Efficiently Supporting Aggressive Network Capacity Growth in Next-Generation ROADM Networks

Introduction

Society's demand for connectivity continues unabated and there is every indication that this will continue, with the introduction of augmented reality/virtual reality (AR/VR) applications and the Internet of Things (IoT) expected to dominate data traffic in the near future and the emergence of applications we have yet to conceive. Optical networks continue to be the only means to support this relentless traffic growth.

We are however, approaching a fundamental limitation in the amount of information that can be packed into an optical fiber. This impending "capacity crunch" is a significant milestone in optical networking given that we have historically implemented capacity growth by developing technology to make more efficient use of available bandwidth in a fiber. With the effectiveness of this mode of growth rapidly diminishing, we will soon reach the practical maximum capacity achievable in a single optical fiber. Coping with ever increasing demands will require future-proof approaches to building cost-effective optical networks.

Addressing Network Traffic Growth

On average, optical network traffic is growing at approximately 30% compound annual growth rate* (CAGR) which is equivalent to a doubling of capacity every 2.5 years.

Historically, during the non-return-to-zero (NRZ) era, capacity growth was achieved by increasing baud rate. When baud rate increases were not sufficient to keep pace with growth, spectral efficiency was improved with the introduction of coherent technology. Following this was a period where both baud rate and spectral efficiency increased to achieve capacity growth. Recently however, spectral efficiency has reached a point where limited improvements are achievable as we approach the Shannon limit for a given reach (blue line in Figure 1a) and practical baud rate growth alone cannot continue to keep pace with the assumed 30% rate of growth required (orange line in Figure 1b).

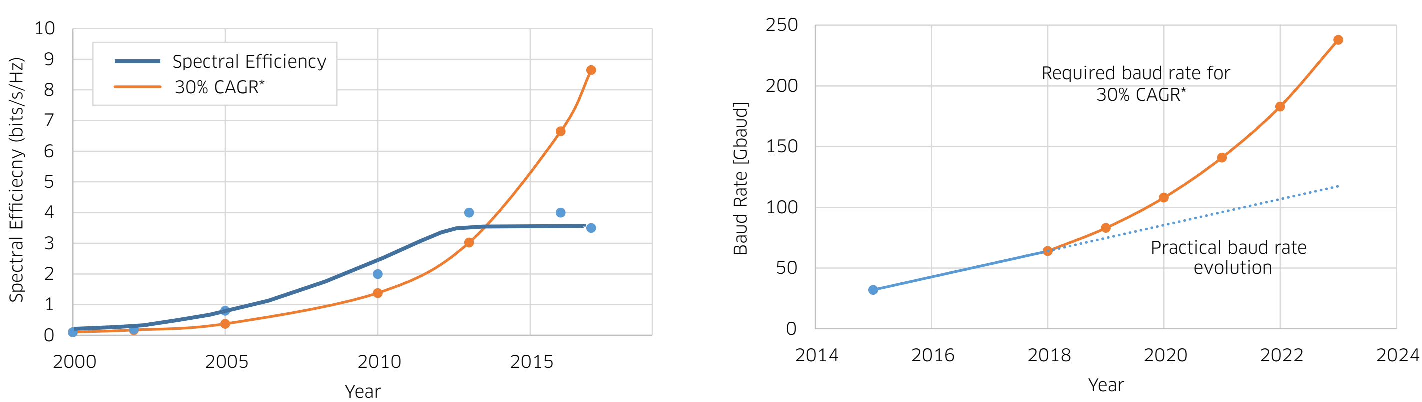

Figure 1. (a) Recent spectral efficiency evolution compared to 30% CAGR and (b) Baud rate growth required to keep pace with 30% CAGR

* 30% CAGR used for illustrative purposes only, actual network growth can vary by region, network type, and other factors

Given that we cannot rely on the combination of spectral efficiency improvements and/or baud rate increases to meet traffic growth requirements, the only way to support growth for a given reach will be to increase the total amplified bandwidth per node at nominally the same rate as traffic is growing (Figure 2a).

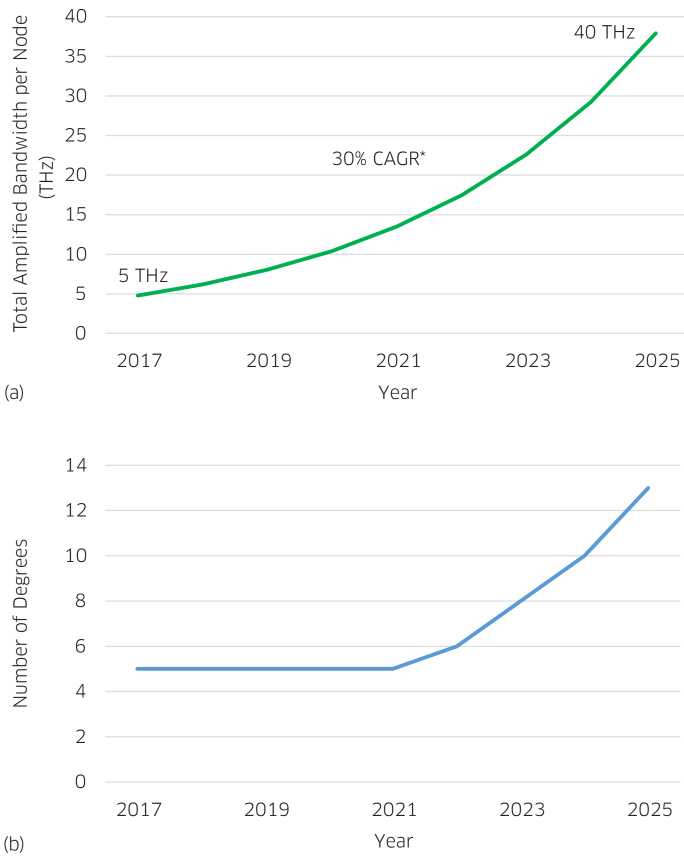

Figure 2. (a) Example total amplified bandwidth per node to support 30% CAGR traffic growth and (b)Example of number of fiber degrees required for 30% bandwidth growth based on 5 physical directions

Overlaying additional fiber pairs per route (Figure 2b) is a practical approach to increasing total amplified bandwidth that can provide multiple increments of C-band capacity growth. An alternative approach, desirable for some operators with limited fiber availability, is to extend the optically amplified bandwidth to include both the C and L bands. While this only provides a 2x increase in bandwidth, it does reduce the amount of fiber required and delays the need for additional fiber overlay by a few years.

Efficient Utilization of C-band Bandwidth

The majority of deployed ROADM networks today are based around a fixed 50 GHz ITU grid regardless of whether the optical hardware supports flexible grid wavelength selective switch (WSS) technology or not. This is entirely due to the fact that the baud rate of today's core network traffic, whether 100 Gbps or 200 Gbps, does not typically exceed 32 Gbaud.

One option for increasing the total capacity per node is to continue with this strategy and fill each fiber with 50 GHz spaced channels, deploying C-band overlay fibers where required and maintaining the 50 GHz grid structure for all of the traffic as the capacity grows (Figure 3a).

An alternative option would be to take full advantage of improved cost per bit from higher baud rates and future multicarrier transceivers and expand the bandwidth of channels (Figure 3b). Figure 3c details how channel bandwidth might evolve in this example, from 50 GHz to 300 GHz with a combination of higher baudrate and increased number of carriers, along with the data rates that could be supported per channel.

Figure 3. Options for dividing amplified bandwidth into optical channels

* 30% CAGR used for illustrative purposes only, actual network growth can vary by region, network type, and other factors

The Benefits of Increasing Channel Bandwidth

In the scenario where fixed bandwidth channels are used as shown in Figure 3(a), the number of active channels per node grows exponentially in line with the growth in node bandwidth. Alternatively, where channel bandwidth is increased through increasing baud rate and/or number of carriers, the number of active channels per node grows more gradually and relatively linearly compared to the exponential growth in node bandwidth. Figure 4 compares the growth in number of active channels per node for fixed 50 GHz spaced channels (green line) with the case where channel bandwidth is increased (blue line). Also shown is the successive introduction of higher bandwidth channels over time. In this example, 75 GHz channels (orange bars) are introduced, capping any further growth in 50 GHz channels (blue bars) and so on as channel bandwidths and network capacity increase.

Clearly, the use of increasing channel bandwidth results in fewer active channels per node compared to the case of fixed 50 GHz bandwidth channels, and in this example, up to 60% less over the life of the network. This is important from a ROADM infrastructure perspective since it significantly reduces the number of add/drop ports required within a node and minimizes the number of line WSS ports needed since fewer colorless/directionless/contentionless (CDC) add/drop modules are required.

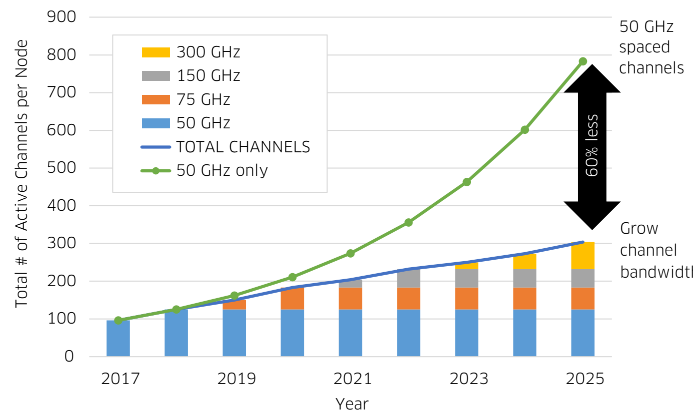

Figure 4. Number of active channels per node (for assumed 30% growth) for fixed 50 GHz channels bandwidth vs growing channel bandwidth

By simply taking advantage of increasing baud rate and/or embracing the use of multicarrier transceivers, future ROADM nodes require relatively smaller port count line WSSs and significantly fewer CDC add/drop modules while still supporting aggressive network traffic growth. The result will be simpler nodes with a lower cost.

Impact on ROADM Infrastructure

The impact of employing increasing channel bandwidth on ROADM infrastructure is best described using a simple example that assumes 25% add/drop traffic[1] at a 200 Tbps node[2]. Figure 5 shows the resulting node architecture based on both fixed 50 GHz bandwidth channels and increasing bandwidth channels. Since the number of active channels transiting the node is significantly fewer for the increasing channel bandwidth case, only three CDC modules are required to achieve 25% add/drop, compared to 11 CDC modules[3] in the fixed 50 GHz channel scenario.

Growing channel bandwidth significantly reduces the number of CDC modules required as shown in Figure 5 and as a result, minimizes the number of line WSS ports required within each degree. This not only lowers the cost for the same capacity, but consumes significantly less power in a smaller equipment footprint.

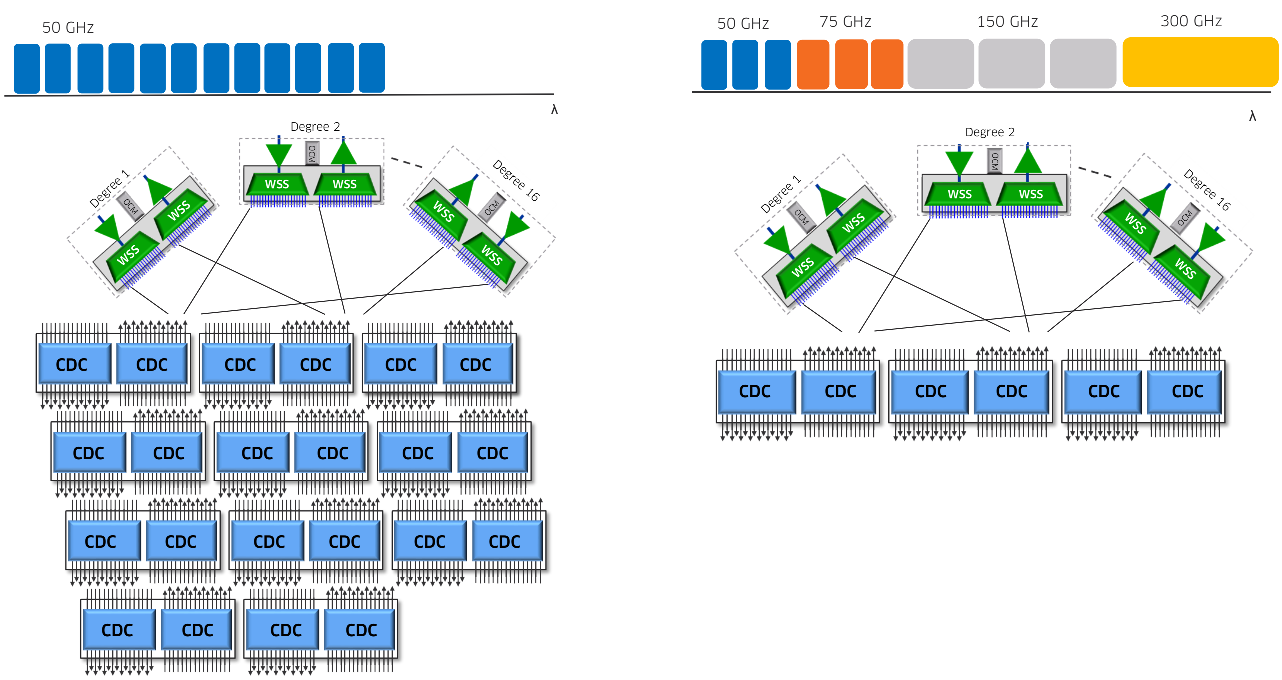

Figure 5. Comparison of 200 Tbps node architecture with fixed 50 GHz channel bandwidth vs increasing channel bandwidth

[1] 25% is the nominal average expected percentage traffic added/dropped at a ROADM node used for illustrative purposes only
[2] 200 Tbps is the expected node capacity after 8 years of assumed 30% CAGR traffic growth
[3] Assuming CDC modules with 24 add/drop ports

The Bandwidth Bottleneck
Current-generation CDC mux/demux solutions leverage PLC-based multicast switches (MCS) constructed using a cascade of 1xN power splitters and Mx1 selector switches. Multicast switches possess high loss, driving the requirement for erbium-doped fiber amplifier (EDFA) arrays between the degree WSS and the MCS (Figure 6). The maximum power required by each EDFA is driven by the loss of the MCS. Increasing MCS port count, increases loss and consequently, the maximum power required by the EDFA array.

Modern coherent signals have nominally constant power across their spectrum, so as the overall bandwidth of the channel increases, the total power of the channel increases proportionally. For example, a 150 GHz width channel has 5 dB (3x) higher power than a 50 GHz width channel, while a 300 GHz channel possesses 8 dB (6x) more power per channel. So as channel bandwidths scale from 50 GHz to higher bandwidth, EDFA arrays associated with the multicast switch must support significantly more total power (Figure 6). For a typical 8x16 MCS, the EDFA array output power requirement becomes impractical even for a 150 GHz channel width.

This inherent "bandwidth bottleneck" means that there is a limit to the maximum channel bandwidth and port count that an MCS can practically accommodate. If an MCS-based network is deployed with an EDFA array that cannot support higher channel powers and thus wider bandwidths, that network may not support future coherent transceivers.

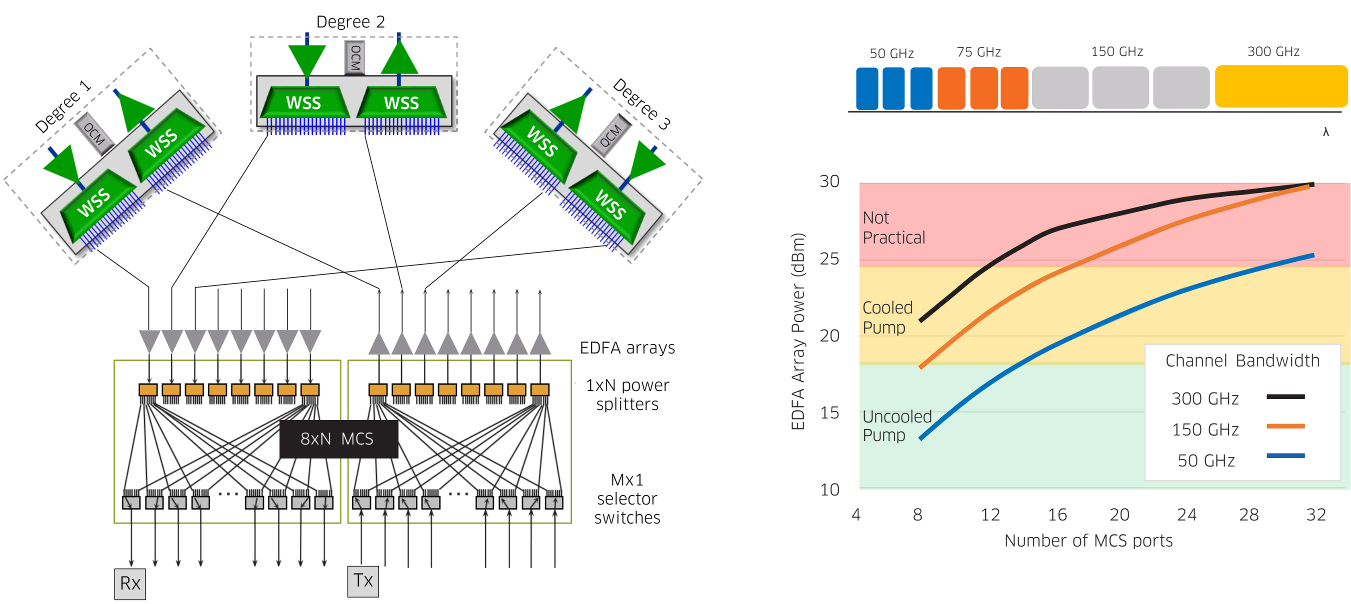

Figure 6. Power scaling of MCS EDFA array with increasing channel bandwidth

A Future-Proof ROADM Network

Recent advances in liquid crystal on silicon (LCoS) and optical design technology have allowed the development of a commercial contentionless MxN WSS which meets the needs of next-generation CDC ROADM networks. Functionally, the high-loss power splitters of the MCS are replaced by low-loss wavelength selective switches (Figure 7), tightly integrated in such a way as to provide both add and drop capability within a single module. Flexible grid filtering from the WSS eliminates the accumulation of out-of-band noise generated by transmitters in the add direction, while removing multichannel noise at coherent receivers in the drop path. Consequently, coherent Tx and Rx requirements can be relaxed and overall system performance is improved as a result.

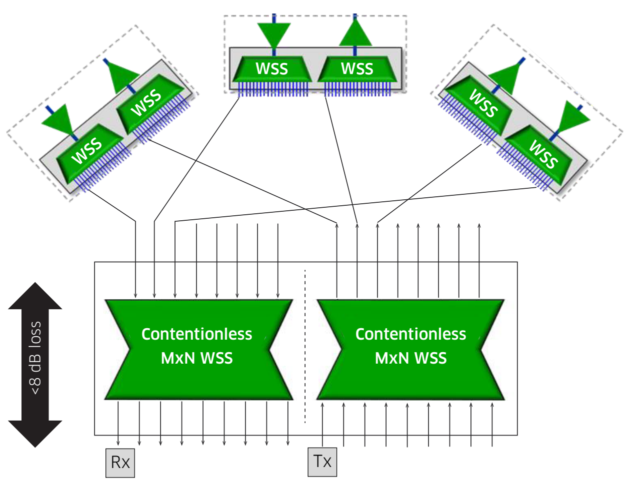

Figure 7. Low-loss contentionless MxN WSS removes the need for EDFA arrays

With no EDFA arrays in the add/drop path, there are no limitations on channel bandwidth or power as would be the case with multicast switch implementations. The result is that contentionless MxN WSS can seamlessly support wider bandwidth channels of any total optical power.

Conclusion

With traffic growing exponentially, nominally doubling every 2.5 years, and spectral efficiency and baud rate growth not keeping pace, coherent transceivers must aggressively expand in bandwidth to provide an effective means of supporting this capacity growth.

Future CDC ROADM networks must be compatible with these evolving coherent interfaces without incurring constraints on channel bandwidth and/or power. While today's MCS-based solution with EDFA arrays cannot easily provide this flexibility, contentionless MxN WSS will provide a path to higher capacity CDC ROADM networks with improved performance and lower total cost of ownership.

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