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PERFORMANCE EVALUATION ON WAVELENGTH PATH RELOCATION VIA NODE-SIDE CONTROL IN AWG-STAR NETWORK

Osanori Koyama, Minoru Yamaguchi, Hiroaki Maruyama
Takumi Niihara and Makoto Yamada

Graduate School of Engineering
Osaka Prefecture University
Gakuen-cho 1-1, Naka-ku, Sakai, Osaka 599-8531, Japan
{ koyama; myamada }@eis.osakafu-u.ac.jp; { su106040; sv106044; swb01119 }@edu.osakafu-u.ac.jp

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Abstract. *Arrayed waveguide grating (AWG) has developed optical fiber communication networks in order to satisfy rapidly increasing traffic demands. We showed novel AWG-STAR network which had a function of dynamic wavelength path relocation using only some optical switches deployed in communication node without improving AWGs itself in previous studies. In this letter, we demonstrate in detail some performances about the dynamic wavelength path relocation function of the AWG-STAR network by controlling optical switches. An experimental network based on the AWG-STAR network was constructed so as to evaluate the relocation performances. It was demonstrated that the transmission capacity between communication nodes could be dynamically increased by enabling looped-back wavelength path via node-side control in the experimental network. Furthermore, IP packet loss characteristic on the relocation was investigated. Then, optical loss in the experimental network was measured. It was clarified that the optical loss increased to approximately 4.8 dB if the wavelength path was looped-back once.*
Keywords: Arrayed waveguide grating, Wavelength division multiplexing, Local area network, Ethernet

1. **Introduction.** Communication networks including core network, metropolitan area network (MAN) and local area network (LAN) which contains corporate network, campus network and data center network require enhancement in transmission capacity due to the huge data volume of digital media content and the increased use of network communications by the diffusion of Internet access devices. To satisfy the rapidly increasing traffic demands, various optical fiber networks have been proposed, for example, networks using arrayed waveguide grating (AWG) [1-3], which can route lightwaves according to their wavelength. This trend has led to introduction of optical transmission technologies into LANs. In addition, low-cost optical devices have been developed for use in LANs, because LANs require cost-effective components.

From the viewpoint of achieving enhancement and flexibility of transmission capacities in LANs which have optical fibers and optical transceivers, layer-3 switches, and so on, we previously proposed and fabricated a reconfigurable add-drop multiplexer (ROADM) that could be placed in communication nodes as a wavelength router in an Internet protocol (IP)-Ethernet over wavelength division multiplexing (WDM) network [4]. The ROADM could dynamically relocate wavelength paths by changing the status of 2×2 optical switches installed in the ROADM [5]. This method is referred to as node-side control. We demonstrated that traffic congestion in the experimental network could be effectively circumvented with wavelength path relocation function by controlling node-side optical switches [6].

In AWG-STAR networks proposed in previous reports [1-3], the AWG itself was improved to achieve flexible allocation of wavelength paths [7,8]. However, the AWG itself improvement is expensive. And so, we recently proposed a novel AWG-STAR network using conventional AWG without particular developing [9]. The AWG-STAR network is capable of dynamically relocating the wavelength paths by looping-back the wavelengths transmitted to the communication nodes by changing the states of the optical switches installed in the communication nodes [10] through IP-routing control system [11,12]. This approach is cost effective, because it only requires some optical switches and the AWG does not need to be improved. Such network is suitable for use in the networks which requires cost-effectiveness such as LANs. In this letter, we demonstrate that the looped-back wavelength paths can enhance the transmission capacity between the communication nodes via node-side control in experimental network based on the AWG-STAR network we constructed. Moreover, we evaluated the impact of dynamic wavelength path relocation on IP packets loss in detail. Finally, the optical loss due to relocating a wavelength path once was clarified. In Section 2, we explain about AWG-STAR network with wavelength path relocation function realized by controlling optical switches. In Section 3, we show performance evaluations about transmission capacity, packet loss and optical power along wavelength path on experimental network we constructed. Finally, we summarize the results of the research in Section 4.

2. **AWG-STAR Network with Wavelength Path Relocation Function.** Figure 1 shows a schematic of the AWG-STAR network with function of wavelength path relocation. The $N \times N$ AWG in Figure 1 can route lightwaves according to their wavelengths, logically provides wavelength paths with a full-mesh topology, and physically connects to communication nodes by a pair of single-mode optical fibers (G.652) with a star topology. Each communication node consists of local networks and a gateway. The gateway consists of an optical add-drop multiplexer (OADM) that can multiplex and de-multiplex N wavelengths, N optical switches (OSWs) corresponding to the wavelengths, and an electrical layer-3 switch (L3SW) for Ethernet-switching and IP-routing. The local network communicates with the other nodes through the gateway. At any given time, each OSW has one of two states, either C_{PT} or C_{LB}, as shown in Figure 1. When the state of the OSW is C_{PT}, an optical transceiver installed in the L3SW can input/output optical signals to/from the OADM. When the state of the OSW is C_{LB}, the wavelength inputted from the OADM is looped-back to the OADM through the OSW. Each L3SW can switch Ethernet frames in the data link layer and route IP packets in the network layer.

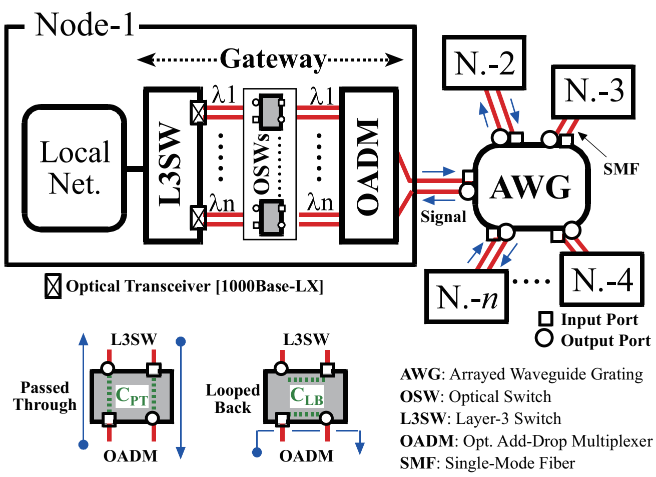

FIGURE 1. Schematic of AWG-STAR network with wavelength path relocation function

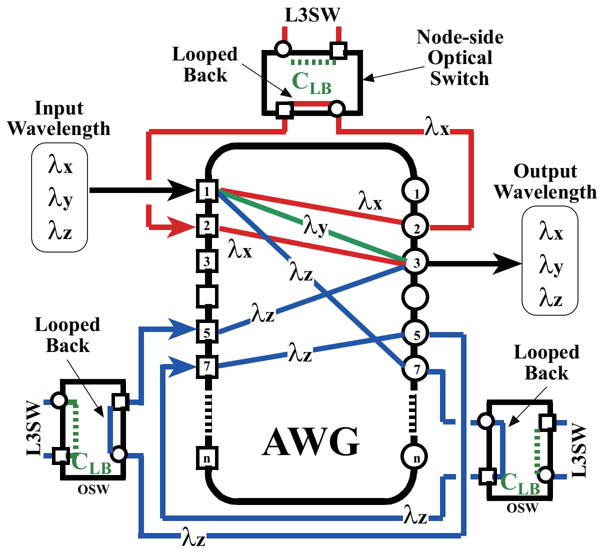

FIGURE 2. Loopback by switching OSWs

The transmission capacity between communication nodes can be enhanced by the looped-back wavelength path, as shown in Figure 2. When wavelengths (for example, λ_x, λ_y, λ_z) are input into input port 1 (InP-1) of the AWG, the wavelengths are output from different output ports (OutPs) by a wavelength routing function (OutP-2: λ_x, OutP-3: λ_y, OutP-6: λ_z). Wavelength λ_x is transmitted to node 2. It can be looped-back to InP-2 of the AWG by changing the state of the OSW corresponding to λ_x in node 2. The looped-back λ_x is then input into InP-2 and subsequently routed to OutP-3. In the same way, λ_z is looped-back to InP-6 in node 6. Then, λ_z is routed to OutP-5 and is input into InP-5 in the same way as λ_z is looped-back in node 5. Finally, λ_z is routed to OutP-3. In this example, the transmission capacity between communication nodes 1 to 3 increases threefold via node-side control. The wavelength can be looped-back multiple times until the accumulated optical loss given by the AWG, OADMs, OSWs, optical fibers, and so on, is within an allowance.

3. **Performance Evaluation for Transmission Capacity, Packet Loss and Optical Power along Wavelength Path.** We constructed the AWG-STAR network experimentally in our laboratory. Table 1 shows the wavelength routing function of the 8×8 AWG installed in the experimental network (λ_1: 1610 nm, λ_2: 1470 nm, λ_3: 1490 nm, λ_4: 1510 nm, λ_5: 1530 nm, λ_6: 1550 nm, λ_7: 1570 nm, λ_8: 1590 nm). Figures 3 and 4 show the measured optical losses of the AWG used for the experiment depending on wavelength. Figure 3 indicates the loss values of the wavelength paths from InP-1 to OutP-k ($k = 1, \ldots, 8$). It is found that the optical losses at the transmission wavelengths are around 4.5 dB, and the isolations are larger than 20 dB. In the same way, the loss values of the wavelength paths from InP-2 to OutP-k are shown in Figure 4. All the other losses of the transmission wavelengths from InP-3 through InP-8 were also measured. The variations of the measured insertion losses were very small, and the losses were also around 4.5 dB. The transmission lengths between the nodes can be estimated to be about 50 km, when optical transceivers with power budget of 22 dB are used, and the loss of the fiber is 0.35 dB/km, including the splice losses. Since the L3SWs in the experimental network supported standard 1000BASE-LX, optical transceivers with the power budget of 22 dB were used. Therefore, transmission capacity of one wavelength path was 1 Gbps. The OADM in a communication node could multiplex and de-multiplex eight wavelengths. Eight OSWs were connected to the OADM shown in Figure 1. Each wavelength could

be transmitted to the L3SW or looped-back to the OADM, depending on the OSW state (C_{PT} or C_{LB}).

Table 1. Loopback by switching OSWs

AWG Port	OutP-1	OutP-2	OutP-3	OutP-4	OutP-5	OutP-6	OutP-7	OutP-8
InP-1	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8
InP-2	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
InP-3	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
InP-4	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5
InP-5	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4
InP-6	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3
InP-7	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2
InP-8	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1

Label	Wavelength [nm]
λ_1	1610
λ_2	1470
λ_3	1490
λ_4	1510
λ_5	1530
λ_6	1550
λ_7	1570
λ_8	1590

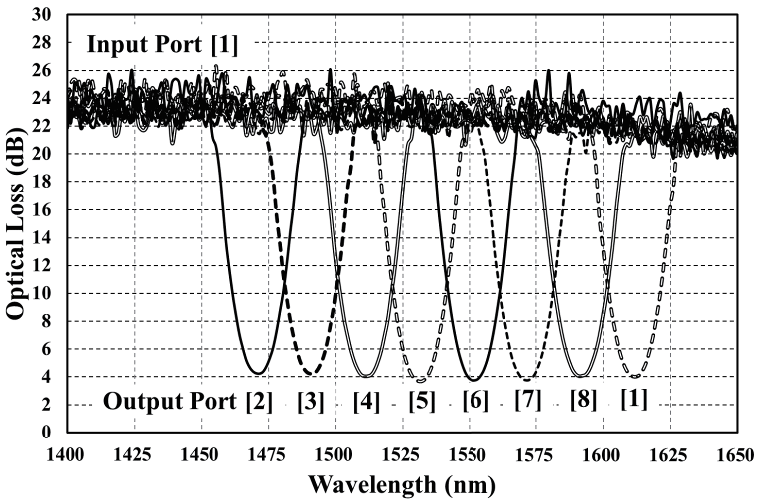

Figure 3. AWG optical losses from input port [1] to other ports

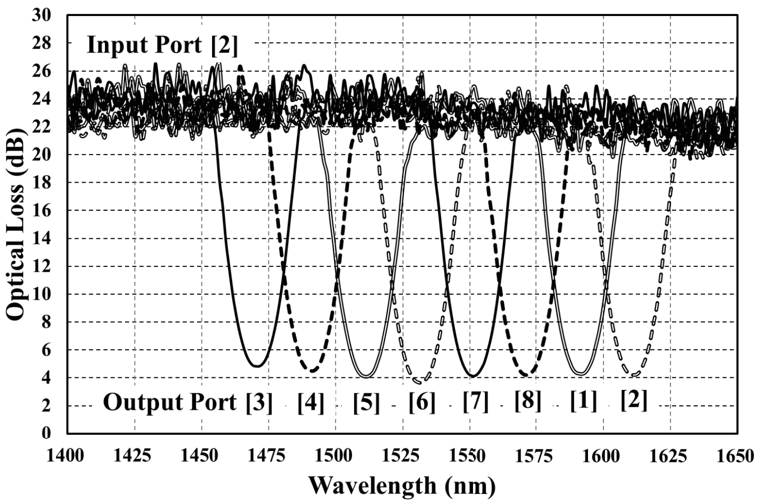

Figure 4. AWG optical losses from input port [2] to other ports

3.1. **Transmission capacity and packet loss.** In the experimental network, we demonstrated the enhancement of the transmission capacity between the communication nodes by enabling a looped-back wavelength path. The experimental network and setting are shown in Figure 5. Wavelengths λ_2 and λ_3 multiplexed in the OADM in node 1 were input into InP-1 of the AWG. A direct wavelength path (λ_3) between nodes 1 and 3 was constructed because λ_3 was routed to node 3 by the routing function of the AWG, as shown in Table 1. In the same way, λ_2 was routed to OutP-2 and transmitted to node 2. When the state of OSW corresponding with λ_2 in node 2 was changed from C_{PT} to C_{LB}, λ_2 was looped-back to the AWG. The looped-back λ_2, which was input into InP-2 of the AWG, was routed to OutP-3. Thus, a looped-back wavelength path was enabled, because λ_2 was transmitted to node 3. Consequently, the transmission capacity between communication nodes 1 to 3 could be increased twofold.

Figure 6 shows the experimental result for the increased transmission capacity between nodes 1 and 3. The size of IP version 4 (IPv4) packets was set to 1500 bytes. Router tester shown in Figure 5 generated two IP-packet streams (St.1 and St.2). The streams were input to L3SW in node 1. Then, they were transmitted from node 1 to node 3. Finally, the router tester received them and measured throughput and packet loss. Total measured

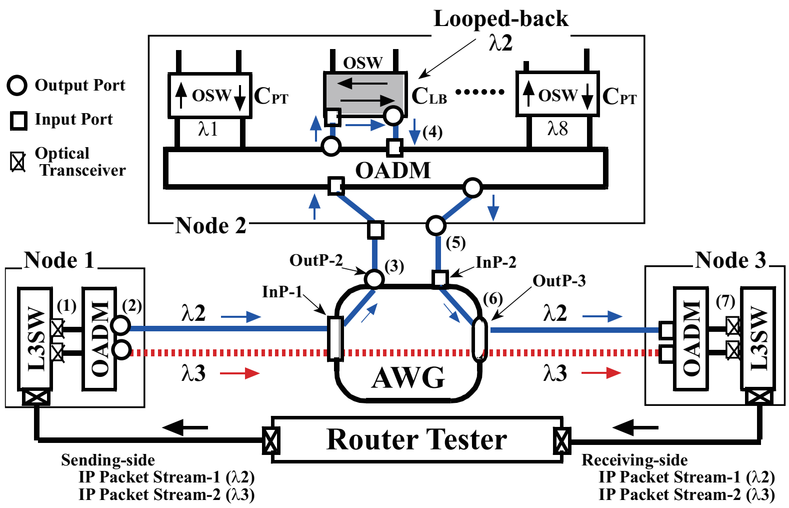

FIGURE 5. Experimental network and setting for evaluating wavelength path relocation performance

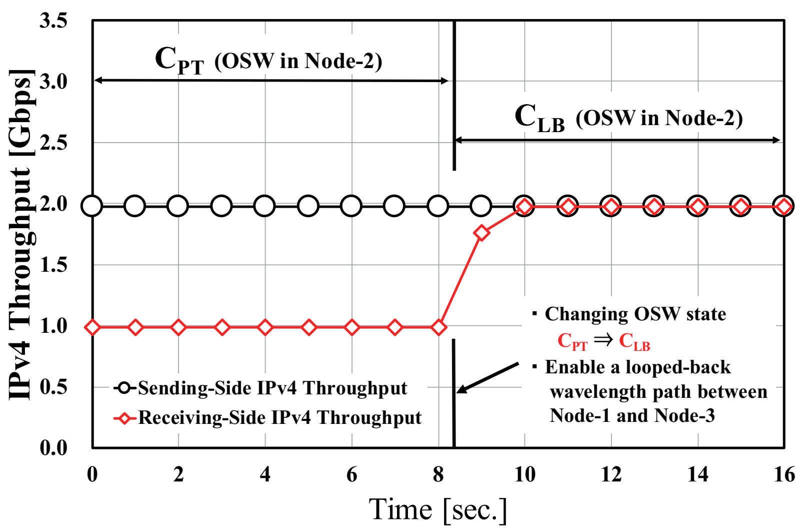

FIGURE 6. Change on throughput

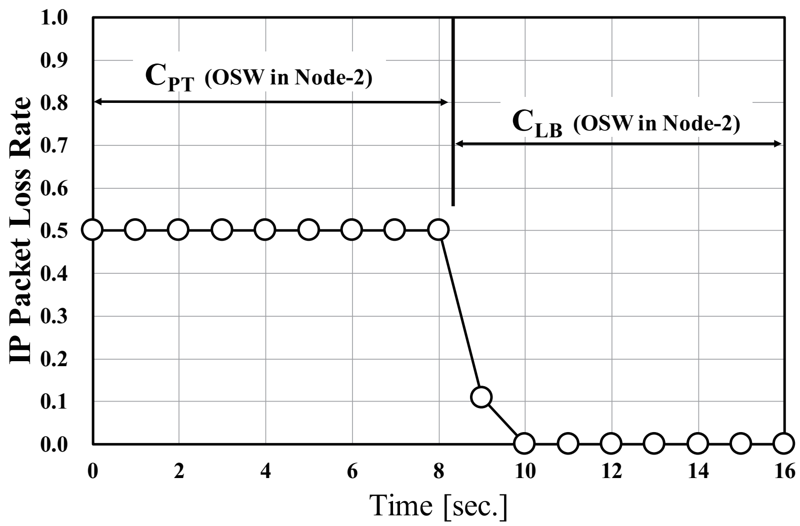

Figure 7. Change on packet loss rate

transmitting-side IPv4 throughput including St.1 and St.2 was 1973 Mbps, as shown in Figure 6. When the state of the OSW (λ_2) in node 2 was C_{PT}, the two streams were transmitted to node 3 by only a direct wavelength path (λ_3). Total measured receiving-side IPv4 throughput including St.1 and St.2 was 987 Mbps, because the streams shared the transmission capacity of the direct wavelength path (λ_3). The state of the OSW (λ_2) in node 2 was then changed from C_{PT} to C_{LB} at approximately 8 seconds after the beginning of measurement. A looped-back wavelength path (λ_2) between nodes 1 and 3 was activated after the state of the OWS was changed. Only St.2 was transmitted through the looped-back wavelength path (λ_2), and St.1 was still transmitting through the direct wavelength path (λ_3). Accordingly, the total receiving-side IPv4 throughput increased to 1973 Mbps, because each stream could be dedicated to one wavelength path. Figure 7 shows averaged IP packet loss rate on St.1 and St.2. When the wavelength path between nodes 1 and 3 was only λ_3, the packet loss rate was 50%. After the state of the OWS in node 2 was changed, the rate decreased to 0% for the case that λ_2 and λ_3 were between nodes 1 and 3. This result indicates that this node-side control approach for adding looped-back wavelength paths did not create adverse effects for the communication services. Furthermore, the transmission capacity between nodes was enhanced dynamically by controlling the state of the OSWs installed in the communication nodes.

3.2. **Optical power along wavelength path.** Figure 8 shows the measured optical powers corresponding to λ_2 (through looped-back path) and λ_3 (through direct path) at various points of the experimental network. The notation ($x : 1, 2, \ldots, 7$) shown in Figure 8 indicates the locations in experimental network as shown in Figure 5. The measured output powers of optical transceivers installed in the L3SW of node 1 were 1.61 dBm (λ_2) and 1.85 dBm (λ_3) at (1) shown in Figure 5. The powers passed through OADM in node 1 were −3.07 dBm (λ_2) and −3.34 dBm (λ_3) at (2), respectively. The powers along the direct wavelength path (λ_3) were −7.77 dBm at (6), and −9.00 dBm at (7). On the other hand, the output powers along the looped-back wavelength path (λ_2) were −7.24 dBm at (3), −7.54 dBm at (4), −7.90 dBm at (5), −12.57 dBm at (6), and −14.04 dBm at (7). The total optical losses of the direct wavelength path (λ_3) and the looped-back wavelength path (λ_2) were 10.85 dB and 15.65 dB, respectively. It was found that the optical loss increased to approximately 4.8 dB if the wavelength path was looped-back once. It was also confirmed that the optical losses were sufficiently low because the acceptable powers at which optical transceiver could recognize received IP packets accurately were −22 dBm and each received power at (7) was higher than the acceptable power.

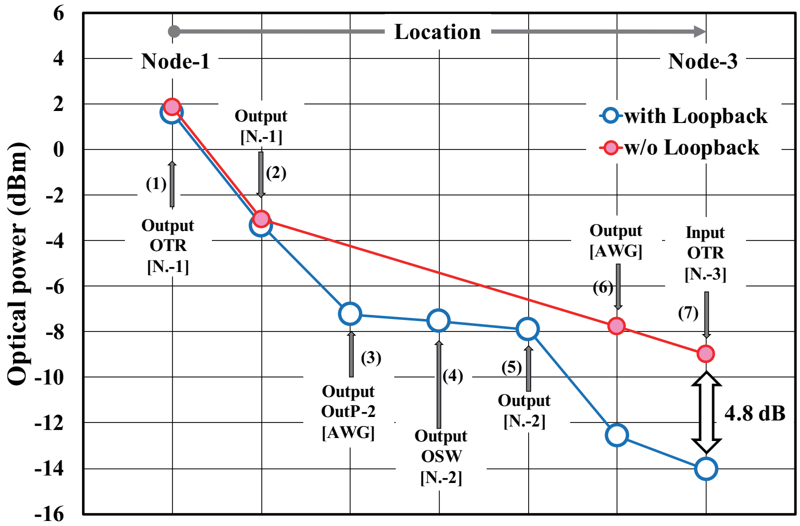

Figure 8. Measured optical powers corresponding to looped-back wavelength path (λ_2) and direct wavelength path (λ_3)

4. **Conclusions.** We demonstrated the performances of the dynamic wavelength path relocation function of the AWG-STAR network by controlling optical switches in detail. The experimental network based on the AWG-STAR network was constructed in our laboratory actually. It was confirmed that the transmission capacity between communication nodes could be enhanced dynamically by enabling a wavelength path that was looped-back via node-side control in the experimental network. It was also found that the optical loss increased to approximately 4.8 dB if the wavelength path was looped-back. It is, therefore, necessary to compensate for the optical losses of looping-back in order to make wavelength relocation more flexible. In our future work, we will study an appropriate amplifier for the AWG-STAR network and incorporate this amplifier into the network design.

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