Accelerating worldwide connectivity across subsea networks

Comprehensive and differentiated solutions for end-to-end subsea-terrestrial networks

Subsea networks are the lifeline to global connectivity

Fiber optic networks provide the connectivity ubiquitous to modern society, enabling the flow of data needed for financial transactions, business critical traffic, national defense, entertainment and personal interactions across the globe. Optical fiber extends to homes, businesses and 5G radios in metro networks, connects cities within countries, and countries within continents. Subsea fiber cables spanning seas and oceans extend that connectivity between continents.

The massive data-carrying capacity of optical fiber has led to wide deployment of subsea fiber cables. Today over 570 in-service subsea cables carry >99% of all international traffic and connect data centers around the globe to deliver cloud-based and emerging AI services.

A massive global data center build-out is currently underway to driven by the compute needs of AI training and inferencing. These build-outs are being led by a range of AI and cloud providers, including hyperscale, neo-cloud and AI companies, all of whom are seeking to develop market-leading AI models and AI-based agents and applications that promise to transform work and society. These data centers will house ever-larger clusters of inter-connected xPUs, which serve as the engines for machine learning and AI training.

Modern AI training and large language models (LLMs) require a “scale-up” design, where thousands of xPUs function as a single logical unit, with the bandwidth needed to interconnect these xPU clusters soon exceeding 1 Pettabit per second; multiple orders or magnitude greater than the server-based internet traffic of traditional data centers. The interconnection bandwidths needed within a data center will explode this “scale up” bandwidth to connect xPUs within a rack or a pod, and also the “scale across” bandwidth to interconnect across many xPU racks in a data center. The need for greater data center interconnection (DCI) bandwidth across metro, regional and long-haul distances will also increase, as limits on maximum DC size and improvements in training protocols require, and enable, connectivity for AI training to be distributed across multiple DCs using “scale-across” architectures.

Beyond terrestrial DCI links, the roll-out of AI applications and cloud services delivered from data centers to global end-users will drive the need for more global subsea capacity and connectivity. Today fiber optic networks connect over 11,000 data centers worldwide, with over one thousand being hyperscale data centers. Combined these generate over one thousand petabytes per day of WAN traffic. Nokia Bell Labs is forecasting that global AI WAN traffic will add over 1,088 Exabytes/month of capacity by 2033, growing with a 24% CAGR, on top of continued growth in cloud-based services. In terms of annual bandwidth growth, this represents a continuation of the recent industry trend of approximately 30% per year growth in bandwidth transmitted over subsea cables.

Subsea networks will play an increasingly important role in extending the benefits and capabilities of AI and cloud services globally, enabling digital equity for economies and people around the planet. With new cables planned for deployment and capacity upgrades on existing cables, subsea networks will provide the critical fabric to connect data centers within regions and across the globe.

How are subsea fiber networks built?

The defining feature of all subsea fiber optic networks is their deployment along the sea floor, with all the attending constraints this imposes. Subsea cables can span tens or hundreds of kilometers, connecting between islands, along coasts, across channels, or to off-shore platforms used for oil exploration or wind farms, for example. They can also span thousands of kilometers, connecting continents and vast regions across seas and oceans.

Depending on the distances involved, optical amplification along the subsea cable is used to boost the signals being transmitted. Un-repeatered cables, typically no more than 500 km, can span a subsea link without any actively powered subsea amplification, while repeatered cables are used to span longer distances, over ten thousand kilometers in some cases. A repeatered cable utilizes specially designed Erbium-doped fiber amplifiers (EDFAs) that can operate on the sea floor, and are remotely powered via copper conductors that are co-packaged within the subsea cable. In some cases, cables may have underwater branching units that separate out the traffic to different directions, or tap off some portion for a local connection to land. The totality of all these subsea elements is often aptly called the “wet plant”.

Subsea fiber cables differ in multiple ways from their analogs in terrestrial networks. Firstly, subsea fiber cables require significantly greater mechanical protection, including armoured metal sheathing, to withstand the pressures of being buried on the sea floor, and to protect against possible damage from ship anchors or fishing nets. Due to the constraints imposed by this rugged design, subsea cables typically have 4 to 12 fiber pairs, compared to hundreds in terrestrial networks. More recently, higher fiber count cables are being deployed supporting 16 to 24, or more, fiber pairs, and these are often described as spatial division multiplexed (SDM) cables.

Finally, to maximize transmission performance over thousands of kilometers and optimize optical signal-to-noise ratio (OSNR), subsea optical amplifiers operate with a constant power output that assumes all wavelengths are active, and are also evenly spaced along subsea cables, typically every 60-80 kilometers in today’s modern cables. This contrasts with terrestrial networks where in-line amplifier (ILA) spacing can vary significantly, from 40 to 120 kilometers, influenced by the site and power availability of huts used to house ILAs, and terrestrial ILAs often leverage dynamic gain to adjust output power based on the number of active wavelengths in operation.

The traffic carried over a subsea cable passes through a cable landing station (CLS), where the subsea cable originates and terminates. These CLS house the optics and electronics needed to originate and terminate the subsea traffic, called the submarine line terminating equipment (SLTE). In many cases, subsea cables do not exist in isolation; the traffic they carry must reach its ultimate destination on land using a terrestrial fiber optic network, often termed a “backhaul” network. These terrestrial backhaul networks connect subsea traffic transiting through a CLS to a data center, point-of-presence (PoP), peering point, internet exchange (IX), or in the case of international traffic connecting across intermediate terrestrial crossings, back to another CLS.

What are the building blocks of an SLTE?

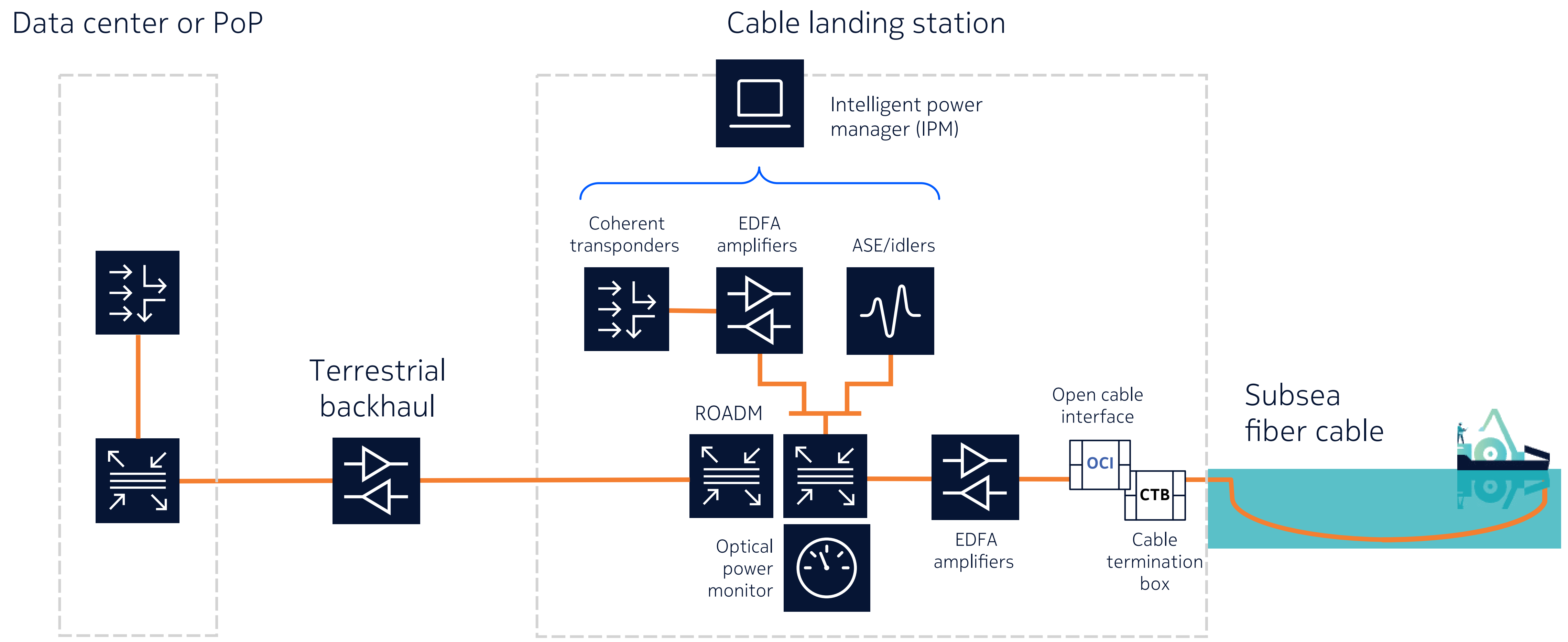
The transmission and detection of the signals sent over subsea cables originates on land. High-performance coherent optics in transponders aggregate the data traffic , with multiple transponders sending data in parallel on distinct wavelengths across the spectrum of the subsea fiber, typically in the C-band. Transponders can be deployed at a CLS site where the subsea fiber cable originates/terminates, or can be located at the end-points of the traffic demands, at a data center, PoP, or IX.

When the subsea traffic is terminated at the CLS, back-to-back connections are used to hand-off the subsea traffic from the SLTE transponders to additional transponders that then re-transmit the data over the terrestrial backhaul network. In contrast, when the transponders are deployed at the origination/termination points of the subsea traffic, typically a DC or PoP, the wavelengths are transparently passed through the SLTE at the CLS and directly into the subsea fiber cable.

In either case, the SLTE at the CLS includes a wavelength switching element such as a reconfigurable optical add/drop multiplexer (ROADM). The ROADM at the CLS, along with other specific features in the SLTE, play a critical role in enabling the key functionality needed for operation across subsea fibers. These include:

- Adding and dropping wavelengths to and from the subsea cable to their appropriate transponders, sometimes complemented by the use of channel mux/demux elements.
- Managing the spectrum allocation and use over the subsea fiber, which is an important aspect of spectrum sharing when two or more users operate wavelengths over fractional portions of the spectrum over the same subsea fiber pair.
- Ensuring protection of the subsea spectrum when a channel or spectrum block fails. In many cases this relies on the ROADM card having the capability to add amplified spontaneous emission (ASE) into portions of the subsea fiber spectrum, to replace missing or failed service wavelengths.
- Integrated optical channel monitor (OCM), often integrated with the ROADM, to provide high-resolution measurement and monitoring of the subsea spectrum, which assists in system optimization, turn-up and spectrum protection.

The transponders, ROADM, and other key optical functions at the SLTE combine to enable the unique features needed for subsea networks and the highest level of performance to maximize capacity across challenging trans-oceanic subsea fiber cables.



Optimized solutions for end-to-end subsea-terrestrial networks

Nokia's subsea solutions provide network operators with a complete set of features optimized for all subsea network applications and use cases.

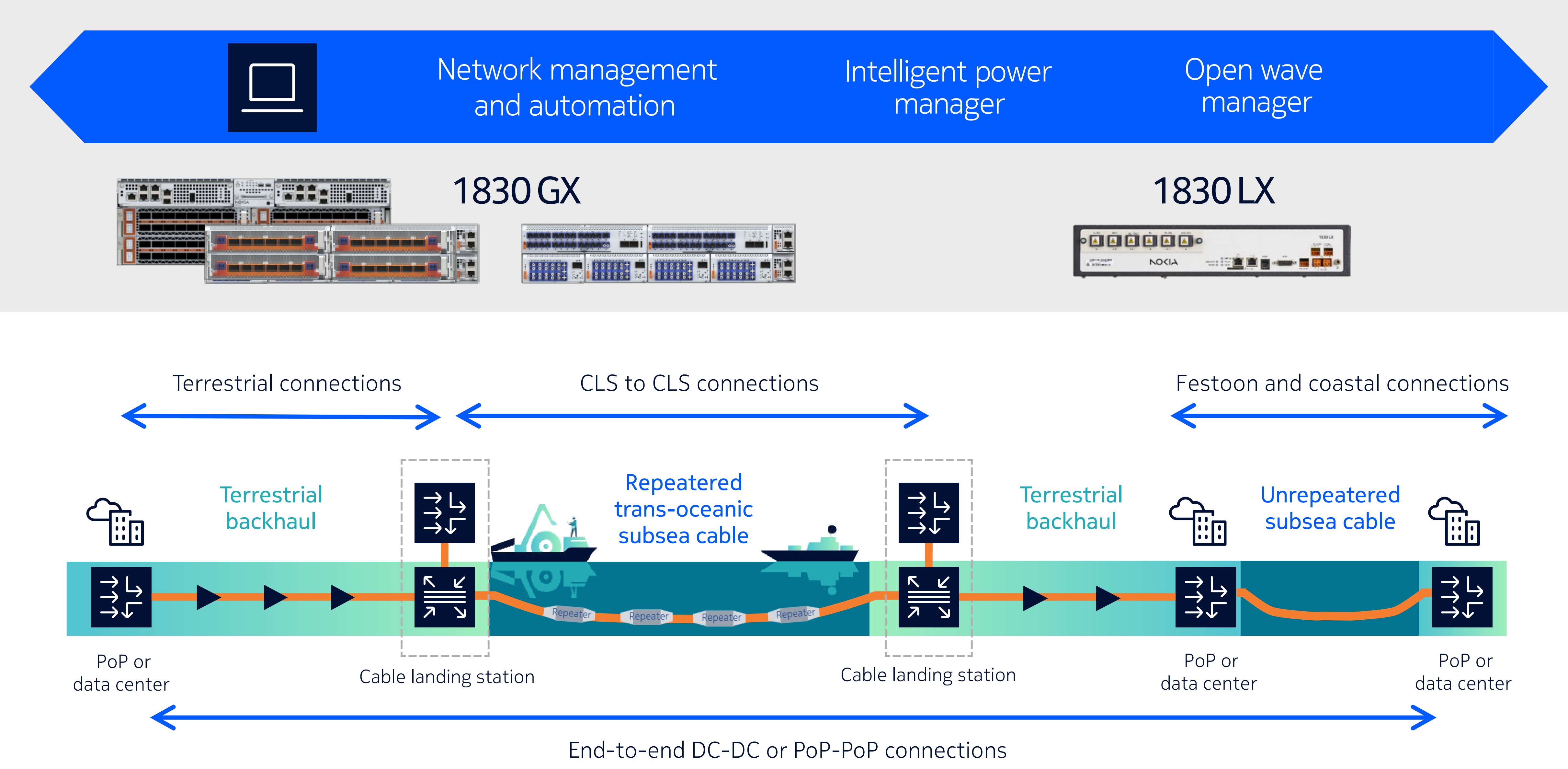
The 1830 Global Express (GX) compact modular DCI-optimized platform provides a complete solution for all subsea/SLTE and terrestrial backhaul network applications, enabling network operators to deploy a unified network end-to-end.

For transponder applications, the 1830 GX supports high-performance coherent optics operating at 140+ Gbaud and up to 1.2 Tb/s per wavelength, enabling trans-oceanic capacities of 800Gb/s to 1Tb/s per wavelength. Important features such as Probabilistic Constellation Shaping (PCS) up to 64QAM, Nyquist filtering and continuous baud rate adjustment enable network operators to maximize fiber capacity up to the Shannon Limit.

The 1830 GX Optical Line System (OLS) supports all the needed SLTE functions including ROADM-based wavelength switching and spectrum management, insertion of ASE spectrum or continuous-wave (CW) idler channels, an optical channel monitor and OTDR. For terrestrial backhaul networks, the 1830 GX OLS supports C+L operation to maximize capacity per fiber and reduce costs for leasing backhaul fiber capacity. Other options such as constant power mode ILAs support end-to-end DC-to-DC connections across unified subsea-terrestrial networks, while optional OTDR and 1+1 optical protection features address operators needs for fiber monitoring and fault localization, and service protection in case of fiber cuts or equipment failures.

The benefits of Nokia's unified end-to-end solution for subsea-terrestrial networks is complemented by the Open Wave Manager (OWM) tool to support the deployment and operation of 3rd-party coherent optics via an 1830 GX SLTE terminal.

The 1830 Link Xtender (LX) provides ultra-high power EDFA and Raman optical amplification options to close unrepeatered fiber spans up to 500 km. The 1830 LX can be used in conjunction with the 1830 GX and 1830 Photonic Service Switch (PSS) platforms to extend terrestrial network connectivity across channel crossings, for inter-island networks, coastal festoon links and to connect off-shore oil and gas platforms and windfarms.



Automation in subsea networks

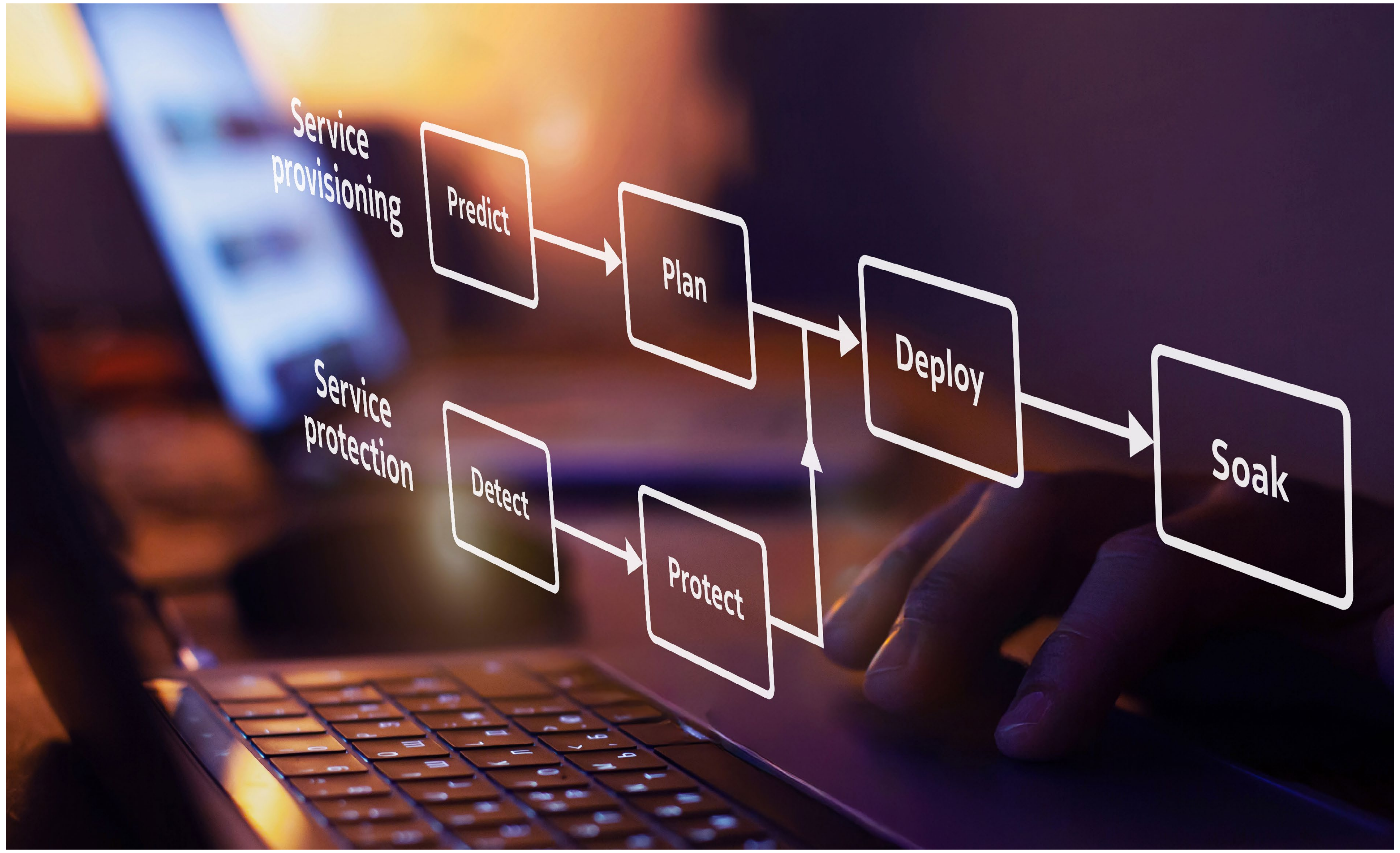
Nokia's network automation and management applications enable subsea network operators to rapidly deploy new subsea capacity, optimize their network, enhance network survivability, and simplify and automate a wide range of network operations to reduce the manual time and effort needed. These benefits are enabled through advanced methodologies and secure policies, and are complemented by support for open networking practices and standards using open APIs and data models.

Network automation can shorten the time to provision, configure and deploy new subsea capacity, using zero-touch commissioning tools to automate subsea channel optimization and service configuration, reduce the manual time and effort needed, and ensuring optimal performance and resource usage. Real-time planning and provisioning using intent-based service requests for layer 0 and layer 1 connections helps search for new routes while ensuring optical impairment validation and contention resolution, performs optical performance validation, and automates service provisioning and turn-up.

Network automation also coordinates and manages software-based optical restoration in case of network failures, by monitoring alarms and system/connection performance, performing fault isolation and impacted service analysis, and automatically searching for new routes while performing optical impairment validation, contention resolution and validating resource availability checks to re-provision impacted services across the network.

Using insights from network KPIs, Nokia's network management and automation applications enable real-time network optimization including performance and power consumption, allow operators to proactively plan and schedule maintenance activities, and quickly adapt to changing network demands and events to ensure maximum service availability.

Nokia's network automation solutions is complemented by the Intelligent Power Manager (IPM) suite of applications designed to simplify the day-to-day nodal and link operations of a submarine network. IPM works hand in hand with transponder and ROADM hardware to simplify and automate critical operational functions such as predicting fiber spectrum performance, spectrum planning, and transponder deployment and soak testing. In service protection scenarios, IPM works with SLTE hardware to detect optical power faults, protect the spectrum using ASE, assist in the redeployment of spectrum and capacity after a repair, automate soak testing before services are handed over, and automatically document the entire process in an editable format for ongoing spectrum maintenance.



Fiber sensing

Fiber network operators worldwide need to ensure the physical security of their networks to breakage. Despite being engineered and armoured to resist the rigors of installation on ocean floors, subsea fiber cables are also vulnerable to ship's anchors, bottom dragging fishing nets, and there is increasing concern about vulnerability to sabotage, via submarines or underwater drones. These vulnerabilities are not unique to subsea fibers, and also apply on terrestrial networks which can often be damaged or perturbed by construction, natural disasters and atmospheric events, amongst many examples.

Fortunately, optical fibers also make great sensors, and their expanse allows sensing across entire ocean crossings. The ability to leverage subsea fiber cables' sensing ability provides many areas of value-add for fiber network operators; such as advance warnings of possible threats or problems, error/failure detection and localization, proactive fiber protection, and even enabling the network operator to provide a societal good, such as early earthquake and tsunami detection and location, for example.

Nokia has been at the forefront of demonstrating innovative new sensing capabilities, derived from market-leading high-performance coherent DSP ASICs and research from Nokia Bell Labs (NBL). NBL's pioneering work applied machine learning (ML) to pattern detection of measured State-of-Polarization (SoP) data from coherent DSPs, to convert the sensed signals into recognizable event signatures.

Multiple network operators are now training their networks to recognize and categorize possible network disruptions, leveraging sensing applications in Nokia's WaveSuite automation suite.

Another area of sensing collaboration with subsea network operators has been demonstrating the ability of fiber networks to act as seismic monitors. Nokia's Subsea Sensing Unit (SSU) leverages the existing subsea cable infrastructure to sense and localize seismic and tidal events by comparing direct and reflected pulses from coherent optical channels and third-party subsea repeaters, which are then analyzed in real-time to display measured events.

Nokia Bell Labs is further pushing the boundaries of fiber sensing innovation and research, with the development of coherent optical frequency domain reflectometry (C-OFDR). C-OFDR uses a coherent, phase-based, frequency modulated signal to create a probe light that travels the length of the subsea fiber. Physical changes around the fiber due to a wide range of effects – earthquakes, swells, anchors, ships, and more – create changes to the fiber that cause changes to the backscatter signal, which is then processed back at its origin. This technique provides accurate localization and enables long term cable monitoring, and has been demonstrated in multiple field trials with both terrestrial and subsea network operators.

Network security

Securing everything with quantum-safe networks

The increasing ubiquity of network-delivered services for all aspects of personal interactions, business applications, financial transactions and more demands robust network security solutions that will protect in-flight data from physical intrusion and future quantum-based threats. As enterprises shift to cloud delivered services and implement AI applications delivered from data centers, there will be more potential vulnerabilities in optical transmission networks.

Threats to encryption, such as cryptographically relevant quantum computers (CRQC) and eavesdropping, can jeopardize network integrity. An approach that combines optical transmission with robust encryption standards such as 256-bit Advanced Encryption Standard (AES-256) with strong encryption keys having high entropy, leveraging classical physics- or quantum-based sources, will keep optical network data safe from threat actors.

Nokia Quantum-Safe Networks (QSN) mitigate these risks by incorporating defense-in-depth solutions with advanced symmetric cryptography and quantum-resistant high entropy random key sources to enable crypto-resilient optical transport networks. These features, powered by Nokia Bell Labs research and Nokia quantum partners, safeguard data against classical and quantum attacks, and ensure long-term security against harvest now, decrypt later decryption attempts in the future.

This comprehensive approach enables subsea network operators to build a resilient defense-in-depth framework across their end-to-end optical network, including subsea links and terrestrial backhaul networks. With application layers migrating towards post-quantum cryptography (PQC) algorithms in the future, the complimentary protection of QSN at the optical transport layer allows operators to safeguard their critical infrastructure against quantum threats to securely enable new applications and digital transformation, both today and in the future.

Future trends in subsea networks

The critical role played by subsea networks in connecting continents is only increasing with the expansion of cloud-based and AI services across the globe. The roll-out of AI applications delivered from data centers to global end-users will continue to drive an estimated 30% annual bandwidth growth over subsea cables. Given that deployment of a new subsea cable is highly capital intensive and may take several years between cable design and turn-up, overlaid with the need for ever-greater capacity per cable, means that vendors and operators are continually exploring new approaches to get more capacity from of their subsea networks. Operators are also increasingly focusing on issues such as rack space and footprint and power consumption for SLTE equipment needed at either cable landing stations or data centers, both of which drive operational costs. These industry dynamics and cost pressures for operators are leading to exciting new technology developments in subsea networks.

One of these approaches focuses on increasing the number of physical paths contained within a trans-oceanic subsea cable. This technique is referred to as Spatial Division Multiplexing (SDM), and is the spatial equivalent of Wavelength Division Multiplexing, which increases fiber capacity by transmitting multiple data channels, each on a different wavelength, in parallel over a single fiber. The application of SDM to increase the capacity of subsea cables is happening along two different and complementary paths. The first involves increasing the number of fibers that are bundled together in a single cable, using a combination of smaller outer diameter fibers and more advanced cable designs. This enables an increase from the traditional 8-12 fibers per cable to 24 today, and up to 48 fibers in the future. The second approach uses multi-core fibers, where each fiber has more than one core that can carry separate data streams, with 2-core fibers already in deployment. Combined, these approaches will enable a four-fold or greater increase in capacity per cable and reduce the cost per bit for new subsea cables.

Another area of investigation in subsea cables is to increase the available WDM spectrum of each optical fiber to transmit more wavelengths in a given fiber. This approach is already widely utilized in terrestrial networks that expand WDM operation across the L-band of the fiber,

and has enabled a doubling of capacity per fiber, or even a 2.5x increase using Super-L band. Since operation in the L-band also utilizes Erbium-Doped Fiber Amplifiers for in-line amplification, the use of L-band spectrum in future repeatered subsea cables can adapt well-established technology from land-based networks for reliable submarine use.

Today's trans-oceanic fiber cables can operate at 800Gb/s per wavelengths across 24 fibers to deliver enormous bandwidth, of 500Tb/s or more per cable. With advances in SDM and L-band technologies enabling a further tenfold or greater increase, subsea network operators will be increasingly challenged to support the rack space and power needed to terminate all this subsea traffic, especially at cable landing stations where both of these are often constrained.

Fortunately rack space and power can be reduced significantly using pluggable coherent optics, which are inherently designed to consume less power per bit than embedded optics. Continued advances in silicon IC node geometries has enabled coherent DSPs used in pluggable optics to pack ever-more features and performance to increase the capacity-reach of pluggable coherent optics, while requiring less space and power. Thus operators are starting to leverage pluggable coherent optics in repeatered subsea cable applications. For example Nokia's ICE-X 800G ZR+ pluggable coherent optics are being used to connect regional subsea cables spanning distances of several thousands of kilometers, with future advances expected to support operation over trans-Atlantic subsea cables.

At Nokia, we are driving the evolution of optical networks into new frontiers, to help you build networks that are ready for tomorrow's bandwidth demands. With extensive experience deploying some of the world's longest subsea cable networks, combined with a history of technical innovation in optical transport technologies, Nokia will continue to provide the scale, performance and efficiency needed for the evolution of subsea fiber networks.

Contact our sales team or visit our website to learn more about how Nokia can help you to evolve your subsea networks with a market-leading and proven portfolio of subsea-optimized optical networking solutions.

Nokia OYJ
Karakaari 7
02610 Espoo
Finland

Tel. +358 (0) 10 44 88 000

CID: 215251 (December)

nokia.com

About Nokia

Nokia is a global leader in connectivity for the AI era. With expertise across fixed, mobile, and transport networks, we're advancing connectivity to secure a brighter world.