

A Filterless Design with Point-to-multipoint Transceivers for Cost-Effective and Challenging Metro/Regional Aggregation Topologies

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Abstract—Point-to-multipoint (P2MP) optical coherent transceivers, which take advantage of digital subcarrier multiplexing, can greatly simplify design, planning and operations in next-generation high-capacity metro aggregation networks.

In this paper, we investigate their utilization over two complex network scenarios: urban/industrial and suburban/rural. We provide evidence that with P2MP technology, it is possible to achieve a 32% Capital Expenditure (CAPEX) savings compared to the use of traditional point-to-point (P2P) transceivers, and 41% in the case of increased aggregation in a short-term scenario.

Index Terms—Point-to-multipoint, coherent technology, digital subcarrier multiplexing, passive optical network, metro aggregation

I. INTRODUCTION

Access and metro networks are among the most challenging segments in telecommunications in terms of topology and traffic growth. The geography and distribution of urban/industrial and suburban/rural areas can lead to particularly complex topologies, and IP data traffic can only be sustained by continuous innovation, for example, from cloud applications, enterprise migration to the cloud, and 5G, making traffic growth difficult to predict [1]. Network aggregation plays an important role in metro/access segments and consists of numerous intermediate stages where channels are electrically aggregated. In the currently ubiquitous P2P configuration, a considerable number of transceivers are required for this purpose [2], with consequent increased complexity and high costs for the aggregation sites. Furthermore, geographic peculiarities, such as those embedded in the case provided by Telecom Italia (TIM) in this study, can greatly complicate the management of network topologies. A special challenge arises when introducing a filterless line system [3] aimed at reducing the total cost of ownership.

In this work, we use P2MP transceiver technology to simplify the design and planning of these challenging network

topologies. In [4], the use of digital subcarrier multiplexing (DSCM) with coherent technology was proposed as an efficient method for aggregating information. Previously, DSCM was considered mainly as a technique to increase tolerance to nonlinear Kerr effects [5], [6] and narrow filtering [7], [8].

Here, we will analyze ways in which DSCM can allow for a paradigm shift in the design of optical networks through the flexibility introduced by subcarriers (SC)s, i.e., virtual digital channels. DSCM-based P2MP will be used to combine different network branches by means of a simple passive optical component, a combiner/splitter, to achieve significant network simplification and associated savings. The proposed DSCM technology requires filterless or filtered nodes with drop-and-continue capability. In this study, we considered filterless nodes, but similar results would have been obtained with filtered drop and continuous nodes, even if the transmission design criteria would have been different. Relevant studies on a filterless architecture – like the one considered in this work – are the cost analysis presented in [9] and the physical layer validation in [10].

In this paper, we present the transmission performance and techno-economic results obtained by designing with P2P and P2MP two network aggregation scenarios, urban/industrial and suburban/rural, that are representative among the most challenging topologies. The primary value of our study consists of the application of DSCM technology to challenging, real topologies, and a realistic traffic forecast, showing the cost-saving potential of P2MP solutions.

II. CHALLENGING METRO AND REGIONAL AGGREGATION TOPOLOGIES

The TIM national network includes hundreds of metro/regional aggregation segments, whose topologies are based on a principal horseshoe that collects traffic from a few leaf nodes to two hubs, producing a dual-homing connection from each leaf to the hubs as schematically illustrated in Fig. 1-(a). In the leaf nodes (also called local aggregator nodes), all traffic from the access segment is collected and aggregated to be transported to its final destination. A maximum of 7 leaf nodes are employed in the

Antonio Napoli, João Pedro, Emilio Riccardi and Marco Quagliotti would like to thank the European Union's Horizon 2020 research and innovation program B5G-OPEN Project, grant agreement No. 101016663, for the partial support of their research.

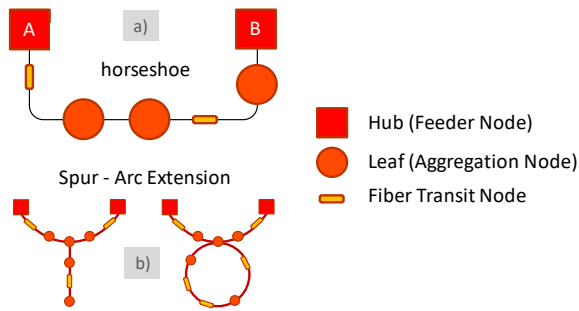


Fig. 1: Nomenclature for a generic metro/regional aggregation topology within TIM networks, differentiating between horseshoe (a) and spur-arc extension (b). The fiber transit node (in yellow) allows the installation of an optical amplifier.

horseshoe, for an average length of ~ 50 km and ~ 100 km for urban/industrial and suburban/rural, respectively. For the latter, the maximum distance can be up to 250 km. Traffic is collected at the Ethernet/IP level, and statistical multiplexing greatly reduces the bandwidth needed at the dense wavelength division multiplexing (DWDM) layer. Given the geographical/terrain challenges (fiber routes, accessibility) around small, ancient Italian cities, horseshoe networks have increased over time and become operationally challenging. Often, they evolve towards more complex topologies such as those illustrated in Fig. 2 (urban/industrial) and Fig. 3 (suburban/rural).

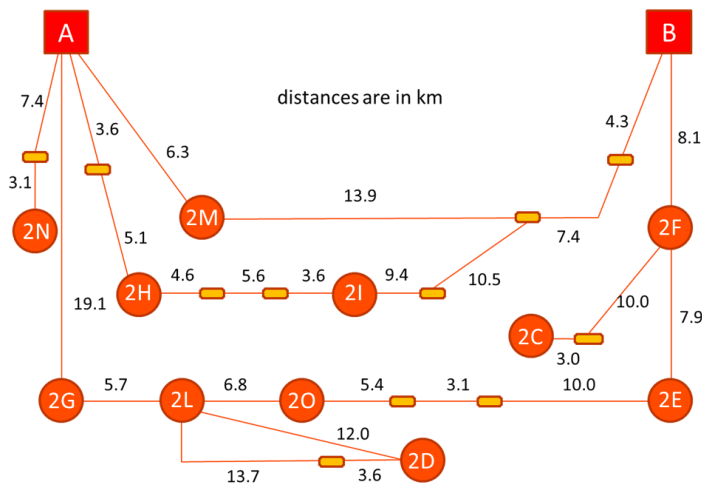
As shown in Fig. 2 and Fig. 3, it is also quite common that a few aggregation networks are connected to the same two hubs. Generally speaking, each pair of hubs collects, on average, traffic from two to five main arcs, and the arcs can be regular (a chain of nodes that begins and ends on the hubs with leaves in the middle) or have branches. The branches (spur-arc extensions, see Fig. 1-(b)) can be linear offshoots or rings that branch off from one of the leaves (called “hinge nodes”) of the main arc (see Fig. 1-(b)). Note that all nodes that are not on the main arcs, and are located on the branches, have a lower survivability level than those on the main arcs, since a failure on the hinge node precludes the reachability of both hubs. The branches are used to collect limited traffic needs from areas where fiber availability is limited or its deployment is very expensive.

In the current deployment, each aggregation segment is a fully aggregated optical domain [11]. This is generally built on single-vendor systems with reconfigurable optical add drop multiplexer (ROADM) nodes both at the hubs and at the leaves, and intensity modulated, direct detection (IM/DD) 10G transponders, all supplied by the same vendor that provides the optical line system. DWDM line systems are dispersion managed because of the presence of 10G IM/DD transceivers, which do not perform electronic compensation of the accumulated dispersion. The compensated DWDM system has the ability to carry higher bit rate circuits, specifically 100 Gb/s channels, using 100G coherent transponders. In summary, based on the current deployment, the TIM aggregation network

is a compensated DWDM network with the possibility of realizing P2P connections, by choosing between two available bit rates, 10G (IM/DD) and 100G (coherent). The packet devices at both the leaf and hub nodes are connected to the transponders with gray optics, and the demarcation between the packet and optical domains is clear.

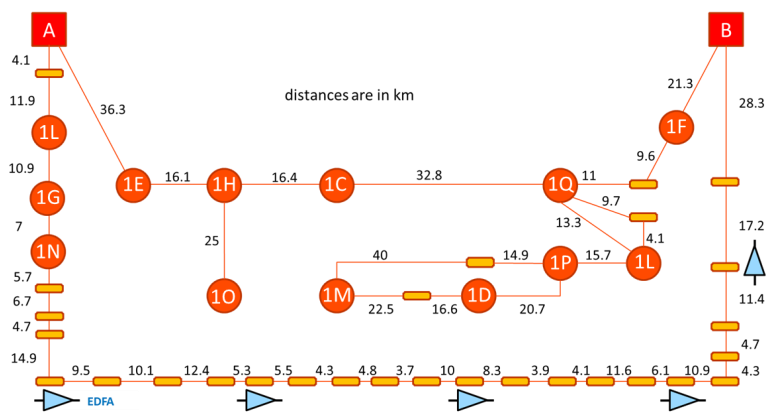
The typical demand for traffic in the short-term (where reliable forecasting is possible) is such that a single 10G circuit (sometimes under-used) is adequate to carry traffic from a leaf to each of the two hubs. Traffic is expected to grow significantly – see the tables in Fig. 2- 3 – both in the medium-term, when typically two or more 10G circuits from a leaf to each of the hubs will be sufficient, and in the long-term, when the need either for more 10G, or for a few 100G circuits is expected. The growth of IP data traffic is harder to predict, as it depends on the growth of traffic on the aggregation networks in the next few years. However, by assuming a year-over-year traffic growth of 40%, the gradual change described above could occur within the next 6 to 7 years. It is important to note that the traffic exchanged by the leaves to the hubs can vary considerably from leaf to leaf, up to a factor of 10 within the leaves on the same arc. In the short term, for example, within the same arc, the leaf with the lowest traffic requirement may need to exchange 2 Gb/s of traffic to the hubs, while the leaf with the highest requirement may require up to 20 Gb/s. This introduces the issue of the level of circuit utilization (the ratio of traffic carried and the nominal rate of the circuit), which depends both on the traffic to be carried and on the available circuit data rates. In the currently deployed network, as stated, 10G and 100G P2P circuits can be used. In the case of 40 Gb/s of traffic to be transported, we can choose five 10G with a level of utilization of 80% or one 100G with a utilization of 40%. In the first case, we have high circuit utilization, but we use numerous DWDM channels and circuits (five pairs of 10G transponders); in the second, the utilization is low, but only one channel/circuit is used (one pair of 100G transponders). The urban/industrial aggregation network (Fig. 2) and the network covering a suburban/rural area (Fig. 3) considered in this study, have been selected as complex and challenging examples where: (i) several main arcs are connected to the same hubs, allowing us to explore the advantages of P2MP in reducing the optical interfaces at the hub terminating several arcs on the same interface; (ii) length and attenuation of the links among nodes are challenging even for coherent interfaces, mainly due to transit in intermediate sites and from the fiber repair margin ; and (iii) traffic is heterogeneous, with a mix of low traffic from some leaf sites and higher and fast increasing traffic from others. Furthermore, we expect that a cost-effective transmission solution, capable of effectively managing these complex and challenging topologies, will have large-scale applicability across the entire network.

In our analysis, we propose replacing the actual monovendor network based on ROADM and transponders, with a much simpler, partially disaggregated optical solution based on filterless DWDM, and leverage flexible coherent DSCM pluggable modules P2MP to completely replace transponders



| Traffic in Gb/s | Short term | | Medium term | | Long term | |
|-----------------|--------------|--------------|--------------|--------------|--------------|--------------|
| | 1A | 1B | 1A | 1B | 1A | 1B |
| 2E | 2.9 | 2.9 | 11 | 11 | 42.2 | 42.2 |
| 2F | 7.1 | 7.1 | 12 | 12 | 29.2 | 29.2 |
| 2G | 7.8 | 7.8 | 29.9 | 29.9 | 114.5 | 114.5 |
| 2L | 69.8 | 69.8 | 87.9 | 87.9 | 134.5 | 134.5 |
| 2O | 23.3 | 23.3 | 48.8 | 48.8 | 177.7 | 177.7 |
| 2C | 2 | 2 | 7.4 | 7.4 | 29 | 29 |
| 2D | 6.3 | 6.3 | 9 | 9 | 17.5 | 17.5 |
| 2H | 11.7 | 11.7 | 71.4 | 71.4 | 89.5 | 89.5 |
| 2I | 1.5 | 1.5 | 60.2 | 60.2 | 75.7 | 75.7 |
| 2M | 5.4 | 5.4 | 7.3 | 7.3 | 10.7 | 10.7 |
| 2N | 6.5 | 6.5 | 23.3 | 23.3 | 88.1 | 88.1 |
| Average | 13.1 | 13.1 | 33.5 | 33.5 | 73.5 | 73.5 |
| Total | 144.3 | 144.3 | 368.2 | 368.2 | 808.6 | 808.6 |

Fig. 2: Example of metro/regional aggregation for urban/industrial topologies in TIM networks with traffic demands. The table reports the traffic matrix between leaf nodes ○ and hubs □ in Gb/s for the three evaluated time frames.



| Traffic in Gb/s | Short term | | Medium term | | Long term | |
|-----------------|-------------|-------------|--------------|--------------|--------------|--------------|
| | 1A | 1B | 1A | 1B | 1A | 1B |
| 1D | 0.6 | 0.6 | 2.3 | 2.3 | 8.5 | 8.5 |
| 1M | 1.7 | 1.7 | 6.3 | 6.3 | 23.9 | 23.9 |
| 1C | 1.5 | 1.5 | 4.1 | 4.1 | 14.2 | 14.2 |
| 1E | 5.3 | 5.3 | 6 | 6 | 8.8 | 8.8 |
| 1F | 7.8 | 7.8 | 29.7 | 29.7 | 114 | 114 |
| 1G | 6.7 | 6.7 | 11.9 | 11.9 | 30.1 | 30.1 |
| 1H | 5.8 | 5.8 | 22.3 | 22.3 | 85.4 | 85.4 |
| 1I | 1.5 | 1.5 | 5.7 | 5.7 | 21.6 | 21.6 |
| 1L | 2.6 | 2.6 | 9 | 9 | 31.7 | 31.7 |
| 1N | 4.6 | 4.6 | 17.4 | 17.4 | 66.8 | 66.8 |
| 1O | 0.6 | 0.6 | 2.3 | 2.3 | 8.8 | 8.8 |
| 1P | 1.7 | 1.7 | 5 | 5 | 17.7 | 17.7 |
| 1Q | 10.6 | 10.6 | 26.5 | 26.5 | 87.4 | 87.4 |
| Average | 3.9 | 3.9 | 11.4 | 11.4 | 39.9 | 39.9 |
| Total | 51.0 | 51.0 | 148.5 | 148.5 | 518.9 | 518.9 |

Fig. 3: Example of metro/regional aggregation for suburban/rural topologies in TIM networks with traffic demands. The bottom horseshoe presents erbium doped fiber amplifiers (EDFA), which have been placed every 18 dB fiber attenuation losses. The table reports the traffic matrix between leaf nodes ○ and hubs □ in Gb/s for the three evaluated time frames.

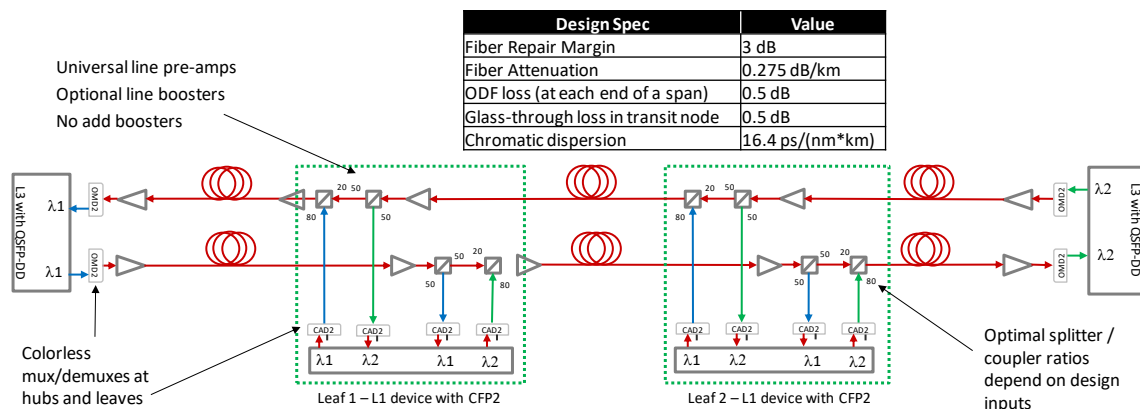


Fig. 4: Considered block diagram for the link engineering used in Sec. III. The table describes the system level requirements.

as described in [4]. We propose hosting coherent P2MP pluggables on the IP routers of the hub site, eliminating the need for separate transponders and allowing 400GbE economics at Layers 1 and 3 (L_1 / L_3). With DSCM, we support the bandwidth per hosting device at 25 Gb/s granularity: where each SC has a symbol rate of 4 GBaud¹ and a modulation format of 16 quadrature amplitude modulation (16QAM), allowing for a natural pay-as-you-grow model. The number of SCs may vary, depending on the total data rate, e.g. 4 in the case of 100G (4×25 G) and 16 in the case of 400G (16×25 G). Importantly, the proposed P2MP solution also enables multiple horseshoe networks to collapse into one single filterless domain, leading to significant network simplification. In turn, this clearly results in CAPEX reduction, faster service activation, and improved network reliability. At the leaf sites, we assume that coherent P2MP pluggables are hosted in a simple demarcation device that enables P2MP pluggables to aggregate traffic from legacy edge routers with 25GbE or 100GbE interfaces.

The 25 Gb/s granularity fits well with the predicted traffic profile for the network under analysis, as it includes sites with moderate growth, together with sites with stronger demand for bandwidth. Today, these sites are served with 10G IM/DD transponders over dispersion compensated links, and without DSCM slicing at $N \times 25$ Gb/s, service providers such as TIM would be forced to jump directly to 100 Gb/s coherent (P2P) interfaces to serve the sites with higher traffic growth.

Fig. 2 shows the exact distance in kilometers between each of the nodes, including the transit nodes. Note that in this topology, four branches depart from the left hub [A], while only two exit the right hub [B]. Note also that transit nodes, in intermediate central offices that are not adding/dropping traffic, have to be included in the design to account for the total transit insertion loss. Finally, two spur-arc extensions connecting low traffic nodes, are also present. Fig. 3 shows the topology and distances between the nodes for the suburban/rural network. In this case, we have two spurs on the upper arc, while on the lower arc some EDFA is required, as the path is long and challenging, with many intermediate transit transmission nodes. The right part of Fig. 2 and Fig. 3 presents a table with the traffic requirements in Gb/s between the leaf nodes and the reference hubs for the three periods considered. As already mentioned, the traffic is quite different between the leaf nodes within the same network. In particular, there are nodes on the spurs (such as 1O or 2C) which have particularly low traffic requirements. For these nodes, traffic is collected by 10G gray optics and aggregated at level 2 on hinge nodes (e.g., 2F (hinge) aggregate traffic at level 2 for 2C (spur)). Furthermore, within the same period, the traffic on the urban/industrial network (both the average value and the total value exchanged by the leaves with the hubs) is notably greater than that of the suburban/rural network, as might be expected.

¹The value of 4 GBaud per SC comprises the overhead for forward error correction, OTN frame, etc.

III. TRANSMISSION PERFORMANCE

We carried out extensive transmission simulations to evaluate the possibility of successfully combining some or all branches. We considered all three traffic scenarios described in the Tables in Figs. 2 and 3. We consider the long-term as a reference for dimensioning the equipment.

The block diagram for link engineering – employed for the two considered topologies – is depicted in Fig. 4. The table in Fig. 4 lists the physical layer requirements. Here, two of the specifications are worth a detailed description: a) “connector loss” is the attenuation of optical distribution frames connecting the outside and inside the fiber plant, and b) “glass-through loss” is incurred when passing a transit node without active equipment. In general, the margin and fiber attenuation are quite high in metro/regional networks, to account, for example, for the repair margin, as reported in the table in Fig. 4. The most important consequence of the reported design requirements is that a large number of links become challenging despite not being very long. This is true in the examples analyzed and, more generally, in the aggregation network.

Hubs are configured with passive colorless directionless add/drop (splitter and combiners) and EDFAs. Leaf nodes have a filterless structure with a suitable split ratio, EDFAs as preamplifier or booster (the latter only used if strictly needed), and similar passive add/drop modules (Fig. 4). Note that filterless line systems have been featured in several previous studies, although usually they assume the deployment of P2P transceivers [12], [13]. Fig. 5(a) shows how the branches are combined to create two filterless systems in the case of urban/industrial, while Fig. 5(b) reports the case with the suburban/rural scenario. In the first case, the blue lightpath (LP) is composed of two segments; the upper is 31.9 km, and the lower is 54.1 km. The two segments are combined at the hubs together with the green LP, composed of an upper path 66.1 km long and a much shorter path of 10.5 km.

Conversely, in a P2P approach, the network described in Fig. 5-(a), would require separate LPs for each hub and leaf connection, and therefore separate modules or transponders at the two hubs. For both the P2MP and P2P solutions, the spur-arc extensions (gray links in Fig. 5) are managed with ad hoc solutions. Traffic is aggregated in the packet layer at the hinge nodes and then transported to the hubs with the DSCM system; For the short- and medium-term, a simple backhaul using 10 Gb/s gray optics is the most efficient solution.

We evaluated the OSNR margin according to the network requirements and transceiver performance [4] and observed that the segments that form the blue and green LPs in Fig. 5-(a) can be combined as they still maintain a sufficient OSNR margin. In this particular case, an OSNR margin > 6 dB was guaranteed in both combined LPs. However, when aggregating all LPs (blue and green) into a single pluggable at the hub, the OSNR margin is impacted by the power imbalance caused by significantly different link characteristics, which can lead to a considerable difference in the accumulated ripple and

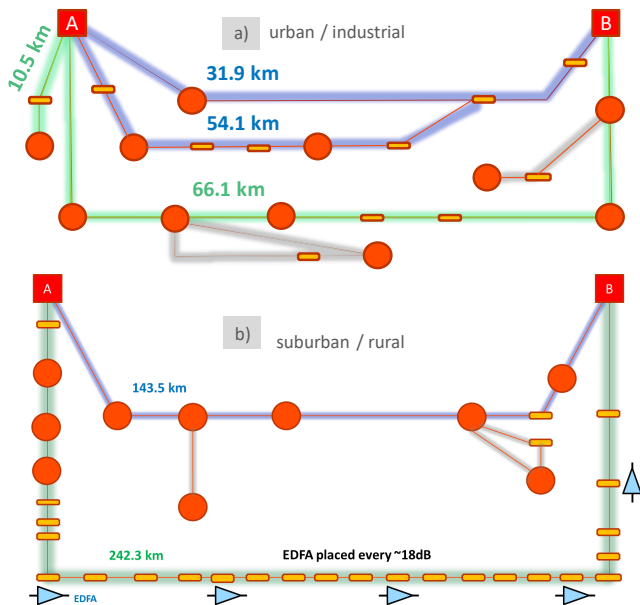


Fig. 5: Different level of aggregation for (a) urban/industrial and (b) suburban/rural. The blue and green colors in (a) and (b) denote the aggregated LP.

noise. Several approaches to aggregate even more LPs could be explored in future studies: the addition of dynamic gain equalizers (DGE)s, placing boosters at the hub, and EDFA placed outside of leaf sites. Although each of these approaches could increase overall CAPEX, they could also enable the consolidation and aggregation of traffic into even fewer 400G transceivers at the hub sites (by combining the blue and green branches shown in Fig. 5 into a single LP).

Fig. 5-(b) shows that those LPs would greatly benefit from further aggregation, as only 3 sites are present over a >240 km long LP. In this particular topology, we observed that the OSNR margin was not sufficient to allow the merging of the 2 LPs shown in Fig. 5-(b) without adding further components to the green LP (e.g., booster). One option would be replacing the combiners at the hub with array waveguide grating (AWG) to equalize the two LPs, limiting the effect of power imbalance.

IV. COST ANALYSIS

After verifying the transmission performance and validating the design, we analyzed how P2MP transceivers at 100 Gb/s or 200 Gb/s in the leaf nodes and 200 Gb/s or 400 Gb/s at the hub, with 25 Gb/s granularity could carry the traffic in the three scenarios in Figs. 2 and 3, and compared the total cost with P2MP to that of using P2P transceivers. The choice of the 100 Gb/s, 200 Gb/s or 400 Gb/s was made according to the long-term demand for each site as shown in the table in Fig. 6. In particular, Fig. 6-(a) reports the number of 25 Gb/s subcarriers per each leaf based on the traffic profile reported in Fig. 2 and Fig. 3. It is observed that a single subcarrier is sufficient for each leaf except leaf 2L, which requires 4 subcarriers at the beginning of life (BOL). The quantity and

type of P2MP pluggables is then defined; it was decided to base the capacity of the transceiver on long-term needs, so that all costs are upfront. A different approach would be to upgrade the pluggable only when the required threshold is reached, following a pay-as-you-grow model. Fig. 6-(b) shows the number of subcarriers and the consequent number and type of pluggables needed at the hub sites where the LPs are combined, as shown in Fig. 5.

Cost evaluations are made in an arbitrary cost unit (acu) as described in [2]. In the specific case, all the costs are related to the cost of a 100GbE QSFP-28 interface, which costs 1 acu by definition.

We assumed coherent optical transceivers of different data rates and cost points: 100 Gb/s for 2 acu, 200 Gb/s for 3 acu, and 400 Gb/s for 4 acu. We further assumed the use of DSCM with 25 Gb/s granularity, allowing traffic to be groomed at the hub site. The hub sites were assumed to be populated with modern core IP routers with support for 100GbE, 200GbE and 400GbE in QSFP-DD ports, capable of hosting coherent pluggable optics. The smaller edge nodes have much lower traffic demand and were assumed to be legacy routers with 100GbE QSFP-28 cage, so a network demarcation device with a cost of 1 acu was assumed to be hosting the coherent pluggable optic.

Incremental capacity planning was performed for the three scenarios. For the P2MP case, separate hub transceivers were required to aggregate traffic from the green and blue LPs in Fig. 5(a-b). The cost results are summarized in the table reported in Fig. 7, showing significant savings for P2MP transceivers, especially in the short- and mid-term scenario with less traffic. The table also shows how P2MP with 25 Gb/s DSCM provides a natural pay-as-you-grow structure, where the hub sites can be filled with transceivers as the total aggregated traffic increases, while in a traditional P2P scenario the full investment is needed in the first year, if high capacity interfaces are employed, or more DWDM channels at IOG are to be installed from time to time, using the spectrum in a less efficient way. CAPEX savings were found to be 32% in the short- and mid-term, declining to 22% in the disruptive long-term scenario. Similar results were obtained on the suburban/rural scenario, with savings of 34% and 23% being achieved in short-/ mid-term and in the long-term, respectively. These results provide evidence that DSCM can be effectively deployed across different topologies and meet traffic and link engineering requirements. A future study might investigate how the introduction of 800 Gb/s P2MP transceivers could increase savings in the long-term scenario.

Finally, an exercise was performed to understand the value of further traffic aggregation. As discussed in the previous section, the two LPs may be combined into a single optical domain, albeit at the expense of increasing the cost of the line system. The resulting ability to aggregate traffic flows from a larger set of leaf nodes was shown to reduce the number of interfaces at the hub node, translating into P2MP savings of 32% to 41% in the short-term scenario.

| a) | | Number of 25 Gb/s Subcarriers per Period per Leaf | | | | | | Number and Type of Pluggable per Leaf | | | | |
|-------------------|----|---|----------|----------|----------|----------|----------|---------------------------------------|---------------|---------------|---------------|---|
| | | Short | | Medium | | Long | | Number of ports for Long Term | | | | |
| | | to Hub A | to Hub B | to Hub A | to Hub B | to Hub A | to Hub B | 100G to Hub A | 100G to Hub B | 200G to Hub A | 200G to Hub B | |
| Urban Industrial | 1C | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| | 1E | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - | - |
| | 1F | 1 | 1 | 2 | 2 | 5 | 5 | - | - | 1 | 1 | - |
| | 1G | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | - | - | - |
| | 1H | 1 | 1 | 1 | 1 | 4 | 4 | 1 | 1 | - | - | - |
| | 1I | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - |
| | 1N | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | - | - | - |
| | 1Q | 1 | 1 | 2 | 2 | 7 | 7 | - | - | 1 | 1 | - |
| | 2E | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | - | - | - |
| Suburban Regional | 2F | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | - | - | - |
| | 2G | 1 | 1 | 2 | 2 | 5 | 5 | - | - | 1 | 1 | - |
| | 2L | 4 | 4 | 4 | 4 | 7 | 7 | - | - | 1 | 1 | - |
| | 2O | 1 | 1 | 2 | 2 | 8 | 8 | - | - | 1 | 1 | - |
| | 2H | 1 | 1 | 3 | 3 | 4 | 4 | 1 | 1 | - | - | - |
| | 2I | 1 | 1 | 3 | 3 | 4 | 4 | 1 | 1 | - | - | - |
| | 2M | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | - | - |
| | 2N | 1 | - | 1 | - | 4 | - | 1 | 1 | - | - | - |

| b) | | Number of 25 Gb/s Subcarriers per Period per Hub | | | | | | Number and Type of Pluggable per Hub | | | |
|--------------------|----------|--|-------|--------|-------|-------|-------|--------------------------------------|-------|----------|-------|
| | | Short | | Medium | | Long | | 200 Gb/s | | 400 Gb/s | |
| | | Hub A | Hub B | Hub A | Hub B | Hub A | Hub B | Hub A | Hub B | Hub A | Hub B |
| Suburban / Rural | LP Blue | 4 | 4 | 6 | 6 | 17 | 17 | 1 | 1 | 1 | 1 |
| | LP Green | 2 | 2 | 2 | 2 | 4 | 4 | 1 | 1 | - | - |
| Urban / Industrial | LP Blue | 3 | 3 | 7 | 7 | 9 | 9 | - | - | 1 | 1 |
| | LP Green | 9 | 8 | 11 | 10 | 29 | 25 | - | - | 2 | 2 |

Fig. 6: Number of subcarriers and pluggables per (a) leaf and (b) hub into filterless domains (green and blue LPs in Fig. 5) enabled by P2MP transceivers.

| a) | | Urban / industrial | | |
|---------|-------|--------------------|------|--|
| Urban | Short | Mid | Long | |
| P2P | 123 | 123 | 123 | |
| P2MP | 84 | 84 | 96 | |
| Savings | -32% | -32% | -22% | |

| b) | | Suburban / rural | | |
|----------|-------|------------------|------|--|
| Regional | Short | Mid | Long | |
| P2P | 106 | 106 | 106 | |
| P2MP | 70 | 70 | 82 | |
| Savings | -34% | -34% | -23% | |

Fig. 7: CAPEX in arbitrary cost units for the three considered traffic scenarios and savings of P2MP with respect to P2P: (a) urban/industrial; (b) suburban/rural.

V. CONCLUSION

The application of point-to-multipoint technology enabled by digital subcarrier multiplexing to two challenging Telecom Italia metropolitan aggregation scenarios demonstrates that it can reduce deployment costs and greatly simplify network architecture. For the highly representative contexts studied – urban/industrial and suburban/rural – we report CAPEX savings up to 32% over a traditional point-to-point approach, providing evidence that this architecture is a compelling alternative for network operators with complex aggregation networks.

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