R&D of Innovative Optical Fiber Facility Technologies

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Abstract

NTT Access Network Service Systems Laboratories is promoting research and development (R&D) of optical fiber facility technologies that contributes to the sustainable development of communications networks. This article outlines the R&D of large-capacity and advanced optical fiber facilities for the All-Photonics Network, which is one of the three key elements of IOWN (the Innovative Optical and Wireless Network) concept advocated by NTT. This article also introduces the R&D activities of optical fiber facilities in response to social changes and demands such as the decrease in the working population, diversification of communication services, and reduction in environmental impact.

Keywords: optical fiber facilities, space division multiplexing optical fiber, IOWN

1. Situation surrounding optical access facilities

Network traffic has continued to increase [1] and this trend is expected to continue. In terms of the working population, the number of construction workers at NTT facilities is expected to decrease by about 35% over the next 10 years. We also believe that the requirements for optical access facilities will diversify as communication services diversify from person-to-person communication to object-to-object communication. In response to the demands of environmental management, NTT Group has formulated the "NTT Green Innovation toward 2040" [2] and believes that it is necessary to develop technologies that take into account environmental performance in optical access facilities. In other words, it is necessary to continue to develop optical fiber facility technologies that can respond to the demands of and changes in society.

The All-Photonics Network (APN), one of the three elements of the Innovative Optical and Wireless Network (IOWN) concept, aims to achieve the following three target performances through the introduction of photonics technology from the network to the terminal: 1) low power consumption (power efficiency 100 times), 2) high quality and high capacity (transmission capacity 125 times), and 3) low latency (end-to-end delay 1/200) [3]. From the research and development (R&D) of optical fiber facility technologies, we would like to contribute to achieving these target performances.

2. Space division multiplexing optical fiber cable technologies

We first introduce space division multiplexing (SDM) optical fiber cable technologies. The capacity of optical transmission systems has increased 1000 times in 20 years and has advanced by using time division multiplexing transmission technology and wavelength division multiplexing transmission technology. However, the transmission capacity limit of conventional single-mode fiber (SMF) is about 100 Tbit/s per fiber and soon expected to reach the transmission capacity limit. To overcome this limit, we at NTT Access Network Service Systems Laboratories are promoting the R&D of SDM optical fiber that expands the transmission capacity by setting multiple space channels (number of modes × number of cores) in a single optical fiber. **Figure 1** shows an overview of SDM optical fiber and the flow assumed for its introduction. SDM optical fibers are roughly divided into two types: multi-core fiber (MCF) in which multiple cores are arranged in one fiber, and multi-mode

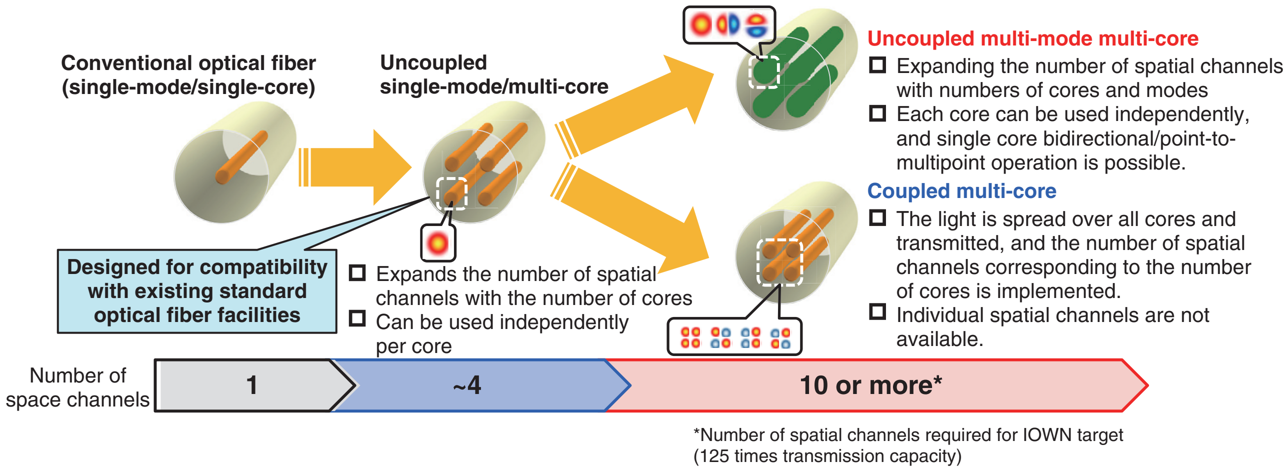

Fig. 1. SDM optical fiber.

fiber in which multiple modes are propagated as signals in one core. These types are further classified into two types: uncoupled, which does not allow signal crosstalk between cores or modes, and coupled, which actively allows signal crosstalk. To introduce SDM optical fiber, we consider uncoupled single-mode MCF as the primary target, considering the expansion of spatial channels and compatibility with existing facilities. However, to achieve the performance target of "125 times the transmission capacity" of the IOWN APN, space channel expansion of 10 or more is considered necessary. There are two types of MCF as candidates for more than ten space channels: uncoupled multi-mode MCF and coupled MCF, and we are promoting R&D on each. When considering the introduction of uncoupled single-mode MCF, by adopting the cladding diameter equivalent to current SMF (standard cladding diameter: 125 µm), it is possible to expect the same optical fiber manufacturability as the conventional one and ensure high compatibility with the current optical fiber equipment such as the use of the existing optical cable structure and optical connector interface. For standard cladding diameter uncoupled MCF, the number of cores is considered to be up to four due to the amount of crosstalk. For such MCF, we developed the design technology of the refractive index profile in accordance with the application area such as short-range network, metro/core network, and long-haul submarine network as with current SMF. **Figure 2** shows the application area of standard cladding diameter MCF and its practical application. A promising application area for such MCF is the area where demand for large capacity or multiple fiber is high such as submarine networks and datacenters in terrestrial networks. Since submarine cables have limited space for fiber accommodation due to their structure, transmission capacity expansion can be expected without increasing the number of cables laid by introducing standard cladding diameter MCF. Since the conduit space of terrestrial fiber cable is limited, transmission capacity expansion can be expected by introducing standard cladding diameter MCF without adding cables and conduits. We decided to begin the practical application of SDM optical fiber from a submarine network to reduce the facility construction cost while continuously expanding the transmission capacity.

To construct a standard cladding diameter MCF cable system, it is necessary to develop peripheral technologies, such as fiber connectors, fiber-fusion splicer, fan-in-fan-out (FIFO) devices for MCF-SMF conversion, and related products such as optical wiring racks/closures and promote technological development considering compatibility and commonality with existing and commercial technologies. A prototype standard cladding diameter MCF cable was laid in a tunnel at NTT's R&D center, and good optical characteristics (connectivity and long-term stability) have been confirmed. We also demonstrated the world's first large-capacity transmission (1.6 Tbit/s/fiber, 10 km) assuming large-capacity datacenter networks under the same field environment [4].

As an example of expanding the application area of standard cladding diameter MCF, we proposed a power-over-fiber system using MCF. A single MCF

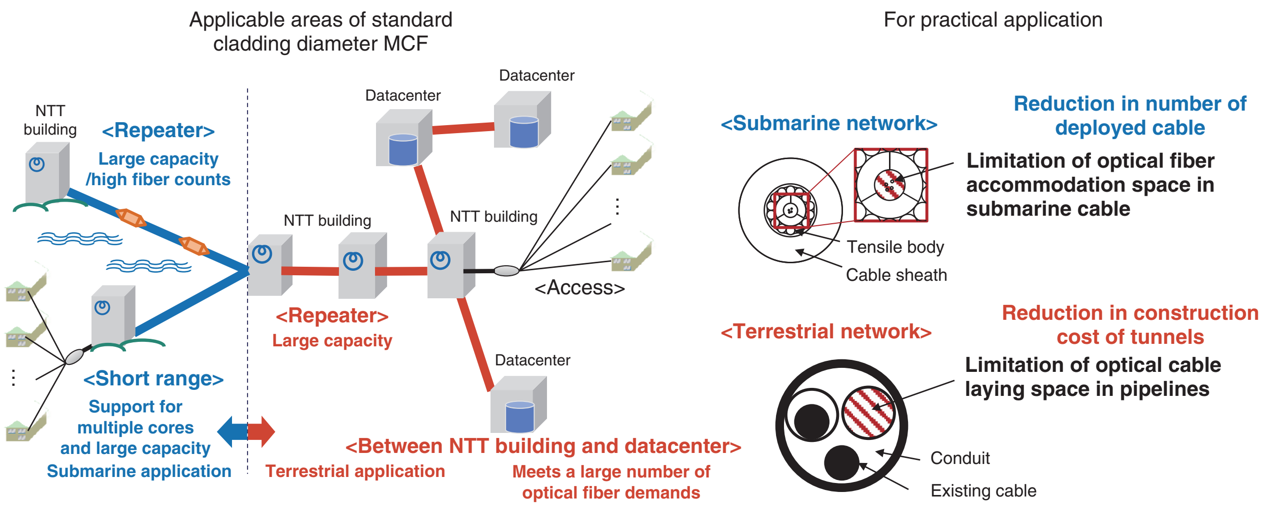

Fig. 2. Application areas of the standard cladding diameter MCF and its practical application.

can simultaneously transmit signal light and feed light and achieves the world's highest optical feeding capability (14 W · km) and optical transmission capability (140 Gbit/s · km) [5].

Uncoupled multi-mode MCF with more than ten channels uses a mode-multiplex transmission line. The technical problem with this line is the signal quality degradation caused by the optical intensity difference between modes caused by the mode deviation of the transmission line loss and that of the optical amplifier. To overcome this problem, we proposed an optical waveguide device that variably compensates for the difference in optical intensity between different modes and demonstrated wide-band compensation of the gain difference generated in a two-mode optical amplifier for the first time [6].

A coupled MCF with more than 10 channels has succeeded in 7280-km optical amplification transmission using 12-core-coupled MCF [7]. We designed and fabricated multi-core optical amplifiers for 12-core-coupled fiber transmission lines and demonstrated for the first time that power consumption can be reduced by 67% compared with conventional technologies [8].

3. Remote-operated optical-fiber-switching nodes

Figure 3 shows the remote-operated optical-fiber-switching node technology that enables remote control of optical path switching operations without any on-site manual work. The remote-operated optical-fiber-switching nodes consist of internal and external nodes, and execute path switching by remotely controlling the external node installed at the path switching point of the optical transmission line from the internal node installed in the communication building. The remote-operated optical-fiber-switching node technology is composed of three elemental technologies: 1) power-over-fiber for remote control, 2) optical cross-connect technology, and 3) optical port monitoring technology. We implemented these three elemental technologies as an optical path switching unit, optical monitoring unit, and remote control unit, respectively, and fabricated an integrated prototype of an external node that enables optical path switching by cooperating with these units. The prototype of an external node is unitized to enhance maintainability, and it is waterproof (equivalent to IPX7) due to the double structure of the inner and outer cases since use in underground maintenance hole is assumed.

4. Flexible optical line construction technologies

With the diversification of communication services, it is expected that a wide variety of terminals, such as Internet-of-Things devices, will be connected to networks. The problem is that many networks need to be built to accommodate this. As a solution to the problem, an optical coupling technology that can branch the optical fiber in communication without cutting the fiber is shown in **Fig. 4**. This technology enables the connection of the terminal to the necessary

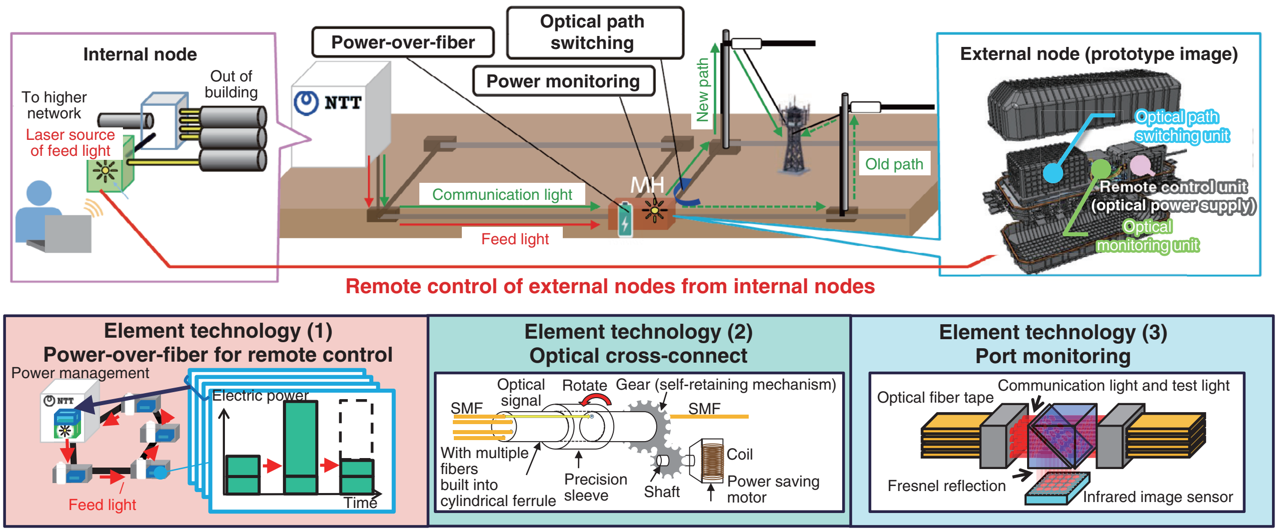

Fig. 3. Overview of remote-operated optical-fiber-switching nodes.

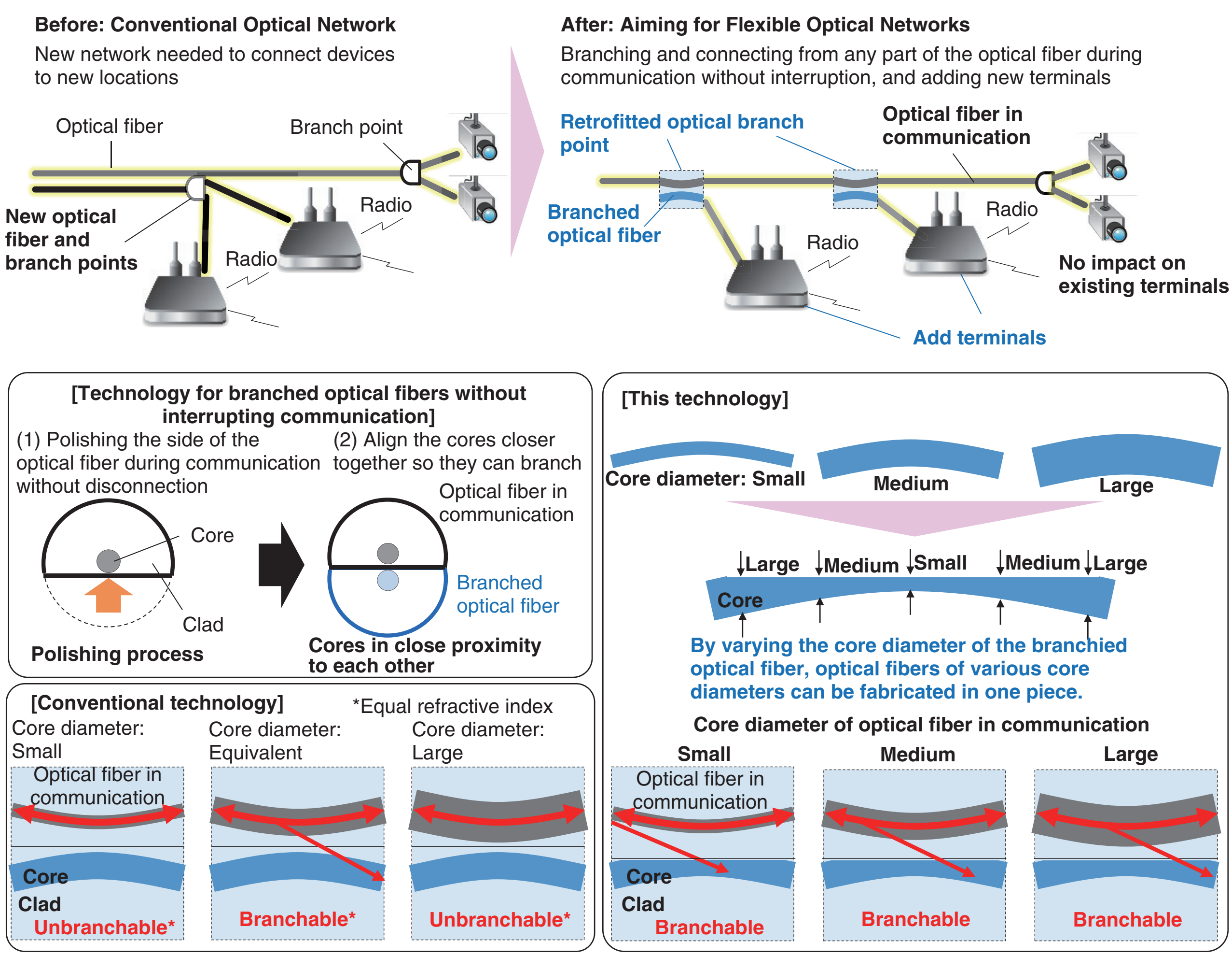

Fig. 4. Optical coupling technology.

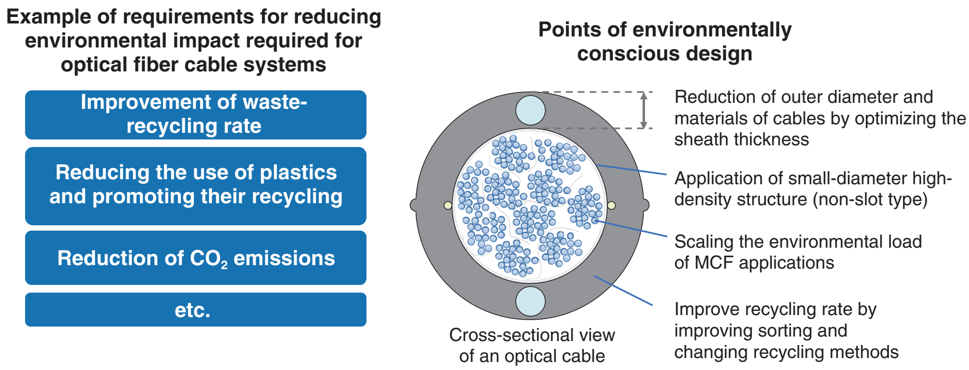

Fig. 5. Environmental considerations for optical fiber cable systems.

place in the existing network at the appropriate timing. The principle of this technology is to polish the side surface of the existing optical fiber to enable communication to the vicinity of the core without affecting communication and bring the pre-polished branched optical fiber and core close to one another to enable optical coupling. This technology has been difficult to use in commercial facilities where optical fibers with different effective refractive indices coexist since it is necessary to use optical fibers with the same effective refractive index for optical fiber in communication and branched optical fiber. To address this issue, we designed and fabricated a branched optical fiber with tapered core diameters and demonstrated for the first time that a single type of branched optical fiber can be used to couple optical fibers with various effective refractive indices [9].

We also developed an optical fiber cable technology for on-road surface wiring without using poles and conduits. Specifically, we developed an optical fiber cable that maintains the basic optical characteristics while achieving both flexibility and reduced diameter and a connector that can easily splice optical fibers. This technology enables cost-effective and rapid laying of optical fiber cables without requiring large-scale construction.

5. Environmentally friendly optical fiber cable technologies

Figure 5 shows an example of the requirements for reducing the environmental impact required for optical fiber cable systems and points of environmentally conscious design. To reduce the environmental impact of optical fiber cables, it is necessary to reduce the amount of plastic used and disposed of, improve the recycling rate, and reduce carbon dioxide (CO_2) emissions. To meet these requirements, it is important to achieve a good balance of conventional reliability, workability, economy, and environmental performance. The key point in designing optical fiber cables considering environmental impact is to examine the entire life cycle by changing the cable structure (slot structure → high-density structure), changing the fiber type (SMF→MCF), and changing the recycling method. High-density optical fiber cables with a small diameter have been developed to improve the economic efficiency and workability of cables and reduce environmental impact. From the viewpoint of reducing environmental impact, the use of plastic parts can be reduced by approximately 30% compared with conventional slot-structure fiber cables, and CO_2 emissions over the entire life cycle can be reduced by 35%. The high-density optical fiber cable has been extended from the access section (overhead and underground) to the special section (bird and insect damage section) and the repeater section (underground). By expanding the use of the high-density cable structure, the effect of high density is maximized, and the development of cables with excellent environmental characteristics and unification of peripheral parts and skills can be expected.

By using SDM optical fiber, the number of optical fibers can be greatly reduced compared with current SMF cable if the number of cores is the same as that of an optical fiber cable. In addition to saving resources, CO_2 emissions can be reduced throughout the entire life cycle by reducing energy consumption during manufacturing and disposal.

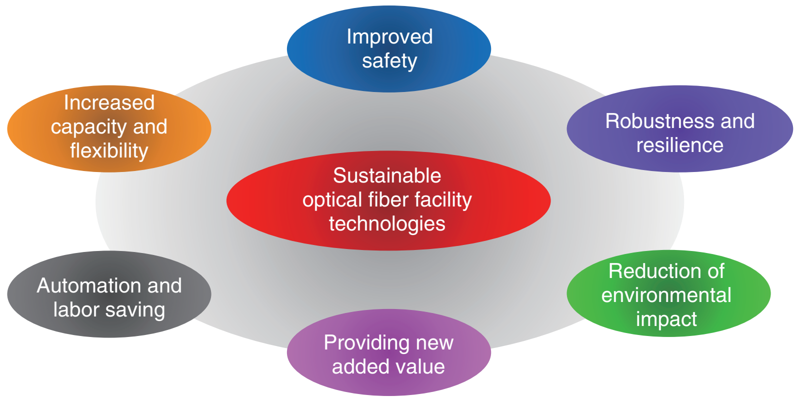

Fig. 6. Future perspectives for R&D of optical fiber facility technologies.

6. Future perspectives for R&D of optical fiber facility technologies

The future perspectives for R&D of optical fiber facility technologies are shown in **Fig. 6**. We will promote R&D to develop sustainable optical fiber facility technologies that can continue to respond to the advancement and diversification of services, maintain communications services in the face of a declining workforce and disasters, and protect resources and the environment.

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