CDCG-ROADMs for Flexible Optical Trunk Line Networks

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The rapid increase in traffic flowing through data centers and mobile networks in recent years is making it increasingly important that the supporting optical trunk line networks have high-speed, high-capacity, long-distance, and high-reliability features. Various types of applications have been discussed for flexibly reconfiguring the optical trunk line networks, and it is agreed that flexibility and high availability are needed at the optical level. In its development of a re-configurable optical add/drop multiplexer (ROADM) that serves as an optical-direction switch, Fujitsu focused on the implementation of "colorless, directionless, contentionless, and gridless (CDCG)" functions to meet the needs of telecom carriers for greater flexibility, remote operation, and higher capacity. This paper introduces the key devices and elemental technologies of CDCG-ROADMs, describes CDCG-ROADM functions, and touches upon the application of CDCG-ROADM technology to future optical trunk line networks.

1. Introduction

The wide and rapid spread of LTE and other broadband services and the delivery of high-resolution video have been major factors in the dramatic jump in traffic flowing through data centers. At the same time, technical innovations such as the Internet of Things (IoT) and machine-to-machine (M2M) communications are expected to bring about an explosive increase in traffic flowing through optical trunk line networks. Dense wavelength division multiplexing (DWDM) technology has been used as a means of increasing transmission capacity in an optical trunk line network, and further increases in capacity are being achieved by improving transmission speed per wavelength and increasing the number of multiplexed wavelengths. The maximum transmission capacity per optical fiber deployed in commercial terrestrial optical trunk line networks reached 9.6 Tbps (96 wavelengths × 100 Gbps) in 2015.

The configuration of optical trunk line networks has become increasingly complex, starting with the simple point-to-point type in the 1990s, moving to the ring type in the 2000s, and reaching the mesh type in 2010. This progression has created problems when restructuring a network because maintenance and operations such as route switching have become increasingly complicated and costly. In addition, there has been growing public demand that regions not be cut off from communications when instantaneously switching to alternative routes at the time of a network failure due to an earthquake or other disaster. To enable remote assignment of wavelengths and setting of paths at the time of such route switching, the practical use of re-configurable optical add/drop multiplexers (ROADMs) has been advanced. Since the optical wavelengths of ROADMs were initially fixed, there were problems, such as contention between two paths with the same wavelength (blocking), at the time of network restructuring, which, in turn, meant less flexible operations.

The demand from Fujitsu's telecom carrier customers for improved ROADM technology for operating large-capacity, flexible networks consequently became increasingly strong. This demand led to the implementation of a technology that combines "colorless, directionless, contentionless, and gridless" functions with ROADMs (CDCG-ROADMs). A control method is being studied called software-defined networking (SDN) that will enable integrated control of CDCG-ROADMs over the entire network, and implementation of flexible networks is being accelerated from both hardware and software perspectives.

This paper describes the elemental CDCG-ROADM technologies and a Fujitsu product that incorporates them, presents the effects of applying them to optical networks, and discusses the future outlook for CDCG-ROADMs.

2. CDCG functions and elemental optical devices

CDCG-ROADM node consists of a variety of elemental optical devices including wavelength selective switches (WSSs) and multicast switches (MCSs) (**Figure 1**). An optical amplifier array is additionally used for compensating for component loss as needed.

This section introduces CDCG-ROADM functions and the elemental optical devices used to achieve them.

2.1 CDCG functions

1) Colorless function

This function means that no restrictions are applied to multiplexed wavelengths, that is, to signal wavelengths (colors) on signal paths within a ROADM node (DWDM can be performed for any wavelength).

2) Directionless function

This function means that no restrictions are applied to the direction of an outgoing signal in ROADM node (a signal can be connected to a path going in any direction).

3) Contentionless function

This function eliminates wavelength contention in optical signals assigned to different paths within the same ROADM node (multiple instances of the same wavelength may exist within ROADM).

4) Gridless function

In contrast to wavelength multiplexing on an equally spaced optical frequency (wavelength) grid conforming to ITU-T specifications, this function enables the optical source to be set to any optical wavelength and a path direction to be assigned.

The application of CD (combining the colorless and directionless functions) and CDC (combining the colorless, directionless, and contentionless functions) enables the building of flexible networks with enhanced path switching at the time of faults and the attainment of improved network accommodation rates.[1)–6)] In addition, the gridless function can support capacity upgrades on the level of 400 Gbps to 1 Tbps per wavelength, as shown in **Figure 2**, without having to replace ROADM.

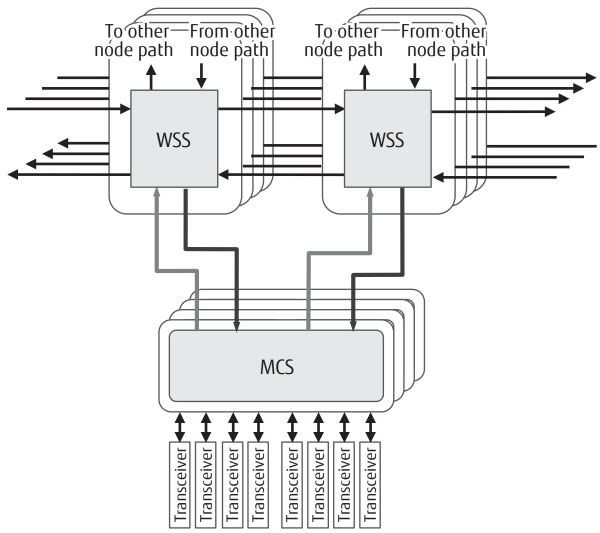

Figure 1
CDCG-ROADM configuration.

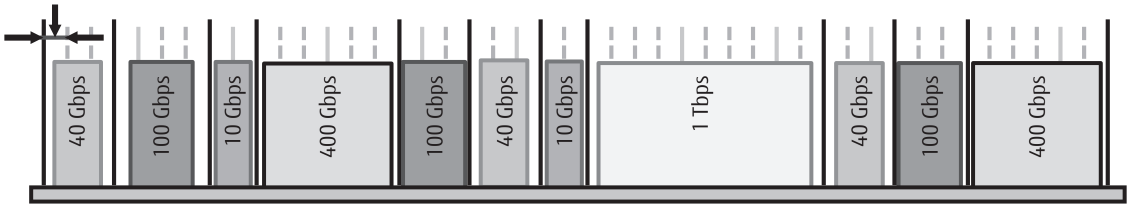

Figure 2
Example of wavelength arrangement for greater capacity using gridless function.

2.2 Elemental optical devices

1) WSS

A WSS incorporates signal power-adjustment and switching functions, enabling optical path switching of individual wavelength division multiplexed (WDM) signals from multiple rings. In other words, a WSS is a single element achieving CD functions. It also incorporates a variable bandwidth function, thereby achieving the gridless function as well.

The configuration of a WSS is shown in **Figure 3**. The diffraction grating separates the wavelengths constituting the input WDM signal, and the moveable mirror element establishes the direction of each wavelength. This makes it possible to perform automatic optical power management in units of wavelengths at the optical coupling position with the collimator and to assign any wavelength to any port. In addition, the use of liquid crystal on silicon (LCoS) technology in the mirror element achieves a gridless function that enables flexible bandwidth changing in contrast to the fixed ITU-T grid with 50- or 100-GHz intervals.[7)]

2) MCS

An MCS is an optical device for achieving CD functions. Additionally, it can assign any path to optical signals of the same wavelength, thereby providing a contentionless function that eliminates wavelength contention restrictions.

The configuration of an MCS is shown in **Figure 4**. The left side shows the drop-side MCS, which guides signals from a WSS to the receiver. This MCS distributes each WDM signal input from a ROADM path direction to a 1 × *N* optical splitter (SPL) and selects an output path direction for a desired WDM signal using an *M* × 1 optical switch (SW). As a result, optical signals with different input paths having the same wavelength as optical signals output to the receiver side are blocked and guided to the output side by *M* × 1 optical SWs at different output ports. There is consequently no wavelength contention at ports outputting signals to the receiver side.

The right side of the figure shows the add-side MCS, which guides signals from the transmitter to a WSS. This MCS guides optical signals from the transmitter to specific output paths using 1 × *M* optical SWs, multiplexes optical signals of different wavelengths at *N* × 1 optical couplers (CPLs), and connects the multiplexed signals to ROADM path directions. This configuration makes it possible to output any wavelength from the transmitter to any path direction.[8)]

An MCS features a configuration that combines compact optical devices (optical splitters, optical couplers, and optical switches) using planar lightwave circuit (PLC) technology and micro-electro-mechanical systems (MEMS) technology. In principle, an optical

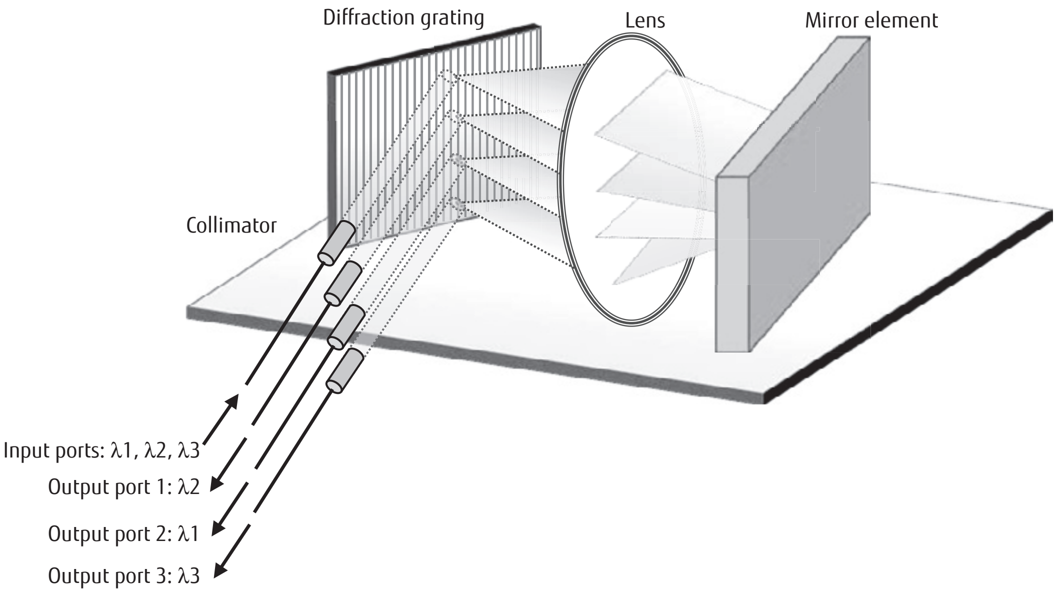

Figure 3
WSS configuration.

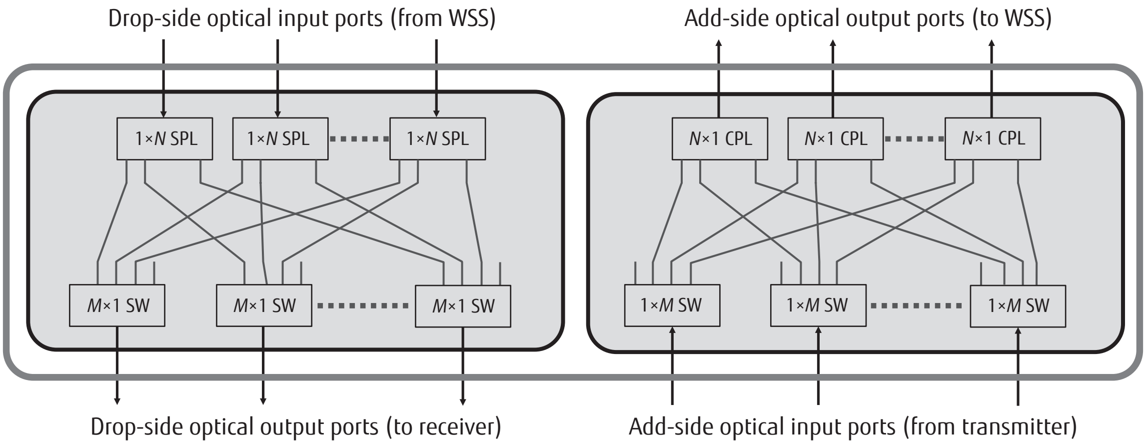

Figure 4
MCS configuration.

splitter generates considerable branching loss, but this loss can be compensated for by using an optical amplifier array as described next.

3) Optical amplifier array

As a result of the MCS operations described above, both add-side optical signals guided from the transmitter to a WSS and drop-side optical signals guided from a WSS to the receiver become attenuated, resulting in insufficient optical power. An optical amplifier array can be used to compensate for this loss in power. We therefore developed an optical amplifier array that can be incorporated in both (add/drop) sides within a single module and achieved a high-density implementation by applying a compact pump laser for optical amplification and devising a scheme to reduce overall power consumption.

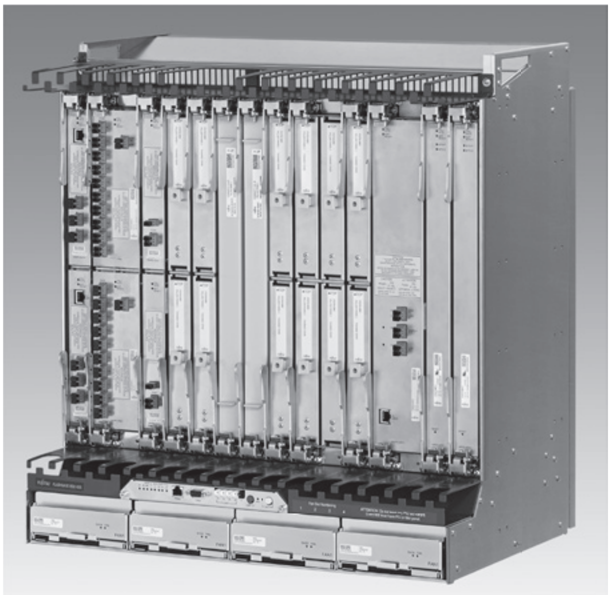

Figure 5
FLASHWAVE 9500 CDCG-ROADM.

3. Functions of FLASHWAVE 9500 CDCG-ROADM

Fujitsu has implemented these CDCG-ROADM functions in its FLASHWAVE 9500 packet optical transport system (**Figure 5**). This system features a highly extendible platform and provides several key functions.

1) Flexible switching by CDC functions

It provides a switching function that can connect an optical signal from any client port to any path direction for any wavelength. This enables remote setting and switching of optical signals to the ports desired, thereby eliminating the need to physically change optical fiber connections. It also enables transmitters and receivers to be connected as desired to any port when booting up equipment or adding new wavelengths, which can reduce connection errors and complex operations as well as shorten the time required for booting up equipment.

2) Gridless function

The gridless function and superb optical passband characteristics of the WSSs support 100-GHz signals in the narrower 37.5-GHz bandwidth plus super-channels (400 Gbps and 1 Tbps). The number of wavelengths can be extended to 128. These features can improve frequency utilization efficiency and thereby achieve large-capacity communications at low cost.

3) Power level control function

This control function automatically adjusts 400-Gbps and 1-Tbps optical signals and the optical signals of diverse modulation systems to optimal power levels for each type of system and signal.

4) ILA coordination function

This product provides, on the same platform, in-line amplifiers (ILAs) having only an optical amplification function. Using these ILAs and inter-node communication channels, the ILA coordination function enables the ROADMs to automatically determine the number of connected ILAs and automatically optimize optical power levels. This function can therefore support a wide range of networks on the same platform, from metro networks to ultra-long-distance networks (>2,000 km).

5) Extendibility in response to system requirements

Elemental optical devices such as MCSs and optical amplifier arrays can be added in conjunction with the addition of new add/drop optical signals or the addition of new ROADM path directions and can be extended without affecting service. We can expect future CDCG-ROADM equipment to have a configuration extendible to 16 path directions by incorporating many-port WSSs.

4. CDCG-ROADM network application effects

Here we describe the effects of applying CDCG-ROADMs to a network.

1) Advanced path restoration through many paths and wavelength flexibility

CDCG-ROADMs have been given a recovery function that can handle signal failures among paths in more than two directions from the equipment, thereby superseding the conventional failure recovery function. This means that the network can effectively recover from a severe disaster in which multiple optical fibers are simultaneously disconnected and thus provide even higher levels of reliability than past systems. Since wavelengths can be flexibly selected at the time of such a disaster, wavelengths in vacant slots can be effectively used, thereby reducing the number of transceivers needed for standby paths.

In addition, combining transceivers that can increase transmission capacity by changing the modulation system with regenerators (equipment for regenerating/relaying optical signals by combining receivers and transceivers) enables the provision of large-capacity alternative routes with no distance restrictions. In the example shown in **Figure 6**, unit 1 of the CDCG-ROADM applies a signal-failure recovery function to paths in three directions (that is, the paths connecting unit 1 with units 7, 8, and 2). On detecting a signal failure caused by fiber disconnection between units 1 and 8, the function changes the wavelength from λ1 to λ2 and switches the path from unit 8 to unit 2 to achieve path restoration.

2) Efficient use of network capacity

The capacity of a ROADM network is limited by the wavelength bandwidth. CDCG-ROADM technology makes it possible to optimally arrange the wavelengths of optical signals (defragmentation) by changing wavelengths and bandwidths (modulation method). That is, wavelengths can be used more efficiently by changing fragmented wavelengths in the network to wavelengths in vacant slots (**Figure 7**).[4)]

5. Future outlook

Finally, we discuss the outlook for future CDCG-ROADM development.

1) Application of many-port devices

The development of new devices such as a WSS having many input and output ports will facilitate the

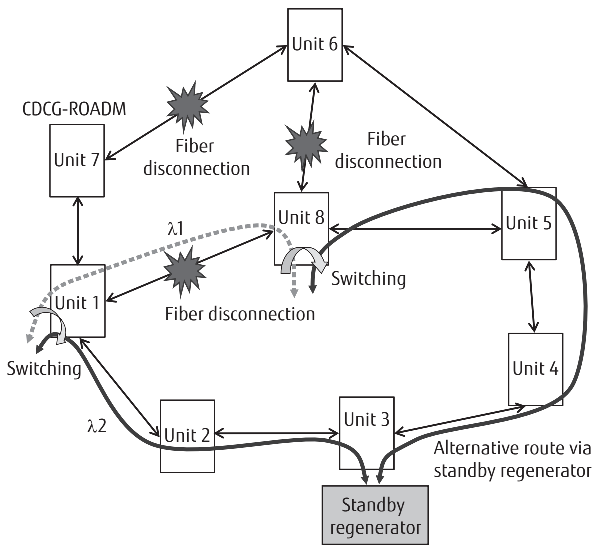

Figure 6
Failure recovery (path restoration function).

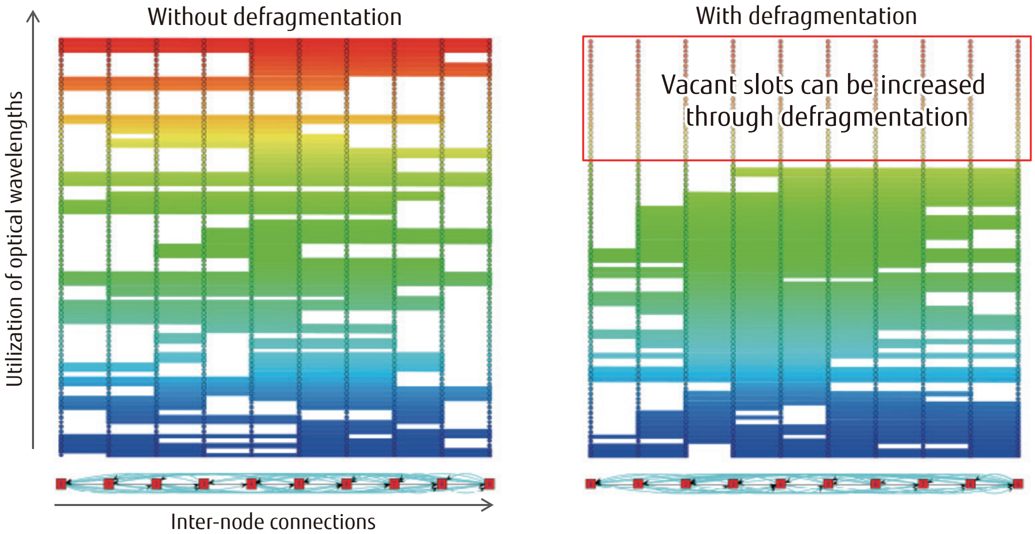

Figure 7
Effect of defragmentation.

integration of CDCG-ROADMs, which are currently composed of many optical devices, and further reduce the cost and size of CDCG-ROADM nodes.

2) Application of high-function monitor

The development of an optical performance monitor (OPM)[9] for detecting the quality of optical signals such as the optical signal-to-noise ratio (OSNR) will make it possible to consolidate information on optical-signal quality. This will enable creation of a system that can maximize the transmission performance of newly added wavelengths by coordinating the optical-path and optical-wavelength settings in a CDCG-ROADM. Linking CDCG-ROADMs with such next-generation SDN technology should improve multi-functionality and performance in the system.

6. Conclusion

The expanding scale and capacity of optical trunk line networks and their increasing complexity has forced telecom carriers to face a number of issues involving network failures, inefficient operations, etc. Against this background, ROADM technology has come to be seen as a promising technology for resolving these issues.

The FLASHWAVE 9500 packet optical transport system provides both flexibility and extendibility and can be applied to various types of networks. Application of this system should lead to a dramatic jump in total network value as it enables expanding coordination with SDN and the application of peripheral devices. Fujitsu is committed to developing products that provide more flexibility, greater value, and smaller configurations as the environment surrounding optical trunk line networks continues to expand and diversify.

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