Point-to-Multipoint Coherent Optics for Re-thinking the Optical Transport: Case Study in 5G Optical Metro Networks

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***Abstract*—Point-to-multipoint (P2MP) coherent optics using digital subcarrier multiplexing have recently been proposed as a promising new technology to potentially reduce the costs and complexity of optical transport networks, particularly in metro aggregation scenarios. In this paper, we perform a case study on a realistic 5G metro reference network, mixing a mesh metro core and edge rings, comparing P2MP and point-to-point (P2P) transponders with varying relative costs. Results indicate that if the costs of commercial P2MP transponders are up to 50% higher than P2P transponders, P2MP optics can reduce the total transponder costs, in addition to offering other advantages such as flexibility and significantly reduced hardware.**

Keywords—Point-to-multipoint coherent optics, 5G optical metro, cost analysis

I. INTRODUCTION

The continued growth in traffic and increase in capacity requirements with the advent of 5G drives the need for transport technology innovations to reduce the cost per transported bit [1]. In metro aggregation networks, traffic flows are typically hub-and-spoke in nature, where several endpoints consume traffic aggregated by a smaller number of hub nodes. However, the optical transport technology used in such networks is point-to-point (P2P), requiring individual optical transponders of the same capacity at both ends. This leads to transponder inefficiency since traffic requirements on the edge side are much smaller than those on the core side. Recent advances in coherent transmission have resulted in the development of novel point-to-multipoint (P2MP) pluggable optics based on subcarrier multiplexing, which can bring new degrees of flexibility and potential cost reductions for hub-and-spoke traffic flows and arguably mesh setups [1][3][4]. A P2MP technology, referred to as XR optics, uses digital signal processing to subdivide a single carrier wavelength into multiple lower-bandwidth Nyquist subcarriers. The subcarriers can be independently modulated, managed, grouped and routed to different destinations allowing high speed transceivers to connect directly to multiple lower speed transceivers at different locations. Such coherent optical P2MP communication was demonstrated in [3][5] and is expected to be commercial in 2021.

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In [1] a CAPEX study indicating significant savings was performed over a 5-year period using P2MP pluggable optics for a reference set of metro network chains and hub-and-spoke traffic assuming fixed transponder costs. In this paper, we perform a case study on the 5G metro reference scenario, comprised of a two-tier physical infrastructure and three types of traffic flows, and the capacity planning algorithm described in [6]. We compare costs of the capacity planning solution using P2MP pluggable optics in comparison with only P2P transponders and a combination, for different relative transponder costs. Results indicate that significant CAPEX savings can be achieved with the P2MP and hybrid solutions when the costs of P2MP transponders are up to 50% higher than P2P. Furthermore, employing P2MP transponders dramatically reduces the number of devices, which can lead to space and power savings.

II. REFERENCE SCENARIO AND SIMULATION SETUP

The 5G optical metro reference scenario used for this study is taken from [6]. The physical network topology with 52 nodes and 77 bidirectional links is structured into two tiers: a meshed metro core (where a subset of nodes are connected to the backbone) and a set of rings or weakly-meshed metro aggregation nodes, as shown in Figure 1. Optical transparency is assumed within the entire regional network.

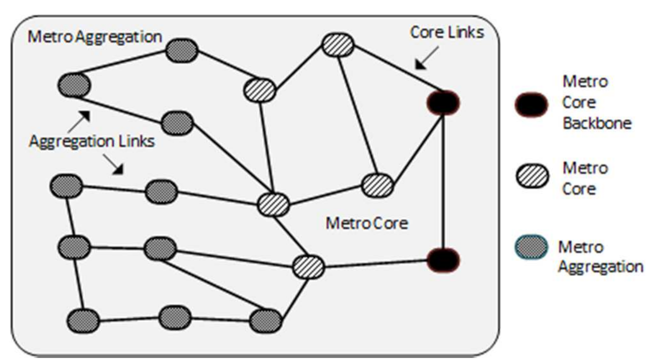


Fig. 1 Topology structure of Telecom Italia reginal networks.

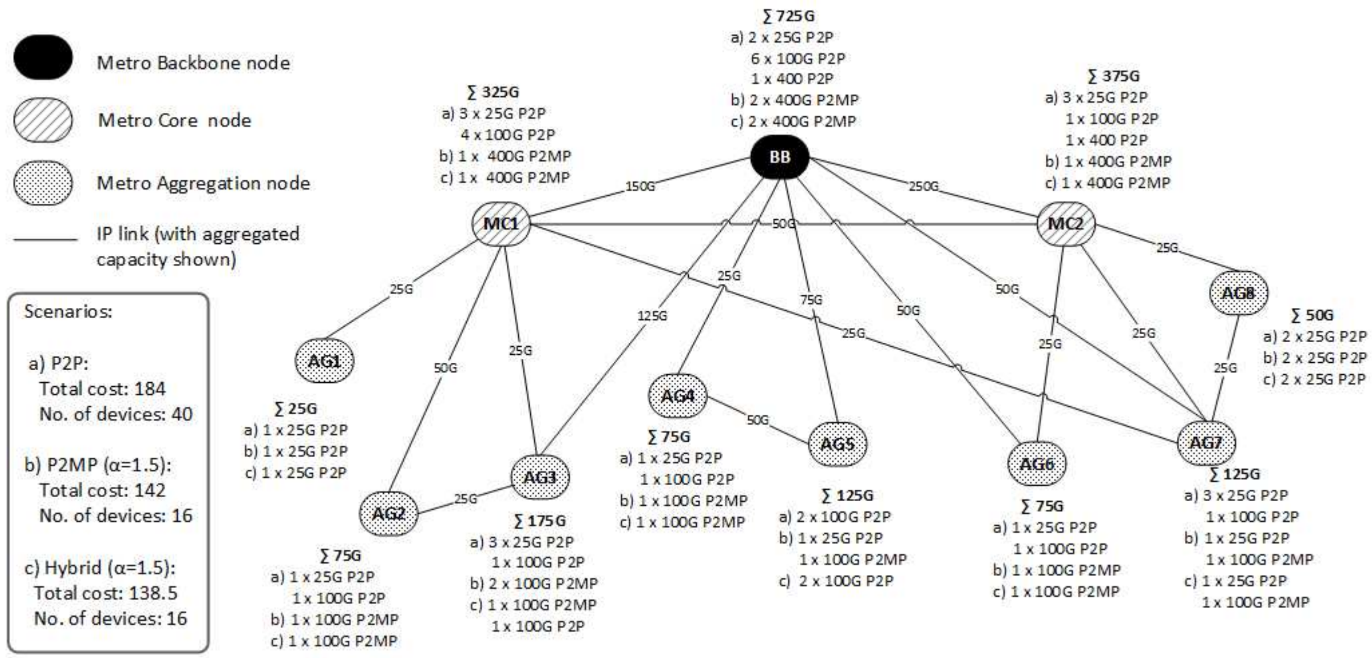


Fig. 2. Example of an IP topology for the metro refernce scenario and corresponding transponder placement for the P2P, P2MP and Hybrid scenarios.

A static traffic model is considered comprised of 3 types of traffic flows: (i) point-to-point traffic, (ii) heterogeneous server-mediated traffic and (iii) edge computing and storage services. The three traffic types are structured as network service chains composed of a sequence of network functions interconnected via virtual links. The virtual links are set as IP circuits where an IP link is implemented as a link aggregation group (LAG) comprised of multiple parallel lightpaths of the same rate and same end nodes. The established lightpaths are assumed to be bidirectional composed of 2 unidirectional lightpaths in opposite directions.

The simulation setup is performed with Net2Plan [7] and NIW library (NFV over IP over WDM) [8]. The capacity planning algorithm proposed in [6] is used to determine the IP links, along with the associated routing and spectrum assignment of the lightpaths. The output of this algorithm gives an IP virtual topology with associated aggregate capacities for each LAG. An example of such an IP topology is given in Figure 2. While the IP topology is not purely hub and spoke since IP links are also established between aggregation nodes, the topology exhibits clear metro core and backbone hubs, with significantly fewer and lower rate IP links between aggregation nodes.

Transponder allocation is calculated for the IP topology generated by the capacity planning algorithm without fault tolerance according to the following 3 scenarios:

a) ***P2P***: Only P2P transponders are deployed with rates 25G, 100G and 400G.

b) ***P2MP***: Lower rate (25G) transponders are P2P while higher rate (100G and 400G) transponders are P2MP with 25G subcarriers.

c) ***Hybrid***: Lower rate (25G) transponders are P2P, while higher rate (100G and 400G) transponders can be either P2P or P2MP (with 25G subcarriers).

For each scenario, the transponders are chosen to minimize the total costs. Individual transponder costs are shown in Table I following the cost model from [9] for P2P equipment. Since P2MP are still not commercial, we apply a factor α to model their costs, varying α in range [1,3] in increments of 0.5. This allows us to investigate for which relative cost, deploying P2MP equipment becomes profitable.

TABLE I. TRANSPONDER COSTS [9]

Transponder type	Cost
25G P2P	3.5
100G P2P	5
400G P2P	12
100G P2MP	α·5
400G P2MP	α·12

Figure 2 shows the transponder allocation for each of the 3 scenarios (assuming α=1.5) and the given IP topology. For example, at aggregation node AG3, the sum of the required line rates is 175G distributed among 3 IP links. In the P2P scenario, IP link AG3-BB could be set with 1 x 100G P2P transponder and 1 x 25G P2P at each end node while the remaining 2 IP links require a 25G transponder each at each end node. Thanks to the multipoint feature in the P2MP scenario the associated lightpaths could be established by using 2 x 100G P2MP transponders at node AG3. In this case, one groups all 4 subcarriers to realize 100G rate between AG3-BB, and the other uses one subcarrier (25G) for each of the 3 links, with 25G spare capacity which could be used to upgrade any of the 3 links.

In the Hybrid scenario, the 100G rate between AG3-BB is more cost effective using a P2P transponder since it does not require the P2MP feature. The number of devices and total transponder costs are also shown for each scenario. It can be seen that the number of devices is dramatically reduced by employing P2MP pluggable optics and also reduces total transponder costs for α=1.5.

III. Numerical Results

Transponder allocation was calculated for the IP topology generated by the capacity planning for the 52 node network and static traffic. The total costs and number of transponders for each scenario with varying α, are shown in Table II, along with the deviation in % with respect to P2P in parenthesis. It can be seen that employing P2MP optics can reduce the total transponder costs for α≤1.5 in the P2MP scenario and all cases in the hybrid scenario. Furthermore, the number of devices is significantly reduced for α≤2.5. Note, while the total transponder costs increase for higher α values, P2MP devices can still provide other advantages such as significantly reduced equipment (space and power savings), as well as flexibility for upgrades or reconfiguration in the presence dynamic traffic demands or failures.

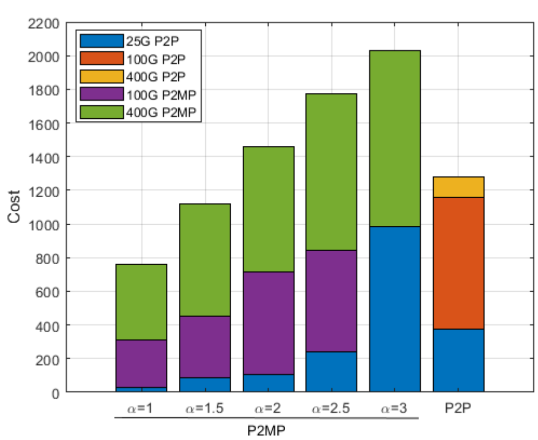
To gain more insight into the cost distribution and transponder allocation, Figures 3 and 4 show the total costs and number of devices per transponder type for varying α values for the P2MP and hybrid scenarios, respectively, in comparison to P2P. Figure 3 shows that as α increases, the multipoint feature stays profitable for higher rate transponders but many 100G P2MP transponders are replaced with multiple lower rate 25G P2P transponders. In the hybrid scenario shown in Figure 4, it can be seen that for increasing α values, the transponder distribution converges towards the P2P solution, while multipoint devices play significant role for α≤1.5. For α=1.5, more higher rate P2MP devices (400G) are allocated than 100G P2MP transponders since hub nodes are of large degree (15-25) and can, thus, effectively exploit higher rate P2MP devices. For non-hub nodes, in many cases it is more cost effective to employ 100G P2P transponders rather than P2MP.

All data and algorithms for reproducing the numerical results are available in [10].

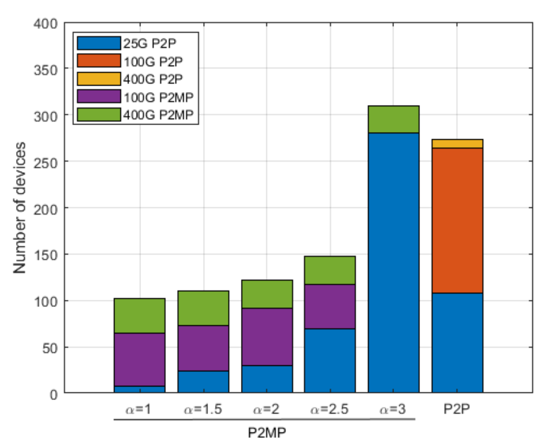
TABLE II.

TABLE III. Total costs and number of transponders for the P2P, P2MP and Hybrid Scenarios

	P2P	**P2MP Optics**									
		α = 1		*α = 1.5*		*α = 2*		*α = 2.5*		*α = 3*	
		P2MP	*Hybrid*	*P2MP*	*Hybrid*	*P2MP*	*Hybrid*	*P2MP*	*Hybrid*	*P2MP*	*Hybrid*
Total cost	1278	757 (-40.8%)	757 (-40.8%)	1121.5 (-12.3%)	1068 (-16.4%)	1459 (+14.2%)	1225.5 (-4.1%)	1771.5 (+38.6%)	1263 (-1.0%)	2027.5 (+58.7%)	1276 (-0.1%)
No. of devices	274	102 (-62.8%)	102 (-62.8%)	110 (-59.9%)	134 (-51.1%)	122 (-55.5%)	211 (-23.0%)	148 (-46.0%)	252 (-8.0%)	310 (+13.1%)	265 (-3.3%)



(a)



(b)

Fig. 3. The (a) costs and (b) number of devices in the P2MP scenario (for varying α) in comparison to the P2P scenario

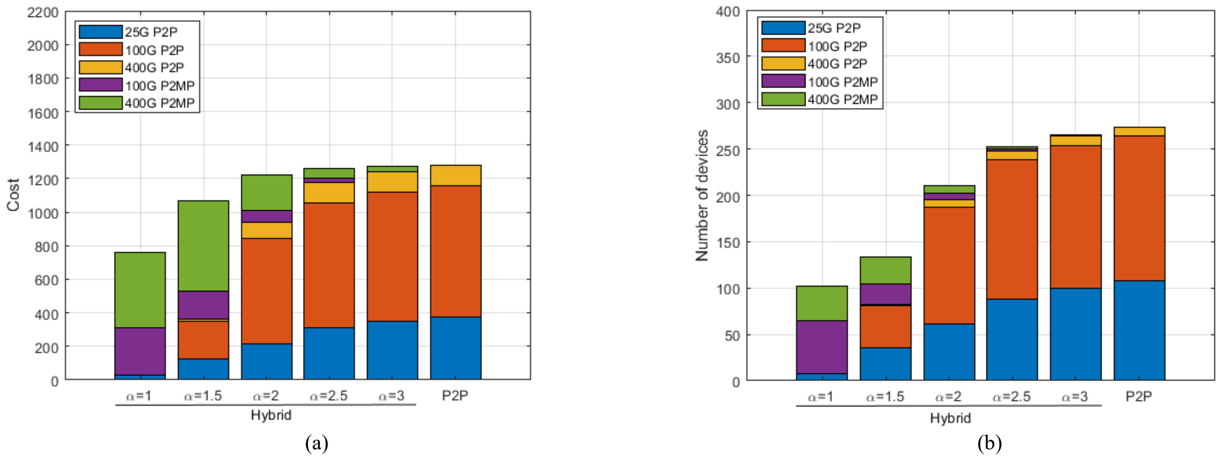


Fig. 4. The (a) costs and (b) number of devices for the Hybrid scenario (for varying α) in comparison to the P2P scenario

IV. CONCLUSION

In this paper, we perform a case study on a realistic 5G metro aggregation scenario to evaluate potential benefits of employing P2MP pluggable coherent optics. Results indicate that deploying exclusively 100G/400G P2MP transponders is profitable if P2MP transponder costs are ≤50% higher than P2P. For higher relative costs, deploying a combination of P2MP and P2P transponders yields the best savings. The P2MP feature also significantly reduces the number of transponders, leading to space and power savings, in addition to the inherent flexibility offered for reconfiguration and upgrades. Note that the results presented here consider a capacity planning algorithm which does not take into consideration the multipoint feature to determines the IP links. Further cost savings could possibly be achieved by developing a tailored capacity planning algorithm exploiting this feature.

REFERENCES

[1] Cisco Annual Internet Report (2018-2023) White paper [Online] Available: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html. Accessed on Feb. 2021.

[2] J. Bäck et al., "CAPEX Savings Enabled by Point-to-Multipoint Coherent Pluggable Optics Using Digital Subcarrier Multiplexing in Metro Aggregation Networks," 2020 European Conference on Optical Communications (ECOC), Brussels, Belgium, 2020, pp. 1-4.

[3] A. Rashidinejad, A. Nguyen, M. Olson, S. Hand and D. Welch, "Real-Time Demonstration of 2.4Tbps (200Gbps/λ) Bidirectional Coherent DWDM-PON Enabled by Coherent Nyquist Subcarriers," 2020 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2020, pp. 1-3.

[4] D. F. Welch, "Disruption Cycles for Optical Networks: How Point to Multi-Point Coherent Optics can Transform the Cost and Complexity of the Optical Network," 2020 European Conference on Optical Communications (ECOC), Brussels, Belgium, 2020, pp. 1-3.

[5] H. Sun et al., "800G DSP ASIC Design Using Probabilistic Shaping and Digital Sub-Carrier Multiplexing," in Journal of Lightwave Technology, vol. 38, no. 17, pp. 4744-4756, 1 Sept.1, 2020

[6] P. Pavon-Marino et al., "Techno-Economic Impact of Filterless Data Plane and Agile Control Plane in the 5G Optical Metro," in Journal of Lightwave Technology, vol. 38, no. 15, pp. 3801-3814, 1 Aug.1, 2020.

[7] Net2plan – The open-source Network Planner. [Online]. Available: https://net2plan.com. Accessed on: Feb. 2021.

[8] J.L. Romero-Gázquez, M. Garrich, F.J. Moreno-Muro, M.V. Bueno-Delgado, and P. Pavón-Mariño, "NIW: A Net2Plan-based Library for NFV over IP over WDM Networks," *Int. Conf. on Transp. Opt. Netw. (ICTON)*, Angers (France), Jul. 2019.

[9] J. Alberto Hernandez et al., "Comprehensive model for technoeconomic studies of next-generation central offices for metro networks," in IEEE/OSA Journal of Optical Communications and Networking, vol. 12, no. 12, pp. 414-427, December 2020

[10] XROptics public repository of Girtel group [Online]. Available: https://github.com/girtel/Net2Plan/tree/feature/xrOpticsONDM21 Accessed on: Feb. 2021.