Whitepaper

June 2021

Increasing Disaggregation in Optical Networks

Fueled by interoperable pluggable modules and open-source networking software

Advent of open networking in data centers and mobile access networks has led to adoption of disaggregated networking by service providers. Leveraging multi-sourcing and eliminating the traditional integration issues, the network operators are simplifying operations in disaggregated networks and can rapidly launch new services while reducing capital and operating expenses. As regional networks move to IP over DWDM in 2023, disaggregation will continue to grow.

Figure 1 shows the architecture of a disaggregated transport system proposed by the Open Optical & Packet Transport project group of the Telecom Infra Project (TIP-OOPT). The pluggable transceivers in the transponder boxes are separated from the open line system consisting of ROADMs and Amplifiers [1]. Coherent technology is a key enabler of the pluggable transceivers which can be directly plugged into routers and switches. These can carry IP signals over DWDM, particularly at 400G, since the line side and client side modules have identical form factor. Transceiver modules incorporating coherent DSP and silicon photonics enable compact OSFP and QSFP-DD line side modules. All leading equipment providers in the industry currently offer partially disaggregated networking products and two network equipment integrators are offering whiteboxes, which are highly disaggregated using standard module interfaces and transponder abstraction interface (TAI) along with network operating system (NOS) software.

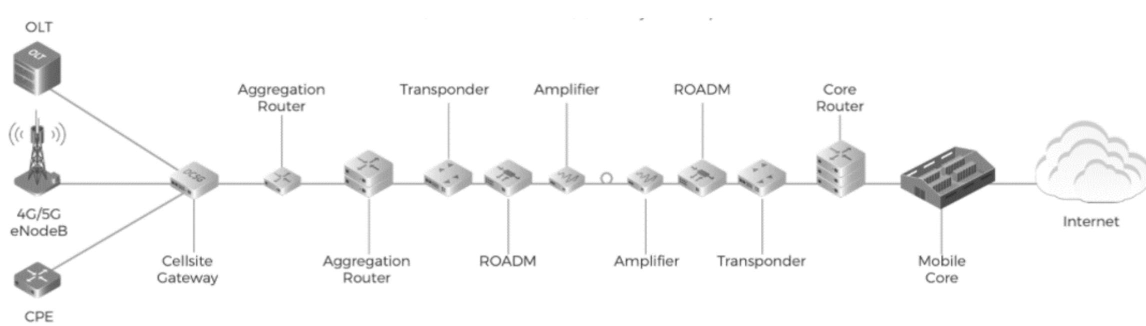

Figure 1: TIP-OOPT - Disaggregation of pluggable transceivers and open line transport system and related network control software

The management-control interfaces of transponders include many proprietary elements. The interface specification and architecture of TAI, which enables disaggregation of hardware and software was proposed for the first time by NTT to the TIP-OOPT project [2]. There are however some gaps in the supplier independent parameter for monitoring the quality of transmission (QoT) and network design validation. This includes setting up connections to select the right equipment and assure the quality over time. A supplier neutral planning tool is essential and an industry agreement is needed to enable the open optical networks. Initiative for QoT within TIP-OOPT and development of open source, community developed GNPy library for building route planning and optimization is very promising for enhancing the benefits of network disaggregation in the future.

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[1] V. Lopez, et al., "Whitebox Flavors in Carrier Networks," Optical Fiber Conference (OFC), March 2019.

[2] Hideki Nishizawa, et.al, "Open Whitebox Architecture for Smart Integration of Optical Networking and Data Center Technology," JOCN, Vol. 13, Jan. 2021.

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Whitepaper

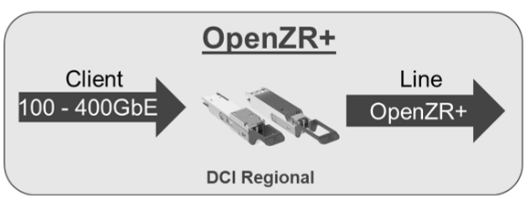
June 2021

OpenZR+ Advancing Coherent Pluggable Modules

Acceleration in pluggable module deployment in longer reach Ethernet Optical Networks

Progress in standardization of 400ZR DCI module has led to interoperability and multi-sourcing of low cost coherent modules. OpenZR+ MSA has published specifications of 400ZR+ transceiver with higher gain oFEC, compatible with OIF 400ZR module slot, for longer reach 500-1000km applications [1]. Client and line side modules now have the same size enabling incorporation of OpenZR+ module directly on a router or switch box (Fig.1). In general, the size of the module is limited by the level of optical integration, whereas power dissipation is determined by the electronic devices such as the DSP. The module power dissipation is typically split 50:50 between the DSP and optical sub-assembly. Silicon photonics and 7nm CMOS based DSP are key technologies for the compact pluggable coherent modules such as the QSFP-DD and OSFP. Interoperability test between modules from three vendors using different DSPs having oFEC has verified the compatibility of the modules in 400ZR+ and 4x100GE muxponder modes [2].

OpenZR+ specifications based on high-gain oFEC, cover multiple line rates, multiplexing and extended reaches in QSFP-DD and OSFP modules. This enables network operators to address 400G regional interconnects longer than 1,000km and long-haul links with 200G reaches beyond 2,500km using pluggable modules based on interoperable modes, as shown in Table 1 [1].



OpeZR+ Modes	EDFA Link (km)	EDFA+Raman Link (km)
400ZR+ (16QAM)	480	1040
300ZR+ (8QAM)	1600	2320
200ZR+ (QPSK)	2880	2880
100ZR+ (QPSK)	5840	5840

Figure and Table 1: OpenZR+ module operation modes and link reaches for amplified links with EDFA only, and EDFA+Raman amplification. The link consists of 80km spans of G.654 SMF.

The net coding gain of oFEC is higher than for CFEC by nearly 0.8dB. This is a critical element of OpenZR+ Coherent module. The oFEC engine is a block-based encoder and iterative Soft-Decision (SD) decoder having the net coding gain 11.1 dB for QPSK, and 11.6 dB for 16QAM, with pre-FEC BER threshold of 2.0×10^{-2}. The combined latency of the encoder and decoder is less than 3 µs. The higher gain FEC allows OpenZR+ modules to achieve better OSNR tolerance of 24dB vs. 26dB for CFEC based 400ZR. This helps to mitigate link impairments, such as filter narrowing in 75GHz grid or dispersion effects, and extend links to longer reaches. Low latency is beneficial in a variety of access and short reach data center applications.

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[1] http://openzrplus.org/documents/ Whitepaper: "OpenZR+ 400G Digital Coherent Optics for Multi-Haul".

[2] A. Srivastava, "Interoperable Coherent Optics for Extended Reach - Assisting Data Center Evolution," Paper M5G.2 in Proc. OFC, (2021).

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Whitepaper

December 2020

Coherent Everywhere!

Industry considers expanding coherent from long-haul to short reach networks

Introduction

Modern fiber optic communication infrastructure is revolutionized by the recent advances in coherent transmission systems, which are being deployed to address the exponentially growing demand for bandwidth in telecommunication and datacenter networks. Currently, 100 to 600 Gb/s data rate WDM systems are being deployed in the terrestrial and undersea fiber optic networks supporting 10-20 Tb/s capacity per fiber. The advances in highly integrated photonic devices and the next generation CMOS based high performance DSPs has made it feasible to introduce coherent systems in the datacenter networks which need to support the increasing I/O data rates for the switch ASICs [1]. The developments in the new CMOS based DSP technology and significant progress in the photonic integrated devices including the silicon photonics are enabling small form factor pluggable modules for 400 Gb/s and 600 Gb/s WDM interconnects for the datacenters. Higher data rate 400 Gb/s ZR modules are starting deployment in the datacenter interconnects standardized at the Optical Internetworking Forum (OIF). The next generation small form factor OSFP and QSFP-DD pluggable 400G modules are designed to provide I/O for the next generation switch ASICs with 12.8Tbps and higher capacity.

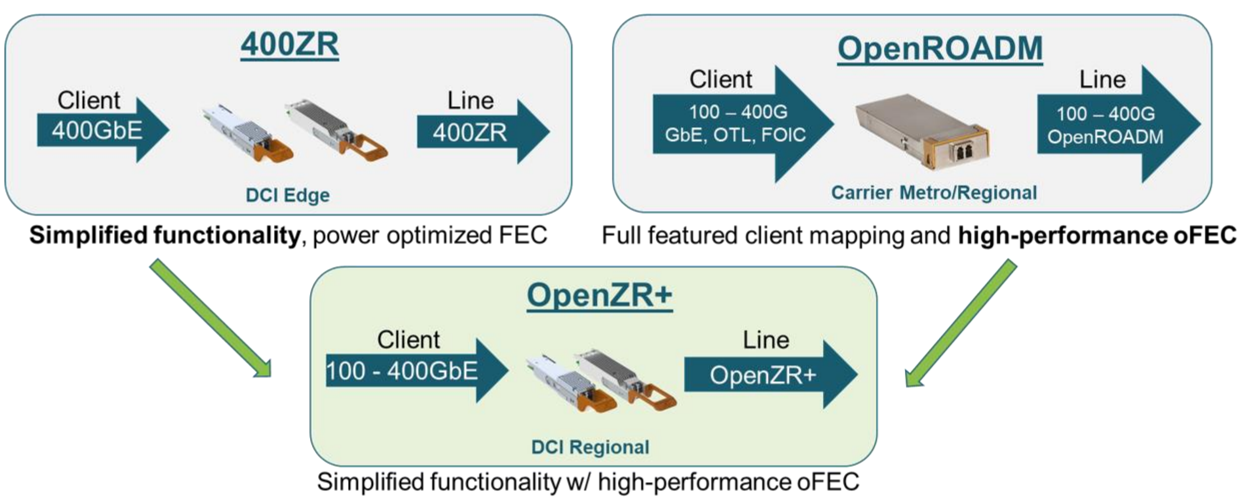

Fig. 1: OIF 400ZR DCI, OpenROADM metro/regional and OpenZR+ DCI regional modules.

OpenZR+ MSA recently announced that using higher gain oFEC standardized at OpenROADM MSA, the same module can be used for longer reach applications such as the regional and long-haul interconnects in hyperscale data center applications, and also supports service provider requirements. OpenZR+ enables network operators to address 400G regional interconnects beyond 1,000km and even long-haul requirements with 200G reaches beyond 2,500km using pluggable modules based on interoperable modes [2].

Standardization of the next generation 800G modules has been initiated for possible application in ZR and 2-10km distances. There is debate about the use of direct detection PAM4 solution for 2-10km reach. There are concerns about the link performance and power dissipation for PAM4. Coherent technology can surely meet the performance with wide margin for these links but the cost of DSP is still a major issue. For 800G links, both formats have a chance of success, however for higher data rates at 1.6T coherent seems to be the only feasible solution. If successful, at 800G and higher data rates, coherent will make inroads into shorter reach links including high volume links inside the datacenters.

In this paper, an overview of the recent progress of the coherent DSP technology and Silicon Photonics integrated Coherent Sub-assembly (COSA) devices for the small form factor modules for application in the terrestrial and datacenter networks is presented.

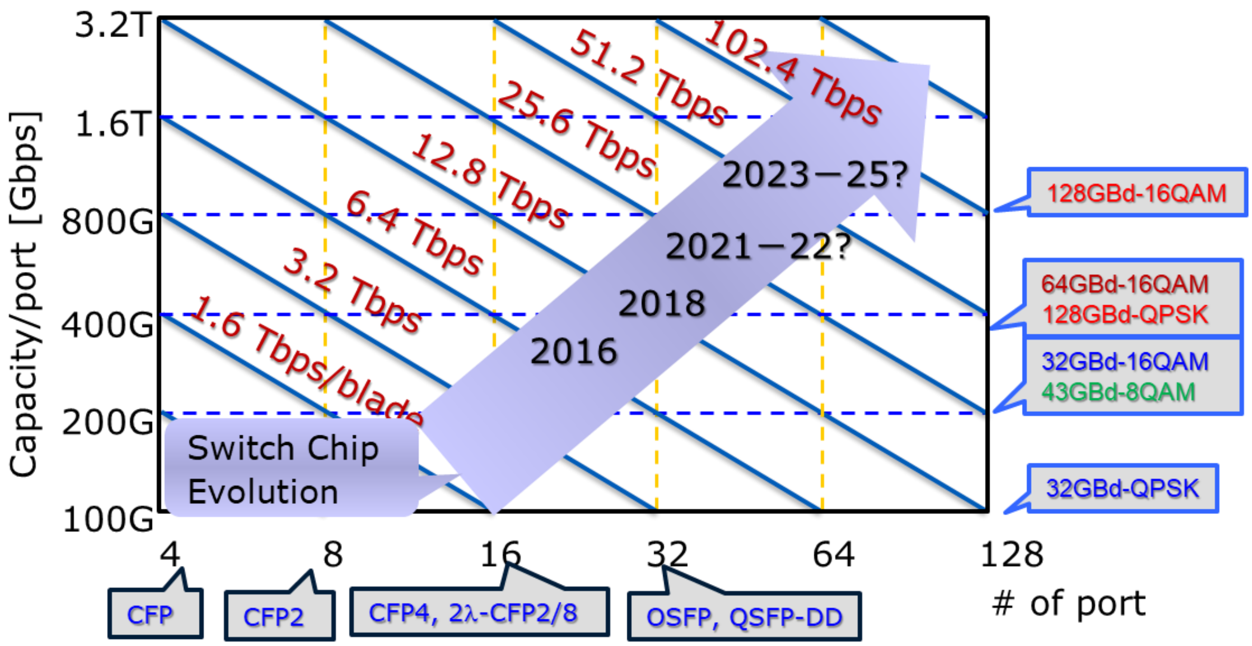

Fig. 2. Evolution of I/O Capacity per port vs. the number of transceiver modules per line card for achieving full Switch throughput capacity.

Figure 2 shows the relationship between the capacity per blade and the number of module ports per blade as the switch ASIC capacity has evolved in last few years. In order to keep up with the switch ASIC I/O capacity demand, both the data rate of pluggable transceiver port and the number of ports per blade need to increase. Higher data rate pluggable transceivers have shrunk in size and are using a higher baud rate and/or advanced modulation formats. The OIF published an implementation agreement on coherent transceivers based on the C form-factor pluggable2 (CFP2)-analog coherent optics (ACO) form factor [3].

CFP2 transceivers supporting 200 Gb/s are now commercially available, which corresponds to 1.6 Tb/s/blade in Figure 2, assuming 8 CFP2 transceivers per blade. In order to further reduce the size of the future transceiver modules, new optical device technologies with higher integration have to be employed. In addition, the power dissipation of DSPs needs to be reduced to manage the cooling of the blade line card. In general, the size of the module is determined by the level of optical integration, whereas power dissipation is governed by the electronic devices such as the DSP [4].

DSP in Coherent Systems

Figure 3 shows the block diagram of a low-power DSP, which has three-chip functions successfully integrated into a single chip and still has less than half power consumption as compared to the previous generation 16nm chip set. In order to achieve the same functionality, the earlier generation DSPs required external OTN Framer and transmitter MUX chips. The new DSP outputs 4 x 28/32G/64G analog waveforms including QPSK and 16QAM for 100G, 200G and 400G, respectively from the Digital-to-Analog Converter (DAC). It includes a framer to accommodate 100GE signal into OTU4 frame, and a spectral shaping filter that can realize spectrally efficient Nyquist pulse.

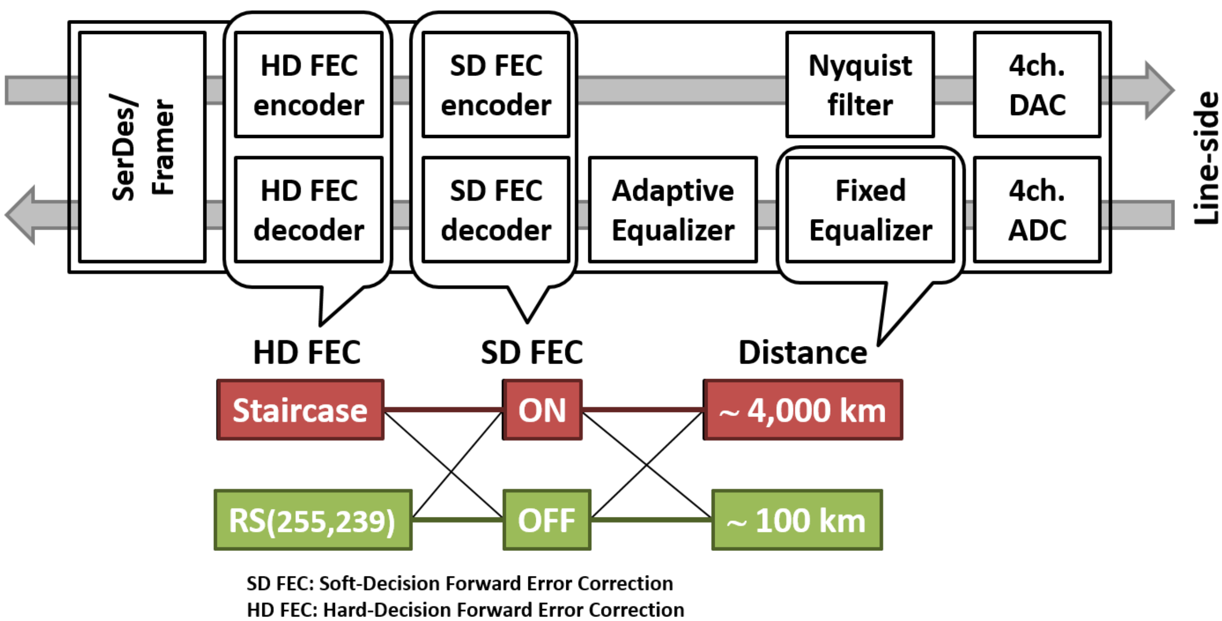

Fig. 3. Block diagram of a low-power DSP. OTN Framer and 4ch DAC are integrated in the chip. Lower part shows examples of Flexible DSP operation for 100km and 4000km transmission reach with optimized performance and power dissipation.

Functional optimization with regard to power consumption has been realized with selectable FEC and CD compensation options for trade-offs on performance requiring higher computational complexity. State of the art 7nm CMOS technology can achieve DSP for higher data rates such as 600 Gb/s (64Gbaud and 64QAM) while reducing the power consumption even further. A 7nm DSP for 400ZR application needs to have less than 10W power dissipation in order to fit into a 15W transceiver module**.** The DSP has been designed to provide flexibility where the performance and power dissipation can be optimized for the application. Figure 3 shows an example of such optimization for application range 100km and 4000km. The same transceiver can be used for metro and short reach applications by suitably selecting the options of FEC elements, equalizers for the CD compensation and Nyquist filter to optimize the power dissipation by 20-25% [5].

Silicon Photonics in Integrated Transceiver

As discussed earlier, higher level of photonic integration is key to the development of the next generation smaller size 400G transceiver modules. State of the art Silicon Photonics is a promising platform for lower cost integrated photonic devices which can leverage mass production capability of CMOS technology [6]. Silicon photonics based Modulators, Ge PDs, polarization beam splitter/combiners, polarization rotators, grating couplers and coherent mixers have been demonstrated for 64Gbaud applications in 400ZR module. Insensitivity to temperature and humidity in silicon photonic devices such as modulators eliminate the need of TEC and for temperature control and shrink the package size and eliminate hermetic sealing. Recently, silicon photonics based COSA devices have been reported [6].

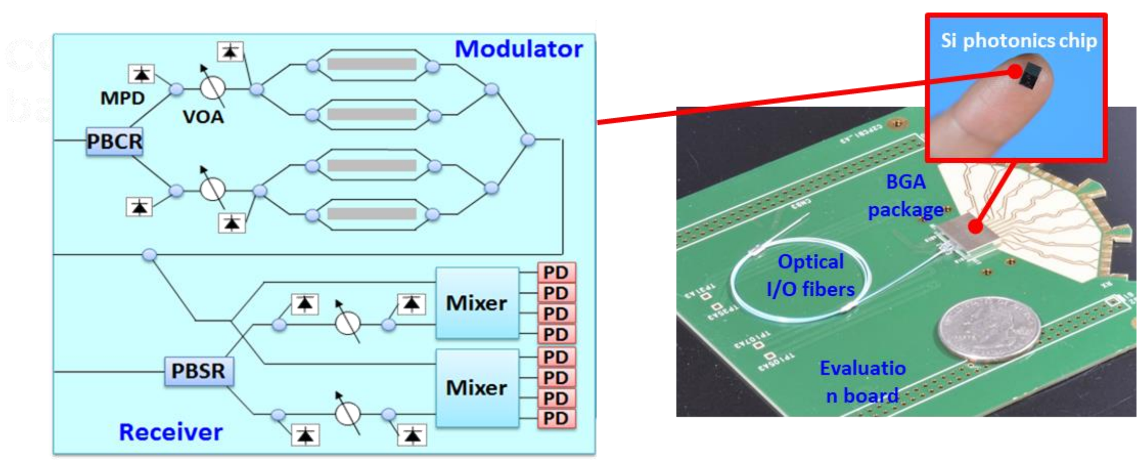

Fig. 4. Silicon Photonics Coherent Optical Sub-assembly (COSA) device schematic

Figure 4 shows a schematic of the Silicon Photonics COSA device. All elements of the optical transceiver except the laser are integrated into a single package. These include two inphase/quadrature (IQ) modulators, a polarization beam combiner and rotator (PBCR), a polarization beam splitter and rotator (PBSR), couplers, a coherent mixer, and photo diodes are integrated into a single Si Photonics chip. The Si Photonics chip is co-packaged with a 4-channel modulator driver IC and 4-channel trans-impedance amplifier IC. Three edge-coupled fibers are used as the optical interfaces for the input port from the laser, signal output port from the modulator, and signal input port to the receiver. The input port from the laser is a polarization maintaining fiber, and the other ports are non-polarization maintaining fibers. Light output from the laser is shared between the modulator and the coherent receiver. As shown in the picture on the right, the package is non-hermetic 2.2mm in height and does not need TEC. The non-hermetic packaging of the device also allows optical edge coupling without a lens. It also includes a flexible printed circuits (FPC) for DC and RF connections which makes it suitable for the next generation small size transceiver modules.

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Whitepaper

December 2020

Coherent Technology Accelerating the Whitebox Revolution

Introduction

The COVID-19 pandemic has accelerated the adoption of digital infrastructure in all walks of the society. In order to address the growing bandwidth demand of the modern communication networks, the service providers and hyperscale datacenter operators continue to advance the data rate and architecture of the optical networks. Coherent technology is a key enabler of the advances in the data transmission rates from 100G to 400G and future 800G. Compact transceiver modules incorporating coherent DSP and silicon photonics technologies in the CFP(2) and QSFP from factors have been standardized. In addition, networks architecture is evolving to adapt to the trends in the disaggregation of hardware and related open source software. The leading equipment providers in the industry currently have networking products which support disaggregation to different degrees. At least two network equipment integrators are offering whiteboxes which are highly disaggregated using standard module interfaces and transponder abstraction interface (TAI) and network operating system (NOS) software. Disaggregation of the hardware from software offers several benefits such as incorporation of the latest technologies independent of the product cycle. Additional benefits include adaptation of APIs and tools for designing and optimizing optical-transmission paths and establishment of “network resource discovery” and an automatic-optimization method for a multi-vendor environment [1].

In this whitepaper we provide an overview of trends in the evolution of the disaggregated whiteboxes enabled by coherent interfaces and open source software based NOS.

Coherent Modules

Traditionally, the network equipment has been built using proprietary hardware and software. The transponders and transport switch boxes consist of standard modules on the client interfaces, whereas the line side interfaces have traditionally been proprietary. Standard modules offer the benefit of interoperability and sourcing from multiple vendors thereby lowering the cost. Standardization of optical parameters and FEC in coherent interfaces on the line side at 100G, 200G and 400G by CableLabs and OIF, respectively has opened the door for plug-and-play coherent modules.

Figure 1 shows the evolution of the generations of coherent modules incorporating both the DSP and integrated photonic components. Over the years, the modules have reduced in size and power dissipation. Generally, the size of a module is limited by the optical components and the power dissipation is decided by the electronic components such as the DSP. The current generation of modules for 400ZR applications have OSFP/QSFP-DD form factor with total power dissipation of 15W, as specified by the OIF. The current generation of DSPs for this application is based on 7nm CMOS node and optical components use integrated silicon photonics.

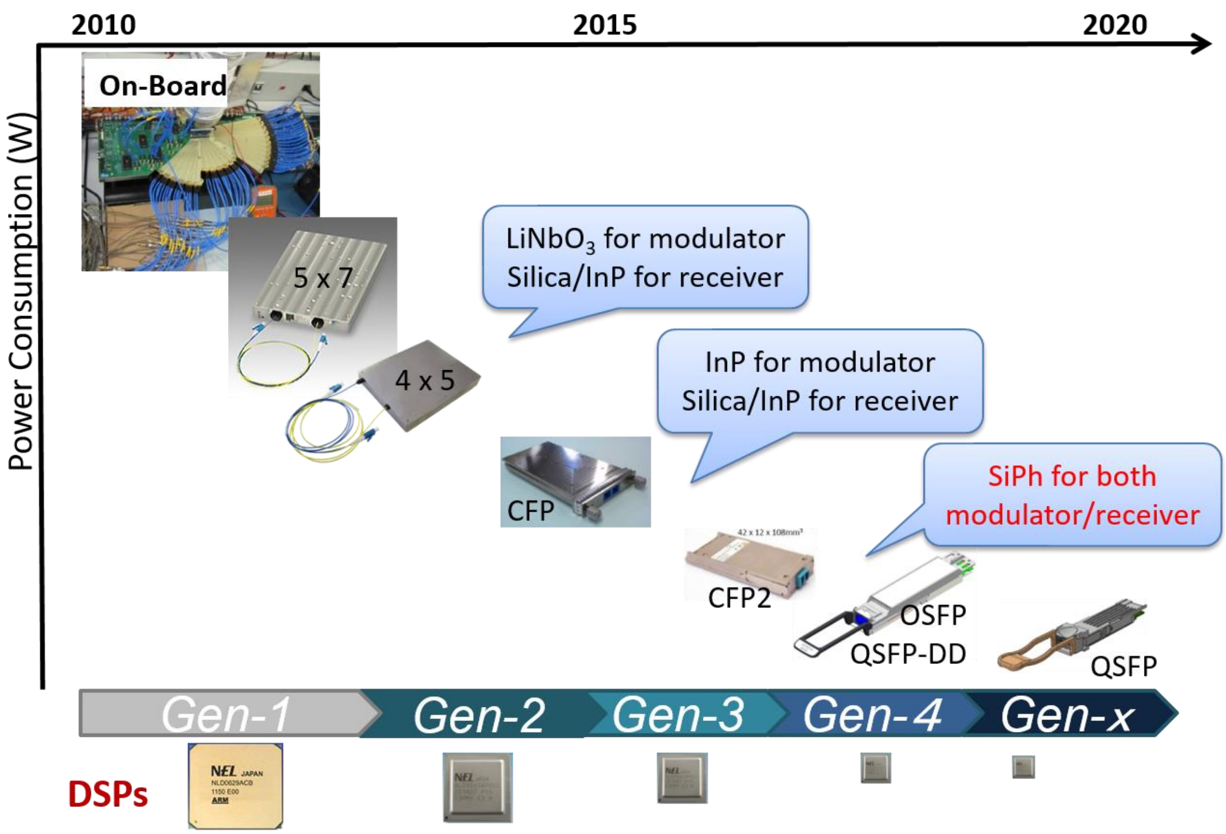
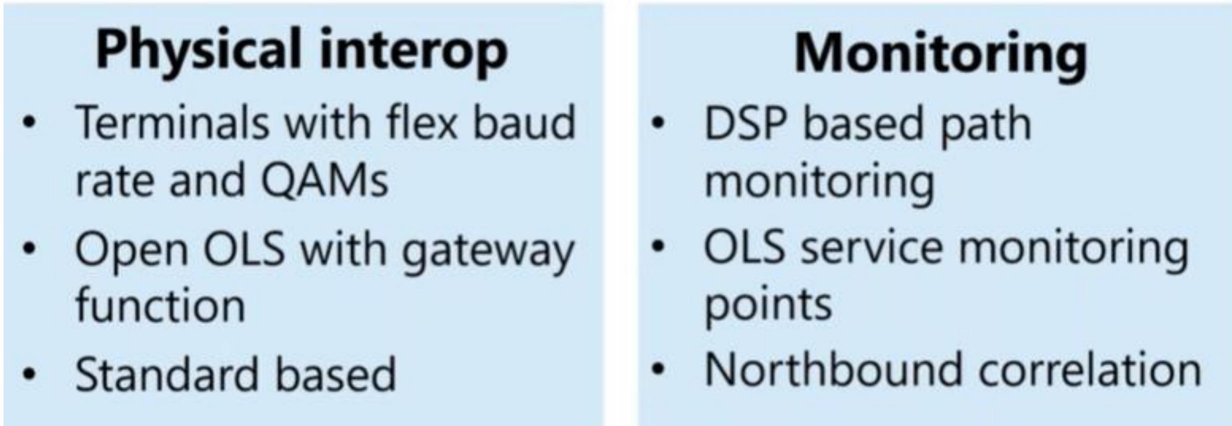


Figure 1: Evolution of the coherent modules and enabling technologies

The coherent technology has additional features which favor the disaggregation of optical transport hardware. It enables decoupling of terminals and line system. In a direct detection based transport systems, the terminals and the line systems have to be designed and optimized together to ensure system performance. In coherent systems, DSP can be configured to operate at different data rates and modulation formats and is able to compensate for signal impairments arising from SNR, chromatic and polarization mode dispersion. In addition, signal monitoring in DSP provides additional advantage. Benefits of these features covering physical interop and monitoring are listed below:



TAI and NOS Software

The management-control interfaces of transponders traditionally include many elements that are often proprietary, which has been a barrier to the disaggregation. First interface specification and architecture of TAI which enables disaggregation of hardware and software for transponders was proposed by NTT to the Open Optical & Packet Transport project group of the Telecom Infra Project (TIP-OOPT). The TAI and the software libraries of different vendors allow multi-vendor optical network elements to be managed and controlled using a common software code [2].

Figure 2 shows the whitebox packet transponders “Cassini” and “Galileo” which integrate an x86 processor, a switch ASIC and coherent transceivers on a modular-type open hardware. Their software architecture is similar to that in an OCP-compliant whitebox switch, which is easy to adapt to operation tools such as Open BMC and ONIE. This allows operators to automate operations independent of specific vendors. In addition, the TAI and vendor libraries enable multi-vendor compatibility of coherent modules CFP2-ACO/DCO. An “open” transponder applicable to virtualization technology has been created with whitebox approach.

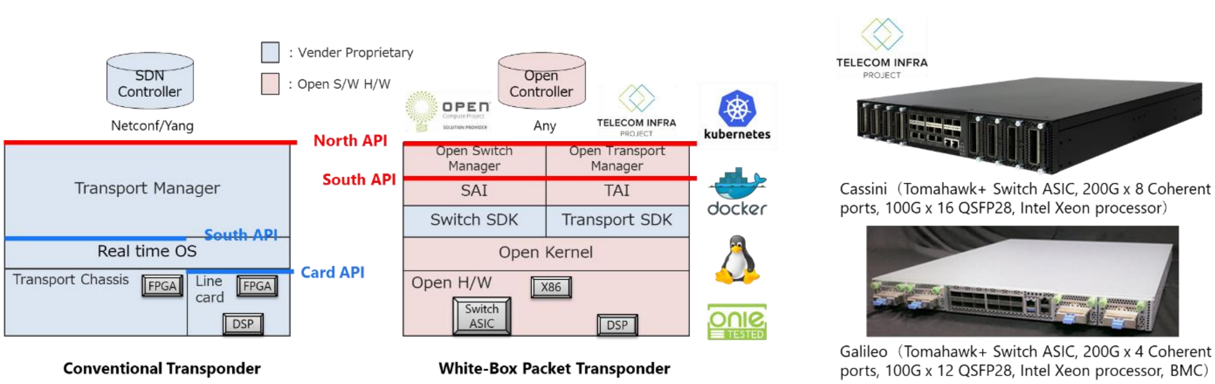


Figure 2: Conventional transponder (left) and Whitebox packet transponder (right)

Aiming to create practical and multi-vendor compatible line systems, some organizations such as TIP-OOPT and Open ROADM MSA are working to define an open API [3]. The goal of TIP-OOPT is to build an end-to-end simulation environment which defines the network models of the optical device transfer functions and their parameters [4].

An “open transport” concept with TAI is shown in the left diagram of Figure 3. If an open API such as TAI can be defined for the coherent DSP and optical module in the transmission equipment, the operators can use information about transmission-path performance parameters such as SNR, chromatic dispersion, polarization-mode dispersion, and received optical power for automatically designing and optimizing optical transmission paths. Open source library for route planning and optimization tool such as GNPy could be suitable for this.

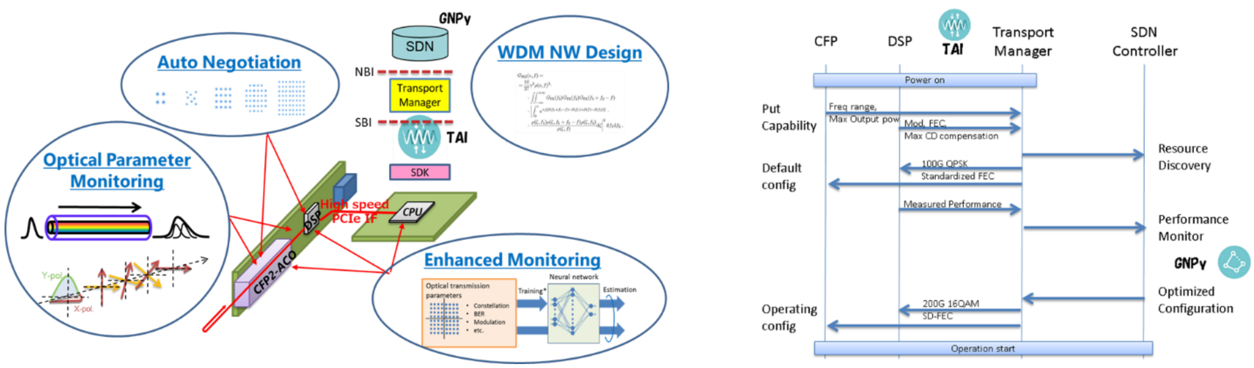


Figure 3: “Open Transport” Concept (left) and Auto provisioning (right)

An example of a whitebox packet transponder and GNPy on an SDN controller for automated provisioning is shown in the right diagram of Figure 3. When the whitebox packet transponder starts operating the CFP module and coherent DSP send information about the capability of the components such as DWDM frequency range, maximum optical output power, modulation format, FEC type, and maximum chromatic-dispersion tolerance to the transport manager and SDN controller. The SDN controller keeps track of the resources on the network. At the same time, the transport manager connects to the opposite equipment via default 100G QPSK mode with staircase FEC, and then measures the performance (received optical power, received SNR, etc.), and sends the measurement result to the SDN controller. The SDN controller compares the performance values measured by the transport manager with the margin of the optical transmission path designed using GNPy, selects the optimal communication mode, and sends the operational configuration to the transport manager. In the example in the figure, there is a surplus OSNR margin in the optical-transmission path, so 200G 16QAM (with larger bandwidth than 100G QPSK) is selected as the configuration for the operation.

In order to make auto provisioning available on multi-vendor environment, it is necessary to define some new APIs on the TAI and to standardize the automation procedure. The latest optical fiber monitoring technology with coherent DSP such as visualizing longitudinal signal power profile [5] will be a key enabler of automated network design over multiple spans.

Enhanced monitoring and analysis are made possible by implementing the latest machine-learning applications by using x86 processor and Linux-based architecture of the whitebox.

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