WHITE PAPER

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OPTIMIZING THE PERFORMANCE OF COHERENT 100G IN 10G DISPERSION-MANAGED NETWORKS

How Enhanced Solutions Enable Coexistence

Network operators looking to deploy 100G DWDM technology are typically faced with a choice: deploy 100G on their existing 10G network or build a new coherent-only overlay network. Building a coherent-only network can maximize the reach of 100G technology but can increase both CapEx, by requiring the building of a new optical layer, and OpEx, by requiring the operator to manage two networks or migrate traffic from the 10G network to the 100G network. This white paper describes the impact of 10G wavelengths and dispersion compensation on 100G performance and explains the enhancements Coriant has made to its metro and long haul solutions to enable 100G to optimally coexist with 10G, thus providing network operators with a cost-effective alternative to building a coherent-only overlay.

THE CASE FOR ADDING 100G TO AN EXISTING 10G NETWORK

Until quite recently, the majority of new DWDM networks were optimized for 10G noncoherent transmission. In recent years, many new long haul networks have been optimized around coherent-only transmission starting as a niche with coherent 40G, then entering the mainstream with coherent 100G. In the metro, 10G still maintains its dominance with the vast majority of 100G deployed alongside 10G in mixed networks.

Drivers for 100G include providing high speed router interconnect, offering 100G client services, and relieving congestion on heavily utilized routes and spans in the short term, while increasing spectral efficiency to accommodate longer term traffic growth.

Footprint reductions up to 70% and power consumption reductions up to 30% can also be motivators for deploying 100G, with 150G and 200G modulations offering even larger improvements. Furthermore, as 100G technology evolves with cost-optimized digital signal processors (DSPs) and pluggable optics, it will start to benefit from a cost per bit advantage over 10G.

ADD 100G TO THE EXISTING NETWORK OR BUILD A NEW COHERENT-ONLY OVERLAY?

Network operators wanting to add 100G to their network have two options: either add 100G to their existing network and essentially create a hybrid 10G/100G network or build a brand new coherent-only network. Factors to consider in this decision include the current wavelength utilization of the network, the forecasted traffic growth, the age of the existing DWDM hardware, the required reach, and whether the superior reach of a coherent-only network would be a benefit. All of these factors must be considered together with CapEx and OpEx budgets.

For example, if the utilization of the network and traffic growth forecast are both high, the existing equipment is old, coherent-only transmission would give a valuable reach advantage, and the budget can support it, then a new coherent overlay would likely be the best option. However, if there is plenty of room to grow in the existing network and reach requirements would not receive a significant advantage from coherent-only transmission, then adding 100G to the existing network is likely the best option. This will be especially true if the DWDM equipment was deployed more recently or if budgets are highly constrained.

THE IMPACT OF 10G AND DISPERSION COMPENSATION ON 100G PERFORMANCE

Existing 10G networks pose two performance challenges to coherent 100G. The first challenge relates to the 10G DWDM signals themselves, while the second relates to the dispersion compensation equipment typically found in 10G networks.

IMPACT ON 100G PERFORMANCE: 10G WAVELENGTHS & CROSS PHASE MODULATION (XPM)

10G most commonly uses a modulation scheme called On-Off Keying (OOK), which is based on amplitude (or power) modulation to communicate data. However, OOK is not practical at 100G bit rates as the baud rate would be too high for even state-of-the-art electronics and dispersion tolerances would be too low for practical use.

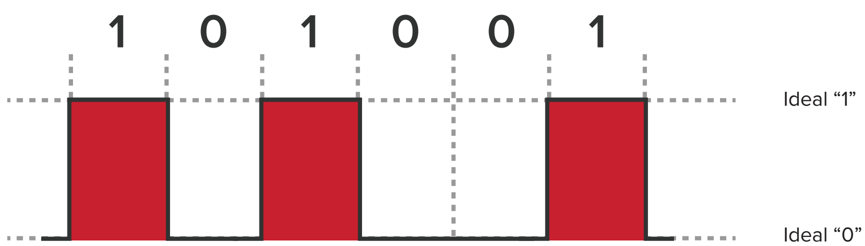

FIGURE 1 – 10G Modulation: On-Off Keying (OOK)

100G transmission most commonly uses a modulation scheme called Polarization Multiplexed-Quadrature Phase Shift Keying (PM-QPSK) to transmit data. QPSK alters the phase of the transmitted signal, rather than adjusting the amplitude, to transmit more bits per symbol enabling high-capacity transmission at a lower baud rate. With QPSK modulation, the phase of each symbol (nondifferential encoding) or the change in the symbol phase (differential encoding) is used to communicate two bits per symbol rather than the one bit per symbol of OOK. The two polarizations of PM-QPSK double this to four bits, enabling the baud rate to be reduced by a factor of 4, relative to a hypothetical 100G OOK signal.

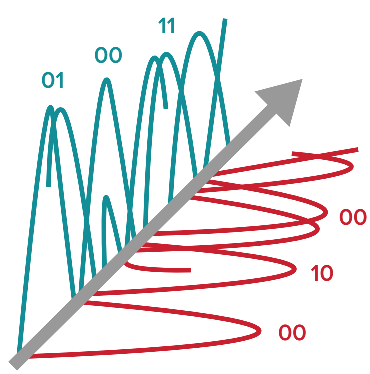

FIGURE 2 – 10G Modulation: Polarization Multiplexed-Quadrature Phase Shift Keying (PM-QPSK)

The refractive index describes the speed with which light travels through a material. However, the power of each wavelength slightly alters the refractive index of the fiber. This change in refractive index can alter the phase of the wavelength itself, a nonlinear effect known as Self Phase Modulation (SPM), or the phase of other wavelengths, a nonlinear effect known as Cross Phase Modulation (XPM).

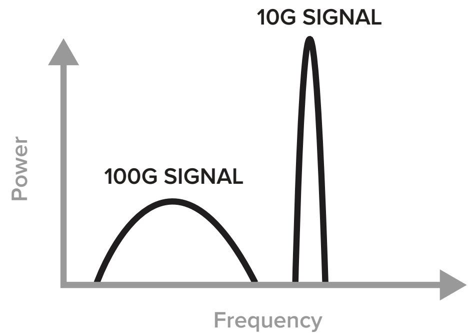

FIGURE 3 – Signal Power Density: 10G vs. 100G

10G signals based on OOK have a much higher power density (i.e., a large amount of power in a very small spectral range) than coherent 100G, causing them to have a much greater impact on the refractive index than 100G. Additionally, as PM-QPSK modulation is based on phase, unlike 10G OOK which is based on amplitude, it is much more severely impacted by effects that alter the signal's phase. For these reasons, XPM from 10G wavelengths can have a significant impact on the reach of 100G wavelengths in a mixed 10G/100G network.

IMPACT ON 100G PERFORMANCE: LOW CHROMATIC DISPERSION

Chromatic dispersion occurs due to the fact that different frequencies travel at different speeds through the fiber. Even the different frequencies of the same channel travel at slightly different speeds and eventually distort the signal.

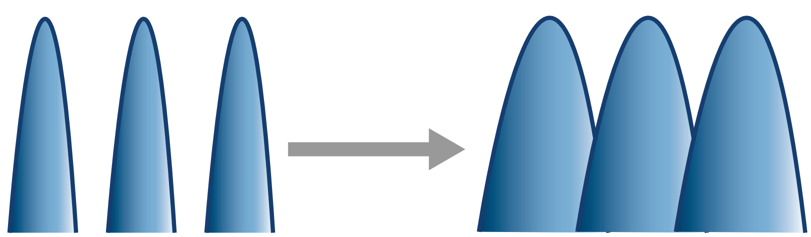

FIGURE 4 – Chromatic Dispersion

10G DWDM receivers based on OOK can typically only tolerate 80km~100km of chromatic dispersion. For this reason, dispersion compensation modules (DCMs) are typically deployed in 10G networks that need to achieve unregenerated reach greater than the chromatic dispersion tolerance of the 10G receivers. These DCMs typically consist of spools of fiber with negative chromatic dispersion to cancel out the chromatic dispersion of the span itself, thus keeping any residual dispersion within the tolerances of the 10G receiver.

However, somewhat counter-intuitively, low chromatic dispersion is actually a disadvantage for coherent transmission. In the absence of chromatic dispersion, the symbols of each channel could all alter the refractive index of the fiber at the same time, thus maximizing the impact on the fiber's refractive index and thereby increasing XPM. By causing the channels to travel at slightly different speeds, chromatic dispersion reduces the time correlation between the symbols, thus reducing the buildup of nonlinear penalties including XPM and SPM.

OPTIONS FOR MAXIMIZING THE PERFORMANCE OF 100G IN 10G NETWORKS

Coriant has invested considerable R&D resources across both its metro and long haul solutions to ensure optimal 100G performance in mixed 10G/100G networks. This enables Coriant to provide many network operators with a compelling alternative for adding 100G to their existing 10G networks without the significant cost and disruption of building a coherent-only overlay.

METRO ENHANCEMENTS FOR HYBRID 10G/100G NETWORKS

In its metro product portfolio, including the Coriant® 7100 Packet Optical Transport Solutions, Coriant has developed a highly innovative method of adjusting how the DSP tracks the incoming signals. In addition, Coriant has developed specialized algorithms within the DSP to recover the transmitted data stream. Furthermore, Coriant metro optical link control maintains a relatively low output power level of transmitted signals. The combination of these innovative approaches significantly reduces the penalty of XPM caused by the high powered 10G signals on the same fiber.

Based on lab and live network validation, when compared to solutions without these enhancements, the Coriant solution provides nearly double the performance of 100G signals in 10G/100G hybrid networks even with 10G channels directly adjacent to the 100G signals. With the Coriant solution, 100G wavelengths can reach unregenerated distances up to 1,000 km on a fully dispersion-managed 10G network, even when the network is composed of purely ROADM cascades. This distance is based on 80 km spans and includes 3dB OSNR margin. Even longer distances become possible if some of the ROADM nodes are replaced with OLAs and/or Raman amplification is used.

LONG HAUL ENHANCEMENTS FOR HYBRID 10G/100G NETWORKS

Advanced long haul optical link control software and Coriant CloudWave™ Optics technology enable Coriant long haul solutions to deliver unregenerated 100G reach up to 2,000 km in mixed 10G/100G networks based purely on EDFA-based amplification. Even longer distances can be achieved with Raman amplification.

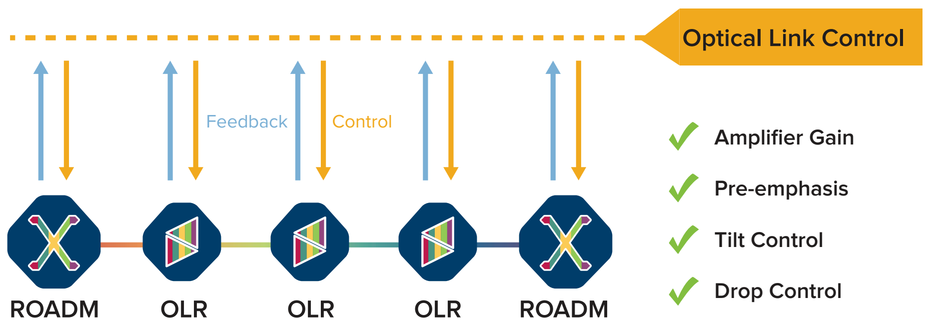

FIGURE 5 – Coriant Long Haul Optical Link Control

Coriant long haul link control software with hundreds of man-years of R&D is field proven in some of the world's most demanding long haul networks. Key functions include optimizing the gain of each amplifier, optimizing the power level of each channel, tilt control to compensate for the wavelength-dependent loss of each channel, and drop control to optimize the drop power to the sweet spot of the receiver. This link control software also optimizes the power levels of both 10G and 100G channels to maximize end-to-end performance in a hybrid dispersion-managed network. For a more detailed description, refer to the Coriant white paper Maximizing 100G+ Reach in Long Haul Networks with Challenging Fiber Conditions.

Coriant CloudWave™ Optics technology is currently supported in the Coriant® hiT 7300 Multi-Haul Transport Platform, Coriant® mTera® Universal Transport Platform, and Coriant Groove™ G30 DCI Platform and can deliver terrestrial reach up to 5,000 km and submarine reach up to 11,000 km in coherent-only networks with Raman amplification. Coriant CloudWave™ Optics enhancements including 25% Soft Decision Forward Error Correction and optimizations to carrier phase estimation algorithms on the DSP maximize performance in mixed 10G/100G networks and contribute to an unregenerated 100G reach of up to 2,000 km with EDFA-only amplification.

GUARD BANDS

The term guard band is used to describe the practice of not using one or more channels between the 100G and the 10G channels. For example, if a 100G wavelength is deployed on channel 25, then channel 24 and channel 26 are left empty to accommodate 10G wavelengths on channels 23 and 27.

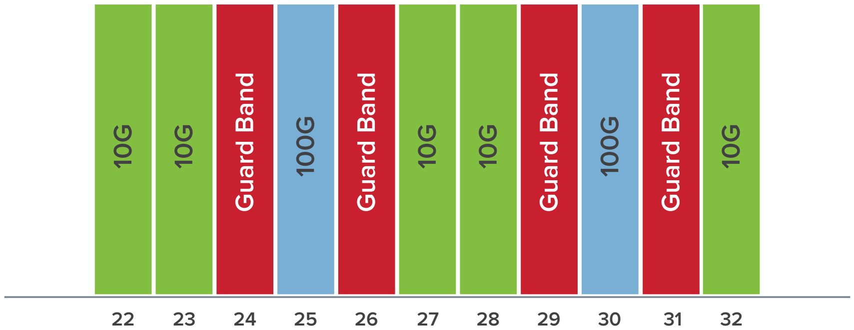

FIGURE 6 – Guard Bands Example

Alternatively, the spectrum in the C-band can be split so that 10G channels use one contiguous part of the band while 100G uses a different contiguous set of channels with empty channels creating a guard band between the 10G and 100G spectrum. However, this approach limits future flexibility and may not be possible if 10G wavelengths are already spread across the available spectrum.

Guard bands can provide an incremental reach advantage for 100G in mixed 10G/100G networks. The size of this advantage is relative to the difference in power levels between the 10G and 100G signals, with less benefit as the power for 10G drops relative to 100G. In a typical long haul scenario based on Coriant CloudWave™ Optics in the hiT 7300, the difference in reach might be around 20%, as shown in Figure 7.

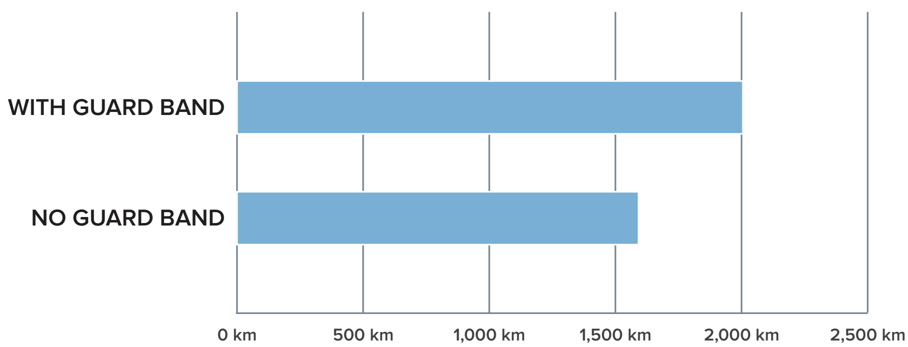

FIGURE 7 – The impact of guard bands on Coriant CloudWave™ Optics 100G reach in 10G/100G long haul networks

However, guard bands cause two significant problems in transport networks: reduced spectral efficiency and planning challenges. Guard bands do not use certain wavelengths, thus wasting their potential capacity. Additionally, in a mesh network where different wavelengths are used in different parts of the network, maintaining guard bands through the entire network can be extremely challenging. Fortunately, for many long haul networks, reach up to 1,600 km in EDFA-only mixed 10G/100G networks with no guard band will be more than sufficient.

NONPERIODIC DISPERSION COMPENSATION

An additional technique that can be used to improve 100G performance in mixed 10G/100G networks is to adjust the dispersion plan to increase the chromatic dispersion for the coherent 100G in order to reduce nonlinear effects while keeping the end-to-end residual chromatic dispersion within the limits of the 10G receivers.

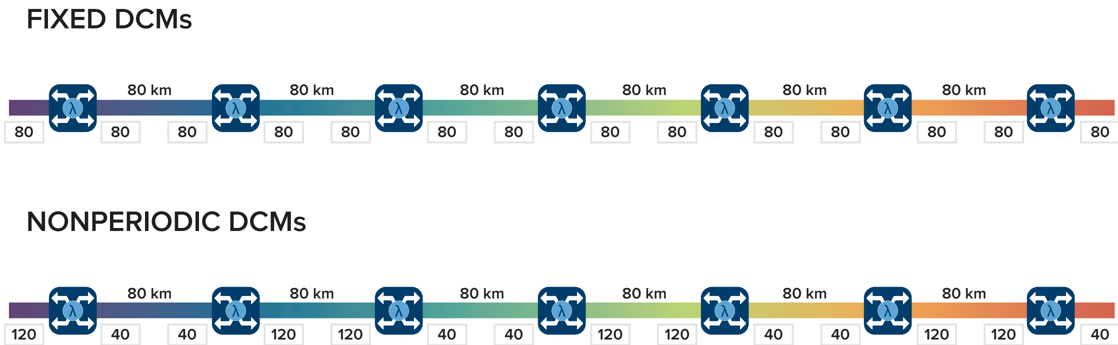

FIGURE 8 – Fixed vs. Nonperiodic Chromatic Dispersion Compensation

As shown above, the traditional approach to dispersion planning is to compensate each span to the maximum, leaving the minimal amount of residual chromatic dispersion possible. By selectively under-compensating, 100G performance can be improved. Depending on the span lengths/losses, the number of ROADM cascades can be increased by between 20% and 40% relative to a network with 100% compensation on each span (i.e., no residual chromatic dispersion). However, this percentage gain will be reduced depending on the amount of residual chromatic dispersion already in the network and by the constraints placed on the planner's ability to change the dispersion plan by the 10G wavelengths.

For newly deployed networks this approach can be incorporated into the network design. However, in existing networks where the DCMs have already been deployed, there will be a small cost to change the DCMs plus the risk of some disruption for unprotected services as the DCMs are swapped. This approach also requires careful planning to avoid compromising 10G performance. Fortunately, Coriant network planning tools can assist in determining the optimal chromatic dispersion plan for 10G/100G hybrid environments.

CONCLUSION

Until recently, the vast majority of long haul DWDM networks were built for 10G OOK transmission, as is still the case in the metro. A variety of drivers including router interconnect, 100G client services, and congestion relief are leading many operators to deploy 100G DWDM technology. This need to deploy 100G solutions leaves operators with two choices: build a new coherent-only overlay or add 100G to their existing network.

In scenarios where there is still plenty of room to grow in the existing network, 100G reach would not receive a significant advantage from coherent-only transmission, and where the equipment was deployed more recently or budgets are highly constrained, adding 100G to an existing network could prove to be the best choice. However, 10G networks create performance challenges for 100G signals due to XPM from the 10G signals and the lack of chromatic dispersion that could reduce the buildup of XPM.

To provide an option that enables network operators to effectively support 100G on their existing networks, Coriant has invested considerable R&D resources across its metro and long haul solutions. Coriant has enhanced its metro solutions with DSP optimizations to support 100G reach up to 1,000 km over ROADM cascades in mixed 10G/100G networks. Coriant long haul solutions, enabled by Coriant long haul link control software and Coriant CloudWave™ Optics technology, support 100G wavelengths up to 2,000 km in mixed 10G/100G networks without the need for Raman amplification.

ABOUT CORIANT

Coriant delivers innovative, dynamic networking solutions for a fast-changing and cloud-centric business world. The Coriant portfolio of SDN-enabled, edge-to-core transport solutions enables network operators to reduce operational complexity, improve utilization of multi-layer network resources, and create new revenue opportunities. Coriant serves leading network operators around the world, including mobile and fixed line service providers, cloud and data center operators, content providers, cable MSOs, large enterprises, government agencies, financial institutions, and utility companies. With a distinguished heritage of technology innovation and service excellence, forged by over 35 years of experience and expertise in Tier 1 carrier networks, Coriant is helping its global customers maximize the value of their network infrastructure as demand for bandwidth explodes and the communications needs of businesses and consumers continue to evolve. Learn more at www.coriant.com.