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Photonic Networks and their Forward View

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This paper introduces a vision for photonic networks and presents their forward view in which this network will provide a vast increase in capacity and a flexible, expandable, and highly reliable transparent network for the 21st century. First, this paper describes the concept and development road maps of photonic networks. Then, it discusses wavelength division multiplexing technology, optical node technologies such as the optical add-drop multiplexer and optical cross-connect systems, and the new optical components and devices that will support photonic networks.

1. Introduction

Communications traffic is increasing explosively due to the Internet, emerging multimedia applications, mobile communications, and high-speed access technologies. Especially, Internet and IP data traffic have been increasing several times a year in recent years. IP-based networks are expected to be used even more in intranets and virtual private networks (VPNs) with the improvement of security technology. Wavelength division multiplexing (WDM) systems are now widely used by communication carriers to cope with this drastically increasing traffic. The market size of WDM transmission systems has increased from about \$50 M in 1995 to \$1 B in 1997 and is forecast to grow to \$4 B in 2001. WDM will be the key technology for photonic networks, and these networks will be used to construct an IP-centric broadband network that is expected to supply cost-effective services. The U.S. government is promoting the Next Generation Internet (NGI), which will provide 100 to 1000 times the bandwidth of the current network. In Japan, the number of host computers connected to the Internet is increasing rapidly and construction of a Gigabit Network has already started.

This paper summarizes our photonic network vision and how it can be applied to achieve flexibility and expandability in networks and a vast increase in capacity in the 21st century. This paper also summarizes the key supporting technologies for nodes and transport systems and introduces several new optical components and devices.

2. Photonic network concept and development phase

Figure 1 shows the expected configuration of the next-generation network. The network has a Photonic backbone and makes intensive use of passive optical networks (PONs) in the access network. Photonic networks, which are based on WDM technology, are not limited to transport as they also realize node functions in the photonic regime. Photonic networks utilize the independent characteristics of the multi-wavelength network and can simultaneously accommodate various kinds of signals, including SDH/SONET, ATM, and IP (**Figure 2**). This transparency, or independence of characteristics in protocol and

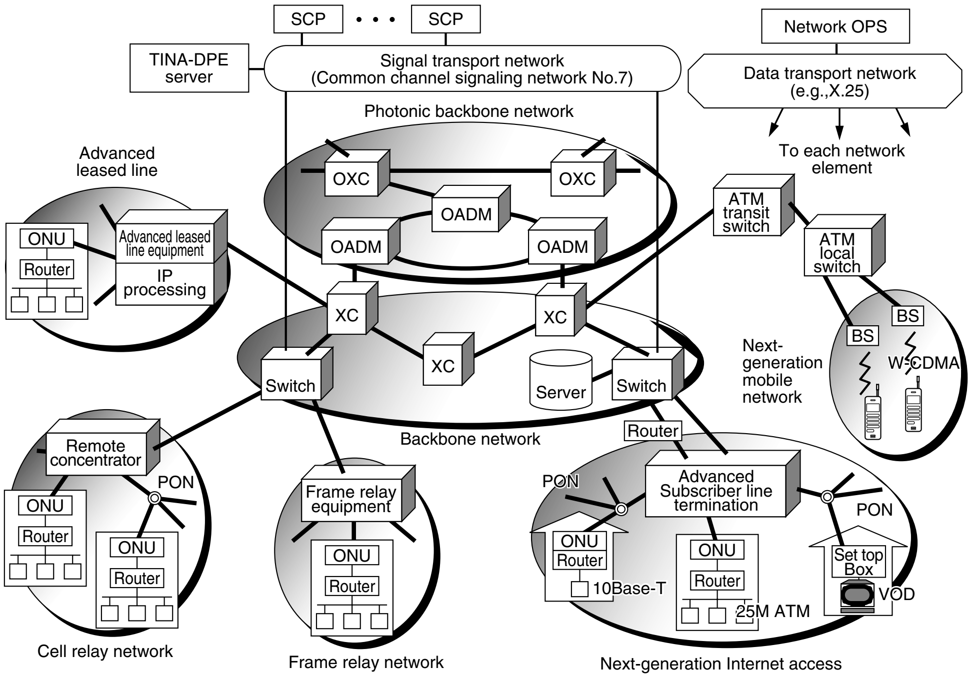

Figure 1
Next-generation network.

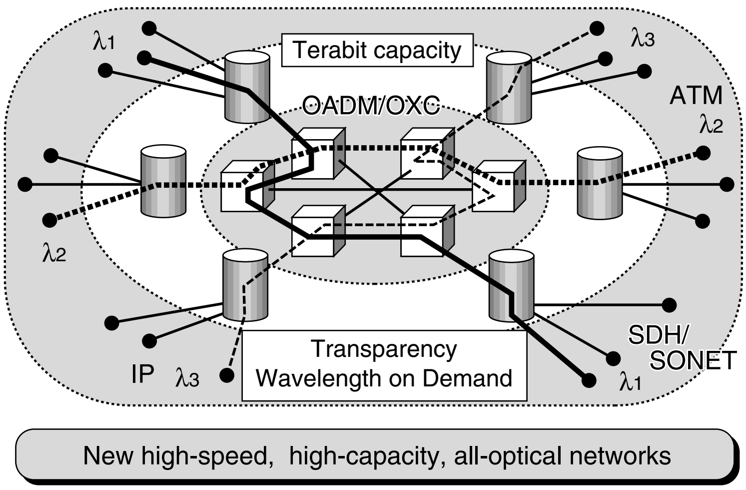

Figure 2
Photonic layer.

signal format/speed, is the major advantage of a flexible and expandable photonic network that realizes a very large network capacity through extensive wavelength resources.

In the photonic network, a new concept of Photonic Layer will be required that is based on WDM and NMS technologies. This will enhance expandability, which will allow a cost-effective increase in the transmission capacity as demand gradually increases. Another advantage of the photonic networks is their flexibility, which allows the transmission capacity and routes to be changed according to changes in network needs, for example, in case of a failure in part of the network.

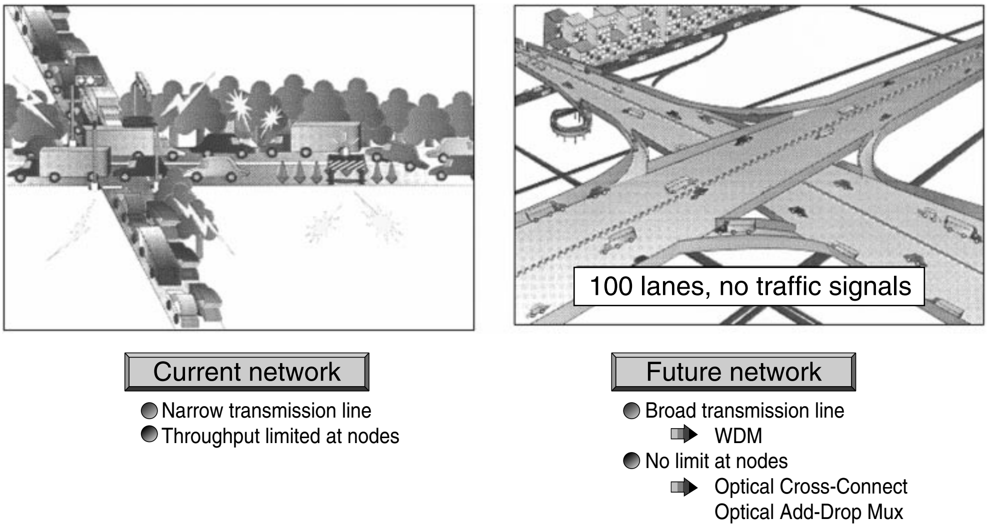

Figure 3
Photonic highway.

As high-capacity transmission becomes possible with WDM technology, the cost of communication nodes is becoming relatively high. In the coming photonic networks, such functions as multiplexing, switching, and routing will be performed in the optical domain. This will give redundancy to the network and improve the network's overall reliability. The available wavelength count will increase from 32 to 64, 128, and eventually 1000. In this multi-wavelength situation, the application area is also spreading to lower rate interfaces. If the wavelength count is large enough, it will become feasible to directly address destinations by wavelengths or to assign one wavelength for each virtual path. In the future, we can expect to see the implementation of all-optical processing, which will enable cost-effective processing of large-capacity signals.

To give a realistic image and help the reader understand the expandability, flexibility, and increase in reliability described above, I would like to use the analogy of road traffic. The capacities of conventional roads, which have only 1 or 2 lanes, cannot be drastically increased. The many traffic signals cause traffic delays, and an accident can cause a heavy traffic jam. A photonic network is a highway with 100 lanes but without traffic signals (**Figure 3**). In the photonic highway, the maximum speed of each lane is high; moreover, there are many lanes and different speeds are allowed in each lane. An optical add-drop multiplexer (OADM) corresponds to an interchange where cars come in and go out, and an optical cross-connect (OXC) node corresponds to a highway intersection where signals can transfer to another transport route.

Signal characteristics are also changing. The volume of data traffic that consists of IP packets is rapidly increasing compared to the volume of conventional SDH and ATM traffic, which is analogous to the transition from trains to trucks. A more convenient and cheaper system is evolving for customers as the infrastructure develops.

The electrical ADM and cross-connect systems used in conventional communication systems are suited to networks for voice-based communication. However, with the increase in the amount of information being communicated, this scheme is becoming inefficient and the optical scheme is becoming more cost-effective. Going back to the highway analogy, in conventional communication systems, the payloads of a truck are unloaded at each interchange, then each payload is opened, and the desired package is extracted. Finally, the

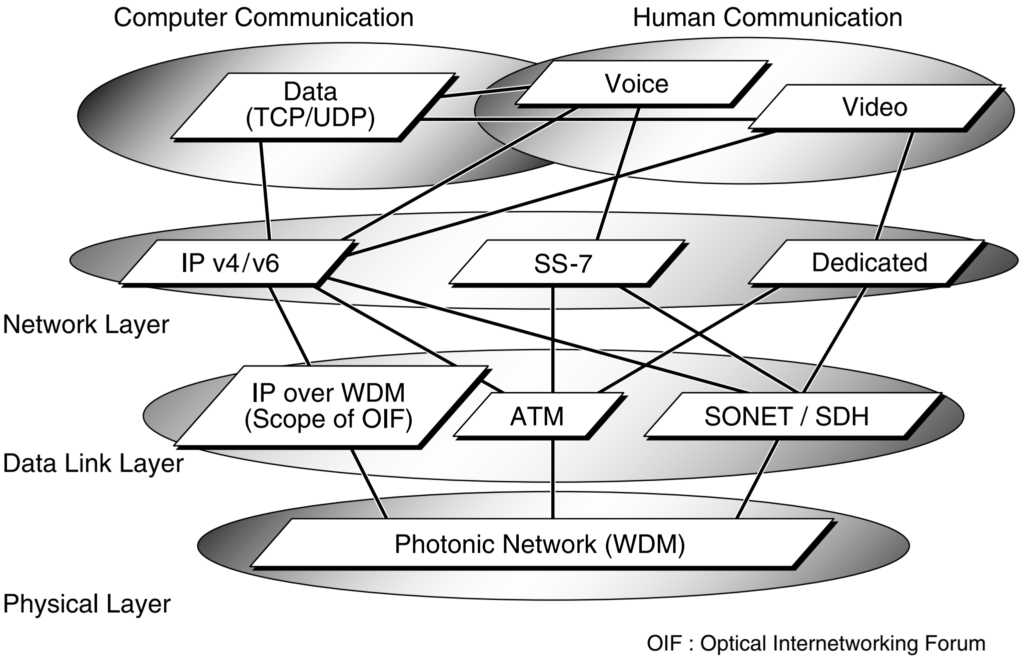

Figure 4
Network architecture.

payloads are repacked and loaded back onto the truck. In OADM systems, one wavelength can be allocated to a certain destination and payloads are not opened at intermediate interchanges. The signals in photonic networks are analog signals, so they must be restored at some point to compensate for the accumulated degradation. Currently, the capability of feasible optical processing is rather limited and new devices are required to enlarge the optical processing capability. Because of its limitation, optical processing will firstly be used to manipulate wavelengths and in applications where electronic processing is too slow.

Certain functions are required for photonic layers, i.e., mux/demux of large-capacity signals, routing of large-capacity signals, protection and restoration, and path/channel supervising for faults and degradation.

Network management is vital in photonic networks. For example, in an ultra-large-capacity network using a terabit transmission system, an outage of the system can have a big influence on social life. Protection against node and cable failures are therefore essential for a high-reliability network. Monitoring, supervising, provisioning, and protection switching are required basic functions. In photonic networks, optical signals are amplified, added, dropped, and switched in the optical domain and the signal-to-noise ratio and wavelength deviation must be monitored. Components that perform these functions are being developed. NMS and a network element controller having monitor functions for photonic signals have actually been integrated into OADM and OXC nodes which employ a user-friendly GUI; these parts are being developed using a CORBA-based platform.

To construct and promote photonic networks which process huge amounts of traffic by combining the WDM and IP technologies, we must develop a simple interface. Currently, IP information is mapped in an ATM or SDH/SONET frames and implemented in WDM systems. A simpler interface in which IP information is directly transported by WDM technology is preferable (**Figure 4**). The Optical Internetworking Forum

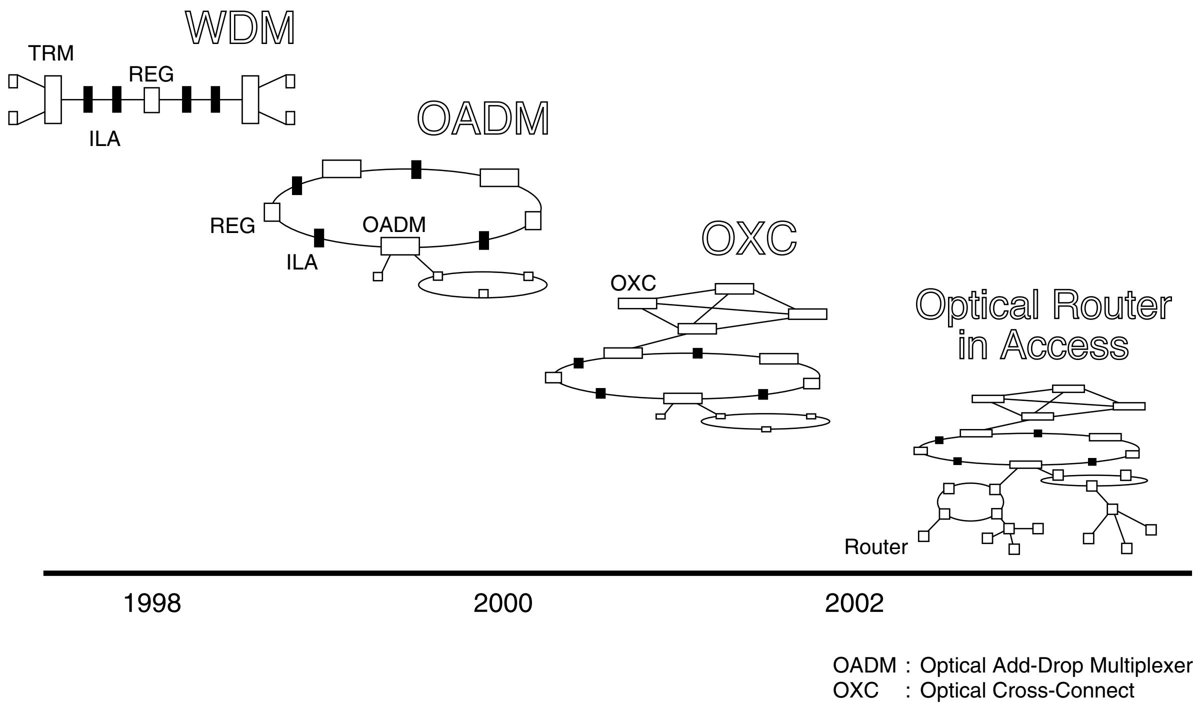

Figure 5
Evolution of photonic networks.

(OIF) was established in 1998 as an open forum for discussing the interface. Major communications carriers and vendors, including Fujitsu, are participating in the OIF. New proposals are discussed in three technical fields: the physical interface, management, and inter-layer adjustment.

3. Deployment road map

We assume there are four stages in the deployment of photonic networks (**Figure 5**). The first stage is point-to-point transmission deployment. In this stage, WDM technology effectively increases the transport capability, i.e., the main function of the photonic network is multiplexing. The independent characteristics of each wavelength allow assignment of the wavelength to different applications and services, which enables the generation of a new photonic network architecture that can accommodate various protocol signals. It is possible to cost-effectively upgrade by installing the wavelength count on demand, and this is expected in not only trunk systems but also in access networks.

The second stage of the photonic network includes the concept of the optical path network. The communication path is redefined by incorporating wavelength, and functions such as adding, dropping, and switching can be obtained optically. In this stage, photonic elements such as the optical add-drop multiplexer (OADM) play a major role. There are two types of OADM: the fixed wavelength OADM and the dynamic or reconfigurable OADM.

The third stage requires the optical cross-connect (OXC) function. OXC has more complex processing, i.e., route changing and wavelength exchange. There is currently much discussion about role sharing between electrical XC and optical XC.

In the fourth stage, IP packets will be directly transported by WDM technology. IP signals from routers are the main signals in this stage, where a simple interface to the photonic network and standardization and cost are the main concerns. A new protocol for the photonic layer will

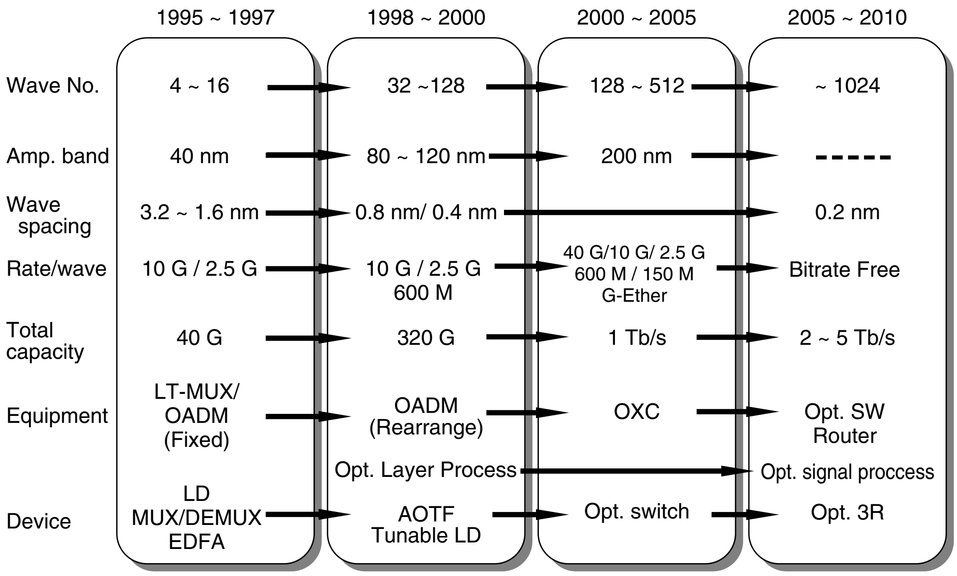

Figure 6
Photonic technology road map.

be used. In the first step, optical packets will be routed by combining electrical processing and optical processing. The concept of mapping IP addresses into the wavelength domain and using a hierarchical address structure in wavelength addressing are also being discussed. An optical router having a very-high-speed optical header recognition function will ultimately be developed.

These stages will overlap each other, and their development road map is already in progress (**Figure 6**). Although the architecture of the photonic network and its supporting technologies require much discussion to ensure that they will conform to the emerging requirements from applications and services, we are developing new node and component technologies and are striving to find total solutions for the photonic network architecture.

4. Photonic network components and required devices

4.1 WDM transport

The usable bandwidth, or wavelength count, is increasing with the advent of optical amplifier technology. The first-generation EDFA has a gain in the so-called "conventional" or "medium" band of around 1530 to 1560 nm. The second-generation amplifier covers the longer wavelength region of 1570 to 1600 nm, which is often called the "L-band". A wideband optical amplifier having a new amplifier configuration is under development which has a wide dynamic input range and a new control scheme to obtain stabilized transient responses.

The shorter wavelength bandwidth is covered with Raman amplifiers that use newly developed high-power pumping lasers. The entire bandwidth from the 1300 to 1600 nm band corresponds to about 50 THz. This means that if we allocate wavelengths with a 50 GHz (about 0.4 nm) separation, we can use up to 1000 waves in a single strand of fiber.

For the optical light source, a tunable laser will be an essential device. Tunability over about 30 nm is desired, and several approaches are being investigated.

As for the optical filters, currently a separation of 100 GHz (0.8 nm) is commonly used. In the future, a 50 GHz separation (0.4 nm) will be used, and even a 25 GHz separation, which would conform to the minimum grid separation of the ITU-T standard, will be feasible. Flat passband characteristics, a high cross-talk rejection ratio, and tunability are the required characteristics. To meet these requirements, the acousto-optic tunable filter (AOTF) is a good candidate. Also, optical surface mounting technology using a planar lightwave circuit is an attractive approach to assembling many complex components.

In more dense WDM transport systems, better optical frequency stabilization and multi-level modulation schemes having compact sidebands are also required.

4.2 Optical add-drop multiplexer (OADM) system

In the OADM node, desired signals are dropped from the transmitted WDM signal and the remaining signals are transmitted through to the output port. New signals can be added to vacant channels. The key device here is an optical filter which has demultiplexing and dropping functions. The filter characteristics of the Through Port are also important because the filtering effect accumulates and limits the available wavelength region and the concatenated number of nodes. The first-step product is the fixed wavelength type OADM, which has been developed using fixed optical filters. The second-step product is the dynamic or reconfigurable type OADM, the key device of which is a tunable filter. The acousto optic tunable filter (AOTF) is a promising device because it provides a narrow bandwidth, wide tunability, and high rejection ratio. The AOTF can also drop multiple desired channels simultaneously. Low crosstalk is an essential requirement in these filters because remaining crosstalk generates beat noise and causes deterioration in optical signals. A protection scheme using a working OADM and an emergency OADM in one node is also being considered.

4.3 Optical cross-connect (OXC) system

An OXC having multiple input and output ports is expected to make it possible to realize more powerful provisioning, reconfiguration, and path restoration functions in the photonic network. In the OXC, the input signal in each port is wavelength demultiplexed and then switched in a spatial switch to change the route and multiplexed again for transmission into the output port. The loss of these optical components should be low and constant over the entire wavelength range and over whichever route is used. The insertion loss of these devices must be compensated for by the optical amplifier. The noise added by the amplifier should not seriously deteriorate the signal-to-noise ratio. The better noise performance of the EDFA is attractive; however, the compact semiconductor optical amplifier (SOA) is also another candidate for a single wavelength amplifier. In OXC systems, network management is more important. A prototype NMS has been developed.

4.4 Optical router

The optical router will route and send optical packets according to the destination. The information in the header address is resolved and the optical packet is routed according to the information. Optical recognition will be used in the second step, which is currently in its infant stage. Optical delay, which is currently realized by a fiber delay line, will be another research target.

4.5 Optical processing

This area mainly covers dispersion/non-linearity compensation, wavelength conversion, and optical regeneration. For the dispersion compensation, a wideband and compact dispersion compensation module (DCM) is required. Current DCM mainly uses dispersion compensating fiber (DCF), which is bulky and expensive. Dispersion slope compensation is also becoming an important concern, especially in submarine transport. In 40 Gb/s systems, compensation for polarization

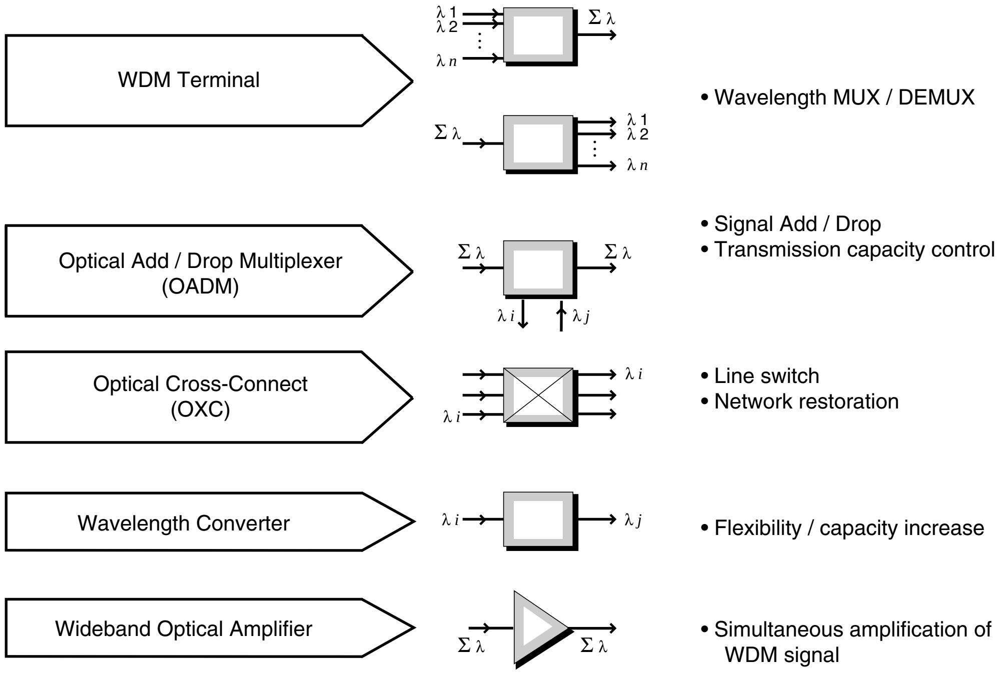

Figure 7
Main elements in photonic layer.

mode dispersion (PMD) will be necessary. Wavelength conversion is another big target of optical processing, and phase conjugate technology using four wave-mixing (FWM) is showing promise as a way to achieve it. Optical timing extraction, timing recovery, and regeneration using ultra-short pulses are being investigated for future photonic networks.

Figure 7 summarizes the main elements in the photonic layer. Fujitsu provides a product line of long-distance high-capacity WDM transport systems (FLASHWAVE 320G) which can carry 32 channels of 2.5 Gb/s or 10 Gb/s signals over 320 km of single mode fiber or 600 km of non-zero dispersion fiber. The number of channels in the FLASHWAVE 320G is scheduled to be increased to 40, 80, and 170. The FLASHWAVE Metro has been developed for short-distance medium-capacity transport systems. It can carry 16 channels of 2.5 Gb/s signals over 60 km of single mode fiber. The optical add-drop multiplexer is the FLASHWAVE ADX, which can be dynamically reconfigured and has a span/ring protection capability. The optical cross connect system is the FLASHWAVE-OXC.

5. Optical access network

From the beginning, the optical access network has been regarded as a way to provide services to businesses and society in general in the forthcoming multimedia information age – an age in which high-speed and broadband services as well as low-speed legacy services will be flexibly and economically delivered to the home. Especially, the optical access network is expected to play an essential role in meeting the growing need for broadband accessibility to communication and information networks due to the growth of the Internet. Vigorous efforts in research and development have already been made to satisfy this demand. However, the final drops to users are still mostly made using metallic lines. The key factors that are preventing early introduction of broadband optical access networks into homes

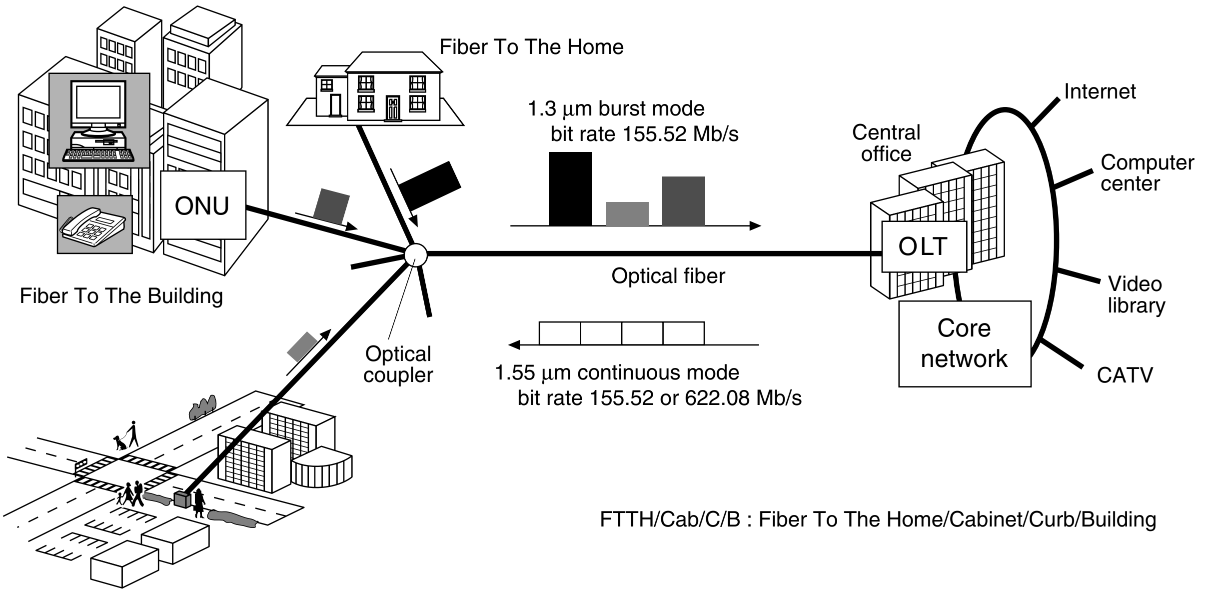

Figure 8
Optical access system based on the ATM-PON.

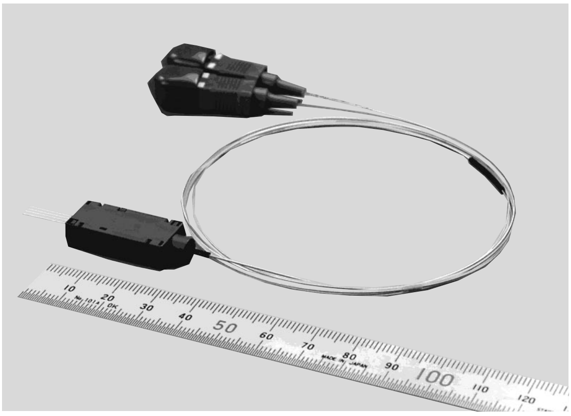

Figure 9
PLC module for an optical access system.

are the technical and economical barriers. Worldwide, much work has been done to overcome these barriers and meet users' requirements.

One of the outcomes of this work has been an initiative organized by major telecom operators called the Full Service Access Networks (FSAN). FSAN has been promoted as a way to standardize a common optical access platform suitable for broadband services delivery and to construct a multi-vendor environment which leads to a cost-effective system due to worldwide mass-production of standard components. Major telecom suppliers have collaborated in this activity, and Fujitsu has actively contributed to it. The asynchronous transfer mode passive optical network (ATM-PON) has been regarded as a viable optical transport scheme to support a wide range of Fiber-To-The-x (FTTx, where x = Home, Building, Curb, or Cabinet) access network architectures. As a result of this activity, the Recommendation of ITU-T G.983.1 was formally approved as the ATM-PON physical layer specification in October 1998.

Figure 8 shows an optical access system based on the ATM-PON which provides cost-effective shared optical access media to a large number of users. We have already developed an initial version of a commercial ATM-PON system, and this system is already in use, mainly providing economical leased lines over a nationwide area. The version of the ATM-PON system currently under development will provide more economical and global optical access systems that are compliant with the ITU-T standards.

We have also been developing an optical access network that can cope with the ever-increasing IP traffic and customer needs. This network employs leading edge technology and state-of-the-art manufacturing methods and represents a major step towards the fulfillment of our global vision. One of the key requirements to overcome cost barriers is to realize low-cost optical modules and devices. These can be manufactured by an innovative passive alignment assembly technology for optical semiconductor devices and a planer lightwave circuit (PLC) platform technology which integrates optical devices such as taper-waveguide integrated laser diodes, corner illuminated photodiodes, and wavelength division filters on a silicon substrate. **Figure 9** shows an example of a PLC module for an economical optical access network.

Some of the main technologies for an economical and global optical access system with IP service support functionality will be described in detail later in another paper.

6. Conclusion

The development of photonic networks for the 21st century that fully utilize the vast bandwidth of the optical spectrum has been started. However, development work is just beginning to explore the possibilities. By introducing a photonic layer that includes optical node functions such as OADM, OXC, and optical processing, we will obtain an expandable, flexible, and highly reliable network with an enormous capacity. R&D of photonic networks is also being conducted very actively in the U.S. and Europe.

We are going to promote this photonic technology, collaborating with our global partners and customers, to make it our next main product in the communications area because this technology might become one of the main strengths of Fujitsu in the coming global race among IT industries.

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