Photonic transport networks for power utilities

Network modernization with the Nokia 1830 Photonic Service Switch (PSS)

Application note

Abstract

Utility communications networks face new challenges as capacity demands increase, new IP/packet-based grid applications are introduced and embedded technologies age. The continued evolution of smart grid systems is combining with increased requirements for facility surveillance, data center interconnect (DCI) and other corporate IT functions while continuing to support existing operational technologies, such as SCADA and teleprotection. These factors and the pressure to ensure service reliability while controlling costs are forcing utilities to invest in the modernization of communications networks. Many technology choices are available to evolve the communications transport network toward a highly agile, easily scalable and efficient asset that the utility can depend on for the next few decades.

This paper focuses on the photonic transport technologies and solutions of the Nokia 1830 Photonic Service Switch (PSS). Related papers discuss packet transport over the optical network and time division multiplexing (TDM) to packet migration strategies.

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Modernizing power utility communications

The power utility grid in most countries was constructed in the early to mid-20th century. Power generation was centrally located and powered by coal or oil. Power was transmitted over high-tension lines to substations that reduced voltage for distribution to energy consumers. In many places, decades passed with few upgrades to transmission or distribution facilities. Yet in the last 20 years, advances in power line transmission, communications, monitoring and control technologies have offered utilities the possibility of reducing wasted energy while improving service reliability, customer satisfaction and safety. The advent of broadband communications services also presents many utilities with the opportunity to utilize their unique right-of-way position to realize new revenues.

Communications infrastructure must help the utility deliver energy to its customers with greater efficiency and reliability. In doing so, utilities improve customer satisfaction and operational performance. The communications network needed in a modern utility is quite different from that of a few years ago. Most power utilities are adopting smart grid technologies to efficiently and remotely monitor, control and automate service delivery. Many utilities are converging corporate operations and IT networks into shared WAN infrastructures. Some are also delivering broadband services to their end customers. Each utility has a strategy to modernize its communications network, which requires an architecture that can support existing operations, ensure consistent service delivery and adopt new technologies. Taking the first step requires careful consideration of projected needs, embedded investment and available resources.

Requirements: Moving toward a packet optical network

The landscape of communications networks is rapidly changing as utilities deploy advanced grid control devices to improve energy efficiency and customer service while also reducing operational costs. These devices utilize different data protocols to communicate, yet need to operate across a common infrastructure. Modernization does not occur in a single step; older systems are replaced over time. The network must be capable of gradual upgrade, with ongoing support for older systems. At the same time, the network must be highly reliable and secure because it is the common foundation for the operation of the entire utility. The network is truly mission-critical.

A utility communications network must meet several requirements to deliver the promise of modernization. Specifically, it must offer:

- **Flexibility and scalability**: Application-specific networks are no longer viable in an environment where needs rapidly change, and resources are limited. For example, a utility network may need to support surveillance video as well as teleprotection, SCADA, advanced metering infrastructure and voice traffic. As utilities undertake grid modernization, 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**: For any utility application, the network must be highly resilient. 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 to a region's stability, power utilities must protect their networks from an intrusion that could lead to service outages and protect consumer information from theft.

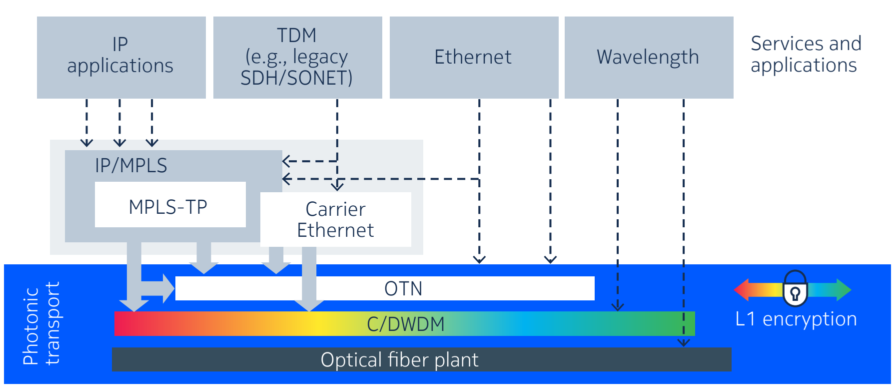
- **Deterministic performance**: The network should assign priority to critical applications to ensure availability during peak traffic periods. For example, teleprotection and surveillance video traffic should be assigned a higher priority than data center backup traffic, such that if total demand exceeds available bandwidth, only the lower priority data center backup 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**: Organizations require that capital assets be depreciated over relatively long time periods. A modernized network must support technologies from at least 15 years ago and for 10 years in the future. This implies use of a modular and extensible architecture, allowing older technologies to be easily maintained or phased out while new technologies such as software-defined networking (SDN) are gradually introduced.
- **Cost benefit**: All these 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.

Utilities are increasingly moving toward applications needing IP or Ethernet connectivity. As a result, the need for packet transport is also increasing. Yet at the same time, there is a persistent need for transport of TDM-based applications. Packet optical transport meets these needs while providing room for growth in the coming years.

Photonics in the modernized utility network

Meeting the requirements outlined above demands a network that makes use of modern technologies. Packet optical transport combines the efficiency and flexibility of packet services with the scalability, reliability and determinism of optical transport. Packet optical transport usually includes technologies such as WDM, SDH/SONET, G.709 OTN, MEF 2.0 Carrier Ethernet and MPLS-TP. Each offers benefit to the utility; the exact choice depends on specific applications and operator objectives. It is helpful to consider the major functions of each technology when making network design choices. Optical transport technologies are discussed below; packet technologies, such as Carrier Ethernet and MPLS-TP are outlined in other papers.

Figure 1. Optical transport ecosystem



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

Photonic layer

At the photonic layer, fiber is commonly used to build the physical network that connects utility offices, data centers and field operations. In a utility communications network, this may be accomplished through a privately owned outside fiber plant, and sometimes complemented with leased dark fiber, terminated by utility-owned equipment. Capacity can be scaled easily using coarse or dense wavelength division multiplexing (C/DWDM) systems. In optical WDM systems, each fiber can carry at least 96 wavelengths, each delivering traffic at speeds exceeding 400 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 multiplex 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 utilities upgrade their networks, they need the ability to efficiently carry both circuit-based TDM services and packet-based services. Technologies such as circuit emulation services over Ethernet (CESoE) and transparent SONET over packet (TSoP) emulate circuit services over packet networks, essentially reversing roles.

SDH/SONET was developed in the 1980s to transport increasing volumes of voice traffic over fiber, based on fixed increments of voice channels. By the early 2000's, the ITU-T had defined an Optical Transport Network (OTN) in which optical networks reduced the complexity associated with scaling capacity and service diversity. In OTN, any client protocol, including packet or TDM, is placed into a flexible container as a payload for transmission over an optical channel. As the entire client signal is carried as payload, OTN is transparent to the end application. Also, OTN 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., 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.

Table 1. SDH/SONET and OTN comparison

	SDH/SONET	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 requires external framing hardware for transport of some protocols.	Transparent: Asynchronous mapping of client signals and matching frame and client rates allow transport of any protocol.
OAMP capabilities	Strong	Strong
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 ODUs, maximizing wavelength utilization

Migration from an SDH/SONET network toward an OTN transport network is not done solely for reasons of increasing capacity. OTN offers scale plus the ability to transport any protocol including packet-based services such as IP, multiprotocol label switching (MPLS) or Ethernet. Virtually any application can be encapsulated into an OTN payload container for transport. These capabilities enable the utility to cleanly manage and maintain separation among internal applications, such as corporate IT and operational functions.

Security and encryption

Ensuring data integrity is essential to utility communications; networks must be safe from data theft and intrusion. Data must be protected while at rest in a data center, contained within storage media or in-flight across a network. Protecting data in-flight requires layers of control working together using a “defense in depth” approach. A utility may decide to utilize encryption at one or multiple layers, employing methods such as IPsec, MACsec, MPLS network group encryption (NGE) or Layer 1 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**: Application of AES 256-bit cipher prior to transmission
- **Centralized key management**: A symmetric key management system that ensures 256-bit key strength while controlling key rotation, expiration and destruction
- **Optical path monitoring**: 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 FIPS 140-2 and common criteria (CC).

Layer 1 encryption, as the name implies, 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 that are desirable as part of a comprehensive security strategy. The main advantages of Layer 1 encryption are:

- **Span security**: Physical layer encryption offers protection from data theft as traffic transits across any span outside of immediate operator control. It can serve as a final protection for all traffic on a fiber after it leaves a controlled environment. Layer 1 encryption also conceals activity between application users as activity is encoded within the cipher text.
- **Low latency**: Encrypting aggregate signals composed of multiple and lower rate clients yields lower latency and delay variation (jitter). This performance is vastly better than that incurred when 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 ten 1 GigE encrypted clients are transported in the ODU2 payload.
- **Protocol transparency**: Almost any client type or 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.

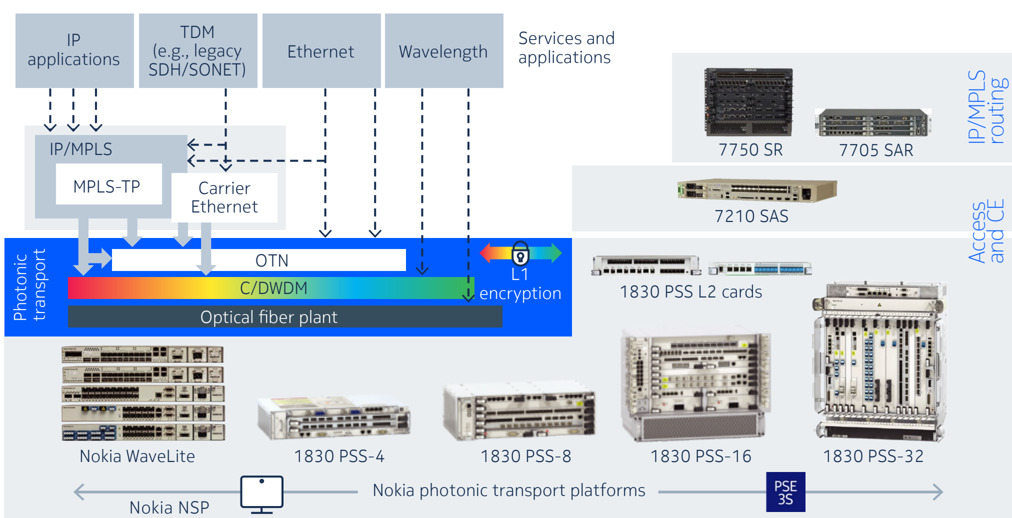
Modernized photonic transport solution

A modernized photonic transport network provides a foundation for any application or service needed for utility operations and corporate IT support. It includes a scalable packet optical transport 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 MPLS-TP or Carrier Ethernet and TDM. The network should also be safe from theft or intrusion through certified Layer 1 encryption with centralized, symmetric key management.

The Nokia 1830 PSS offers capabilities exceeding the requirements of a modernized utility transport 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 supporting MPLS-TP and Carrier Ethernet or through other Nokia products such as the Nokia 7210 Service Access Switch (SAS). Legacy TDM services are supported by 1830 PSS interfaces on Layer 2 cards. 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 transport network for utility communications requires a range of technologies spanning optical transmission, Carrier Ethernet, IP/MPLS and SDN. Nokia offers solutions based on decades of experience delivering advanced communications networks to utilities, service providers and enterprises. Leveraging Nokia Bell Labs as its innovation engine, Nokia solutions build dependable, scalable, yet flexible network infrastructure that brings together IP routing, optical transport and software.

Figure 2. Nokia portfolio in the transport ecosystem



The relevant products from the Nokia optical and IP portfolios that can be used to modernize utility networks are shown in Figure 2. 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 Photonic Service Switch forms a flexible transport layer through agile photonics, multi-layer switching capabilities and network intelligence. Using the Nokia Photonics Service Engine (PSE), the 1830 PSS is built upon the first commercially available 100G coherent DWDM solution. It enables great scale, 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 different chassis types with few limitations. Highlights of the 1830 PSS platform include:

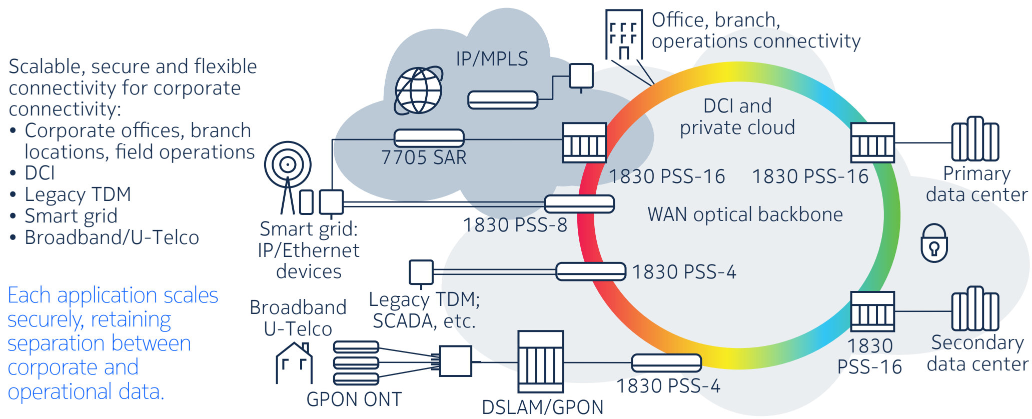
- Chassis sized to match application needs, including DCI, optical access/aggregation and optical WAN backbone with capacities ranging from 240 Gb/s to beyond 8 Tb/s
- PSE super-coherent silicon technology, which provides the basis for software-controlled interface cards capable of optimizing span reach and data rate. The PSE-3, our third-generation processor, supports adaptive modulation, variable baud rates, advanced soft decision FEC and optical super channels as well as per-span capacity and reach optimization through probabilistic constellation shaping (PCS).
- Advanced packet optical transport interfaces, providing MEF 2.0 carrier Ethernet and MPLS-TP capabilities, seamlessly operating with Nokia IP routing platforms through the Nokia Service Router Operating System (SR OS)
- 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; centralized, symmetric key management with key strength exceeding NIST and NSA recommendations, and FIPS 140-2 and CC EAL 2+ certification.

As utility communications evolve, secure high-speed optical technology will be essential for corporate IT and operational functions. DCI, interoffice field connectivity, smart grid and teleprotection are all best served through a single, agile optical backbone, built with the capability of keeping these applications distinct and separated.

Summary

Utility communications networks face increasing demands from across the organization. Faced with integration of operational technology and IT functions, utilities 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 illustrates how this network could be built as a corporate mission-critical WAN, with the Nokia 1830 PSS forming an optical backbone that transports traffic from various applications.

Figure 3. Utility mission-critical WAN with 1830 PSS



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 transport core supporting Ethernet and IP traffic
- Protocol-agnostic photonic transport utilizing OTN
- Flexible Layer 2 architecture, capable of supporting multiple technologies such as carrier Ethernet and MPLS-TP
- 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 utility communications requirements. The Nokia 1830 PSS offers the most powerful photonic transport solution to meet these needs.

Abbreviations

AES	Advanced Encryption Standard
CC	common criteria (security standards)
CC EAL	common criteria evaluation assurance level
CE	Carrier Ethernet
CESoE	circuit emulation service over Ethernet
CWDM	coarse wavelength division multiplexing
DCI	data center interconnect
DSLAM	digital subscriber line access multiplexer
DWDM	dense wavelength division multiplexing
FEC	forward error correction
FIPS	Federal Information Processing Standard

GPON	Gigabit passive optical network
IPsec	IP security
IT	information technology
ITU-T	International Telecommunication Union – Telecommunication Standardization sector
L1	Layer 1
L2	Layer 2
MACsec	media access control security
MEF	Metro Ethernet Forum
MPLS	Multiprotocol Label Switching
MPLS-TP	MPLS - Transport Profile
NGE	network group encryption
NIST	National Institute of Standards and Technology
NMS	network management system
NSA	National Security Agency
NSP	Network Services Platform
OAM	operations, administration, and maintenance
OAMP	operations, administration, maintenance and provisioning
OC-n	optical channel n
ODU	optical data unit
ODUk	optical data unit k
OSI	Open Systems Interconnection
OTN	optical transport network
PCS	probabalistic constellation shaping
PDH	plesiochronous digital hierarchy
PON	packet optical network
PSE-2	Photonic Service Engine version 2
PSS	Photonic Service Switch
RF	radio frequency
SAM	Service Aware Manager
SAR	Service Aggregation Router
SAS	Service Access Switch
SCADA	Supervisory Control and Data Acquisition
SDH	synchronous digital hierarchy

SDN	software-defined networking
SONET	synchronous optical network
SR	Service Router
SR OS	Service Router Operating System
TDM	time division multiplexing
TE	traffic engineering
TPoP	transparent PDH over packet
TSoP	transparent SDH/SONET over packet
WDM	wavelength division multiplexing

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