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Critical Issues for the Flexible Spectrum Network

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The industry is consolidating quickly on 100 G systems over a 50 GHz channel grid for the next round of core network build-outs. And, network designers are looking at developing technologies for the next generation of transmission line rates and the optical networks that will carry them.

While there is little consensus on which modulation formats or line rates to use for the improved spectral efficiency required, there is growing agreement that the optimal spectral allocation for systems of 400 G and beyond will not align to the channel spectrums available in today's 50 GHz systems.

To ensure maximum flexibility when scaling their networks, carriers envision systems that not only automatically provision and switch end-to-end optical channels, but that flexibly allocate bandwidth to best suit channel line rates and modulation formats.

This added network flexibility, combined with improved network OSNR required for very high line-rate transmission, would let carriers efficiently set up new higher-rate channels without constraints and ensure that evolving transmission technologies do not render their networks obsolete.

The Lumentum TrueFlex™ suite of key optical networking products fully addresses these requirements for network transformation.

This white paper briefly reviews several issues critical to making flexible grid networks a reality:

- The Wavelength Selective Switch is Key
- Limitations of Broadcast-and-Select Architectures
- Advantages of Route-and-Select Architectures
- The Role of the Optical Channel Monitor
- The Role of Enhanced Amplification

The Wavelength Selective Switch (WSS) is Key

The WSS is the key enabler for flexible spectrum networks. The current generation of micro-electrical-mechanical-system (MEMS)-based WSSs has set the performance standard for 100 G-capable 50 GHz systems. However, the MEMS approach is not appropriate for the fine-granularity spectral control needed for faster line rates. A finely pixilated, multi-array switching technology is required, such as liquid-crystal-on-silicon (LCoS).

The WSS must also meet new node requirements as ROADM networks evolve to colorless-directionless-contentionless (CDC) architectures. Furthermore, 400 G and higher line rates will impose new optical performance requirements. The CDC ROADM nodes will need to support more degrees and multiple directionless add/drop structures with the effect of increasing WSS port counts from today's 1x9 to 1x20 ports.

Requirements for a Flexible Spectrum Network

- Flexible spectrum twin-WSS
- Flexible spectrum OCM
- Colorless mux/demux
- Hybrid Raman-EDFA amplifiers
- Advanced network control

Limitations of Broadcast-and-Select Architectures

Today's ROADMs commonly use a broadcast-and-select architecture. This architecture positions a WSS at the outbound side of each degree, and the WSS blocks all copies of channels not intended to continue out that degree. The extent of this blocking is critically important to avoid signal-impairing interference with a provisioned channel.

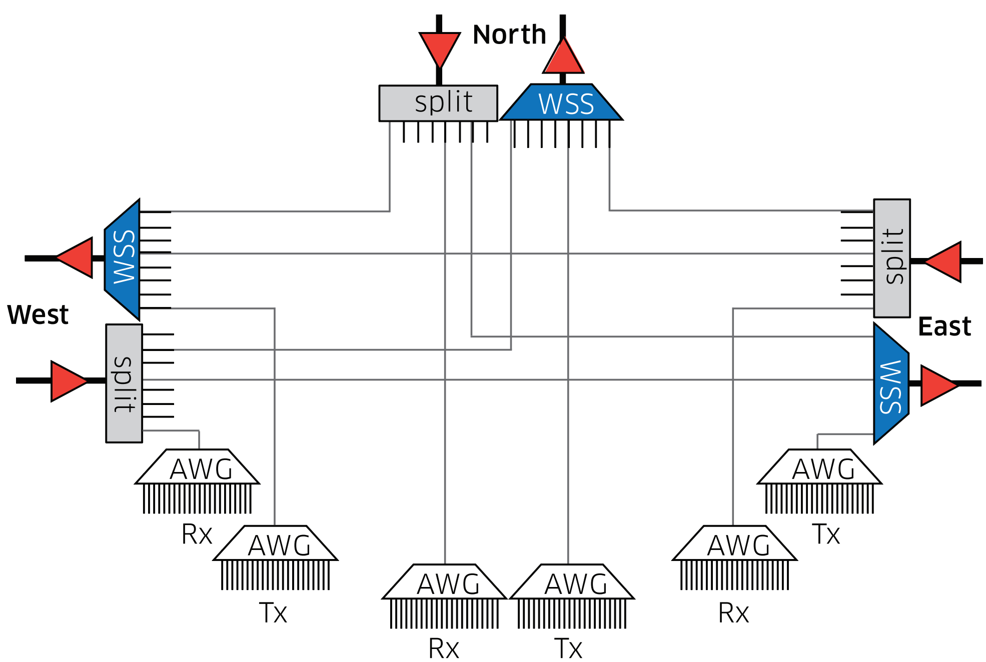

Figure 1. Broadcast-and-select node architecture with fixed add/drop

As the number of WSS ports increase, so does the number of possible paths of optical interference. Thus, WSS isolation must increase equivalently. Furthermore, as line rates beyond 100 G will be targeting higher spectral efficiency and modulation density, the formats will tolerate same-wavelength interference much less. This means that the isolation requirement of the WSS will likely increase beyond 45 dB.

This level of isolation is a difficult target even for today's lower-port-count WSSs. It is a formidable challenge for higher-port-count (~20) WSSs, particularly when they also have to deliver flexible spectrum with suitable bandwidth granularity, faster switching times for quicker wavelength provisioning, compact form factors, and lower cost points.

Advantages of Route-and-Select Architectures

A compelling strategy to accomplish the required performance levels, functionality, and cost points is to use a route-and-select architecture. With this approach, a second WSS replaces the splitter that is typically used with a broadcast-and-select architecture. A pair of WSSs resides in each degree and relieves WSS isolation requirements by providing two points of suppression for all interference paths. By significantly easing the port-isolation requirement for each WSS, it is feasible to achieve the necessary cumulative isolation, a high port count, and fast switching. A node-optimized, twin-WSS implementation can be compact and very cost-effective as well.

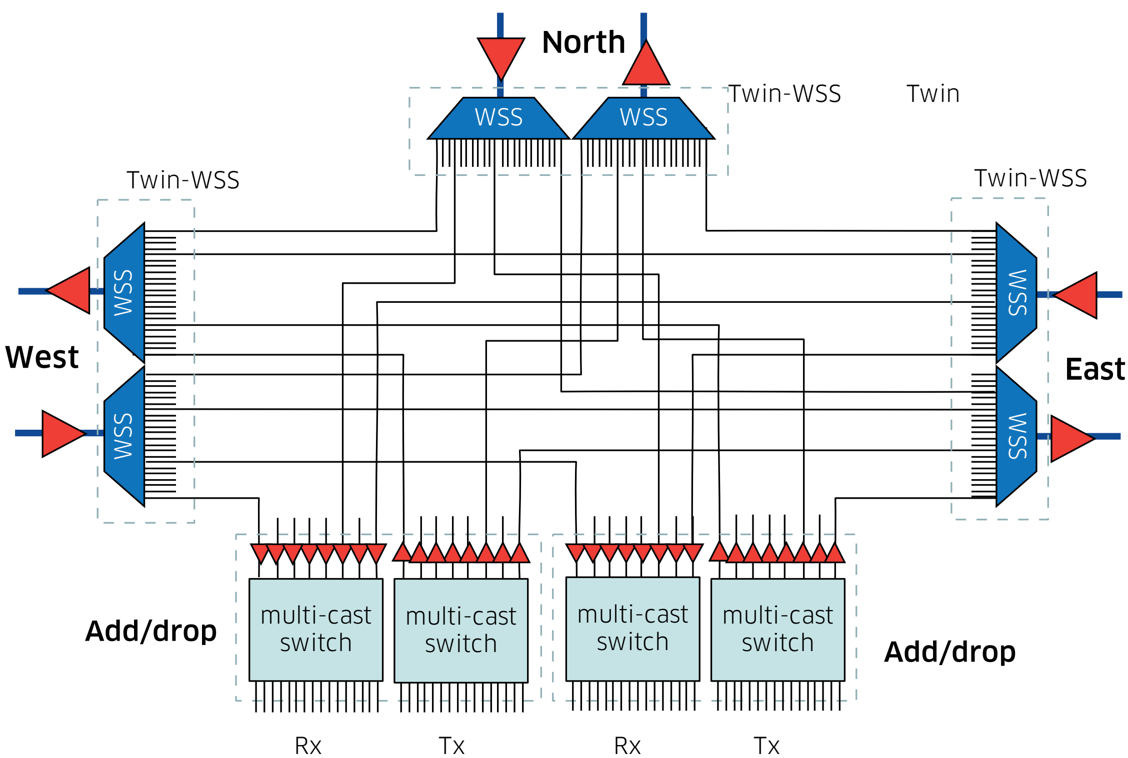

Figure 2. Route-and-select node architecture with CDC add/drop

Furthermore, replacing the splitter with a routing WSS reduces the total insertion loss for express channels through the node. This improves the OSNR of channels expressed through the node, a critical factor for line rates of 400 G and beyond.

Using a route-and-select architecture also simplifies the local add/drop of the flexible spectrum network. The demux WSS can selectively route only the channels destined for local drop to the CDC demux. This lowers the complexity and cost of the the demux by reducing the power of the drop amplifiers and allowing coherent receivers to be used for colorless demultiplexing.

The Role of the Optical Channel Monitor (OCM)

As with the WSS, a flexible spectrum network imposes requirements on the OCM that monitors the channel power for channel power control. In today's networks, the OCM reports on channels whose center wavelength and width are defined and fixed. Flexible spectrum networks require monitors that can measure power levels across the full spectrum in relatively small slices, as narrow as 12.5 GHz or less.

To achieve spectral efficiency targets, 400 G signals will more fully occupy the available flex-channel bandwidth and the OCM will need to maintain good measurement accuracy and sufficient spectral resolution to cleanly measure channel power towards the channel edge without experiencing crosstalk error from adjacent channels.

Also, increasing channel-provisioning times will require faster measurement rates across multiple monitoring points. This increased resolution and scan time is within the capabilities of higher-end scanning filter technologies that are currently in development. However, the algorithms to effectively do this in the time scales required to provide responsive system control loops require ongoing development.

The Role of Enhanced Amplification

The move to a flexible spectrum network with 400 G+ line rates is fundamentally driven by the need to at least double spectral density to keep pace with increased network traffic demand.
To deliver higher spectral efficiency without compromising
un-regenerated reach, flexible spectrum networks require significantly improved end-to-end network OSNR.

The broad deployment of advanced distributed Raman amplification in concert with current EDFAs is a critical enabler of this improved performance. Like the flexible spectrum WSS and OCM, these advanced amplifiers, both for line amplifiers and for pre- and post-amplifiers at ROADM sites, must be part of the initial deployment in the flexible network for the network to seamlessly incorporate higher line-rate connections in the future.

Conclusions

In addition to appropriate flexible spectrum WSSs and OCMs and enhanced Raman amplification, significant advances are required in the network control systems that will provide timely route selection and control for channels of varying spectral widths without excessive spectral stranding. These network control systems will need to extend to the new switching elements and incorporate appropriate power-level control over next-generation amplifiers.

For network operators anticipating the deployment of 400 G+ transmission, the concept of the flexible spectrum network is indeed compelling. However, flexible spectrum networks that deliver both required optical performance and true port-to-port network routing capability require innovative new optical-module solutions such as the Lumentum TrueFlex product suite as well as the associated network control-plane upgrades.

These technologies are currently the focus of intense R&D activities that promise to deliver on the vision of the flexible spectrum network in time to intercept the commercial arrival of next-generation transmission rates.

The Lumentum TrueFlex product suite consists of:

- Twin co-packaged flexible spectrum high port count (1x20) WSS ROADM module
- Four-port flexible spectrum optical channel monitor
- Dual co-packaged 8x16 multi-cast switch module
- Hybrid Raman-EDFA amplifiers
- EDFA amplifier array

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