Transponder Aggregator for 64-degree CDC-ROADM Nodes

Keita Yamaguchi, Kenya Suzuki, and Osamu Moriwaki

Abstract

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) nodes will require throughputs exceeding 8 Pbit/s by 2035, and transponder aggregators supporting high-degree and multi-band functionality will be crucial devices. We demonstrated a low-loss multicast switch capable of supporting a 300-nm bandwidth and 64 degrees, a suitable device for this purpose. The prototype's insertion loss was less than 8.0 dB in all paths, and the extinction ratio exceeded 40 dB.

Keywords: ROADM, MCS, WSS

1. Introduction

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) has been widely deployed in core and metro networks due to its high flexibility [1–5]. Due to the rapid growth in network traffic at a rate of 30% per year, the handling granularity and node throughput at ROADM nodes have increased by approximately 10 times over the last decade (**Table 1**). Extrapolating this trend, it is anticipated that in 2035, signal handling granularity will reach 10 Tbit/s, and node throughput will be required in the order of 8 Pbit/s. In contrast, the frequency-utilization efficiency is approaching saturation [5]. Instead of increasing capacity per band, it is essential to increase the wavelength bandwidth and number of connected degrees of nodes, which is equivalent to the number of connected transmission fibers. For example, on the basis of a 16-degree node using the C+L bands currently in practical use, a configuration that triples throughput by 2030 can be achieved by combining a 1.5-fold increase in bandwidth (utilizing the S-band) and a doubling of the number of fibers (supporting 32 degrees). By 2035, a configuration could achieve eight times the throughput by doubling the bandwidth and quadrupling the number of fibers (supporting 64 degrees).

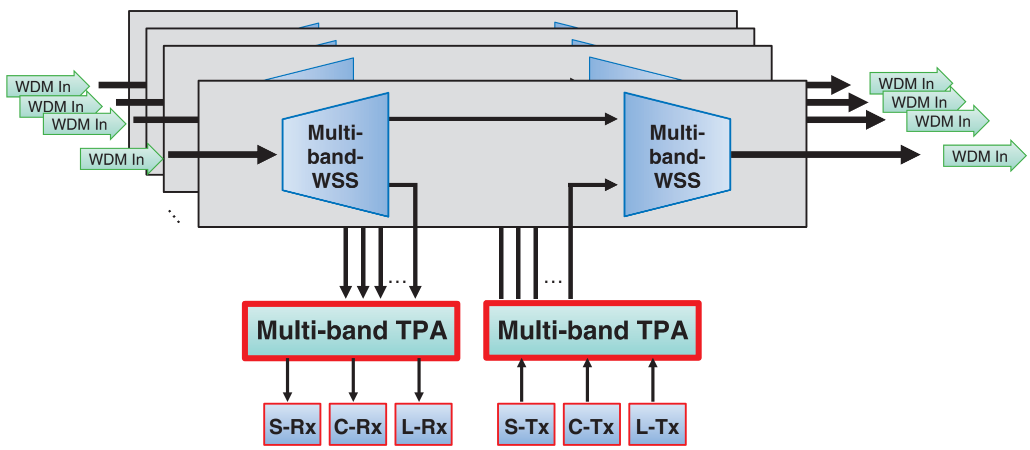
Even within such high-throughput nodes, the functionality of CDC to interconnect transponders in any direction at any wavelength remains important. To fulfil this requirement, transponder aggregators (TPAs) supporting increasingly wide wavelength bands and an extended number of degrees are necessary. We analyzed the requirements for TPAs in this context and their impact on switching characteristics and developed multicast switches (MCSs) as suitable enablers. We also developed a prototype 64×4 MCS, based on a planar lightwave circuit (PLC) platform for 64-degree links, and demonstrated its operation with less than 8-dB loss from the S- to L-bands and a high extinction ratio at a bandwidth of 300 nm.

2. TPA for future CDC-ROADM nodes

A conceptual diagram of a CDC-ROADM node supporting multi-degree and multi-band functionality is shown in **Fig. 1**. It consists of a wavelength cross-connect [6–8] and transponder aggregation [9–12]. The typical configuration consists of a pair of wavelength-selective switches (WSSs) for each link degree and wavelength-path routing. Therefore, the expansion of link degrees is accompanied by an increase in the number of WSSs. WSSs with multi-band support can also accommodate signals over a wide wavelength band [13, 14]. TPAs, however, offer

Table 1. Configuration of CDC-ROADM nodes and various requirements.

Year	2013	2019	2024	2030	2035
Handling granularity	100 Gbit/s	400 Gbit/s	800 Gbit/s	**3.2 Tbit/s**	**~10 Tbit/s**
Node throughput	77 Tbit/s	200 Tbit/s	820 Tbit/s	**2.5 Pbit/s**	**~8 Pbit/s**
Capacity/Band	9.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s
Node degree	8	8	16	**> 32**	**> 64**
Band	Single (C/L)	Single (C/L)	Dual (C+L)	Dual plus extra waveband (S-L)	**More waveband (S-U)**



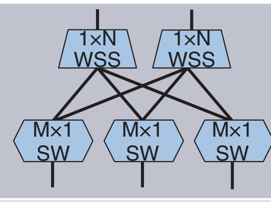
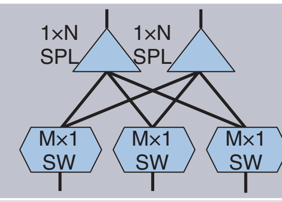
Rx: transmitter antenna
Tx: receiver antenna
WDM: wavelength division multiplexing

Fig. 1. Schematic of a CDC-ROADM node supporting multi-degree and multi-band functionality.

CDC functionality, namely the capability to connect transponders to all link degrees regardless of wavelength. Thus, two qualitative changes are required: an increase in the number of ports on the side connecting to the WSSs and support for a wider wavelength range.

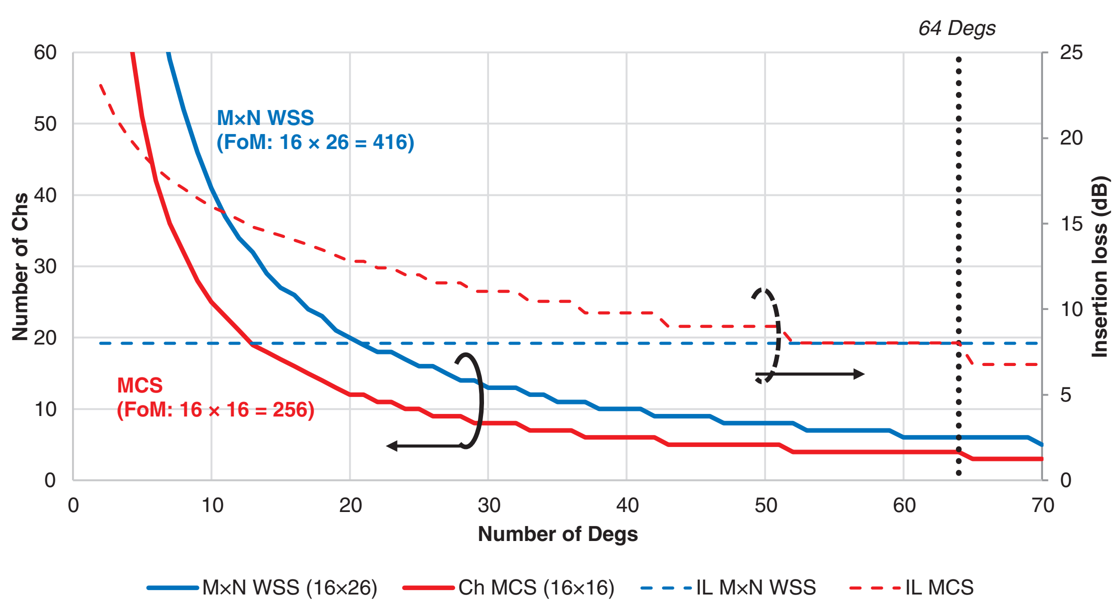
Two types of switches are currently in practical use as TPAs, the characteristics of which are summarized in **Fig. 2**. One type is the contentionless M×N WSS with multiple 1×N WSSs and M×1 switches facing each other. This type of switch can independently switch each wavelength channel, resulting in no intrinsic loss and achieving an insertion loss as low as 7 dB even when accommodating numerous transponders [10]. However, the integration of multiple WSSs into a single module with spatial optics leads to relatively high size and cost. The other type is an MCS with 1×N splitters and M×1 switches facing each other [11]. This switch can be built using only waveguides, reducing size and cost. However, as the number of channel ports increases with the number of transponders to be accommodated, branching losses occur at the splitter. For example, the branching losses when the number of channel ports is 4 and 8 is 6 and 9 dB, respectively.

For both types of switches, the figure of merit (FoM) of the switching scale is the product of the number of degree ports, which are the ports connected to the WSS in each degree, and the number of channel ports [9]. The same FoM can be achieved at a similar size and cost on the same platform. To accommodate an increase in the number of link degrees of nodes, the number of degree ports in the TPA is increased, and the number of channel ports is reduced accordingly, assuming the same FoM. The graph in **Fig. 3** shows the relationship between the number of channel ports and insertion loss of the TPA in relation to the number of link degrees. The FoM is

	Contentionless M×N WSS	PLC-MCS
		
Waveband	C or C+L	S+C+L
Insertion loss	7 – 8 dB	Intrinsic splitting loss +2 dB
FoM: Deg # × Ch #	8×24 / 16×24	16×16
Wavelength filter	Yes	No
Cost	High	Low
Size	Large	Small

SPL: splitter
SW: switch

Fig. 2. Types and characteristics of TPAs.



Ch: channel port
Deg: degree port
IL: insertion loss

Fig. 3. Varied numbers of channel ports of a TPA switch with number of node degrees.

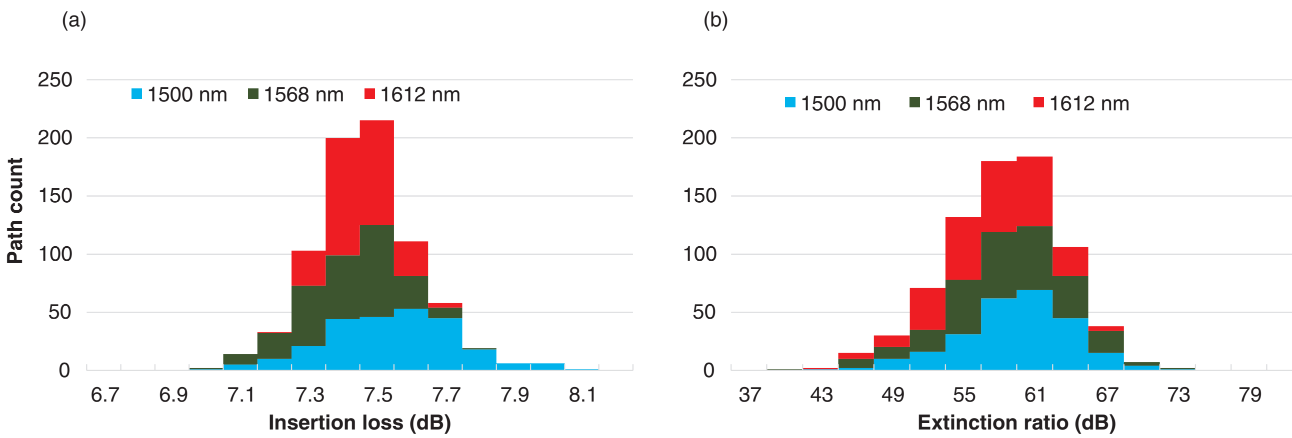


Fig. 4. Histograms of (a) insertion loss and (b) extinction ratio experimental values for the 64×4 MCS prototype.

assumed to be 16 × 26 = 416 for the M×N WSS [14] and 16 × 16 = 256 for the MCS [15]. Note that the insertion loss of the MCS decreases with the number of channel ports, and the number of link degrees of the nodes increases. The loss of the M×N WSS remains constant at around 8 dB regardless of the number of node degrees, while the loss of the MCS decreases to the same level as the number of node degrees increases to 64. The number of channel ports corresponding to 64 degrees is 6 for the M×N WSS and 4 for the MCS, which is not a significant difference. This indicates that in a CDC-ROADM node in 2035, when the number of node degrees will increase to 64, the disadvantages in terms of optical characteristics of the MCS caused by losses due to branching are almost eliminated, and the size and cost advantages become more prominent. The number of transponders that can be connected to the TPA is reduced to 6 or 4, which is inconsistent with expanding node capacity, but considering the trend of increasing handling granularity, parallelization can solve the mismatch.

3. 64×4 MCS based on PLC

A prototype 64×4 MCS with a silica-based PLC was demonstrated to verify low-loss operation across multiple bands and support for high-order links. The PLC uses a 2%-Δ core and was fabricated through a combination of flame hydrolysis deposition and reactive ion etching [16]. The circuit configuration comprises a combination of a 16-in-1 4×4 MCS and 4-in-1 1×16 switch circuits. The chip size is 85 × 50 mm, and the Mach–Zehnder interferometer switch and splitter/coupler are designed for the wide wavelength bandwidth, as previously reported [17].

The evaluation results of the optical properties from the S- to L-bands on the prototype are as follows. The average insertion losses in the S-band (1500 nm), C-band (1568 nm), and L-band (1612 nm) were 7.49, 7.37, and 7.40 dB, respectively. **Figure 4(a)** shows histograms of the insertion loss in each band for all connection paths, including the connection losses at the single-mode-fiber-waveguide interface at two locations. All connection paths and wavelength bands exhibit insertion losses below 8 dB, which is almost equivalent to the M×N WSS over a wider wavelength band. **Figure 4(b)** shows the extinction ratio in each band for all connection paths, demonstrating a robust extinction ratio of over 40 dB under all conditions.

The transmission spectra are shown next. **Figure 5(a)** shows the extinction-ratio spectrum for the connection between a single degree port (Deg #22) and all channel ports (Ch #1, #2, #3, #4). Similarly, **Figure 5(b)** shows the extinction-ratio spectrum for the connection between a single channel port (Ch #1) and four degree ports (Deg #1, 22, 43, 64). In both cases, the extinction ratio remains above 40 dB across the wide range of 1400–1700 nm, equivalent to more than a four-band wavelength range from the S- to U-bands. These results indicate that PLC-based MCSs supporting 64-degree links can operate with low losses and high extinction ratios over a wide bandwidth of 300 nm and beyond. As the number of links increases in future CDC-ROADM nodes, the size and cost advantages of PLC-MCS will become more prominent, rendering this type of switch a suitable TPA.

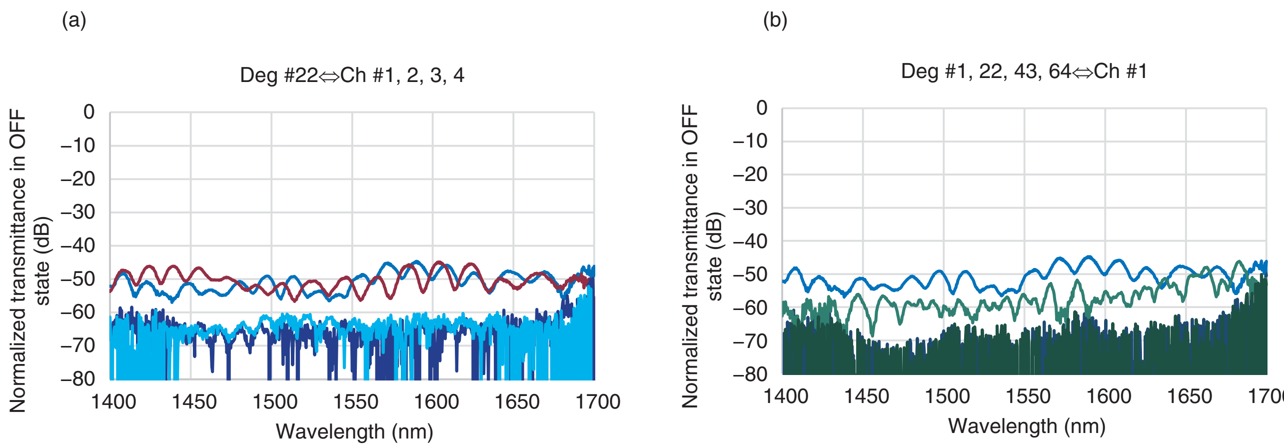


Fig. 5. Extinction-ratio spectra between (a) a single degree port and all channel ports and (b) a single channel port and four degree ports.

4. Summary

In contrast to the CDC-ROADM node configuration of 16 degrees using the C+L bands, which is currently being implemented, in 2035, a configuration with 8 times the throughput can be envisaged by supporting 4 bands and 64 degrees, corresponding to double the bandwidth and 4 times the number of fibers. To provide CDC functionality in such a node, a TPA corresponding to the increased bandwidth and number of degrees is required. In this context, we developed an MCS as a suitable enabler. We also developed a prototype 64×4 PLC-MCS supporting 64 degrees and demonstrated its operation with less than 8-dB loss from the S- to L-bands, alongside a high extinction ratio at a bandwidth of 300 nm.

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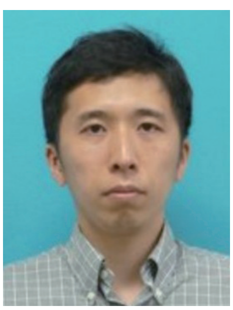

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