Next-generation Optical Switch Technologies for Realizing ROADM with More Flexible Functions

Yohei Sakamaki, Takeshi Kawai, and Mitsunori Fukutoku

Abstract

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) has been attracting considerable attention recently for its potential use in constructing cost-effective photonics transport networks in long-haul and metro area transmission systems and improving their operational flexibility. This article describes the latest trends in the research and development of optical switch technologies for realizing CDC-ROADM.

Keywords: ROADM, optical switch, WSS

1. Overview of multi-degree ROADM

Reconfigurable optical add/drop multiplexing (ROADM) has brought new flexibility and scalability to conventional static photonic transport networks. Multi-degree ROADM was developed after the introduction of basic 2-degree ROADM in order to realize mesh-based network topologies [1].

We first describe here the multi-degree ROADM node configuration. A 4-degree ROADM node configuration connecting two ring networks is shown in **Fig. 1** as an example. The incoming wavelength-division-multiplexing (WDM) signals from the degree-1 input fiber are delivered to the drop-side optical switch. If these signals are to be transferred to other ROADM nodes, the optical switch selects the optical path to degree 2 (red line), degree 3 (orange line), or degree 4 (green line) for each wavelength signal. When the transponders at this node receive these signals, the optical switch selects the drop path (purple line) to deliver the signals to another optical switch, namely a transponder aggregator (TPA). Then, the TPA allocates the input signals to each desired transponder for each wavelength channel. On the add side, the output signal from the transponder is routed to an add-side optical switch by way of an add-side TPA. The add-side optical switch collects add signals and signals that pass through this node and then launches them into the output fiber.

Today, in addition to the multi-degree function, colorless, directionless, and contentionless (CDC) functions are expected to play important roles in achieving more flexibility in terms of wavelength routing and wavelength assignment [2].

2. Optical switch technologies for realizing CDC-ROADM

Next, we describe in detail the optical switch technologies required for constructing a CDC-ROADM node.

2.1 Colorless function

The freedom provided by the colorless function is that the optical signal wavelength is not fixed by the physical input/output port of the TPA and can be set using software control. The colorless function is shown in **Fig. 2** in more detail. Note that the figure shows the optical switches of degrees 1 and 3 extracted from Fig. 1(b).

The switch structure of the TPA without the colorless function is shown in Fig. 2(a). To connect the optical paths of the WDM signals between the input/output fibers of each degree and the transponders at

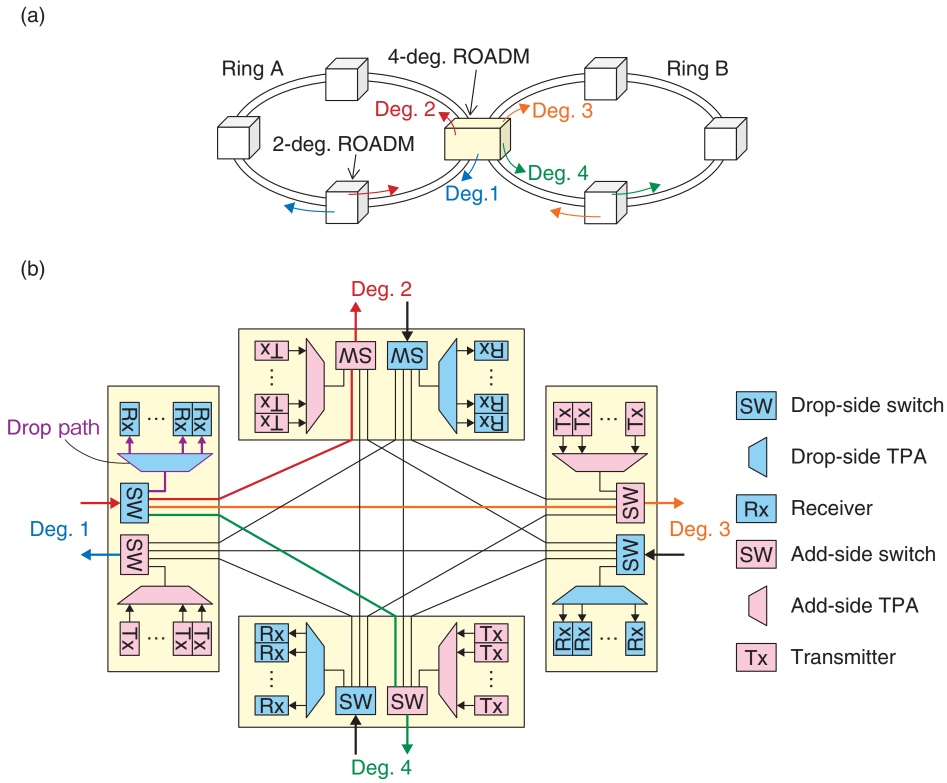

Fig. 1. (a) Example of multi-ring network and (b) 4-degree node configuration.

the ROADM nodes, the TPA must select the signal path to the desired transponder for each wavelength channel. Since a conventional TPA consists of an arrayed-waveguide grating (AWG) where the output port assignment is determined by the wavelength of the optical signal, the signal wavelength of the transponder is also determined by the port connected to the TPA. This switch structure causes certain problems with respect to operation. For example, if the signal wavelength of the transponder needs to be changed from λ1 to λ2 to deal with a traffic change, the connection port of the TPA must also be changed. This connection port change involves tasks that must be performed manually in the field at the site where the node equipment is located, and this reduces the flexibility of the network operation.

This restriction can be lifted by using a wavelength-selective switch (WSS) instead of an AWG at the TPA. The switch structure of the colorless TPA is shown in Fig. 2(b). The WSS can deliver the input WDM signals to any output port for each wavelength channel. Moreover, these output port assignments can be changed under software control. Therefore, by

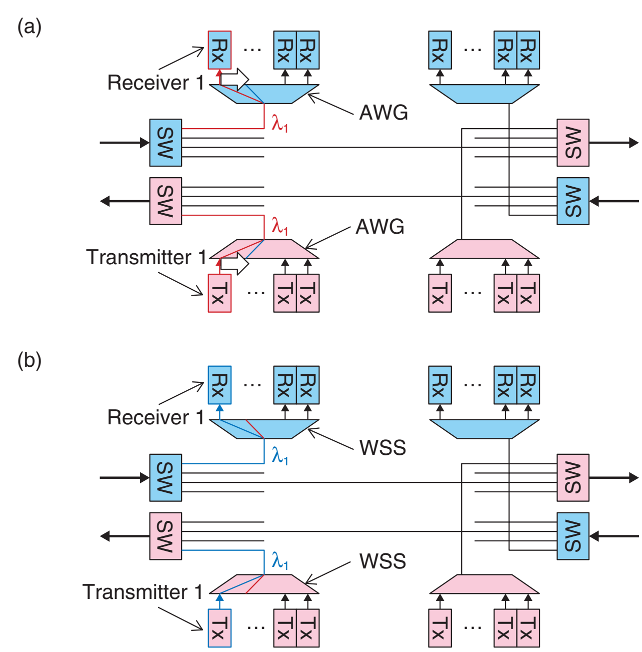

Fig. 2. (a) Colored TPA and (b) colorless TPA.

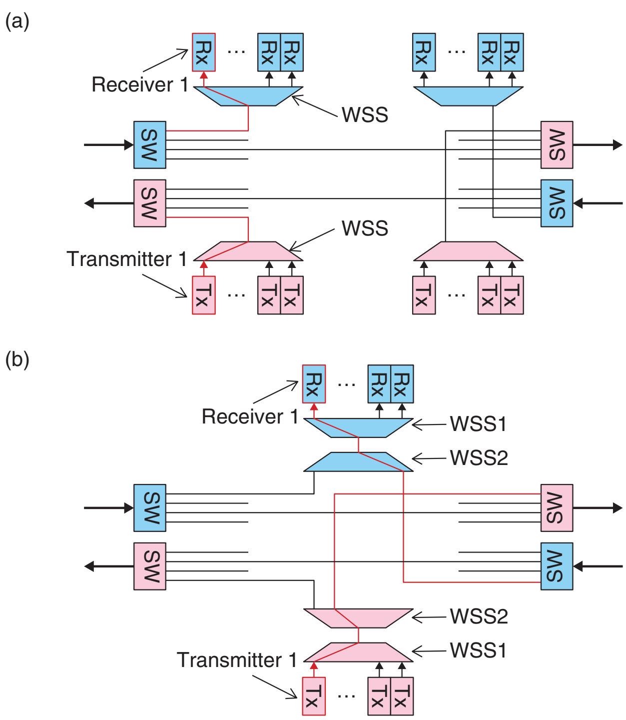

Fig. 3. (a) Directed TPA and (b) directionless TPA.

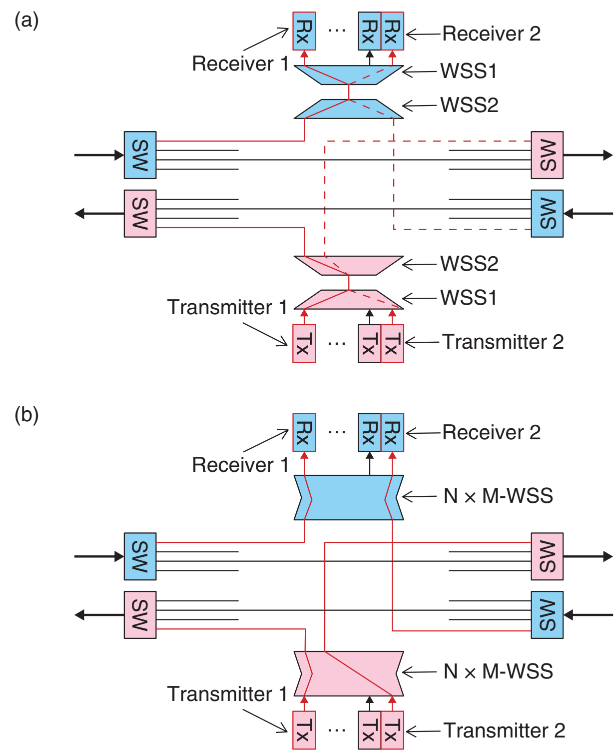

Fig. 4. (a) Contention TPA and (b) contentionless TPA.

using the WSS, we can change the wavelength path setting without having to do any work in the field. This added function is called colorless because the path between the transponders and the input/output fiber is not fixed by the wavelength (= color) of the optical signal.

2.2 Directionless function

A directionless function provides the freedom to connect the signal path from the transponder to any input/output fiber by connecting the TPA to every degree of the ROADM node. The switch structure of the directed TPA is shown in **Fig. 3(a)**. Since commercially available WSSs have a 1 × N switch structure, the signal path from the transponder can be connected to only one input/output degree. This restriction presents no problem for a conventional 2-degree ROADM, but it imposes an operational limitation on a multi-degree ROADM.

As shown in **Fig. 3(b)**, the opposite WSSs provide a way to overcome this restriction. WSS1 aggregates the signals from the transmitters (or to the receivers), and then WSS2 connects them to the desired input/output fiber for each wavelength channel. This added function is referred to as directionless. The directionless function provides numerous benefits. For example, a colorless and directionless ROADM allows spare transponders to be shared among all the wavelength channels and degrees in the node.

2.3 Contentionless function

A contentionless function removes the wavelength restriction from the TPA. This function allows multiple wavelength channels of the same wavelength at a single TPA. Thus, a transponder can be assigned to any wavelength as long as the number of wavelength channels with the same wavelength does not exceed the number of degrees.

The switch structure of a TPA with colorless and directionless functions and CDC functions are shown in **Figs. 4(a)** and **(b)**, respectively. In Fig. 4(a), multiple wavelength channels with the same wavelength cannot be input because a single fiber connects two WSSs (WSS1 and WSS2). This TPA structure imposes a restriction; that is, when the path of an optical signal with a wavelength of λ1 is connected between transponder 1 and the input/output 1-degree fiber, the path of the signal with a wavelength of λ1 cannot be connected between transponder 2 and any input/output fibers, even those other than the 1-degree fiber.

The contentionless function removes this wavelength restriction from the TPA. A TPA with the contentionless function is shown in Fig. 4(b). To realize this function, we expect to see the development of an M × N WSS, where one of the M input ports can be connected to any of the N output ports. However, M × N WSSs are not yet commercially available because of the high level of difficulty involved in achieving them. Thus, multi-cast switches have been attracting considerable attention as an alternative.

3. Recent trends in WSS development

Next, we provide a brief introduction to recent R&D activities related to the development of the WSS, which is essential if we are to realize CDC-ROADM.

(1) High port count: We must increase the number of output ports of the WSS if we are to increase the number of degrees and transponders in the ROADM node. The 1 × 2 and 1 × 4 WSSs were developed at an early stage, and the 1 × 9 WSS is now commercially available. To realize a large-scale node such as that required for 8-degree ROADM, a target of 20 or more output ports is expected.

(2) Downsizing: The equipment size increases as the number of optical switches in the ROADM nodes increases. Thus, downsizing the WSS module is an important issue in terms of realizing more functional nodes within a limited equipment size. Now, the realization of a two-in-one concept whereby a single module has the same functionality as two separate WSSs has become the development goal.

(3) Performance improvement (wider bandwidth and lower insertion loss): Successive optical filtering as a result of cascading ROADM nodes with the WSS has led to a reduction in the available bandwidth and an increase in optical signal loss. This performance degradation becomes more significant with increases in the number of WSSs that an optical signal passes through. Therefore, to suppress the degradation effect caused by introducing CDC functions into ROADM nodes, it is important to improve such optical characteristics as the bandwidth and the insertion loss of a single WSS. For example, we must achieve a wider bandwidth so that the performance degradation caused by filtering can be almost halved compared with that of a conventional WSS.

(4) Flex grid: The elastic optical network has been attracting considerable attention regarding the construction of next-generation optical communication systems with higher spectral efficiencies [3], and there has been extensive research and development activity with a view to achieving this concept. In such networks, it is essential to realize a flex grid where the frequency bandwidth occupied by a single wavelength channel can be flexibly adjusted. Thus, it is also necessary for the WSS to be able to adjust the channel bandwidth during operation.

4. Activities of NTT laboratories

Finally, we describe the recent activities of NTT laboratories in relation to CDC-ROADM. We proposed a CDC-ROADM node configuration composed of a 1 × 43 WSS and an 8 × 12 MCS based on silica-based planar lightwave circuit (PLC) technology. These optical switches were first developed in our laboratories. Our proposed approach will contribute to a substantial reduction in the size and cost of the CDC-ROADM node equipment. In addition, we reported the results of a transmission experiment showing that the introduction of these optical switches imposed no significant penalty on 100G PDM-QPSK (polarization-division-multiplexing quadrature phase-shift keying) signal transmission systems [4].

5. Future development

The traffic generated by the expanding use of various new services continues to increase. To deal with the larger amounts of traffic while maintaining or lowering network costs, we need to ensure that ROADM nodes to achieve greater flexibility, for example, by providing a CDC function. Meanwhile, to satisfy the various demands caused by the extension of the ROADM application range, it is important to achieve the optimal balance between node scale and cost. Thus, optical switches with more input/output ports and flexible connections will play important roles in achieving such optical nodes. In the future, we believe that the sophistication and miniaturization realized by integrating additional functions such as optical channel monitoring into optical switches will steadily progress once a WSS with a higher port count or an M × N WSS becomes commercially available.

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