and modifying the slot-less optical cable structure, we developed a smaller-diameter and lighter-weight cable structure with improved workability, which will become the mainstream for optical fiber cables in all network equipment.

The demand for optical fiber connection in datacenters has increased. Optical wiring conditions under raised floors is often unknown, which induces cable congestion and degrades air conditioning efficiency. NTT developed an estimation method of cable-stacking height by considering the cable type and number of laying cables and established an optical wiring



HVDC: high-voltage direct current
IDM: integrated distribution module
MDF: main distribution frame
OLT: optical line terminal
ONU: optical network unit

Fig. 1. Technologies and current trends in optical access networks.

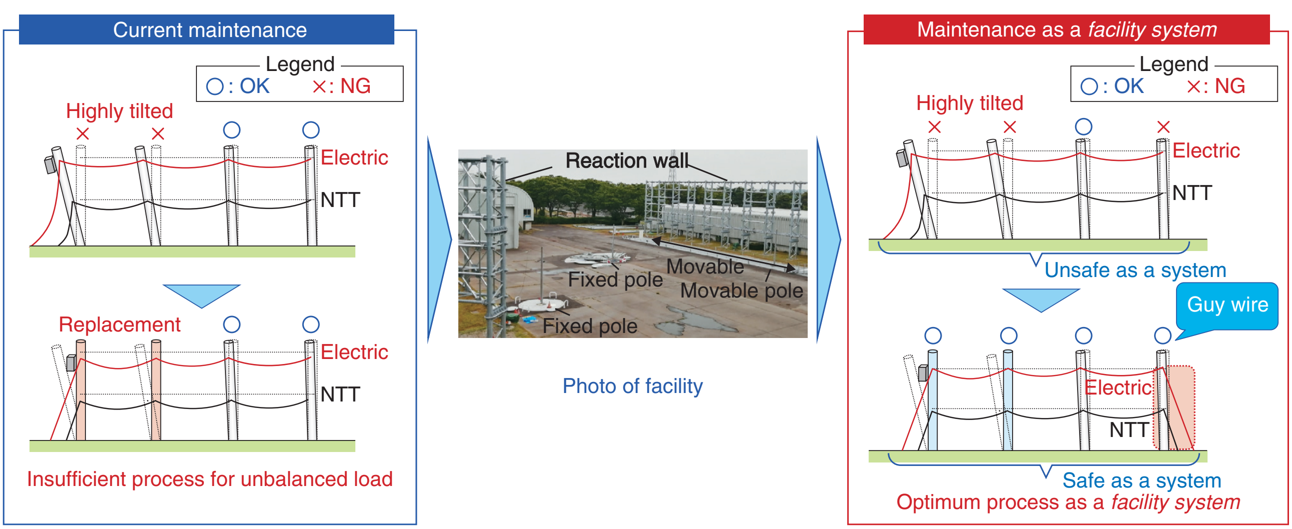


Fig. 2. Overhead Structure Comprehensive Verification Facility.

technology to improve air conditioning efficiency and reduce power consumption.

Next, we describe our efforts in maintenance technology for overhead structures. **Figure 2** shows the Overhead Structure Comprehensive Verification Facility. It has been clarified that unbalanced loads must be considered during the safety evaluation of utility poles, cables, and other components supporting overhead structures, which are considered to be one *facility system* of multiple utility poles connected by various cables. However, as shown on the left in Fig. 2, the conventional maintenance procedure of utility poles and other components do not provide a solution to this unbalanced load. NTT has constructed the Overhead Structure Comprehensive Verification Facility to verify the overhead structure as a facility system. At this facility, which simulates an actual environment, the fundamental cause of

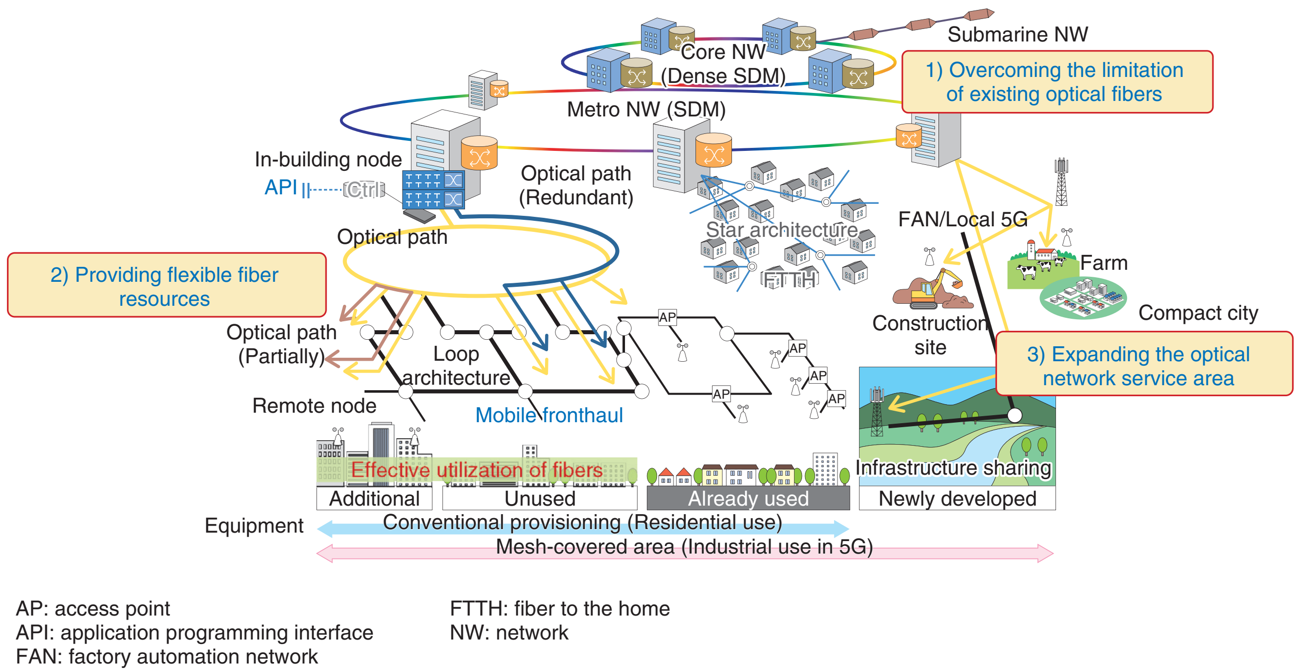


Fig. 3. Future optical transmission line facilities.

unbalanced loads are clarified and optimal measures are devised and implemented, as shown on the right of Fig. 2, achieving long-term safe use of the entire system. This approach is also very effective as a countermeasure against severe natural disasters.

The above are our latest developments in optical transmission line technologies for economization and upgrading optical access networks. NTT Access Network Service Systems Laboratories will continue to develop safe and secure optical transmission line technologies to support the sustainable development of telecommunication network services.

2. IOWN and future optical access networks

In 2019, NTT proposed the concept of the Innovative Optical and Wireless Network (IOWN) to overcome the processing limit and power-consumption increase in the smart society and the delay limit of the Internet. IOWN consists of the All-Photonics Network (APN), which uses photonics technology from networks to equipment to achieve large capacity, low latency, and low power consumption; Digital Twin Computing, which digitizes real space and creates new value in cyberspace; and the Cognitive Foundation, which optimally operates information and communication technology resources that comprise the above two components. NTT Access Network Service Systems Laboratories is conducting R&D to establish innovative optical transmission line technologies needed to implement the APN.

Figure 3 shows the future of the optical transmission line facilities we have proposed. Optical transmission line facilities are premised on long-term use, and it is necessary to ensure technical neutrality and openness for passive optical facilities. It is also necessary to respond to the diversification and advancement of services in a smart society and the development of high-speed wireless communications such as fifth/sixth generation mobile communications systems (5G/6G). To construct optical transmission line facilities that support such next-generation communications services, we established the following three directions and are promoting R&D on the basis of them: “Overcoming the limitations of existing optical fibers,” “Providing flexible fiber resources without restriction of existing architecture,” and “Expanding the optical service area to new destinations.”

With regard to “Overcoming the limitations of existing optical fibers,” there is concern that demand for transmission capacity will increase exponentially every year and that by the late 2020s the required transmission-system capacity will exceed the transmission-capacity limit of existing single-mode fibers

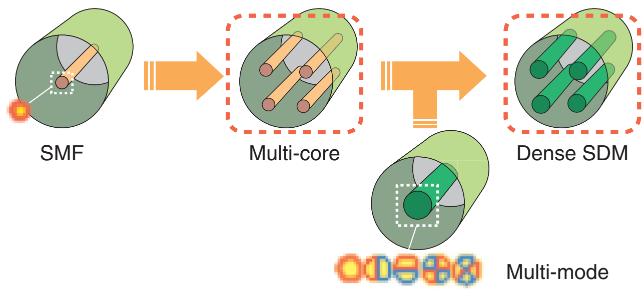


Fig. 4. SDM fibers.

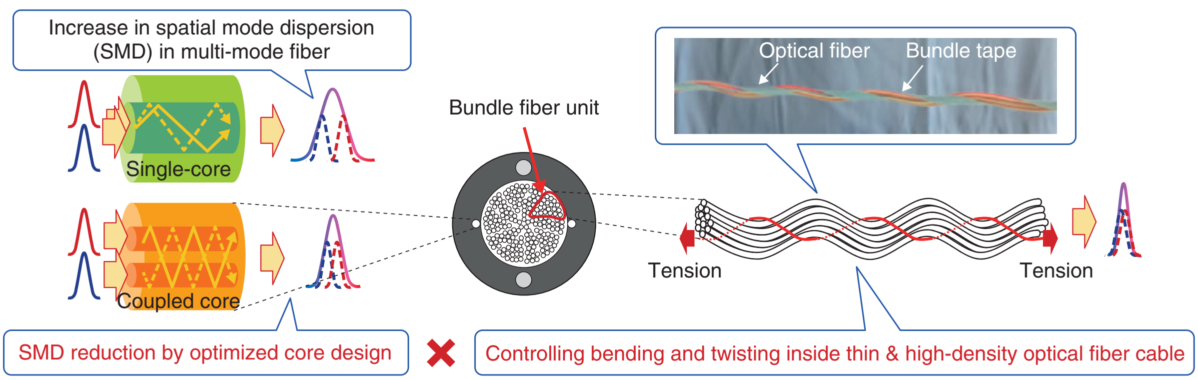


Fig. 5. Controllability of SDM fibers with cable structure.

(SMFs), which is considered as approximately 100 Tbit/s. Space division multiplexing (SDM) technology, which provides the space domain as a new multi-axis in addition to time and wavelength domains, has recently attracted interest worldwide. SDM transmission requires SDM fibers with multiple spatial channels in a fiber. An overview of SDM fibers is shown in **Fig. 4**. SDM fibers are roughly classified into multi-core with multiple core regions, multi-mode with multiple spatial channels in one core, and multi-mode multi-core, which achieves ultrahigh density SDM. NTT has recently proposed an SDM fiber cable that is compatible with existing optical fiber standards and optical equipment and is actively studying methods of accelerating the practical deployment of multi-core fiber lines. We are also conducting R&D on ultrahigh-density SDM optical fiber cable technology and its related technologies to further increase density and capacity.

Figure 5 shows an optical fiber cable with ultrahigh-density SDM fibers. In such SDM fibers, optical signals are generally transmitted while being intermingled between spatial channels and demodulated by signal processing at the receivers. It is known that the transmission-delay difference between spatial channels deteriorates transmission characteristics. We have demonstrated for the first time that the transmission characteristics of an SDM fiber cable can be controlled by the simultaneous optimization of the optical fiber and optical cable structure by minimizing the transmission-delay difference through the structural design of SDM fibers and by controlling their bending and twisting in an optical cable.

With regard to “Providing flexible fiber resources without restriction of existing architecture,” considering the future deployment of 5G/6G base stations, the conventional provision of fiber resources based on household distribution will not be sufficient, and a network configuration that can flexibly provide the necessary amount of fiber resources will be required. It is also important to ensure network reliability by assuming services that do not allow service interruption such as self-driving cars. We have started R&D on an access network design with concatenated loop

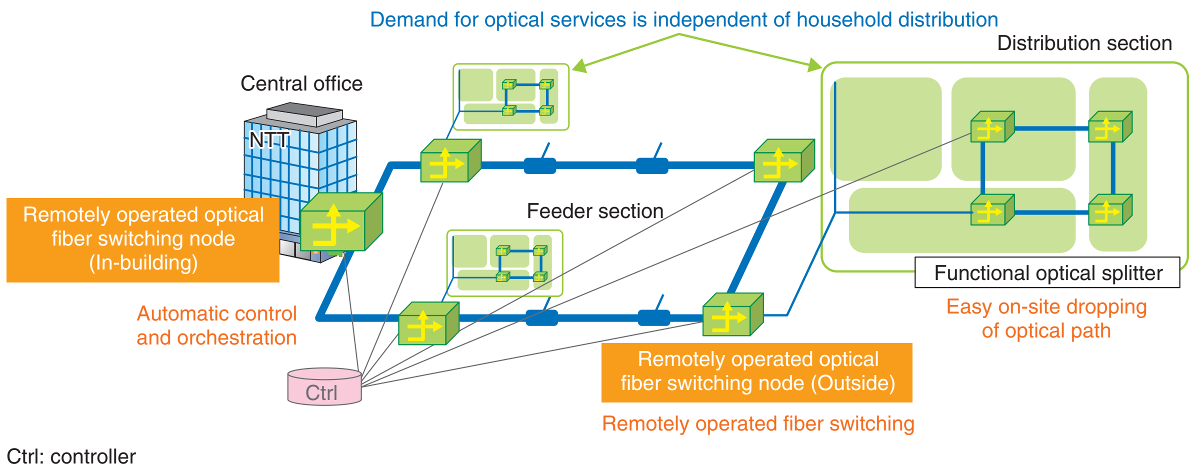


Fig. 6. Optical path switching in optical access network with concatenated loop topology.

topology (**Fig. 6**). This network configuration is equipped with a new remotely operated optical fiber switching node that can switch the optical path remotely at the fiber level. By overlaying this network configuration on the existing access network, it is possible to effectively use the fiber without services and to improve reliability by making the network redundant.

Regarding "Expanding the optical service area to new destinations," 5G base stations will be deployed not only in urban areas but also in rural areas with industrial potential. However, there are rural areas where optical equipment is not provided; thus, a method for economically and efficiently installing optical equipment will be essential. In urban and suburban areas, the expansion of base stations is expected to increase, and in non-residential areas, the demand for optical services is expected to expand. However, the cost burden of installing new optical equipment is particularly high in areas where optical equipment is not yet available. For this reason, we have started R&D on an economical and efficient method of installing optical fiber cables in areas that were not previously considered.

3. Future perspectives

NTT Access Network Service Systems Laboratories is committed to continuous R&D and establishment of safe and secure optical transmission line technologies to contribute to the sustainable development of the information and communications industry. In particular, it is necessary to consider natural disasters, which have become increasingly severe. To actualize IOWN, we are promoting innovative R&D of optical transmission line facilities that can be connected anytime and anywhere as well as smart-facility-operation technologies.

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He joined NTT Access Network Service Systems Laboratories in 1997, where he engaged in research on home area networks. Since 2007, he has been engaged in research on an intermediate session control server, optical line switching system, and optical fiber cable systems. He is a member of the Institute of Electronics, Information and Communication Engineers.