OcNOS® Packet Optical Transport

Overview

The exponential growth of data transmission, estimated at approximately 25%–50% year-over-year, primarily driven by on-demand content, bandwidth-hungry mobile apps, high-definition video streaming, and new cloud-based IT applications. Traditional optical transport systems with capacity of 10 Gbps per channel are unable to keep up with the massive scale and unpredictable traffic patterns and hence techniques to increase optical bandwidth per channel within the same optical fiber efficiently and economically is the only viable solution for next generation data transmission systems.

Methods to increase optical bandwidth cost-efficiently through wavelength-division multiplexing (WDM) have begun to get more complex and therefore more technically challenging to implement. The recent advent of coherent digital optical transmission has increased the native capacity of a fiber optic link multi-fold, versus a transmission modulation of simple on/off such as in 10G WDM networks. Coherent transmission modulation encodes information via phase and polarization, and the permutations of these variables are many times greater than on/off keying in traditional WDM systems.

1.1 Scope

The scope of this article is to review the progress and techniques used to increase optical channel capacity from 2.5Gbps to 100Gbps and beyond, with a particular focus on coherent transmission technologies, that has been proven to deliver cost-effective and highly reliable optical transport.

1.2 Audience

Packet Optical System Architects, Designers, Developers, Integrators and the technical community interested in Next Generation Optical Transport Systems.

1.3 References

1. Rongqing Hui, Maurice O'Sullivan, in Fiber Optic Measurement Techniques, 2009
2. Coherent WDM Technologies. Infinera whitepaper
3. Edgecore 'Cassini' Packet Transponder announcement for TIP project Nov. 8, 2017
4. NeoPhotonics Photonic IC Enabled Coherent Optical Systems white paper

Use Case Description

The use case targets Metro-DCI and Ultra-long-haul transmission with bandwidths of nx100Gbps with the goal of using existing fiber and reducing cost per bit and power per bit.

1.4 Metro-DCI

The largest cloud infrastructure operators and internet content providers are moving from leasing bandwidth from service provider's networks to leasing or buying dark fibers and building private networks. These networks are increasingly dependent on higher speed optical solutions. Traffic between data centers is increasing at a faster rate than traffic between users and the data centers.

Many enterprises are moving from operating their own datacenter to cloud based services that offer lower cost and greater flexibility to scale as their needs increase. This transition is leading to larger data centers where resources are consolidated. The interconnect requirements for these mega-data centers are driving demand for solutions that are optimized for these point to point links. Instead of many smaller data centers with moderate connectivity requirements, these mega-data centers require massive bandwidth over fewer paths. This architecture reduces the need for granularity and places the highest value on cost per bit.

Traffic patterns in the cloud networks are different from traditional data centers. Where the traditional network has a lot of north-south traffic between the servers and users, cloud networks have far more east-west traffic between servers. This traffic is used for synchronization and load balancing to maximize the utilization of available resources.

1.5 Long Haul Networks

Long haul terrestrial networks link major population centers within continents, spanning distances from 1,500 km to more than 2,500 km. Today's cloud networks are constantly mirroring data between servers in geographically diverse locations.

Cost effective upgrades and expansion to 100 Gbps and above is necessary to meet this growing need for data. Long haul terrestrial and subsea networks must be upgraded to provide higher bit rate dense wavelength division multiplexing (DWDM) technology to carry data from different sources simultaneously.

Long haul networks put a high value on performance. The ability to communicate over longer distances reduces the number of regeneration stages, where signals are converted from the optical domain to electrical and back. This can have significant cost savings to the overall network.

In addition to prioritizing reach, it is important to maximize the amount of traffic on each fiber, known as the spectral efficiency. Coherent technology has very high spectral efficiency and enables network operators to maximize their utilization of this constrained resource.

Business Model

Coherent systems provide a much higher spectral efficiency and simpler transmission infrastructure. A very compelling business case can be made in favor of a converged open network platform that integrates the packet switching and optical transport driving down CAPEX and OPEX for data center and service providers.

Present Mode of Operation

The necessity to meet the performance and ever-changing needs of the hyperscale cloud has created the demand for higher bandwidth requirements on transport networks that interconnects data centers. Traditional systems are leveraging DWDM to increase transmission efficiency leading to higher bandwidth across the same fiber.

DWDM is a technology that multiplexes several data signals on to a single fiber using different wavelength for different data signal. It increases the capacity of embedded fiber by assigning incoming data signals to different wavelengths and then multiplexes the resulting signal onto a single fiber.

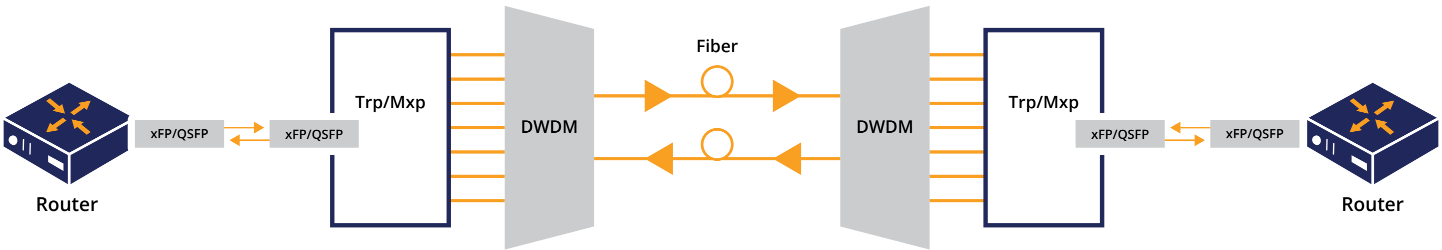

Figure 1: DCI – Optimization using DWDM

This traditional way of DCI for high bandwidth and extended reach is not very cost effective, requires more rack space and has vendor lock-in.

To address these issues of traditional DWDM system, several organizations started researching on the idea of Open Packet DWDM which combines packet switching and DWDM technology for metro and long-haul fiber optic transport networks. Facebook released the first version called Voyager with other open compute ODMs following suit.

Future Mode of Operation – Transformation

This section focuses on the advancement of lightwave transmission using Coherent technology where transmission modulation encodes information via phase and polarization, and the permutations of these variables are many times greater than on/off keying in traditional WDM systems.

1.6 Transmission (Modulation) Principle

At its most basic, coherent optical transmission is a technique that uses modulation of the amplitude and phase of the light as shown in Figure 2, as well as transmission across two polarizations as shown in Figure 3, to enable the transport of considerably more information through a fiber optic cable. Using digital signal processing at both the transmitter and receiver, coherent optics also offers higher bit-rates, greater degrees of flexibility, simpler photonic line systems, and better optical performance.

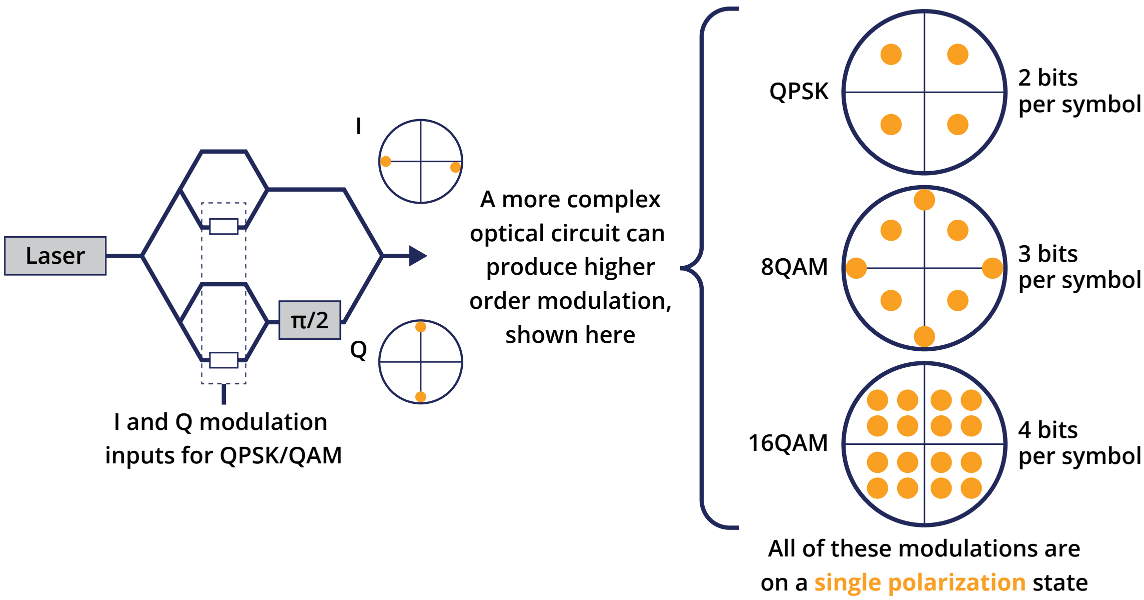

Figure 2: Higher order amplitude and phase modulation. *Source: Infinera.*

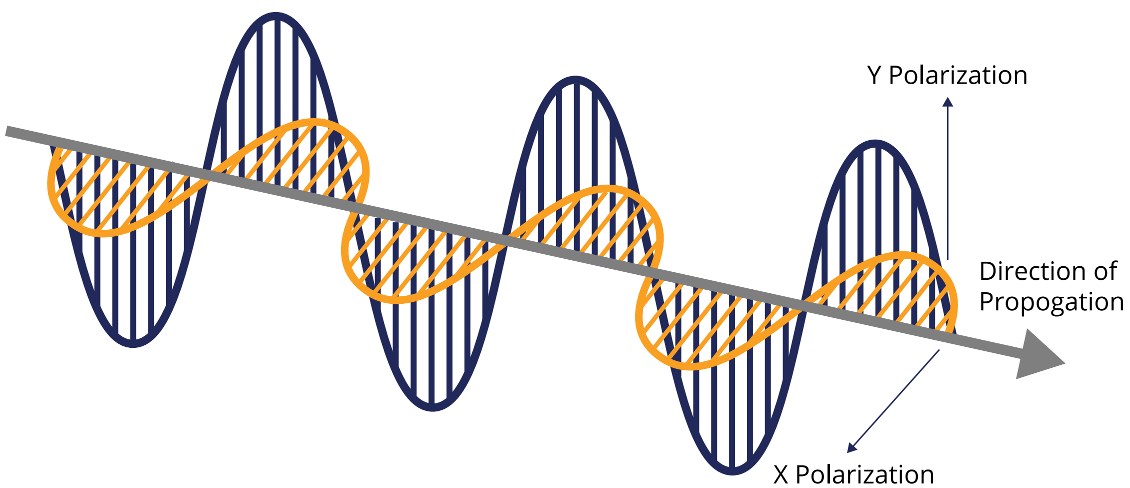

Figure 3: Optical Signal Polarization. *Source: Infinera.*

Note that polarization multiplexing can effectively double the spectral efficiency of a given modulation technique while using the same PM receiver. In this case a symbol is the combination of amplitude/phase states and polarization states, which can be referred to as a "dual-pol symbol."

1.7 Receiver (Detection) Principle

The key feature of a "coherent" system is characterized by its capability to do "coherent detection," which means that a receiver can track the phase of a transmitter (and hence have "phase coherence") so as to extract any phase and frequency information carried by a transmitted signal.

Coherent detection originates from radio communications, where a local carrier mixes with the received RF signal to generate a product term. As a result, the received RF signal can be demodulated, or frequency translated.

A block diagram of coherent detection is shown in Figure 4. In this circuit, the received signal m(t) $\cos(\omega_{sc}t)$ has an information-carrying amplitude m(t) and an RF carrier at frequency ω_{sc}, whereas the local oscillator has a single frequency at ω_{loc}. The RF signal multiplies with the local oscillator in the RF mixer, generating the sum and the difference frequencies between the signal and the local oscillator as described by the following equation:

$m(t)\cos(\omega_{sc}t)\times\cos(\omega_{loc}t)=m(t)\{\cos[(\omega sc+\omega_{loc})t]+\cos[(\omega_{sc}-\omega_{loc})t]\}/2$

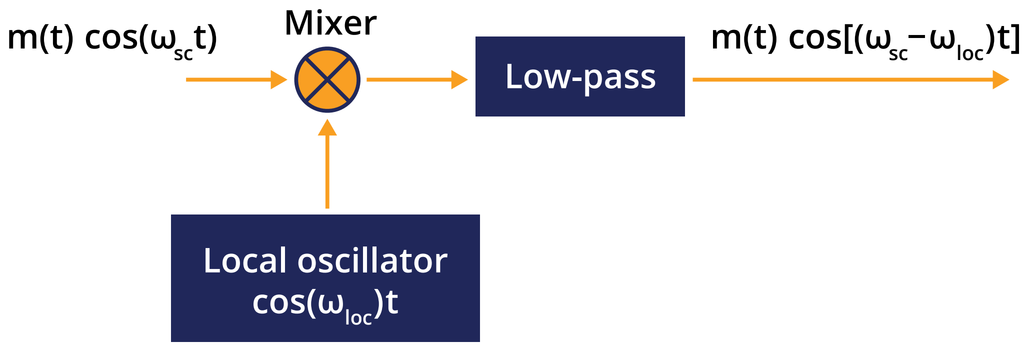

Figure 4: Block diagram of coherent detection in radio communications. *Source: ref [1]*

A lowpass filter is usually used to eliminate the sum frequency component and thus the baseband signal m(t) can be recovered if the frequency of the local oscillator is equal to that of the signal ($\omega_{loc} = \omega_{sc}$). For coherent detection in lightwave systems, although the fundamental principle is similar, its operating frequency is many orders of magnitude higher than the radio frequencies; thus, the required components and circuit configurations are different.

Coherent optical technology forms the foundation of the industry's drive to achieve transport speeds of 100G and beyond, delivering Terabits of information across a single fiber pair. Digital signal processors electronically compensate for Chromatic and Polarization Mode Dispersion (CD and PMD) to enable robust performance over old and new fibers alike and eliminate the need for dispersion-sloped compensating modules from the photonic line. Coherent optics enables greater network flexibility and programmability by supporting different baud rates and modulation formats. This results in greater flexibility in line rates, with scalability from 100G to 400G and beyond per single signal channel, delivering increased data throughput at a lower cost per bit.

Advanced coherent optical technology has a few attributes that are key for lower CAPEX and OPEX including:

- **High-gain soft-decision Forward Error Correction (FEC)**, which enables signals to traverse longer distances while requiring fewer regenerator points. It provides more margin, allowing higher bit-rate signals to traverse farther distances. This results in simpler photonic lines, less equipment, and lower costs—while, of course, increasing bandwidth significantly.
- **Spectral shaping**, which provides greater capacity across cascaded Reconfigurable Optical Add-Drop Multiplexers (ROADMs), resulting in increased spectral efficiency for super channels. Beyond 100G, using a single carrier could become extremely expensive and impractical to design using today's electronics. Super channels will be the next wave where 'n' carriers are muxed together in a single line card to create 'n' times the transmission capacity out of single port. This allows the use of low frequency clocking electronics that is $(1/n)^{th}$ the super channel transmission capacity and is available today. By deviating from the ITU grid 50 GHz grid, the 'n' carrier super channels combined will have the same spectral width as a single ITU channel. Super channel wavelength specificity coherent detection makes it possible to recover each muxed channel reliably without anti-aliasing distortion. Spectral shaping is critical in flexible grid systems because it allows carriers to be squeezed closer together to maximize capacity.
- **Programmability**, which means the technology can be tailored for a wide variety of networks and applications and the same card can support multiple modulation formats and/or different baud rates, enabling operators to choose from a variety of line rates. Fully programmable coherent transceivers provide a wide range of tunability options with fine granularity between incremental capacities, enabling network operators to make use of all available capacity and convert excess margin into revenue-generating services.
- **Strong mitigation to dispersion**, which offers better optical performance at higher bit-rates. Coherent processors must account for dispersion effects after the signal has been transmitted across the fiber, including compensating for CD and PMD. The advanced digital signal processors in coherent optics take away the headaches of planning dispersion maps and budgeting for PMD by mitigating these effects. Additionally, coherent processors improve tolerances for Polarization-Dependent Loss (PDL) and must rapidly track the State of Polarization (SOP) to avoid bit-errors due to cycle slips that would otherwise affect optical performance. As a result, operators can deploy line rates up to 400G per carrier across longer distances than ever; high bit-rate signals can even be deployed on old fiber that previously couldn't support 10G.

Also, as transmission speeds move to 200G and 400G per channel through higher order modulation protocols and higher symbol rates, even higher performance optical components are required.

Optical Transponder Physics

Optical component manufacturers are fabricating Digital Signal Processors (DSPs) that maximizes per-fiber DWDM capacity seamlessly, from 5Tbps for tens of thousands of kilometers Ultra Long Haul (ULH) to over 30Tbps for 120km ZR transmission reaches, and further doubling the capacity by using both C-band and L-band. These new DSPs support flexible line capacities by combining multiple Baud-rates and modulation-formats, from 100Gbps/λ by 32GBaud Quadrature Phase Shift Keying (QPSK) to 600Gbps/λ by 64GBaud 64 Quadrature Amplitude Modulation (QAM) in order to support the above capacity and reach. Their high-speed real-time coherent processing at 64GBaud enables thousands-of-kilometers LH transport at 200Gbps/λ by Dual-Polarization (DP) QPSK, hundreds-of-kilometers Metro transport at 400Gbps/λ by DP 16QAM, or 120km ZR transport at 600Gbps/λ by DP 64QAM.

Figure 5 is an example of 400G optical transponder transmission front-end. The transmission distances are first-order estimate and depend on inter-office distances, fiber types, and optical amplifier types.

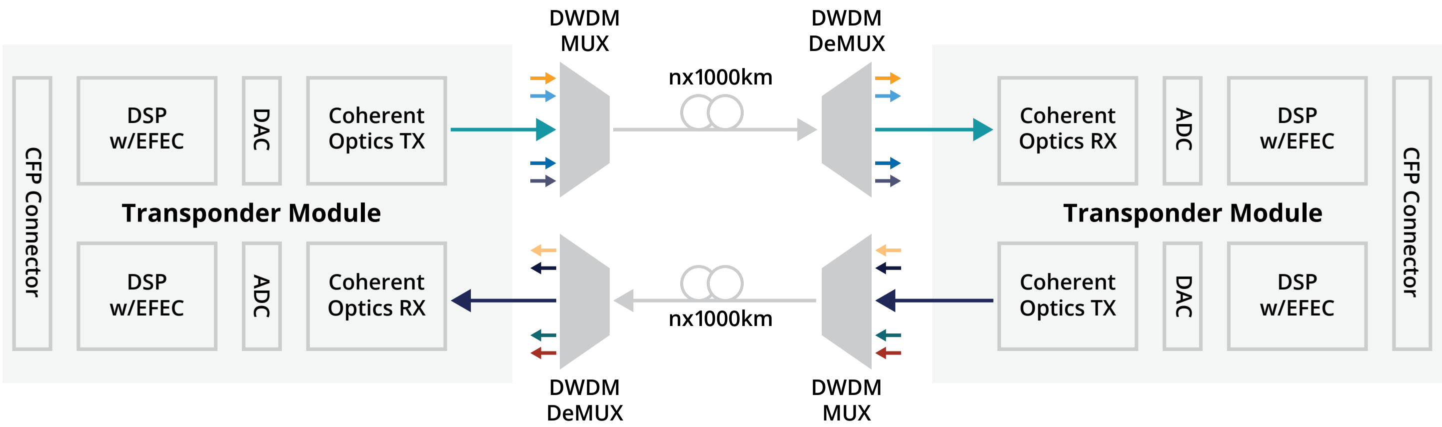

Figure 5: Block Diagram of Coherent Optical Transponder.

The Solution Design

IP Infusion has decided to port OcNOS on Open Optical Packet Transponders leveraging the Cassini platform from Edgecore.

Edgecore Networks, recently announced the general availability of its Cassini open packet transponder - the industry's highest capacity and first modular whitebox packet transponder offering a flexible mix of 100 Gigabit Ethernet (GbE) packet switching ports and 100/200 Gbps coherent optical interfaces for data center interconnect and service provider optical network use cases. Cassini is an open disaggregated product that reduces network operator costs and allows for choice of optical and software technology. Cassini supports coherent DSPs and optical transceivers from leading optical partners such as Acacia Communications, Finisar Corporation, Fujitsu Optical Components Ltd., NTT Electronics and also complies with the Open Networking Foundation (ONF) Open Disaggregated Transport Network (ODTN) platform guidelines.

The ONF community has incorporated Cassini as an open packet transponder platform into the ONF's ODTN reference design, providing a set of open source and commercial software options for deploying Cassini in an optical network.

Besides switching and routing functions, OcNOS also is responsible for managing the Ethernet as well as Optical interfaces of the transponder thus eliminating the need for additional hardware and software making it a very cost effective and compact Optical Transponder solution.

Features & Building Blocks for the Solution

The Cassini packet transponder is a fully open source hardware design, as Edgecore has contributed the full design to TIP. Cassini is a 1.5RU form factor with system throughput of 3.2Tbps. Cassini has sixteen fixed 100 Gigabit Ethernet QSFP28 ports, plus eight line card slots to incorporate a flexible mix of additional 100GbE ports or ACO/DCO optical ports based on coherent DSP and optical transceivers from leading optical technology partners. The following line cards are available, providing the network operator with a scalable pay-as-you-grow platform.

- 100GbE Line Card: 2 x 100GbE QSFP28 with MACsec
- DCO Line Card: 1 x 100G/200G CFP2 with MACsec, supporting DCO pluggable transceivers including the Acacia AC200 CFP2-DCO Module
- ACO Line Card: 1 x 100G/200G CFP2 with NTT Electronics ExaSPEED 200 DSP, supporting CFP2-ACO Coherent Optical Transceiver modules from Finisar and Fujitsu Optical Components

Figure 6 represents the components of a fully integrated Open Optical Packet Transponder system.

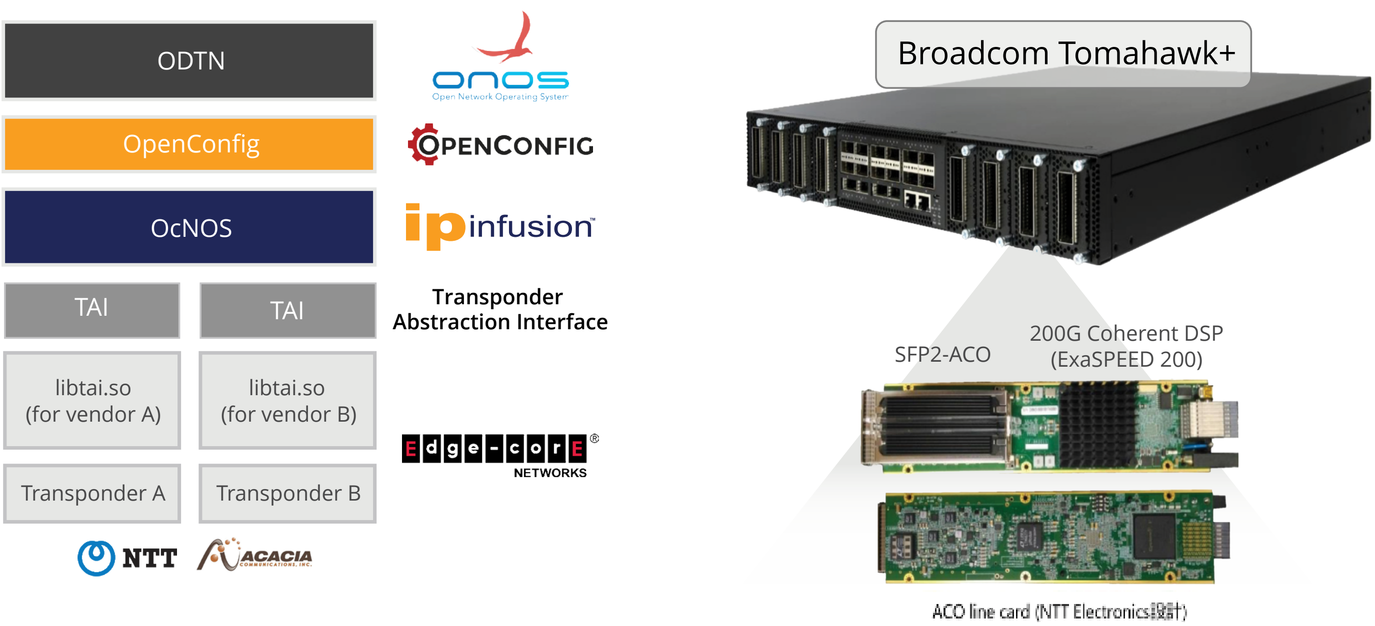

Figure 6: Fully integrated Packet Optical Transponder.

As an open network platform, Cassini supports commercial software offerings including OcNOS from IP Infusion, a leading whitebox switching & routing NOS optimized for service provider and data center interconnect use cases.

OcNOS will support EVPN-VxLAN for L2 and L3 interconnect over multivendor ACO/DCO transponders for a larger eco-system and wider scope.

1.7.1 TRANSPONDER MANAGEMENT AND MONITORING

1.7.1.1 Receiver Management

Receiver front end modules for Analog/Digital Coherent Optics (ACO/DCO) includes a monitor photodiode and a Variable Optical Attenuator (VOA) that can be tuned for improvements of up to 10 dB for dynamic range of signal input power thereby extending fiber reach. This functionality is currently achieved by comparing the received signal spectrum against prefabricated statistical templates and making pre-defined adjustments for optimal performance, but various North Bound Interfaces (NBI) can be enabled in OcNOS for manual/interactive adjustment of relevant parameters as/if deemed necessary. For example, one could select standard 7% FEC for 6.8 dB gain or 15% Soft-Decision FEC for 8.2 dB gain to match transmitter FEC mode. Receiver also needs to be configured for the type of modulation i.e. DP-QPSK, DP-8QAM, DP-16QAM, etc. to match the transmitter modulation.

1.7.1.2 Transmitter Management

Advanced transponders are capable of changing baud rates and modulation order on the fly to adjust reach and bandwidth. This feature can be enabled in OcNOS for tailoring transmitter characteristics via NBI to adapt to the various deployment requirements. For example, in DCI use case, the typical interconnection distance is usually shorter than 80km. As a result, the coherent system design is very different from that of a long-haul system. For this application, one can try to maximize the baud rate and constellations i.e. number of symbols representing amplitude and phase of the optical signal thereby increasing spectral efficiency and effectively transmission bandwidth such that the Optical Signal to Noise Ratio (OSNR) is still around 30~32dB, which is significantly relaxed compared to typical metro-core or long-haul systems. Similar principle can be applied to optimize spectral efficiency in metro-core and long-haul transmissions and still maintain sufficient OSNR to reliably recover the signal at the receiver. Another parameter could be DP-QPSK, DP-8QAM, DP-16QAM modulation selection for various spectral efficiency level.

1.7.1.3 Transponder Monitoring

The DSP monitoring tools provided by the module vendors currently provide pre and post Forward Error Correction (FEC) Bit Error Rates (BER) along with the constellation graphs. This information can be integrated and made available via the OcNOS Digital Diagnostic Monitoring (DDM) framework which may then be lifted via NBI to the management plane for further action.

Also, OcNOS DDM will be utilized for monitoring *thermals* of these ACO/DCO modules and providing proper operating environment that is crucial in maintaining rated transponder characteristics for better OSNR and thereby guaranteeing optimum performance.

Summary

IP Infusion sees the benefits of long-distance packet optical transport with webscale performance and lower TCO to data center and service provider customers by extending the open network, disaggregated model to the integration of packet switching and optical transport technology.

OcNOS network operating system already supports a rich set of switching and routing features. Now, the introduction of OcNOS on Edgecore's Cassini packet optical transponder will help network operators easily extend and migrate existing metro and long-haul Dense Wavelength Division Multiplexing (DWDM) networks to add new 100G capacities and extend inter-DC L2 and L3 services.

ABOUT IP INFUSION

IP Infusion, the leader in disaggregated networking solutions, delivers enterprise and carrier-grade software solutions allowing network operators to reduce network costs, increase flexibility, and to deploy new features and services quickly. IP Infusion is headquartered in Santa Clara, Calif., and is a wholly owned and independently operated subsidiary of ACCESS CO., LTD. Additional information can be found at **http://www.ipinfusion.com**

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