Breaking through network capacity limits

How C+L-band WDM systems help carriers meet the growing demand for data services

White paper

Network operators are looking for economical ways to increase capacity so that they can keep pace with demand for a wide range of data-intensive services. Many of these operators run their optical networks on leased fiber pairs. Once these networks are filled, they lease more fibers and overlay them with new wavelength-division multiplexing (WDM) systems. This approach can be expensive.

This paper describes how operators can double their network capacity and avoid the need to lease more fiber pairs by deploying C+L-band WDM systems on their existing optical networks. It highlights the flexible deployment options that that these systems can provide, along with self-tuning techniques that can prevent performance issues caused by wavelength tilt.

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Introduction

The ever-increasing demand for high-speed data, internet and video services is compelling network operators to keep upgrading their networks to support higher transport capacities. Work-from-home initiatives intended to slow the spread of COVID-19 have accelerated this demand. As the pandemic has spread, some operators have reported experiencing 30–50 percent bandwidth growth – a typical range for an entire year – in a matter of weeks. Longer-term capacity needs also continue to increase because of the ongoing shift to cloud-based software applications, 5G systems and Industry 4.0 applications.

Network operators are searching for cost-effective ways to meet this demand. Many run their networks over leased fiber pairs (e.g., dark fiber) instead of owning and operating their own fiber cables. These operators typically need to lease a second pair of fibers and overlay new wavelength-division multiplexing (WDM) systems once their existing C-band WDM networks are filled. Unfortunately, leasing fibers over regional or long-haul 1000–3000 km routes and building overlay networks can be prohibitively expensive.

Operators can reduce costs and meet new capacity demands by deploying C+L-band WDM systems on their existing optical networks. Adding L-band capacity enables them to double the capacity of their existing fiber pairs and eliminate the need to lease a second pair of dark fibers.

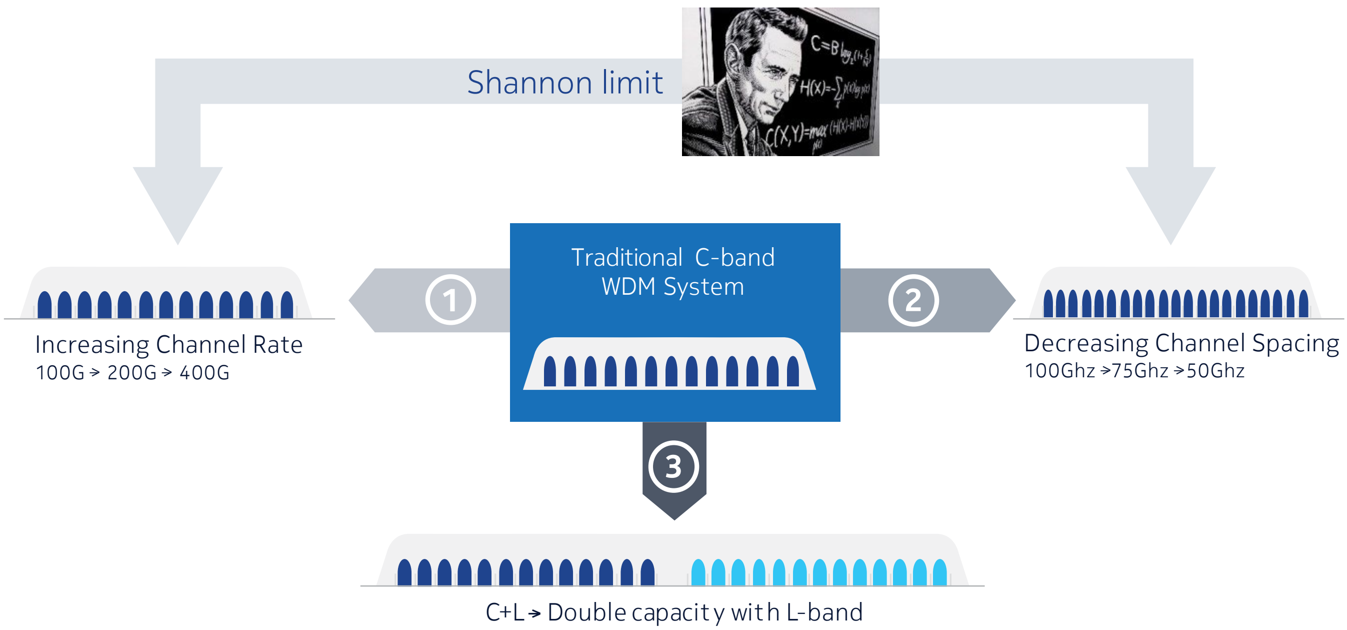
Reaching C-band limits

Network operators have traditionally kept pace with new bandwidth needs by utilizing higher-speed wavelengths and reduced channel spacing to increase network capacity over the C-band (Figure 1). They have added capacity to their networks by deploying faster and faster wavelengths, from 10G to 100G, 200G to 400G. Or they have added more channels to the network by decreasing the channel spacing from 100 GHz to 50 GHz. These two options are interrelated. Both are constrained by the overall Shannon limit on fiber capacity.

Over the last ten years, advancements in coherent digital signal processors (DSPs) and optics have brought tremendous capacity improvements while reducing overall cost per gigabit. For example, modern fourth- and fifth-generation coherent DSPs offer multi-baud rates, multiple modulation formats and strong forward error correction (FEC) to ensure optimized wavelength capacity at any reach — from metro to subsea distances. Coherent-optimized Colorless Directionless Contentionless – Flexgrid (CDC-F) ROADMs can leverage the 200G–600G wavelength modes of these DSPs that require new channel spacings (e.g., 62.5 GHz, 75 GHz, 87.5 GHz). However, with modern transponders operating so close to the Shannon capacity limit, future capacity and spectral efficiency improvements in the C-band will be fairly limited.

How, then, can operators efficiently and cost-effectively expand their network capacity? By deploying WDM systems that add L-band capacity to their C-band networks, operators can double the capacity of their existing networks. This capacity boost is critical for operators that run their networks over leased dark fiber.

Figure 1: Network capacity options



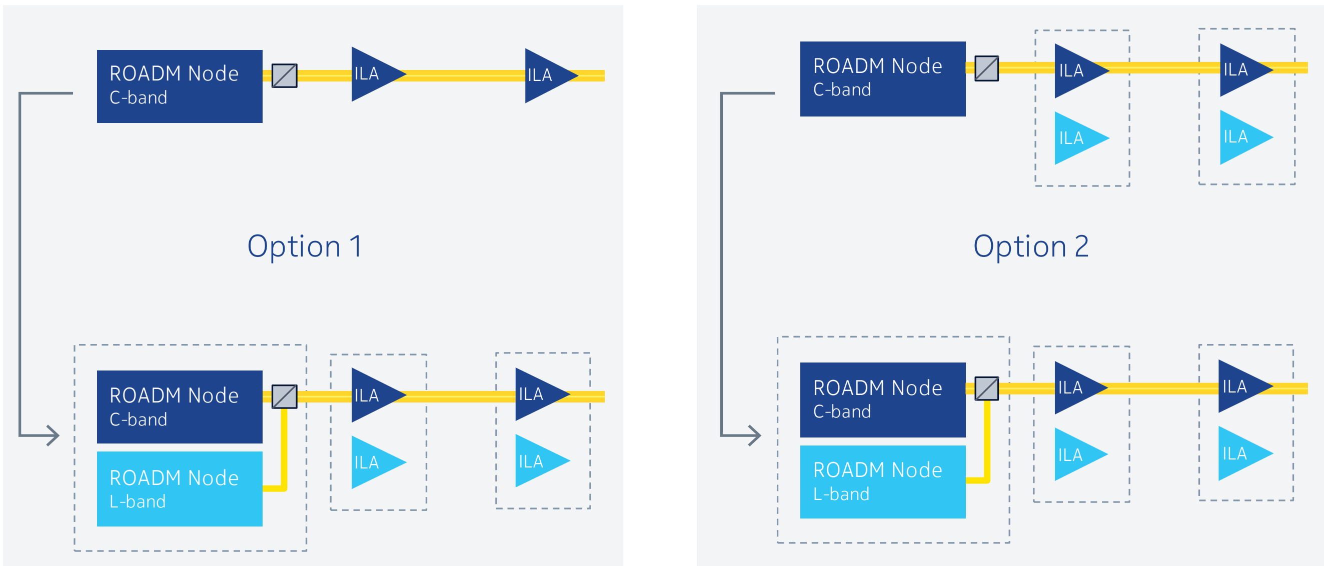
Flexible upgrade options

One key aspect of C+L-band WDM systems is that they deliver an efficient and cost-effective network upgrade. They make it easy to add the L-band system to existing, deployed C-band networks by supporting modular, flexible upgrade options that ensure wide industry adoption. These options enable operators to meet their different operational and CAPEX requirements and avoid the inevitable limitations of one-size-fits-all approaches.

For example, many operators have chosen to deploy their C-band WDM systems according to normal, standalone C-band WDM procedures. With C+L-band WDM systems, they can add L-band equipment to the existing ROADM and in-line amplifier (ILA) sites once the C-band is filled. The L-band equipment is only added when needed, so there is no expensive initial cost or stranded L-band investment. Shown in Figure 2, Option 1, this approach provides the ultimate pay-as-you-go upgrade process.

Some operators may prefer to install ILA sites as C+L ILA nodes from initial deployment. Since backbone ILA nodes tend to be located at remote sites, installing C+L ILA nodes as part of the initial deployment saves time and reduces operating cost by eliminating the need to revisit the remote ILA sites during the L-band upgrade. When the operator needs additional L-band capacity, it simply needs to upgrade the ROADM sites with the additional L-band equipment, as shown in Figure 2, Option 2. ROADM nodes are typically located in staffed central offices and data centers, so the operator can perform the upgrades quickly and efficiently.

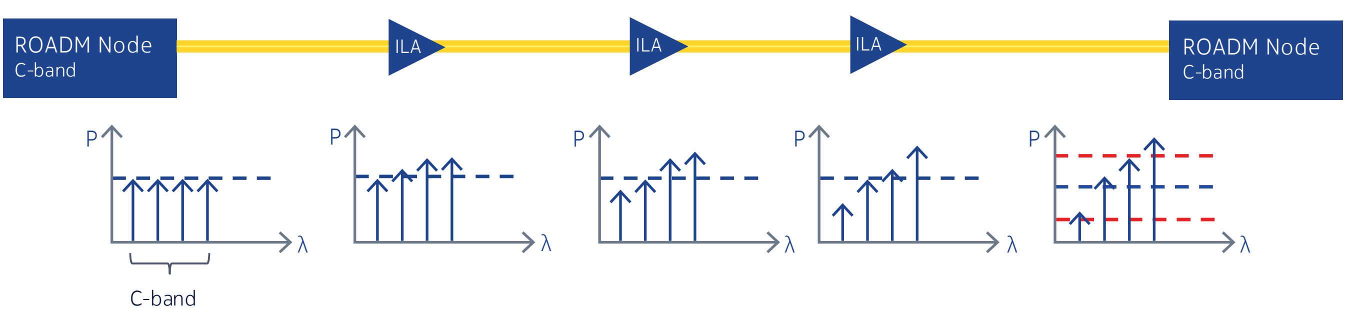
Figure 2: Flexible upgrade options



Understanding SRS tilt management

Operators must consider performance-limiting issues in deciding whether to deploy C+L-band WDM systems to maximize network capacity, efficiency and cost per bit. One issue that affects WDM network performance is Stimulated Raman Scattering (SRS). SRS is a nonlinear effect in optical fibers that causes optical power to shift from shorter wavelengths to longer wavelengths, resulting in wavelength tilt across the spectrum. This effect is present in C-band-only WDM systems, as shown in Figure 3, as well as in C+L-band WDM systems.

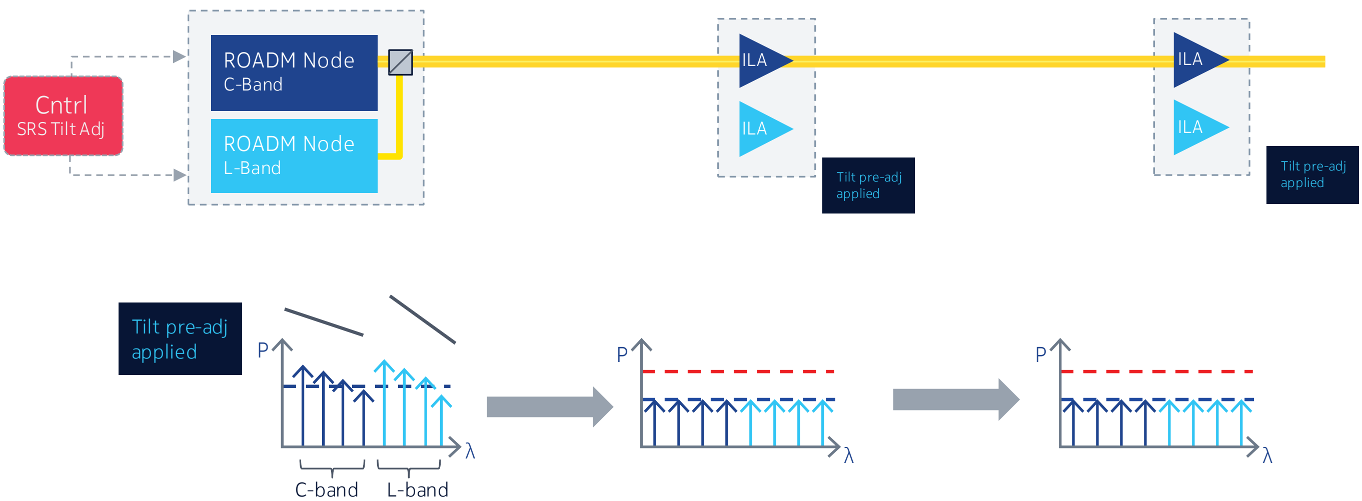
Figure 3: SRS tilt effects



Within a single C-band, vendors manage SRS tilt by applying a pre-emphasis to the wavelengths at each amplifier site. The amplifiers monitor the power of every wavelength at each node and slightly increase the shorter wavelength's power to ensure a flat wavelength response. WDM systems automatically adjust SRS pre-emphasis as wavelengths are added or deleted from the network. This dynamic, self-tuning SRS tilt management ensures that operators never have to worry about SRS tilt.

On C+L networks, SRS tilt still occurs within the individual bands, as well as across C- and L-bands. Modern, state-of-the-art WDM systems incorporate control systems that operate across both C- and L-band systems. As shown in Figure 4, these control systems adjust the tilt profile and per-channel wavelength powers in the C- and L-band amplifiers to ensure a flat wavelength spectrum across both bands. The amount of pre-emphasis tilt applied to each C- and L-band is dynamically adjusted, depending on the wavelengths used within each band. These self-tuning WDM systems provide optimized SRS tilt and per-channel power management over the C+L-band networks without any operator intervention or adjustment. It is automatic and worry-free.

Figure 4: Self-tuning networks — automatic SRS tilt management across C+L bands



An alternative method for supporting dynamic SRS tilt management over C- and L-bands requires "noise loading" of unused channels. Used in subsea systems, noise loading is a technique that involves loading unused optical channels with artificial optical noise power, which is sometimes referred to as "dummy light." Noise loading is required in subsea networks because of the type of amplifiers (constant power) used in subsea systems. When applied to terrestrial networks, noise loading effectively operates the WDM line system as if it were completely filled.

Even with noise-loaded systems, SRS tilt pre-emphasis is still required on both C-band-only systems as well as C+L-band WDM networks, but it is not dynamically adjusted as wavelengths are added or deleted to the network. Noise-loaded systems result in slightly higher upfront costs because both C-band and L-band noise-loading modules have to be incorporated into the WDM system with the initial deployment. Also, in fault scenarios where a noise-loading module fails, the system still needs to perform dynamic SRS tilt adjustment to prevent service degradation.

Conclusion

Recent improvements in optics and coherent DSP technology have dramatically increased network capacity and reduced the cost per gigabit for optical networks. As the optical networking industry approaches Shannon fiber capacity limits, bandwidth and spectral efficiency improvements will be more limited. This will make it more challenging for operators to keep up with fast-growing demand for data, internet, video, cloud and Industry 4.0 applications.

By deploying C+L-band WDM systems, operators can double the capacity of their existing networks, which is ideal for networks running over dark fiber. C+L-band WDM systems eliminate the need for additional leases of costly dark fiber.

Modular and flexible C+L-band WDM systems ensure that operators can upgrade their networks in the most efficient and cost-effective way. Automated self-tuning systems with SRS tilt management that can operate over the C- and L-bands will play a key role in enabling worry-free optical network operations.

Abbreviations

CDC-F	Colorless Directionless Contentionless – Flexgrid
DSP	digital signal processor
FEC	forward error correction
ILA	in-line amplifier
ROADM	reconfigurable optical add-drop multiplexer
SRS	Stimulated Raman Scattering
WDM	wavelength-division multiplexing

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