G.654.E Fibre Cable

A Game Changer for the Future of Long-Distance Networks

Enabling fewer repeaters and regenerators
in 800 Gb/s transmission and beyond

SUMITOMO ELECTRIC
Connect with Innovation

ACOME GROUP

Table of contents

G.654.E Optical Fibre

A Game Changer for the Future of Long-Distance Networks

About us

Sumitomo Electric Industries, Ltd.

Sumitomo Electric Industries, Ltd. (Sumitomo Electric) produces a wide range of products from optical fibres, cables and components to electronic devices and automotive parts.

Through effective research and diversification, Sumitomo Electric has become one of the world's leading companies in information and communication technology.

The Company operates in more than 40 countries, employing over 290,000 people. Sumitomo Electric reported group net sales of $30.5 billion for the fiscal year ended March 2024.

For more information, visit www.sumitomoelectric.com

ACOME Group

ACOME Group is a leading innovative international industrial cooperative, recognised globally for our cutting-edge cabling systems designed for telecom networks.

As a high-tech European manufacturer, we bring over 25 years of specialized experience in fiber optic cables. This extensive expertise has been critical in supporting the large-scale fiber roll-out for major European operators.

Our strategic long-term vision drives continuous Research and Innovation. We are dedicated to developing technologically advanced products that offer high added value to our partners, covering everything from the data center to the home.
Our focus is squarely on enhancing fiber roll-out efficiency and promoting sector sustainability through our solutions.

For more information, visit www.acome.com

Introduction

While it is often said that optical fibre offers virtually unlimited bandwidth, practical transmission constraints still exist. Although light-based transmission and multiplexing enable the transport of multiple high-capacity channels, limitations become increasingly apparent when transmitting ultra-high data rates – such as 800 Gb/s and beyond – over long distances of several hundred kilometres or more.

This white paper, jointly developed by ACOME and Sumitomo Electric Industries, Ltd., explores how rising data demands are approaching the physical limits of current transmission technologies, such as Direct Detection and G.652.D fibre, and highlights the emerging solutions that can overcome these challenges.

Increasing data demands on existing telecom network infrastructure

The digital era remains in its early stages, as demonstrated by the exponential growth of global data generation. Over the past four years, the volume of data created worldwide has increased at a compound annual growth rate (CAGR) of 33%, reaching 149 zettabytes (ZB) in 2024.[1]

Similarly, data transmitted over fixed and mobile networks has grown at a comparable pace, with a CAGR of 26% over the same period, and is projected to reach 7,222 exabytes (EB) by 2024.[2]

The rise of disruptive technologies such as generative Artificial Intelligence (AI) is significantly contributing to the acceleration of data generation. As a result, global data volumes are expected to grow at a combined CAGR of 41% over the next four years.

Telecommunications networks, particularly the long-distance backbone infrastructure that aggregates high-capacity traffic, are under increasing strain to accommodate this surge, with some already approaching their capacity limits.

149 Zettabytes
data created in 2024 across the world

7,222 Exabytes
data shared in 2024

41% growth
in the next 4 years

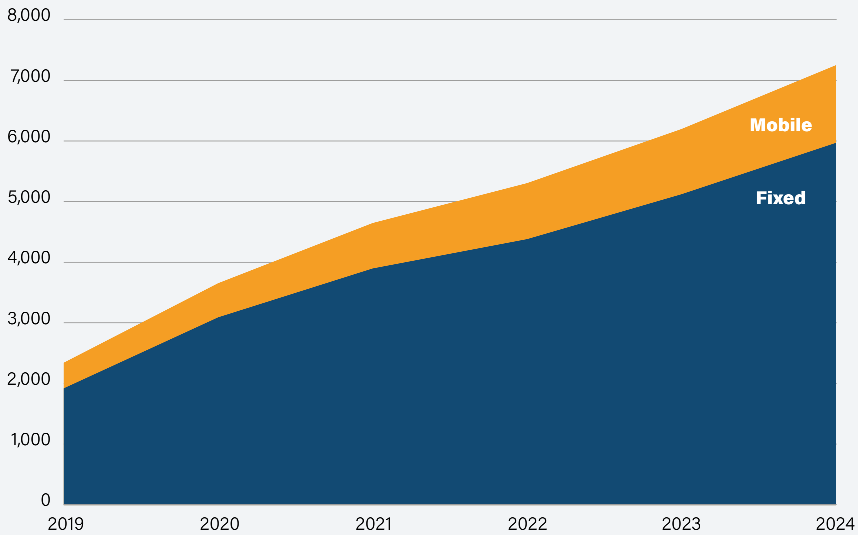
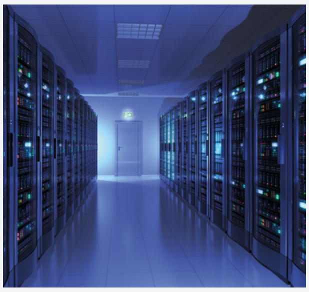


Fig. 1 – Worldwide fixed and mobile Internet traffic in Exabytes *(1 EB = 10^12 MB)*

1 Statista - https://www.statista.com/statistics/871513/worldwide-data-created/
2 ITU - https://www.itu.int/itu-d/reports/statistics/2024/11/10/ff24-internet-traffic/#chart-1

Ongoing expansion of long-distance fibre network capacity

Further development of the long-haul terrestrial network is essential to address a range of emerging demands, as explored below:



The rapid development of major data centre hubs

The rise of AI is driving a significant expansion in data centre construction, with available power capacity serving as a key metric of this growth. In Europe, data centre power capacity is projected to increase from 10,826 MW in 2024 to approximately 13,100 MW by 2027, reflecting a 21% rise. However, this expansion is constrained by energy supply limitations. According to the International Energy Agency (IEA), globally data centres consumed 460 TWh of electricity in 2022. This figure is projected to rise sharply – fuelled by the proliferation of AI and cryptocurrency technologies, with total consumption anticipated to reach between 800 and 1,000 TWh by 2026, an increase of up to 117% over four years (IEA, January 2024).

The growth of regional and edge data centres

The deployment of data centres is increasingly expanding beyond major urban hubs, with a notable rise in facilities located in suburban and less densely populated regions. This trend is driven by several factors, including lower land and construction costs, access to renewable or surplus energy, and the need for improved service latency. Edge data centres in particular are being established closer to end-users to deliver faster, localised digital services. These smaller-scale facilities are especially valuable for supporting small and medium-sized enterprises (SMEs), content delivery networks (CDNs), IoT platforms, and latency-sensitive applications such as gaming and real-time analytics.

Beyond technical performance, regional data centres contribute to local economic development by creating jobs, stimulating investment, and enhancing digital infrastructure in underserved areas. They also improve regional resilience and reduce dependency on centralised infrastructure.

The increasing geographic diversification of data centre infrastructure is a significant driver of long-haul and metro network expansion. This is consistently highlighted in the strategic updates and infrastructure development plans of major telecom and network operators, as they adapt to the evolving landscape of distributed cloud computing and edge services.

Enhancing network resilience

The decommissioning of traditional copper-based communication networks is under way across Europe. As of 2024, over 70% of European citizens have access to internet services via optical fibre, according to the FTTH Council Europe. With fibre networks becoming the dominant fixed access infrastructure, ensuring their resilience and reliability is increasingly critical, especially in the context of rising climate-related disasters such as floods and wildfires, where dependable communication is vital for emergency response and public safety. This shift is prompting further investment in upstream fibre deployments to strengthen the core network, enhance overall performance, and build a more robust and climate-resilient digital infrastructure.

Network specifications must anticipate decades of use

Telecommunications networks are complex systems composed of multiple infrastructure layers, each with its own operational lifespan:

Civil infrastructure: this includes ducts, manholes, poles, and pylons, which typically have life expectancies exceeding 50 years, assuming proper maintenance and construction standards.

Cabling: when installed according to best practices, fibre optic cables can last for more than 40 years, maintaining mechanical integrity and optical performance over decades.

Electronic equipment and transceivers: these components, such as routers, switches, and optical transceivers, have significantly shorter lifespans, usually ranging from 5 to 10 years, due to rapid technological advancements and evolving performance standards.

Software and digital services: software systems are updated frequently, often on cycles of months to a few years, to introduce new features, address security vulnerabilities, and ensure compatibility with evolving hardware.

While networks may appear static once deployed, they are in fact dynamic systems that evolve over time through continual hardware and software upgrades. However, upgrading civil infrastructure or replacing cabling is far more costly and disruptive than refreshing electronics or software. Therefore, strategic foresight is essential when specifying passive components like fibre.

Fibre optics serve as the core transmission medium in modern networks, particularly in long-distance and high-capacity backbones, where aggregated bandwidth is increasing dramatically and will continue to do so in the decades ahead. Selecting the right type of fibre is thus critical for ensuring long-term scalability and cost-effectiveness.

Optical fibre and its protective cabling structure are intrinsically linked. The fibre itself is a thin strand of high-purity glass engineered to transmit light signals with minimal attenuation. The cable acts as a mechanical and environmental shield, protecting the fibre from stress, moisture, temperature changes, and other hazards encountered over its service life.

The longevity of an optical fibre is directly correlated with the quality of its encasing cable. This relationship extends beyond mere durability; the cable's protective properties, such as mechanical strength, moisture resistance, and thermal stability, also play a crucial role in preserving the fibre's optical integrity and minimizing signal attenuation. Consequently, cable design directly affects the system's overall optical budget and, by extension, its transmission efficiency and long-term reliability.

To ensure infrastructure investments remain viable over decades, both the fibre and its cabling must support evolving bandwidth demands. This requires high-performance materials and construction standards capable of withstanding environmental stress, while accommodating future increases in data throughput.

WDM: no longer sufficient to sustain capacity growth in optical networks

Wavelength division multiplexing (WDM) has long been a foundational technology for expanding the capacity of optical fibre networks. By enabling multiple data channels to be transmitted simultaneously over a single fibre, with each on its own distinct wavelength, WDM has efficiently supported the escalating bandwidth demands of the past three decades.

This approach has proven remarkably effective. From the 1990s to the early 2000s, per-wavelength transmission rates advanced from 10 Gb/s to 40 Gb/s. In the last decade alone, technological innovations, particularly in coherent optics and modulation formats, have accelerated this trend – boosting speeds from 100–200 Gb/s to 800 Gb/s, and now reaching 1.2 Tb/s and 1.6 Tb/s per wavelength in cutting-edge systems.

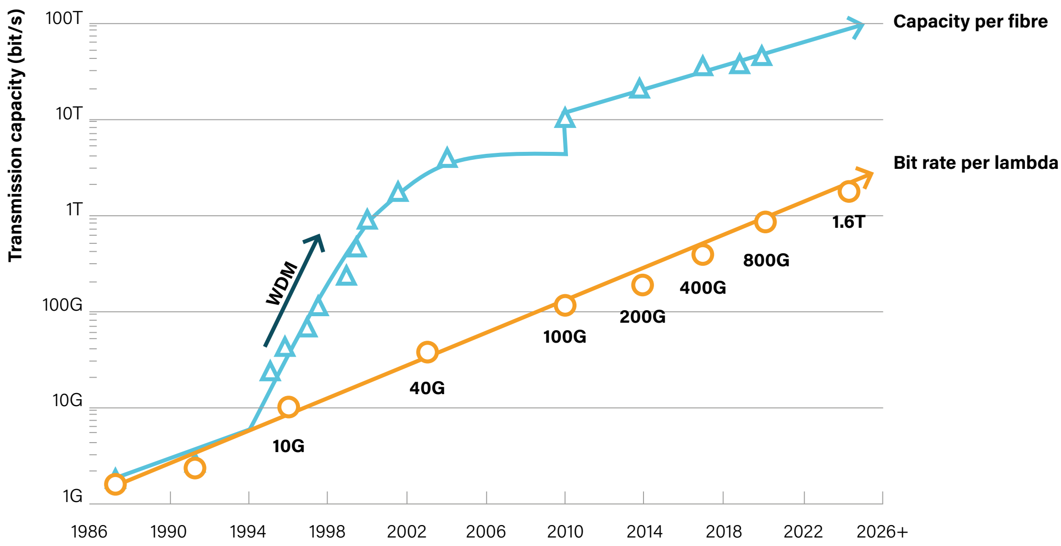


Fig. 2 – Bit rate evolution

However, physical constraints are beginning to limit the scalability of WDM. The transmission capacity of an optical link is fundamentally constrained by a trade-off between data rate and transmission distance. As per-wavelength bit rates increase, so does the required optical signal-to-noise ratio (OSNR), which degrades with distance due to fibre attenuation, chromatic dispersion, non-linear effects, and amplifier noise. Consequently, higher bit rates reduce the maximum viable transmission distance unless compensated by advanced technologies or additional repeater and/or regeneration.

In conventional G.652.D single-mode fibres (still the most widely deployed) these limitations are increasingly problematic. As bit rates rise, maintaining an acceptable OSNR becomes more difficult over long distances, often necessitating more frequent use of repeaters and regenerators. This leads to significantly higher capital expenditures (CAPEX) and operational expenditures (OPEX).

Compounding the challenge is the growing environmental footprint of scaling networks by simply multiplying fibre links and active components. The manufacturing, deployment, and energy requirements of additional optical cables, amplifiers, and transponders contribute to both financial and ecological strain. This linear scaling model is no longer sustainable in the face of massive digital growth.

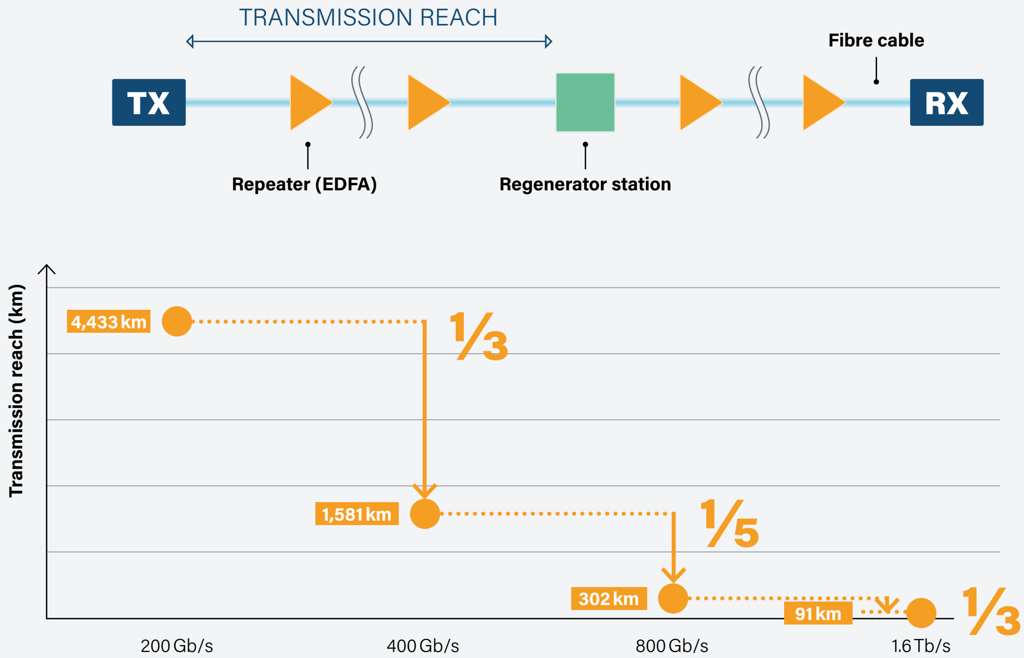


Fig. 3 – Typical transmission reach using a G.652.D fibre depending on the bit rate per wavelength

Modern data-intensive applications, such as artificial intelligence (AI), 8K streaming, and high-performance cloud computing, are accelerating bandwidth demand at a pace that outstrips the capabilities of conventional infrastructure. As a result, the industry must urgently explore more energy-efficient and scalable alternatives.

This raises critical questions for the future of optical networking:

- How can existing architectures evolve to sustainably accommodate this data explosion?
- What new fibre types, such as G.654.E, or system innovations can break through the limitations of traditional G.652.D-based links?
- And how can we build networks that are not only higher capacity, but also cost-effective and environmentally resilient?

Signal amplification and regeneration: a key challenge for long-distance networks

Long-haul optical networks, designed to carry signals across hundreds or even thousands of kilometres, rely on more than just transceivers and WDM systems. Two critical components that underpin long-distance transmission are optical amplifiers and signal regenerators.

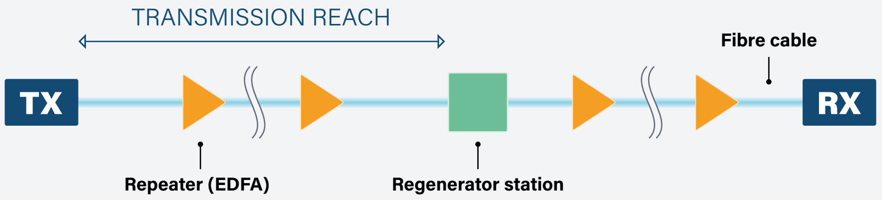


Fig. 4 – Long-haul optical link

As optical signals travel through fibre, they gradually lose strength due to attenuation. Erbium-Doped Fiber Amplifiers (EDFAs) are widely deployed along the transmission path to compensate for this loss by boosting signal power across all wavelengths simultaneously. While efficient and cost-effective, these amplifiers also increase the level of accumulated noise in the system, particularly amplified spontaneous emission (ASE), which degrades the Optical Signal-to-Noise Ratio (OSNR). A lower OSNR limits the maximum achievable transmission distance and can result in increased bit error rates.

To overcome OSNR degradation and other impairments – such as chromatic dispersion and fibre nonlinearities, regenerators are employed at certain intervals. These devices perform 3R regeneration (Reamplify, Reshape, Retime), converting the degraded optical signal into an electrical signal, cleaning it up, and then retransmitting it optically. However, regeneration is both wavelength-specific and transponder-intensive, making it complex, costly, and power-hungry, especially as the number of wavelengths and fibres scales up.

While these amplification and regeneration strategies have supported remarkable progress in optical communications over the past decades, they are increasingly strained by surging bandwidth demands. Expanding capacity by simply multiplying fibre links or regeneration sites leads to prohibitively high CAPEX, OPEX, and energy consumption, undermining efforts to build sustainable, future-ready infrastructure.

As a result, network operators face a strategic challenge: how to maintain performance and scalability without compromising environmental goals. This is where the next generation of optical technologies comes into play.

Modern innovations, particularly coherent optics paired with advanced digital signal processing (DSP), now enable transmission rates of 400 Gb/s, 800 Gb/s, and up to 1.6 Tb/s per wavelength over extended distances. Coherent systems mitigate signal impairments more effectively and allow for better spectral efficiency, laying the foundation for high-capacity, long-haul optical networks that are both scalable and energy efficient.

Coherent optics: mastering the properties of light

Coherent modulation in optical transmission is a sophisticated technique that significantly enhances spectral efficiency compared to conventional amplitude modulation, commonly referred to as direct detection systems.

Traditionally, data transmission in optical networks has relied on On-Off Keying (OOK), a form of amplitude modulation in which the presence or absence of light represents binary data. While simple and cost-effective, this method becomes increasingly limited at higher data rates– typically beyond tens of gigabits per second – due to physical constraints on how rapidly the light source can be modulated.

To overcome these limitations and achieve higher transmission rates, modern optical systems employ coherent detection, which leverages not just the amplitude, but also the phase and polarization of light to encode data. This approach enables the use of advanced modulation formats such as QPSK, 16-QAM, and beyond, allowing for data rates of 400 Gb/s, 800 Gb/s, and even 1.6 Tb/s per wavelength. By significantly improving the number of bits transmitted per symbol, coherent optics has become a cornerstone technology for high-capacity, long-distance optical networks.

The modulation order (denoted as M) refers to the number of distinct signal states or symbols used to encode information within a given time interval. A higher modulation order enables the transmission of more bits per symbol, thereby increasing the overall data rate. For example, On-Off Keying (OOK), a basic form of amplitude modulation, has a modulation order of M = 2, representing binary values '0' and '1.'
In contrast, modern advanced modulation formats – such as those based on amplitude, phase, or polarization modulation, support significantly higher modulation orders (e.g. M = 4, 8, 16, or greater). These higher-order schemes enable more efficient spectral utilization and greater data throughput, which are essential for meeting the growing demands of high-capacity optical transmission systems.

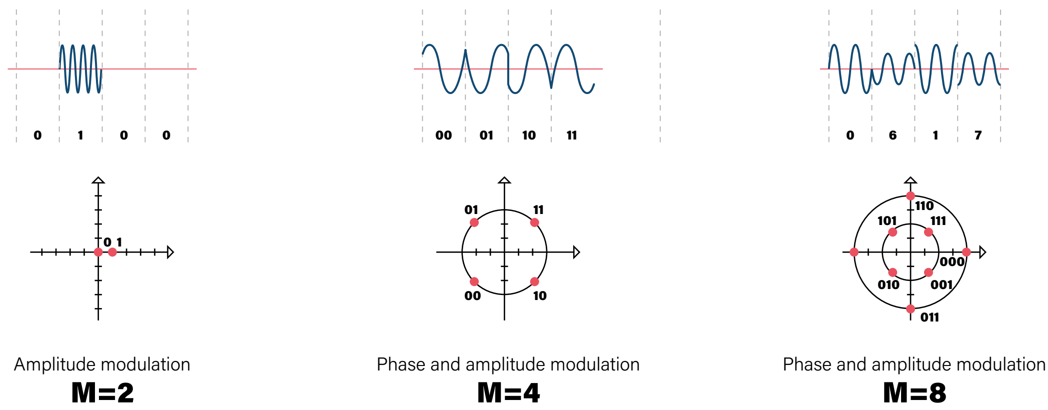


Fig. 5 – Modulation of amplitude and phase

Coherent optical communication has emerged as the primary technology for achieving ultra-high data rates, enabling transmission speeds of several hundred gigabits per second per wavelength. According to a recent study by CIR and LightCounting (2023), the adoption of ultra-high-speed coherent transceivers is expected to accelerate significantly, with the global market projected to double between 2026 and 2028.

This advancement is driven by two key factors: higher-order modulation formats and increased symbol rates (baud rates). While higher-order modulation – such as 16-QAM, 64-QAM, and beyond – enables more bits to be transmitted per symbol, the symbol rate itself has also seen substantial progress. Thanks to cutting-edge digital signal processors (DSPs) fabricated using advanced CMOS nodes (16 nm, 7 nm, and 5 nm), symbol rates have increased to 64, 96, and even 120+ Gbaud.

The combination of these two enhancements – modulation order and baud rate – underpins the current generation of high-capacity optical transceivers. Commercial deployment of 800 Gb/s coherent links is now underway, and the first 1.6 Tb/s demonstrations have recently been achieved, signalling the next leap in optical transmission performance.[1]

Relationship between OSNR and transmission reach: the trade-off between distance and bit rate

Higher-order modulation formats require more densely packed constellation points in the signal space. As the number of these points increases, their spacing decreases for a given average signal power, making the signal more susceptible to noise and other transmission impairments. Simultaneously, increasing the symbol rate (baud rate) also reduces the system's tolerance to noise.

As a result, higher bit rate signals demand a proportionally higher Optical Signal-to-Noise Ratio (OSNR) to maintain acceptable performance over a given transmission distance. For instance, transmitting at 800 Gb/s requires approximately 7.2 dB higher OSNR than at 400 Gb/s, based on typical performance thresholds for coherent systems. This substantial increase in OSNR translates into a significant reduction in maximum reach. Specifically, under equivalent conditions and assuming G.652.D standard single-mode fibre (SMF), the transmission distance for 800 Gb/s could be reduced by a factor of five compared to 400 Gb/s - which brings the effective reach without regeneration below 300 km.

Furthermore, to double the transmission distance for a given bit rate, an additional 3 dB of OSNR is typically required. Therefore, OSNR improvement is critical for enabling long-distance transmission of high-speed signals such as 800 Gb/s in long-haul and ultra-long-haul networks.

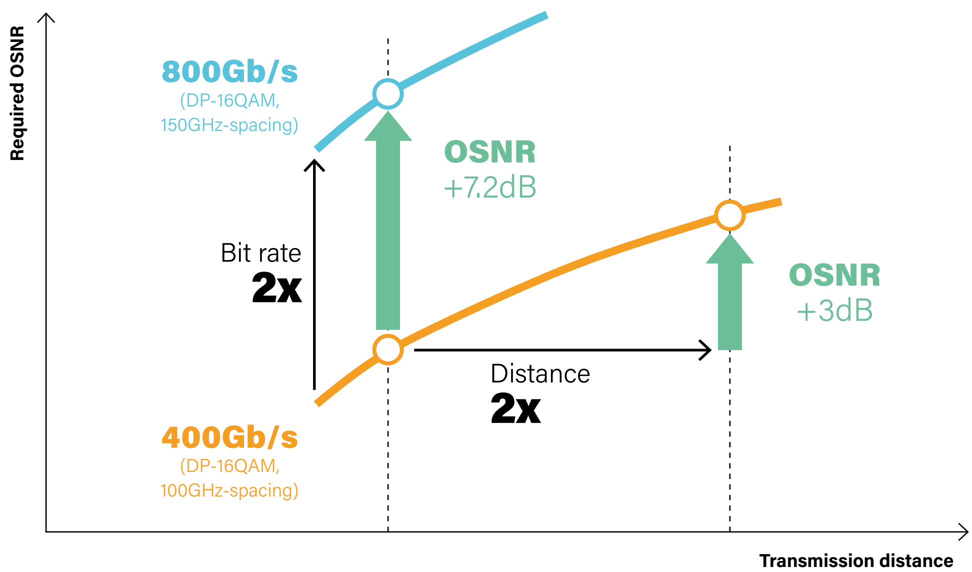


Fig. 6 – OSNR improvement leads to higher distance and/or higher bit rate

1 Ciena press release: https://investor.ciena.com/news-releases/news-release-details/telia-norway-and-ciena-achieve-first-live-16-tbs-data

G.654.E fibre: empowering ultra high-capacity long-haul transmission

Historically, ITU-T G.655 non-zero dispersion-shifted single-mode fibre played a pivotal role in long-haul terrestrial WDM optical networks due to its low dispersion characteristics. However, with the widespread adoption of coherent optical transmission, sensitivity to chromatic dispersion has significantly diminished. Consequently, the emphasis has shifted from dispersion management to optimising the Optical Signal-to-Noise Ratio (OSNR), which is now a critical factor in achieving high-capacity transmission over extended distances.

To enhance OSNR in optical links, employing fibres with ultra-low attenuation and larger effective areas has proven effective. Lower attenuation directly reduces signal loss, thereby improving OSNR. Additionally, fibres with larger effective areas mitigate nonlinear effects, allowing for higher launch powers without degrading signal quality. This combination is particularly beneficial for supporting high-speed signals over long-haul networks.

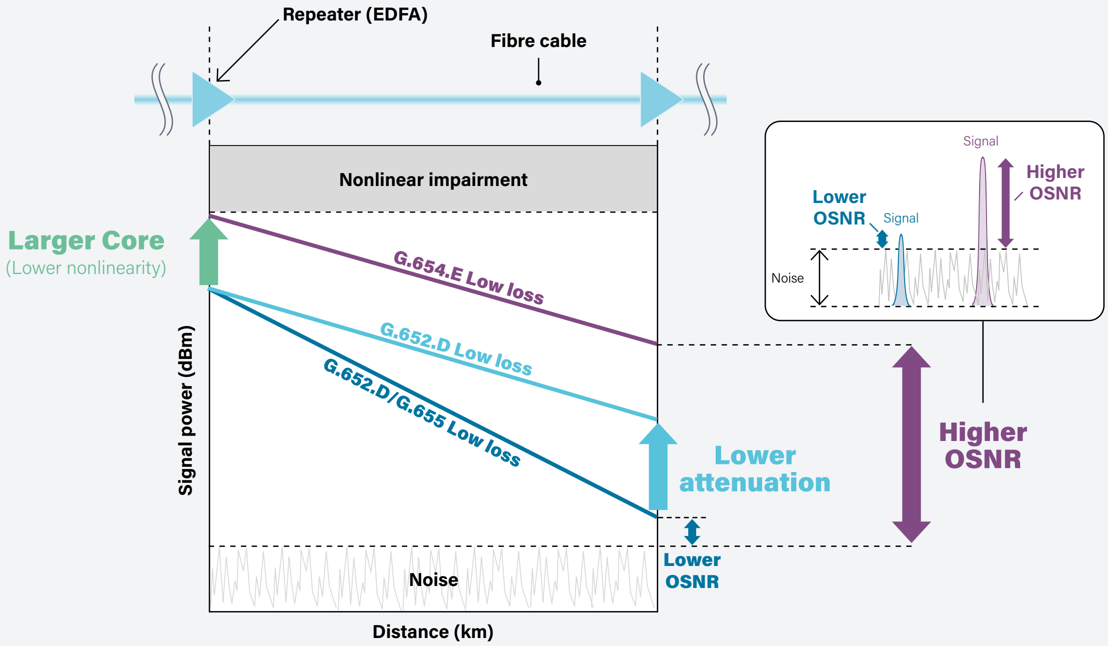


Fig. 7 – G.654.E: More input power and lower linear attenuation for a higher OSNR

ITU-T Recommendation G.654.E specifies optical fibres designed with these attributes for terrestrial high-bit-rate transmission. These fibres are characterized by low attenuation and enlarged effective areas, optimised for use in the C and L bands (1,530–1,625 nm). Originally developed for submarine applications, G.654 fibres have been adapted for terrestrial use to meet the demands of modern high-capacity networks.

Introduced in 2016, G.654.E fibres have been deployed in various terrestrial networks worldwide, including long-haul backbone links, wide-area data centre interconnects (DCIs), and submarine cable landings. For instance, Sumitomo Electric's PureAdvance™ series, compliant with G.654.E, offers fibres with ultra-low attenuation (≤0.16 dB/km) and a large effective area: PureAdvance™-110 with 110 μm² and PureAdvance™-125 with 125 μm², thereby enhancing OSNR and transmission performance in long-haul applications.

Field trials have demonstrated that G.654.E fibres can significantly improve OSNR margins compared to standard G.652.D fibres. For example, a 1,539.6 km transmission system utilizing G.654.E fibre showed OSNR improvements of up to 2.76 dB for 200 Gb/s signals, enabling longer transmission distances without regeneration.

The table below presents a comparison of key attributes between ITU-T G.654.E and G.652.D fibres. G.654.E is characterized by its low attenuation and large mode field diameter (MFD), while maintaining macro-bending loss performance comparable to that of G.652.D.

	ITU-T G.652.D	ITU-T G.654.E
Mode field diameter (MFD) @1,310nm [μm]	8.6-9.2 (±0.4)	—
Mode field diameter (MFD) @1,550nm [μm]	Typ. 10.4*	11.5-12.5 (±0.7)
Effective area (A_{eff}) @1,550nm [μm²]	Typ. 80**	Typ. 110-125**
Macrobending loss (r=30mm) @1,625nm [dB/100turns]	≤ 0.1	≤ 0.1
Cable cut-off wavelength [nm]	≤ 1,260	≤ 1,530

**Typical value. MFD at 1,550nm is not specified for ITU-T G.652.D.; **Typical value. Aeff is not specified in ITU-T Recommendations.*

Fig. 8 – Recommended value by ITU-T for G.652.D and G.654.E fibres

The table below highlights some key characteristics of Sumitomo Electric's G.654.E fibre - PureAdvance™-125. Leveraging decades of expertise in pure-silica core fibre technology, developed since the company's first deployment of submarine fibres in 1989, these fibres deliver ultra-low attenuation of 0.16 dB/km or less (typically 0.156 dB/km) and feature large effective areas (A_{eff}) of up to 125 μm² at 1,550 nm. Sumitomo Electric also offers additional G.654.E-compliant variants: PureAdvance™-110, with a typical A_{eff} of 110 μm², and PureAdvance™-80, which provides a mode field diameter (MFD) compatible with G.652-standard single-mode fibres, in accordance with ITU-T G.652.B and G.654.C recommendations.[1]

	PureBand (SSMF)	PureAdvance™-125
ITU-T Recommendation	G.652.D	G.654.E
Mode field diameter (MFD) @1,550nm	Typ. 10.4 μm	Typ. 12.5 μm
Effective area (Aeff) @1,550nm	Typ. 80 μm²	Typ. 125 μm²
Attenuation @1,550nm	≤ 0.20 dB/km Typ. 0.185 dB/km	≤ 0.16 dB/km Typ. 0.156 dB/km
Cable cut-off wavelength	≤ 1,260 nm	≤ 1,520 nm

Fig. 9 – Product specification comparison between G.652.D and G.654.E

1 https://global-sei.com/fttx/optical-fibres/pureadvance/

Comparative use cases: G.654.E vs G.652.D fibre in coherent transmission networks

Case study 1
Brownfield deployment – upgrading an existing link to increase capacity

In this scenario, a long-haul network operator aims to increase capacity on an existing link by replacing the incumbent G.652.D fibre with G.654.E fibre, while maintaining the current repeater station locations. The link spans 500 km with a repeater spacing of 80 km. Erbium-Doped Fibre Amplifiers (EDFAs) are used at each repeater station to compensate for signal loss.
By upgrading to G.654.E fibre, the operator achieves a capacity increase from 22.4 Tb/s to 26.2 Tb/s – representing a 17% gain in per-fibre bandwidth – without altering the network architecture. This improvement is due to the enhanced optical signal-to-noise ratio (OSNR) performance of G.654.E, which supports higher-order modulation formats more effectively than G.652.D.

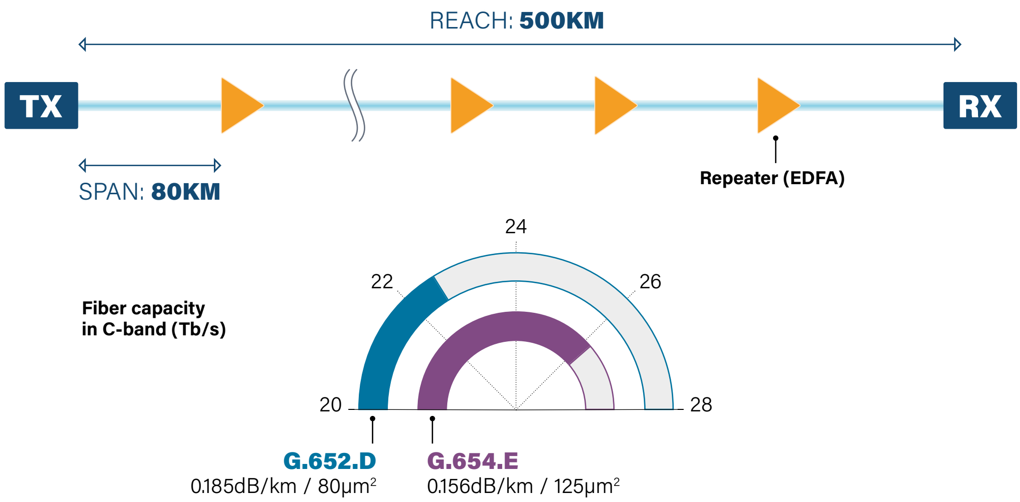


Fig. 10 – Capacity increase of the link when switching G.652.D to G.654.E fibre

Case study 2
Brownfield deployment – eliminating a repeater station in an existing link

In this second case, the operator manages a 600 km long-haul link and is seeking to reduce operational expenditure while supporting 400 Gb/s transmission today and preparing for future 800 Gb/s deployments. By replacing G.652.D fibre with G.654.E, the improved OSNR and lower signal degradation allow the operator to eliminate up to half of the existing repeater stations.
This reduction leads to substantial CAPEX and OPEX savings, including lower equipment, housing, energy, and maintenance costs. Additionally, removing active infrastructure significantly reduces the network's carbon footprint.
Importantly, this upgrade also future proofs the network. When higher bit rates such as 800 Gb/s are required, typically demanding shorter spans, a repeater can be reinstalled at the previously removed site, facilitating an efficient upgrade path without a complete network redesign.

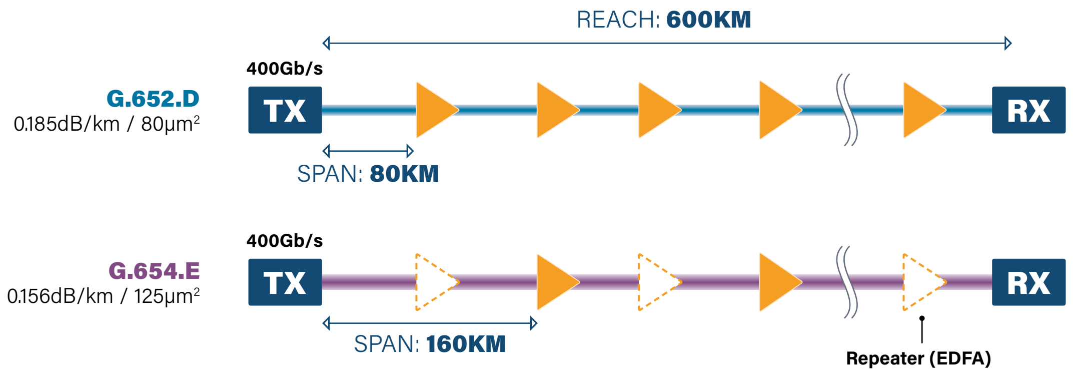


Fig. 10 – Typical link configuration when switching an existing link from G.652.D to G.654.E fibre for the same bit rate

Case study 3

Greenfield deployment – building a long-haul link with fewer regenerators

In this last case study - a greenfield deployment of a new 600 km long-haul link, designed to be 800 Gb/s-ready from inception, the choice of fibre becomes critical. Standard G.652.D fibre would limit the reach of 800 Gb/s coherent signals to under 300 km due to higher attenuation and increased OSNR demands. As a result, at least one regenerator station would be necessary mid-span to restore signal integrity. Regenerator stations, unlike amplifiers, require optical-to-electrical-to-optical (OEO) conversion for each WDM channel (e.g. 48 channels at 400 Gb/s or 32 at 800 Gb/s), significantly increasing both CAPEX and power consumption.

By deploying G.654.E fibre, the operator can maintain 800 Gb/s transmission over distances exceeding 600 km using only optical amplifiers, completely eliminating the need for regeneration. This results in a simpler, more cost-effective, and energy-efficient network architecture optimised for future high-capacity requirements.

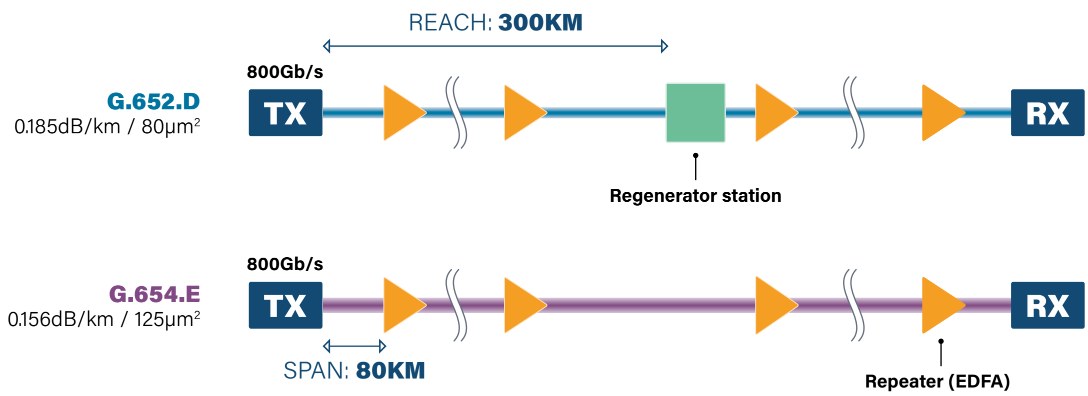


Fig. 11 – Building a green field 800G link with G.654.E

These case studies underscore the strategic value of G.654.E fibre in a range of network environments, including:

- Upgrading existing links to support 800 Gb/s and higher rates,
- Metro and long-haul data centre interconnects (DCI),
- Terrestrial extensions of submarine cable landings,
- Greenfield long-haul builds with fewer optical regenerators.

Thanks to its ultra-low attenuation and large effective area, G.654.E fibre enables longer transmission distances, higher data rates per wavelength, and reduced infrastructure requirements. These properties make it a key enabler for energy-efficient, scalable, and future-proof optical transport networks.

Delivering optical excellence over wired networks

Optical cables for telecommunications are highly engineered products designed to withstand both environmental conditions (e.g. aerial or underground exposure) and the specific mechanical stresses associated with installation methods - such as pulling, blowing, or water-jet-assisted placement. The primary goal is to preserve the optical fibre's intrinsic transmission performance - particularly linear attenuation, throughout its service life.

Ideally, the transmission performance of the cabled fibre should closely match that of the bare fibre. Achieving this parity, especially with high-performance fibres like G.654.E, requires advanced cabling techniques and precision-engineered designs. A key consideration is mechanical protection, especially control of fibre elongation, which must remain minimal (typically below 0.2%) and fully reversible to ensure long-term reliability. This is defined by the cable's Maximum Allowable Tension (MAT).

Other critical cable attributes include:

- Crush resistance to prevent micro-bending and signal loss,
- Impact resistance for mechanical durability,
- Thermal and climatic endurance (performance typically guaranteed between -40°C and +70°C),
- Aging resistance, including protection from thermal cycling, UV radiation, and aeolian vibrations,
- Fire resistance, with ratings up to B2ca where required,
- And rodent and termite protection to ensure long-term operational stability.

Matching the cable to the application

As emphasized previously in this white paper, cable design must align with the environmental and operational demands of its deployment. Below are key examples of application-specific cable designs:

Cables for Installation Underground in Ducts
These all-dielectric cables feature composite reinforcements embedded within a high-density polyethylene (HDPE) outer sheath. A flexible fibre glass strength member completes the structure, offering robust protection against mechanical stresses, rodents, and termites. For installations in buildings or confined spaces, flame-retardant variants with fire performance ratings up to B2ca are available.

High-Density Mini Cables for Blowing into Micro-ducts
Blowing techniques are widely used for efficient installation over long distances – up to several kilometres. Micro-ducts may be buried, pulled, or blown into conduit systems, offering great installation flexibility.

Miniaturized cables for this method require:
- Low-friction jackets,
- Compact, robust construction,
- And optimised material selection for durability under high-speed air-assisted placement.

These all-dielectric cables incorporate a central strength member and are designed for seamless integration into both new and upgraded micro-duct networks.

Ruggedized Multi-Use Cables

In many long-distance networks, cable routes alternate between underground and aerial spans. Multi-purpose cables address both scenarios by combining rugged mechanical features with installation flexibility. These all-dielectric cables can support aerial spans up to 200 meters and are engineered for high-wind, ice-loading, and even anti-ballistic environments.

Key features include:
- Reinforced rodent and impact protection,
- Compatibility with underground conduit or direct burial,
- Enhanced structural stability for hybrid deployment scenarios.

Preserving G.654.E fibre performance post-cabling

Fig. 12 below presents the linear attenuation measurements of G.654.E fibre after being cabled using the above structures. Results confirm that high-quality cabling processes maintain the fibre's intrinsic ultra-low attenuation – typically 0.156 dB/km, making it one of the lowest attenuation values recorded for terrestrial fibre deployments.

	Max. measured optical attenuation (dB/km @1,550 nm)
G.652.D cabled reference	0.185
G.654.E induct cabled	0.156
G.654.E blown mini-cabled	0.156
G.654.E multiuse cabled	0.156

Fig. 12 – Building a green field 800G link with G.654.E

In comparison, G.652.D fibre exhibits higher attenuation under the same conditions, reinforcing the superior performance of G.654.E. These results validate G.654.E fibre as an ideal candidate for ultra-long-haul deployments where low signal loss is critical, enabling longer repeater spans and higher data throughput with fewer network elements.

Strategic fibre selection for long-haul networks

As network technologies and transmission standards evolve over decades, choosing the right optical fibre mix for long-haul infrastructure becomes a long-term strategic decision. Cables are often deployed with a hybrid fibre mix. For example, combining G.652.D (the industry-standard single-mode fibre) with G.654.E - to maximize flexibility and futureproof the network.

This hybrid approach enables:

- Compatibility with existing transmission systems,
- Pathways for future upgrades to high-capacity, coherent transmission (800G and beyond),
- And a smoother migration to next-generation network architectures without needing full infrastructure overhauls.

By deploying cables that incorporate both fibre types, operators can adapt to increasing bandwidth demands while optimising network efficiency and minimizing lifecycle costs.

Interconnecting G.654.E to external networks – splicing considerations

Special attention is required when splicing G.654.E optical fibre with other fibre types, due to its distinct characteristics - particularly its large mode field diameter (MFD). Following industry best practices for fusion splicing and OTDR-based splice loss measurements, as outlined in the Europacable Technical Newsletter: OTDR Principle and Good Practices (October 2023), two splicing scenarios were evaluated:

1) G.654.E to G.654.E
2) G.654.E to G.652.D

Scenario 1: splicing with a standard fusion splicer in auto-mode

Tests were conducted using a standard core-alignment fusion splicer in automatic, or "default" mode. Splice loss measurements were carried out using bidirectional OTDR, and the final results represent the average of both directions.

G.654.E to G.654.E (Pure Advance™-125)
This configuration yielded excellent splice compatibility, as expected when connecting identical fibre types. The average splice loss was measured at 0.019 dB, with a standard deviation of 0.011 dB – well within industry limits.

Splices	G.654.E ↔ G.654.E		
Attenuation	**Loss**	**Apparent gain**	**Average loss**
Average (dB)	0.086	-0.048	**0.019**

Fig. 13 – G.654.E/G.654.E splices

G.654.E (MFD ≈ 12.4 µm) to G.652.D (MFD ≈ 10.4 µm)

Despite the substantial MFD mismatch, the splicing results were still within acceptable levels. The measured average splice loss was 0.163 dB, with a standard deviation of 0.010 dB.

Splices		G.654.E ↔ G.652.D	
Attenuation	**Loss**	**Apparent gain**	**Average loss**
Average (dB)	1.76	-1.434	**0.163**

Fig. 14 – G.654.E/G.652.D splices

Scenario 2: splicing with a G.654.E optimised fusion splicer

Splicing performance, particularly for mismatched MFD scenarios, can be significantly improved using fusion splicers equipped with G.654.E specific splicing software and advanced core-alignment algorithms.

Modern splicers, such as the Sumitomo Electric TYPE-72C+, feature automatic fibre recognition and dedicated G.654 splicing programs. These tools enable highly precise alignment and consistent splice quality, even with specialty fibres.

- **For G.654.E to G.654.E,** such splicers can achieve typical splice losses as low as 0.01 dB, comparable to G.652.D-to-G.652.D connections.
- **For G.654.E-to-G.652.D,** the splice loss is slightly higher due to the intrinsic MFD mismatch, but remains within acceptable design limits for coherent transmission systems.

		G.652.D–G.652.D	G.654.E–G.654.E	G.652.D–G.654.E
MFD at 1,550 nm		10.4 µm - 10.4 µm	12.4 µm - 12.4 µm	10.4 µm - 12.4 µm
Typical splice losses at 1,550 nm	Standard splicer "auto" mode	0.010 dB	0.019 dB	0.163 dB
	Latest splicer G.654.E featured	0.010 dB	**0.010 dB**	**0.110 dB**

System-Level Impact of G.652.D–G.654.E Splice Loss

In a typical long-haul deployment using G.654.E fibre, the vast majority of splices occur between identical G.654.E cables such as within repeater spans, where fibre lengths can extend for several kilometres. Splices involving G.652.D generally occur only at the terminations of each span, such as:

- At the input/output interfaces of EDFA repeaters, or
- When connecting to patch cords or pigtails at equipment endpoints.

A representative power diagram across an 80 km repeater span (with cable segments of 4 km each) demonstrates that:

- The minor attenuation caused by the two G.652.D–G.654.E splices at either end is negligible in the context of the total span loss.
- The overall span attenuation using G.654.E remains significantly lower than what would be achieved with G.652.D fibre.

These splice losses were factored into the overall transmission performance simulations detailed in case studies 1–3 of this white paper.

In summary, while fibre-type mismatches can introduce small incremental splice losses, modern splicing tools and careful engineering design ensure that these do not materially affect the system performance of G.654.E-based optical networks. The benefits of G.654.E, particularly its ultra-low attenuation and high capacity, far outweigh the minor splice losses introduced at fibre transitions.

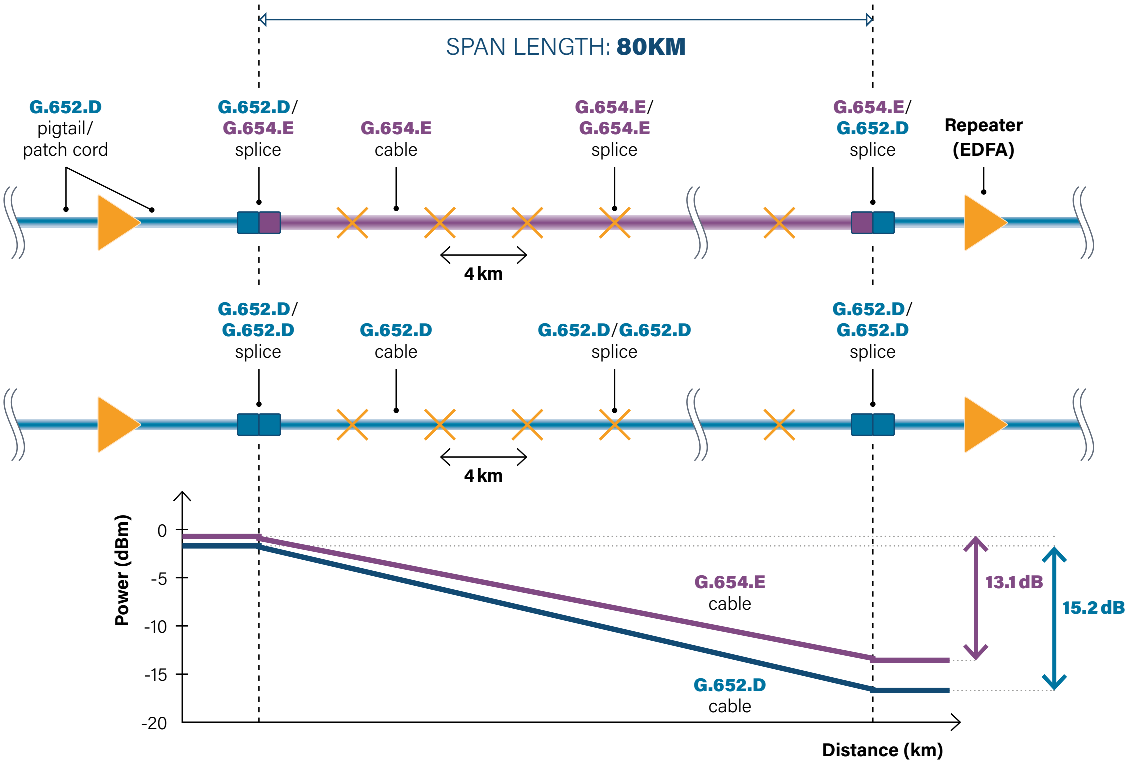


Fig. 15 – Overall splicing and cable losses for both G.652.D and G.654.E links

Coherent optical technology and G.654.E fibre: a high-performance, sustainable networking solution

Digital technologies are estimated to account for approximately 2–3% of global carbon emissions – a figure that is steadily rising. As digital infrastructure expands, it is essential to assess and adopt technologies through the lens of sustainability, with an emphasis on reducing environmental impact. Next generation solutions must demonstrate not only superior performance but also a significantly lower carbon footprint.

G.654.E fibre is a critical enabler of this transition. With its unique characteristics of ultra-low attenuation and a large effective area, it allows for higher optical signal-to-noise ratios (OSNR), enabling long-distance, high-capacity transmission with reduced need for amplification. By minimizing signal loss, G.654.E fibre reduces the number of amplifiers and regenerators required, directly lowering network energy consumption and operational complexity.

Compared to conventional fibres such as G.652.D or G.655, G.654.E supports significantly higher bit rates over longer distances. When combined with coherent optical transmission technologies and high-density transceivers, network efficiency is further enhanced. These technologies increase spectral efficiency - transmitting more data per wavelength, while also reducing power consumption and the physical footprint of network equipment

Coherent innovations have dramatically improved data throughput while lowering the energy and spatial requirements of high-speed optical transmission.[1]

This translates into a tangible reduction in the number of fibres, transceivers, amplifiers, and associated infrastructure required to achieve a given capacity. It also means lower consumption of raw materials and fewer emissions related to manufacturing, deployment, transport, and ongoing operation. Furthermore, fewer equipment sites and less cooling infrastructure are needed, reducing both capital and operational expenditures.

For greenfield deployments, especially in the context of growing bandwidth demand, the ability of G.654.E fibre to support longer distances between regeneration points allows for simplified network architecture. This minimizes the number of amplification/regeneration sites, reducing installation complexity and environmental impact.

Networks built with G.654.E fibre and coherent optics are inherently more scalable and adaptable to future increases in data traffic. This not only extends infrastructure lifespans but also minimizes the need for frequent equipment upgrades and the environmental toll of constructing new facilities.

1 Source: Ciena – Greener Networks Made Possible by Coherent Innovations

Conclusion

The amount of data generated globally is still in its infancy as data traffic continues to grow rapidly each year, driven by the proliferation of artificial intelligence (AI), cloud services, video streaming, and IoT. This exponential trend shows no signs of slowing. To accommodate rising bandwidth demands, equipment vendors are steadily increasing per-wavelength transmission rates. For metropolitan and long-haul networks, 800G coherent optical systems are already commercially available, although widespread deployment is still emerging. Looking ahead, next-generation technologies capable of 1.2 Tbps and 1.6 Tbps per wavelength are currently under development.

However, conventional G.652.D optical fibres are nearing their technical limits for high-capacity, long-distance transmission. Overcoming these limitations often requires additional optical amplification or signal regeneration, which drives up capital expenditures (CAPEX) and operating expenses (OPEX). In contrast, G.654.E fibres – designed with a larger mode field diameter (MFD) and ultra-low attenuation – significantly improve the optical signal-to-noise ratio (OSNR), making them ideally suited for advanced coherent transmission systems. This enables longer reach and higher data rates with fewer repeaters and regenerators, ultimately lowering cost per bit.

Given that fibre infrastructure is expected to remain in service for decades, hybrid cables that combine both G.652.D and G.654.E fibres offer a practical and future-proof solution. They enable operators to deploy cost-effective networks today, while ensuring scalability for next-generation high-bit-rate applications.

Contributors

Yoshinori Yamamoto
Sumitomo Electric Industries, Ltd.

Yoshinori Yamamoto joined the Optical Communications Laboratory at Sumitomo Electric Industries, Ltd., Japan, in 2002, where he was involved in the research and development of optical fibres, including ultra-low-loss fibres. Since 2018, he has been responsible for market development and engineering of optical fibres within the Optical Fiber and Cable Division at Sumitomo Electric.

Kevin Lenglé
ACOME Group

Kévin Lenglé, Ph.D., combines a master's degree in engineering from ENSSAT and a doctorate in physics with a strong background in ICT. His experience spans research at the French National Centre for Scientific Research (CNRS) and product line management within telecom equipment manufacturing. Since joining ACOME as France Marketing Manager in 2021, he leverages his ICT expertise in optics and telecommunications to drive the development and commercialization of sustainable optical cables.

SUMITOMO ELECTRIC
Connect with Innovation

ACOME GROUP