Optimal Line-Rates for IP-over-DWDM in Metro and Core Networks: Comparison of ZR+ and Xponder Architectures

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Abstract. With the advent of pluggable ZR/ZR+ and embedded optics at 400Gb/s and beyond, we consider optimal network architectures and line-rates in access, metro and core networks. Simulations across a US-core network are demonstrated. ©2022 The Author(s).

1. Introduction

Coherent optics has matured with probabilistic constellation shaping [1] becoming a standard feature in detection of multi-QAM supporting transmission systems. With 7-nm CMOS integration process technology used to create miniature DSPs [2] that can fit into pluggable as well as embedded line interface designs for access, metro and core networks. As has been the case during the adoption of 100Gb/s technology, there seems to be a similar bifurcation of approaches as line-rates cross the 400Gb/s mark. This bifurcation is at two levels: (i) the size/power consumption of transmission sub-systems, and (ii) the architectural alternatives to support multiple line-rates across network hierarchy. The network is broadly divided into access, metro and core segments based on distance, reach, capacity and equipment size. A key question going forward is what are the appropriate technology choices and evolution models for each network segment from the perspective of adoption of high-line-rate coherent optics.

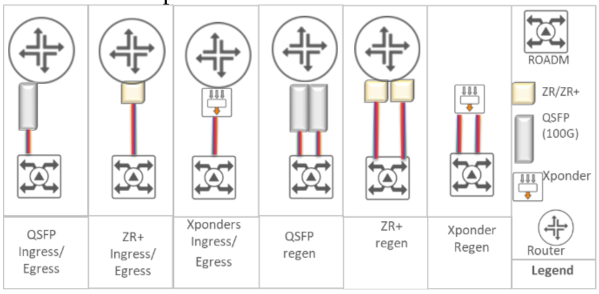
To that end, we outline architectural choices and then lay out options in terms of technology evolution. Clearly, such exercise must also consider the IP layer. Particularly, adopting an IP-over-WDM architecture is envisioned as paramount to effectively supporting the near doubling of traffic expected every other year. To implement the IP-over-WDM architecture, there are three main models: using pluggable coherent optics such as QSFP28 (100Gb/s), ZR, ZR+ (at 400Gb/s) that are plugged into routers and which feed into WDM line systems (ROADMs) and embedded optics-based transponders-muxponders (Xponders) (where routers are used only at either ends of a lightpath [3, 4, 8]. Xponders support specialized optical functions such as multiple line-rates, higher baud-rate and longer reach and impactful compensation of the received signal. In the Xponder model, the signal expresses through nodes that do not require a lightpath to be dropped/processed/regenerated, using a ROADM function at the optical layer.

The goal of this paper is to understand from a CapEx (hardware count) perspective, which model is best suited for a particular network segment and optimize transport line-rates based on traffic profiles. A typical service provider network comprises of users, both residential and enterprises that are connected to access rings, using client interfaces. Larger enterprise customers are connected to metro rings, which also provide aggregation of traffic from access rings. Metro rings generally use Provider Edge routers (PE-routers) at the IP layer, supported by ROADMs at the optical layer. In addition to these, private leased-line traffic enters the metro network in the form of OTN clients mapped onto WDM channels using OTN ADMs [7]. The core network usually has a mesh topology and consists of nodes that have larger Provider (P) routers, supporting logical full-mesh capabilities at the IP layer, along with OTN cross-connects (XCs). The routers and OTN XCs are connected to multi-degree ROADMs through either pluggable coherent modules or embedded coherent engines (i.e., Xponders).

We have a choice of technologies: using 100Gb/s QSFP28 (100ZR), modern 400Gb/s ZR/ZR+ or 400-800Gb/s Xponders. Each of these three choices can be implemented in the access, metro and core network. This paper attempts to answer the question, as to which of these options best match a particular network architecture.

2. Architectural Considerations

We consider the three technology choices outlined towards the end of the previous section aligning to the way the industry approach towards leveraging routers, pluggables and Xponders in meeting provider requirements for IP-over-WDM (Fig. 1) [4]. The QSFP28 and QSFP-DD are used in similar manner – these are plugged into routers at ingress and egress nodes, as well as at regenerator sites. The pluggables are connected to a ROADM line-system. At a regen site, the WDM signal is demultiplexed by a ROADM, and the specific wavelength is dropped onto a router via a pluggable (QSFP28/QSFP-DD). The router facilitates local traffic grooming of the signal and sends it back to the ROADM line system. In the approach of using Xponders, traffic from routers is sent using grey optics at the ingress and egress nodes into an Xponder. Typical Xponders today can tune across multiple-line-rates [8, 9] (from 300Gb/s to 800Gb/s). We consider a 95Gbaud engine [6] that can serve line-rates from 400-800Gb/s depending on traffic requirements, reach limitations and number of interim nodes (ROADMs). Whenever the signal must be regenerated using Xponders, it is done so without resorting to a router, as the Xponder is assumed to provide through its backplane complete regeneration capabilities (Fig. 1). Shown in Fig. 1 are the reference reach distances possible for the various technologies being considered: the QSFP28 (for 100Gb/s), the ZR, the ZR+ and the Xponders for various number of ROADMs between ingress and egress.



	QSFP28/ 100ZR (100Gb/s)	ZR transceiver (400Gb/s)	ZR+ transceiver (400Gb/s)	Xponders (400Gb/s)	Xponders (600Gb/s)	Xponders (800Gb/s)
Reach in km for 0 interim ROADMs	300	120	960	6000	2620	720
Reach in km for 4 ROADMs	80	0	880	5680	2320	400
Reach in km for 8 ROADMs	40	0	720	5360	1920	0
Reach in km for 12 ROADMs	0	0	0	5040	1600	0
Reach in km for 16 ROADMs	0	0	0	4720	1200	0
Reach in km for 20 ROADMs	0	0	0	4400	0	0

Fig. 1. Main architectural options and reference reach table.

3. Network Modelling

We have considered 9-scenarios of varying QSFP28, ZR+ and Xponders across each of the access, metro and core segments and compute the optimal mapping per scenario. The premise of our model is developed based on regenerator computation. Regenerators are directly linked to the technology used, the traffic juxtaposed, as well as directly indicate router port usages. While regenerators are the single variable factors, in terms of hardware count, they must be computed with some caveat, taking extreme situations into consideration. For example, consider the use of 100Gb/s QSFP28 transceivers everywhere (access, metro, core), resulting in not just large number of regenerators, but also in wavelength exhaustion (which has an impact on network design through excess fiber overbuilds). A second extreme situation is the use of Xponders everywhere (even access) resulting in few regenerators, but low-per-wavelength utilization in the access. Hence, a solution is considered only when the occupancy per wavelength is beyond a certain threshold and excess overbuilds are avoided. For example, we could say that if we deploy ZR+, then such deployment would be only when the ZR+ runs at least at 250Gb/s [4, 5]; similarly, when a Xponder is considered in a metro environment, then the deployment assumes minimum of 600Gb/s per channel, while in core networks, assumes minimum 300Gb/s per channel, hence also factoring in the different reach requirements. Table 1 outlays the boundary conditions that we have adopted in this work.

Technology	QSFP28	ZR/ZR+		Xponders	
		Metro /Access	Core	Metro	Core
Minimum Bandwidth per wave	75Gb/s	200Gb/s	250Gb/s	600Gb/s	400Gb/s
Max allowable margin	1dB	1.5dB	1.2dB	1.5dB	1.2dB

Table 1: Technology selection boundary conditions.

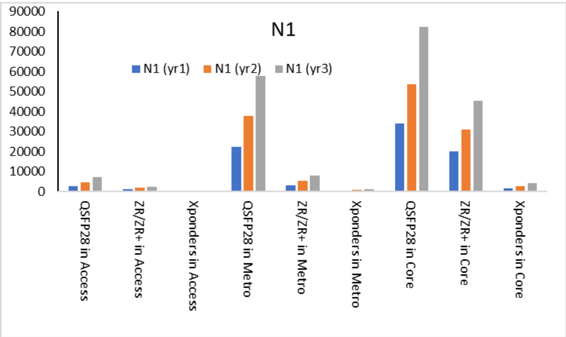
We built a mixed integer linear program (MILP) model whose objective is to minimize regens across all the traffic requests for a particular technology and implementation choice. The MILP takes traffic demands, technology options, nodal adjacency, link distance and regen sites as inputs. To make the solution tractable in time (given the huge combinational possibilities in regen site selection), we restrict the number of nodes that the MILP considers to 6 in each iteration, with a max of 3 iterations. This approximation speeds up the MILP to $\leq$ 5 min per iteration. Constraints include: (a) provisioning traffic demands; (b) number of channels supported (96 for QSFP28, 64 for ZR/ZR+, 42 for the Xponders); (c) wavelength continuity for a lightpath; (d) nodal degree constraints mapped on to ROADM and (e) margin constraints, which ensure that not more than 2dB margin is allocated for ZR/ZR+ and the Xponders, while for the QSFP28 case, no such restrictions exist as nodes in the access could be very close to each other. If the optimization results in a higher margin, then the solution is dropped in favour of another, potentially more cost-effective, technology choice (ZR/ZR+ instead of Xponders or QSFP28 instead of a ZR/ZR+).

For our modelling purposes, we consider 3 reference networks with synthetic traffic, as shown in Table 2.

Network name	Edge nodes	Metro nodes	Metro rings	Average metro length (km)	Core Nodes	Average core path length (km)	Average hop	Traffic year 1 (Tb/s)	Traffic year 2 (Tb/s)	Traffic year 3 (Tb/s)
N1	7000	650	100	70	20	2162	3.41	140	210	305
N2	8000	720	120	80	40	2385	4.21	160	300	550
N3	9500	900	150	90	80	2950	4.34	190	320	600

Table 2: Reference network characterization.

Shown in Fig. 2, 3, and 4 is the number of regenerators required in the network. Since, the three technologies are of different line-rates (100, 400, 600, 800Gb/s), we consider the number of regenerators required as a function of service. So, while the actual number of regens may be lower (due to most requests groomed on to wavelengths, and regens being wavelength specific), this number presented in Fig. 2,3,4 gives a service-wide count. In each of the figures, we consider all the 9 scenarios. We observe that for the 3 networks, in the access, the Xponders need no regens, while 33% of the demands in N1 require regens using QSFP28; 12% of the demands in access require regens when provisioned via ZR/ZR+. In the metro, 76% of the demands require regens when provisioned using QSFP28, while 38% of the demands require regens when provisioned using ZR/ZR+. In the core, the number of regens for QSFP28 and ZR+ significantly outnumber the regens required by Xponders in ratio almost 8:1 for N1. Similar trends are observed in the other networks (N2 and N3) as well.



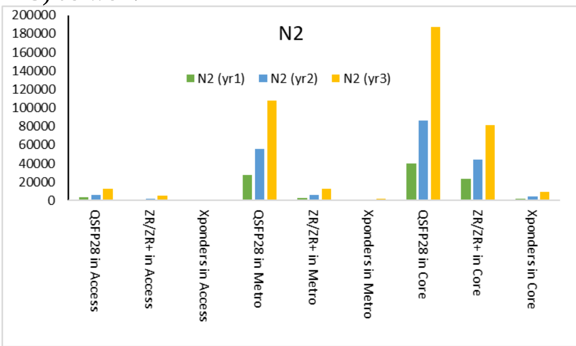
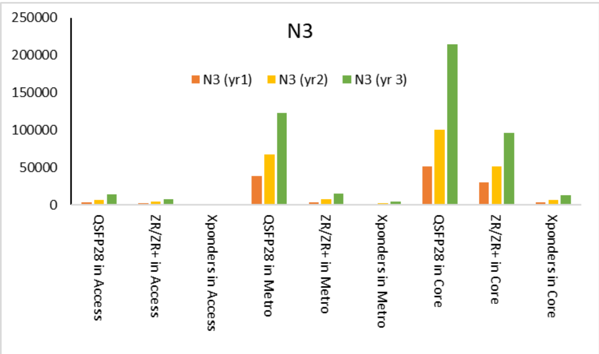


Fig. 2. Regens for N1. Fig. 3. Regens for N2

Shown in Fig. 5 is the percentage of times a particular technology solution is successful in a segment (i.e., access/metro/core). By success, we imply that the load carried as well as the margin is within the range specified in Table 2 for that technology option. Note, Fig 5 along with the earlier three figures give a full overview as to which technology option is most suited for a particular network segment. For Fig. 5, though we assume regens are present, we concatenate the margin and the bandwidth requirements together to determine suitability of a technology option.



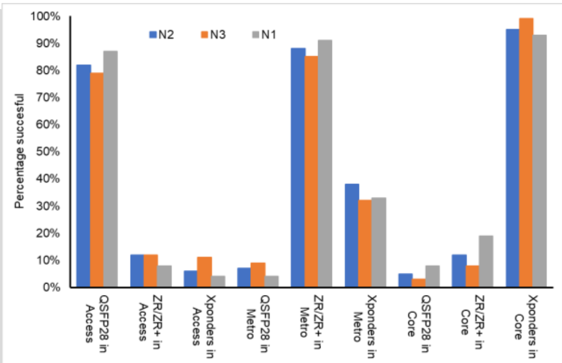


Fig. 4. Regens for N3 Fig. 5. Technology success for a segment.

4. Conclusion

We have considered the use of QSFP28, ZR/ZR+ and Xponders as solutions for transport in access, metro and core networks. This analysis supports the vision of adopting coherent transmission across almost all network segments and having as reference line rates 100/400/800G for access, metro and core networks.

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