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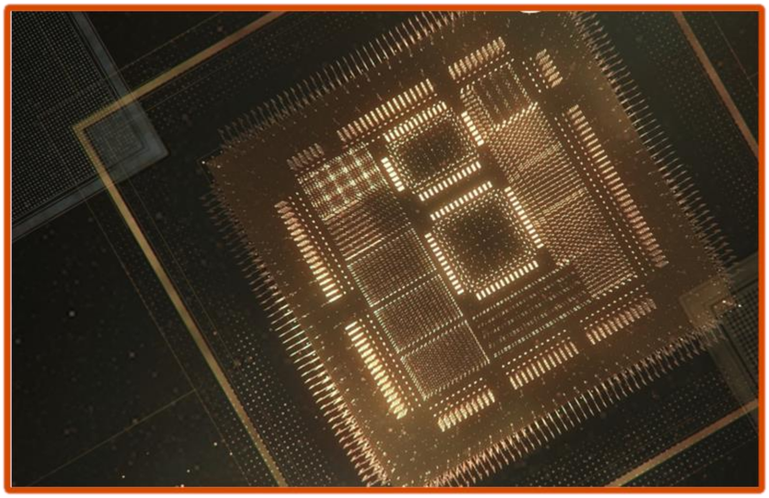
Nokia PSE-3 Coherent Chipset



Photonic Service Engine 3

The Power of In-House DSP Development

Nokia's PSE-3's Advantage Lies in Probabilistic Constellation Shaping (PCS)

The PSE-3s DSP chip represents the best of Nokia's latest coherent optical technology and supports the company's ongoing strategy of developing coherent DSP processors in-house. The company believes that controlling its DSP technology will provide a market advantage in leading the transition to 400G/600G speeds.

DSP- External vs. Internal

Companies have the choice to either create their own DSPs internally or to outsource. For those that seek to outsource, DSP suppliers NTT Electronics (NEL) and Acacia both plan to have 600G silicon ready for production at the end of the year. Companies including Cisco have already made the decision to source externally, and Infinera is likely to make the same choice for some of its future needs. Under these circumstances, one must ask why Nokia is determined to build its own DSPs.

The argument for DSP vertical integration rests on having end-to-end control of coherent algorithms, considered necessary to deliver superior performance and beat time to market. Ciena is one company which decided to keep its last DSP development in-house, and doing so allowed the company to get the Wavelogic AI to market with 400G technology (See *Ciena Wavelogic Ai and 400G Roadmap*). From all accounts, Ciena shows no intention of changing course and sourcing externally for future designs.

Nokia is taking the same in-house approach. The company believes that controlling the DSP technology will be a strategic advantage in leading the transition to 400G/600G speeds.

One need not look far back to see that history supports this view. Nokia was successful in the 200G market with its in-house **PSE-2**, which accounts for approximately one of every eight coherent ports (13%) shipped to applications outside of China during 2017. Only Ciena shipped more; claiming 22% of shipments. Together, these two companies plus Cisco accounted for almost all coherent 200G deployed outside China. **And all three of these market leaders relied on in-house DSPs for 200G** (though Cisco did ship a fraction using Acacia as well).

During the 200G coherent technology transition, equipment companies had essentially two choices; purchase a DSP from Acacia or build one themselves. This time, options have improved; in addition to Acacia, NTT Electronics will offer a 400G/600G solution which will arrive at roughly the same time as Nokia's PSE-3. Given the market alternatives, it is important to then analyze what unique value Nokia's PSE-3s offers if it is to truly provide a competitive advantage.

Specification Overview

Nokia has developed two new and different devices; the **PSE-3s** and the **PSE-3c**. The PSE-3s is the star of the announcement and is the focus of this report. The second chip (PSE-3c) should be considered an updated version of the PSE-2 and will be used in low power, higher density 1830 PSS metro applications. The upcoming PSE-3c will be available this year - we don't examine it here.

A cursory review of the PSE-3s specifications does not indicate significant differences when compared to the upcoming solutions from NTT Electronics or Acacia arriving this year. The PSE-3s:

- Supports a maximum of **67 Gbaud operation with 64QAM modulation**. The baud rate can be throttled back to fit into 50Ghz wave spacing for brownfield installations.
- Provides dual carrier support**; 2x600 Gbps maximum throughput for a total chip transmission capacity of 1.2T**. This is 2x the DSP density of Ciena's solution and is comparable to the upcoming Acacia Pico and NEL Tera chipsets.
- Is built using **16nm silicon process technology**, the most aggressive geometry available in production today.
- Supports **FlexEthernet & Flex OTN & Full OTN client termination**.
- Nokia expects equipment using the PSE-3 to **arrive in 1Q19**.

However, there is one additional feature that sets the PSE-3s apart from other options; **Probabilistic Constellation Shaping (PCS)**.

Audio vs. Optical Modems

Remember the audio modems used in personal computers? They are a great model to use when thinking about how optical coherent links work. Depending on how noisy the link is (distance, link characteristics, lots of other factors), two audio modems operate at 1200 baud, 2400 baud, 9600 baud, or even 38.4 kbaud. If you turned the speaker on, you could hear the modem changing tones while searching for the fastest link.

But what if your modem link worked at 9600baud but it failed at 19.2k? By default, you'd be forced to operate at 9600. There was no other option in between those two points because the modems used **hybrid modulation**, meaning that they had a preset selection of speeds that they were forced to choose from. Even if the link could potentially function at 15000 baud, you had no choice but to run it at the lower 9600 baud level.

Keeping this simple example in mind, we then consider the Nokia PSE-3s, which uses Probabilistic Constellation Shaping to operate on a **continuous spectrum of speeds** - analogous to operating a modem link at 15000 baud, 25000 baud or anything else on the spectrum between 1200 and 38,400. The PSE-3 doesn't waste the extra bandwidth and it's not forced to default to a lower threshold, and this is its advantage.

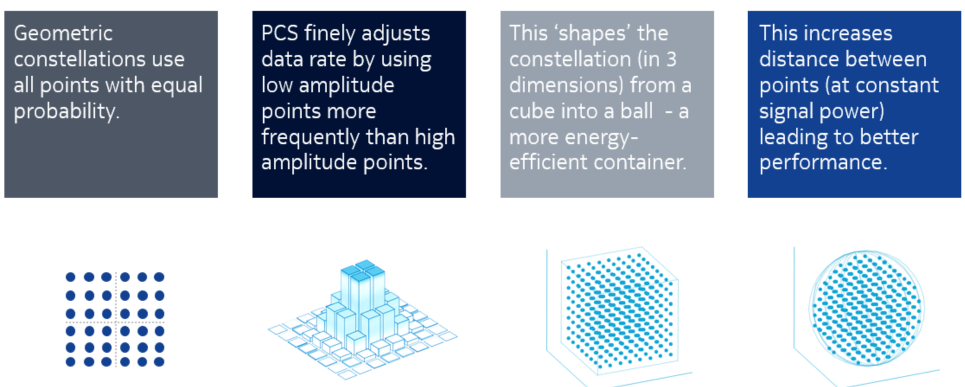
Probabilistic Constellation Shaping

Most coherent DSPs to date have used hybrid modulation, including Nokia's PSE-2. Nokia has a *whitepaper* outlining the technology behind PCS, but here's a summary:

First, consider a polarization-mixed 64-QAM modulation operating at 67 GBaud - that's 6 bits of data sent 67 billion times every second over two polarizations. This yields a maximum raw bit rate of 6 x 67 x 109 (67Gbaud) x 2 = 792 Gbits/sec. Roughly 25% of that bandwidth is used for forward error correction (FEC) and what remains yields a maximum data rate of 600Gbs.

The problem with standard 64-QAM modulation is that it only works over short distances. This is why other DSPs support a wide range of modulations: PM-QPSK for long distances, 16-QAM for the 1000-2000 km range. Competing chips use a hybrid approach to select a modulation to get the best bandwidth at a given distance - but they use all 4, 16, or 64 constellation points in a given modulation equally. Just like those audio modems that could operate at a maximum 9600 kbaud but over noisy copper phone lines, they might be forced down to 2400 kbaud or a quarter the speed.

PCS - Capturing the Ultimate dB



PCS adds a 3rd dimension to modulation by selecting how often constellation points are utilized Source - Nokia.

Enter the PSE-3. This DSP will be a different story, because the PCS feature can dynamically adjust how often each of these individual constellation points is used, shaping the signal to fit the maximum capacity of the channel.

Where another DSP would leave some margin on the table with 16-QAM at 200G, but 32-QAM would fail, the **PSE-3s can continuously adjust to a bandwidth** that sits logically in-between these two points. This process effectively shaves off the last bit of linear noise margin that exists in an optical link - supporting Nokia's claims of algorithmically closing the gap with the Shannon Limit, the maximum theoretical capacity of the channel.

The raw performance gains from PCS are around an optical dB (25%) when compared to links that don't have it. An extra dB will help make 200G coherent usable in almost all terrestrial applications and will extend the reach of 400Gbs solutions.

Operational Simplicity

Unlike competing DSP providers, Nokia expects its PSE-3s customers to operate all greenfield links at 75GHz spacing and 64-QAM modulation regardless of distance. PCS will algorithmically tune the signal to the maximum effective bandwidth and free the operator and the control plane from selecting and changing modulation formats from link to link. Also, PCS works just as effectively in existing 50GHz situations and brings the same performance gains to these applications, just at a lower baud rate.

The result is that, for greenfield situations, **PCS helps solve the complex wave plans of super-channels**. Network operators can make 75GHz the common denominator throughout the network without having to compromise performance.

Competition

PCS is not a secret. It's been used before in other applications (including your old modem). Infinera demonstrated a PCS algorithm but has not implemented it in silicon.

The key challenge of PCS is that it is a tough algorithm to fit within the design constraints of a 16nm process technology. Nokia claims to have a Bell Labs algorithm called the "Distribution Matcher" which overcomes this hurdle, and thereby **this is the core competitive advantage that Nokia claims to have - not the algorithm itself but the way to efficiently build it into silicon**.

Both Acacia and NTT Electronics intend to bring coherent DSPs to market this year with 600G capabilities, but lacking PCS features. Acacia's product supports hybrid modulation, but Nokia believes PCS should give it a 25% edge in performance over Acacia's DSP.

Summary

In-house silicon solutions effectively conquered the market for 200G coherent links, as they did initially for 100G coherent. Now there is yet again a rush to higher speeds, as 400G and beyond beckons.

New 600G chipsets from Acacia, NTT Electronics, and Nokia are all expected to reach the market within less than a year of each other. Nokia believes that PCS and engineering control of the optical link end-to-end will once more give it a market advantage that justifies the costs of fielding a 16nm coherent DSP internally.

Both Nokia and Ciena are expected to continue using in-house expertise to retain control of the market as it transitions to higher speeds. Cisco, ADVA, Coriant, and others are pursuing a different path using external DSPs and attempting to differentiate their products through other means.

Considering PCS closes the gap on the Shannon Limit, does this mean it will become harder in the future for equipment companies to differentiate with in-house silicon?

We think the answer is yes. Nokia made a huge investment in silicon to seize just 25% more margin and didn't leave room for further algorithmic improvement. Effectively, the company cleaned out the store for any remaining optical margin. But this does not signal the end of improvements for coherent performance.

After the implementation of PCS, the point of diminishing returns for DSP algorithms appears near. Improvements to link speed and capacity will come in other ways. One is pure speed (higher baud rates), though it comes at the cost of using additional optical spectrum. Other options include improving the quality of optics and amplifiers to remove noise, using L-band amplification, and even looking at attacking non-linear noise by comparing adjacent wavelength interference.

While the end of developing DSPs in-house may be on the horizon, companies such as Nokia believe that, in the near term, an edge coming from in-house development can spur better market results and deliver superior solutions for network operators.

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