Next Generation Optical Transport Technology

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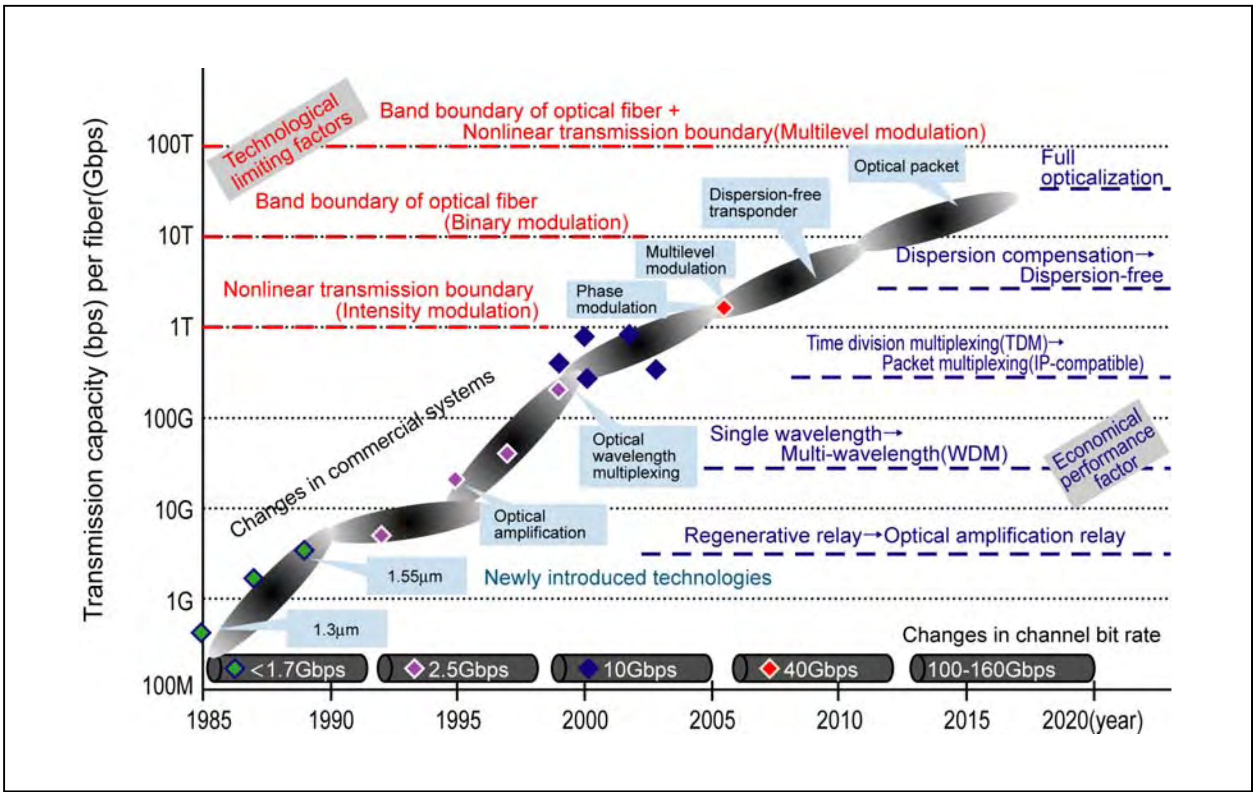
Abstract

The transmission capacities of the optical transport technology commercialized for core network applications in the 1980s has been developed remarkably both for submarine and land systems due to the optical amplifier technology and optical wavelength multiplexing technology developed in the 1990s. With the opticalization of the access network in the 2000s, almost all of the networks have entered the age of optical communications. This paper outlines the optical transmission technologies that support the development of these networks together with the technological trend in the future.

The figure shown below represents the road map of optical transport technologies.

For opticalization of the access systems, one-to-N connection topology with optical splitters installed along the transmission route is applied. The technologies used for this arrangement include instantaneous bit synchronization and high-speed automatic gain control (AGC) technologies for burst transmission and avalanche photo diode (APD) receiving technology for the expanded dynamic range.

As for the technologies related to the metro and core networks, the phase modulation technology and multilevel modulation technology shown in the figure have been studied. The technologies are considered effective for overcoming the difficulty that the distance of optical transmission at 10 Gbps or higher is limited due to wavelength dispersion and polarization dispersion of optical fibers.



Roadmap of Optical Transport Technologies

This figure shows the roadmap of optical transport technologies. The technologies were introduced for the marine and land core networks in the 1980s. Then, optical amplification and wavelength multiplexing technologies remarkably increased the transmission capacities. The technologies were also introduced in the access systems, thus realizing FTTH in the 2000s. Expansion of metro and core network transmission capacities has been increasingly demanded due to the influence of the achievement with the access systems. New technologies such as phase modulation and multilevel modulation are expected to serve the applications.

**Information Technology R&D Center   **Communication Networks Center*

1. History and Technological Trends of Optical Access System

In Japan, optical fiber was first introduced in the trunk line network in the 1980s and optical amplifiers and optical wavelength multiplexing technology were introduced to promote the opticalization of metro and core networks in the late 1990s, with the long-distance transmission capacities of the networks remarkably increased.

At the beginning of the 1990s, optical fibers were introduced in the access network for increased economic efficiency obtained by multiple subscriber access and multiple service distribution. Then, in the 2000s, the passive optical network (PON) of 1Gbps was standardized [1] to prevail as FTTH in Japan in particular.

Figure 1 shows the configuration of the networks. This paper outlines the optical transmission technologies which have supported the evolution of these networks and the future of the networks. For details concerning respective technologies, refer to the references indicated in the text below.

1.1 Configuration of networks

The GE-PON method is employed for the access network. For details on the configuration, etc. refer to each report included in this issue. The trend in optical transmission technologies is introduced here.

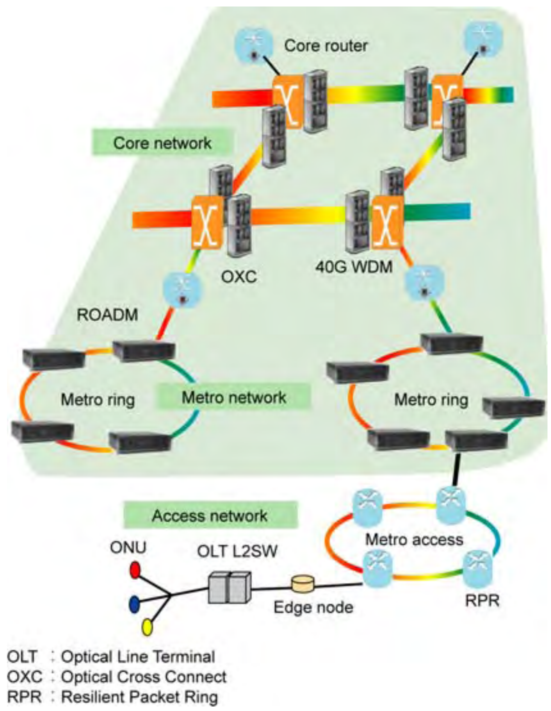


Fig. 1 Configuration of networks

1.2 Transport technologies to support passive optical network (PON)

PON, with splitters positioned on the transmission route, provides bi-directional optical communications. Its specific technological requirements include the burst transmitter and receiver for time division multiplex communication in the upward direction and a wide dynamic range to compensate for the optical level loss at splitters. Mitsubishi Electric has solved these issues by using high-output LD send and APD receive technologies and burst bit synchronization technology. As for this burst bit synchronization technology, Mitsubishi Electric has developed digital phase selection type technology in which proper phase is selected by detecting the bit timing burst signals by preparing multiple-phase clocks synchronized with the station-side clocks that are frequency-synchronized.

1.3 Trend of research in future

The standardization of the next generation PON, in the form of 10G PON in which the bit rate is increased by a factor of ten, was started by the IEEE and ITU-T. Multi-rate arrangement in which the ONUs used in the conventional 1-Gbps PON are also accommodated for the simultaneous use with 10-Gbps ONUs is being considered for the 10G PON. Other technologies under consideration for applications in the future are transmission distance extension technology using optical amplifiers for a distance of 20 km or longer, multisplit technology for 64 splits or more, outdoor installation of optical network units (ONUs), and triple wave multiplexing technology for providing image stream services in the downstream direction. Also in the future, technologies such as optical code division multiple access (OCDMA) and optical frequency division multiplexing (OFDM) will be applied in the same way as with radio transmission.

2. Optical Transport Technologies for Metro and Core Networks

2.1 Metro network

Figure 2 shows the history of the technologies applied to optical metro and core networks. The mainstream in the conventional technologies were point-to-point transmission using SONET/SDH system optical transmission devices or other network methods that configure such transmission arrangements in the form of a ring. However, networks based on an optical add drop multiplexer (OADM) that converts all the signals at one node into electric signals without processing the signals with all information passing through remaining as optical data are confirmed to be efficient and OADM is becoming the mainstream technology. The major devices that compose Reconfigurable OADM (ROADM) are wavelength-tunable optical transponder and OADM circuit provided with optical switching function. It is important to transmit with stable performance with respect to the set wavelength also with the wavelength variation range on the transmitter side secured as wide as possible, regardless of the temperature or the length of service.

Mitsubishi Electric has also proposed photonic cross connect (PXC) that can connect light into a mesh-shaped structure for increased optical path accommodation efficiency [(2), (3)]. The reliability and maintainability of optical switches themselves are very important for PXC. However, since optical paths are formed into a mesh structure, the control of the optical paths is also a very important matter to be considered. As a control method, Mitsubishi Electric has been working on the development of a dispersion control method using generalized multi-protocol label switch (GMPLS).

Though it is a technology to be realized in the future, Mitsubishi Electric has started a study on optical node technology based on wavelength conversion by using semiconductor amplifiers [(4), (5)].

2.2 Core network

One of the features of the core network is its economical efficiency owing to the optical communication scheme: 10-Gpbs ring type or linear type network devices are commercially available for both marine and land systems today. The challenge with the long distance optical transmission system is the technologies that can reduce transmission penalties; the most important technologies are dispersion compensation technology and error correction technology.

As a dispersion compensation technology, a method of compensation that uses dispersion compensation fibers having the opposite characteristics of the transmission channels has been used so far. However, the operational problem with the method is that different dispersion compensation fibers must be introduced newly when the transmission distance changes due to removal for problems or the like. Mitsubishi Electric has proposed a tunable dispersion compensation device using fiber grating as a solution; dispersion compensation is automatically performed with ps/nm of several hundreds.

The error correction method performs well with the WDM system using optical amplifiers: Originally the Reed-Solomon code having a redundancy of 7%, specified in ITU Standard G.975, was used for optical communications. To further improve the coding gain, Mitsubishi Electric proposed repetitive decoding in which the redundant codes are designed two dimensionally, in both the vertical and horizontal directions, and decoding in vertical and horizontal directions is performed alternately. As a result, coding gain was improved from 6 dB to 8 dB. In addition, Mitsubishi Electric realized a coding gain of 10 dB, to mark further improvement, by applying the turbo codes for block codes to suppress the coding redundancy low and combining the codes with a soft decision circuit [(6), (7)].

When it comes to an increase in bit rate, the industry's expectations include a 40-Gbps class. However, 40-Gbps systems are likely to confront several difficulties. For example, the influence of dispersion on a 40-Gbps system will be 16 times that on a 10-Gbps system and it will also be necessary to improve the S/N ratio when structuring the network without changing the installation intervals of transponders. Lowering the symbol rate by multilevel optical modulation to reduce the influence of dispersion and employing more powerful error correction technology to improve the S/N ratio could be an option. But the option still has to face the challenges associated with the size of the circuit or the like. Mitsubishi Electric has been working on a highly efficient error correction circuit of a moderate size [(8)].

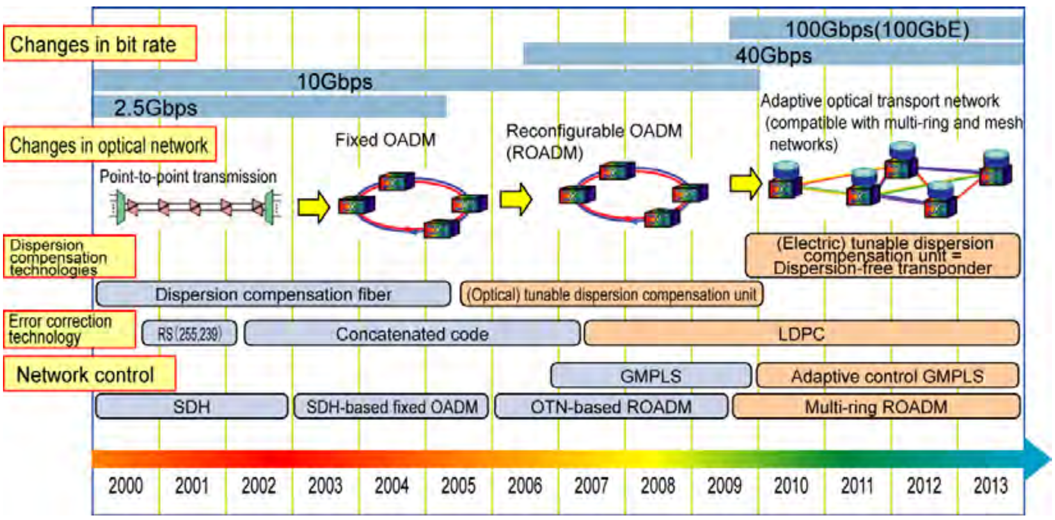


Fig. 2 Changes in Optical Metro/Core Network Technologies

2.3 Future technologies for optical transmission and optical network

Optical communications have provided communication services with information carried by optical on and off signals. Today a new technology that can make optical phases and frequencies carry information by using vector modulation such as phase modulation and optical delay detection technologies is being developed for practical applications with enhanced transmission characteristics. Furthermore, with the LSI micro-machining technologies developed, A/D and D/A converters for several tens of Gbps capacity have become practical realities. Consequently, many research institutions have started studies on dispersion equalization technologies based on optical phase modulation, multi-level modulation and demodulation, and electric processing by the combination of electric signal processing with those optical circuits. In the future, various types of modulation methods combining signal processing by electric circuits and optical technologies will be introduced and format conversion technologies for the different modulation methods will also be studied. When dispersion equalization is realized by an electrical scheme, the dispersion compensation fibers used in 10-Gbps WDM systems will be eliminated completely, thus probably reducing the cost remarkably.

Optical interfaces of 100-Gbps Ethernet signals, multiplexig with four parallel transmissions at 25 Gbps, are being examined by the IEEE. On the other hand, ITU is now discussing the method to transfer 100-Gbps Ethernet by the next generation optical transport network (OTN) frame. Expectations are high for interfaces of over 100-Gbps class; we predict that systems of such a class will be practically available in a few years. Development of optical transmission technologies that support such bit rates has also started by different sectors of the industries.

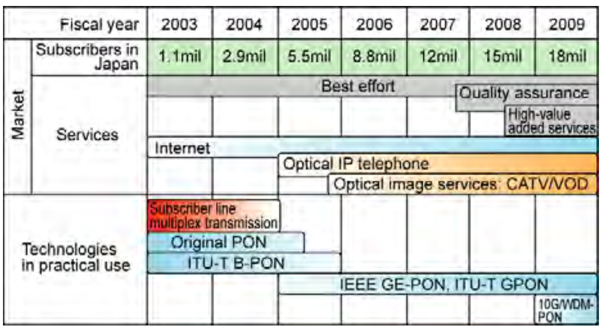


Fig. 3 Roadmap of optical access

3. Conclusion

We mainly discussed the recent trend of the technological developments associated with optical transport technologies above. An increase in the capacity of today's access network will lead to an increase in the demand for the metro and core networks in the future with much larger capacities required respectively.

Under the circumstances mentioned above, technologies of much higher levels are required for optical communications/optical transport technologies in the future. Mitsubishi Electric will continue research and development to develop new technologies that will contribute to the innovation of social infrastructure.

References:

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