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LETTER

Demonstration of extended ROADM architecture to enable end-to-end optical connections with covering class-S access infrastructure

Yasutaka Kimura[1, a)], **Naotaka Shibata**[1], **Shin Kaneko**[1], **Jun-ichi Kani**[1], **and Tomoaki Yoshida**[1]

Abstract We demonstrate an extended ROADM architecture with remote TRx control and a turn-back function that enables end-to-end direct optical connections covering access. The acceptable access loss of the turn-back path is within 3–19 dB, thus meeting the requirements of the class-S optical access infrastructure.

Keywords: ROADM, end-to-end optical connections, turn-back, remote TRx control

Classification: Network system

1. Introduction

Future use cases of network services such as telemedicine and digital twin computing will require a guaranteed large bandwidth and extremely low end-to-end latency and jitter [1]. Current networks typically convert optical signals into electrical signals for aggregation or multiplexing when transferring traffic at nodes between the access area and the metro area, which limits the effective bandwidth per user or service and causes delays and jitter. To overcome this, the All Photonics Network (APN), which provides end-to-end optical connectivity covering user premises, is under discussion at the IOWN Global Forum (IGF) [2]. APN flexibly provides direct optical connections between any user premises (see Fig. 1), and research into techniques such as dynamic optical path provisioning [3] is currently underway.

Reconfigurable Optical Add/Drop Multiplexer (ROADM) is a candidate system for APN because it enables flexible optical path management and provides ultra-high-speed and ultra-low latency optical paths. However, in the current ROADM architecture, the endpoints of optical paths are assumed to be located in the telecom operator's buildings, thus preventing the achievement of end-to-end (i.e., user-to-user) optical connectivity. The following three functional extensions to the ROADM architecture will allow the optical transmitter/receiver (TRx) of the ROADM to be installed on user premises, thus enabling end-to-end optical connectivity between any two points [4].

(i) Turn-back function to connect TRxs under the same ROADM

(ii) Remote control function for TRxs located at sites where there is no direct connectivity to the Data Communication Network (DCN)

(iii) Ensuring optical requirements that accommodate TRxs are located separately from the ROADM

In this paper, we first compare various implementation options for the turn-back and remote TRx control functions. Next, we present the optical requirements of the ROADM system for extending the ROADM optical transmitter/ receiver to the user premises. Finally, we discuss the experiments we performed using a commercial ROADM product and demonstrate that the acceptable loss in the access section is in the range of 3–19 dB, thus meeting the requirements of the class-S optical access infrastructure.

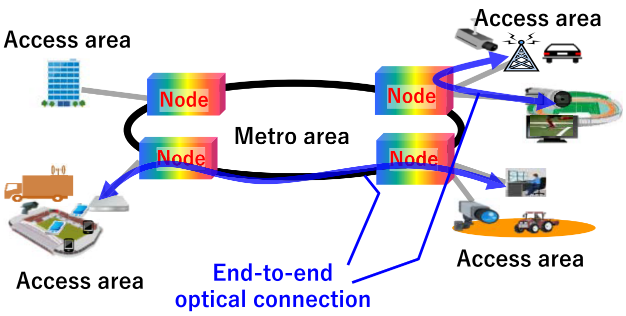

Fig. 1 End-to-end optical connections covering user premises.

[1] NTT Access Network Service Systems Laboratories, NTT Corporation, 1-1 Hikarinooka Yokosuka-shi, Kanagawa 239-0847, Japan

a) yasutaka.kimura@ntt.com

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2. Implementation options for functional extensions

Below, we consider how to implement the three functional extensions on top of the conventional ROADM configuration, which consists of Dir (Direction/Degree), SRG (Shared Risk Group or Add/Drop), and TRx [5].

2.1 Turn-back function

One way to implement the turn-back function is to equip ROADM with Dir, which consists of a pair of $1 \times N$ Wavelength Selective Switches (WSSs) for turn-back, as shown in Fig. 2(a), with the Multi-Wavelength (MW) ports of Dir connected to each other. However, this implementation requires an additional Dir.

An alternative implementation that does not require additional equipment is shown in Fig. 2(b), where the uplink ports of SRGs are connected to themselves and to neighboring SRGs. Although this configuration consumes an additional SRG port for turn-back, it requires no additional equipment and is cost-effective at the initial introduction.

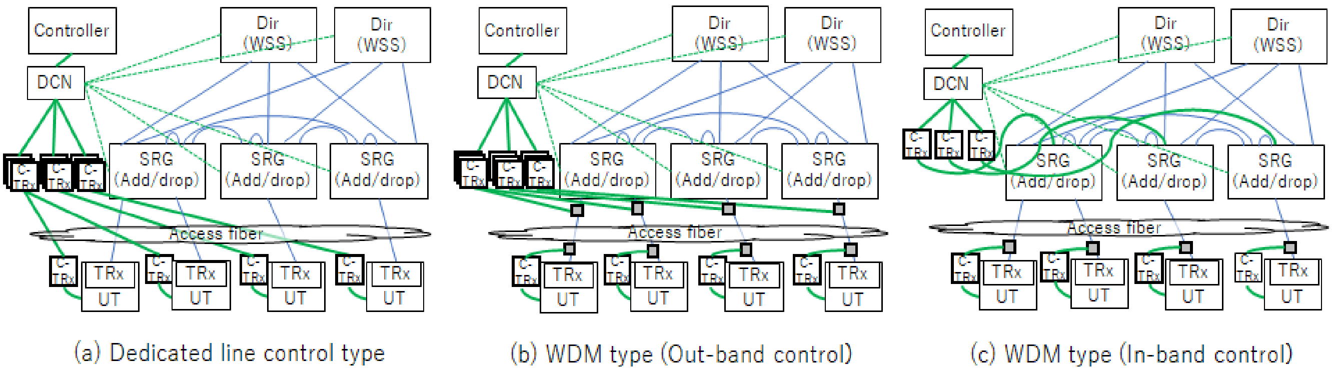


Fig. 3 Implementation options for remote TRx control.

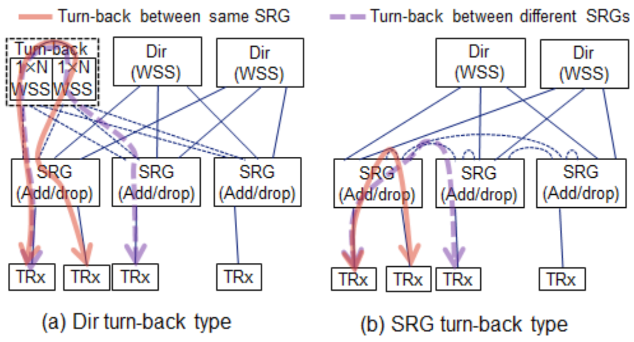


Fig. 2 Implementation options for turn-back.

To avoid wavelength collision in the ROADM, it is necessary to use a contention-less type ROADM for both the configurations in Fig. 2(a) and (b) so that TRx using the same wavelength for Tx and Rx, as with a digital coherent transceiver, can be connected to the ROADM.

2.2 Remote TRx control function

For the remote TRx control, we cannot use the in-channel Operation, Administration, and Maintenance (OAM) fields of the main signal (i.e., data channel) because the control signal must be inserted and extracted in the middle of the end-to-end optical path. Consequently, one option is to prepare a control-TRx (C-TRx) that transmits/receives control signals to/from the TRx in the User Terminal (UT) and provides a dedicated line for DCN to the site where TRx is located, as shown in Fig. 3(a). However, this implementation requires an additional fiber.

Alternative implementations that do not require additional fiber are shown in Fig. 3(b) and (c). In (b), the remote TRx control is achieved without an additional fiber by inserting a wavelength filter between the SRG and TRx. Here, the wavelength filters (small gray boxes) are responsible for wavelength multiplexing of the main signal and the control signal. However, in this configuration, the same number of pairs of C-TRx as the TRx connected to the SRG must be provided.

In contrast, in Fig. 3(c), while the insertion of a wavelength filter at the user side is the same as in (b), the C-TRx at the ROADM side is connected to the uplink port of the SRG. The switching function of the SRG allows a single C-TRx to select which TRx to control. Wavelength for the control signals needs to be one of the DWDM channels supported by WSS, while a wideband WDM can be applied in the case of Fig. 3(b). The configuration in (c) requires fewer additional components for remote control than the configuration in (b), while there is additional port consumption the SRG.

2.3 Optical requirements

To equip TRxs on user premises, it is necessary to enable end-to-end optical connectivity where access fibers exist between ROADM and TRx. ITU-T G.986 defines a class-S access infrastructure in which the fiber loss ranges from 0 to 15 dB and the maximum distance is 10 km [6].

3. Experimental results

Figure 4 shows the experimental setup for examining the end-to-end optical connection between two User Terminals (UTs) under the implementation of turn-back and in-band remote control of UTs. In this setup, to minimize the amount of additional equipment, we implemented the turn-back with the SRG turn-back type shown in Fig. 2(b) and implemented the remote control with the option shown in Fig. 3(c).

A commercial Colorless, Directionless, Contentionless (CDC) ROADM was prepared as the SRG. To pass control signals through the WSS, whitebox switches (WB-SWs) with a gigabit Ethernet DWDM C-TRx transmitted/received control signals in the 1563.863 nm (191.70 THz) band to/from the UTs.

For each UT, a C-band tunable CFP2-ACO TRx was inserted in Galileo as the coherent transport switch to transmit/receive the 100 Gbps DP-QPSK main signal. The wavelength of the CFP2-ACO TRx was allocated according to the control signal received by a Media Converter (MC) equipped with a gigabit Ethernet DWDM C-TRx. The wavelength of the main signal was allocated within the wavelength range of 1529.163 nm (196.05 THz) to 1540.162 nm (194.65 THz) to multiplex/demultiplex the main signal and control signals with the wavelength filter at each UT and uplink port of SRG. Fibers were connected between a and a, b and b, c and c, and d and d for control signal paths. A Variable Optical Attenuator (VOA) was inserted between the SRG and TRx to simulate access fiber.

Figure 5 shows the results of controlling the wavelength of the UT's digital coherent transceiver from the controller via WB-SW using this experimental configuration. The ability to change the transceiver wavelength confirms that remote

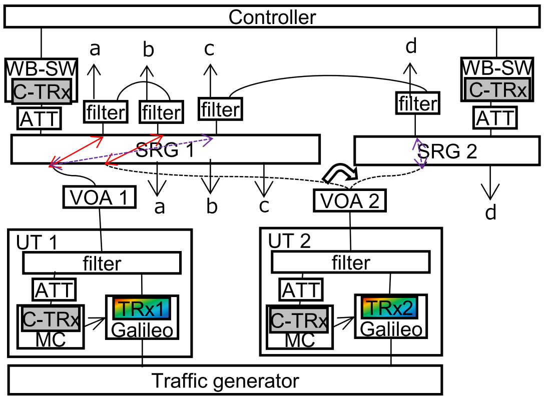


Fig. 4 Experimental setup.

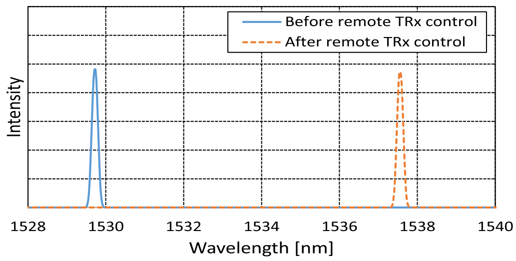


Fig. 5 Wavelength control by remote TRx control.

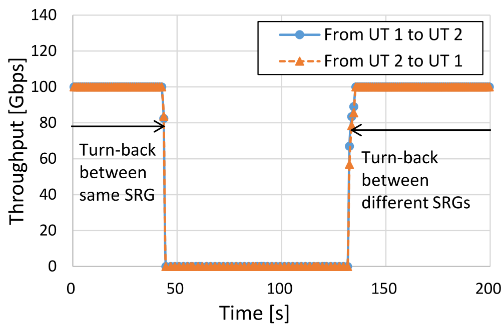
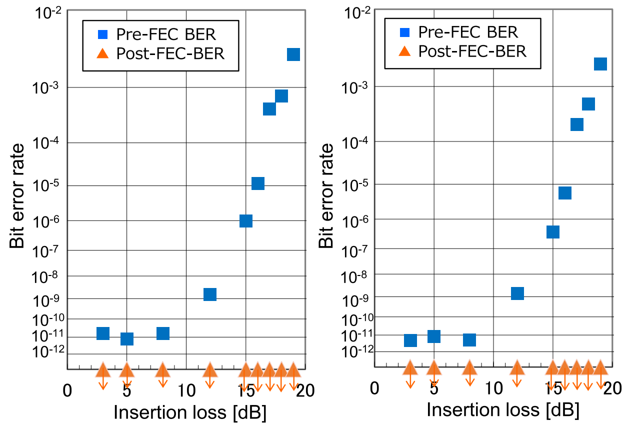


Fig. 6 Throughput before and after switching to turn-back state.

transceiver control is possible.

Figure 6 shows the throughput between UT 1 and UT 2 when a turn-back optical path was established between both UTs connected to the same SRG (SRG 1) and then UT 2 was connected to another SRG (SRG 2) from SRG 1 and the optical path was switched (from the red line to the purple line in Fig. 4) by a controller. During this switching, the traffic generator kept 100 Gbps of data flowing in both directions. We confirmed that the optical paths between UTs connected to the same SRG as well as between those connected to different SRGs can be established by this turn-back function.

The results of Pre-FEC BER and Post-FEC BER measurements are shown in Fig. 7(a) and (b), where the parameter is the insertion loss between SRG and UT before and after the optical path switching described above. The values of VOA 1 and VOA 2 were set to be equal and changed within the allowable input level of the ROADM and within the range where the traffic generator received data. Under both conditions, if the VOA losses were in the range of 3 dB to 19 dB, the Post-FEC BER was less than 10^{-12} and no frame loss was detected by the traffic generator. Namely, this configu-



(a) Turn-back between same SRG (b) Turn-back between different SRGs

Fig. 7 Bit error rate in turn-back configuration.

ration supported a dynamic range of 16 dB and a maximum loss of 19 dB. These results demonstrate that it is possible to establish an end-to-end optical path under the turn-back condition even if UTs are located at user sites, as long as the loss in the access fiber is in the class-S range (0–15 dB) with the addition of an attenuator whose attenuation is 3–4 dB.

4. Conclusion

We demonstrated an extended ROADM architecture that realizes turn-back and remote transceiver control functions.

Experiments confirmed that in-band remote TRx control and optical path rearrangements of turn-back are both feasible with the presence of access fibers where the loss ranges from 3 to 19 dB, thus supporting the requirements of the class-S access infrastructure. This extended ROADM architecture is a strong candidate for enabling end-to-end optical connections covering user premises.

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