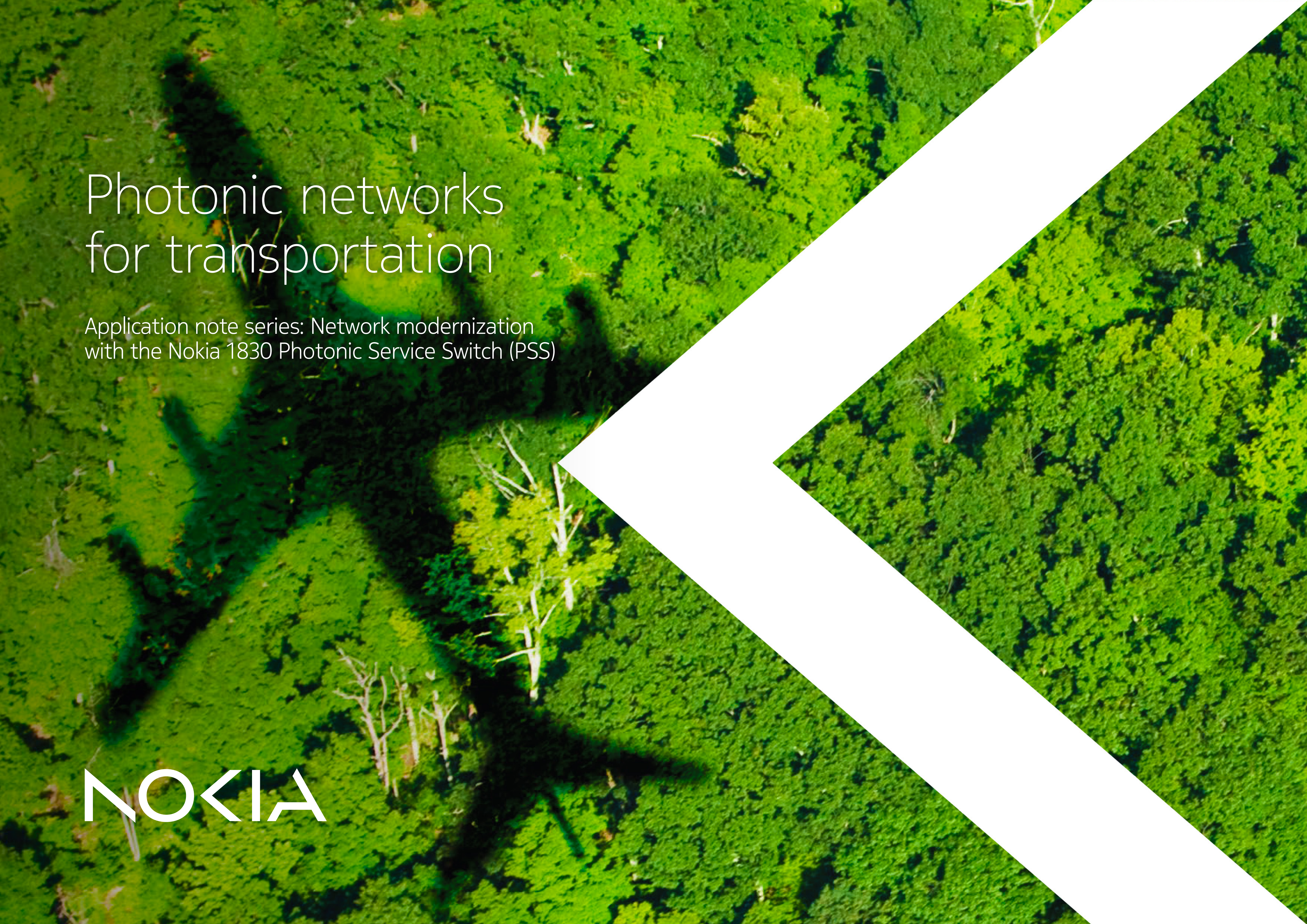


Photonic networks for transportation

Application note series: Network modernization with the Nokia 1830 Photonic Service Switch (PSS)

Abstract

Transportation systems link people to their daily lives and business to its daily operations, providing the basis for a functioning society. Road, railway, air and maritime transportation systems all can benefit from adoption of Intelligent Transportation Systems (ITS) that monitor and control traffic flow through connected devices in a transportation Internet of Things (IoT). ITS yields public benefit through improved safety, reduced energy consumption, increased economic output and better quality of life.

Photonic transmission provides the foundation for a modernized network that securely connects elements of the ITS, field offices, public safety agencies and data centers. It provides the backbone for mobile, wireless and fixed IP networks, supporting smart city transportation and other initiatives that move people and commerce.

This application note outlines photonic layer requirements and highlights the Nokia 1830 Photonic Service Switch (PSS) as a foundation for ITS initiatives.

Contents

Turning the wheels of 21st century society

Roadways, railways, airways and maritime transportation provide the means for people and businesses to go about their daily routines and operations. Transportation systems have evolved with technology, giving people greater mobility between where they work and live, and giving businesses greater ability to access raw materials, exchange goods and reach wider markets.

The 20th century featured the rise of aviation and the automobile while rail and maritime saw roles shifting toward freight transport in North America and mass transit in Europe and Asia. Yet the modern age brings new challenges as these systems keep pace with increasing urban populations, widely dispersed manufacturing, escalating energy costs and concerns about greenhouse gas emissions.

Increased processing power and electronics integration has led to wider availability of machine-to-machine (M2M) computing devices. These devices offer the promise of utilizing very large numbers of sensors and actuators, connected through an IoT, supporting any mode of public transport. Wide scale deployment of such devices into a roadway ITS, for example, could improve roadway traffic management, automatic toll collection, integrated public safety and public works communications, and could even supervise autonomous vehicles. All of these applications would yield improvements in safety, traffic flow, incident management, maintenance avoidance, energy consumption and citizen quality of life.

Similar systems could be implemented for railway, air traffic and maritime port control. Together, these integrated ITS will improve regional sustainability and economic development.

Construction of an ITS requires a means to reliably connect multiple applications, including the transportation IoT, related operational facilities, multimedia, video and data centers through a flexible, highly scalable and secure networking foundation: a fiber optic photonic backbone. The network should be highly scalable, allowing for current and future capacity needs. It also should be capable of providing connectivity for embedded, legacy systems that may continue in operation for years. At the same time, the network must be capable of connecting future applications and systems.

Lastly, the network must be highly secure. In a dangerous world, transportation systems must be safe from interruption and able to recover quickly from any unforeseen disaster.

Requirements: Moving toward a packet optical network

Building transportation infrastructure that delivers on the ITS promise requires a modernized, scalable, agile network that supports existing transportation communications and control systems. Modernization cannot occur in a single step; older systems are replaced over time, with gradual upgrades. Throughout the modernization process, the network must be highly reliable and secure to ensure continuity of transportation system operation.

To deliver on the promise of ITS, a transportation communications network must consider the following requirements.

- **Flexibility and scalability:** Application-specific networks are no longer viable in an environment where needs change rapidly and resources are limited. For example, a transportation network may need to simultaneously support video protection of a toll station as well as higway monitoring telemetry, public safety and voice traffic. As a region increases its utilization of technology for ITS and transportation, networks need to scale in capacity while being flexible enough to support any type of data protocol, including Ethernet, IP, TDM, video, Fibre Channel and others.
- **Reliability:** Especially in ITS deployments, the network must be highly resilient to ensure safety and continuity of critical transportation infrastructure. Networks must be built using equipment designed for high availability, utilizing redundant systems and automatic protection mechanisms. The network also should utilize diverse connectivity paths and a rich set of diagnostics to predict and prevent outages before they occur.
- **Security:** As essential infrastructure, transportation communications networks must be protected from intrusion and data theft that could lead to disruption of road, rail, air or maritime travel.
- **Network traffic segregation and multitenancy:** Using a shared physical network for multiple applications requires measures to segregate different network traffic streams. The transportation network backbone will likely be shared among several user classes and other government agencies as well as public or commercial applications. This implies a need for logical network segregation.
- **Deterministic performance:** The network should assign priority to critical applications, ensuring availability during peak traffic periods. For example, train control application and emergency communications should be assigned a higher priority than passenger information, such that if total demand exceeds available bandwidth, only the lower priority traffic is temporarily impacted.
- **Ease of use:** The network must be easy to provision, operate and maintain. Software control should extend across network elements, reducing the need for physical hardware changes and allowing remote provisioning.
- **Long asset life:** Transportation infrastructure budgeting typically requires that capital assets be depreciated over long periods. A modern network must support technologies from at least 15 years ago and for decades into the future. This implies use of a modular and extensible architecture, allowing older technologies to be easily maintained or phased out while new technologies are gradually introduced.
- **Economically attractive:** All of the previous requirements must be met with a high degree of economy, balancing initial capital expense with ongoing operational expense. Use of common platforms for multiple applications and a high degree of software control are desirable, as are modular equipment architectures and common software control.

Photonics in the modern transportation communications network

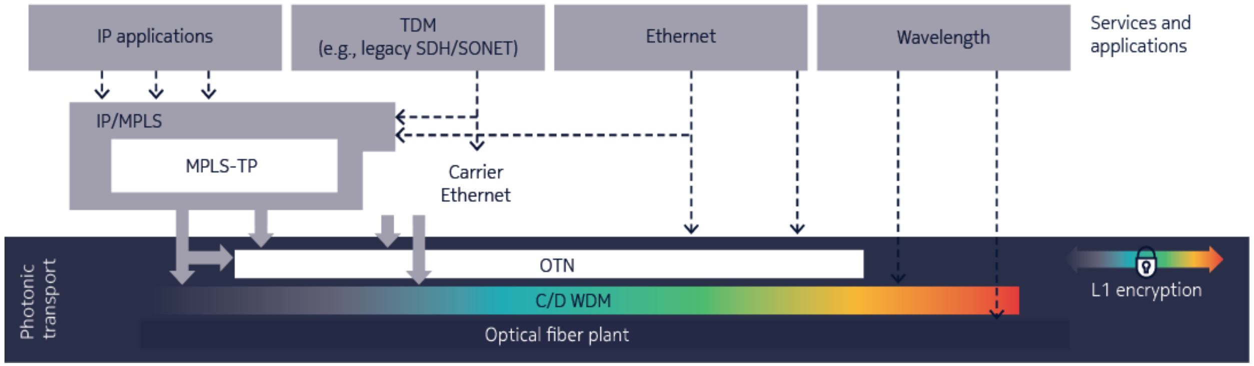
Meeting the requirements outlined in the previous chapter demands a network that makes use of moderntechnologies. Packet optical transport (P-OT) combines the efficiency and flexibility of packet services with the scalability, reliability and determinism of optical transport. P-OT usually includes technologies such as:

- Wavelength division multiplexing (WDM)
- Synchronous Digital Hierarchy/Synchronous Optical Network (SDH/SONET)
- ITU-T G.709 optical transport network (OTN)
- MEF 2.0 Carrier Ethernet
- Multiprotocol Label Switching – Transport Profile (MPLS-TP).

Each technology offers different benefits to the transportation network; the exact architectural choice depends on specific applications and objectives. Optical transport technologies are discussed in this application note. Packet technologies, such as Carrier Ethernet, provider Ethernet bridging and MPLS - TP, are outlined in future application notes within this series.

Together, photonic layer transport, switching and routing technologies provide connectivity for applications and services that accomplish a given task. Figure 1 shows these technologies positioned roughly within the Open Systems Interconnection (OSI) reference model and shows their chief interdependencies.

Figure 1. Optical transport ecosystem



Photonic layer

At the photonic layer, fiber is used to build the physical communications network that connects offices, data centers, operational applications, sensors, closed circuit television (CCTV) cameras, sensors and controllers. This may be accomplished through a combination of privately owned outside fiber plant complemented with leased dark fiber. Fiber is terminated by organization-owned or leased equipment. Capacity can be scaled easily using coarse or dense wavelength division multiplexing (CWDM/DWDM) systems.

In optical WDM systems, each fiber can carry at least 96 wavelengths, each delivering traffic at speeds exceeding 200 Gb/s or greater. Individual wavelengths can be dropped or added around the network and reconfigured as needed. In some applications, individual wavelengths provide logical separation between user groups carried along the same fiber.

In addition to pure capacity, optical WDM can transport data over a wide range of distances, from very short spans within a data center to undersea cables connecting continents.

SDH/SONET and OTN

Optical wavelength capacity is usually shared among applications and users through various multiplexing and switching technologies. SDH/SONET is a TDM method that was widely used to share capacity, deliver circuit-based services and ensure high reliability. As networks are upgraded, they must efficiently carry both circuit-based TDM services and packet-based services.

Interestingly, technologies have emerged to emulate circuit services over packet networks, essentially reversing roles. Standards for this emulation include Circuit Emulation Service over Ethernet (CESoE) and Transparent SONET over Packet (TSoP).

SDH/SONET was developed in the 1980s to transport increasing volumes of voice traffic over fiber. Data rates were set based on fixed increments of voice channels plus signaling overhead. Exponential increases in demand for packet data were not part of the design.

In 2001, the ITU-T offered standards that define an OTN in G.872, later refined in G.709 and G.798.

OTN evolves optical networks beyond TDM transport and reduces the complexity associated with scaling capacity and service diversity. OTN is often called a digital wrapper technique because any client protocol, including packet or TDM, is placed into a flexible container as a payload for transmission over an optical channel. Because the entire client signal is carried as payload, OTN is transparent to the end application.

OTN also provides a much stronger forward error correction (FEC) mechanism through use of a Reed- Solomon 16-byte scheme, resulting in significant improvements in optical link signal-to-noise ratio. This improvement is very valuable as data rates or span lengths increase.

OTN places no restrictions on switching line rates; as the industry advances, higher bit rates (i.e., higher capacity optical transmissions units/optical data units [OTU/ODU]) can be added to the standards, providing broad scalability.

OTN also offers comprehensive operations, administration and maintenance (OAM) capability.

Table 1 shows a comparison of SDH/SONET and OTN. As legacy TDM technologies reach end of life, OTN is likely to remain as a core network transport mechanism.

Migration from an SDH/SONET network toward OTN is not done solely to increase capacity. OTN offers scalability plus the ability to transport any protocol, including packet-based traffic such as IP/MPLS or Ethernet. Virtually any application can be encapsulated into an OTN payload container for transport.

To ensure data integrity, client traffic from different end applications or user sets can be segregated from other traffic through provisioning onto separate optical payload units. Aggregated traffic can then be encrypted for further security. For a transportation network, the decision to upgrade from an SDH/SONET network should be driven by overall capabilities and expected future services.

Table 1. SONET/SDH and OTN comparison

Feature	SONET/SDH	OTN
Timing distribution	Tight timing distribution **required** to recover data at terminals	**Not required**
Protocol transparency	**Not transparent**: Designed for TDM voice transport. Synchronous payload mapping, fixed frame size per line rate require external framing hardware for transport of some protocols.	**Transparent**: Asynchronous mapping of client signals and matching frame and client rates allows transport of any protocol.
OAMP capabilities	**Strong**	**Strong**
Forward Error Correction (FEC)	**Limited**: In-band frame checks at certain rates.	**Strong**: HD or SD-FEC through out-of-band 16-byte interleaved scheme.
Line rate limit	Standards ceased at OC-768; **40 Gb/s**	**Essentially unlimited**: Currently standardized to 112 Gb/s (OTU4) but capable of higher scale.
Sub-wavelength grooming	**Not capable**	Designed to map various clients into Optical Data Units (ODUs), **maximizing wavelength utilization**.

Security and encryption

Ensuring data integrity is essential to communications supporting vital transportation infrastructure such as railways, roadways or airports; networks must be safe from data theft and intrusion. Data must be protected while at rest in a data center, and contained with storage media or in-flight across a network. Protecting data in-flight requires layers of control working together using a "defense in depth" approach. The network operator may decide to utilize encryption at one or multiple layers, employing methods such as IPSec, MACsec, MPLS network group encryption (NGE) or optical encryption.

Security measures at the optical layer protect higher layer applications within a wavelength, multiple wavelengths or an entire fiber cable. Security measures should include:

- **Optical encryption:** Utilization of the AES-256 cipher across optical links.
- **Centralized key management:** A symmetric key management authority that ensures 256-bit key strength while controlling key rotation, expiration and destruction.
- **Optical intrusion detection:** Methods to monitor minute changes in received optical power levels, which could indicate tampering along a fiber span.
- **User authentication and network element control:** Multiple levels of user classes with robust password protection.
- **Independent certification:** Solutions should be certified by independent entities for compliance with relevant standards, including NIST FIPS 140-2 and common criteria (CC).

Layer 1 encryption, creates cipher text at the physical layer. This could include electrical, optical or RF signals prior to transmission across their respective media. Layer 1 encryption offers several advantages, including:

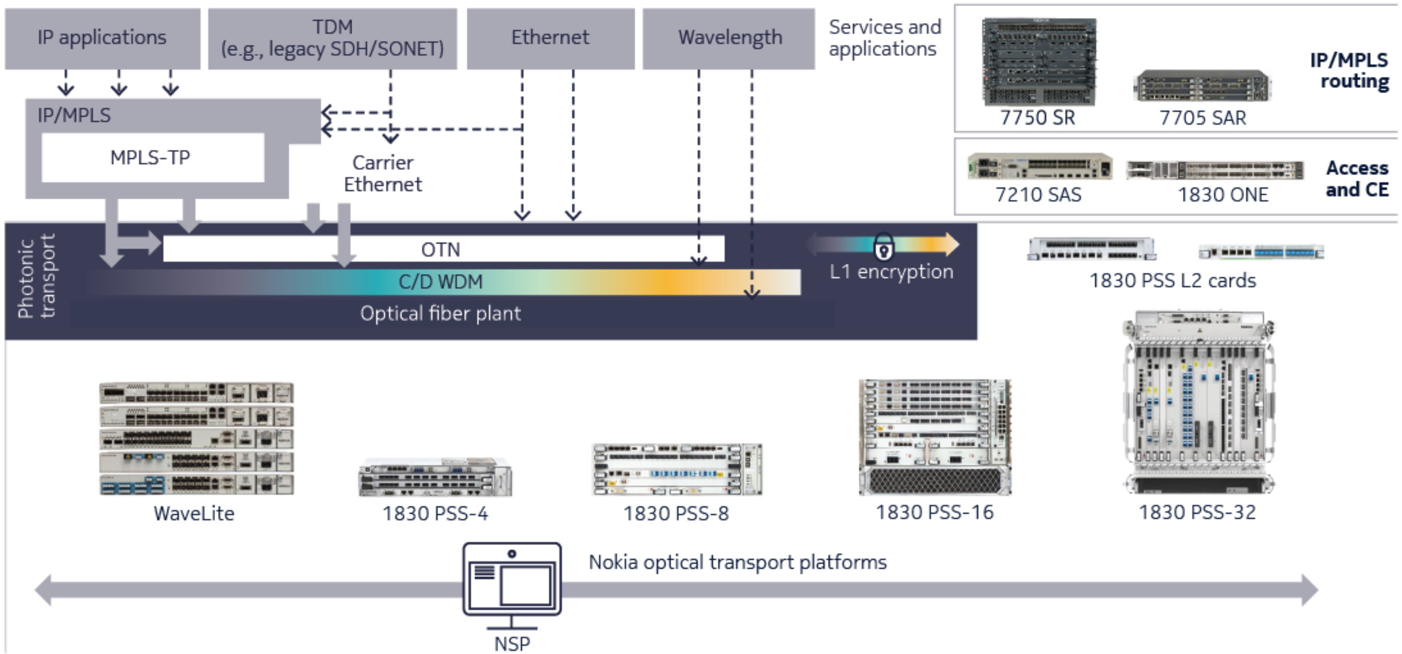
- **Span security:** Physical layer encryption offers protection from data theft across any span outside immediate operator control. It can serve as a final protection for all traffic on a fiber after the traffic leaves a controlled environment. Layer 1 encryption also conceals activity between application users because activity is encoded within the cipher text.
- **Low latency:** Encrypting aggregate signals composed of multiple, lower rate clients yields lower latency and delay variation (jitter) compared to individually encrypting multiple applications at the IP layer.
- **High bandwidth utilization:** Optical encryption utilizing OTN allows for maximum throughput at a given line rate. For example, at the OTU2e (11 Gb/s) rate, a full payload of 10, 1 GE encrypted clients are transported in the ODU2 payload. Similarly, ten 10GE clients may be securely transported in an ODU4 payload.
- **Protocol transparency:** Any combination of client types can be encapsulated in the ODU and encrypted for transport. This transparency reduces the need for planning, purchasing and managing multiple appliance types from multiple vendors.
- **Cost efficiency:** Optical encryption is inherently simpler and yields the lowest cost per encrypted bit because of all the factors listed here.

Nokia modernized photonic transport solution

A modernized photonic network provides a foundation for any application or service needed for transportation infrastructure. It includes a scalable P-OT network that can support any traffic type, including IP/MPLS, Ethernet or legacy TDM. This foundation utilizes OTN encapsulation and switching and has native support of packet transport methods such as Ethernet provider bridging, MPLS-TP or Carrier Ethernet as well as TDM transport capabilities. The network should also be safe from theft or intrusion through certified Layer 1 encryption with centralized, symmetric key management.

The Nokia 1830 Photonic Service Switch (PSS) offers capabilities exceeding the requirements of a modern photonic network. This includes a chassis sized to match network capacity needs, flexible modules for optical transponder, amplification and add-drop functions, packet switching and transport, and Layer 1 encryption. The 1830 PSS supports Layer 2 packet switching through integrated switching cards that support provider bridging, MPLS-TP and Carrier Ethernet service or through other Nokia products, such as the Nokia 7210 Service Access Switch (SAS).

Figure 2. Nokia portfolio in the transport ecosystem

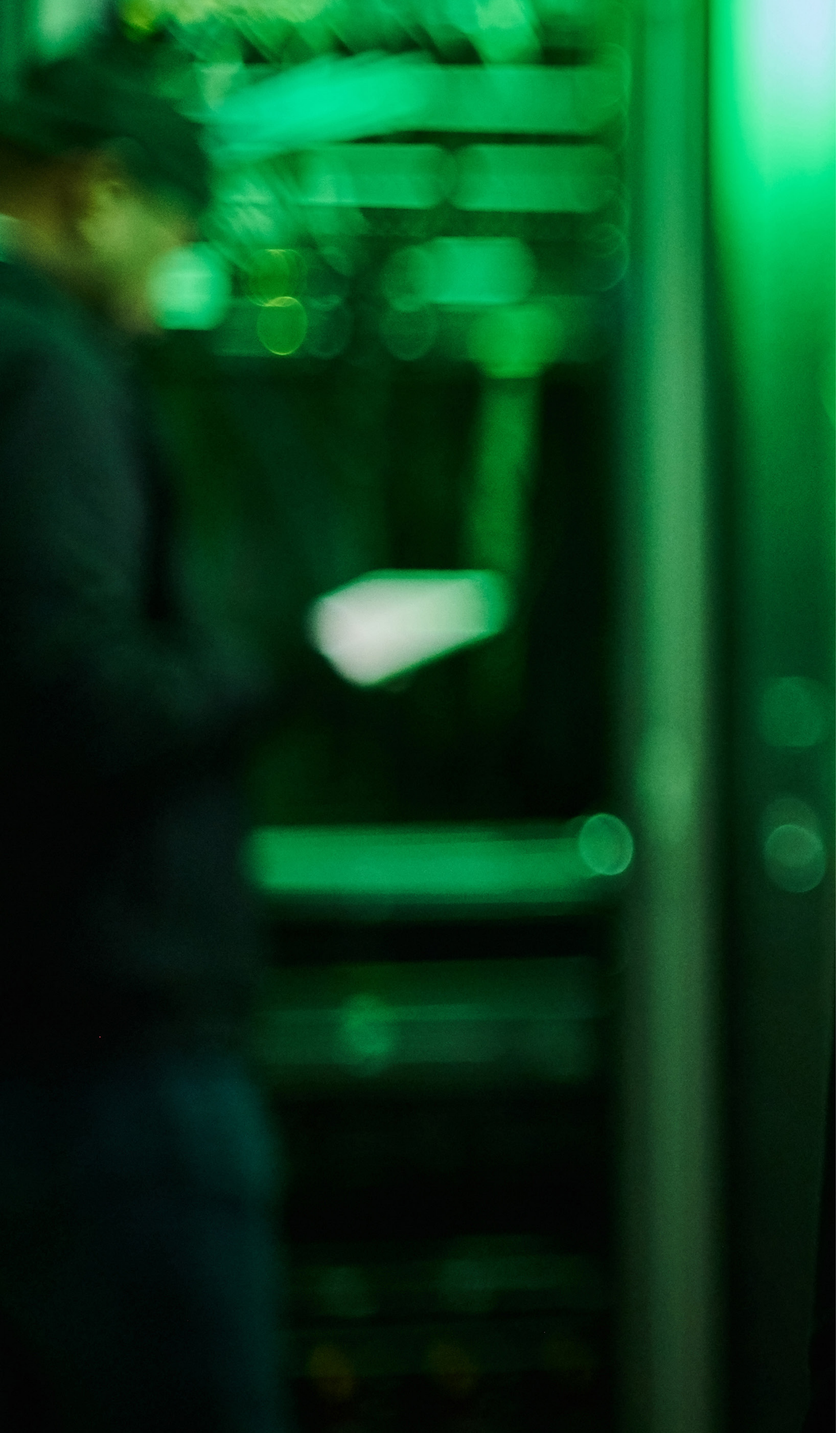


Legacy TDM services are supported by 1830 PSS interfaces. Additionally, these services are complemented by the IP/MPLS routing of the Nokia 7750 Service Router (SR) and Nokia 7705 Service Aggregation Router (SAR) product families.

Meeting the requirements for an agile and scalable network for transportation communications requires a range of technologies spanning optical transmission, Carrier Ethernet, IP/MPLS and softwaredefined networking (SDN). Nokia offers solutions based on decades of experience delivering advanced communications networks to transportation authorities, government, enterprises and service providers.

Leveraging Nokia Bell Labs as the innovation engine, Nokia solutions build dependable, scalable, yet flexible network infrastructure that bring together IP routing, optical transport and software.

Figure 2 shows the relevant products from the Nokia optical and IP portfolios that can be used to modernize transportation networks. Products can be selected to match needs based on service type, density, form factor and technology functionality.



Nokia 1830 PSS product family highlights

The Nokia 1830 PSS forms a flexible transport layer through its agile photonics, multi-layer switching capabilities and network intelligence. Using the Nokia Photonics Service Engine (PSE), the 1830 PSS is built on the first commercially available 100G coherent DWDM solution. It enables high scalability, easier operations, accelerated provisioning and reduced cost. The 1830 PSS employs distributed OTN switching and a range of interface cards that can be used across the different chassis types with few limitations.

Highlights of the 1830 PSS platform include:

- Chassis sized to match application needs, including data center interconnect (DCI), optical access/aggregation and an optical WAN backbone with capacities ranging from 240 Gb/s to beyond 8 Tb/s
- PSE super-coherent silicon technology provides the basis for software-controlled interface cards capable of optimizing span reach and data rate. The PSE adaptive modulation, variable baud rates, advanced soft decision FEC and optical super channels.
- Advanced P-OT interfaces, providing MEF 2.0 Carrier Ethernet and MPLS-TP capabilities, seamlessly operating with Nokia IP routing platforms through the Service Router Operating System (SROS)
- TDM migration options through Layer 2 packet interfaces, providing a flexible means to evolve toward packet services
- Optical encryption and security capabilities, including AES-256 encryption per wavelength and centralized, symmetric key management with key strength exceeding NIST and NSA recommendations, certified to FIPS 140-2, CC EAL and ANSSI standards.

As networks evolve, secure high-speed optical technology will be essential for the varied end applications supported. DCI, inter-office field connectivity, IoT connectivity, broadband backhaul and agency WAN are all best served through an agile optical backbone.

The Nokia 1830 PSS offers transportation systems the scalability, agility and efficiency to maximize value through an integrated optical backbone. With a feature set supporting SDH/SONET, Carrier Ethernet, storage area networks and other interfaces, plus OTN and packet switching capabilities, and optical encryption, the Nokia 1830 PSS is the premier optical backbone solution.

Conclusion

Transportation operators can enhance safety, reduce energy consumption, enable economic development and improve citizen quality of life through construction of intelligent transportation systems. Highly connected roadways, railways and airways make use of M2M computing through a transportation IoT that monitors and controls traffic in any transportation mode. These tools need communications networks that are agile to meet constantly changing service requirements, scalable to carry increasing capacity demand, and highly secure to protect vital infrastructure.

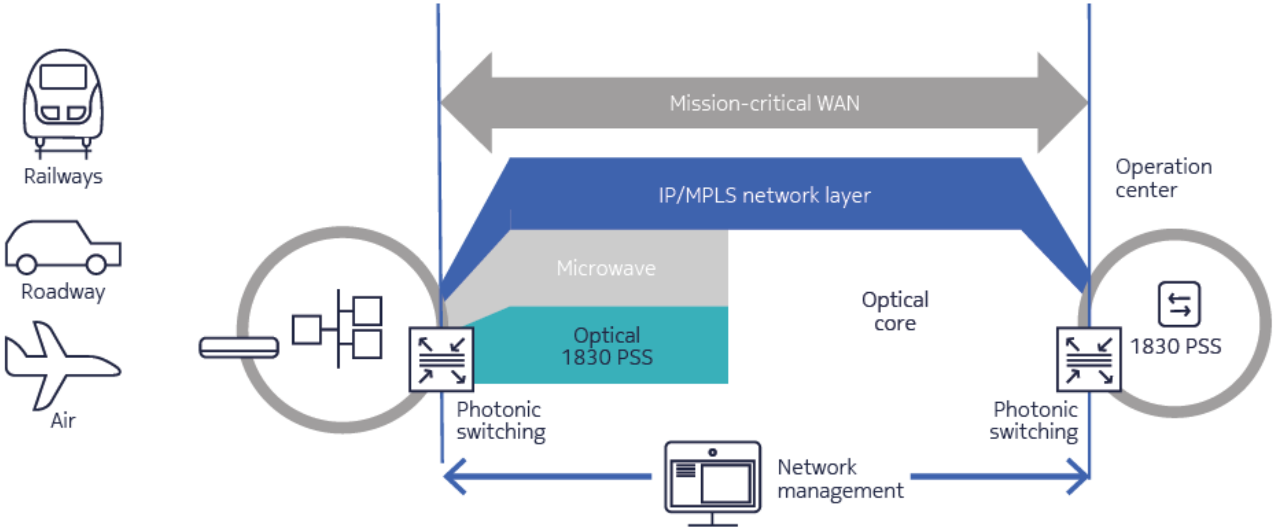
Figure 3 shows how this network could be built as a transportation mission-critical WAN, with the Nokia 1830 PSS forming an optical backbone that transports traffic from various applications.

This paper has provided context for several of these choices and the Nokia solutions that support them,specifically:

- Capacity scaling and continued capabilities for embedded traffic such as TDM services
- Migration toward a packet-optical transport core supporting Ethernet and IP traffic
- Protocol-agnostic photonic transport utilizing OTN
- Flexible Layer 2 architecture, capable of supporting multiple packet technologies
- Secure transport through Layer 1 optical encryption as part of a defense-in-depth strategy.

The Nokia product portfolio offers the industry's most complete set of options to meet modern transportation communications requirements. In addition, Nokia has the experience and pedigree from hundreds of successful mobile access and fixed backhaul projects supporting transportation operators over the past 30 years. The Nokia 1830 PSS offers the most powerful photonic transport solution to meet these needs. To learn more, visit our optical networking web site on nokia.com.

Figure 3. Transportation mission-critical WAN with the 1830 PSS



Acronyms

AES	Advanced Encryption Standard
CC	common criteria (security standards)
CC EAL	common criteria evaluation assurance level
CESoE	Circuit Emulation Service over Ethernet
CWDM	coarse wavelength division multiplexing
DCI	data center interconnect
DWDM	dense wavelength division multiplexing
FEC	forward error correction
FIPS	Federal Information Processing Standard
IoT	Internet of Things
IPSec	IP security
ITS	Intelligent Transportation System(s)
ITU-T	International Telecommunication Union – Standardization Sector
L1	Layer 1
L2	Layer 2
M2M	machine-to-machine
MACsec	media access control security
MEF	Metro Ethernet Forum
MPLS	Multiprotocol Label Switching
MPLS-TP	MPLS - Transport Profile
NIST	National Institute of Standards and Technology
NSA	National Security Agency
OAM&P	operations, administration, maintenance and provisioning
ODU	optical data unit
OTN	optical transport network/networking
PON	passive optical network
P-OT	packet-optical transport
PSE-2	Photonic Service Engine version 2
PSS	Photonic Service Switch
PTN	packet transport network
SAM	Service Aware Manager
SAR	Service Aggregation Router
SAS	Service Access Switch
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
SR	Service Router
TDM	time division multiplexing
TSoP	Transparent SONET over Packet
WAN	wide area network
WDM	wavelength division multiplexing

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At Nokia, we create technology that helps the world act together.

As a B2B technology innovation leader, we are pioneering networks that sense, think and act by leveraging our work across mobile, fixed and cloud networks. In addition, we create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

Service providers, enterprises and partners worldwide trust Nokia to deliver secure, reliable and sustainable networks today – and work with us to create the digital services and applications of the future.