A Dense-wavelength-division-multiplexing Optical Network System

Masahiro Ojima, D. Eng.
Hiroyuki Nakano, D. Eng.
Shinya Sasaki, D. Eng.
Shoichi Hanatani

OVERVIEW: A dense wavelength division multiplexing (DWDM) system with 32 wavelengths and 10 Gbit/s/wavelength has been developed. It provides a total transmission capacity of 320 Gbit/s. An OC-192 end-terminal with an ITU-T compliant-wavelength transmitter is directly connected to the DWDM system. An optical amplifier with a gain flatness of ± 1 dB and a maximum total output power of +21.5 dBm is a key component in the DWDM system, in which optical power of each wavelength is kept to the same level by using Er-doped fiber amplifier (EDFA) at the input ports of the DWDM system. Next-generation DWDM will have 128 wavelengths, a total capacity of 1.28 Tbit/s, and networking functions such as optical cross-connect and optical add-drop multiplexing. An optical-protection ring system using a unique matrix of opto-mechanical switches has been demonstrated in order to provide a reliable IP-over-DWDM network with a fast restoration time of 50 ms.

INTRODUCTION

EXPLOSIVE growth of data traffic due to various IP-based communications requires an increase in transmission capacity of the nationwide backbone optical-fiber network. Dense wavelength division multiplexing (DWDM) is a scheme to input different-wavelength laser beams into an optical fiber. Since the conventional multiplexing scheme, time division multiplexing (TDM) is thought to be difficult over several tens of Gbit/s, DWDM is considered the

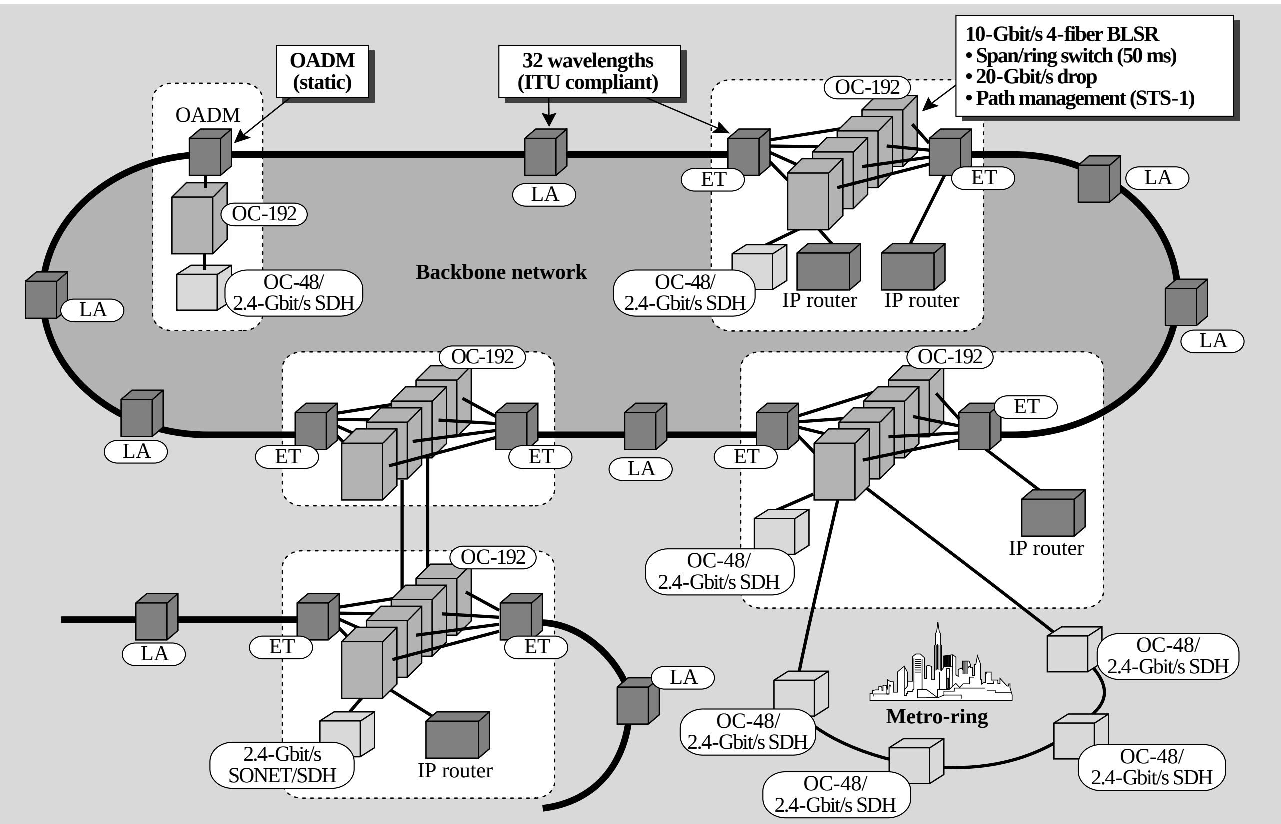


Fig. 1—Backbone Network System Employing DWDM and OC-192.

solution for increasing the capacity of the backbone network. DWDM can increase capacity by 10-100 times without the need for a new optical fiber.

This paper presents Hitachi's latest DWDM system with 32 wavelength channels and a total transmission capacity of 320 Gbit/s when combined with our SONET OC-192 10-Gbit/s transmission system. The latter is described in detail in a subsequent paper in this issue[1,2]. A typical backbone network system using our DWDM and OC-192 is shown in Fig. 1. Next-generation DWDM systems under development are also presented in this paper. Among them, an optical protection ring network using our optical cross-connect prototype is described in particular.

320-Gbit/s DWDM SYSTEM

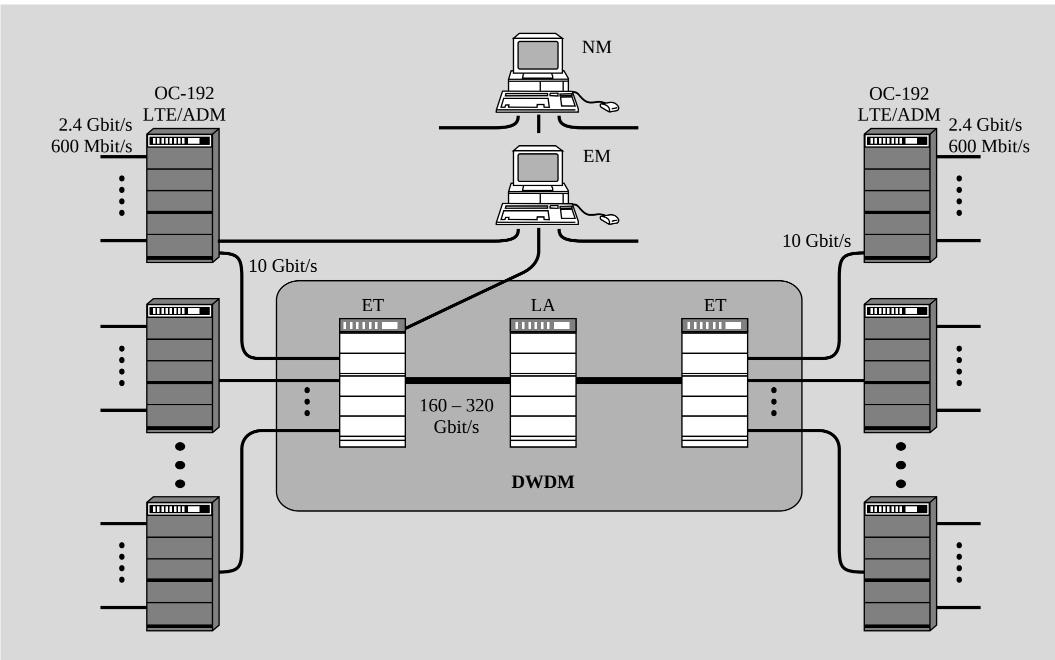
The system configuration of DWDM with OC-192 (line terminating equipment and an add-drop multiplexer) is shown in Fig. 2. DWDM consists of end terminal (ET) and line amplifier (LA) bays at several locations. Maximum transmission capacity is 320 Gbit/s in one direction. Of course, a lower bit-rate system, such as OC-48 (2.4 Gbit/s), is applicable for the system and OC-192/OC-48 mixed transmission is available. The whole system is controlled through an integrated element manager (EM) and network manager (NM). To reduce the initial cost of introducing the huge capacity system, DWDM can be used as a 160-Gbit/s system first. Then as the demand for data traffic increases, the DWDM is upgraded to a 320-Gbit/s system. The upgrade scenario is shown in Fig. 3. The signal band is divided into two bands: a red-band (1,547.72–1,559.79 nm) and a blue-band (1,531.12–1,542.94 nm). Signal wavelengths emitted from OC-192 are set on the ITU grid with a spacing of 0.8 nm (100 GHz). By dividing the wavelength band, the following economical and technical advantages are derived:

(1) Modular packages for an additional wavelength band provide an economical solution so that a customer only has to pay for a half-band equipment in the initial deployment when the number of channels (wavelengths) is less than 16.

(2) Matured technology can be used for a 16-wavelengths system with a bandwidth of around 12 nm. The pump power required for amplifiers is almost half, a gain equalizing technology is established, and the optical components are less expensive than those of a 30-nm system.

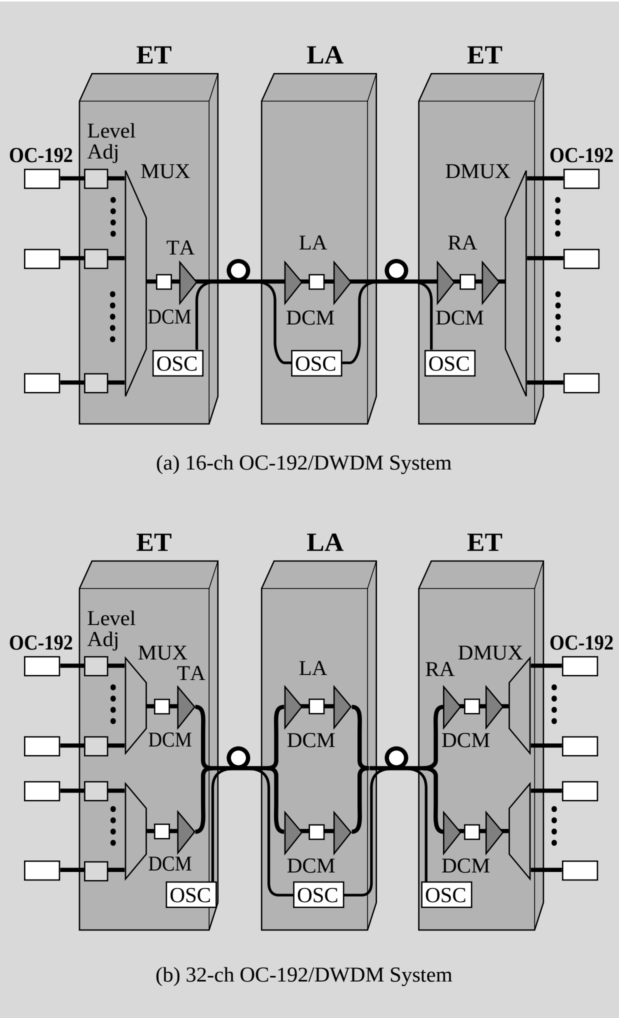
Normally, a 16-channel red-band DWDM system is provided first and is upgraded to a 32-channel system with both red- and blue-bands.

To provide a stable 10-Gbit/s signal performance, optical power level per wavelength is controlled precisely. In the optical amplifiers (TA: transmit amplifier, LA: line amplifier, and RA: receive amplifier), ALC (automatic level control) circuits are used. The power per wavelength is controlled to a constant when any number of wavelengths are amplified. ALC is operated according to the number



ADM: add/drop multiplexer
DWDM : dense wavelength division multiplexer
EM: element manager
ET: end terminal
LA: line amplifier
LTE: line terminating equipment
NM: network manager

Fig. 2—System Configuration of DWDM with OC-192.



DCM: dispersion compensating module
DMUX: demultiplexer
MUX: multiplexer
LA: line amplifier
OSC: optical supervisory channel
RA: receive amplifier
TA: transmit amplifier

Fig. 3—DWDM Configuration and its Upgrade Scenario (16 ch to 32 ch).

of wavelengths. The number is detected at the end terminal site (at the input of the multiplexer) and transported to all the amplifier sites through an OSC (optical supervisory channel) signal in the same fiber having a wavelength of 1,510 nm.

Individual channel power is automatically kept constant by a simplified EDFA (Er-doped fiber amplifier) level adjuster at the input of the wavelength multiplexer. This function enables the transmitted power to be equalized at the output of TA.

Variation of optical output power of the transmitters and variation of loss of the optical connectors are therefore offset. Remote pre-emphasis for the multiplexed signals can be achieved, if needed.

Table 1 lists the main features of the DWDM system. These features support a maximum span loss of 22 dB

TABLE 1. Main Features of 32-channel DWDM

Item	Performance/Function
Number of wavelengths	32 max.
Channel spacing	100 GHz (0.8 nm)
Bit rate per channel	10/2.4 Gbit/s
Wavelength band	Red: 1,547.72-1,559.79 nm Blue: 1,531.12-1,542.94 nm
Output channel power	+6.5 dBm (automatically controlled)
Total output power	+21.5 dBm max.
Maximum gain	> 26 dB
Gain flatness	< ± 1 dB

× 5, which approximately corresponds to 400 km (80 km × 5) with a transmission capacity of 320 Gbit/s (equivalent to 128 OC-48/STM16). For long-haul transmission, a DCM (dispersion compensating module) is used in the mid-stage of LA and RA or input part of TA. Site allocation of the DCM is determined through a computer-simulated database for any type of fibers (conventional single mode fibers, nonzero dispersion-shifted fiber, dispersion shifted fiber in some cases).

Long-haul transmission performance of 10 Gbit/s signals through the DWDM system is confirmed. Bit-error-rate characteristics of a BTB (back-to-back) DWDM system (made up without LAs, with LAs and attenuators) and 280-km NDSF (non dispersion shifted fiber) transmission are shown in Fig. 4. The 280-km (100 km + 100 km + 80 km) transmission characteristics of the red-band 16-channel multiplexed signals are tested. For all cases BTB, with LAs & attenuators, and LAs & 280 km NDSF for ch1 and ch16, receiver sensitivities are less than -30 dBm at a bit-error-rate of 10^{-12}. Similar BER performance of another 16-channel (blue-band) is obtained.

NEXT-GENERATION DWDM TECHNOLOGIES

Fig. 5 shows Hitachi's next-generation DWDM network systems. One development is to increase the number of wavelength channels, and the other is to increase the number of optical networking functions based on optical-path processing wavelength by wavelength.

The optical fiber itself has a potential to carry over 20 Tbit/s, since the low-loss wavelength region is about 200 nm (from 1,450 to 1,650 nm). An optical fiber amplifier with longer wavelength gain spectrum (from 1,570 to 1,620 nm) is under development so that the DWDM spectrum and the number of channels can be

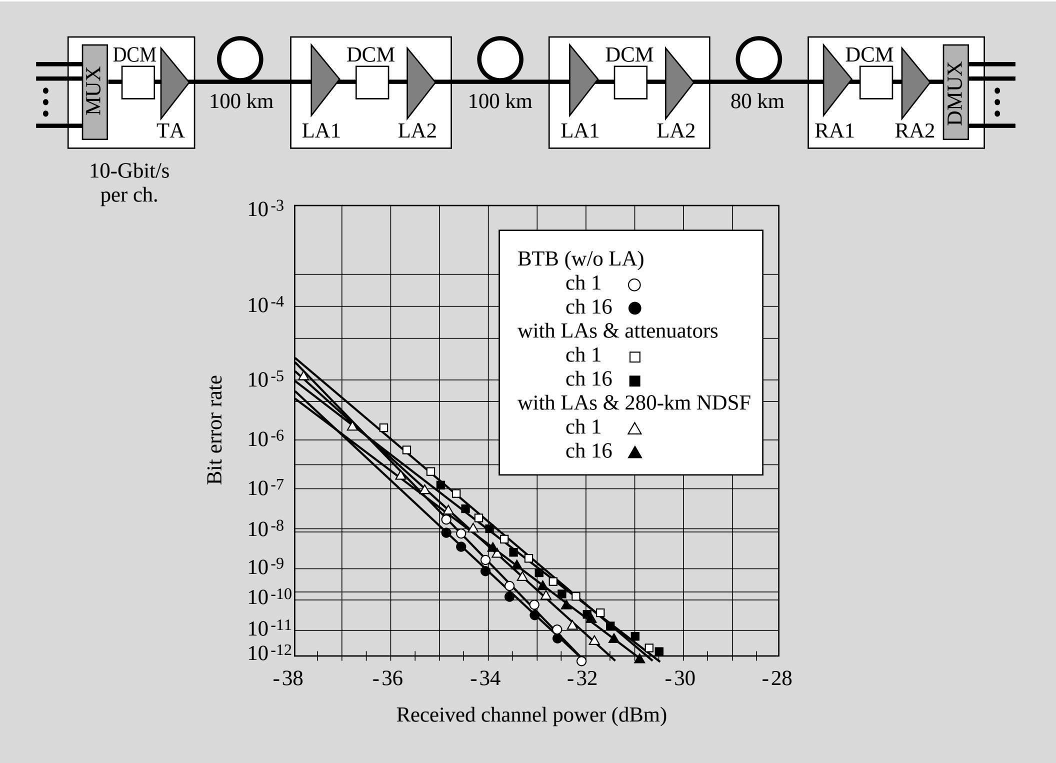


Fig. 4—10-Gbit/s Transmission Characteristics with DWDM.

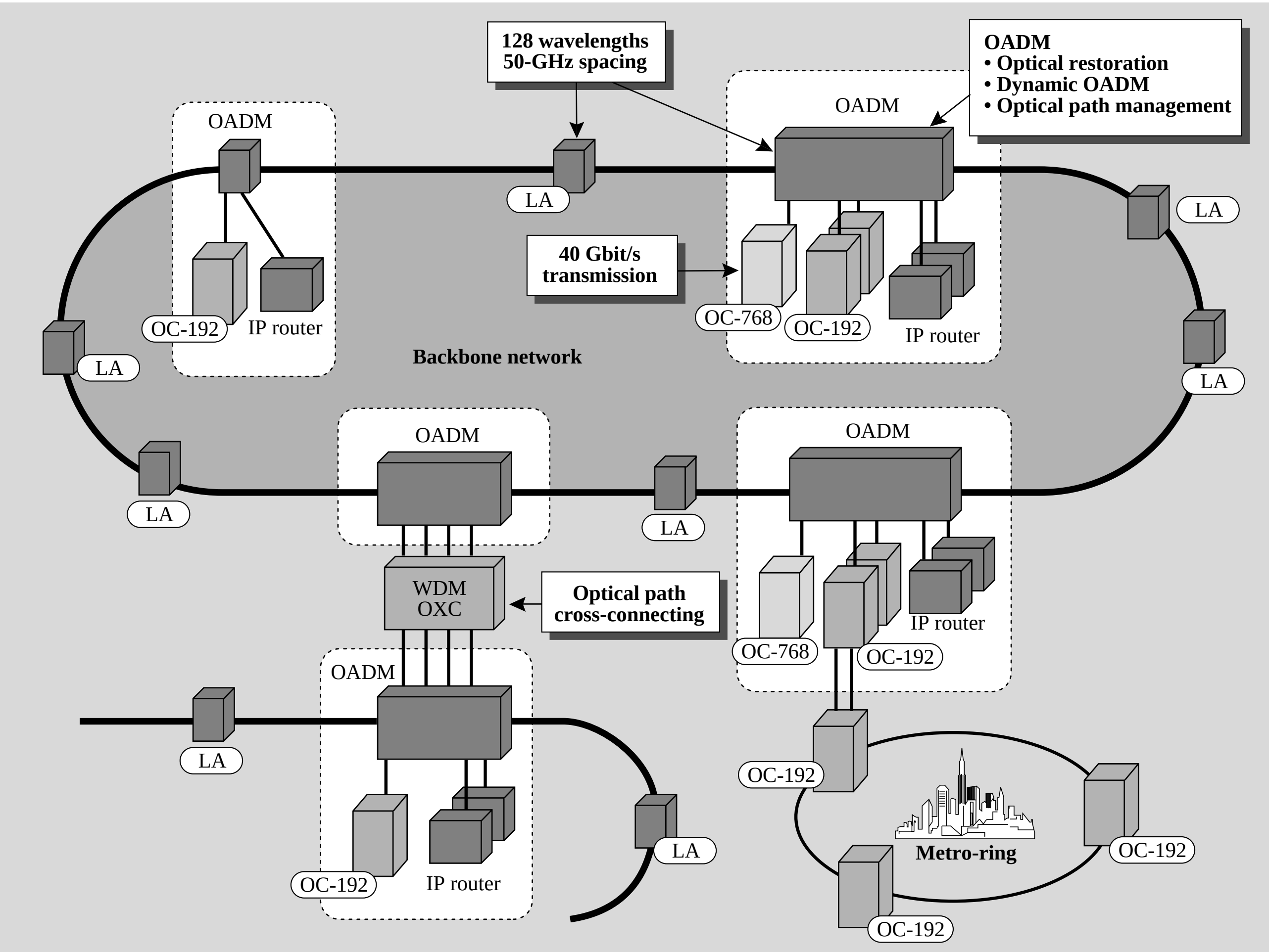


Fig. 5—Next-generation DWDM Network System.

doubled. Further improvements on the wavelength control of the laser source can decrease the wavelength spacing of the DWDM channels to 50 GHz for 10 Gbit/s/wavelength, giving the number of channels double. Therefore, 128 channels with a total transmission capacity of 1. 28 Tbit/s is just around the corner.

As the number of DWDM channels increases, the OE/EO conversions at the network nodes for the electrical processing of every electrical path become burdensome. Optical-path processing wavelength by wavelength without OE/EO conversions will efficiently improve cost performance of networking functions. An optical add-drop multiplexer (OADM) and optical cross-connect (OXC) prototype are under development by using optical switch matrixes for the optical processing. Especially when IP traffic becomes dominant in the backbone network, IP directly over the DWDM network is expected to provide a cost-effective network. The next section describes our OXC prototype for a reliable IP over the DWDM network.

OPTICAL CROSS-CONNECT SYSTEM

Self-healing of a fiber (line) or cable failure is one of the essential functionalities of DWDM networks, because so much data, 320 Gbit/s or more, is simultaneously lost at the failures. A 16 × l6 OXC prototype based on fiber-base optical protection and restoration was developed (Fig. 6). A successful in-field evaluation was obtained through OC-48 (2.5 Gbit/s) and OC-192 (10 Gbit/s) transmission in an installed optical-fiber network; that is, part of the metro Dallas network of MCI WorldCom[3].

In order to accommodate various kinds of traffic demands that will arise in the IP-over-DWDM era, a

Fig. 6—Optical Cross-connect Prototype System.

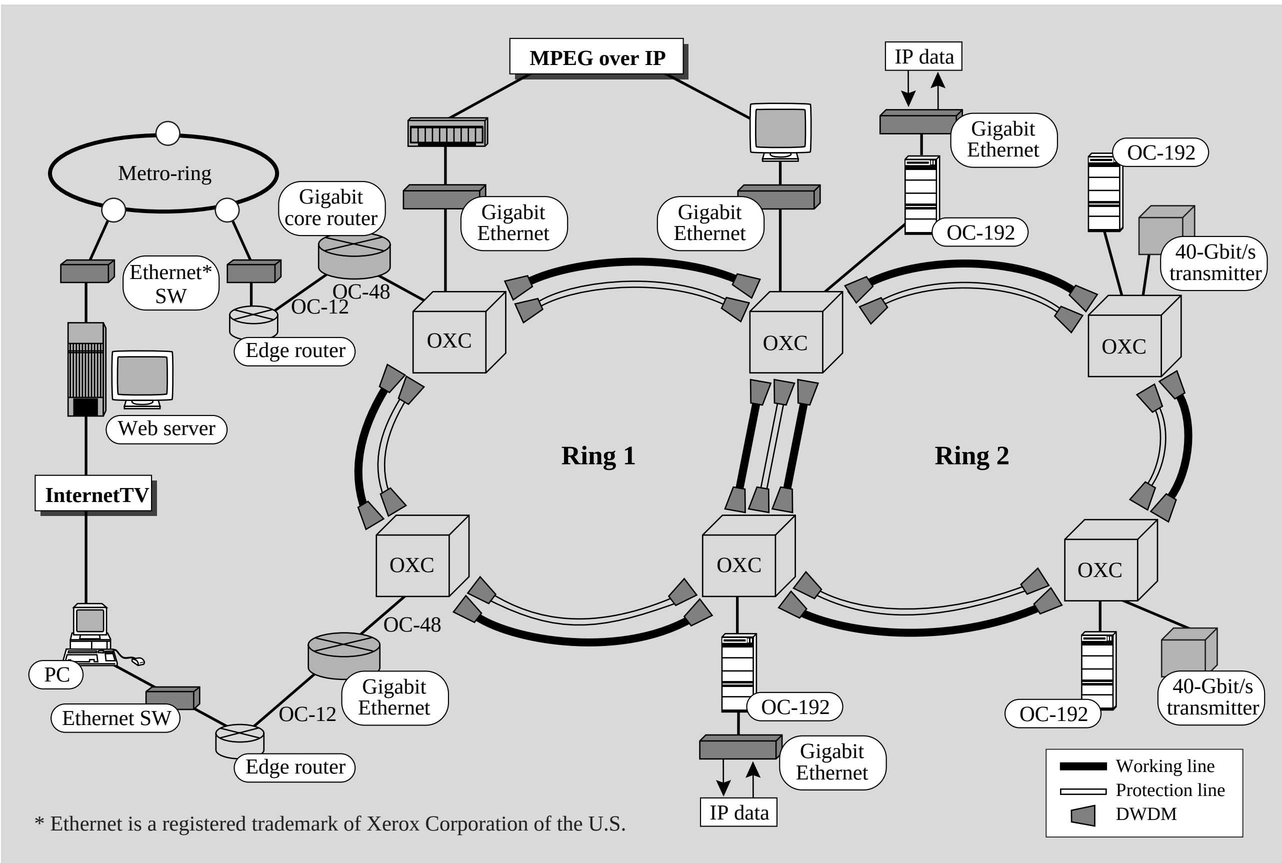


Fig. 7—Optical Shared Protection Ring Trial Network Using OXCs.

novel OXC prototype based on wavelength channel switching has been developed . Bit rate, wavelength, and traffic protocol (format) transparencies of optical switches are utilized. This type of OXC supports optical protection and restoration of point-to-point transmission systems by building an optical ring network. Restoration resources are shared on the ring. A wavelength switch unit has both span and ring switching capabilities that are similar to the SDH/SONET self-healing ring, BLSR. Survivability of the optical ring is the same or better than that of the conventional BLSR. The restoration time is less than 50 ms. Through DWDM, an overlay of the OXC ring network is available on the installed BLSR without changing the installed equipment configurations. This means that flexible and cost-effective network migration is available from the current SDH/SONET systems into SDH/SONET and IP over DWDM.

Using the newly developed OXC prototype, a technology trial of optical rings was also done in the metro Dallas area of MCI WorldCom. Fig. 7 shows the logical configuration of this trial network. The network consists of two rings with dual-ring interconnection and shared restoration. Through the OXC, transmission of gigabit routers, gigabit Ethernets and 40 Gbit/s signals as well as the conventional SONET equipment (OC-48 and OC-192) was successfully obtained. Mixed applications, including MPEG over IP, Internet TV and IP data and voice, were evaluated. Optical restoration to be within 50 ms was achieved with the optical ring.

This trial showed that optical layer restoration based on optical rings can support highly reliable IP-over-DWDM networks.

CONCLUSIONS

A DWDM system with 32 channels and 320-Gbit/s total transmission capacity was developed. The optical power of each channel was kept constant by a newly developed EDFA level controller. Moreover, a next-generation DWDM system, such as 128-wavelength-channel optical-path networking, is under development. The optical protection ring using OXC is expected to provide a reliable IP-over-DWDM network.

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ABOUT THE AUTHORS

Masahiro Ojima

Joined Hitachi Ltd. in 1977, and now works at the Photonic Network Center of the Fiberoptic Transmission Operation, Telecommunications System Group. He is currently engaged in the development of photonic DWDM network systems. Dr. Ojima is a member of the Institute of Electronics, Information and Communication Engineers of Japan and the Japan Society of Applied Physics, and can be reached by e-mail at masahiro_ojima@cm.tcd.hitachi.co.jp

Hiroyuki Nakano

Joined Hitachi, Ltd. in 1981, and now works at the Long Haul Transmission Department of Fiberoptic Transmission Operation, Telecommunications System Group. He is currently engaged in the development of a DWDM transmission system. Dr. Nakano is a member of the IEEE and the Institute of Electronics, Information and Communication Engineers of Japan, and can be reached by e-mail at hiroyuki_nakano@cm.tcd.hitachi.co.jp

Shinya Sasaki

Joined Hitachi, Ltd. in 1980, and now works at the Optoelectronics Research Department, Central Research Laboratory. He is currently engaged in the research and development of photonic network systems. Dr. Sasaki is a member of the IEEE and the Institute of Electronics, Information and Communication Engineers of Japan, and can be reached by e-mail at s-sasaki@crl.hitachi.co.jp

Shoichi Hanatani

Joined Hitachi, Ltd. in 1982, and now works at the Dallas Advanced System Center, Hitachi Telecom (USA), Inc. He is currently engaged in the development of photonic network technology. Mr. Hanatani is a member of the IEEE and the Institute of Electronics, Information and Communication Engineers of Japan, and can be reached by e-mail at shanatan@hitel.com