Optical Core Networks

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Abstract

This article introduces our current work on optical network technology to drive core networks towards our target of 30 million FTTH (fiber to the home) subscribers and describes future prospects of this technology. By responding to the need for IP (Internet protocol) integration of services ranging from telephones to broadband video through the use of revolutionary optical amplification/relay/switching technology and network control techniques, we are contributing to the construction of an advanced reliable network by establishing photonic network technology that adapts promptly and flexibly to traffic concentration and diversification.

1. Previous trends in optical technology

Optical communication technology was introduced as a network medium by NTT and other organizations in the 1980s. Today it is being used to form terabit-per-second-class networks that exploit the full potential of light as a communication medium. In the 21st century, optical technology is entering a new stage where more wavelengths are being used in broader networks and where signals are switched optically.

In the case of high-capacity optical communication, the cost/performance ratio unfortunately does not improve unless the volume of traffic increases. When the traffic increases, the cost per bit decreases. Recently, broadband traffic has continued to grow by a factor of 2–3 times per year. There is a strong trend toward more traffic associated with music downloads and the like, which is expected to continue to grow to a considerable volume. Therefore, there might be a shortage of optical fibers in the future.

A reduction in the point-to-point cost of optical fiber communication can be achieved by making breakthroughs in various optical technologies. A trans-Japanese circuit was completed in 1985 with the opening of a single-mode fiber network covering the whole of Japan. In addition, various other achievements have been made to create other optical communication technologies. To facilitate the running of this fast high-capacity system, we made what were then regarded as revolutionary expansions of network operation based on SDH (synchronous digital hierarchy: an international standard for high-speed digital communications using optical fibers, standardized by ITU-T (International Telecommunication Union Telecommunications Standardization Sector)). This move enabled us to develop the network while maintaining high-capacity signals without incurring higher operating costs.

However, from the viewpoint of increasing capacity, the most important factor is optical amplification. By doping trace quantities of the rare-earth element erbium into a fiber, we can make the intrinsically lossy fiber medium generate gains of 20 or 30 dB. This is an important effect, not only because it allows the span between relays to be increased, but also because it allows the capacity to be substantially increased through the use of wavelength division multiplexing (WDM). At present, an 80-channel × 10-Gbit/s link system with a capacity close to 1 Tbit/s is being operated in the national network of

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By continuing to research and develop other technologies, we hope to eventually arrive at the era of fully optical networks where data is switched according to its wavelength.

1.1 Cost trends

From the changes in the costs of nodes and links, it can be seen that the link cost has fallen dramatically while the node cost has remained more or less constant despite various functional enhancements including the development of new LSIs (**Fig. 1**). In the telephone era there were 60 million subscribers with 64-kbit/s lines, which corresponds to potential network traffic of about 4 Tbit/s. To prepare for the ubiquitous broadband era, NTT aims by 2010 to have increased this capacity to 100 Mbit/s × 30 million subscribers, or 30 petabits per second (30 Pbit/s)—an increase of about four orders of magnitude. With link costs shrinking, the only way to reduce the total cost is to bring down the node costs. Consequently, there is a need to introduce new technology including not only ATM switches and IP switches but also optical switches and novel node technology.

It is thus essential to take steps to maximize the value of NTT Group's facilities and to work towards this target while tackling the issues from three viewpoints: (i) operations and protocols, (ii) SoC (system on a chip) technology for implementing schemes such as SDH on a single chip, and (iii) optical devices such as quartz-based planar lightwave circuits (PLCs).

1.2 Fiber amplifier technology

Optical amplifiers were first used to amplify transmissions in 1989, when it was confirmed in tests that a gain of 30 dB could be achieved. However, the characteristics of the first amplifiers were not necessarily flat. The lowest losses in an optical fiber occur in the 1.55-µm wavelength band where the gain was found to be no more than about 20 dB. However, by making slight changes to the amplification parameters, the characteristics were gradually made smoother and technology capable of amplifying 100 or even 1000 channels began to look possible. Furthermore, by using a various different materials, it became possible to produce amplifiers capable of covering all the low-loss wavelength regions of optical fibers.

The optical capacity of WDM technology has thus increased in leaps and bounds, but in practice the number of photons needed for WDM and TDM (time division multiplexing) has not changed much. For both techniques a transmitter power of about 1 mW is needed for each Gbit/s of bandwidth. In other words, a 1-Tbit/s system with 100 channels of 10-Gbit/s signals would require a fiber output power of 1 W. Although this is not a problem in terms of transmission *per se*, it is surprisingly dangerous in terms of the

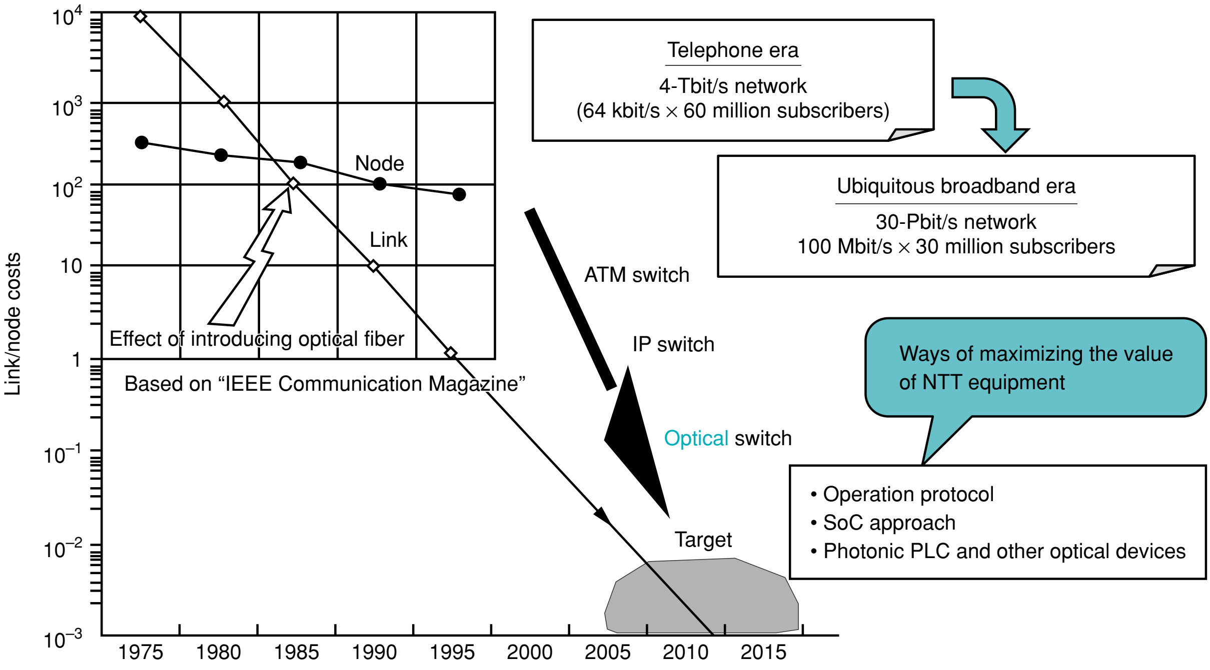


Fig. 1. Cost trend and targets: reductions in both nodes and links.

heat density at the fiber surface and might cause the fiber to melt if anything adhered to it. According to the safety guidelines of the OITDA (Optoelectronic Industry and Technology Development Association), a fiber should be shut down if reflections are seen from the connector surface, but considering product liability law and the like, it is probably about time this situation was reviewed.

A fiber is a passive medium in which the power is greatest at the transmitting end and weakest at the receiving end. However, since it is the power itself that determines the signal-to-noise ratio (SNR) of an optical communication system, less power means a smaller SNR. Of course, ideally fibers would be lossless, but if we contrive to give the fiber itself a positive gain, then the loss conditions can be relaxed. Even if the optical input level is reduced, the same SNR can be achieved without reducing the relay spacing. In other words, amplification can be performed inside the actual fiber transmission medium (Raman amplification technique).

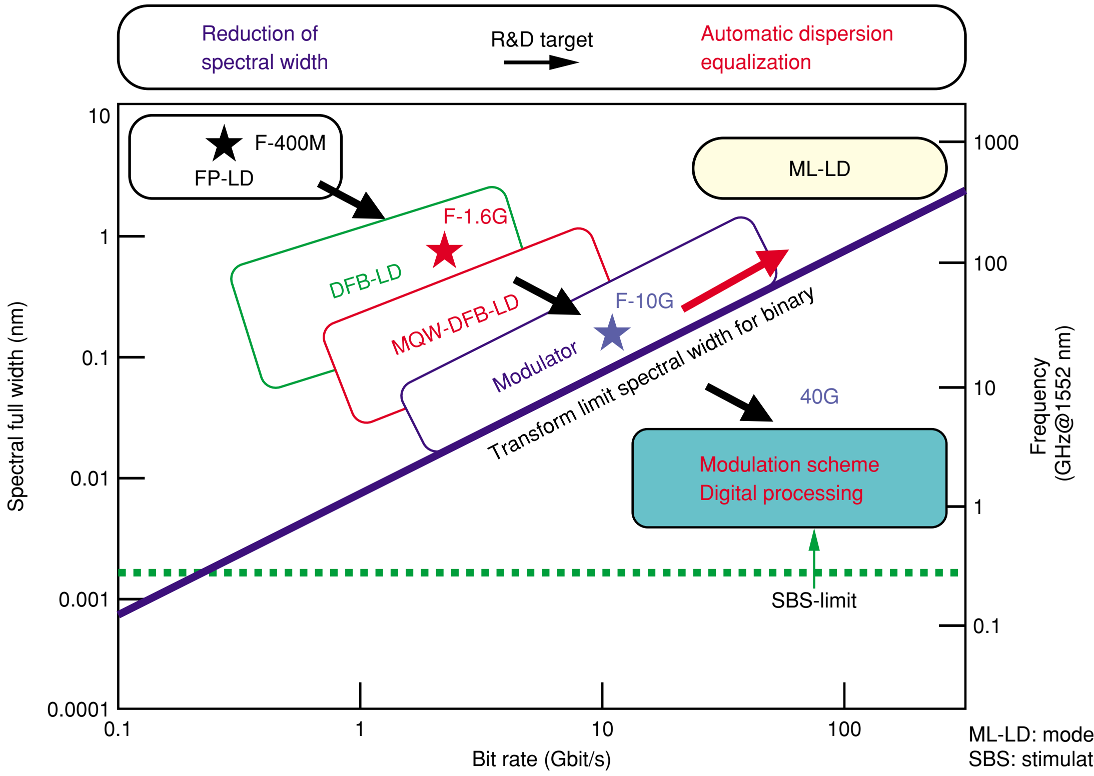
1.3 Bit rate and spectral width

Figure 2 shows the spectral widths of light sources with higher-capacity bit rates. As the speed increases, not only does the circuit itself become harder to operate, but the increased bit rate and narrower pulse width also lead to severer conditions related to dispersion in the fiber (the phenomenon whereby pulses traveling through the fiber gradually broaden out).

The reason why speeds have increased smoothly in spite of this is that the original 400-Mbit/s (Fabry-Perot laser diode) systems had a spectral width of about 5–8 nm, or about 600–700 GHz in terms of frequency spreading, which was very wide. In the drive towards increased capacity, signals have been subjected to more and more spectral compression. As a result, in a 1.6-Gbit/s (distributed feedback laser diode) single longitudinal mode system, the data is transmitted with a spectral width of about 0.3 nm, i.e., less than 50 GHz.

In the future, the frequency occupancy factor will continue to decrease, reaching about 1 for 10-Gbit/s systems, but modulating a 10-Gbit/s signal will result in a bandwidth of about 10 GHz. This is referred to as direct laser modulation, although instead of the laser being actually switched on and off directly, its output is modulated on and off by a lithium niobate optical crystal.

As the bit rate increases, the overall spectral width of the system conversely decreases. Thus, if a rate of 40 Gbit/s can be achieved, then it is likely to decrease



ML-LD: mode-locked laser diode
SBS: stimulated brillouin scattering

Fig. 2. Modulation band vs. spectral width of light source.

still further. However, this rate is close to the limit of ordinary modulation and demodulation, so the spectral width will increase if the bit rate is made any higher. If this happens, the pulse widths will tend to increase and become more susceptible to the effects of fiber dispersion, and it will become necessary to use dispersion equalization techniques to alleviate this problem. A variety of modulation and demodulation techniques are also being applied to wireless communications and ADSL (asymmetric digital subscriber line), where it is thought that improvements can be expected in the same way as with optical signals by applying similar measures to the modulation and demodulation techniques and by employing digital signal processing techniques.

2. From IP packets to wavelengths

The assertion that dealing with the transition to WDM technology is essential in the 21st century is strongly related to the fact that network are converging to IP technology (**Fig. 3**). When information is sent in the form of IP packets, it is inevitably slowed down by the need to read the packet headers at every node in order to forward the packet to its destination, just as a car must stop and give way to other traffic at a series of crossroads. Since this inevitably leads to congestion, one promising idea is to find some way of switching all the interchanges beforehand so that data can travel straight through without stopping. By cutting out all the electrical processing and controlling traffic based on its wavelength, we can make considerable improvements in terms of latency and quality.

When attempting to achieve increased throughput with IP traffic, or when high-end users need to exchange large amounts of data, users are very sensitive to latency. They strongly claim that they want the latency reduced and that it is achievable. Eliminating unnecessary processing would also be beneficial from an environmental aspect because no energy would be wasted.

An important aspect of this technology is that the optical switching can be tweaked according to the traffic so as to increase or decrease the number of exits. Using techniques such as this, our researchers aim to progress from point-to-point WDM transmission to a reconfigurable optical add/drop multiplexer (ROADM) equipped with optical switches, wavelength path networks based on optical crossconnects, and WDM/GMPLS (a combination of optical and IP techniques). The ultimate aim is to perform all the processing optically (optical burst switch networks), although there are still many issues to be tackled before this can be achieved.

2.1 GMPLS research and development

GMPLS (generalized multiprotocol label switching) is being studied as a network control technique

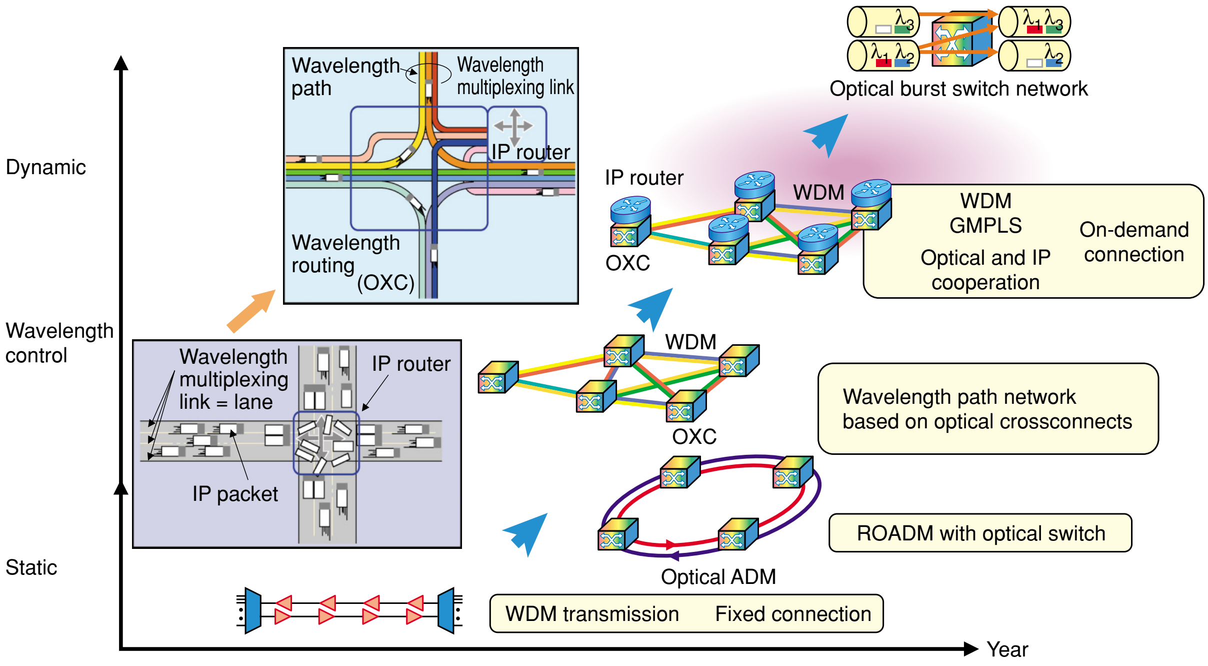


Fig. 3. Research and development of photonic networks.

that allows an optical physical network to be set up quickly in response to IP bandwidth requests. High-capacity IP routers have hitherto been used for this purpose, resulting in high cost and high power consumption, but this load can be reduced at a stroke by allowing signals to pass straight through interchange points according to their wavelengths.

One issue to be resolved in the background to this sort of research and development is the transition to an IP integration network that connects services to the physical layer. Other likely requirements are the need for NTT to provide more reliable communication as a national platform in its role as a major network platform and the need for the network to protect itself against interference by switching optical paths in a suitable manner.

2.2 Demand for photonic networks

Optical network environments currently exhibit the following characteristics:

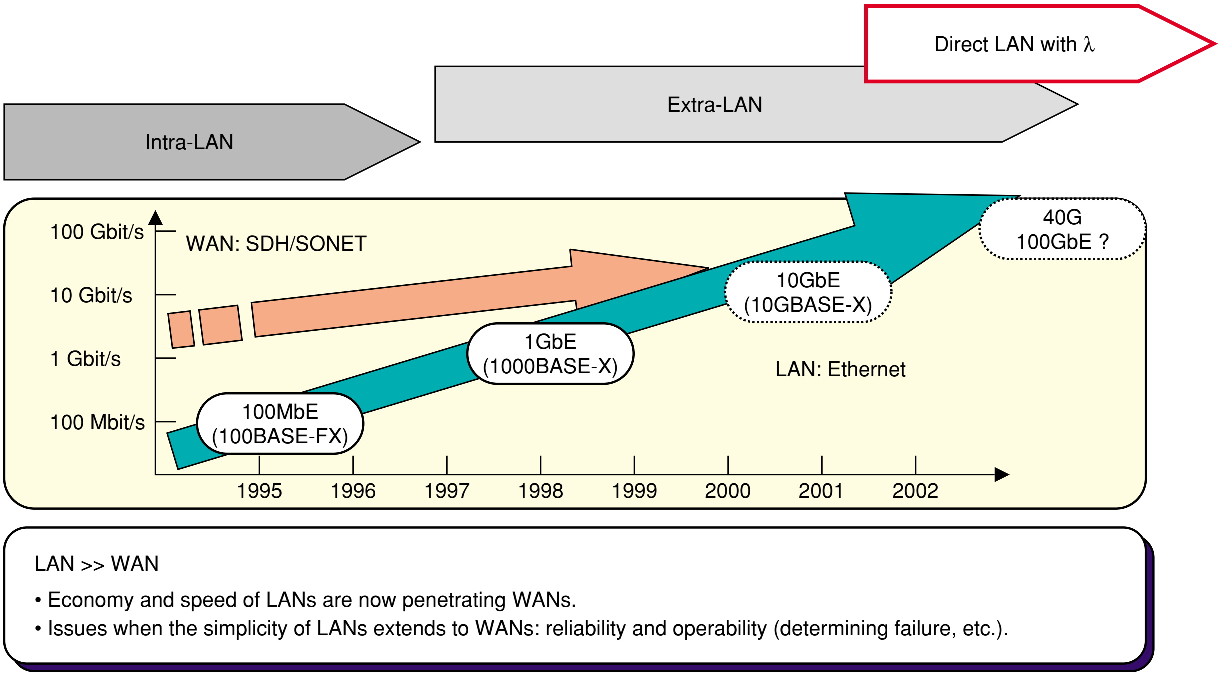
- Commercial traffic is growing vigorously, almost doubling every year.
- Mass users are enjoying the availability of economical broadband environments.
- Academic computer users still have a large appetite for more bandwidth.

User needs are varied, and more research and development from many different viewpoints is needed. Specifically, for the commercial base, metro-system technologies such as ROADM might be used as a basis for development (mountain-climbing approach). Alternatively, for large-scale technology that uses large switches to handle large volumes of data, another approach would be to proceed with research in the form of a national project and pursue development for private consumers only when its usefulness has risen (parachute approach).

In practice, national testbeds are starting up not just in Japan but in other countries as well. Since these testbeds provide a means of reliably evaluating the feasibility of new technology and introducing it into a community, they provide a chance to continue being a player when the technology is subsequently commercialized. The same thing happened when the Internet was starting up. The Internet was initially used for military purposes, and when it was subsequently developed for commercial use, the equipment and environments that had already been provided were inherited directly. It is thus very important to participate in this sort of framework.

2.3 LANs and WANs

Computers are still continuing to grow according to Moore's law. As computer technology develops, local area network (LAN) technology also develops, and it is also rapidly infiltrating carriers. Routers are the best example of this. **Figure 4** shows how Ethernet has evolved. Ethernet started out with a speed of 10



LAN >> WAN

- Economy and speed of LANs are now penetrating WANs.
- Issues when the simplicity of LANs extends to WANs: reliability and operability (determining failure, etc.).

Fig. 4. User-network interface (UNI) drives WAN interface speed.

Mbit/s, then increased to 1 and 10 Gbit/s, and is now aiming even higher. It may overtake the speed of wide area networks (WANs). WANs have already reached Tbit/s-class capacity. Using WDM technology, WANs are gradually converging towards the sort of user-network interfaces (UNIs) needed by users. This could be because the interfaces of LAN users are less expensive.

In terms of both sales value and the number of installed networks, LANs are bigger than WANs, so although WANs have their own technologies geared towards transport, in other respects there is a trend towards the use of LAN technology to achieve savings based on the economy of scale.

2.4 OTN frame standardization

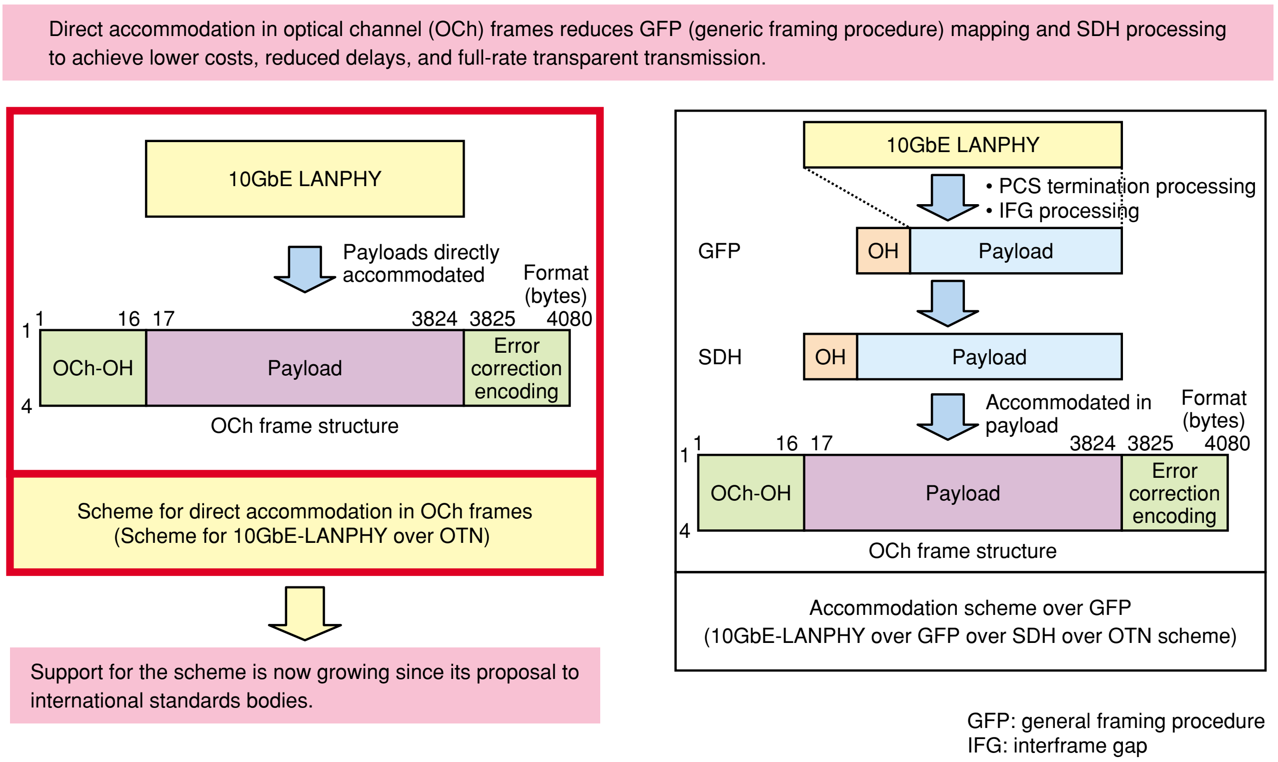
Implementing 10-Gbit/s Ethernet (10GbE) involves addressing the issue of how to interact with the transport layer. An ordinary Ethernet switch can only works at short distances. On the other hand, by making frames that can be maintained and managed over long distances by applying optical transport network (OTN) technology, e.g., forward error correction (FEC), it becomes possible to jump distances either with Ethernet or STM (synchronous transfer mode) networks. Work is therefore under way to standardize the OTN frames, where the current hot topic is what to do about the physical layer (PHY) of 10GbE LANs (**Fig. 5**).

These problems occur because conventional networks are based on STM technology. When a 10GbE network attempts to use LAN PHY, the 10GbE clock rate is slightly too high, so compression has to be used. However, users are sensitive to latency and losses and would probably rather be allowed to go connect directly. In that case, the bit rate would increase and make it impossible to get the data through conventional digital cross-connect switches with ease, so they might as well access the network optically.

Thus, there are an increasing number of applications where large user channels are operated in large numbers, and a great deal of consensus has been achieved with regard to their standardization.

2.5 Latency elimination technique of i-Visto

The introduction of i-Visto facilitates comfortable communication with improved latency. In a satellite + MPEG-2 system, the satellite alone has a latency of 200 ms, and the overall latency of 433 ms is very large. In the case of a fiber + MPEG-2 system, the latency of the fiber part is just 50 ms, so the overall latency is kept down to about 250 ms. On the other



GFP: general framing procedure
IFG: interframe gap

Fig. 5. Proposals to international standards organizations: an accommodation scheme based on using OTN optical channel frames.

hand, if uncompressed data is used (fiber + uncompressed IP i-Visto), the latency can be reduced to about 100 ms, allowing smooth communication to take place across the Pacific Ocean.

3. History and future prospects of transmission schemes

Photonic networks are expected to be utilized at various levels from the metro system to the core system. For this purpose, it is important to make well-balanced developments including communication schemes such as OTN. Looking back on the long history of communication schemes up to the present, the technology has evolved through the analog era into the digital era, from electrical to optical, and from PDH (plesiochronous digital hierarchy) to SDH. Important landmarks include the development of optical amplifiers, which brought about optical relays. However, these relays are still only analog devices, so as before they still need to be maintained and supervised. The fact that they operate transparently means they have to be monitored.

The next big step is digital optical technology, but there are difficult problems to overcome before this can be achieved. Optical switches are at a semi-digital phase, while OTNs are mostly digital in that they employ FEC technology. So although they are not digital circuits in the real sense, they are coming quite close to digital technology.

Looking at the characteristics of FEC, such as the error rate for example, the error rate does not decrease no matter much light is received when there is deterioration in the SNR at the transmitting end. Error correction can be performed by applying FEC. Since binary 0 and 1 values are clearly different, half-way error states do not occur.

4. Future prospects of photonic networks

We are focusing on GMPLS because it connects well with photonic networks. GMPLS sets up the physical layer according to the IP traffic, thereby linking layers 1 and 3 together. By linking with the routers, it is possible to change the routing by operating optical switches to ease congestion or recover from faults.

As traffic continues to increase, there is a limit to what can be done by mass demonstration tactics when faults or interference occur in large amounts of traffic. It is essential to move ahead in combination with operation technology.

Also, with regard to overseas relations, we are participating in the GLIF (Global Lambda Internet Facility) organization, and we are looking into connecting WDM networks together for use in supercomputer applications. In Japan, we are participating in a network called JGNII (Japan Gigabit Network II) made by the National Institute of Information and Communication Technology (NiCT), and we also hope to contribute to national policy.

Profile

■ Career highlights

Executive Manager, Photonic Transport Network Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in physical electronics engineering from the Tokyo Institute of Technology, Tokyo, Japan, in 1978 and 1980, respectively.

In 1980, he joined the NTT Electrical Communications Laboratories, Yokosuka, Japan, where he was involved in R&D on high-speed optical communications systems including the F-1.6G system and the FA-10G system. After serving as a senior manager of Operation Support Systems group of network business unit of NTT Communications, he is now an executive manager of NTT Network Innovation Laboratories. His current research interests include very large capacity optical network systems and media networking technologies utilizing optical networks.

He is a member of the Optical Society of America and the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan. He served as a program co-chair of OAA’93 in Yokohama, Japan and a general co-chair of OAA’94 in Colorado. He served as a chair of Optical Communications Group of IEICE in 2002–2003. He received the Sakurai Memorial Prize from the Optoelectronic Industry and Technology Development Association in 1989, the Oliver Lodge premium from the IEE in 1991, the Kenjiro Takayanagi memorial award in 1994, the achievement award from IEICE in 1994, and the best paper award of first Optoelectronics and Communications Conference (OECC’96) in 1996.