Recent Progress on Wavelength Selective Switch

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Abstract: WSS application scenarios have been illustrated from network core to edge. WSS in core network is focused on higher port count and outstanding performance, while cost is the key factor for WSS in edge network.
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1. Introduction

As the granularity of optical transport network commonly reaches 100Gb/s and advances to 400Gb/s, electrical switches become inefficient in handling traffic management. Reconfigurable optical add drop multiplexers (ROADMs) realized automatic scheduling and restoration at the wavelength level in the optical layer and transformed traditional optical links into reconfigurable networks [1]. For network operators, ROADMs save transceiver cost and power consumption, allow superior network flexibility, and hence have been deployed worldwide.

It is worthwhile noting that the wavelength selective switch (WSS) is the key component in all commercial ROADM systems. A WSS comprises a switching array that operates on light that has been dispersed in wavelength without the requirement that the dispersed light be physically demultiplexed into separate ports. There are several ways to implement the switching element of a WSS, such as Microelectromechanical Mirrors (MEMS), Liquid Crystal (LC) on glass and Liquid Crystal on Silicon (LCoS). LCoS dominates current WSS shipment as LCoS based WSS is able to support low drive voltage, flex-grid, high port count. Since first being widely marketed in 2006, the LCoS-based WSS has continued to develop. The first units had either 4 or 9 ports. Now 20 ports or more are commonly available. Sharing the same optics between two WSS enabled lower cost dual WSS to be built. This in turn made route-and-select nodes affordable. A route and select architecture uses one WSS for each incoming fiber in the node and these WSS for the incoming light route chosen signals to the WSS in front of each fiber going out of the node [2].

To date WSS's have been deployed mainly in the core transport network where traffic is scheduled at wavelength level. However, as wavelength division multiplexing (WDM) has been deployed closer to network edge, there is increasing demand for WSS to support flexibility at the edge. Current high performance WSS are over-engineered for edge applications. Hence WSS design is becoming increasingly specialized for a wide variety of applications. At the high end, in core WSS, the demand for higher port counts and more functionality continues to dominate. While for network edge applications simplicity, low-cost and thermal tolerance are essential.

In this paper, WSS application scenarios across the network core and edge are illustrated. Required features and design challenges of next generation WSS used in core and edge are discussed in detail.

2. WSS applied in a typical metro network

Figure 1 shows a typical optical metro network which is comprised of three layers: core, aggregation and edge/access. Each metro network has different number of nodes in the core layer depending on scale, normally between several to dozens. The first priority for WSS design in core network is to maximize the number of ports, which can be translated into ROADM degrees. The demand for ports comes from two sources: Firstly, regional data centers are more and more likely to be connected directly to the core layer, further increasing the number of nodes. Moreover, these core nodes are often part of the backbone long haul transmission network. For the sake of low latency which is crucial for nowadays 5G and other time sensitive services, traffic is required to reach destination via smallest number of hops. Therefore, full mesh connections are highly preferred in core layer. Hence ROADMs have to support high degrees since there are numerous nodes need to be connected. Secondly, optical 1+1 protection requirements double the WSS port number for protection redundancy. In recently deployed backbone and metro ROADM networks, demand of more than 20 degrees already appeared which cannot be satisfied by commercial 20 port WSS and pushed WSS development to higher port count, such as 32 or 34 ports.

In addition, Core WSS will necessarily be Flexgrid based to accommodate higher baud rate signals. FlexGrid removes the 50 GHz channel spacing and replaces it with 6.25 GHz slices that can be built up into any desired channel width. It is clear that revising the "standard" channel widths is on the way. Meanwhile, dual WSS are becoming increasingly popular in core network since this enables "route and select" node designs at reasonable cost.

These systems share both optics and electronic control circuitry making them only incrementally more expensive to build than single systems.

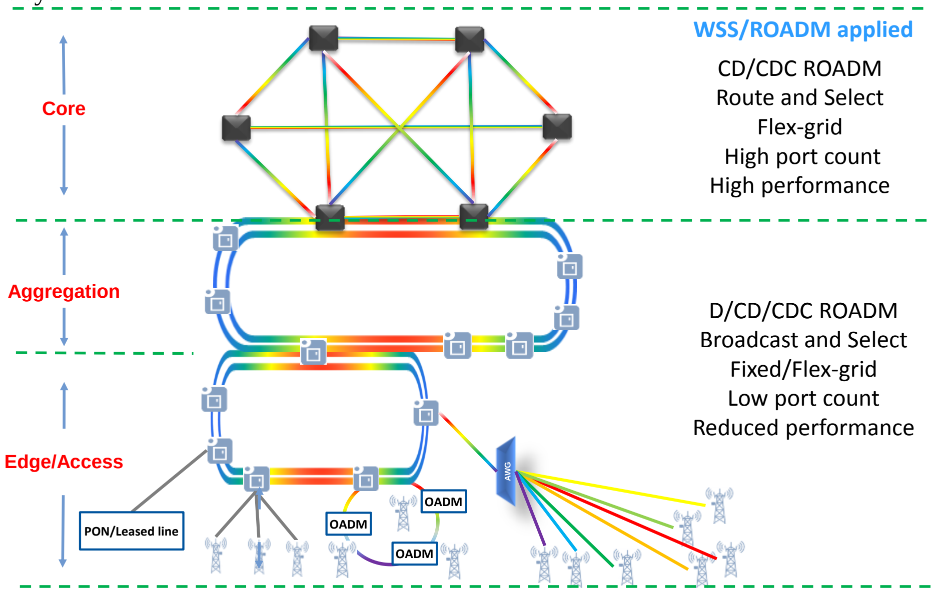

Fig. 1: Typical metro network architecture and WSS applied.

In contrast, ring topology is more popular in aggregation and edge/access networks, hence lower port count WSS might be more efficient. Lower wavelength usage due to less traffic carried and shorter reach engaged allows a potential downgrade of performance and possibly elimination of the need for Flexgrid. A simple version of 16 or 40 channels DWDM is discussed in aggregation and edge/access networks, thus WSS channels can probably be widely spaced across the spectrum. This allows channel spacing of 100 or even 200 GHz, with LCoS having a lower resolution.

3. Core WSS used in core network

Next generation core WSS is being pushed to have higher port counts while maintaining or improving on the specifications and size of their predecessors. This comes with significant challenges and need for innovation at the WSS design level. For the majority of WSS optical designs, fibers are stacked in a 1D array to create the input/output ports, and this array is orthogonal to the axis of frequency dispersion. For such WSS, the thickness is in part limited by the number of ports. While optical fiber manufacturers have worked to reduce cladding diameters to 80um, spacing the fibers closer together makes for poorer port isolation. The length and breadth of the WSS is typically defined by distance required to adequately separate light of different frequencies and create a focused spot size suitable to create high resolution channels. Any degradation in resolution results in a larger transition region between optical channels and wastes precious core network bandwidth. Reducing this width and breath increases aberrations in the system, which will either degrade channel resolution or increase complexity and cost of the WSS.

Figure 2 illustrates designs of WSS key specifications for system performance which center around bandwidth, polarization dependent loss (PDL), insertion loss and crosstalk. Useable bandwidth is critical. Now individual sub-channels are getting wider as modulation speeds increase to 64 Gbaud and beyond. Flexgrid channels are generally chosen so signals just fit and use all the bandwidth up to the edge of the clear channel passband. These channel edge areas can be problematic, not only because insertion loss can roll off as one nears the edge of the clear channel passband, but also group delay ripple will correspondingly increase in these regions through the Kramers–Kronig relation. The need to sharpen these channel edges and reduce guard-bands will drive improvements in the dispersive elements used in WSS, particularly grating design.

Polarization dependent loss (PDL) has always been a challenge for WSS designers. Unlike other effects that can be addressed with software, in the majority of WSS designs, PDL is intrinsic to the mechanical design and a unit that fails PDL must be rebuilt at significant cost. Conversely, the network designer sees PDL as fundamentally limiting transmission distances by mixing previously orthogonal signals. Minimizing PDL, particularly on express ports, increases transmission distances.

There appears to be a trend among many new transmitter designs to have significantly lower output power. On the add ports, this may drive a need for lower loss in the WSS, at least for these ports. While most WSS have a loss around 6 dB, unlike couplers or multicast switches there is no theoretical limit to how low the loss could go.

On the express ports, crosstalk remains a major design issue. With as many as 20 express ports in a WSS, and an optical signal travelling through 30 or more, the potential for signal corruption is significant. Route-and-select architectures roughly halving the crosstalk requirements, compared with broadcast and select architectures. But the requirements of the WSS are still severe. Higher quality optics will be key to reducing scatter and hence crosstalk.

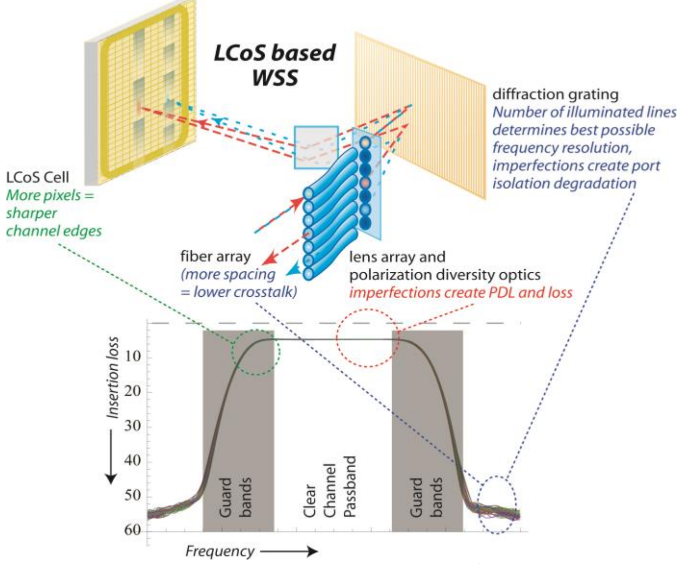

Fig. 2: WSS design related to key specifications

4. Edge WSS used in aggregation and edge/access network

Due to benefits brought to the network such as flexibility, deployment simplicity and low latency, WSS is considered as a candidate for aggregation and edge/access networks with ring topology. Though a 1×2 WSS seems sufficient for a ring network, it is still beneficial to have more ports to support simpler add/drop architecture, especially when more ports don't bring much additional design efforts and cost. To be aware that though Flexgrid is not a must-have option for edge WSS, it could still provide flexibility of network planning and in-band shaping to cooperate signal equalization, plus it comes as a free feature of LCoS platform. 4 ports or more can provide convenient connections for 3 add/drop signals (either coherent or non-coherent) without introducing complicated two stage add/drop architecture, which is suitable for wireless 3 sectors x-haul transmission. Furthermore, as a powerful and flexible platform, the LCoS based edge WSS could expand to support more ports to facilitate different network structures.

For WSS to be a good choice for edge/access networks, the design should allow the module to be small and low cost. There are many factors that would increase WSS cost, such as wide bandwidth and high isolation for long ROADM cascades, narrow channels to support high-order modulation, high speed interface, loopback ports for diagnostics, etc. For low cost, the design should reduce the complexity and total number of components in the WSS and also simplify the assembly and calibration processes to decrease touch time. The reduction in complexity and number of components poses some issues in the design of the optical system, as it reduces the design space to compensate for optical aberrations. Keeping the WSS small brings a number of other limitations, such as upper bounds on the number of ports, reduction in optical resolution and thermal management. Overall, a small and cheap edge WSS would have performance degradations compared with their core network counterparts and, as with most optical systems, there are trade-offs as to which specifications are degraded the most.

5. Conclusion

WSS application scenarios across the network have been illustrated. Core WSS is designed to have more ports for more complex network architecture and higher performance to facilitate transponders of many generations to come. While edge WSS is going to be simple and cheap enough to be considered in harsh edge/access environment.

References

[1] C. Brackett et al., Journal of Lightwave Technology, vol. 11, no. 56, pp. 736 - 753, 1993.

[2] S. Frisken et al., Technology and Applications of Liquid Crystal on Silicon (LCoS) in Telecommunications. Chapter in Book Optical Fiber Telecommunications, pp.709-742, 2013.