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# MAXIMIZING 100G+ REACH IN LONG HAUL NETWORKS WITH CHALLENGING FIBER CONDITIONS

## *Solutions for Leveling the Playing Field*

For many operators, fiber represents one of their most strategic and valuable assets. With dramatic increases in bandwidth driven by ever faster fixed and mobile broadband access and applications including internet video, cloud, and data center interconnect, maximizing the value of this strategic asset is a critical challenge for optical network planners and optical transport equipment vendors alike. Even where fiber is leased, the ability to maximize the value of available fiber provides a distinct competitive advantage.

Fiber types, fiber quality, the distribution of span distances/losses, the deployment method (i.e., underground vs. aerial), and environmental conditions are among the factors that can contribute to challenging fiber conditions. Challenging fiber can result in higher CapEx, higher OpEx, and lost revenues if not addressed with the appropriate technologies. This white paper explores these challenging fiber conditions, describes the costs these challenges can impose on network operators, and provides a checklist of key technologies that can level the playing field to maximize the long haul reach of 100G+ wavelengths under even the most challenging fiber conditions.

## WHAT MAKES FIBER CONDITIONS CHALLENGING?

A number of factors can make it difficult to get the best unregenerated distances for 100G+ wavelengths in a long haul network. These factors include the types of fiber, the quality of the fiber, the distribution of span distances/losses, the deployment methodology (i.e., underground vs. aerial), and the environmental conditions. This section discusses each of these factors in more detail.

### CHALLENGING FIBER CONDITIONS 1: DIFFERENT FIBER TYPES

Since the advent of fiber optic cables for telecommunications in the late 1970s and early 1980s, a wide variety of fiber types have been deployed. Each of these fiber types was perceived to have an advantage at the time. However, for many of these fiber types, what was once an advantage became a disadvantage as technology evolved to DWDM and later coherent technology. Fiber types as defined by the ITU-T, including G.652, G.653, G.654, G.655, and G.656, are described as follows:

- **G.652 Standard Single-Mode Fiber** is the most common fiber type in metro and long haul networks, and the majority of terrestrial DWDM equipment is optimized around support for this fiber type. SMF-28 from Corning is the most widely deployed G.652 fiber. Newer G.652 fiber typically has attenuation in the range 0.18dB/km~0.20dB/km relative to a more typical 0.25dB/km in older fiber.
- **G.653 Dispersion Shifted Fiber (DSF)** was deployed before the advent of DWDM. Deployed primarily in Japan but also in other regions, its compelling advantage was the absence of dispersion at 1550nm where attenuation is also at its lowest. However, the absence of dispersion led to Four Wave Mixing, which severely impacts the ability of G.653 fiber to support DWDM in the C-band.
- **G.654 Cut-off Shifted Single-Mode Fiber** is optimized for low loss in the C-band by using a pure silica core. G.654 is deployed primarily in submarine networks as its large effective area enables more power with fewer nonlinear effects and therefore longer reach, while its higher dispersion also enables better reach for coherent transmission as the dispersion prevents the buildup of nonlinear effects. However, G.654 suffers from a number of disadvantages that make it less suitable for terrestrial networks, including higher cost, a cut-off at 1530nm that prevents the use of 1510nm for the Optical Supervisory Channel (OSC), and a lack of optimized Dispersion Compensation Modules (DCMs). Although, the lack of optimized DCMs is no longer an issue with the move to coherent transmission. In addition, pure silica is more delicate with micro and macro bending having more impact on optical performance. A reduction in Raman gain with G.654 relative to G.652 is largely offset by higher power levels enabled by reduced nonlinear effects.

- **G.655 Non-Zero Dispersion Shifted Fiber (NZDSF)** is the second most common fiber type in terrestrial networks and has been widely deployed in long haul networks. Examples of G.655 fiber types/brands include TruewaveRS, TruewaveClassic, TruewaveReach, TruewavePlus, LEAF, SMF-LS, and Teralight, each with different properties. At the time of its deployment, the key value position for this fiber type was low dispersion including Chromatic Dispersion and Polarization Mode Dispersion (PMD). For long haul transmission based on 10G OOK (On-Off Keying) modulation, low dispersions improved reach as PMD is hard to compensate for with 10G, and Chromatic Dispersion requires DCMs that also act as attenuators. However, for 100G and above transmission based on coherent technology with high tolerance to PMD and Chromatic Dispersion, low dispersion is no longer an advantage. In fact somewhat counterintuitively, low Chromatic Dispersion is actually a disadvantage for coherent transmission. By causing the channels to travel at slightly different speeds, Chromatic Dispersion reduces the time correlation between symbols in neighboring channels thus reducing the buildup of nonlinear penalties such as Cross Phase Modulation (XPM) and Self Phase Modulation (SPM).
- **G.656 fiber with non-zero dispersion for wideband optical transport** is an optimized G.655 fiber that focuses on extending the useful transmission band to include the S and L transmission bands. However, given the C-band now supports 96 channels or more with flexi-grid, based on cost-effective EDFA amplification, the additional value of G.656 over G.655 is mostly hypothetical.

In an ideal terrestrial scenario, all of the fiber would be the latest G.652 fiber. The challenge comes from having to support non-G.652 fiber or a mix of different fiber types. Mixed fiber types could be different fiber types in different spans or even different fiber types within the same span. Mixed fiber is particularly common in leased long haul networks where a network is often pieced together with whatever fiber is available from different wholesale fiber providers.

## CHALLENGING FIBER CONDITIONS 2: FIBER QUALITY

A second consideration is fiber quality defined primarily in terms of loss or attenuation and dispersion (PMD and Chromatic Dispersion). Additional considerations include bad reflections that can occur as a result of poor splices made during installation or repairs to fiber cuts. The quality of the fiber at any point in time will be a function of the quality of the fiber when it was initially installed and the degradation that has occurred due to aging.

### ATTENUATION

Attenuation in optical fiber is measured in dB/km and is caused primarily by the absorption of energy as light travels through the fiber and the scattering that occurs when the light hits particles in the fiber. Newer G.652 fiber typically has attenuation in the range of 0.18dB/km~0.20dB/km, while older fiber is typically closer to 0.25dB/km. However, attenuation significantly in excess of 0.25dB/km is possible. Losses in the range of up to 1dB/km have been seen in geographies with high rates of loosely regulated construction.

Factors that can increase the attenuation of fiber include:

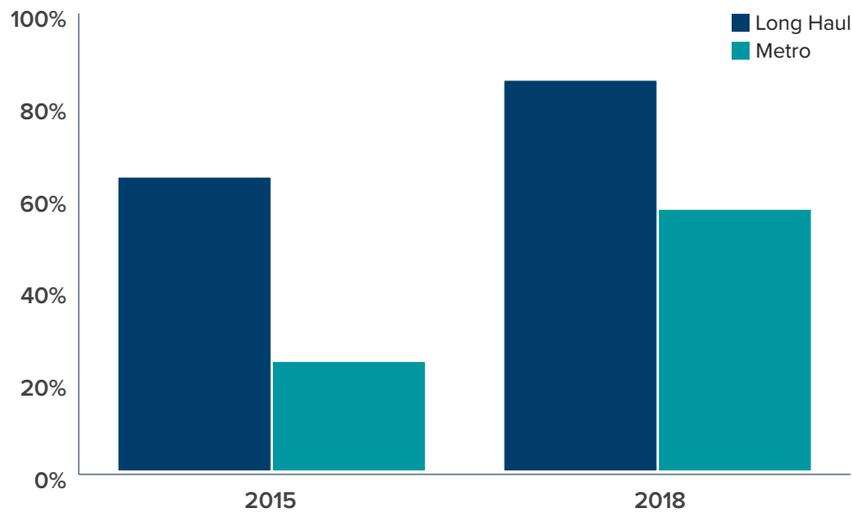
- Splices (installation) – Due to the limited length of fiber reels used for terrestrial deployment, splices are often required every few kilometers. Submarine reels are typically much larger so require far fewer splices during installation.
- Splices (repair) – Where a fiber has been cut and then repaired, a poor quality splice can significantly increase attenuation.
- Fiber Additions (repair) – Additional fiber may need to be spliced in during the repair process, which increases attenuation.
- Connectors – Dirty or poor connectors within the location of the physical DWDM hardware and the optical distribution frames can increase attenuation.
- Bending – Micro and macro fiber bending, again most commonly in the same physical location as the DWDM hardware and the optical distribution frames, can also increase attenuation.
- Environmental conditions – Temperature, humidity, and pressure can also change the properties of fiber over time and thus increase attenuation.

In an amplified DWDM network, attenuation typically impacts reach indirectly. As amplifiers have to provide more gain on spans with high attenuation, they also add more noise into the optical path. As a result, the Optical Signal to Noise Ratio (OSNR) in the network is reduced, and hence the optical reach becomes limited.

## DISPERSION

Dispersion consists of both Chromatic Dispersion and PMD. Chromatic Dispersion occurs because different frequencies travel at different speeds through the fiber causing the different frequencies of a signal within the same lambda to travel at slightly different speeds and eventually distort the signal. PMD occurs as the two different polarizations of light travel at different speeds, since fiber is not perfectly spherical.

However, unlike 10G technology, state-of-the-art coherent technology now has extremely high tolerance to both Chromatic Dispersion and PMD. Unless the fiber has very high PMD, dispersion should no longer be an issue with coherent technology such as Coriant CloudWave™ Optics, which has the ability to tolerate PMD of up to 50ps mean DGD (almost 1,000,000 km with default PMD values for G.652 fiber) and Chromatic Dispersion of >300 ns/nm (>14,000 km). In fact, a certain amount of Chromatic Dispersion is actually good for coherent reach as it prevents the buildup of nonlinear effects. Figure 1 shows that the majority of new long haul installs are now leveraging coherent technology at 100G or above and increasing from 64% in 2015 to over 85% in 2018.



*FIGURE 1 – 100G and above as a percentage of new installs  
 (Source: Infonetics, 100G+ and ROADM Strategies, Global Service Provider Survey, November 2015)*

Older fiber can have very high PMD if asymmetries occurred during the original manufacturing process and/or if it was not laid correctly causing stretching and resulting in permanent damage. Also as with attenuation, dispersion can change over time with temperature and fiber aging.

### REFLECTIONS

The final aspect of fiber quality to consider is reflections, which occur primarily due to bad splices causing the light to be reflected back on itself. This is especially problematic with the use of Raman amplification. Raman amplification works by shooting a powerful laser into the fiber with a lower wavelength (~1420nm) than the C-band, to cause stimulated Raman scattering that serves to amplify the C-band. However, bad reflections can severely impact Raman performance. In fact, bad reflections can even prevent the use of Raman amplification altogether or permanently damage the fiber and/or network equipment.

### CHALLENGING FIBER CONDITIONS 3: DISTRIBUTION OF SPAN LENGTHS/LOSSES

In addition to the type and quality of fiber, a critical factor in determining reach in long haul networks is the distribution of span lengths/losses. The primary reason span lengths/losses are critical is that OSNR decreases dramatically once the sweet spot of the amplifier is exceeded. Maximum reach can typically be achieved with spans in the range of 60km~80km (15dB~20dB).

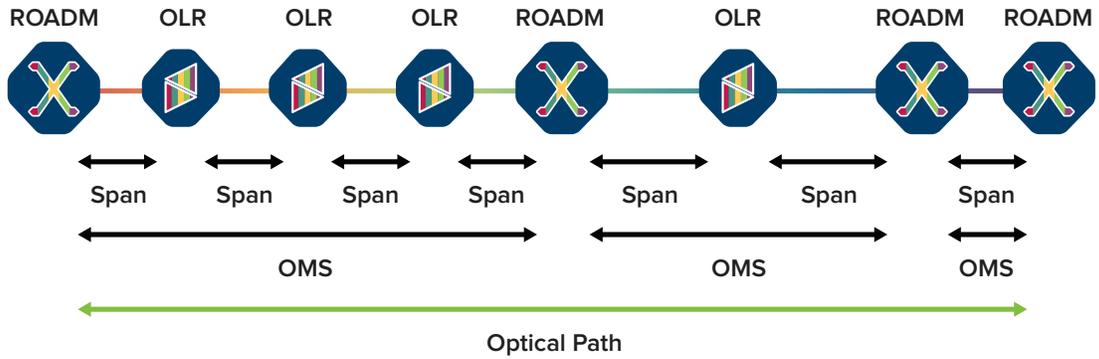


FIGURE 2 – Span, OMS, and Optical Path

As shown in Figure 3, as span loss increases above the threshold, the OSNR of EDFA amplifiers starts to decrease dramatically as the receive power drops to a level closer to the noise, and the noise and DWDM channels both get amplified.

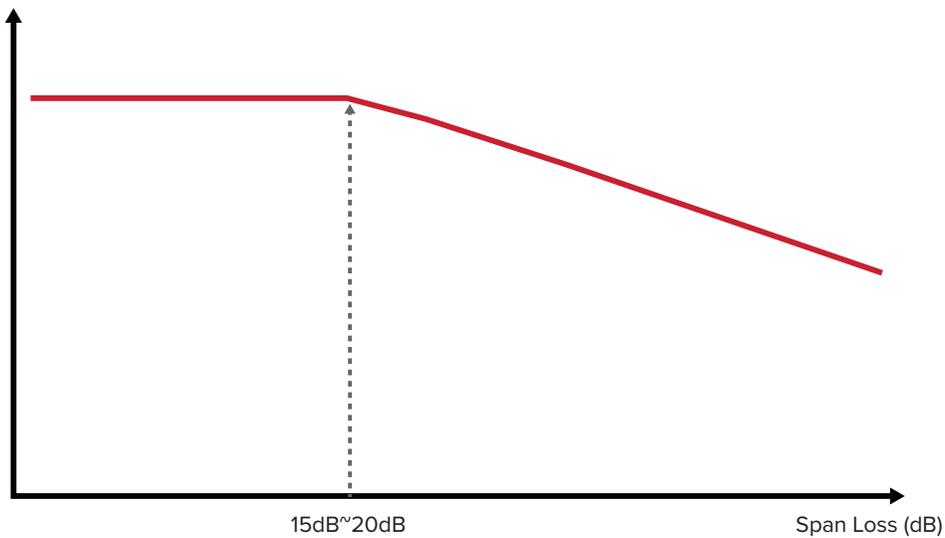


FIGURE 3 – EDFA Amplifier: Span Loss vs. OSNR

One strategy to overcome long spans is to increase the transmit power. However, increased transmit power can increase nonlinear effects such as XPM and SPM and will eventually become counterproductive.

Another strategy is to use Raman and other forms of advanced amplification. However, this comes at a CapEx cost, involves some operational challenges and risks, and has its limits in terms of the ability to make long spans look like sweet spot spans.

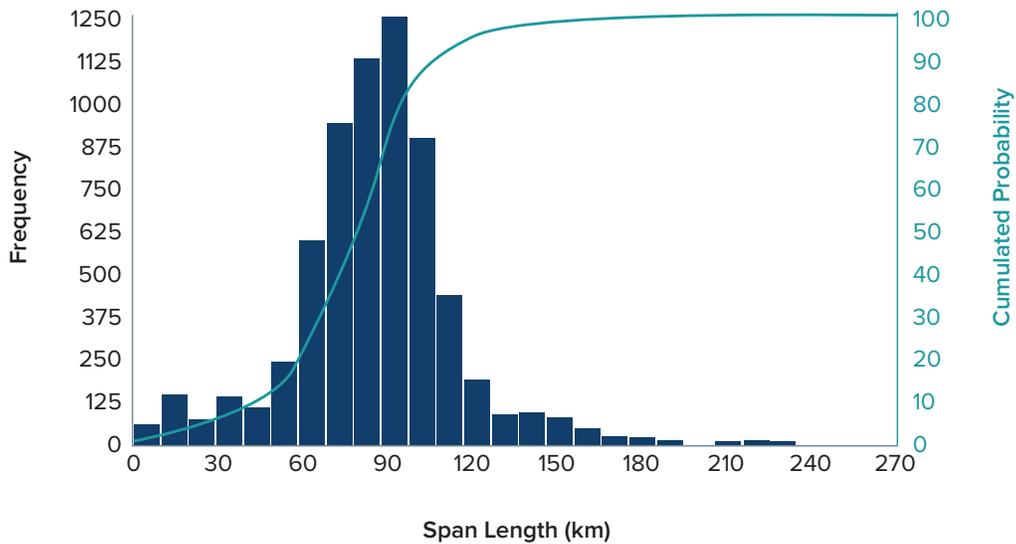


FIGURE 4 – Span Lengths in Long Haul Networks (Source: Coriant)

While reach can be maximized with minimized CapEx when all spans are between 60km~80km, as shown in Figure 4, based on Coriant’s long haul planning experience, longer spans are not uncommon. A key driver for longer spans is the operational cost savings enabled by a reduction in the number of sites that have to be leased, cooled, and powered. Other factors driving the use of longer spans include the availability of sites for Optical Line Amplifiers (OLAs). If these sites do not exist and it is cost prohibitive to build them, then the operator may have no choice but to build their network with long spans.

#### CHALLENGING FIBER CONDITIONS 4: FIBER DEPLOYMENT METHOD

Aerial fiber is highly cost-effective to deploy compared to buried fiber, especially when it is possible to leverage an existing aerial asset such as power utility lines. However, aerial fiber does create some challenges. In particular for coherent technology deployed over optical ground wire (OPGW), lightning strikes are a key challenge.

OPGW is a type of cable used in the construction of electric power transmission and distribution lines that combines the functions of grounding and communications. An OPGW cable contains a tubular structure with one or more optical fibers in it surrounded by layers of steel and aluminum wire. The OPGW cable is run between the tops of high voltage electricity pylons.

OPGW is designed to attract lightning strikes. These lightning strikes cause polarization rotations. For noncoherent transmission (i.e., 10G), this was not a problem. However, given the polarization multiplexed nature of coherent 100G+ modulation, this creates a big challenge for coherent modulation over OPGW, given that in Central Europe OPGW fiber can experience as many as 30 direct lightning strikes per 100 km per year and an even greater number in other parts of the world such as the Americas. These lightning strikes can cause bit errors and loss of frame, which can result in temporary outages that violate Service Level Agreements (SLAs). In addition, the weight and pressure of aerial fiber causes attenuation to increase over time.

## **CHALLENGING FIBER CONDITIONS 5: EXTREME ENVIRONMENTAL CONDITIONS**

Environmental conditions to consider include extremes of pressure/altitude and temperature. Over time, temperature can negatively impact the optical properties of the fiber including attenuation and dispersion. Changes in temperature can cause the optical fiber to be stretched as the metal in the cable expands at a higher rate to the fiber leading to microbends and increased length.

Further challenges involve maintaining the correct operating conditions, including temperature, humidity, and pressure, for the DWDM equipment. Another environmental phenomenon to consider is earthquakes. In addition to the potential for fiber cuts, high point pressures created in an earthquake along with micro and macro bends can significantly increase attenuation and PMD.

## **THE MULTIPLE COSTS OF CHALLENGING FIBER CONDITIONS**

Maximizing reach is critical for operators with challenging fiber conditions due to the significant CapEx, OpEx, and revenue implications, and in order to maintain a level playing field with competitors that benefit from superior fiber conditions.

### **CAPITAL EXPENDITURES**

Challenging fiber conditions can impact CapEx along multiple dimensions. The most obvious is regeneration: if competing network operators require fewer Optical Electrical Optical (OEO) regenerations, they are likely to enjoy a significant cost advantage.

A second impact on CapEx is amplification. Challenging fiber often requires spending more money on amplification hardware, and additional costs can include CapEx to build more sites for OLAs.

Challenging fiber can be less spectrally efficient than less challenging fiber as the network can support fewer channels and/or less spectrally efficient modulation for the same reach. This means challenging fiber will run out of capacity before less challenging fiber, resulting in more CapEx to light new fiber.

Another CapEx penalty occurs if challenging fiber restricts the network operator from using higher modulation and that modulation has a lower cost per bit.

## OPERATIONAL EXPENDITURES

Increased OpEx can include the space and power to house regeneration hardware and extra amplification, the costs of additional sites for OLAs, and the costs to lease additional fiber. Operational costs may be higher if the network operator is forced to use lower order modulation formats when lower footprint and better power efficiency could have been achieved with higher order modulation.

Challenging fiber can also increase OpEx for planning, installation, and provisioning. Planning a network with challenging fiber is almost by definition more challenging. Extra hardware must be installed, which can include more challenging technologies such as Raman amplification. Provisioning is also more complex and costly if there are additional OEO regenerations to install. Extra active hardware increases the risk of network failures while increasing network maintenance costs.

## THE COST OF LOST REVENUES

Longer and more complex planning and provisioning can result in lost business to more nimble competitors. Outages caused by environmental conditions, including increased attenuation and lightning strikes, can result in both SLA penalties and lost business as customers move their business to competitors who can deliver higher quality services.

## MAXIMIZING REACH UNDER CHALLENGING FIBER CONDITIONS

So what are the tools that can level the playing field and maximize the reach and performance of 100G+ coherent wavelengths under even the most challenging fiber conditions?

### TOOL 1: A RANGE OF OPTIMIZED AMPLIFIERS

Amplifiers are a key tool for maximizing reach. Having a range of EDFA amplifiers optimized to maximize OSNR for different span ranges enables OSNR to be maximized for a wide range of span losses. Powerful EDFA amplifiers can also support longer spans without the need for Raman amplification. In addition, EDFA amplifiers with a very wide amplification range enabled by switchable gain can be used to minimize OpEx and simplify sparring, when these are the key priorities.

A range of Raman amplifiers with support for both counter-propagation and co-propagating operations can be combined with EDFA amplifiers for long spans and maximize end-to-end OSNR. All of the amplifiers including high power EDFA and Raman must be Class 1M rated for laser safety to ensure the safety of the engineers responsible for their installation and maintenance.

### TOOL 2: ADVANCED LINK CONTROL SOFTWARE

Link control software optimized for long haul transmission is a critical tool for maximizing reach as well as ensuring robust performance as conditions change. Coriant's 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 and is supported on Coriant long haul DWDM platforms, including the Coriant® hiT 7300 Multi-Haul Transport Platform and Coriant® mTera® Universal Transport Platform (UTP).

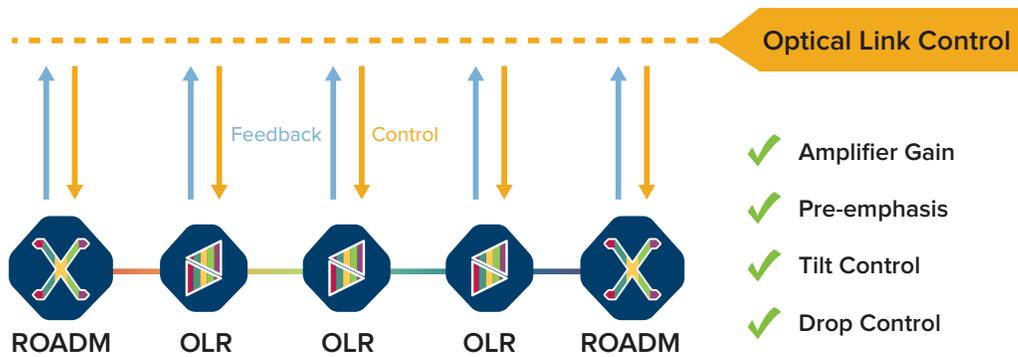


FIGURE 5 – Coriant's Long Haul Optical Link Control

Key functions of Coriant's optical link control include:

- Optimizing the gain of each amplifier
- Optimizing the power level of each channel (pre-emphasis)
- Optimizing the drop transmit power of each channel to the sweet spot of the receiver
- Compensating for the fact that the loss of the fiber varies according to the wavelength (tilt control)

This link control software runs on each network element using the OSC to communicate between network elements. Optimizations are made on a span (i.e., amplifier gain) and Optical Multiplex Section (OMS) basis (i.e., pre-emphasis, tilt control) when the network was planned and then continuously monitored and adjusted with control loops in real time as conditions change. A key benefit of the optical link control is the ability to tolerate large increases in the attenuation of any individual span.

### TOOL 3: STATE-OF-THE-ART COHERENT INTERFACE TECHNOLOGY

Coriant CloudWave™ Optics technology combines an advanced processing engine, integrated photonics, and embedded software to deliver state-of-the-art next-generation 100G and flexi-rate interfaces enabling terrestrial transmission of up to 5,000 km and submarine transmission of up to 11,000 km. Techniques used to increase OSNR tolerance include nondifferential encoding, advanced Soft Forward Error Correction with up to 25% overhead, and pulse shaping.

Dispersion tolerances include PMD tolerance of 50ps mean DGD and Chromatic Dispersion tolerance of >300 ns/nm (>14,000 km) with Chromatic Dispersion pre-emphasis for legacy submarine links. Lightning tolerance is the best in the industry with polarization speed tracking up to more than 3 Mrad/s. This is an order of magnitude better than legacy coherent 100G, and compares to 2 Mrad/s for the worst 1% of lightning strikes. For more details, see the Coriant white paper Lightning Strikes and 100G Transport.

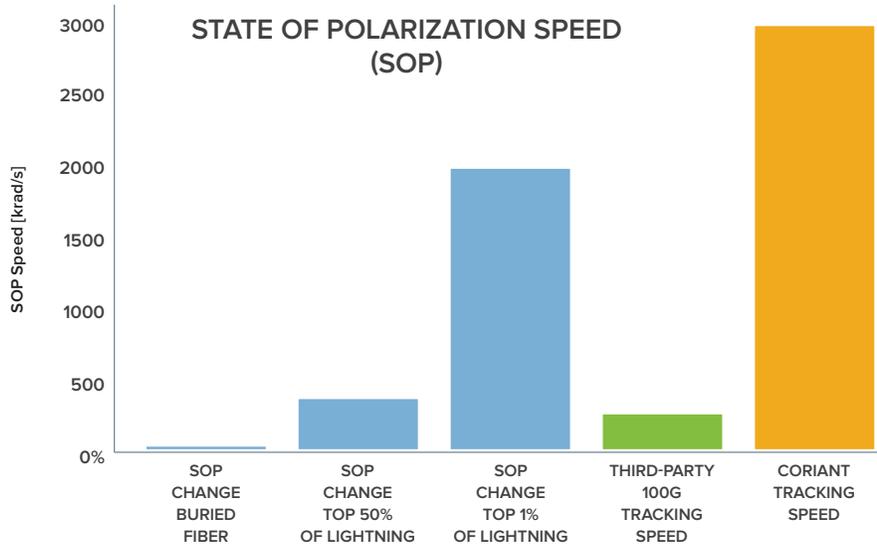


FIGURE 6 – Coriant CloudWave™ Optics robustness against ultra-fast polarization rotations (i.e., lightning strikes)

#### TOOL 4: OPERATIONAL TOOLS

Additional checklist items for maximizing reach under challenging fiber conditions include:

- A planning tool that can accurately model a wide range of fiber types
- Fiber characterization services to enable accurate modeling and optimization
- Integrated test capabilities including integrated Optical Time-Domain Reflectometer (OTDR) to measure reflections and quickly identify the location of fiber cuts, and a Pseudo Random Bit Sequence (PRBS) test and loopback to remotely ensure the quality of each wavelength during commissioning
- Network management with the ability to proactively notify users of changes to the fiber conditions (i.e., increased span loss) before services are impacted
- Control and management planes with optical impairment aware routing

#### SUMMARY

Mixed and nonmainstream fiber types, fiber quality including attenuation, dispersion, and reflections, long and varied span lengths, as well as aerial fiber and extreme environmental conditions can all contribute to challenging conditions for maximizing 100G+ reach. These challenges can have significant implications for CapEx and OpEx while impacting revenue growth including winning new customers and retaining existing ones.

Fortunately, Coriant's long haul solutions, including the hiT 7300 and mTera® UTP, provide a comprehensive set of tools to maximize reach under even the most challenging fiber conditions. These tools include amplifiers optimized for different span loss ranges, sophisticated link control software with hundreds of man-years of R&D that is field proven in some of the world's most demanding long haul networks, and state-of-the-art coherent interface technology powered by Coriant CloudWave™ Optics, together with integrated testing and sophisticated planning and network management.

## 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](http://www.coriant.com).

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