Optical Node and Switch Technologies for Flexible and Economical Networks

Mitsunori Fukutoku, Yasuhiro Sato, and Senichi Suzuki

Abstract

Network traffic is increasing rapidly, and high-performance optical nodes are needed to build networks that can handle it with flexibility and efficiency. This article introduces the latest technical trends in this area, including reconfigurable optical add/drop multiplexer (ROADM) technology, which is used to implement advanced optical nodes, and optical switching technology, which is the basis for the primary devices used for ROADM.

Keywords: ROADM, optical switch, optical node

1. Introduction

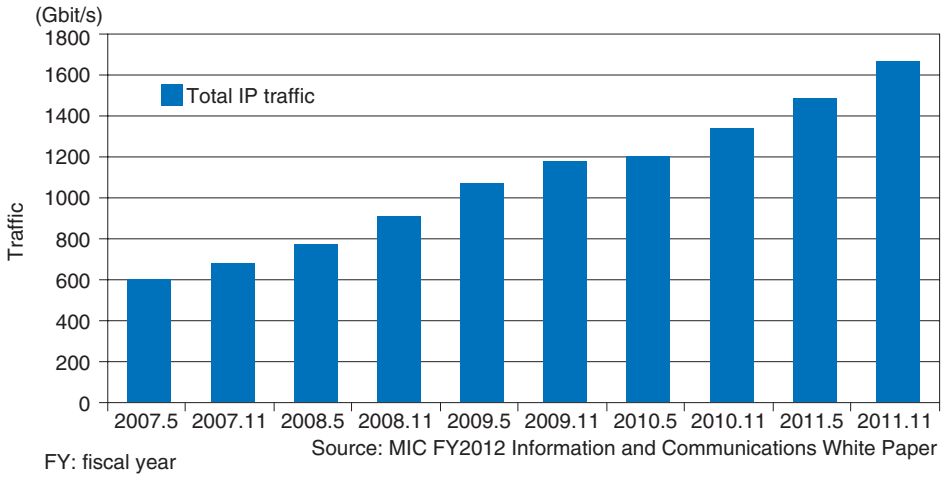
The Internet and various other network services were developed based on their use via personal computers (PCs). However, with the spread of smartphones and tablet PCs, such services have become even more common and have permeated broadly into our lives. NTT's research laboratories have continuously engaged in research and development (R&D) of optical networks as a base technology for providing network services. Domestic and international Internet traffic figures are shown in **Figs. 1** and **2** [1], [2]. As network services have expanded, traffic has increased by a factor of approximately 1.4 each year. In the future, the use of smartphones and tablet PCs will continue to spread, but various other items in our daily lives will also become *networked* devices, or in other words, devices that are always connected to the network and that generate data without human intervention, and communicate machine-to-machine (M2M). When such an environment is realized, the data traffic passing through optical networks will surely increase further still. It has been estimated that global traffic on the Internet will triple over the five-year period from 2012 to 2017 [2]. Such rapid increases in network traffic will require optical network systems, especially long-haul and metropolitan area systems that concentrate data traffic, to accommodate the yearly increases with flexibility, efficiency, and economy.

The latest optical transport technologies achieve ultrahigh-speed communication at 100 Gbit/s on a single channel using digital coherent technology by combining coherent transmission, which uses wave properties widely used in wireless networking, and digital signal processing (DSP) technology [3]. In addition to conventional high-density optical wavelength division multiplexing (WDM), which uses fixed frequency intervals, research has begun on the use of optical frequencies with higher information density for high-capacity, ultrahigh-speed optical network systems [4].

2. Advanced optical node technology for optical networks

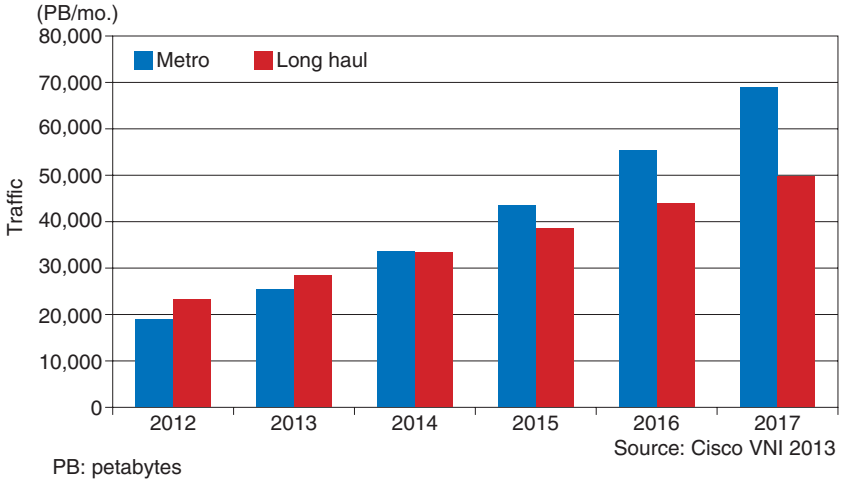
2.1 WDM technology

Similarly, optical cross-connect technology uses high-density WDM technology to achieve flexible and economical optical networking systems. The changes in optical network system architectures over the years are shown in **Fig. 3**. These networks began with point-to-point connections, which realized high capacity through optical signal WDM, and progressed



FY: fiscal year
IP: Internet protocol
MIC: Ministry of Internal Affairs and Communications

Fig. 1. Internet traffic in Japan.



PB: petabytes
VNI: Visual Networking Index

Fig. 2. Global Internet traffic.

through single-ring configurations using reconfigurable optical add/drop multiplexers (ROADM) able to add and drop individual optical signals, to the current economical optical network systems in multi-ring configurations using multi-degree ROADM.

An illustration of ROADM is shown in **Fig. 4**. Input optical signals can be dropped or added, and paths can be selected without converting optical signals to electrical signals. This allows ring network systems to be constructed economically. An example of a basic two-path ROADM configuration is shown in Fig. 4(a). Optical multiplexers and demultiplexers separate multiple wavelengths, and an optical switch adds or drops signals according to the wavelength. Signals can be added and dropped without converting them from optical to electrical, enabling high-capacity optical paths to be provided economically. The optical switches used for ROADM use quartz planar lightwave circuit (PLC) technology, which was first used in components such as optical multiplexers, demultiplexers, and splitters, and is very reliable since there are no moving mechanical parts [5].

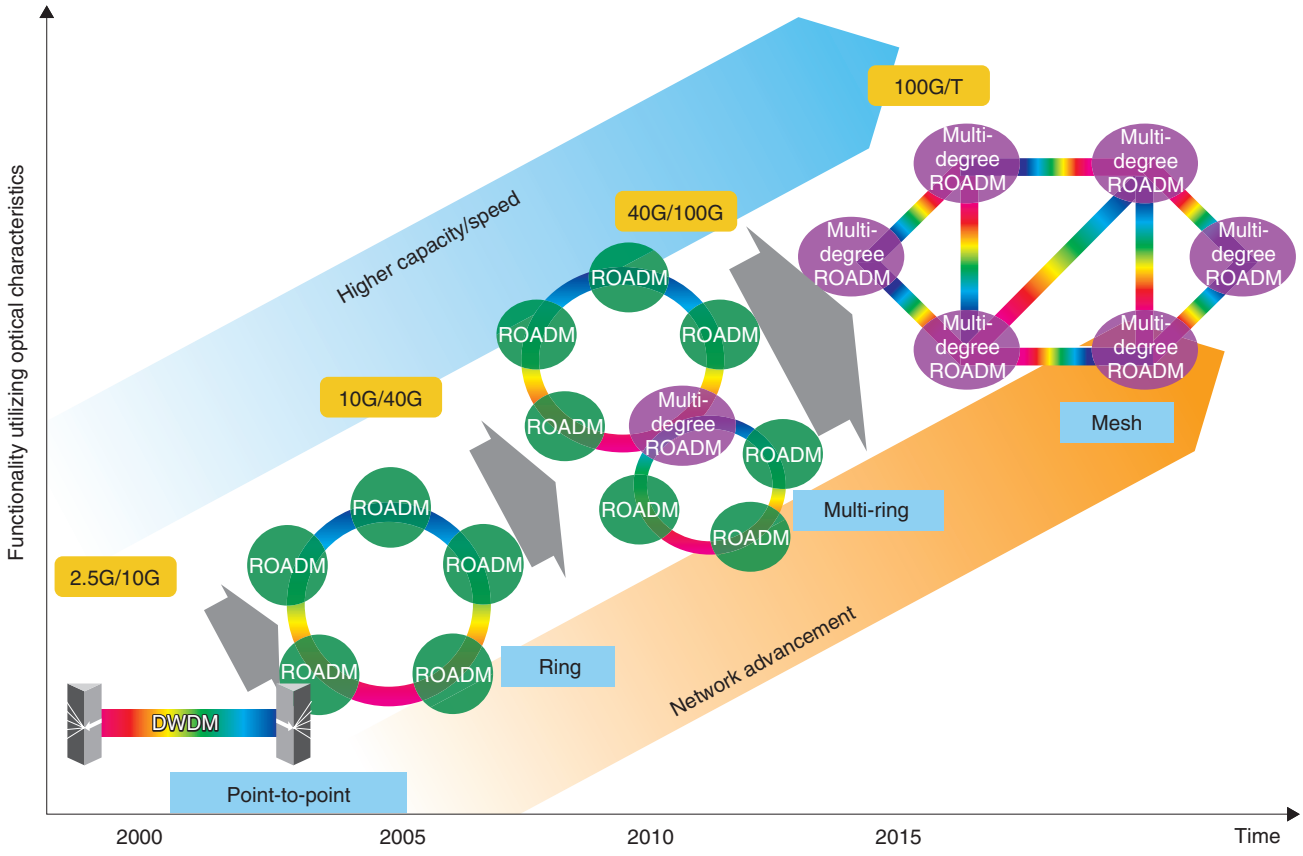
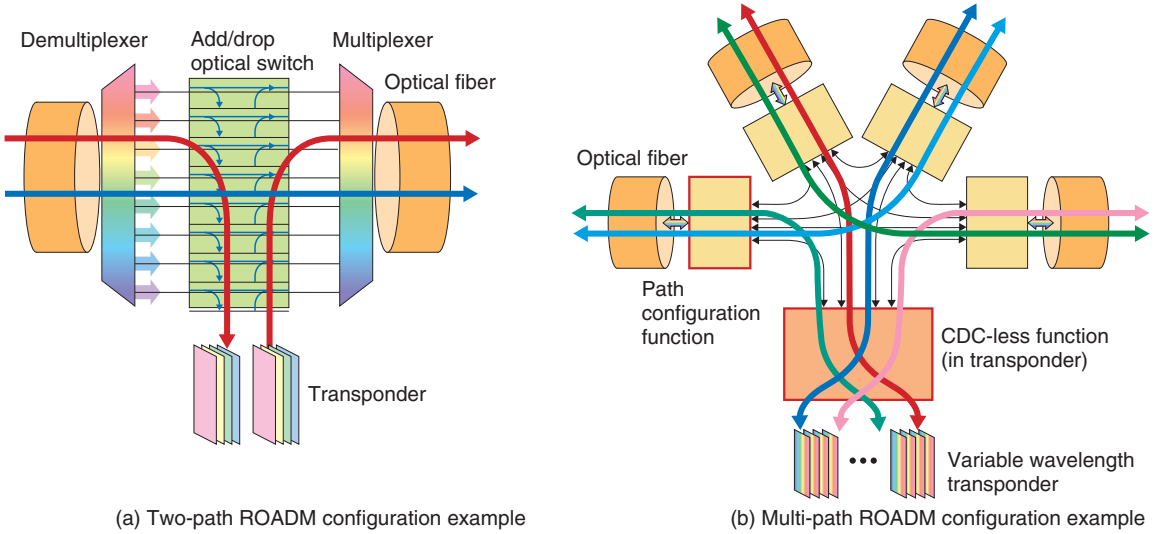


Fig. 3. Optical Network Development.



(a) Two-path ROADM configuration example

(b) Multi-path ROADM configuration example

CDC: colorless, directionless, and contentionless

Fig. 4. ROADM configuration examples.

2.2 CDC technology

An example of a multi-port ROADM configuration implementing a multi-ring mesh network is illustrated in Fig. 4(b). As shown in the figure, with multi-port ROADM, signals carried by multi-path fibers are not converted to electrical signals, and paths can be changed, dropped, or added (optical cross-connect operations) according to wavelength. Currently, in addition to path changes, drops, and adds, even more advanced optical cross-connect operations using ROADM are being studied. With ROADM thus far, the wavelength or path has been fixed for each transponder (the optical transmit/receive interface). Colorless, directionless, and contentionless (CDC) functions are being studied that will enable implementation of flexible and economical network systems in which wavelengths and paths can be configured freely, faults can be switched out by wavelength, and optical paths can be configured remotely. ROADM using CDC functions is called CDC-ROADM. Here, *colorless* refers to functionality that allows input and output wavelengths on ports to be allocated freely through the addition of a variable wavelength function to the demultiplexing and multiplexing filters. The transponder wavelengths can be changed without having to physically switch connections. *Directionless* refers to functionality whereby the directions of input and output paths can be configured freely rather than being fixed by creating switches comprised of transponders. *Contentionless* refers to functionality in optical nodes implementing the previous two functions whereby any wavelength can be allocated to other paths with no restrictions on wavelength configuration. These functions enable signals to be configured freely. CDC-ROADM is described in detail with configuration examples implementing this functionality in the Feature Article entitled, "Next-generation Optical Switch Technologies for Realizing ROADM with More Flexible Functions [6]."

2.3 WSS technology

Currently, the main device used in multi-degree ROADM as a path-configurable switch is the wavelength selective switch (WSS) utilizing spatial optics technology. Wavelength-multiplexed input signals are demultiplexed using a diffraction grating, and add, drop, and path selection operations are implemented without converting signals from optical to electrical. This is done using spatial light modulators such as microelectromechanical systems (MEMS) mirrors or liquid crystal on silicon (LCOS) devices to configure paths by wavelength. It is now possible to implement multi-path path selection using MEMS mirrors or LCOS, and multi-ring optical networks have been implemented with the development of this optical switching technology. Details of WSS are introduced in the Feature Article entitled, "WSS Module Technology for Advanced ROADM [7]."

Several methods for implementing CDC functionality have been studied. One such method uses multicast switches using PLCs; these switches have a simple structure that can be implemented in compact form. The Feature Article entitled, "Multicast Switch Technology that Enhances ROADM Operability [8]," introduces the functions enabled in transponders.

3. Topics covered in Feature Articles

As discussed above, advances in ROADM are necessary in order to implement networks that are able to deal with the increasing traffic flexibly and economically. Currently, NTT Network Innovation Laboratories, NTT Microsystem Integration Laboratories, and NTT Photonics Laboratories are collaborating on optical-switch R&D in order to realize highly advanced ROADM. These Feature Articles introduce the initiatives underway at these three laboratories. First, CDC-ROADM, which is necessary for highly operable and reliable optical networks, is described using practical examples. Then, WSS, which realizes the per-wavelength path configuration function of ROADM, is introduced. MEMS WSS is taken as an example of WSS, and technologies required to implement it are explained, including optical design, implementation design, and control function technologies. Finally, we describe a multicast switch technology that uses PLC technology to implement CDC functions.

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