Optical Full-mesh Network Technologies Supporting the All-Photonics Network

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Abstract

This article introduces the concept of an optical full-mesh network for achieving ultra-low-latency transmission of diverse and large-capacity content in ultra-realistic services and the technologies underlying this network. It also introduces a demonstration of 8K uncompressed video transmission in a large-capacity optical transmission system as an embodiment of the optical full-mesh network concept.

Keywords: ultra-low latency, full-mesh network, large-capacity optical transmission

1. Introduction

NTT laboratories aim to provide ultra-realistic services [1] that break through the time-space wall by enabling the real-time sharing of not only ultra-high-definition video information but also diverse content that includes information conveyed through the five senses such as touch and hearing. However, providing such services to a large number of people will require a network that can transmit diverse and large-capacity content with low latency. To this end, our aim is to achieve the innovative All-Photonics Network (APN) based on photonics technology as a part of NTT's Innovative Optical and Wireless Network (IOWN) [2]. Researchers at NTT Network Service Systems Laboratories, NTT Network Innovation Laboratories, NTT Network Technology Laboratories, and NTT Access Network Service Systems Laboratories are studying an optical full-mesh network as a means of achieving a large-capacity, low-latency transport function for the APN.

2. Concept of optical full-mesh network

In a conventional network, accommodating content to be transmitted requires data compression due to restrictions in the communication line capacity, conversion to Internet protocol (IP) packets for routing control by the IP protocol, and packaging of the data in Ethernet frames for multiplexing/switching control. These requirements generate latency due to data-compression processing, packet-queuing processing, etc., thus have been the dominant factors in communication latency between terminals.

In contrast, the optical full-mesh network shown in **Fig. 1** provides end-to-end optical paths for each service by directly connecting the optical access network and optical backbone network through a

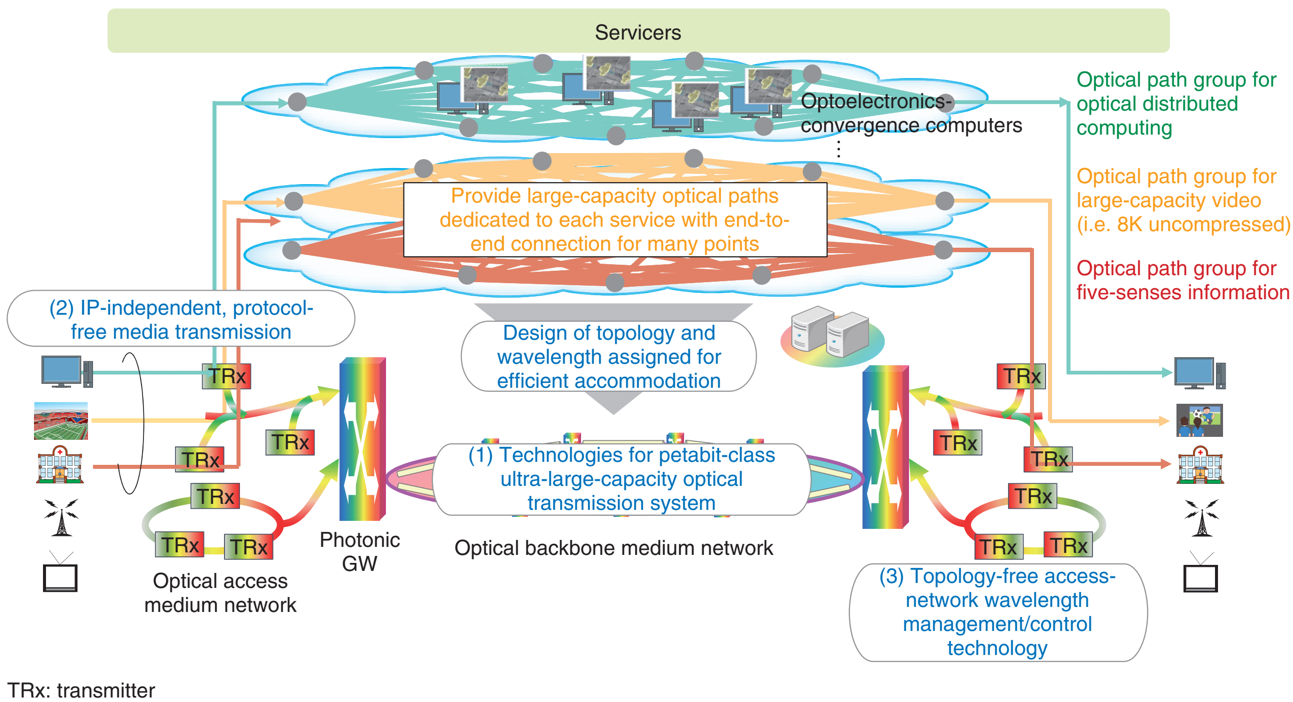

Fig. 1. Overview of optical full-mesh network.

photonic gateway (Ph-GW) that minimizes electronic processing for packet conversion, multiplexing/switching control, etc. This scheme eliminates the latency associated with data compression, packet-queueing processing, etc., which enables to provide a large-capacity and ultra-low-latency network.

3. Key technologies for optical full-mesh network

The following three key technologies are being extensively studied for optical full-mesh network.

(1) Technologies for petabit-class ultra-large-capacity optical transmission system

With the aim of deploying a petabit-class ultra-large-capacity optical transmission system, optical system architecture is being studied based on high-speed optical signal technology, multi-band transmission technology for transmitting wavelength-multiplexed signals over multiple wavelength bands, and spatial multiplexing transmission technology for transmitting optical signals over new types of optical fiber such as multicore fiber. Please see the article "Ultra-high-capacity Optical Communication Technology" in this issue [3] for details on the device technologies supporting these ultra-large-optical transmission systems.

(2) IP-independent, protocol-free media transmission technology

We are studying the transmission technology of diverse types of media data including uncompressed video/audio, the five senses, and emotions as an elementary stream unconcerned with protocol, interface type, and format. Our goal is to achieve large-capacity and ultra-low-latency media transmission via end-to-end optical paths connected by IP-independent path control. Various types of signals, such as 4K/8K uncompressed video signals that flow through serial digital interface (SDI)/high-definition multimedia interface (HDMI) cables, audio signals that flow through multichannel audio digital interface (MADI)/Audio Engineering Society (AES) cables, and peripheral component interconnect (PCI) bus signals that flow among storage, memory, and network interfaces, will be directly accommodated in the all-photonic media transmission paths. To begin with, we have set out to develop interface technology to accommodate SDI signals on optical paths. Although SDI is used to connect video equipment within a broadcast station, our interface technology will enable users to make a connection with a remote location in the same manner as that within a broadcast station without considering transmission protocol, path control, etc. The real-time outside broadcasting of sporting events, concerts, etc. currently requires the dispatching of outside broadcasting vans carrying editing crews and editing equipment. IP-independent and protocol-free media transmission technology will provide an efficient production workflow (remote production) using uncompressed video/audio transmitted from the event venue via an end-to-end optical path. We can envision totally new applications as seen above.

(3) Topology-free access-network wavelength management/control technology

Achieving the APN that provides end-to-end optical paths with diverse user equipment requires remote management/control of wavelengths that user equipment transmits/receives for each optical path. In this regard, studies are underway on wavelength management and control in the access area as one of the main functions of the Ph-GW that connects the access area with a local full-mesh area. To prevent duplication of wavelengths among optical paths that share the same transmission medium, the Ph-GW interacts with the upper-level system that allocates wavelengths to assign wavelengths to each unit of user equipment. It also sends wavelength control instructions to user equipment and performs regular wavelength monitoring. User equipment, in turn, sets the optical transceiver wavelength according to the wavelength control instructions received from the Ph-GW. In this regard, a method is being studied for sending wavelength control instructions from the Ph-GW to user equipment by superposing the management/control signal on the same wavelength as the user signal but in a low-frequency band as an auxiliary management and control channel (AMCC) to prevent interference. The aim is to use an AMCC as a means of achieving an optical network that any type of user equipment can immediately connect to as long as the equipment can connect to optical fiber irrespective of any communications protocol, optical modulation scheme, or network topology.

4. Demonstration: 8K uncompressed video transmission in a large-capacity optical transmission system

We conducted a demonstration to show the effectiveness of an optical full-mesh network based on the key technologies described above. First, we constructed a prototype optical transmission system with a capacity of 0.24 Pbit/s per fiber (approximately 30 times the capacity of current commercial systems) as a large-capacity optical transmission system supporting an optical full-mesh network. In conjunction with this system, we developed a state-of-the-art real-time transponder capable of generating 600-Gbit/s/λ optical signal. As shown in **Fig. 2**, up to 100 wavelengths of the above 600-Gbit/s/λ optical signal was high-density wavelength-multiplexed over the C-band and L-band. We also applied spatial multiplexing technology based on a prototype multicore fiber with four cores to transmit wavelength-multiplexed signals using all four cores. We achieved a large-capacity optical transmission system by using these key technologies.

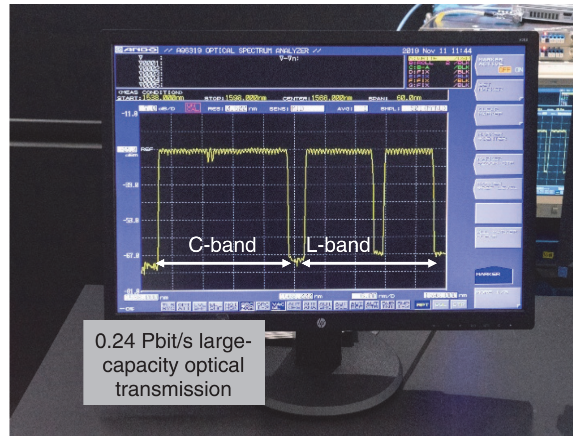

Fig. 2. Optical spectrum of large-capacity transmission system.

In the demonstration, we transmitted 8K video over a 600-Gbit/s/λ optical path using the optical transmission system. This large-capacity optical path enabled real-time transmission of 8K video without compression. We also transmitted 8K compressed video over the same optical path for comparison purposes. The 8K uncompressed video, which is shown on the right in **Fig. 3**, showed no degradation in image quality and achieved low latency about 1/30 that of the 8K compressed video. Further research of IP-independent media transmission technology will enable even further reduction in transmission latency.

5. Future outlook

This article introduced the concept of an optical full-mesh network for ultra-low-latency transmission of diverse and large-capacity content and the technologies needed for deployment. An optical full-mesh

Fig. 3. Transmission of 8K video content.

network can be applied to networks requiring low latency such as those for financial and medical-care systems and can provide stress-free communications unconstrained by bandwidth and transmission delays. Going forward, our aim is to achieve early development of elemental technologies while taking into account network requirements in various application fields.

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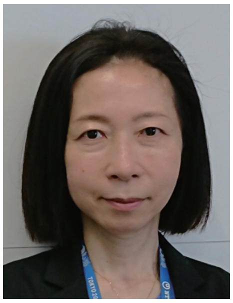

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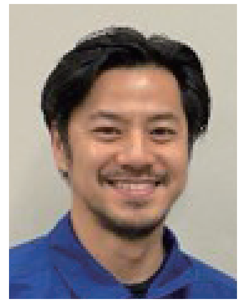

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