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Does Your Fiber Plant Have What It Takes To Support 10G Services?

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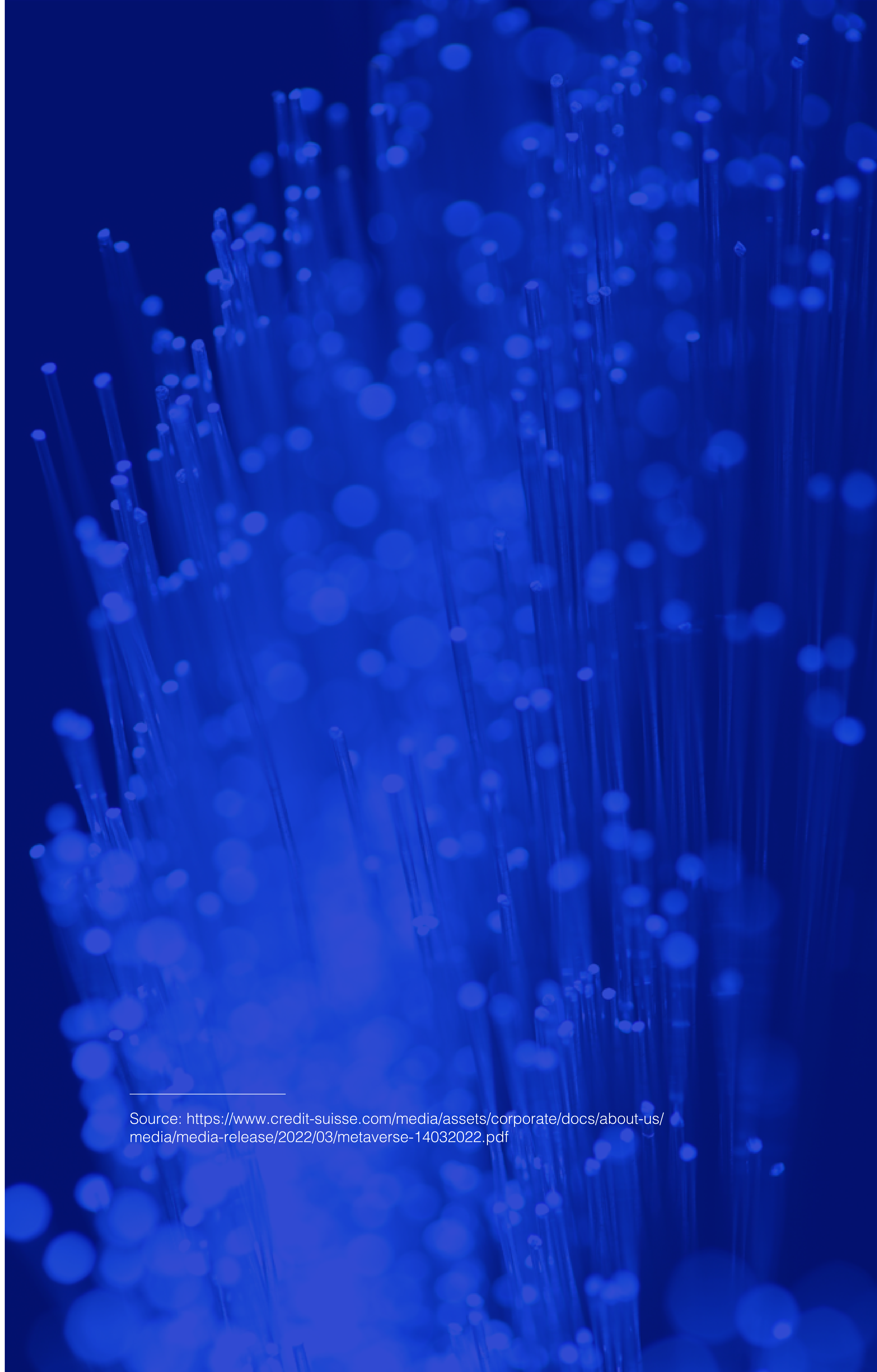
INTRODUCTION

For broadband service providers (BSPs), multi-gigabit services are the future. Households are consuming ever more high-definition online video and gaming, while connecting many more devices. People want to be able to work and learn from home, reliably and without compromising on collaboration. At the same time, businesses are making extensive use of the cloud to run applications and manage their data. When all your data and software are online or in the cloud, a high-speed broadband connection is a must for small business, enterprises, and multinational organizations.

The advent of the metaverse (or metaverses) will likely drive another step change in demand for bandwidth both upstream and downstream. While households consume increasingly immersive entertainment, businesses will use extended reality services for product design and development, as well as training and education. Even modest metaverse usage could drive a further 37% CAGR in Internet traffic over the next decade to 20x current data usage, according to Credit Suisse[1]. In each case, extremely fast and responsive connectivity will be required.

Meeting that demand will require next generation broadband underpinned by cost-effective components that are compliant with rigorous outside plant (OSP) standards. Forward-looking BSPs are rising to the challenge by integrating the latest passive optical network (PON) technologies into their network infrastructure and building high-capacity transport links up to 100 Gbps. Other BSPs will surely follow suit. But before you take the plunge, you need to check that your physical fiber network plant is up to the task.



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KEEPING PACE WITH THE DEMAND FOR BANDWIDTH

As high-definition video conferencing and gaming become commonplace, business and residential customers increasingly need large and equal amounts bandwidth upstream as well as downstream.

Existing Gigabit Passive Optical Network (GPON) implementations are generally limited to an aggregate bandwidth of 2.5 Gbps—well short of the 10 Gbps threshold set by the ITU for next-generation access. BSPs are, therefore, turning to 10 Gbps symmetric variants of PON, such as XGS-PON and NG-PON2. These technologies have been designed for use in both greenfield and brownfield deployments. But, in the case of the latter, the quality and original deployment of the existing optical distribution network (ODN) will determine how much bandwidth the end subscriber actually receives.

As many subscribers are not going to upgrade to 10 Gbps services immediately, BSPs still have sufficient time to review their physical fiber plant to ensure they can make the leap to next-generation access. That review may uncover some unpleasant surprises. The BSP's existing ODN architecture may have been designed and built to support PON technology standards that were ratified as early as 1995.

Even more recently deployed networks that have benefited from newer fiber deployment practices, including splicing and storage techniques that were sufficient for GPON, may not be adequate to support next-generation technologies.

This eBook lays out how PON specifications, fiber characteristics, and deployment standards intersect to limit broadband speeds and what you can do to identify and prevent potential bottlenecks that could impact your monetization plans with your fiber network.

The need for higher bandwidth is increasing across residential and business subscribers.

THE OPTICAL DISTRIBUTION NETWORK

The ODN accounts for a major portion of a BSP's total broadband network deployment costs. The ODN comprises the optical fiber, transport mechanisms, conduits, duct banks, access holes, vaults and transmission poles. It encompasses both active and passive components in the form of electronics and splitters, as well as other civil and fiber construction components.

To make next-generation services commercially viable, BSPs are eager to re-use the existing optical infrastructure for new access technologies. These newer access technologies operate at different wavelengths to traditional technologies which helps to maintain compatibility with legacy standards.

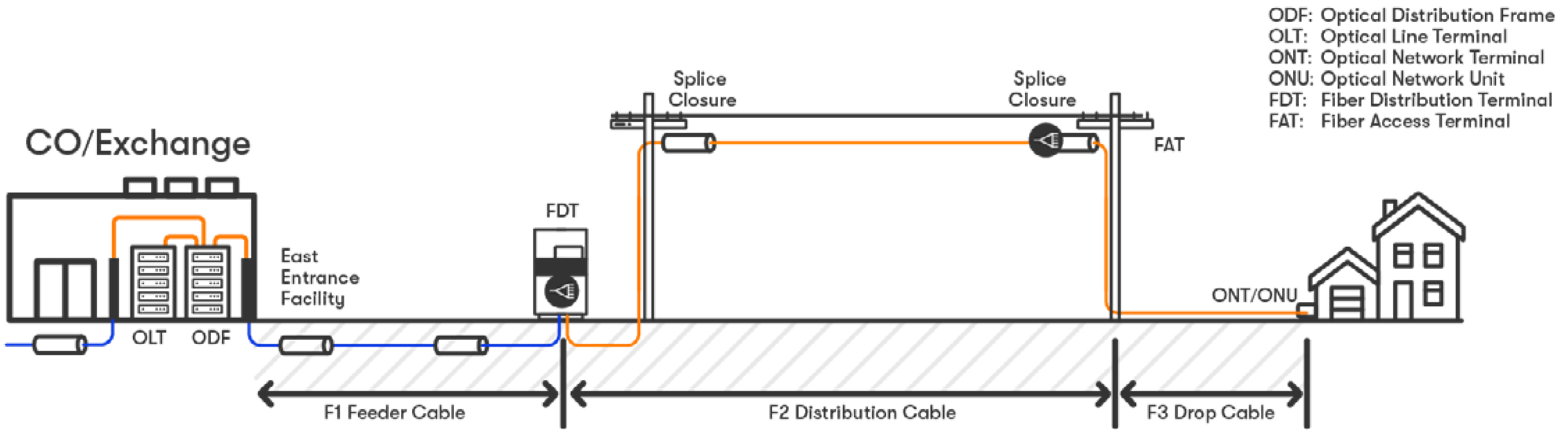
However, attenuation - a loss in the optical signal – can be an issue. Optical attenuation within fiber optic cables is wavelength-dependent - the shorter the wavelength, the greater the attenuation. Signals can be lost through absorption by small amounts of water vapor, trace metals present in the glass, or hydrogen aging. Attenuation can also be due to the bending of the fiber during deployment and at termination points, such as in splice cases and access terminals. Successfully implementing next generation broadband depends on identifying potential trouble spots in your ODN and, where necessary, addressing them.

THE THREE SEGMENTS OF THE ODN

In FTTx networks, there are typically three distinct cable segments—the feeder, the distribution, and the subscriber drop. In each segment, there are placement, plant, and construction methods that can affect the attenuation of the optical wavelengths to different degrees:

- **Feeder cable**—this is the segment from the optical line terminal (OLT) to the fiber distribution terminal (FDT). It is generally routed through a densely populated area, and newer feeder cables can be very high density, employing from 864 up to 1,728 fibers.
- **Distribution cable**—this is the segment from the FDT to a fiber distribution point (FDP), also known as a fiber access terminal (FAT). Distribution cables typically employ 144 to 288 fibers and connect the feeder cable to the subscriber drop cable.
- **Subscriber drop cable**—this is the segment from a FAT to rosette/access termination box (ATB) containing the optical network terminal (ONT). This is generally used outdoors in aerial, direct buried, or ducted installations. The fiber strand count can vary from 1-12 fibers.

Typical PON optical distribution network ODN



MANAGING THE OPTICAL LINK BUDGET

A fundamental parameter in ODN design is the end-to-end optical link budget. This budget should be sufficient to ensure existing subscribers are supported and new subscribers can easily be added without a major reconfiguration of the physical network.

Optical link budgets vary by ODN classification and PON type. While there are different optical interface module transmitter and receiver output and input classifications available, BSPs typically seek to limit losses to 29 dB (the link loss budget) for both XGS-PON and NG-PON2.

The link budget can be adversely affected by the following factors:

- **Bending losses** – Signal loss due to micro and macro bends in the fiber; this particularly impacts NG-PON downstream wavelengths.
- **Spectral losses** – The amount of light lost between the input of the optical signal and the output at the far end of the fiber span due to impurities, manufacturing flaws, and other material anomalies. The value of this attenuation depends greatly on the fiber material and the manufacturing tolerances—older fibers that are not optimized for full-spectrum operation will have a higher loss than newer fibers. In the case of XGS-PON (wavelength 1270-nm), the upstream signal will have a much higher loss than with other PON services operating at longer wavelengths.
- **Splice loss** – Locations where two cables are spliced or fused together; this process will typically result in an attenuation loss of 0.1 dB per splice.
- **Existing fiber optic splitters**— Fiber optic splitters divide the light in the downstream direction into multiple outputs. This introduces attenuation into the signal and has a significant effect on the optical link budget. Splitters will cause additional insertion loss.
- **Co-existence elements** — Components required to combine both GPON, XGS-PON, and NG-PON2 over the same fiber. These elements will result in additional loss that needs to be considered in the overall link budget. As a rule of thumb, factor ± 0.8-dB loss for GPON, ± 1.2-dB for XGS-PON, and ± 1.4-dB loss for NG-PON2. There is no contribution to loss for passive arrayed waveguide grating (AWG).

THE EVOLUTION OF PON STANDARDS

GPON technology is widely adopted by BSPs because of its range, bandwidth speeds, and affordability. Defined by the ITU-T G.984 series, the GPON standard was ratified in 2004 to provide high-speed internet access in the gigabit range. Since then, the ITU has defined next-generation access (G.984.5) as supporting 10 Gbps speeds that can coexist with earlier generations of PON technologies to provide a smooth transition path for BSPs.

GPON was designed to operate at 1490-nm wavelength downstream and 1310 nm upstream, while XGS-PON (per the ITU-T G.987.1 recommendation) uses a 1577-nm downstream and a 1270-nm upstream wavelength. Since there is no wavelength overlap, XGS-PON service can be deployed as an overlay on the same optical plant as the GPON service.

Similarly, NG-PON2 technology, which bundles multiple wavelengths in the upstream and downstream (according to the ITU-T G.989 standard), is also spectrally compatible. The table below shows the performance of each of these technologies, the wavelengths they use, and when they were introduced. The use of different wavelengths minimizes the interference between different PON technologies, but the existing fiber plant will have an impact potentially on the attenuation profile at each wavelength as discussed later. Careful consideration of the placement methods in terminals, splice cases, and jumpers will reduce the impact of attenuation at specific wavelengths.

	Standard	Downstream	Upstream	Downstream Speed	Upstream Speed	Coexistence with GPON	Year Introduced
GPON	ITU G.984	1490nm	1310nm	2.5Gbps	1.244Gbps		2004
XGS-PON1	ITU G.987	1577nm	1270nm	10Gbps	2.5Gbps	Yes	2009
XGS-PON	ITU G.987.1	1577nm	1270nm	10Gbps	10Gbps	Yes	2016
NG-PON2	ITU G.989	1596.34nm	1532.34nm	10Gbps	10Gbps	Yes	2016
		1597.19nm	1597.19nm	10Gbps	10Gbps	Yes	
		1598.04nm	1598.04nm	10Gbps	10Gbps	Yes	
		1598.89nm	1598.89nm	10Gbps	10Gbps	Yes	

FIBER TYPES IN OPTICAL DISTRIBUTION NETWORKS

The fiber cables used in outside plant conform to two ITU specifications – ITU-T G.652 and G.657 single mode fiber.

G.652 SINGLE MODE FIBER

ITU-T G.652 single-mode fiber is used for standard feeder and distribution applications. It is divided into four different categories (A/B/C/D). While each version has been optimized for different performance over time, G.652.D fiber eliminates the water peak for full-spectrum operation and is suitable for all types of PON, including CWDM and DWDM applications. Deployed between 2008 and 2015, it is by far the most widely deployed single-mode fiber (SMF) globally.

Although its lower attenuation characteristics make it well suited for long-distance links (more than 100 km), G.652.D fiber has limited bend resistance—it can only tolerate a bending radius of 30 mm without suffering performance loss. Anything less than 30 mm results in a high loss, especially at the 1550-nm and longer wavelengths - attenuation due to bend radius is greater at higher wavelengths.

G.657 SINGLE MODE FIBER

ITU-T G.657 single-mode fiber is generally used in the subscriber drop segment since it works well for bend-sensitive applications. This fiber type is divided into two categories: Category A fibers for access network applications and Category B fibers for short distances towards the end of access networks.

G.657 Category A	G.657 Category B
Access network applications	Short distances at the end of access fiber plant
▪ G.657.A1 (10-mm minimum design radius) 2015-2016 ▪ G.657.B2 (7.5-mm minimum design radius)	▪ G.657.A2 (7.5-mm minimum design radius) ▪ G.657.B3 (5-mm minimum design radius)

As G.657 Category A fiber is fully compatible with G.652 single-mode fiber, it can be deployed throughout the general feeder and distribution network. Although G.657 Category B is not fully compatible with G.652, it exhibits low bending losses at very small bend radii. That makes Category B well suited for applications inside buildings or near buildings.

The fourth and most recent ITU-T G.657 revision from 2016 modifies the usage of Category A fibers to include all applications, including feeder, distribution, and subscriber drops.

G.657 also has a 200-micron diameter option designed for use in areas where there is limited duct space because it allows for higher count fiber cables. However, splicing together cables with different diameters can be problematic, especially in ribbon cables. Splicing together 200-micron and 250-micron fibers will result in a higher insertion loss, which you'll need to take into consideration when determining your optical loss budget.

CAUSES OF ATTENUATION IN THE ODN

WAVELENGTH-RELATED ATTENUATION

Spectral attenuation and related performance loss in a fiber optic cable is wavelength dependent. The lower the wavelength, the higher the spectral attenuation. For all PON, the terminal equipment operates in the ranges between 1270-nm and 1625-nm. NG-PON2 uses multiple wavelength transceivers so the total bandwidth variants can be between ±10 nm to ±50 nm. In telecommunications, the spectral bandwidth for single peak devices is the difference between wavelengths at which the radiant intensity is 50 percent, or 3 dB down from the maximum value.

Spectral Attenuation for Typical Single-Mode Fiber

Maximum Attenuation

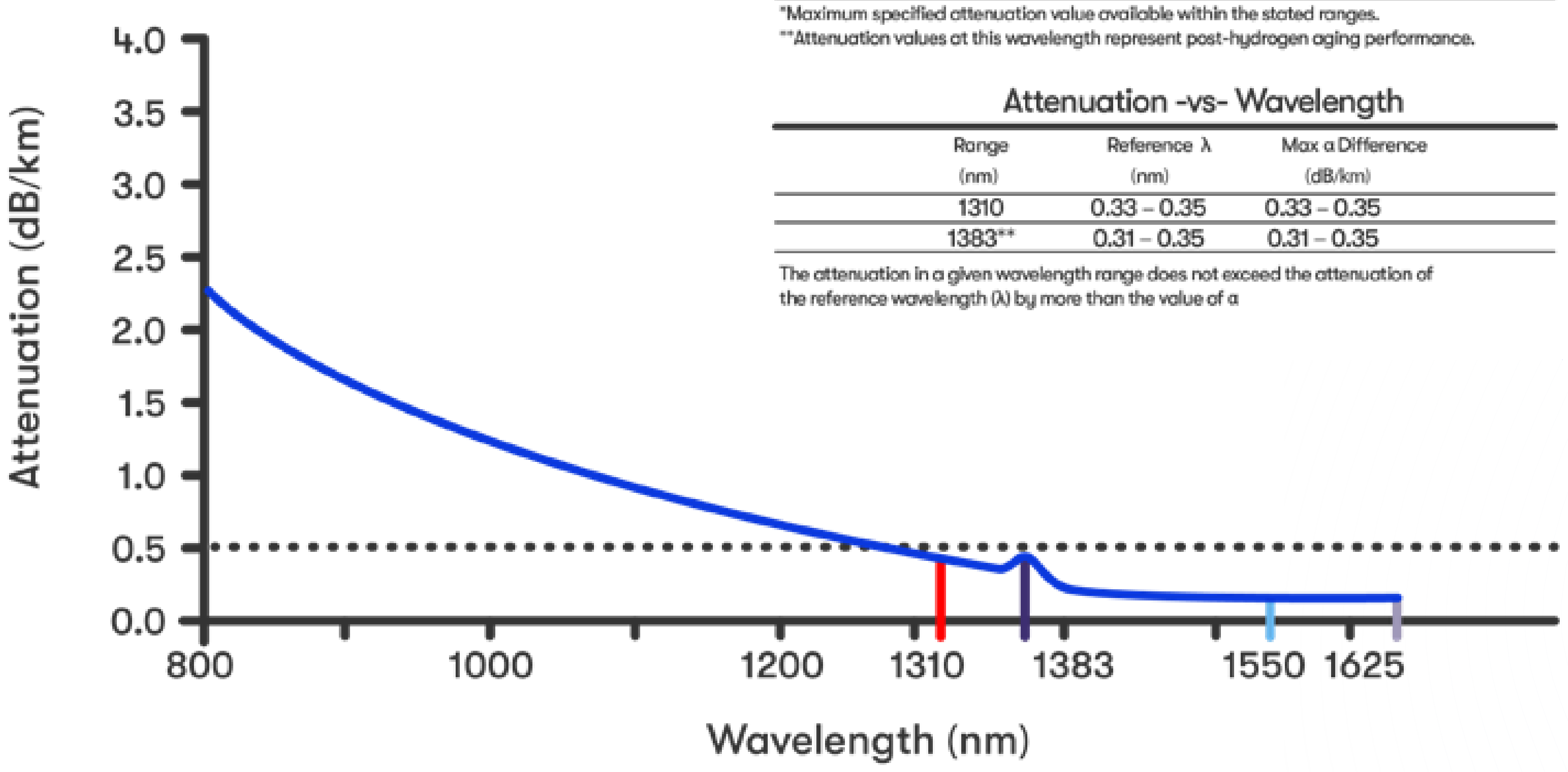
Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1550	0.19 – 0.20
1625	0.20 – 0.23

*Maximum specified attenuation value available within the stated ranges.
**Attenuation values at this wavelength represent post-hydrogen aging performance.

Attenuation -vs- Wavelength

Range (nm)	Reference λ (nm)	Max α Difference (dB/km)
1310	0.33 – 0.35	0.33 – 0.35
1383**	0.31 – 0.35	0.31 – 0.35

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (λ) by more than the value of α



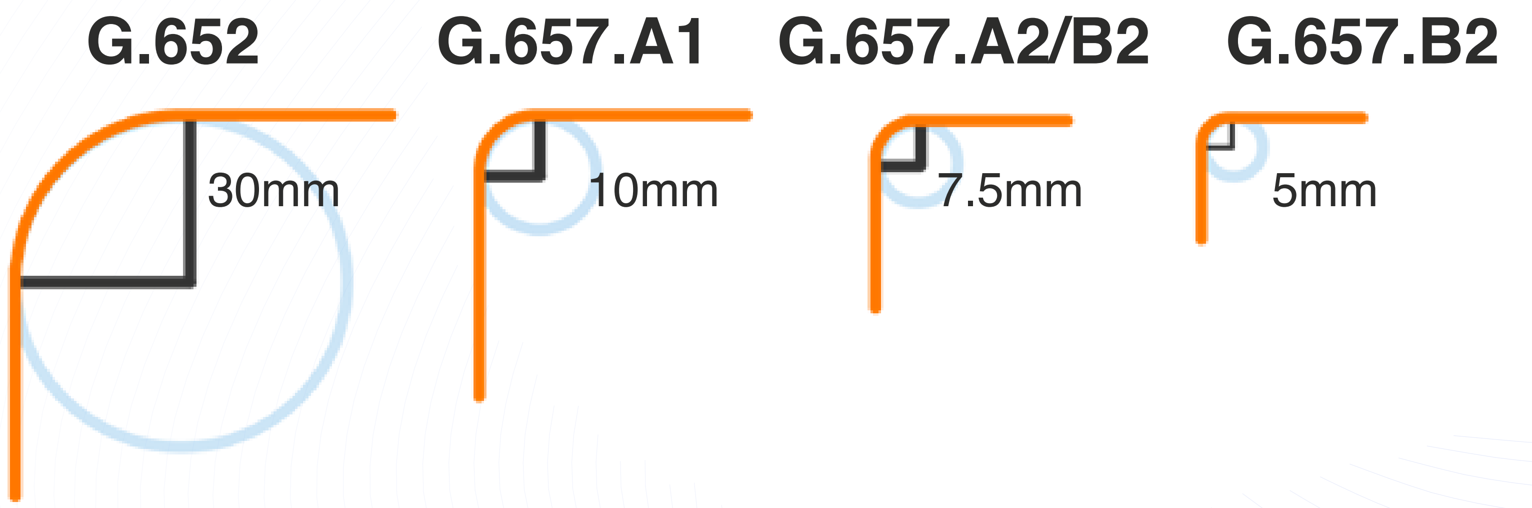
Spectral attenuation for typical single-mode fiber. Spectral attenuation is inversely proportional to the wavelength.

NG-PON2 and XGS-PON work in similar wavelengths meaning those technologies can coexist with GPON on existing fiber plant to a large extent. But as we start increasing the wavelengths for NG-PON2 and XGS-PON, we may find that the losses at those wavelengths will start to increase whether its due to spectral attenuation or physical fiber makeup.

BEND RADIUS-RELATED-ISSUES

Attenuation due to bend radius is also wavelength dependent, and the impact is more pronounced at the higher wavelengths. It is, therefore, particularly important to consider the fiber bending performance of NG-PON2 and XGS PON services operating at longer wavelengths. Care must be taken at splice points, patch panels, and splitter locations to make sure you have sufficient bend radius to accommodate your desired link budget as you move to next generation PON technologies.

In FTTx deployments, fiber distribution panels, termination boxes, splice enclosures, and wall-mount outlets have limited space and thus require tighter fiber angles. Therefore, installers tend to use fibers that support smaller bend radii, such as G.657.A2 fiber. Thanks to its tolerance for bending, particularly at longer wavelengths, G.657.A2 fiber is simpler and easier to install. On the other hand, service providers are cramming more fibers into smaller tubes, leading to a situation where there is less room for fibers to move before touching a buffer tube wall, thereby creating potential microbends.

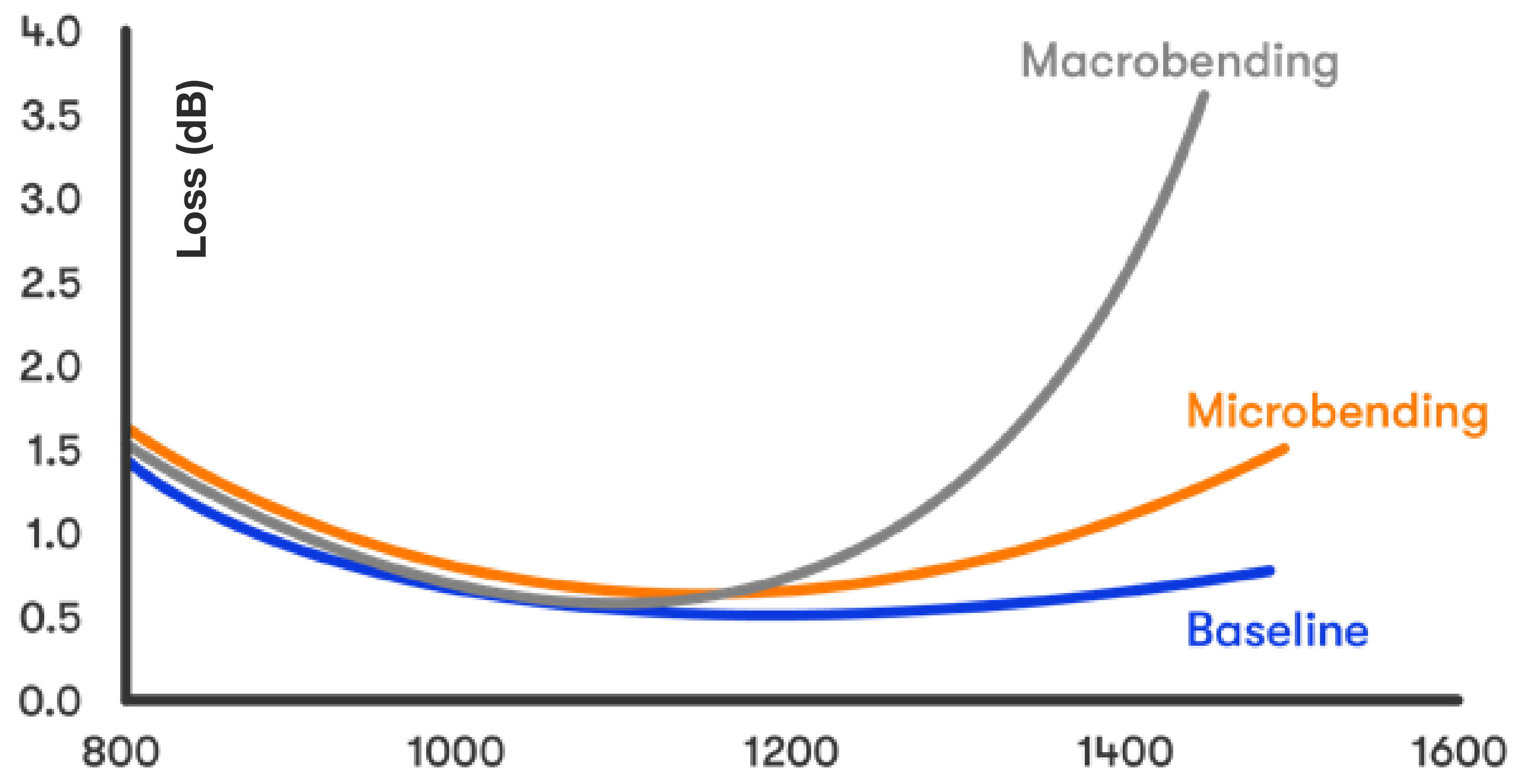


Bend radii for single-mode fiber types

THE IMPACT OF FIBER BENDING IN NG-PON SYSTEMS

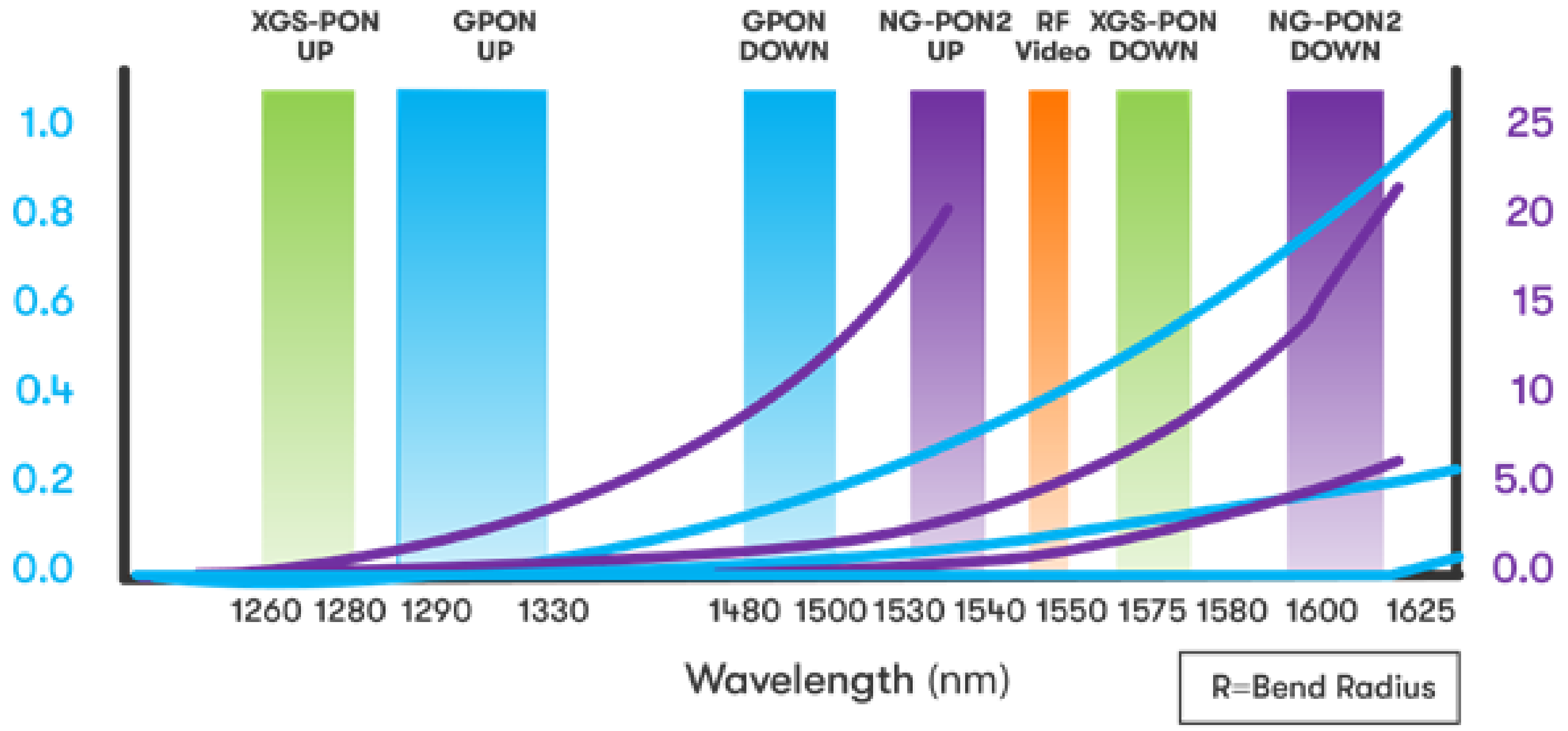
There are two types of bending in fiber networks—macrobending and microbending. While both types produce loss as a function of wavelength and fiber type, the mechanisms and how they manifest differ.

Microbends—small-scale distortion caused by point stresses or loads on the fiber. As stress increases, so does loss. Examples include fiber compression due to freezing water in the splice case, fibers trapped in a door, splice lid, or tray, or even too many fibers crammed into a buffer tube touching each other.



Micro/macro bending signatures versus wavelength.

Macrobends—large-scale distortion caused when the fiber is bent too sharply or tightly. The tighter the bend, the more light escapes the fiber, resulting in additional loss. Examples include tight loops in the fiber or improper routing of fibers in splice trays and enclosures.

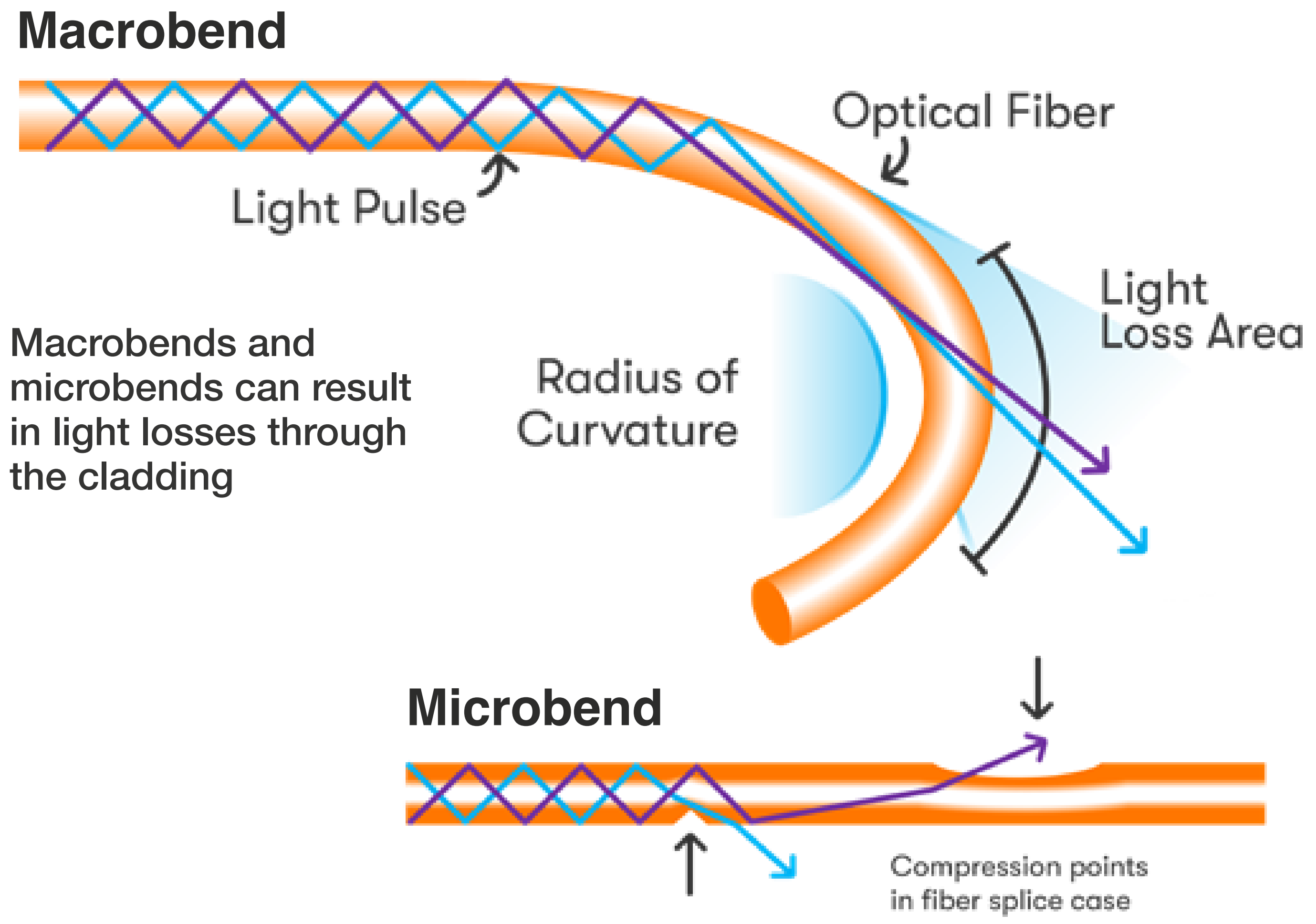


Macro-bending loss of G.652D & G.657A2 fiber types versus PON spectrum.

As fiber networks grow in size, they need to contend with a wide range of environmental and infrastructural factors. Next-generation PON networks are taking fiber into places where legacy GPON fiber has not existed before. Fiber is now commonplace inside businesses and shopping centers. It is frequently being employed in mobile front-haul applications to feed cellular and Wi-Fi sites on top of light poles, building rooftops, and other non-traditional fiber locations.

As a result, there are many points along the route where microbending and macrobending can occur. Bend-related faults in the feeder, distribution, or subscriber drop segments can be due to the cable placement process, but generally they are a result of poor installation practices or improper fiber management.

Microbends and macrobends can increase the angle of incidence to a point that the modes of light are not reflected back into the core, but instead reflect out through the cladding.



Bending in optical splitters in the outside plant can't be overlooked as a potential failure point. Despite stringent testing in accordance with ITU-T and Telcordia recommendations, optical component vendors can miss tiny cracks during production or the final testing stage, and these minute imperfections can degenerate into more serious fractures over time. This is likely to happen when the splitter is exposed to thermal stress in more "hostile" environments.

Care must be taken not to introduce microbends and macrobends at the splice points or within the splice cases. Following the standards on fiber fanout and exposed buffer tubes in splice cases and terminals will also limit the amount of contraction experienced by the buffer tubes that could cause potential macrobending-related attenuation.

Did you know cold weather can cause attenuation in your fiber plant?

Broadband service providers have noticed varying light losses in the network at different times of the year, usually on services with wavelengths above 1500nm. When these BSPs analyzed the networks that were experiencing issues, they found it was more severe for cables exposed to high temperatures (greater than 50°C) followed by low temperatures. The attenuation loss was measured as high as 10 dB to 20 dB. In cold weather environments (-40°C to 0°C), these losses could result in service-affecting failures.

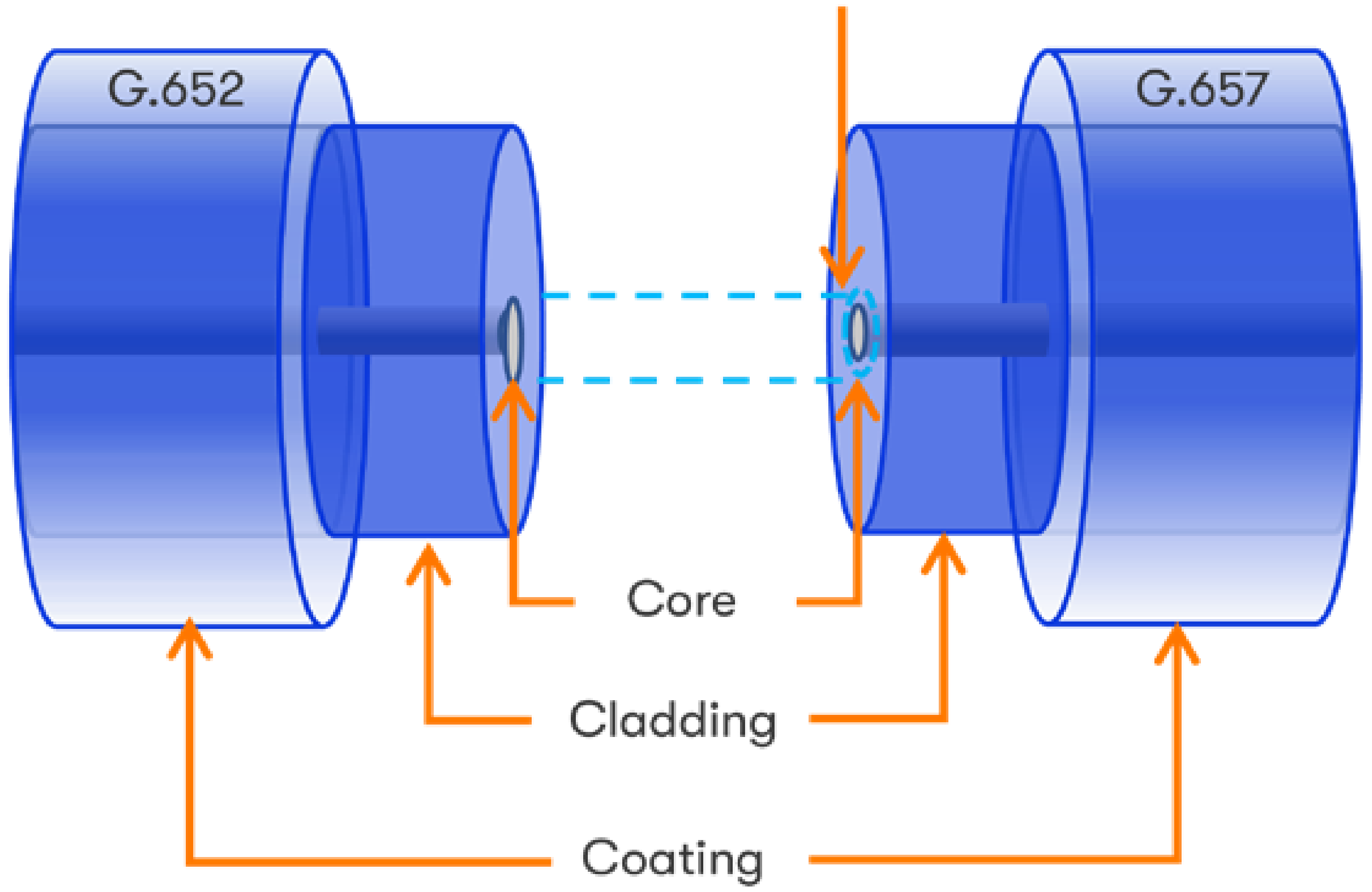
The root cause of this problem is the loose tube cable in splice enclosures or above ground terminals. To ensure adequate sub-unit length, splicers typically provide a mid-span access length of ten to twelve feet of exposed buffer material routed through the closure or terminal.

The losses in cold weather were caused by fiber macrobending when random fibers made contact with the buffer tube walls due to the axial shrinkage of the buffer tubes in the low temperatures. As 90 percent of the failures occur where the length of exposed buffer tubes exceeded 150-inches (12.5-ft), this problem can be solved with some mechanical adjustments to the buffer tubes within the splice closures.

CHANGE IN FIBER TYPE BETWEEN AND WITHIN ODN SEGMENTS

BSPs often leverage different fiber types within their ODN. Even though G.657.A2 is compatible and used in conjunction with G.652.D fiber, there are subtle geometry differences between the two fiber types that FTTx engineers should be aware of. Depending on the vendor or when the fiber was developed, the improved macrobend performance of G.657.A2 fiber was sometimes achieved by adjusting the mode field diameter (MFD). At a fiber splice point that transitions from a larger core to a smaller core fiber cable there will be some loss of light, meaning that as a signal traverses from a G.657 cable to a G.652 cable, there will be attenuation.

Mismatch in MFD



Differences in the MFD of different fiber types can cause attenuation of the optical signal

Cable technology advances in recent years have reduced signal losses and improved macrobend performance, while maintaining the 9.2-μm MFD diameter of legacy G.652.D fibers. This enables seamless integration into pre-existing GPON systems. However, it is important to carefully examine ODNs that pre-date 2013.

OPTICAL SPLITTER IMPACT

The vast majority of optical splitters used in GPON systems today have only been verified in production using legacy GPON wavelengths that are less susceptible to bending. Thus, any bending issues related to longer wavelength operation may have gone untested or undetected.

WAVELENGTH ISOLATION

Wavelength isolation, also referred to as far-end crosstalk, is a measure of how well different wavelengths are separated at the output of a wavelength division demultiplexer. It is defined as the ratio of the optical power at the two output ports of the demultiplexer at a given wavelength, expressed in dB. The higher the far end crosstalk, the higher the insertion loss at the output of the splitter.

CHECK SPECIFICATIONS ON OLDER SPLITTERS WHEN DEPLOYING NEXT GEN PON

Today's optical splitter/couplers have a typical operating wavelength from 1260-nm to 1650-nm. Planar lightwave circuit (PLC) splitters manufactured from 2000 through to 2012 were tested in the operating wavelength from 1300-nm through 1600-nm. You should refer to your manufacturer's specifications to see if there is additional attenuation outside the 1300-nm to 1600-nm window when deploying NG-PON2.

HOW TO SUPPORT YOUR NEXT-GENERATION PON ASPIRATIONS

What can you do to improve the performance of your existing ODN, so that it surpasses the 10 Gbps threshold for next-generation broadband? We recommend a three-step approach:

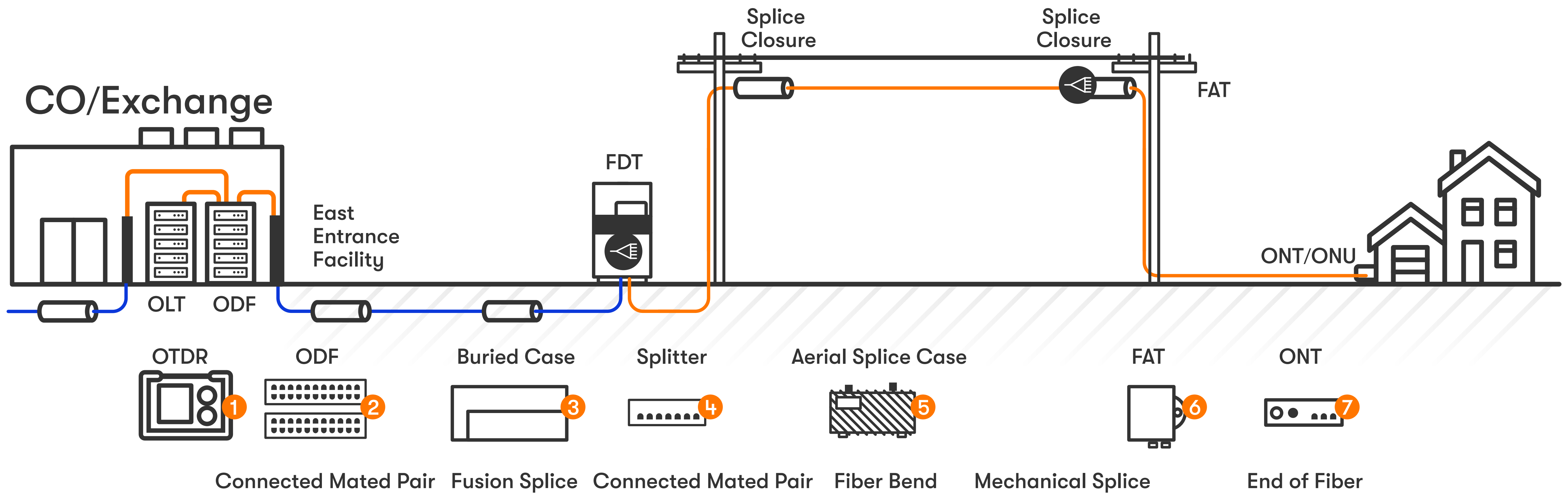
STEP 1: PHYSICALLY MEASURE LOSS BY SIMULATING 10G PON SYSTEMS

Start by performing an assessment of your existing access network by testing its capability to support next generation PON. The vast majority of GPON systems in use today were tested at 1310/1490-nm or 1310/1550-nm wavelengths during the fiber construction phase. But as was pointed out earlier, they haven't generally been verified at the shorter downstream wavelengths required for next-generation access—legacy test practices will not have discovered bend-related losses for next generation PON services.

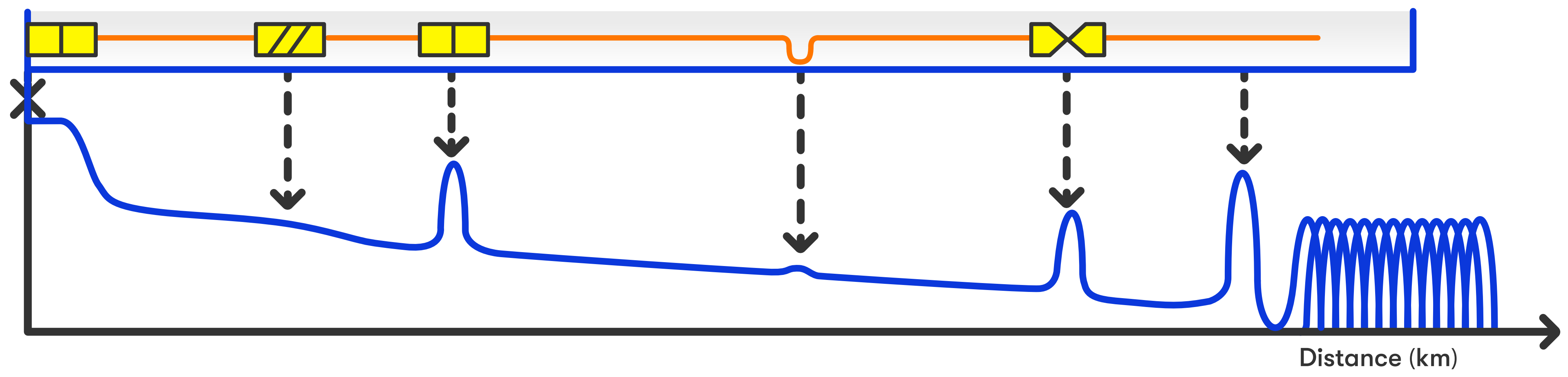
To determine your optical budget for next generation technology, perform the following field tests:

- An optical light source (OLS) and optical power meter (OPM) are used for verifying insertion loss at the PON operating wavelengths. A specialized NG-PON OLS can be connected at the co-existence (CEx) filter in the central office or data center, while an OPM at the ONT location is calibrated at the specific PON wavelengths to verify the total insertion loss.
- An optical time-domain reflectometer (OTDR) is ideal for detecting and locating bends in an optical fiber. A CWDM OTDR is useful to simulate and characterize attenuation in PON systems since several wavelengths per the ITU-T G.694.2 CWDM grid are very close to the PON operating wavelengths.

Using a CWDM OTDR to simulate the various 10G-PON systems being deployed today, you can take a closer look at potential bend-related losses as a function of wavelength on a simple FTTx architecture using G.652D fiber only. You'll need to repeat this test in the other direction, given there will be potential different sizes of fiber, to help you pinpoint the areas of high attenuation.



OTDR evaluation of ODN for next generation PON deployment.

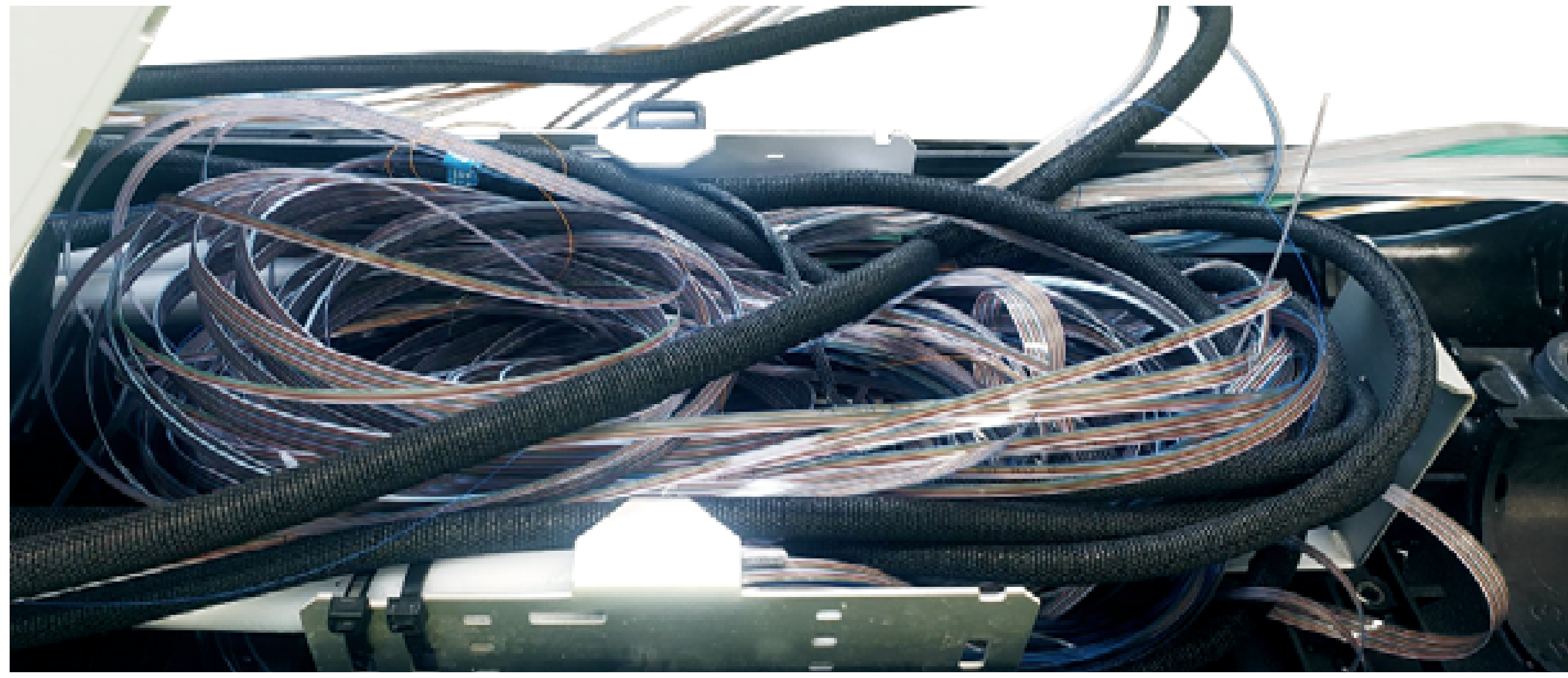


STEP 2: ISOLATE AND IDENTIFY LOCATIONS OF MICROBENDS AND MACROBENDS CAUSING HIGH ATTENUATION

Using your test results from Step 1, you can systematically go to specific splice cases, terminals, and splitters that show up as major sources of attenuation. You can leverage the best practices identified in this eBook to increase the bend radius of fibers or alleviate strain on the fibers themselves to improve the actual loss budget.

STEP 3: PLAN OUT YOUR NETWORK EXPANSIONS AND SUBSCRIBER ADDITIONS

As multi-gig and 10Gbps demand will continue to increase, take a long-term view, as you add additional subscribers to the network or expand your coverage of new areas. Establish a game plan for adding residential or businesses on the existing fibers versus, using new fibers for the higher bandwidth customers.



Practice splice case hygiene - image of a splice case with documented macro and micro bends.

TAKEAWAYS AND CONCLUSIONS

Today, your fiber optic plant can be functioning perfectly, but tomorrow, it might not. Before you introduce next generation PON technologies, ask yourself some key questions:

- **How old is the fiber in each part of the network?**
- **Where are there transitions from larger core cables to smaller core cables?**
- **Where are the data sheets to review the fiber and splitter specifications?**
- **What bend radius did we use and where?**
- **What is the spectral attenuation of the existing fiber plant?**
- **To what extent is the performance of the plant impacted by cold weather?**
- **What are the overall signal losses likely to be with next generation services?**
- **Will these losses have too great an impact on my optical link budget?**
- **Do we need to increase the number of subscribers served?**
- **Was the GPON system built to serve 32 subscribers per feeder cable; and can I build for 64 subscribers?**

To get the answers, consider performing a formal analysis of your existing plant to ensure it is future-proof and will be able to support 10 Gbps next generation services.

Bear in mind that next gen PON operates at additional wavelengths compared to older PON technologies. Impairments that cause higher attenuation at higher frequencies may impact your optical link budget – you need to take that into account in your planning.

You can improve the frequency-dependent attenuation characteristics of your existing plant by testing, identifying, and correcting microbend and macrobend related impairments and following generic requirements for fiber fanout and buffer tube exposure at splice cases and terminals.

CALIX NETWORK CONSULTING CAN HELP

If you need support validating your network readiness for next generation PON, Calix Network Consulting can help you take the steps needed to assess your existing ODN and proactively prepare your plant to support the growing demand for 10Gbps services.

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4 Mike Venter, OptixSource, LLC

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