C+L-band Colorless, Directionless, Contentionless Reconfigurable Optical Add/Drop Multiplexing for High-capacity Network Flexibility

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Abstract

We investigated the possibility of expanding the operating wavelength range of one of the most flexible optical networks, i.e., colorless, directionless, contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM), to the C+L-band. By expanding the operating wavelength range of multicast switches, which are indispensable for CDC-ROADM, to the two bands of C+L, a seamless optical node can be achieved. This concept reduces the complexity in network equipment as well as network operation because it enables operation without operators having to be aware of the bands.

Keywords: C+L-band optical network node, C+L-band multicast switch, CDC-ROADM (colorless, directionless, contentionless reconfigurable optical add/drop multiplexing)

1. Introduction

The All-Photonics Network (APN), one of the three technologies that comprise the Innovative Optical and Wireless Network (IOWN), is expected to leverage photonics technology to achieve a significant increase in the potential of the information-processing infrastructure, something that is difficult to achieve with current electronics technology [1]. The APN is expected to achieve a 125-fold increase in transmission capacity and maximum end-to-end adoption of optical technology from the network to the terminal. For high-capacity optical transmission, it is important to expand the use of wavelength-division multiplexing (WDM), which is currently used in optical networks, in addition to the application of technologies that have not yet been commercialized such as spatial multiplexing. In other words, the wavelength bandwidth used for optical fiber communications will be expanded to achieve higher capacity. Expanding the wavelength bandwidth of WDM is also effective in the end-to-end application of optical technology [2], which requires an increase in the number of optical paths that can be established. In this case, the expansion of the wavelength bandwidth in WDM is also an important issue.

2. Multiband ROADM network

In optical networks, optical switches are essential for routing light as it is. Reconfigurable optical add/drop multiplexing (ROADM) systems have been introduced for optical networks using optical switches, which enable optical signals to be added and dropped at each node. By enabling optical-signal transmission between multiple rings without electrical regeneration, ROADM systems can flexibly reconfigure the network and reduce operation and maintenance costs. The conventional single-ring network has been extended to a more economical multi-ring network, as shown in **Fig. 1** [3]. The optical-node configuration called colorless, directionless, contentionless

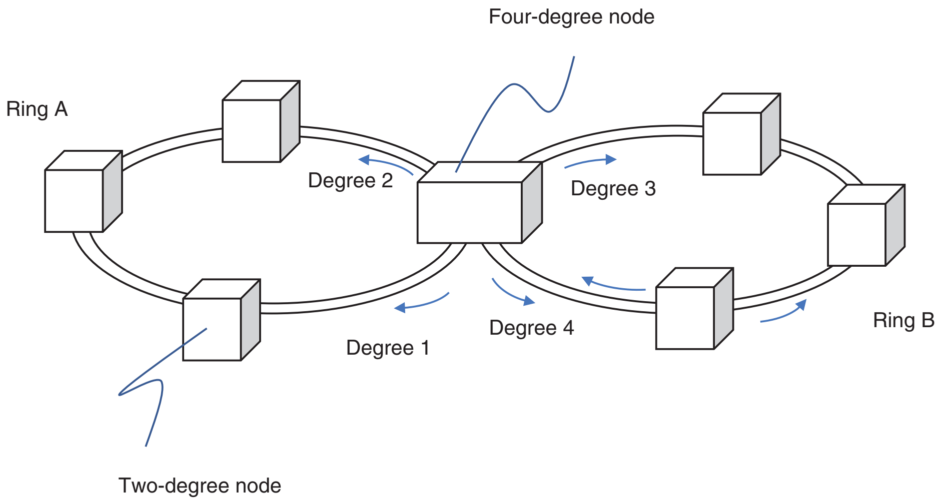
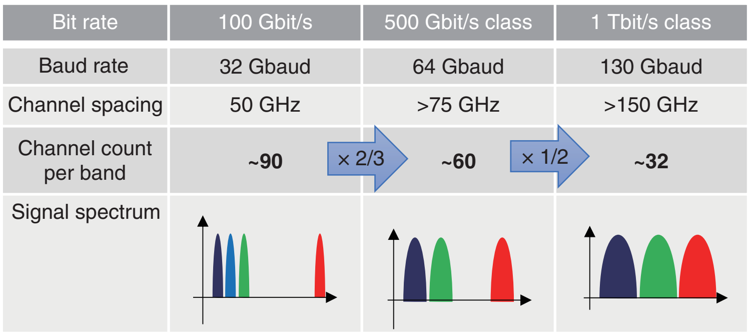


Fig. 1. Example of multi-ring network.



Bit rate	100 Gbit/s	500 Gbit/s class	1 Tbit/s class
Baud rate	32 Gbaud	64 Gbaud	130 Gbaud
Channel spacing	50 GHz	>75 GHz	>150 GHz
Channel count per band	~90	~60	~32
Signal spectrum			

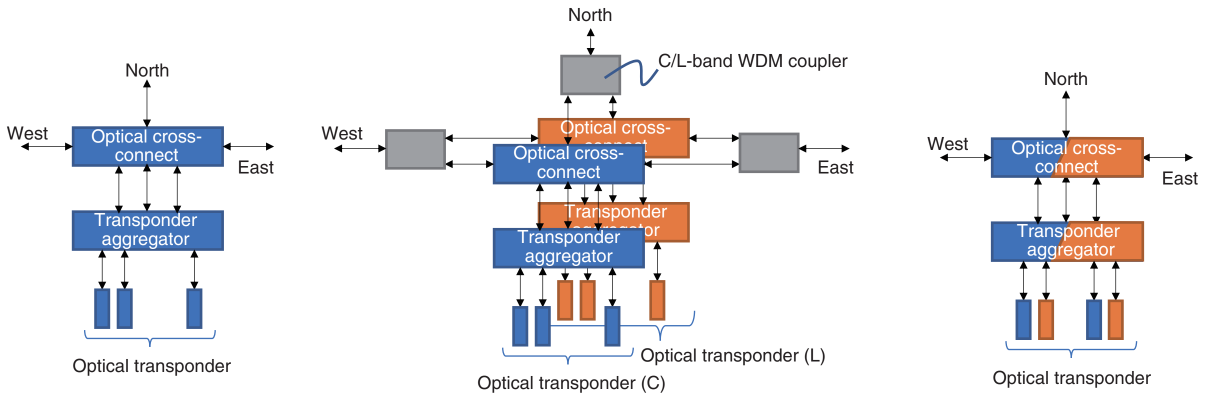
Fig. 2. Relationship between signal baud rate and channel count per band.

(CDC)-ROADM is one of the most flexible optical-node configurations for efficient data communication in multi-ring and mesh networks. It is not only effective for efficient operation of communication resources [4] but also expected to contribute to rapid restoration in the event of optical-transmission-line breakdown during a disaster [5].

Another trend in optical transmission technology is the discussion about increasing the baud rate of optical signals [6]. High baud rates are suitable for transmitting large signals over long distances. This is because a high-baud-rate signal contributes to a reduction in the level of multiplicity when compared with a signal of the same bit rate, thus expected to improve the signal-to-noise ratio. However, high-baud-rate signals occupy a wider signal bandwidth, which reduces the number of wavelengths available in a single-band ROADM system. As shown in **Fig. 2**, for example, a 100-Gbit/s signal occupies about 32 GHz, and about 90 wavelength channels can be deployed in the currently used C-band (1530 to 1565 nm) or L-band (1565 to 1625 nm) [7]. For a 500-Gbit/s-class signal with an occupied bandwidth of 64 GHz or 1 Tbit/s-class signal with an occupied bandwidth of 130 GHz, only about 60 or 30 waves can be placed at most, respectively. The use of both C- and L-bands is an effective solution to this problem.

3. C+L-band CDC-ROADM

CDC-ROADM is an optical network node configuration that makes one of the most efficient use of the optical transmitters and receivers (transponders) installed in a system. Because an optical node must



(a) Single-band CDC-ROADM node

(b) Multiband CDC-ROADM node with conventional switch devices for single band

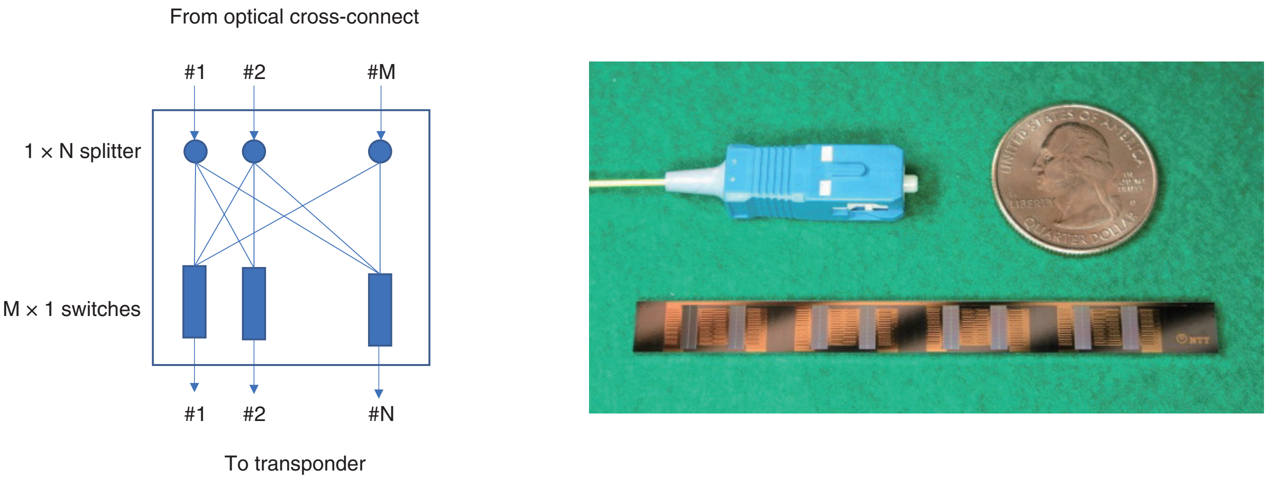
(c) Multiband CDC-ROADM node with C+L-band optical cross-connect and multicast switches

Fig. 3. Configuration of multiband CDC-ROADM node.

be able to communicate with optical nodes in other directions, a CDC-ROADM node can use optical transponders installed in the node for communication with any direction with the fewest restrictions, thus effectively using communication resources. **Figure 3(a)** shows a typical CDC-ROADM configuration, which consists of an optical cross-connect block and optical transponder aggregation blocks. The optical cross-connect switches optical signals from different nodes directly to other paths (e.g., from West to East) or uses these signals for communication between the node and others. The optical transponder aggregator controls the connection between the optical cross-connect and optical transponder for the optical signals handled by the node. In conventional ROADM systems, optical transponders can only be used for communication with a specific direction (directioned), or only one optical transponder of the same wavelength can be used (contensioned). CDC-ROADM is a highly flexible optical node configuration that enables any optical transponder to be used for communication with any path as long as that path's wavelength is not already in use. The NTT Device Innovation Center was the first in the world to successfully implement multicast switches [8].

With the shift to multiband optical transmission, CDC-ROADM, which has been configured with a single C- or L-band, must now also be multiband. If a CDC-ROADM is configured using conventional optical switch devices that operate only in the C- or L-band, it will have a complex configuration, as shown in **Fig. 3(b)**. Both the optical transponder aggregator and optical cross-connect must be prepared for the C-band and L-band, and the optical signals handled by each must be combined and divided by a C-/L-band (de)multiplexer to communicate with the transmission fiber, doubling the amount of equipment compared with the conventional single-band system. This results in complexity in the node configuration as well as operation because operators have to be aware of the bands. For example, optical transponders are optimized for only the C- or L-band, so that the operator needs to be careful into which system he/she should plug the transponders. In contrast, by using a multicast switch with an extended operating wavelength range to the C+L-band, a CDC-ROADM node with a simple configuration can be implemented, as shown in **Fig. 3(c)**. This is thought to contribute to the reduction in errors during operation.

Multicast switches have intrinsic loss due to their principle. **Figure 4(a)** shows the circuit topology of a multicast switch that accommodates M-degree × N transponder ports. The arrow indicates the direction of optical-signal propagation where the figure shows the case of signal drop use. **Figure 4(b)** shows the appearance of the optical circuit chip of the fabricated C+L-band multicast switch. The multicast switch contains a splitter that splits the input signal into N branches. This is the principal loss factor and cannot be avoided. Therefore, it is preferable to reduce the number of branches as much as possible for optical transmission characteristics, but reducing the number



(a) Configuration of multicast switch

(b) Appearance of C+L-band multicast switch

Fig. 4. Multicast switch.

Table 1. Dependence of add/drop ratio on the number of branches of multicast switch and signal baud rate.

	Number of transponder ports of multicast switch				
	4	8	12	16	24
Single-band node with 32-Gbaud signals	6.8%	13.5%	20.3%	27.1%	40.6%
C+L-band node with 130-Gbaud signals	13.0%	26.0%	39.1%	52.1%	78.1%

of branches also impacts the achievable add-drop ratio. However, when dealing with high-baud-rate transmission, the add-drop ratio can be kept at the same level as the conventional single-band version of the node even if the number of branches is reduced. In a high-baud-rate system, such as 130 Gbaud, the number of wavelengths that can be allocated in a band is also reduced, as mentioned above. Therefore, the reduction in the add-drop ratio due to the reduced number of branches can be maintained at the same level compared with a conventional 32-Gbaud system. **Table 1** summarizes the add-drop ratio for a single-band system with a conventional 32-Gbaud signal and a C+L-band configuration of 130-Gbaud signals. The former is assumed to have a channel spacing of 50 GHz and 96 signals in the C-band, while the latter has a spacing of 150 GHz and 64 signals in both the C- and L-bands. The add-drop ratio depends on the size of the wavelength selective switch (WSS) in the optical cross-connect block. In this article, we assume a 1 × 20 WSS, which was available when the single-band system was developed, for the conventional single-band-only system, and 1 × 32 WSS, which has been put into practical use, for the C+L-band ROADM system. As shown in Table 1, a C-band-only system using a multicast switch with 8-degree ports and 16 transponder ports has an add-drop ratio of 27%, while a multicast switch with 8 optical transponder ports has an add-drop ratio of 26% and can be obtained for a 130-Gbaud signal. Therefore, even if the number of multicast-switch branches is halved from 16 to 8, the same level of operability can be secured as with the conventional single-band configuration. In practice, it is reasonable to estimate the required average add-drop ratio by dividing the total number of wavelengths by the number of nodes in the ROADM system. Thus, even a network with 10 or so nodes requires an average add-drop ratio of only 10%. The cases shown in Table 1 clearly satisfy this requirement.

4. Summary

We described the feasibility of a CDC-ROADM configuration with an optical transponder aggregator that operates in the C+L-band. We also successfully conducted feasibility verification experiments of a C+L-band CDC-ROADM node using the aforementioned C+L-band multicast switch [9].

Multiband technology not only increases capacity but also increases the degree of freedom in ROADM systems by expanding the number of transmission channels. Combined with the increase in transmission distance due to higher baud rates, multiband technology contributes to the advancement of optical networks. NTT is currently conducting research and development of the APN for IOWN. To implement the APN, we will continue our research and development to dramatically expand the transmission capacity and improve optical transmission systems by increasing the speed to 1 Tbit/s by using a wider wavelength band such as the S-band as well as using spatial multiplexing technology.

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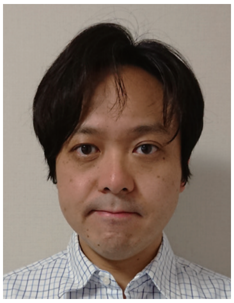

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