ROADM Architectures and Their Enabling WSS Technology

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ABSTRACT

The relationship is explored between reconfigurable optical add/drop multiplexers, fast becoming the standard nodal subsystem for providing flexibility in modern multichannel fiber optic networks, and wavelength selective switches, the predominant technology used to implement ROADMs.

ROLE AND TYPES OF ROADMS

Throughout the 100-year-plus history of telecommunications networks, it is a truism that once a cost-effective method emerges to automate a manual operation, it is implemented universally. The most dramatic example was the replacement of manual switchboards by automated switches. In the last few decades digital cross-connects and synchronous optical network/synchonous digital hierarchy (SONET/SDH) add/drop multiplexers have totally replaced the practice of manually re-arranging individual circuits using back-to-back channel banks. In this context the time is now ripe for reconfigurable optical add/drop multiplexers (ROADMs) to automate the rearrangement of wavelengths on multichannel optical fibers entering and leaving optical network nodes.

Fiber optic networks, which underlie all the world's communications, are expanding at a dramatic rate to support the explosive growth of bandwidth-rich Internet video applications along with traditional voice and data services. Fiber optics is ideal for this task because it can carry information further and at greater density than previous copper-based transmission systems. In particular, using a scheme called dense wavelength-division multiplexing (DWDM), optical fibers can carry up to 100 wavelengths or channels of information simultaneously.

Now this all works very well when transmitting information between two nodes in a network. There is a challenge, however, in adding, dropping, and routing individual channels at individual nodes. In the past this was done by breaking out each and every wavelength at a node using an optical demultiplexer, manually rearranging wavelengths at an optical patch panel, and then combining them again in the desired fiber at a multiplexer for transmission to the next node. Needless to say, this was time consuming and, far worse, prone to human error. Enter the ROADM that today is simplifying these manual operations, and in the future will eliminate them completely.

There are two general types of ROADMs, two-degree and multidegree, where the degree refers to the numbers of DWDM fibers entering and exiting the ROADM node. (This refers to traffic moving in one direction only. In practice, pairs of fibers are generally used with each set carrying traffic in an alternate direction, so there would be twice as many fibers entering and exiting the ROADM as its degree.)

A two-degree ROADM is like a location on a highway with off and on ramps to drop off and accept local traffic. It terminates an incoming DWDM fiber, drops specified wavelengths, and in most cases blocks these wavelengths from propagating further, adds local wavelengths, equalizes the combined traffic of passed-through and added wavelengths, and provides an exit for this traffic toward the next ROADM node.

A multidegree ROADM is like an interchange where highways meet. It is used for interconnecting DWDM rings or for mesh networking. It accepts and rearranges wavelengths from the multiple fibers entering and leaving the multidegree node, as well as adding and dropping local wavelength traffic. The majority of ROADMs — a figure of about 75 percent is most often cited — are two-degree nodes, which are less complex than their multidegree cousins.

THE WAVELENGTH SELECTIVE SWITCH

Before delving into different ROADM configurations we need to introduce their key enabling technology, the wavelength selective switch (WSS). This is an advanced fiber optic module that can be used under software control to dynamically select individual wavelengths from multiple DWDM input fibers and switch these to a common output fiber. Figure 1 illustrates a 9 × 1 WSS with nine inputs. It can be seen that the first wavelength on the common output fiber has been selected from input fiber 8, the second wavelength from input fiber 3, the third from input fiber 5, and so on.

An important feature of the WSS is that it can attenuate the optical power of individual wavelengths exiting the output fiber. This

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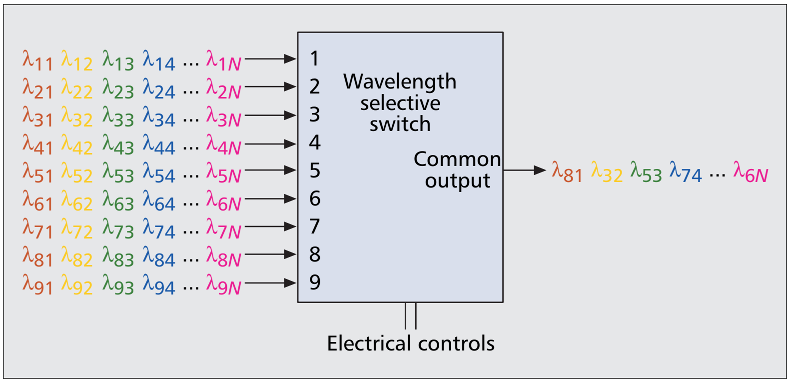
permits equalizing optical power among the wavelengths to maximize overall transmission performance. While the figure shows an $N \times 1$ WSS, these modules can also be configured in the other direction as a $1 \times N$ so that individual wavelengths on a common input fiber can be selectively switched to any of multiple output fibers. The innovation of the WSS is that it can select and switch individual wavelengths on a multiwavelength fiber in the optical domain without expensive electronic conversion.



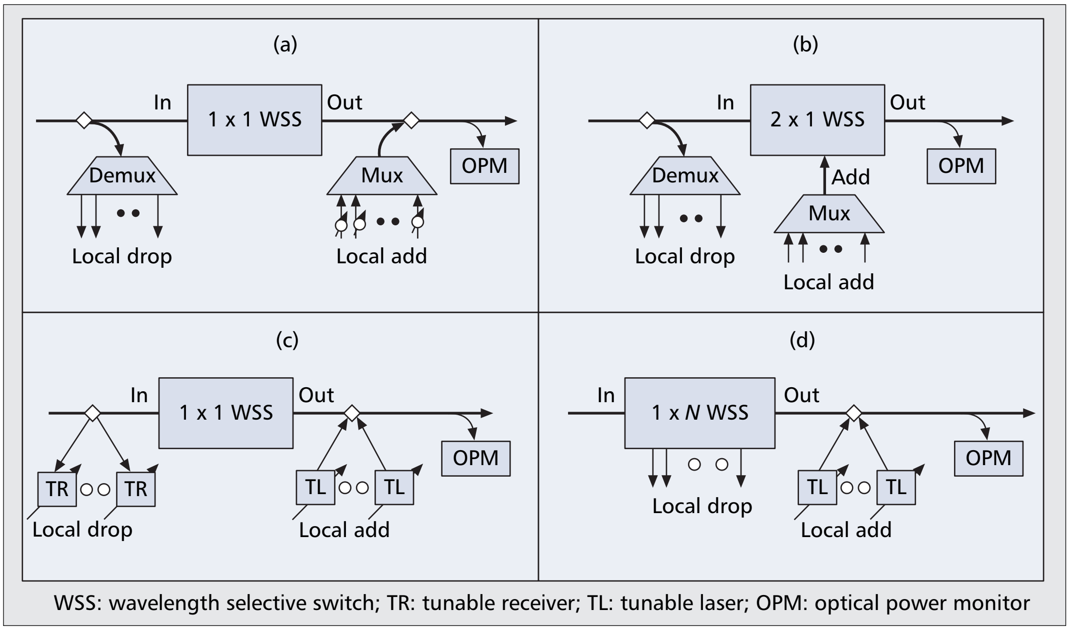
■ **Figure 1.** *A 9 × 1 wavelength selective switch.*

Two-Degree ROADM Architectures

Deployment of ROADMs began in the late 1990s with the architecture shown in Fig. 2a. A multichannel DWDM fiber enters the node, and the optical power is immediately split to provide paths for wavelengths that transit through the node and dropped wavelengths that get routed to a demultiplexer. The through traffic enters a 1×1 WSS (i.e., it has just one input and one output port so there is no switching) that under remote control either passes through, equalizes, or blocks (extinguishes) any or all wavelengths. New wavelengths are added by passive combination after the WSS. The WSS blocks any wavelengths identical to the added wavelengths so that there are no duplicate wavelengths carrying traffic in the same slot. Discrete variable optical attenuators (VOAs) are used to equalize the optical power of the added wavelengths, and an optical power monitor (OPM) provides feedback for the optical power equalization controls of the WSS and VOAs.

Figure 2b shows a variation on this architecture where the locally added wavelengths are still combined at a multiplexer but are now directed to the Add port of a 2×1 WSS. The WSS selects specific wavelengths from either the In or Add port and routes these to the Out port for transmission to the next network node. The WSS in this architecture also equalizes the optical power of the added wavelengths, eliminating the need for discrete VOAs. Both architectures of Figs. 2a and 2b are termed *fixed add/drop* because the dropped and added wavelengths are associated with specific or fixed ports on the multiplexers. While these wavelengths are still connected manually to specific service line cards (e.g., 10 Gb Ethernet, SAN protocol), one school of thought holds that this is of no major concern because it is usually done in conjunction with the manual provisioning of the service line cards themselves. The main advantage of these ROADM architectures is that the multiple wavelengths passing through the node are routed and equalized in an automated fashion.

Figure 2c shows a two-degree ROADM configuration that eliminates the fixed physical associations for the dropped and added wavelengths with the demux and mux ports. The industry calls this feature *colorless* because any color (frequency) of wavelength can be directed to any Drop port and from any Add port. In



■ **Figure 2.** *Two-degree ROADM architectures: a, b) fixed add/drop; c, d) colorless add/drop.*

Technology	Principle of operation	Advantages	Drawbacks
Liquid crystal array	Manipulation of light polarization.	Economical. Non-complex implementation.	Optical performance degrades for high port counts.
Liquid crystal on silicon (LCOS)	Manipulation of light phase.	Flexible for different wavelength plans.	Complex implementation for calibration and maintaining performance stability.
Microelectromechanical systems (MEMS)	Physical displacement of light using mirrored MEMS surfaces.	Scalable over a wide range of port sizes.	Not economical for low port counts. Complex implementation for maintaining performance over attenuation, particularly for 2-axis MEMS.

Table 1. *Wavelength selective switching technologies.*

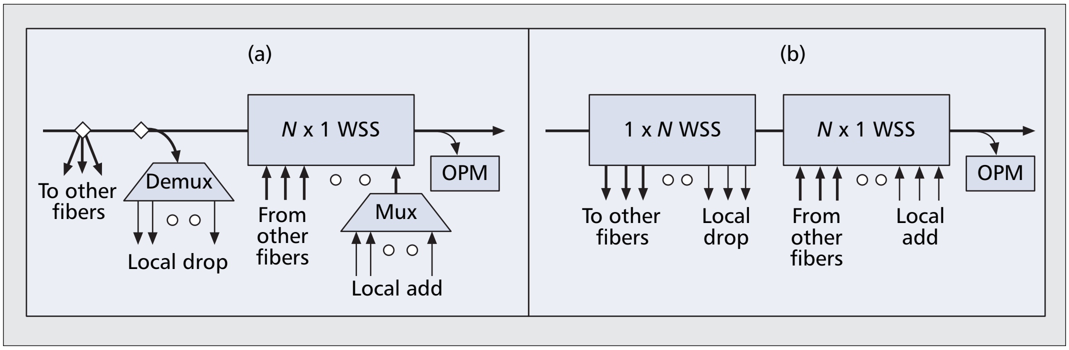


Figure 3. *Multidegree ROADM architectures: a) fixed add/drop; b) colorless add/drop.*

the figure this is achieved using tunable receivers (that today are implemented with a tunable filter feeding a fixed receiver) and tunable lasers that are passively split from and added to the optical path, respectively. Figure 2d shows a variation on this architecture using a $1 \times N$ WSS to dynamically select and drop selected wavelengths. For instance, a 1×9 WSS can drop any eight wavelengths, with the ninth port used for the DWDM output fiber. Colorless architectures are most efficient when it is anticipated that only a limited number of wavelengths need to be dropped and added at a node because of either the optical power losses associated with passive coupling or the fixed port size of the WSS.

Multi-degree ROADM Architectures

Figure 3 illustrates the incremental ability of multidegree ROADM nodes to send optical traffic to and accept optical traffic from other DWDM fibers. Figure 3a shows a segment of a multidegree node with fixed add/drop. The first splitter routes DWDM fibers to the other WSSs in the node, and the second splitter drops local traffic, as in the case of the two-degree node. An $N \times 1$ WSS is then used to accept traffic from the other DWDM fibers in the node, as well as local traffic. For a four-degree node, four 4×1 WSSs are required, an eight-degree node requires eight 8×1 WSSs, and so on. Figure 3b shows a variation for colorless add/drop. Here a $1 \times N$ WSS both routes the DWDM traffic to the other WSS in the node and also drops individual local wavelengths, and an $N \times 1$ WSS performs the corollary function of accepting traffic from the other DWDM fibers and adding local wavelengths. This architecture has advantages in terms of flexibility and reducing the optical power budget, but, of course, is much more expensive because it requires two large WSSs for each segment of the node. An eight-degree node of this variety, for example, requires a total of 16 WSSs.

WSS Technologies

From just this brief discussion it is clear that the variety of ROADM architectures require WSS engines of different sizes and configurations. Today there are requirements for WSSs with port counts ranging from 1×1 through 10×1 (or 1×10), and it is projected that in a few years N will be greater than 20. Moreover, these need to support a stringent set of optical performance specifications at both 50 GHz and 100 GHz wavelength spacings on the DWDM fiber.

At the heart of every WSS reside dynamic optical core technologies that switch the wavelengths among the ports and attenuate their optical power. Table 1 provides a high-level summary of the main technologies currently being used to implement WSSs. Xtellus uses a mix of these technologies to uniquely engineer a complete family of scalable WSSs that can satisfy all ROADM applications. For low port count WSSs, including 1×1, 2×1, and 4×1, we use a pure liquid crystal-based design for economy and ease of manufacture. Our high-port WSSs use a combination of one-axis MEMS for wavelength switching (a less complex technology than two-axis MEMS) and liquid crystal for attenuation.

Conclusion

Reconfigurable optical add/drop multiplexers are being universally deployed to provide automated provisioning in modern multichannel fiber optic networks. They reduce costs, speed up provisioning time, and eliminate human error from manual reconfiguration. Moreover, a variety of ROADM architectures are emerging to fulfill different requirements for two-degree vs. multi-degree nodes, edge vs. core network applications, and fixed vs. colorless add/drop. In turn, this is driving a need for a broad range of wavelength-selective switching engines to enable the ROADM architectures. Xtellus is responding by using a mix of liquid crystal and one-axis MEMS core technologies to provide a family of scalable WSSs.

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