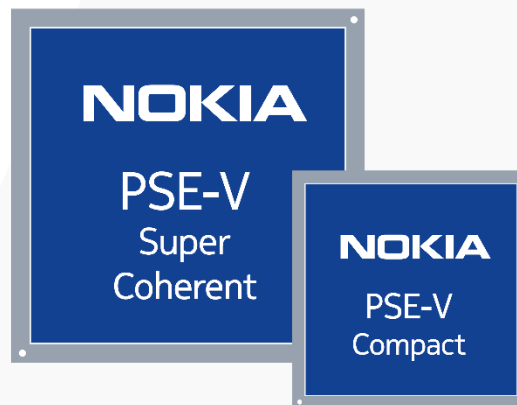




Nokia PSE-V Coherent Chipset



The Next Generation of Nokia DSP Development

Nokia announced its fifth generation of coherent DSPs in May 2020, expanding its Photonic Service Engine (PSE) product line with the PSE-V.

Nokia is one of only two companies which have built five generations of DSPs, and this vertical integration experience is a key competitive advantage in the battle for next generation coherent solutions.

The PSE-V Family

The PSE-V family is comprised of two products, each focused on a different application.

- The PSE-Vc is a power-optimized DSP aimed at a market that includes 400ZR/ZR+ pluggable coherent optics, but also encompassing higher performance CFP2-DCO transceivers supporting mid to long range applications. The PSE-Vc is a completely vertically integrated solution built on an internal Nokia DSP and silicon photonics from the newly acquired company Elenion. Vertical integration is necessary for technology and commercial success in this market, and Nokia joins an elite group of vendors with the opportunity to succeed.
- The PSE-Vs addresses the high-performance coherent market. Nokia chose to focus on 400Gbps transport over any distance with the PSE-Vs DSP initially operationalizing modes up to 600Gbps. This decision reflects an effort to create a lower power, compact, and lower cost solution addressing most high-performance applications without incurring the higher power associated with support of higher rates and the high order constellations they require. For most short reach applications targeted by 64QAM 800Gbps solutions, 400ZR/ZR+ and the PSE-Vc based pluggable coherent transceivers are a more economical option.

The Coherent Optical Market

As coherent optics approach fundamental performance limits in which additional capacity comes at the expense of considerable complexity, the market will evolve into two areas of specialization: higher performance optics and lower power/size pluggable optics.

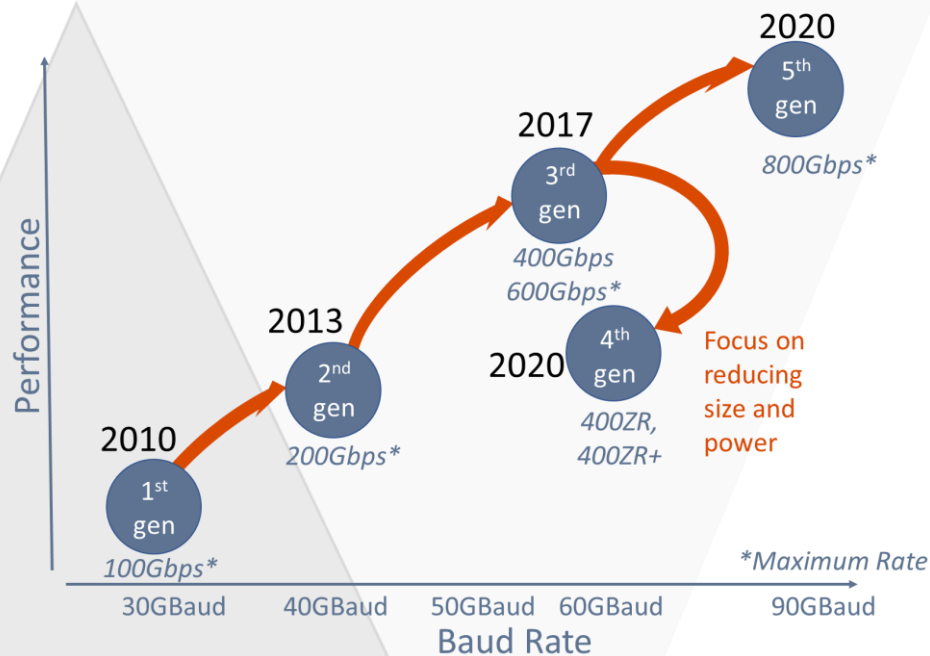


Figure 1: Coherent Optical Generations

The first three generations of optical coherent technology focused on higher performance, measured in increasing maximum speeds and extending span distances. By increasing baud rates and improving digital and optical technology, these generations pushed performance closer to theoretical limits.

For 4th and 5th generation optics, the development path has split, with one path continuing to focus on maximum performance and the other path focused on reducing power and size to expand the market opportunity for coherent optics. While some vendors have offered lower-power versions of previous generations, this is the first time that industry-wide development has focused on standards-based, pluggable coherent solutions.

	4 th Generation Coherent	5 th Generation Coherent
Design focus	Low power, low cost	High performance
Baud rates	32-64GBaud	80+ GBaud
Maximum data rate	400Gbps	800Gbps
Primary applications	Data center interconnect Metro optical links IPoDWDM	High bandwidth metro links Maximum Spectral Efficiency Submarine Networks
Form factor	Pluggable (QSFP-DD, OSFP, CFP2)	Integrated module

4th Generation Coherent Optics

4th generation optics are designed primarily for use in shorter reach, metro/regional networks, and IP over DWDM applications in which coherent optics are plugged directly into switches and routers. Rather than increasing baud rates from 3rd generation optics (600Gbps maximum rate), 4th generation development is focused on lowering DSP and optical power and size to package coherent optics in a pluggable form factor. Examples include the OIF 400ZR and IEEE 802.3cn/ct standards as well as the OpenZR+ and OpenROADM industry group specifications.

400ZR, standardized by the OIF, is limited to 400Gbps line rates, 400GbE client interfaces, and a reach of 80-120km. These limitations were intended to rapidly standardize interoperable hardware in the QSFP-DD or OSFP pluggable form factors. These are standard interfaces for switches and routers, so 400ZR enables IP-over-DWDM deployment with coherent 400Gbps optics. But the application space for 400ZR is limited to very high-density point-to-point datacenter interconnect types of applications, the majority of which are deployed by webscale operators such as Microsoft and Google.

Vendors want to grow the addressable market beyond webscale, and they are adding capabilities to their DSPs to allow greater reach, flexible line rates (100-400Gbps), and support for a variety of client interfaces. This effort is not well-defined, although the OpenROADM and OpenZR+ consortia are driving towards interoperable specifications. The OpenROADM agreement is championed by traditional service providers such as AT&T and covers a wide range of traffic types while the OpenZR+ agreement, championed by Acacia and NEL, is focused on data traffic.

There is also standardization of 100Gbps and 400Gbps coherent client interfaces underway in IEEE 802.3 the traditional forum for standardized optical client interfaces.

Beyond the standardization efforts, there are plans for proprietary solutions with additional capabilities such as OTN client interfaces, more flexible client and line side rates, and additional modulation types. These options are not limited to the power and size restrictions of the standards-based solutions and can be deployed in larger CFP2 form factors and are intended to support a broader range of metro, regional, and long-haul applications.

		Primary Application	Client Protocols	Reach	Form Factor	Power
Standards-Based	400ZR	Short reach data center interconnect	400GbE	80-100km	Undefined, expected to be QSFP-DD / OSFP	Undefined, expected to be ~15W
	IEEE 802.3ct/cw	Short reach data center interconnect	100/400GbE	80km	QSFP-DD / OSFP	Not Defined
Industry Coalition	OpenZR+	Metro Ethernet and data center interconnect	100/200/400GbE	~600km	QSFP-DD / OSFP	<20W
	OpenROADM	Incumbent telco metro networks, multi-haul	100/200/400GbE & OTN	~600km	CFP2	Form Factor Dependent
Proprietary	Regional/Long Haul	Longer reach optical network	Multiple	1000km+	CFP2	Not Defined
	Subcarrier	Access networks	Multiple	~80km	QSFP-DD / OSFP	Not Defined

The first 4th generation devices sampled at the start of 2020, and more are expected throughout this year.

Standards-based 4th generation optics will have the same tight profit margin environment as the client optics market. Therefore, only fully vertically integrated companies with access to both a DSP and optical front end will have the cost structure required to best address this market. Vertical integration will be critical for success in the limited market for ZR optics and should give companies a similar advantage in the broader pluggable coherent market.

To date, only a few vertically integrated companies, including Inphi, Acacia, Infinera, and Ciena, have announced plans to support fourth generation coherent optics. With the acquisition of Elenion and the announcement of the PSE-Vc, Nokia joins this select list.

5th Generation Coherent Optics

5th generation coherent optics continue the earlier trend of faster baud rates and more complex features to maximize performance. Higher baud rates and technical capabilities, such as subcarriers and more advanced PCS/FEC, enable higher speed (800Gbps) short distance transmission and longer distance (>2000km) operation at 400Gbps. These innovations are proprietary to each vendor and therefore preclude any interoperability. Solutions must be deployed on custom line cards or compact modular platforms rather than as pluggable modules.

The compelling application for 5th generation coherent optics is long haul WDM and SLTE, in which superior capacity and spectral efficiency are the highest priorities. However, there will also be applications in metro/regional networks such as multi-hop ROADM networks in which the higher performance is critical. But the market for very short reach, 800Gbps connections will be small and limited to point-to-point, high capacity links with customers who need incremental performance gains beyond the lower cost and interoperable solutions offered by 400ZR and ZR+.

Only a few vendors possess the necessary technical and financial resources to design and build 5th generation coherent solutions. The 7nm silicon process utilized is extremely expensive (vendors have stated costs of \$40 million per chip design spin), the ultra-fast speeds require specialized electronics, and the optical front-end design has very tight performance tolerances. Also, 5th generation solutions will require tight integration between the DSP and the front end, co-packaging the two pieces of the solution to eliminate long traces or wire bond connections that will not work at 90+ GBaud.

With earlier generations of coherent optics, vertically integrated vendors had a massive commercial advantage - these vendors sold more than 80% of all coherent ports in 2019. The greater difficulty of engineering 5th generation optics will only compound the advantages of vertical integration as system integration of the DSP and optical front end become more critical. Vendors who can control all parts will have a technical and first-mover advantage.

Ciena, Infinera, Huawei and now Nokia have announced vertically integrated 5th generation solutions.

4th Generation vs 5th Generation

As the coherent market splits into 4th generation and 5th generation optics, the application space for each solution will coalesce. 4th generation solutions will dominate at the edge of the network and in some cases will reach into the long haul. 5th generation optics will dominate long haul and at times will reach into the edge. 4th and 5th generation optics will compete in the metro, with the winner determined on a case-by-case basis.

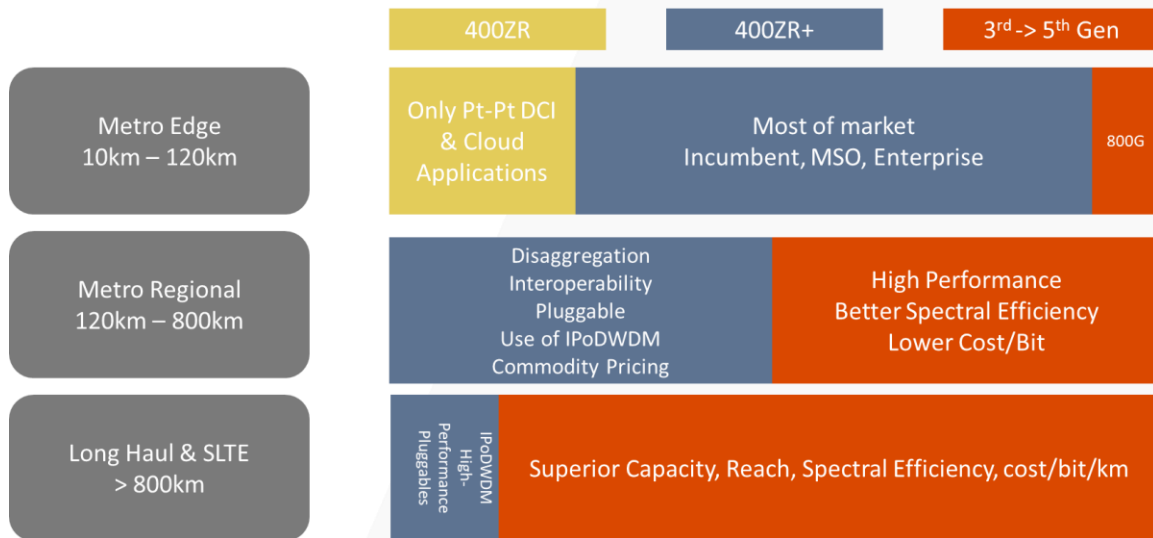


Figure 2: Coherent Market Technology Applications

For metro edge (10-120km) applications, 5th generation solutions operating at top speeds of 800Gbps or more will compete against lower cost, pluggable, and interoperable 400Gbps 4th generation solutions. Long term, 4th generation optics will be the optimal solution at the metro edge with standard 400ZR being used for point-to-point data center interconnections and 400ZR+ being used for most other connections. The market for full-rate 800Gbps short-reach optics at the edge will be very limited.

In the metro regional (120-800km) network, there will be a balance between 4th generation ZR+ and 5th generation optics. The winner in each application will depend on the operator requirements. 4th generation optics will make the most sense in applications where pluggability and interoperability are a priority, such as IP-over-DWDM networks built by data center operators and cable/MSO networks and low-cost regional multi-haul networks preferring pluggable solutions. 5th generation optics will be used in applications in which performance is critical, such as longer-reach networks and flexgrid ROADM-based service provider networks.

In long haul high capacity networks, the superior performance of 5th generation optics makes them the most attractive solution. However, there will continue to be a market for 4th generation ZR+ optics among multi-haul operators who prefer pluggability and interoperability, are satisfied with high performance at lower speeds (100Gbps/200Gbps) and wish to take advantage of the cost savings offered by 4th generation optics.

The Nokia PSE-V Approach

Nokia designed the PSE-V to meet the specialized market requirements addressed by 4th and 5th generation optics.

- The PSE-Vc addresses low-power, pluggable coherent applications. The solution is designed to operate in a range of solutions from regional and long haul to 400ZR+ or 400ZR applications.
- The PSE-Vs is focused on 400Gbps multihaul, ultra-long haul, and subsea high performance applications by using 90GBaud baud rates but not burdening the DSP with the complex 64-QAM modulation circuitry required to reach 800Gbps short-reach operation.

With both the 4th generation PSE-Vc and the 5th generation PSE-Vs, Nokia can offer a competitive portfolio covering all its customers' coherent applications.

PSE-Vc - Lower Power and Pluggable

Nokia positions the PSE-Vc as more than just another 400ZR/ZR+ optical module. Nokia initially designed the DSP in a 400Gbps CFP2-DCO with regional and long-haul capabilities, with plans to eventually offer OpenZR+ and 400ZR versions in smaller packages. The target market covers a wide range of applications, from the edge through the metro and into the long haul, for customers who prefer pluggable optics solutions.

For regional and long-haul performance, Nokia uses proprietary FEC and PCS paired with high-performance optics to achieve the maximum reach. The market for these products is the middle 70%-80% of Nokia's customer applications between short reach DCI and long haul / submarine. For interoperable solutions (OpenZR+, 400ZR), the DSP operates in standard modes to address the portion of the market that prefers commodity, interoperable optics. The interoperable pluggable coherent market is not yet mature, so the PSE-Vc higher performance proprietary solution will allow Nokia to address customer applications while the interoperable market develops.

Commercial success in the pluggable optics market requires a vertically integrated solution, which Nokia has achieved via the acquisition of Elenion. When Elenion's silicon photonics front end and experience in pluggable coherent transceiver design is paired with Nokia's internally developed DSP, the result is a complete, integrated package. The Elenion technology will also find use in Nokia's 3rd generation PSE-3 and in client optics for Nokia's optical and switching/routing product lines.

PSE-Vs - High Performance

5th generation optics solutions will not successfully compete against 4th generation coherent optics in most short reach applications. Nokia determined that building an expensive 5th generation DSP that can operate at the highest possible line rate (e.g. 800Gbps) over short distances does not make economic sense when low-cost 4th generation optics are available for the same application.

In the shorter-reach, point-to-point market addressed by 4th generation coherent, few operators can justify 800Gbps wavelength operation, especially if the cost of 800Gbps is more than 2x the cost of a standards-based 400Gbps pluggable optics solution. As 400Gbps pluggable solutions do not require outboard equipment, real estate, and power, this is a valid assumption to make.

By removing the circuitry necessary to enable 64QAM 800Gbps operation, Nokia expects the PSE-Vs design to be approximately 15% smaller and use 20% less power than competing 5th generation solutions. Nokia believes this size and power advantage creates total cost advantages (equipment, power, real estate) and a competitive edge in the 5th generation coherent market.

Nokia was the first company to develop PCS, and it claims to have a second-generation PCS algorithm for the PSE-Vs that is superior in the industry. Nokia also claims a proprietary enhanced FEC algorithm which pushes the capabilities of the PSE-Vs closer to theoretical limits on data transfer. Every company developing 5th generation coherent optics will be using proprietary techniques to improve performance, and only field trials will determine when and where each has advantages.

Competition

4th Generation Coherent Optics

The 4th generation coherent competitive landscape is complex, with standard 400ZR solutions as well as expanded 400ZR+ solutions being developed. Volume production of 400ZR components is not expected until the end of 2020.

	Ciena	Inphi	Acacia	NEL	Infinera	Nokia
ZR / ZR+	Both	Both	Both	Both	Proprietary	Both
Strategy	Vertical integration	400ZR alone 400ZR+ with Neophotonics	Vertical integration	Partnership with Fujitsu, SEI, II-VI, others	Nonstandard, part of XR Optics	Vertical integration
Module sales	Yes	Yes (ZR) Partners (ZR+)	Yes	Partners	Partners	TBD
Schedule	4Q20	Sampled 1Q20	Sampled 1Q20	TBD	TBD	4Q20

- Inphi and Neophotonics have already announced 400ZR+ solutions that are also compatible with the 400ZR standard.
- Ciena's WaveLogic 5 family includes the WaveLogic 5 nano, a 400ZR/ZR+ solution that uses internally developed silicon photonics and DSP.
- Acacia sampled its 400ZR solution. Acacia, along with NTT Electronics, also formed the OpenZR+ alliance with a focus on building a "standard" ZR+ solution. OpenZR+ is using

a different FEC (oFEC) than the Inphi solution (cFEC), setting up potential conflicting “standard” solutions.

- Infinera does not plan to build at 400ZR solution at this time; choosing instead to focus on development of its proprietary subcarrier-based XR Optics.

5th Generation Coherent Optics

Ciena and Infinera have both announced 5th generation optics with top speeds of 800Gbps for deployment in 2020. Huawei also announced a 5th generation optical solution. Other 5th generation solutions could be announced in 2020 from Acacia/Cisco and ZTE, although neither company has made any firm commitments.

- The Infinera ICE6 and Ciena Wavelogic 5 solutions are vertically integrated using internally developed DSPs and InP components. Both solutions claim a top speed of 800Gbps.
- Huawei announced its 5th generation coherent solution in September 2019 but has not provides implementation details. The Huawei OptiXtreme 7 oDSP is part of Huawei’s OptiXtrans data center solution.

Conclusions

Nokia’s next generation of coherent optical DSPs builds on a long history of Nokia optical development and research.

- The recent acquisition of Elenion makes the low-cost, low-power PSE-Vc one of the most vertically integrated solutions in that market, which should provide a competitive advantage.
- Nokia’s decision to focus the high-performance PSE-Vs on the market needs around 400/600Gbps and not burden the system with 800Gbps is unique in the industry, and consistent with market requirements.

If the power and cost savings from removing 800Gbps from the DSP play out as Nokia predicts, then the PSE-Vs should have a strong competitive position, even against solutions that may come to market sooner. While it is too early to compare performance, Nokia is the only DSP developer announcing a second generation of PCS, which the company believes will boost the performance of the PSE-Vs above other solutions. With the PSE-V series, Nokia has an excellent opportunity to regain its position among the top coherent optical providers worldwide.