Optimal transponder technology for transporting 800 GbE services in IP-over-WDM backbone networks

Serge Melle(1), Thierry Zami(2), Nicola Rossi(2), and Bruno Lavigne(2)
(1) Nokia Optical Networks, USA and (2) Nokia, Nozay, France
serge.melle@nokia.com

Abstract: This network study compares the benefit of Elastic Optical Transponders enabling 130GBaud WDM channels for transporting 800GE services, showing ability to minimize number of required EOTs per Gb/s in regional and long-haul networks. © Nokia 2023

1. Introduction

While IP and Optical network platforms often optimize for different design parameters, a common driver for continued innovation is the need for ever-greater scale and capacity, and lower power consumption. In this context, the latest generation of large-scale packet switching integrated circuits with 112Gb/s serializer/deserializer enable new routing platforms with 800 Gigabit Ethernet (800GE) interfaces [1, 2]. These provide greater network scale and lower power per bit, and allow further scaling of router-to-router interconnections in IP core networks. This leads network operators to seek high-performance coherent optic solutions able to efficiently support full-rate 800GE connections over a broad range of distances, including regional and long-haul backbone networks, while minimizing the need for Optical-Electrical-Optical (OEO) regeneration at intermediate points.

In this context, coherent optics able to operate at wavelength speeds of 800Gb/s or more provides network operators the tools needed to match router port speed upgrades with wavelength speeds, thereby maximizing end-end IP-Optical network scaling. Relevant and critical to this optimization is the ability of coherent optics to minimize the total number of coherent transponder interfaces needed. Also crucial is the ability to support full-rate 800GE transport to avoid rate-limiting IP router ports to speeds to less than 800Gb/s, which otherwise reduces port efficiency, uses more ports for a given network traffic volume, and increases network power consumption.

This paper investigates the use of EOTs able to operate at maximum bit rates of 800Gb/s and 1.2Tb/s and different WDM channel spacings, to transport 800GE IP traffic across regional, national and continental long-haul networks, as well as the associated impact on number of Elastic Optical Transponders (EOT) needed and maximum network capacity achieved.

2. Coherent Optic Transport Technologies

This study compares high baud rate coherent EOTs operating at three possible baud rates; up to 800Gb/s per wavelength at 95Gbaud (Gbd) in 112.5GHz WDM slots, or 106Gbd channels in 125GHz slots, and up to 1.2Tb/s per wavelength at 130Gbd in 150GHz WDM channels. These represent technology options currently or soon to be available for network deployment in support of IP network upgrades to 800GE speeds. EOTs operating at 130Gbd are enabled by the Digital Signal Processors (DSPs) implemented with 5nm Silicon CMOS node geometry, while the 95Gbd and 106Gbd solutions can be implemented in both 5nm and prior generation 7nm DSPs.

The capacity-reach performance of EOTs is calculated based on a Gaussian-noise model accounting for linear noises (amplified spontaneous noise of the crossed optical amplifiers and optical crosstalk) and non-linear noise from WDM transmission, complemented with penalties affecting optical signal to noise ratio (OSNR) due to optical filtering and polarization dependent loss undergone by the transmitted signals. Technologies such as high-gain Forward Error Correction (FEC), Probabilistic Constellation Shaping (PCS) and continuous baud rate adjustment have been shown to enable dramatic improvements in the capacity-reach performance of EOTs, within 1.5dB of the Shannon Limit [3, 4], and these performance gains have been assumed for all the coherent optics modeled in this study.

While short-reach Digital Coherent Optics (DCOs) such as 800ZR are expected to be available in pluggable QSFP-DD800 form factors used for 800GE client optics, their power consumption and performance makes them optimal for metro applications. High-performance 90-130Gbd optics implemented in larger non-standard DCO formats used as a pluggable or embedded optics in transponder-based systems are needed to enable scaling of regional and long-haul networks, with short-reach 800GE client optics to inter-connect routers to transponders.

3. Network Models & Traffic Assumptions

This study compares router connectivity and coherent transport options on three representative networks, which varied in size and scope, number of nodes, and link lengths as described in Table 1. All fiber links are assumed to be standard single mode fibers with 0.22 dB/km loss. The physical Quality of Transmission (QoT) for each technology is calculated over all optical connections, and accounts all impacts on OSNR as described above. Fiber span loss is

Table 1: *Key parameters of regional, national and continental long-haul networks modeled.*

Network Parameters	**G50 (without regeneration)**	**IND71**	**CONUS**
Network Type	Regional or national network depending on country size	National long-haul network	Continental network, such as USA or pan-European backbone
# Service / Core Nodes	42 / 8	63 / 8	63 / 12
# Fiber Links	88	97	99
Avg/Max Link Length	110 / 241 km	228 / 589 km	396 / 1221 km
Diagram / Topology small points are "service nodes" larger points are "core nodes"			

compensated by Erbium Doped Fiber Amplifiers (EDFA) featuring 5.5dB noise figure. Hybrid EDFA+Raman amplification is assumed for the span losses larger than 18 dB in the CONUS network due to the large geographical scope of the network, and enables improved capacity-reach performance to meaningfully reduce the number of EOTs. Unless otherwise stated, OEO regeneration in the transport domain is used only where needed to overcome either insufficient channel QoT or to mitigate wavelength contention along a Light Path (LP). If an appropriate path with available spectral resource cannot be found to serve a requested connection, it is rejected. Random service demands are incrementally added until reaching up to 1% of rejected capacity of overall requested traffic volume.

The network study assumes the use of IP routers at each node connecting to access/edge traffic via low-speed interfaces (ie: 100GE/400GE), and the resulting aggregated packet flows are routed into high-speed 800GE router ports that interconnect over an IP-over-WDM core network as shown above, provisioned with typical traffic engineering rules for average/peak packet flows and excess bandwidth for re-convergence events. The core-side router ports in this study exclusively resort to 800GE interfaces, under the assumption that use of a unified core router interface speed simplifies network deployment and planning.

The core nodes exchange the greatest amount of traffic between them in a meshed topology, while each service edge node exchanges traffic with its two closest core nodes. The traffic model assumes a tiered set of demands between service nodes and core nodes. The first set of traffic demands are fixed and constant, comprising 800GE traffic flows between service-core and core-core nodes, and are provisioned first. Subsequently, additional randomly drawn service demands of 800GE are added between service-core nodes, and core-core nodes, with a traffic mix of 66.6% service-core and 33.4% core-core.

The operating bit rate of the coherent EOTs is variably adjusted to co-optimize for maximum network capacity and minimize regeneration, and we study three options of granularity for the coherent data rates. For the first option modeled, wavelength speeds are adjusted with a granularity of N x 800Gb/s; thus all EOTs are limited to 800Gb/s speeds, including the 130Gbd EOTs which otherwise support a maximum capacity of 1.2Tb/s per wavelength. This option provides the benefit of enabling direct 1:1 mappings of 800GE services to a single 800Gb/s coherent carrier for all service connections, which simplifies service planning & provisioning. The trade-off is that additional regeneration sites may be added along the links too long to be bridged by the 800 Gb/s carriers, thus increasing the number of EOTs needed.

The other two options allow wavelength speeds to be adjusted with a granularity of Nx400Gb/s and Nx200Gb/s. This enables lower speed modes resulting in longer transmission reach and correspondingly fewer regenerators. It also enables operation up to 1.0Tb/s or 1.2Tb/s per wavelength for the 130Gbd technology. This can be done either by connecting via 800GE interfaces to multi-wavelength transponders which can distribute client traffic over multiple coherent carriers, or using break-out cables to split the 800GE interfaces from routers into either 2x400GE or 8x100GE client interfaces to multiple EOTs, albeit with greater complexity in client interconnection. This allows mapping of 800GE services to two or more coherent carriers, with the requirement that the coherent carriers are co-routed in order to ensure proper re-assembly of the 800GE service at the end of the link.

4. Results and Analysis

We utilize two metrics to compare the relative network economics associated with the different network architectures and coherent electro-optic types that were modeled, as follows:

$N_{EOT\,(100G)}$, is defined as the average number of coherent optics used, normalized to 100G of capacity.

Maximum Network Capacity (MNC) is the total network traffic volume in Tb/s provisioned until 1% of the requested throughput is rejected due to spectrum shortage. It reflects total capacity provisioned over single fiber pairs before an overbuild or a new fiber is needed.

Table 2: *Comparisons of N_{EOT} and MNC for different networks and EOT capacity granularity*

Network Types	Network Metrics	N x 800G coherent carriers			N x 400G coherent carriers			N x 200G coherent carriers		
		95Gbd	106Gbd	130Gbd	95Gbd	106Gbd	130Gbd	95Gbd	106Gbd	130Gbd
G50	$N_{EOT\,(100G)}$	0.291	0.267	0.263	0.28	0.255	0.228	0.27	0.261	0.206
	MNC	633	573	484	446	497	456	519	511	509
IND71	$N_{EOT\,(100G)}$	0.767	0.525	0.379	0.466	0.41	0.338	0.415	0.376	0.316
	MNC	582	528	446	389	446	444	369	384	401
CONUS	$N_{EOT\,(100G)}$	0.992	0.656	0.467	0.548	0.459	0.386	0.5	0.447	0.386
	MNC	518	469	392	286	279	274	300	286	274

Table 2 shows the values of these metrics for each network use case. Results were averaged over 100 different random traffic draws following the previously described service allocation and routing algorithm. Results show that higher baud rates always reduce the average number of EOTs needed, with 130Gbd EOTs needing the fewest number of interfaces. The greatest savings occurred with Nx800G granularity of coherent carriers, with savings up to 53% (43%) on CONUS (IND71). This is a direct consequence of the greater reach of 130Gbd EOTs over 95Gbd (106Gb) EOTs, which increases the number of regeneration sites needed by the latter by 61% (33%). This latter comparison is an intermediate outcome of our simulations not reported in Table 2.

When the granularity of the coherent carriers is adjusted to Nx400Gb/s or Nx200Gb/s to enable wavelength speeds of 200, 400 or 600Gb/s, better optimization of capacity-reach on each link avoids regeneration sites along any link, and for the 130Gbd solution, also allows 800GE demands to be aggregated into EOTs operating up to 1.2Tb/s. This ability of transponders to map Nx800GE services over one or more coherent carriers further lowers the number of EOTs needed. In such cases, the 130Gbd solution exhibits the greatest savings in EOTs, up to 30% (29%) on CONUS (IND71) at Nx400Gb/s granularity, and up to 23% (24%) on CONUS (IND71) at Nx200Gb/s granularity compared to 95Gbd solutions, and provides EOT savings in the range of 14-16% EOT compared to 106Gbd solutions, due to the greater reach performance of the latter over 95Gbd solutions. For the G50 network, the ability of 95Gbd and 106Gbd EOTs to cover most of the transparent LPs at 800Gb/s reduces differences in EOT use, while the number of 130Gbd EOTs needed further drops thanks to 1.0-1.2Tb/s channels on the shortest LPs.

MNC is maximized when EOTs run at 800G per carrier, reflecting the greater spectral efficiency obtained when operating all channels at this data rate. When operating at Nx400 or Nx200Gb/s granularity, MNC declines since some coherent carriers work at speeds of 200, 400 or 600Gb/s to avoid regeneration as much as possible, which reduces the average spectral efficiency and triggers wavelength contention at lower network traffic volumes. This effect is less pronounced in both the G50 network, as the smaller scope of the network leads to most links operating with 800Gb/s granularity of the coherent carriers, and in the CONUS/IND71 networks with 130Gbd EOTs, as the increased capacity-reach performance allows a greater proportion of LPs to operate at 800Gb/s speeds or higher.

Table 2 also shows that MNC compared across the different EOTs tends to vary either higher or lower, in many cases primarily due to the different route topologies of each network. This tends to confirm conclusions of prior studies [5] that spectral efficiency in WDM terrestrial networks will henceforth see minimal change with new high-performance EOTs; a direct result of all high-end EOTs now operating close to the Shannon Limit.

5. Conclusions

In this paper we demonstrate the benefit of migrating to 130Gbd coherent technology to reduce the relative number of EOTs needed in regional, national and continental long-haul WDM networks. These savings stem from the increased reach at 800Gb/s speeds of 130Gbd EOTs, which is optimal for transport of 800GE services when scaling IP networks, and secondarily by the ability to operate up to 1.2Tb/s along shorter network light paths. Moreover, we demonstrate that adjusting the channel data rate granularity of EOTs to transport 800GE services over multiple coherent carriers further reduces the number of EOTs required by minimizing the quantity of deployed regenerators.

6. References

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