Using P2MP Transceivers as Regenerators in Disaggregated and Multi-Rate Regional Optical Networks

Ashwin Gumaste[1,*], João Pedro[2]Antonio Napoli[3], Sai Kishore Bhyri[1] and Walid Wakim[1]
[1] Infinera Corporation, 6373 San Ignacio Dr, San Jose, USA, [2] Infinera Unipessoal Lda, Portugal, [3] Infinera Germany
[*] agumaste@infinera.com

Abstract: We investigate the role of point-to-multipoint (P2MP) transceivers as regenerators in multi-rate regional optical networks. By smart placement of P2MP devices, we are able to reduce transceiver count by 29% and free up spectral resources.

1. Introduction

In regional optical networks that span a few-100 km in diameter, there is heavy absorption of IPoDWDM technologies with the advent of sub-8nm silicon in routers and coherent pluggable optics from 100Gb/s to 400Gb/s today and up to 800Gb/s soon. While newer routers [3] are able to support 400Gb/s per port, the fact remains that a significant share of traffic demands continue to be at lower rates, which results in the need to cost-effectively support, for example, 100Gb/s and 200Gb/s rates. Moreover, existing routers struggle to support 400Gb/s pluggables like ZR/ZR+ in QSFP56-(double density) form factor due to high power consumption. Hence, in contemporary regional networks, we see a variability in line-rates and this has a strong impact on network design. From the perspective of network planning, a key optimization parameter is to minimize the number of regenerators. Regens are the single biggest variable in network planning, and much of literature, such as [2], is devoted to linear program-based approaches towards regen minimization. Regens impact system design (due to their placement having an impact on all the channels in the spectrum), router port counts, transceivers and power consumption. When we ask the question as to what is the architectural impact of dense routers (at up to 25.6Tb/s), pluggables like ZR/ZR+, and Xponders (transponder-muxponders) on multi-rate networks whose design is highly cost-sensitive, it becomes clear that there is a need for an optimized network design, especially with respect to regenerators. Whether a provider deploys IPoDWDM using opaque networking (every hop has an IP router by default) or uses optical bypass in a hybrid strategy (interim router based regens only where needed, else all-optical bypass), the regenerator becomes a key element for the design. Regens in such multi-rate networks must have the following characteristics: (1) support for multiple line rates; (2) pluggable into wide-variety of routers; and (3) power/cost efficient. In addition to these requirements is also the need to conserve on wavelengths, which becomes more pronounced in multi-domain regional networks (with access and core rings). Hence, the regen architecture and its optimization is crucial towards achieving low-cost and power efficiency. In this paper we propose the novel use of a P2MP supporting pluggable optical module, that can support much of the above characteristics. We show that by the use of such a module to build a regen, we can not only support multiple line-rates efficiently, reduce power consumption but also reduce the overall wavelength utilization.

2. Network Architectures and Design Methodology

The architecture for regens using P2P is shown in Fig. 1 and P2MP pluggable modules is as shown in Fig. 2. The pluggable module achieves P2MP by the use of digital sub-carrier (DSC) multiplexing, which has been experimentally demonstrated in [1]. Specifically, the device that we consider [1] comes in two-configurations: (a) 16 sub-carriers (SCs) at 25Gb/s each and (b) 4-SCs at 100Gb/s each in the 400Gb/s capable pluggable. The P2MP plugs essentially have a head-end that MUXes up the SCs, and a tail-end that produces one or more individual SCs. Essentially, one or more SCs are available at each tail-end. Note that the P2MP device performs like a P2P device such as ZR/ZR+, when two head-ends are connected to each other across a fiber link. Therefore, it offers a super-set of connectivity capabilities when compared to traditional P2P transceivers. We assume such a pluggable device comfortably fits into a DD-slot (QSFP56), similar to a ZR/ZR+, with slightly additional power, 10% more for sake of generality in supporting P2MP.

Use case 1: As seen in Fig. 2, there are 8-nodes in a network arc, denoted by $N_1, \ldots N_8$, with nodes $N_1, N_2, N_3, N_6, N_7, N_8$ being sources and sinks of traffic, and N_4, N_5 housing two regenerators. As can be seen in Fig. 3, the regen architecture is replaced by P2MP regens at nodes N_4, N_5, and we observe that the number of transceivers drops from 18 to 9. A variation of this use case is when the regen is only at a single node, in which case two P2MP pluggables are used at the router, with both subtending lower rate SCs towards the sources and sinks. *Use case 2*: In large networks there is a further bifurcation with multiple access networks across a regional network, and where provisioning lower-speed

(100Gb/s, 200Gb/s) channels in the regional network is often spectrally inefficient and leads to blocking due to spectrum exhaustion. For this use case we assume that the P2MP are at the edge of the bigger network, enabling lower-speed channels of different granularity in the access networks, and facilitating 400Gb/s channels across the larger network with regens as and when required, formed by back-to-back P2MP devices. Specifically, note that in the case of a single regen two P2MP plugs are used in the same router, with the router backplane/fabric used to connect traffic between the two plugs. The salient feature of using P2MP, is that the MP part of the plugs, i.e., the multiple sub-carriers are used to connect to the various nodes that source and sink traffic, while the head-end that supports the bifurcation of traffic, is used for muxing the SCs. It is explicitly assumed from the architecture in [1] that there is no significantly detrimental performance impact from the far-near problem when the SCs are all individually at different distances from the head end (i.e., a maximum power unbalance between SCs is always met).

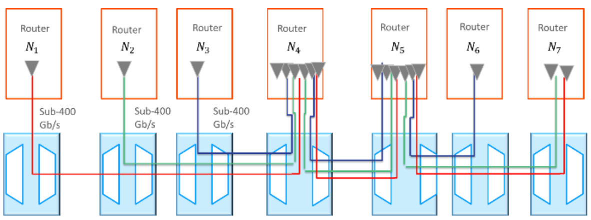

Fig. 1. Nodes D and E hosts regens in generic multi-rate P2P.

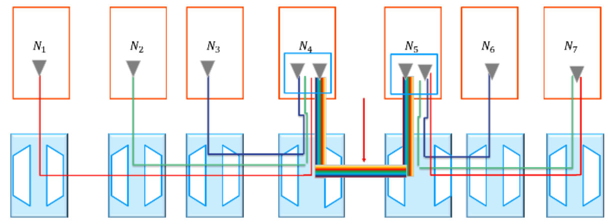

Fig. 2. Number of regens at nodes D and E are reduced using P2MP.

We built a constrained optimization model to initially compute the placement of regens, and further optimize the regen sites to populate with P2MP optics. Our objective function was to minimize the total number of regens in the network, and we wanted to achieve this by collocating as many regens as possible at a site subject to the following set of design constraints: (1) wavelength continuity in all-optical regions, with permissible wavelength conversion across opaque domains, such as at regens; (2) total number of wavelengths that could be allocated in a fiber link is upper-bounded; (3) every demand has to be mapped to an allocated channel, and preference is given to using shortest path.(4) the P2MP optics had 4xSCs possible at 100Gb/s or a combination of 100 and 200Gb/s to yield 400Gb/s. (5) the sites where regens were possible were not exhaustive, but a fixed set and meant a router to be present at the location. (6) The routing fabric was large enough to act as an opaque regenerator. (7) The site thermal constraints (limiting how many regens at a node). (8) the P2P and P2MP pluggables had a fixed reach table, specifically around 1000km for P2P with no interim ROADM, dropping down to 200km with 8 interim ROADMs. Though P2MP plugs have been demonstrated at 1500km [4] we yet assume similar reach for the context of this paper. In order to minimize regens, it means to maximize the utilization of the P2MP plugs, and this became a key byproduct of the optimization model. For simplicity, regen selection was based on a pre-computed reach table, such as the one in [2], which express the reach dependence with the line-rate supported. We use the reach tables for ZR/ZR+ presented in [2] and that for P2MP (due to SCs) as per the measurements in [1] and references thereafter in actual field.

3. Performance Evaluation

Network	Number of nodes	Mean path length	Nodal degree	Year 1 Traffic (Tb/s)	Year 2 Traffic (Tb/s)	Year 3 Traffic (Tb/s)
RN1	28	890	2.31	8.04	12.9	15.3
RN2	45	1265	2.66	27.8	39.2	48.8
RN3	90	1522	2.92	43.5	51.2	68.4
MD1	38	913	2.44	4.25	7.91	13.6
MD2	75	1384	2.53	28.9	44.2	57.8
MD3	99	1761	2.68	47.7	60.9	74.8

Table 1. The six network topologies

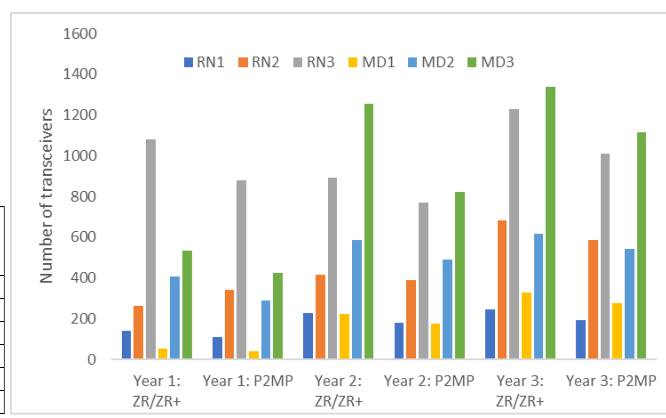

Fig. 3. Transceiver count.

We evaluated the optimization module using a Ryzen Pro 7 with 8 cores on an in-house convex optimization toolkit. We considered 6 realistic network topologies as characterized in Table 1 – three regional networks (with small metros and a regional mesh) and three metro domains (large metro networks). We assumed a distribution of demands of 100, 200, 400 and 800 Gb/s in the approximate ratio 4:2:2:1 in the first year to 2:1:6:2 in the third year. As can be seen in Table 1, the networks are sparse meshes. Moreover, the routers used are assumed to be stackable units and have QSFP-

DD form factor compatibility in every slot, with no restrictions on populating the slots with pluggables of different rates. Shown in Fig. 3 is the transceiver count for each of the six networks over the three-year period, for ZR/ZR+ and for the P2MP solution. On average there is 23% savings in transceiver count when P2MP scheme is deployed. Here we assume that even when grooming possibilities do not exist, for example, if there is a 400Gb/s circuit from A to Z, then at a regen(s) P2MP is used, but without the MP part utilized fully. A subtle insight into the results is that as the load increases, the P2MP performance becomes better. This may appear counter intuitive because our definitions of higher load is that more and more 100Gb/s demands get converted into 400Gb/s demands, but the fact remains that there are significant new 100Gb/s demands that are provisioned through P2MP. A qualitative way of looking at it is to consider all sub-400Gb/s demands that have a need for a regen, end up using P2MP optics as regen and this makes up 23% savings in transceivers.

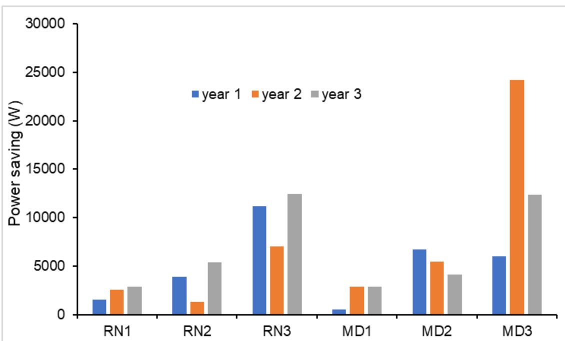

Fig. 4. Power savings (W).

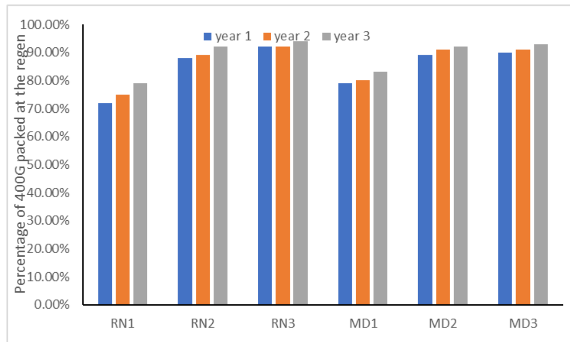

Fig. 5. Efficiency of the P2MP placement.

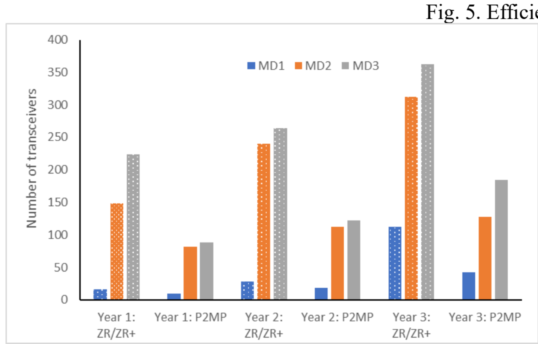

Fig. 6. P2MP regen comparison to P2P in multi-domain networks.

Shown in Fig. 4 is the power savings of using P2MP transceivers compared to using ZR/ZR+ devices. These results factor in both optical transceiver and router port power consumption. We assume router port power to come in three slabs (for 100Gb/s, 400Gb/s and 800Gb/s ports). While numerically the power savings (24%) are identical to the transceiver savings when analyzed further show interesting results – power savings reduce with load, especially as the number of 400Gb/s increases. This is because of the excess use of the pluggables in P2P configuration not taking advantage of grooming capabilities. Finally, in Fig. 5 is the efficiency distribution of the regens itself. The figure illustrates the success possibility of grooming enough lower rate signals at a regen in order to efficiently run the P2MP plug run at 400Gb/s rate. Shown in Fig. 6 is a deep dive into the number of regens required across the multi-domain networks, specially in the metro/core regions. Due to better grooming and efficient aggregation, there is almost 50% benefit in reduction of regens compared to P2P pluggable based regens.

4. Conclusions

We show the advantage of using point to multi-point optics for regenerator architecture in regional networks resulting in 23% transceiver savings, 24% power savings across six different network topologies.

References

[1] D. Welch et al., "Point-to-Multipoint Optical Networks Using Coherent Digital Subcarriers," in Journal of Lightwave Technology, vol. 39, no. 16, pp. 5232-5247, 15 Aug.15, 2021, doi: 10.1109/JLT.2021.3097163.

[2] A. Gumaste, et al, "Optimized IP-over-WDM Core Networks using ZR+ and Flexible Muxponders for 400Gb/s and Beyond," IEEE/OSA Journal of Communication Networks (JOCN), Vol. 14, No. 3, pages 127-139, March 2022.

[3] P. Wright, R. Davey and A. Lord, "Cost Model Comparison of ZR/ZR+ Modules Against Traditional WDM Transponders for 400G IP/WDM Core Networks," ECOC Brussels, Belgium, 2020, pp. 1-4, doi: 10.1109/ECOC48923.2020.9333420.

[4] Online: https://www.infinera.com/press-release/infinera-and-corning-achieve-world-record-400g-transmission-across-2400km/