The next wave of photonic silicon innovation
Scaling optical networks to support 100G service connectivity
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As routers utilize more 100GE interfaces and enterprises demand more 10G connectivity services, a new level of scale and economics is required from optical transport networks. Getting there is critical given the unrelenting rise in demand for high-speed, high-quality, always-on connectivity in an environment of increasing competition. Building on the world’s first programmable, coherent digital signal processor (DSP) — the Photonic Service Engine 2 (PSE-2) — Nokia optical network solutions are ready to scale networks to support the successful delivery of 100G connectivity services.

The PSE-2 combines new unique modulation formats with coherent technology and advanced digital signal processing to create super coherent technology that packs more 100G services into every transport equipment rack unit, wavelength and fiber.

100G services — now

Optical networking is rapidly approaching an inflection point due to mobile data, streaming video, internet content data centers and cloud connect services all requiring the next level of network connectivity — the ability to interconnect 100G services where and when they are needed.

Addressing this network inflection point is paramount for continued success for many internet content providers, carrier-neutral providers and large enterprises. Several of the networks that support these businesses have relied on leased communications service provider (CSP) 10G services to interconnect their data centers and are now finding it difficult to find economical 100G leased services. These businesses are forced to consider building their own private optical networks, a task in which many of them have little experience. The result is the potential for increased operational costs required to operate the network and the risk of delay in critical network capacity enhancements.

For CSPs, the ability to offer leased 100G connectivity to the aforementioned networks represents a new highly differentiated revenue stream. Scaling the network for 100G services also allows CSPs to meet the continuously increasing bandwidth demands from services such as mobile broadband, IP video and the Internet of Things.

Increasing 100G service demand to support 100GE connected network infrastructure over both metro and long-haul network distances is highlighted in Figure 1.
Figure 1. Growing 100G service demand with both metro and national connectivity endpoints

Laying the foundation for scalable 100G services

Network operators need to ensure their networks — which cover a wide range of distances and topologies — can support 100G service demands. They have to monetize their networks by adopting the most efficient, flexible and cost-effective means of transporting 100G services. And to further cut costs, they’re also attempting to reduce power consumption and their overall network equipment footprint, as well automating 100G service delivery.

The Photonic Service Engine

Aware of the pressures facing network operators, Nokia started investigating 100G coherent technologies in 2005. Our strategic investments resulted in world’s first single-carrier 100G coherent interface, followed by the industry’s first programmable coherent digital signal processor (DSP) — the Photonic Service Engine (PSE).
These Nokia innovations ushered in an era that has revolutionized optical networks, such that long-haul networks are now almost exclusively deployed using 100G wavelengths, with 200G deployments currently underway in metro/regional environments. However, until now the vast majority of services transported over these networks have been at 10G rates and below. With the increase in bandwidth demands cited above, plus the widespread adoption of 100 Gigabit Ethernet (100GE) as the predominant interface to core IP routers (Figure 2), network operators are recognizing the need to prepare their networks to transport 100G as a client service. A generational leap in the scale of optical transport networks is required, particularly an increase in transport wavelength capacity, distance capability and spectral efficiency. Recognizing this trend, Nokia has continued its R&D efforts into the next generation of coherent DSP, resulting in the creation of the PSE version 2 (PSE-2).

Figure 2. Global metro and backbone: Core router WAN ports

Scaling the network

A coherent DSP defines the speed and capacity of a given network platform — and possesses its own innate characteristics with respect to power consumption and wavelength capacity and distance. The Nokia PSE-2 development concentrated on two types of deployments: one optimized for transport wavelength flexibility and the other optimized for 100G interface density and lower power consumption. This focus resulted in the creation of two advanced PSE-2 chips.
The PSE Super Coherent (PSE-2s) increases transport wavelength capacity, distance and efficiency. It can be programmed to support optimal 100G to 500G transport wavelength capacities and distances for applications ranging from campus to ultra-long haul. The PSE-2 Compact (PSE-2c) is optimized for delivering services over 100G transport wavelengths with a maximum 100G interface density. In conjunction with the latest advances in silicon-photonics integration, both chips support the creation of optical networking equipment with the following coherent DSP advantages over equipment using current generation technologies:

- The PSE-2s delivers the ultimate transport wavelength flexibility together with up to two times more 100G services per wavelength, while using 50 percent less power.
- The PSE-2c allows for optimized 100G transport wavelengths using more compact cards and “pay as you grow” flexible optics, while using 66 percent less power.

The PSE-2s and PSE-2c allow network operators to scale and optimize their networks along the dimensions of spectral efficiency, power and footprint. The PSE-2s and PSE-2c efficiently address the full landscape of fiber capacity deployments. These can range from long-haul routes with very high traffic growth and limited fiber capacity to metro routes with lower traffic growth and abundant fiber capacity that need a 10G services evolution to 100G.
Efficiently transport 100G services farther and faster

The PSE-2 builds on Nokia real-world experience of widely deployed 100G/200G single-carrier coherent solutions and Nokia Bell Labs innovations including more than 100 patents. It combines new unique modulation formats with coherent technology and advanced digital signal processing to create super coherent technology that packs more 100G services into every transport equipment rack unit, wavelength and fiber.

Inside the PSE-2

Super coherent technology takes coherent wavelength optical networking to a new level of performance and distance — increasing speed, improving performance, and providing better tolerance to fiber impairments to create the network scale required to support a 100G connected world.

A PSE-2’s has the following characteristics:

• Can adjust spectral efficiency by transmitting more or less bits per symbol at a given baud rate
• Digitally processes up to two carriers, and supports the creation of multicarrier superchannels
• Incorporates advanced soft decision forward error correction (SD-FEC) and phase recovery algorithms
• Operates at 32.5 G baud or 44.5 G baud to optimize wavelength performance.

Specialized combinations of these characteristics support a wide range of unique wavelength modulations including:

• Extended 200G wavelength distances for the long-haul environment (from 800 to 2,000 kilometers) with 8-QAM at 44 G baud, offering less deployment complexity and the best alignment with 100GE router/switch interface rates. With this extended 200G distance, long-haul networks can now be built economically using almost entirely 200G transport.

• Lengthened 100G wavelength distances (from 3,000 to more than 5,000 kilometers), enabling unregulated transcontinental reach, including direct connect to sub-sea networks, with a novel 4-Dimensional Set Partitioned QPSK (4D-SP-QPSK) modulation format.

• The industry’s first 400G single-carrier wavelength. Leveraging 64-QAM, this mode results in the highest capacity per fiber available today at 35.2 T b/s.
The next wave of photonic silicon innovation

• Increased 500G superchannel distance with the first two-carrier 500G superchannel addressing both metro and regional distances, providing a combination of leading spectral efficiency and port density.

• Single-carrier wavelength capacity for long haul is from 9.6 Tb/s to greater than 19 Tb/s, and for metro networks the capacity is from 19.2 to greater than 35 Tb/s.

The PSE-2s also supports established BPSK, QPSK and 16-QAM formats to ensure installed base backwards compatibility. The result is that the PSE-2s is the most flexible, scalable and efficient photonic silicon on the market.

Figure 4 PSE-2s – Super coherent design

More 200G distance
• 800km to 2000+ km, making 200G ready for long haul
• 200G is now more efficient than 100G for majority of network links

More 100G distance
• 3000 km to 5000+ km
• 100G ultra-long haul + direct connect to sub-sea networks

More 500G efficiency
• 5 x 100G into 2 x 250G carriers
• 500 G metro/regional distances

More single-carrier wavelength capacity & efficiency
• Long-haul capacity from 9.6 Tb/s greater than 19 Tb/s
• Metro capacity from 19.2 Tb/s greater than 35 Tb/s

Network locations with an abundance of fiber may favor a lower start-up cost for 100G services with a “pay as you grow” cost model. For these locations silicon optimized for 100G is the best approach. The Nokia PSE-2 Compact (PSE-2c) has been designed for these types of 100G deployments. By focusing on the essentials of 100G wavelength transport, power requirements can be significantly reduced, leading to the design of dense 100G cards with a high degree of functional integration in addition to supporting CFP2 ACO pluggables for cost-deferrable and field-replaceable coherent optics.
Simplified deployment, protection and spares inventory

The PSE-2s support for flexible 100G to 500G transport wavelength capacities and distances enables one card, or device, to be used for many fiber route distance applications. It also allows for efficient 1:N equipment protection of several fiber routes of various distances and/or the deployment of time-of-day extra capacity across fiber routes. These unique traits simplify transport wavelength deployment, and equipment spares inventory.

The PSE-2c enables the support for cards with CFP2 ACO pluggables; this also leads to simplified 100G service deployments, protection and equipment spares inventory.

Seamless evolution to CDC-F wavelength routing

The PSE-2 leverages the ability of Flexgrid reconfigurable optical add/drop multiplexers (ROADMs) to accommodate high baud rate signals, while maintaining compatibility with deployed 50 GHz systems, thus providing a practical evolution path from fixed grid to colorless, directionless, contentionless with Flexgrid (CDC-F) wavelength routed networks.
Resilience and quality
The PSE-2 receiver includes advanced algorithms to compensate for chromatic dispersion, polarization mode dispersion (PMD), as well as the fastest polarization tracking speed available. Additionally, transmission is configurable to reduce phase slips (sometimes called cycle slips) for deployment in optical fiber also carrying 10G services. The chipset also provides for chromatic dispersion pre-compensation to further improve tolerance to non-linearity and increases reach in niche fiber applications.

Fast wavelength synchronization
The wavelength frequency and high-speed phase recovery capabilities also allow the PSE-2 to support ultra-fast coherent signal acquisition, which enables 50 ms protection and rapid wavelength restoration. These are foundational qualities for creating more dynamic and efficient software-defined networks.

Wavelength-shaping for greater capacity
Through programmable digital filter configuration, the PSE-2 can narrow wavelength spectrum to create ultra-efficient multicarrier superchannels, which allows for optimal fiber utilization and puts in place the foundation for petabit-capable optical networks.

A PSE-2-powered portfolio
The PSE-2 chips are integrated into multiple Nokia 1830 Photonic Service Switch (PSS) device form factors, allowing them to economically scale networks for the delivery of differentiated 100G services, while maximizing network capacity, optimizing space and power, and extending 100G service reach and performance.

The PSE-2 also provides a smooth evolutionary path for the 1830 PSS product portfolio, allowing network operators to leverage their existing investment and migrate to higher service rates at their convenience. PSE-2-powered transport wavelengths deliver unprecedented performance over virtually any fiber infrastructure or topology. Bandwidth can be scaled at any pace to support 100G services delivery, while power consumption and footprint are minimized.

Some of the initial PSE-2-based 1830 PSS products are described below.
1830 PSS 500G DWDM Muxponder

Powered by PSE-2 Super Coherent (PSE-2s) technology, the 500G DWDM Muxponder card helps network operators achieve 100G service goals by flexibly transporting up to five 100G services in a compact form factor. The 1830 PSS 500G DWDM Muxponder has the following capabilities:

- Significantly and simultaneously scales network capacity, reach and density, making feasible the mass delivery of 100G services over extremely efficient DWDM transport wavelengths
- Can efficiently fill transport wavelengths with both 100G and sub-100G services
- Optimizes transport wavelength spectral efficiency for both capacity and distance, maximizing achievable fiber bandwidth without compromising wavelength availability.

With support for PSE-2s flexible transport wavelength operation, this 500G Muxponder allows for one card to address deployments ranging from metro to ultra-long-haul, thus simplifying sparing and provisioning. Additionally, the programmable nature of this flexibility offers efficiency through agility, enabling new levels of flexible and dynamic multi-layer restoration and optimization, reducing IP and optical interface requirements. With up to five 100GE clients, transport wavelength throughput from 100G to 500G, and reach from metro to sub-sea, no other competing product offers similar performance or flexibility.

Key features of the 500G DWDM Muxponder are as follows:

- Two-slot PSE-2s based card for the 1830 PSS-8, PSS-16 and PSS-32 platforms
- Support for flexible PSE-2s transport wavelength modulations
- Two line ports with independently provisionable modulation format and network path
- Line ports fully tunable across C-Band, Flexgrid-capable
- One card for many transport applications including dynamic extra capacity across fiber routes
- Five CFP4 pluggable clients supporting 100GBASE-LR4, 100GBASE-SR4, and OTU4
- Link Layer Discovery Protocol (LLDP) snooping on client ports
- Wavelength Tracker™ technology for operationally efficient end-to-end wavelength operations, administration and maintenance (OAM)
1830 PSS-24x Packet/OTN switch

With initial support for 9.6 Tb/s of electrical switching capacity per shelf, 19.2 Tb/s per rack, together with 400G-capable PSE-2 cards, the Nokia 1830 PSS-24x offers industry-leading optical transport network (OTN) and packet switch scale, 100G and 200G port densities, and 200G wavelength distances, while also using less power per bit.

This new level of switching scale is enabled by intelligent electrical fabric design coupled with PSE-2-powered transport wavelength cards, and services cards with high client port density. The result is a platform with the following advantages over current generation products:

- Three times more electrical switching scale
- Sixty percent more 200G port density
- More than 2X 200G wavelength distance
- Fifty percent less power utilization
Figure 7. 1830 PSS-24x - A new level of packet/OTN switching scale and 100G service density

Flexible 100G-400G super coherent transport wavelengths

Designed to support 48 Tb/s of electrical switching capacity in a single rack, together with terabit-capable card slots, the 1830 PSS-24x also offers a network evolution path to keep up with bandwidth demands.

The following PSE-2-based transport wavelength cards are part of the 1830 PSS-24x initial release:

- **400G Long haul/Ultra long haul transport wavelength card**
  - One-slot PSE-2s based card, 24 per PSS-24x shelf
  - Support for flexible PSE-2s 100G to 400G transport wavelength modulations
  - Two line ports with independently provisionable modulation format and network path
  - Line ports fully tunable across C-Band; Flexgrid-capable
  - One card for many transport applications including efficient 1:N protection and dynamic extra capacity across fiber routes
  - Wavelength Tracker technology for operationally efficient end-to-end wavelength OAM

- **4 x 100G Regional/Long haul transport wavelength card**
  - One-slot card, 24 per PSS-24x shelf
  - PSE-2c 100G QPSK transport wavelengths
  - Pay-as-you-grow CFP2-ACO pluggables
  - Lines fully tunable across C-Band, Flexgrid-capable
  - Wavelength Tracker technology for operationally efficient end-to-end wavelength OAM

Optimized for 100G interface density
Flexible 100G-400G super coherent transport wavelengths

- 3X scalability
- 60% more 200G port density
- 2X more 200G distance
- 50% less power

PSE-2c
PSE-2s

Application Note
The next wave of photonic silicon innovation
A PSE-2 powered network with a future

Bandwidth demands are skyrocketing. And with mobile devices becoming ubiquitous, video streaming increasing in popularity and social networks eating up more and more data, that's not going to change. The result is that networks are increasingly being stressed to support underlying 100G connectivity to keep up with service demands.

The PSE-2-powered Nokia 1830 PSS portfolio provides instant relief by scaling network capacity to efficiently support the delivery of 100G connectivity. The PSE-2-based solutions leverage super coherent technology to drive a lower cost per managed transported bit, allowing 100G services to be economically deployed where and when they are needed.

Acronyms

4D-SP-QPSK  4-Dimensional Set Partitioned QPSK
CDC-F  colorless, directionless, contentionless with Flexgrid
CSP  communications service provider
DP-BPSK  dual-polarization binary phase shift keying
DP-QPSK  dual-polarization quadrature phase shift keying
DSP  digital signal processor
DWDM  dense wavelength division multiplexing
ICP  internet commerce provider
LLDP  Link Layer Discovery Protocol
OAM  operations, administration and management
OTN  optical transport network
PMD  polarization mode dispersion
PSE-2  Photonic Service Engine 2
PSE-2c  PSE Compact
PSE-2s  PSE Super Coherent
QPSK  quadrature phase shift keying
ROADM  reconfigurable optical add/drop multiplexer
SD-FEC  soft decision forward error correction