Bandwidth-flexible ROADMs as Network Elements

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Abstract: The continuing need to reduce transmission costs drives the requirement for higher spectral efficiency in optical communication systems. We review here the use of Bandwidth-flexible ROADMs as one of the enablers of higher capacity systems.

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1. Introduction

Deployment of Reconfigurable Optical Add Drop Multiplexers (ROADMs) in the Core, Metro and, ultimately, Edge networks is now recognized as providing network operators with significant OPEX and CAPEX reductions. Furthermore, the never-ending demand for more cost-effective transmission (lower $/Mbit/sec/km) is driving the introduction of coherent modulation formats and hence network operators must carefully plan potential ROADM deployments to ensure that they are forward-compatible with a diverse range of future modulation formats and corresponding channel bandwidths. This paper reviews some of the options available to network operators in the area of advanced ROADM functionality, focusing in particular on recent developments in the area of flexible frequency grid architectures.

To give some perspective here, it is worth noting that when the ITU grid was first proposed in the mid '90s, the concept of a high-bit-rate dense WDM channel was RZ/NRZ at 2.5 Gbit/sec in a 200 GHz channel. Since then, the median channel spacing in network deployments has dropped; first to 100 GHz and more recently to 50 GHz. Simultaneously, the channel data rates have ramped up to the currently-deployed 40 Gbit/sec with future extensions to 100 Gbit/sec and beyond. The introduction of coherent modulation transmission techniques such as Dual-Polarization Quadrature Phase Shift Keying (DP-QPSK) and Orthogonal Frequency Division Multiplexing (OFDM), means that it is now possible to transmit 100 Gbit/sec within a 50 GHz channel but beyond this point we will need to start 'opening-up' the channel bandwidth again to accommodate the 400 Gbit/sec (and higher) signals of the future.

A flexible frequency grid network therefore requires that the optical channel bandwidth and centre frequency can be varied in some manner to optimize the overall performance of the network [1]. This may be to allow close stacking of high-bandwidth signals with different data rates, to adjust the transmission channel bandwidth to accommodate varying channel bit rates or to overcome different levels of impairments in the system. An example of this is the "SLICE" network architecture from NTT which was recently demonstrated [2].

An additional aspect that is often overlooked is that, as bandwidth consumption continues to double every two years or so [3], spectral efficiency becomes increasingly important as operators seek to maximize the carrying capacity of their installed plant. The ability to pack additional channels onto a fibre also provides the operator with incremental revenue opportunities for low capital expenditure – a feature which requires a level of flexibility not currently deployed in optical networks.

2. Flexible Bandwidth ROADMs

In a network, the available optical bandwidth for each transmission channel is limited by the channel bandwidth of the ROADMs in the network, (due to their channel filtering characteristics) hence the need for Bandwidth-flexible ROADMs. For current and future ROADMs, this primarily means that the Wavelength Selective Switches (WSS) which form the core switching element of the ROADM are capable of supporting flexible channel allocation.

The key to a bandwidth-flexible ROADM is the ability to independently control the centre frequency and channel bandwidth of the Wavelength Selective Switch (WSS) which sits at the heart of the ROADM. For current networks, this is, typically a 9x1 WSS, although 4x1 WSS are used in some smaller nodes whilst 2x1 WSS are gaining traction at the network edge.

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First generation WSS (typically based on MEMS [4] and/or Liquid Crystal [5] technologies) allocate a single switching element (pixel) to each channel which means that the channel bandwidth and centre frequency are fixed at the time of manufacture and cannot be changed in service. In addition, many designs of first-generation WSS (particularly those based on MEMs technology) show pronounced dips in the transmission spectrum between each channel due to the limited spectral 'fill factor' inherent in these designs. This prevents the simple concatenation of adjacent channels to create a single broader channel.

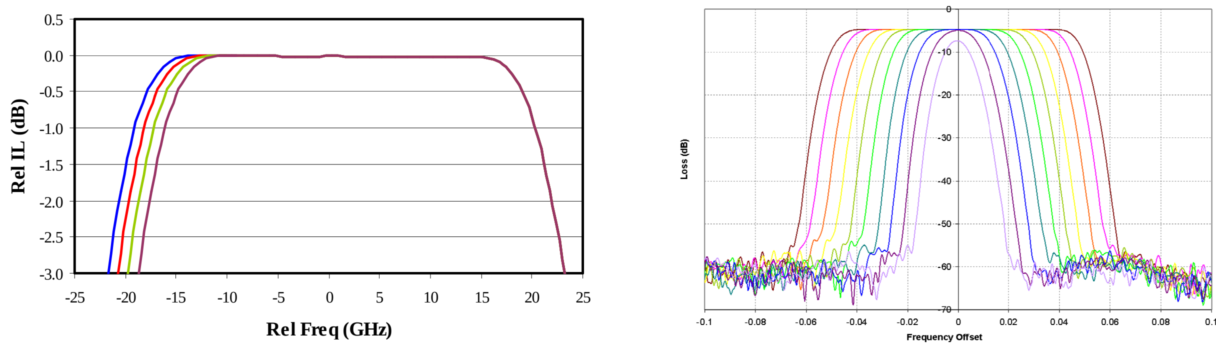

Figure 1 Channel Spectra for an LCoS-based WSS showing ability control one (LHS) or both (RHS) edges of the channel with 1 GHz resolution

Second generation WSS, based on Liquid Crystal on Silicon (LCoS) [6] or 2D MEMS mega-pixel matrix switching arrays [7] permit dynamic control of channel centre frequency and bandwidth through on-the-fly modification of internal pixel arrays via embedded software. The degree of control of channel parameters can be very fine-grained. For example, the ability to independently control the centre frequency and either upper- or lower-band-edge of a channel with better than 1GHz resolution in an LCOS-based WSS is shown in Figure 1.

Control of the channel bandwidth and position with GHz resolution has been utilized in many research papers investigating the requirements for future optical networks (see, for example [8]) and is particularly attractive when combined with the precise spectral control available through OFDM modulation formats. However, in a practical network a trade-off must be made between the degree of flexibility offered in terms of channel position and bandwidth and the complexity of managing the network. Whilst this remains an area for further study, a channel bandwidth granularity of 12.5 GHz ((Figure 2) is likely to be sufficient to meet future channel bandwidth management requirements.

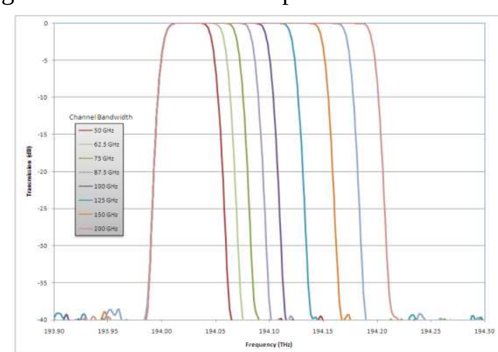

Figure 2 Channel shapes for a Flexible-bandwidth LCoS-based WSS showing ability to increment bandwidth in 12.5 GHz steps.

3. Add/Drop (Colorless/Contentionless/Directionless) Architectures

In currently-deployed ROADMs, the core switching functions are colourless and automated, but the Add/Drop functionality generally involves some form of coloured component (typically an AWG on the drop side) to separate the non-express wavelengths onto individual fibres. These fibres must then be manually connected to appropriate transmitters or receivers. A goal of many proposed network architectures is to remove the fixed wavelength per port allocation due to the AWG (Colorless) whilst automating the manual patching of the Drop and Add ports (Directionless) and doing this without introducing any blocking points in the Add/Drop architecture (Contentionless). Hence the term "CDC Architectures". In this way, the network operator's goal of "zero touch" network reconfiguration can be realized (Figure 3).

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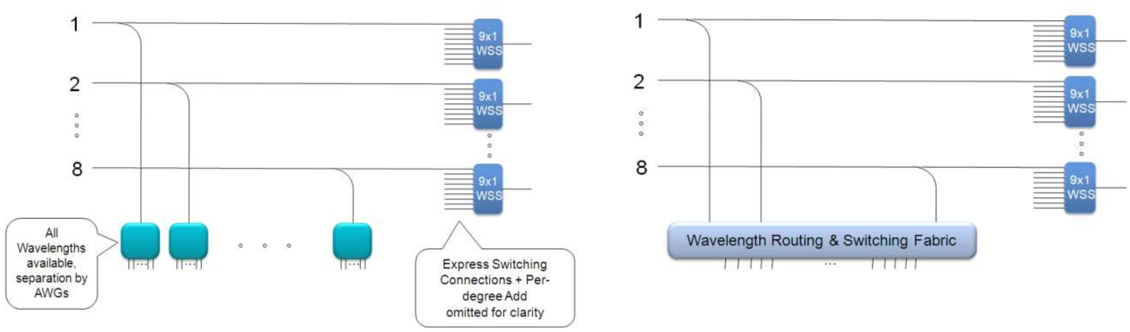

Figure 3 Current (LHS) and exemplar CDC (RHS) ROADM Architectures.
For clarity, only the Drop section of the ROADM is shown

There are many different proposed architectures for implementing the CDC Wavelength Switching and Routing Fabric on Add/Drop ports in ROADMs, all of which involve trade-offs in terms of channel count, size, cost, complexity and levels of contention, and a complete analysis of these trade-offs is beyond the scope of this paper. However, for all the various architectures, the requirement for flexible channel allocation implies that any filter arrays, multiplexer/demultiplexer modules or WSS which sit within the Wavelength Switching and Routing Fabric on the Add or Drop paths of the ROADM must also be capable of supporting flexible channel centre frequency and bandwidth allocation.

4. Other Considerations

The discussion here has focused on the requirements for the wavelength-selective elements in a flexible-grid ROADM as these will be the first part of the flexible grid network that has to be deployed to ensure the network is future-proofed. However full roll-out of flexible grid networks will also require additional component developments including scanning optical channel monitors capable of handling polarization multiplexed signals with varying bandwidths and signal formats, together with signal (and local oscillator, for coherent systems) lasers capable of operating at the finer frequency increments implied by flexible grid architectures (6.25 GHz for 12.5 GHz channel increments and 12.5 GHz for 25 GHz channel increments).

5. Conclusions

Flexible allocation of Optical Bandwidth is an important enabler to achieve maximum spectral efficiency and hence cost-effective delivery of data in the next generation of flexible optical transport networks. The optical infrastructure that is being put in place over the coming years will be the legacy networks of the next generation of the high bandwidth transmission systems and so it is important to define and implement the flexible bandwidth ROADMs required for these networks as part of the next generation of optical transport hardware.

6. References

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