High-Capacity Home Optical Network System, Employing 1550nm-Band Coarse WDM Technology and Single-Mode Optical Fiber

Keiko MORIYAMA*, Nguyen Hoang Viet**, Satoru FUJIMOTO**, and Yutaka KATSUYAMA**

* Japan Solderless Terminal Manufacturing Co., Ltd, Japan

** Graduate School of Engineering, Osaka Prefecture University, Japan

E-mail: kmoriyama@jst-mfg.co.jp, katsu@neptune.ees.osakafu-u.ac.jp

Abstract

A high-capacity home optical network system was investigated and constructed. A novel approach was tried to give integrated broadband services between each terminal in a user premise and public content/service provider. The system consists of a newly-constructed home controller to connect terminals and public provider, 1550nm-band coarse wavelength-division-multiplexing (WDM) technology for standardized 1000Base/100Base-F optical transceivers, and single-mode optical fiber bus installed in a user premise. Multi-terminals in 2 rooms can request/receive 100Mbps signals independently in a single premise, and that is possible for maximum 4 rooms. This system enables us to accelerate introduction of optical broadband services, such as video-on-demand, into customer premises in fiber-to-the-home era.

Keywords: *home optical network, coarse WDM, gigabit Ethernet, 1000Base-F, optical bus*

1. Introduction

Recently data-traffic volume continues to grow at an explosive rate, mainly due to the internet services. Many approaches have been tried to the development of optical internet networks to transmit such huge traffic volumes through IP-over-optical network architecture [1]. These approaches include not only to the core backbone networks but also to the metropolitan/regional and access networks. Such researches accelerate the optical fiber introduction, supplying broadband services to general users. In the access networks, the cost reduction is the major issue to be solved for such an opticalization. Optical fibers are introduced into apartments or high-density residential areas, where many users are concentrated so as to supply optical fibers in a cost effective way.

Inside customer premises, different technologies are used and investigated. For the business use in offices, LAN technologies are used, and high-speed products are introduced: 10, 100 and 1000Base-X technologies. It seems that the broadband technologies inside single houses are not investigated explicitly. It should be clarified what system is suitable in the coming fiber-to-the-home (FTTH) era. Electrical power and telephone lines are installed in general houses. And UTP (unshielded twist pair) cables are also installed, if personal computers are used for the internet connection. Home networks are investigated [2] to interconnect electronic products and systems, enabling remote access to and control of those products and systems, and any available content such as music, video or data. We addressed an issue whether single-mode optical fibers are necessary or not in home networks for the integrated broadband services in the FTTH era. As a first step, we investigated a novel approach to a high-capacity home optical network system, employing coarse WDM technology and single-mode optical fibers. The system requirements were specified and the overall network was designed. The system was implemented and the performance was examined, showing successful results. The design and performance are described.

2. System Design and Configuration

2.1 Requirements

The home optical network system configuration is shown in Fig.1. A single-mode optical fiber is installed so as to connect all the rooms as an optical bus. A room interface (IF) is attached to the optical bus, supplying communication capability to the terminals in the room. A controller (CR) is installed in each home, being attached to the optical bus. This CR has a switching function to connect all the terminals in the home and/or public

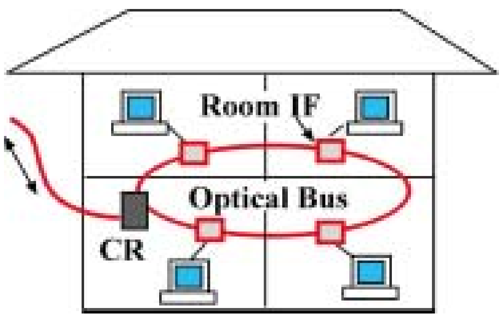

Fig.1 Home Optical Network Configuration

content/service provider.
Table 1 summarizes the requirements for the system. The communication services are supposed to be provided by the independent connections between rooms inside the home and between each room and public providers. The maximum number of the rooms is 4. The transmission speed should be 100 Mbps for each room, allowing the users to enjoy broadband service, such as video-on-demand, in addition to common internet browsing. An easy in-service construction is also required. This means that terminals can be added or removed easily after the service is in use. This is such a case as a new terminal is introduced in a room, where no services are provided yet with the optical bus, or as an in-use terminal is removed.

2.2 System Design

As a first step of the design, a question was discussed which is suitable, optical fibers or UTP cables. It is possible to install UTP cables from the controller to the rooms, respectively. However, additional cable construction is needed, leading to the high cost in general, when a new terminal is required in a room without having a UTP cable installed. From this point of view, the optical bus is preferred, because it is ready to use by adding just a room IF.
The system was designed so as to satisfy the requirements listed in Table 1.

2.2.1 Connection Function Design, Employing Hybrid Lambda Switching

In the system, the controller plays an important role to connect the requested communication independently. For this purpose electrical/optical hybrid lambda switching was designed. This is based on the combination of wavelength-division-multiplexing (WDM) in an optical domain and the layer 3 switch in an electrical domain. A particular wavelength is allocated to each room, and the optical wave is added/dropped to/from the optical bus with a wavelength-selective optical add/drop module. The layer 3 switch has an IP-based routing function, and is used for switching for the present purpose. Each terminal is given an IP address in such a way that all the terminals in a room belong to one subnet in the room, and each room has different subnet. The virtual LANs are specified in the layer 3 switch, corresponding to the rooms and public providers, respectively. Therefore, the layer 3 switch has as many virtual LANs as the room number + 1 (public provider), and can connect links between virtual LANs on IP-based technology. Thus, hybrid lambda switching scheme was designed.

2.2.2 Optical Bus Design

To utilize high-bandwidth, single-mode optical fibers were selected. Four wavelengths of coarse WDM standard were specified: 1470, 1510, 1550 and 1590 nm. The 1550nm band was selected for the 4 wavelengths, because WDM/DWDM technologies are investigated intensively, making wide range of products applicable to the system. The 40nm-wavelength spacing was selected, because wavelength-sensitive optical components are potentially easy to be fabricated.

3. System Implementation and the Performance

The home optical network system was implemented, according to the design.

3.1 Experimental Configuration

Figure 2 shows the configuration for the experiment. The system consists of the following 3 major components:
(1). Controller: it consists of a layer 3 switch (L3SW), gigabit wavelength-allocated optical transceivers (GbWA-TRs) and optical wavelength-dependent couplers. One of the GbWA-TRs is operated at a wavelength of 1310nm-band for a public provider connection, and the others are

Table 1 Requirements for the Home Optical Network System

Item	Requirements	
Service	Independent Communication between Each Room and Public Content/Service Provider	
	Independent Communication between Rooms inside the Home	
	Room Number	Maximum 4
Transmission	Speed	100Mbps
	Connection	By a Controller Installed in the House
	Optical Band	To Service Provider: 1310nm Between Rooms: 1550nm Band
Network	Optical Bus	Single-Mode Optical Fiber
	In-Service Construction	Easy Addition/Deletion of terminals

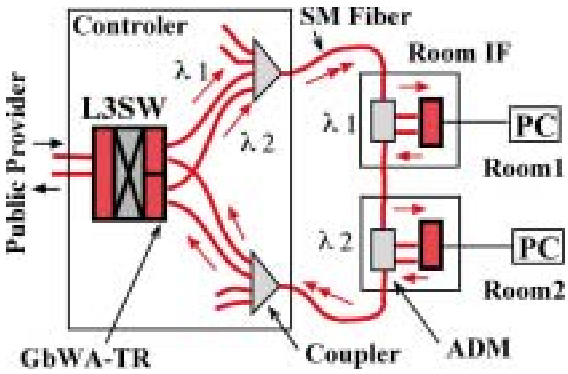

Fig.2 Experimental Configuration

operated at 1550nm-band, as described in section 2.2. The maximum number of the 1550nm-band GbWA-TRs is 4, but less number of GbWA-TRs can be installed. The controller has two wavelength-dependent couplers: one of them is for the multiplexing, and the other is for de-multiplexing. Both the couplers have functions for coupling/splitting 4 wavelengths, even if the installed GbWA-TR number is less than 4, because they should be used for the new room IF addition.

(2). Room IF: it consists of an optical add/drop module (ADM) and a GbWA-TR. The ADMs have a function to add/drop one allocated wavelength, and pass the other 3 wavelengths. Since a wavelength λ_1 was allocated to Room1, the ADM of the room IF adds/drops λ_1 in Room1, and so on. The same wavelength λ_1 was allocated to the GbWA-TR of Room1.

The GbWA-TR has an electrical gigabit-T interface, providing a port to a hub connection or a direct connection to a personal computer (PC). Two room IFs were installed in this experiment, as illustrated in Fig. 2.

(3). Optical bus: A standard single-mode (SM) optical fiber (G652 fiber) is used so as to form an optical ring starting from the coupler to the splitter of the controller in such a way to connect all the room IFs.

3.2 Experimental Network Evaluation

The network was constructed, as shown in Fig.2, and the characteristics were measured.

Four pairs of GbWA-TRs were prepared and one set of them was installed in the controller. Each GbWA-TR of the other set was installed in each room IF. The wavelengths of 1470, 1510, 1550 and 1590nm were allocated to each pair, as described in section 2. The light sources were DFB lasers and were packaged into the transceivers by standardized 1000Base-F technology. Table 2 lists the measured peak wavelengths and output powers. The peak wavelength value differences from the nominal values were within 2 nm, and the drifts were within 2 nm in time. The measured output power values were larger than +2dBm for all the transceivers. The allowable loss can be determined to be larger than 22 dB, since the minimum detectable level of the transceivers is -20dBm.

The optical wavelength-dependent coupler and splitter were fabricated, having a structure of plastic-base waveguides and optical filter inserted in the optical path of the waveguides. We selected the plastic-base structure, because it is fabricated in low-cost fabrication processes. The low cost approach is important especially for such home-use systems. Figure 3 shows measured wavelength dependent of optical loss of the splitter installed in the controller. It has a common (COM) port through which the multiplexed 4 different-wavelength lightwaves are input and has 4 individual ports through which the split lightwave is output, respectively. The optical losses of the 4 optical paths are shown in Fig. 3. It is found that the insertion losses are 6 to 7 dB for the 4 ports, and the isolations are around 20dB.

The optical add/drop modules were fabricated, having also the same plastic-base structure as the coupler, because of the low-cost approach. The wavelength dependence of the optical losses was measured. The result of the 1510nm-add/drop module is shown in Fig.4. The losses for the adding and dropping were about 6 dB, and the isolation was about 18 dB. Two add/drop modules

Table 2 Measured Characteristics of the Optical Transceivers

Optical Transceiver	CR-1	RIF-1	CR-2	RIF-2	CR-3	RIF-3	CR-4	RIF-4
Nominal Wavelength (nm)	1470		1510		1550		1590	
Peak Wavelength (nm)	1472	1472	1510	1511	1551	1550	1591	1590
Output Power (dBm)	2.3	2.4	2.5	2.3	2.5	2.6	2.8	2.8
Minimun Level (dBm)	-20							

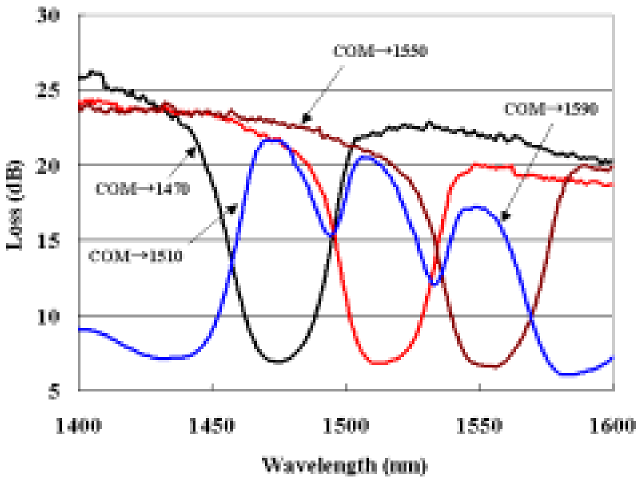

Fig.3 Measured Optical Loss of Optical Coupler

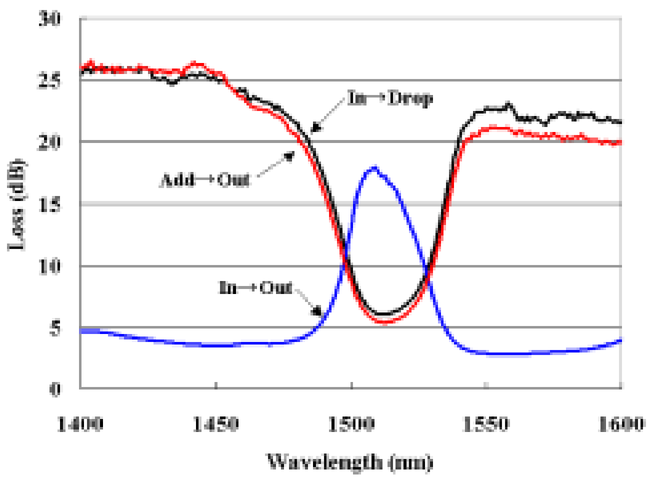

Fig.4 Measured Optical Loss of Add/Drop Module

were installed in the system, though the transceivers, the coupler and splitter had the functions for the 4 wavelengths. The 2 wavelengths of the installed ADMs were 1510nm for Room1 and 1550 nm for Room2.

The home optical network was constructed as shown in Fig.2, and the connection experiment was conducted. A web server was connected to the controller with 1310nm optical transceivers as a public content provider. The PCs in Rooms 1 and 2 got access to the web server, and the home pages could be displayed, respectively. The data on the home pages could be used in Rooms 1 and 2. The connections were confirmed to be established between the PCs in Rooms 1 and 2 by sending a ping command and receiving the reply each other. Thus, the communication capability was confirmed in the constructed network.

3.3 Discussion

To consider the communication stability in time, the pass-bands of the coupler/splitter and the add/drop modules were evaluated from the measured wavelength dependence of the optical losses. The results are listed in Table 3. The pass-band means the wavelength range where the optical losses are smaller than the minimum value + 0.5dB. It is found from Table 3 that the wavelength spacings of the pass-band are 10 to 18 nm. This result clarified that the optical signal can be transmitted between the controller and the destination ADM, depending on the allocated value, and wavelength drifts have no significant influence on the transmission. This is because the wavelength drifts of the transceivers are within 2 nm, which is fully inside the pass-bands.

The maximum room number is limited by the optical loss. It can be confirmed as follows. The maximum downstream loss L_{DOWN} and the maximum upstream loss L_{UP} from/to the controller are given by the loss summation of all the components along the path from the controller to the farthest ADM. The losses are given by

$$L_{DOWN} = L_C + (n\text{-}1)L_{THROUGH} + L_{DROP} + L_{BUS}$$
$$L_{UP} = L_S + (n\text{-}1)L_{THROUGH} + L_{ADD} + L_{BUS},$$

where L_C and L_S are losses of the coupler and splitter, $L_{THROUGH}$, L_{DROP}, and L_{ADD} are passing-through, dropping and adding losses of the add/drop module, L_{BUS}, and n are optical loss of the bus and number of the add/drop modules, respectively. Since the losses of coupler and splitter are almost the same, and $L_{DROP} = L_{ADD}$, the above 2 equations are identical. Therefore, the maximum number n is given by the n value satisfying

$$L_{DOWN} \leq 22dB,$$

since the allowable loss was 22dB, which was obtained for the optical transceivers. The result is n=4, when the typical values of L_C =6dB, $L_{THROUGH}$ =3dB, L_{DROP} =6dB and L_{BUS} =1dB are input. Thus, the networking for maximum 4 rooms is possible in this configuration, though the experimental results were obtained in the 2-room networking.

4. Conclusion

A high-capacity home optical network system was investigated. The system requirements were specified and overall network was designed and constructed. A novel approach was tried to give integrated broadband services between each terminal in a user premise and public content/service providers. The system consists of a newly-constructed home controller to connect terminals and public provider, 1550nm-band coarse WDM technology for standardized 1000Base/100Base-F optical transceivers, and single-mode optical fiber bus installed in a user premise. Multi-terminals in 2 rooms can request/receive 100Mbps signals independently in a single premise, and that is possible for maximum 4 rooms. This system enables us to accelerate introduction of optical broadband services, such as video-on-demand, into customer premises in fiber-to-the-home era.

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References

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Table 3 Measured Pass-Band

Type	Port	wavelength (nm)	Pass-Band (nm)
Coupler	1470	1475	1469-1481
	1510	1512	1507-1521
	1550	1556	1546-1560
	1590	1583	1577-1595
Splitter	1470	1472	1467-1478
	1510	1513	1508-1520
	1550	1553	1547-1560
	1590	1580	1576-1594
1510ADM	Drop	1512	1506-1519
	Add	1513	1506-1520
1550ADM	Drop	1552	1548-1558
	Add	1552	1546-1559