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Use cases and drivers for optical grooming in 5G transport networks

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***Abstract*— The introduction of fine granularity flexible optical networking technology featuring SDN-based fast reconfigurability brings the possibility of using the optical layer as the multiplexing layer for highly variable traffic rather than the packet layer. This optical-by-passing approach brings relevant savings in packet switching and provides QoS guarantees hard to provide at the packet layer without over-provisioning. The paper discusses several use cases that illustrate the potential of Sliceable Bandwidth Variable Transponders (S-BVTs) as ultra-low latency optical grooming alternative, especially under the scope of 5G services.**

Keywords—SBVT, grooming, 5G, SDN, CAPEX

I. SBVT ROLE IN 5G NETWORKS

Bandwidth Variable Transponders (BVTs) can adjust their transmission rate by varying the number of subcarriers and modifying the modulation format. This flexibility is improved by Sliceable Bandwidth Variable Transponders (S-BVTs) which enable multiflow transport, changing the traffic rate per flow and the number of destinations on demand [1].

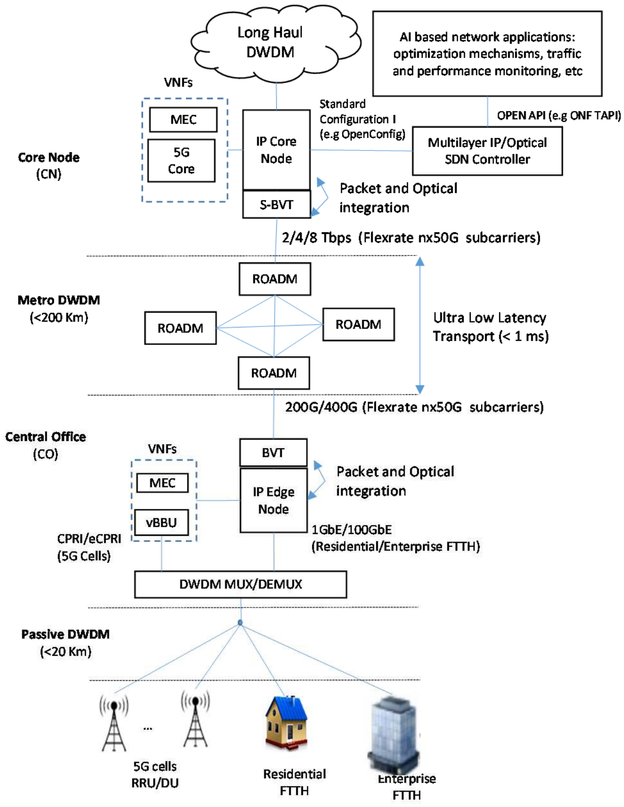

Figure 1. S-BVT based E2E 5G Transport Architecture

An End-to-end (E2E) 5G transport network (Fig. 1) based on a combination of programmable BVTs and S-BVTs at the Telco Central Office (CO) and Core Nodes (CN) can provide ultra-low latency 5G transport as well as optical grooming capabilities enabling statistical multiplexing optimization mechanisms. This work analyses three use cases of this architecture. Namely, the IP and optical network optimization in statistical multiplexing scenarios (Section II), Shared Protection MEC (Section III), and Ultra-low latency B2B services (Section IV).

II. USE CASE 1: IP AND OPTICAL OPTIMIZATION DUE TO STATISTICAL MULTIPLEXING GAIN AT THE OPTICAL LAYER

According to the proposed architecture in Fig. 1, IP Edge and Core Nodes can be connected by means of flexible optical point-to-point circuits composed by a variable number of optical subcarriers (e.g., 50Gb/s). An SDN controller can dynamically modify the number and wavelength of the subcarriers allocated to each circuit taking into account near-real time traffic models generated by Artificial Intelligence (AI) applications. Therefore, S-BVT-based fine granularity and SDN programmable implementations can support optical grooming [2]. Both IP and optical resources can be optimized taking statistical multiplexing gain into account.

The MAN network can be generally seen as a composition of several ring-star topologies in several layers or Hierarchy Levels (HL). Each node of a given level *n* is connected to, at least, a pair of nodes in *n -1* level at the logical IP level. HL1 nodes correspond to nodes (routers) that form the top level of the IP network on national levels, that is, the backbone network. HL2s do not aggregate traffic and only forward traffic to the right HL2 or HL1 node, so that the metro HL1 and HL2 nodes make altogether the top hierarchy of the metro network (HL1/2). CDN (Content Delivery Network) or caching services are usually located at HL2. The layer of HL3s aggregates and distributes traffic from different geographic areas of the MAN. HL4s are the routers located at the bottom layer of the IP network, which classify traffic, authenticate users, validate policies, etc. HL4s aggregate traffic from different locations of the Metro, including OLTs.

The topology used to quantify this use case is the PASSION Metro topology of reference [2]. This topology is made up of:

- 6 HL1/2s, with an average nodal degree of 6.0
- 33 HL3s, with an average nodal degree of 3.42
- 380 HL4s, with average nodal degree of 2.50

Essentially, there is one HL1/2 per 5.5 HL3 and 63.33 HL4s on average. Also, there is one HL3 per 11.51 HL4s.

The purpose of this use case is taking advantage of the fact that most traffic (90%) is hierarchical traffic (uplink aggregation and downlink distribution) to optimize its transport through the MAN. The idea is aggregating at the electronic layer of HL4s the traffic from their HL5s and perform an all-optical transport light path from each HL4 nodes to the closest HL1/2 by-passing HL3s at the optical layer. HL4s are equipped with 2Tb/s S-BVTs and HL1/2 are equipped with either 8 or 16Tb/s S-BVTs (the latter considers exploiting dual-polarization multiplexing). HL3 IP layer is only used for non-hierarchical traffic and to add/drop its local traffic.

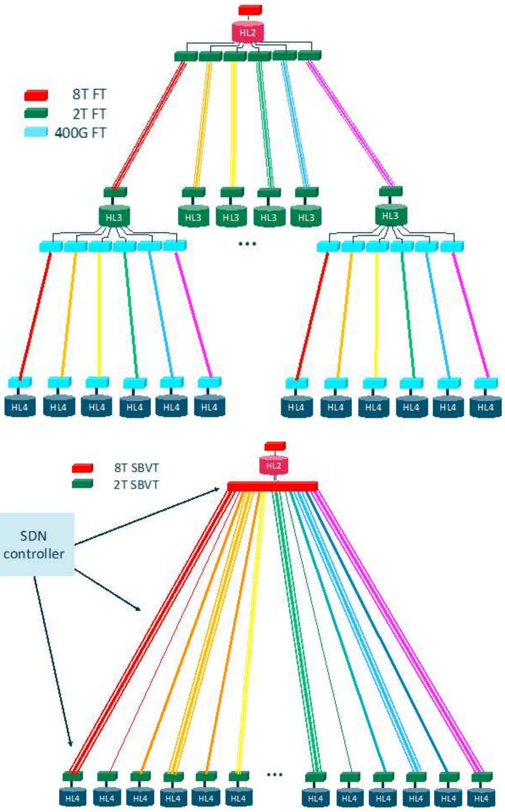

Figure 3. IP over WDM vs HL3 IP-Offloading.

It should be noted that this does not mean that HL4-HL4 or HL4-HL3 connectivity is not supported. As a matter of fact, this non-hierarchical traffic can be carried without the need for additional transceivers. In this use case, we shall not make use of the sliceability property of S-BVTs that may be used for connecting neighboring-HL4s or for HL4-HL3 links to carry non-hierarchical as in Fig. 3, because according to Telefonica's estimation the fraction of this traffic is under 10% and could be left out of the calculus to provide a gross estimate of infrastructure cost [3].

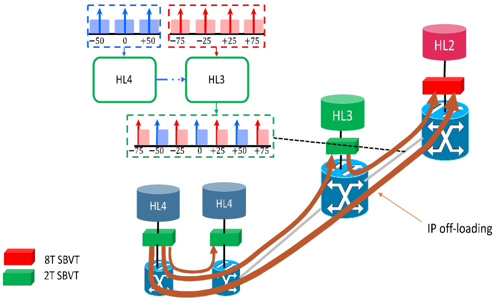

Figure 2. Connectivity options provided by sliceability in the MAN for an HL4 node.

In past preliminary analysis this use case was regarded as medium impact. However, the detailed cost analysis which follows reveals that this use case has a high economic impact due to the savings in intermediate FTs (Fixed Transponders) at the HL3 level. The methodology designed to estimate this saving is outlined in Figure 4Figure 4. The procedure makes use of an SBVT planning and techno-economic tool developed in PASSION project. This tool takes an input: (1) the network topology, (2) the Year-0 (Y0) traffic demand plus a forecasted yearly growth rate, (3) a list of device's unitary costs and (4) a deployment/planning strategy (*IPoverWDM*, *IPoWDM_bp* and *Passion*, as defined below). In our comparison, we shall use the PASSION reference topology [3] assuming an unlimited number of fibers among nodes, will assume a demand at year 0 (Y0) with a normal distribution across HL4 nodes and will use current market price estimates for operators.

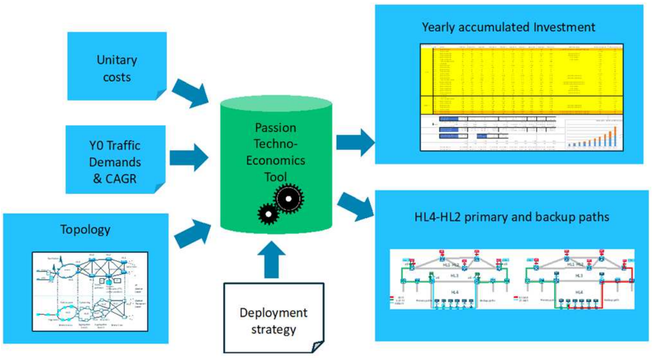

Figure 4. Tool and data used in the analysis cost of the different network planning strategy.

The tool generates all the optical channels between each HL4 router and the closest HL1/HL2 router required to fulfill the traffic demand and provides an inventory of devices to be deployed according to the selected planning strategy, and a cost breakdown for the accumulated investment through the years.

A. Network planning strategies

To show the economic feasibility and benefits of the PASSION solution, this will be compared with two classical network dimensioning strategies. Namely, the scenarios under study consider:

1) IP over WDM strategy with 400G Fixed Transponders (FT) and IP traffic grooming at the HL3 nodes (IPoWDM_gr).

In this scenario, HL4 nodes are equipped with small IP routers and connected with 400G Transponders toward the next hierarchical layer, i.e. HL3. Here, all HL4 traffic is collected and aggregated together to further be forwarded toward the HL1/2 layer. Such HL3 traffic grooming is employed by medium-size IP routers at the HL3 nodes. In addition, 1/2 traffic oversubscription is assumed thanks to the statistical multiplexing benefits of traffic aggregation. This dimensioning strategy applied to the PASSION topology implies that each HL3 node collects the traffic of 11.51 HL4 nodes on average (plus its local traffic) and uses IP grooming to forward only 50% of the peak traffic towards the next hierarchical level HL1/2. Each HL1/2 node receives on average the amount of traffic of 5.5 HL3 nodes. Essentially, the IP routers at the HL3 and HL1/2 must have sufficient capacity to handle about 11-12x the traffic of an HL4 IP routers and about 32x the traffic of an HL4 IP router (one HL1/2 per 64 HL4 nodes with 50% oversubscription at HL3). In addition, both HL4, HL3 and HL12 nodes are dimensioned to be equipped with sufficient 400G FT to cover with peak traffic values.

2) IP over WDM strategy with 400G Fixed Transponders and optical bypassing at the HL3 nodes (IPoWDM_bp).

In this scenario, HL4 nodes are equipped with small IP routers and connected with 400G FT directly toward the HL1/2 nodes, thus by-passing all-optically intermediate HL3 nodes. HL3 nodes are then equipped with small IP routers acting as HL4 nodes, sending their traffic directly toward the HL1/2. This dimensioning strategy applied to the PASSION topology implies that each HL1/2 receives the peak traffic of about 63-64 HL4s and another 5.5 HL3s. Cost savings are expected with respect to solution #1 since HL3 nodes are a lot simpler than the previous case, both in terms of IP routers and number of downstream and upstream transponders at the HL3s.

3) PASSION solution with 2T-8T-16T S-BVTs with 50Gb/s lambda granularity and optical-bypassing at the HL3 nodes (Passion).

This scenario considers the PASSION solution whereby all nodes are equipped with multi-Tb/s S-BVTs in a pay-as-you-grow fashion, that is, only the necessary number of fixed VCSEL (Vertical Cavity Surface Emitting Laser) at 50G are activated to fully cover the traffic requests of the light paths. Intermediate HL3 nodes are all-optically by-passed like in strategy #2; these HL3s are dimensioned as HL4 nodes again, with smaller IP routers and less transponders. This dimensioning strategy applied to the PASSION topology implies that each HL1/2 receives the peak traffic of about 63-64 HL4s and another 5.5 HL3s. Cost savings are expected with respect to solution #1 since HL3 nodes are a lot simpler than the previous case, both in terms of IP routers and number of downstream and upstream transponders at the HL3s. In addition, extra cost-savings are expected thanks to the pay-as-you-grow strategy where peak traffic is provided in steps of 50G capacity units rather than 400G units as it is the case of FTs. In addition, the cost of grey optics is avoided in this third solution since the S-BVTs are directly plugged into the IP routers.

B. *Traffic assumptions and cost estimates*

Two traffic scenarios are assumed for a 10-year period CAPEX analysis:

- Year 0 (Y0) traffic of 150G offered per HL4 and 40% Compound Annual Growth Rate (CAGR)
- Year 0 (Y0) traffic of 600G offered per HL4 and 15% CAGR

Regarding the equipment costs, Table I summarizes the unitary costs used in the analysis regarding optical equipment, IP routers, transponders, and grey optics. Normalized cost units (CU) have been assumed for privacy reasons. The value of 1 CU is equal to the cost of a 10G grey transceiver, in line with the techno-economic studies of other past projects (e.g., 5G PPP H2020 Metrohaul).

TABLE I. EQUIPMENT USED FOR THE TECHNO-ECONOMIC STUDY.

Item	**Description**	**Normalized Cost Units (CU)**
IP Routers		
Small	Intended for HL4 nodes (and HL3 nodes in bypass scenarios)	250.00
Medium	Intended for HL3 nodes in IP grooming scenarios	1666.67
Large	Intended for HL1/2 nodes	2500.00
Photonic mesh		
1D-ROADM	ROADM degree node. A node with degree 6 must multiply this amount with 6x	88.96
WDM Transponders		
Chassis	Can allocate up to 4 transponders	28.66
100G FT	Fixed transponder	62.50
400G FT	Fixed transponder	100.56
2T S-BVT	Passion's VCSEL-based SBVTs. Cost estimated as twice the cost of a 400G Fixed Transponder	201.11
Grey optics		
100G grey transceiver	N/A	3.33
400G grey transceiver	N/A	36.96

Figure 5 shows the comparison between the three strategies on a 10-year period. As shown, the PASSION architecture achieves large cost savings, not only the first year Y0, but also on the other ones too. In particular, the TCO is 0.22 million CU for Passion on Y0, while classical IP over WDM implementations with 400G FT comprise 0.41 MCU and 0.34 MCU respectively. Even larger CAPEX savings are observed in Y9, where the cost of Passion architecture is between 1/3 and ¼ than that of classical IP over WDM strategies.

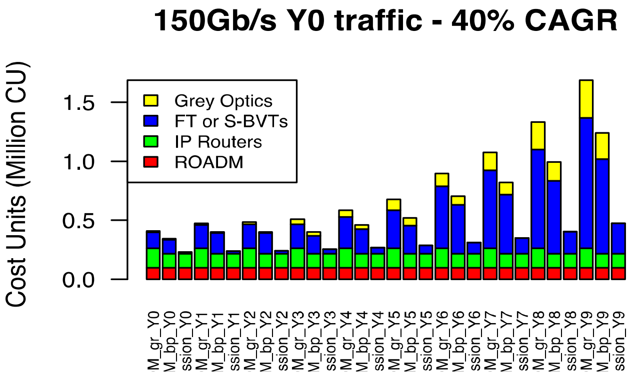

Figure 5. Scenario #1: 50Gb/s Y0 traffic per HL4 and 40% CAGR.

Essentially, the cost savings are achieved thanks to the 50G granularity traffic dimensioning in the pay-as-you-grow license model for the S-BVTs, but other important savings are obtained thanks to the no-need for grey optics and lighter IP routers in the HL3s (IP offloading). Interestingly, while traffic increases by 40% each year, CAPEX increases 15.20% and 13.72% for the two classical IP over WDM with grooming and bypassing respectively. The PASSION solution only increases at a CAPEX rate of 7.6% in this scenario.

Figure 6 shows the second scenario where Y0 offered peak traffic is 600 Gb/s per HL4 node and the annual traffic growth is 15%. As shown, again the PASSION architecture is a lot cheaper in all cases than the two classical IP over WDM dimensioning cases. In particular, the TCO is 0.26 million CU for PASSION on Y0, while classical IP over WDM implementations with 400G FT comprises 0.59 MCU and 0.46 MCU respectively. Larger CAPEX savings are observed in Y9, where the cost of PASSION architecture is between 1/2 and 1/3 of the one of the classical IP over WDM strategies. Again, cost savings are mainly achieved thanks to the 50G granularity traffic dimensioning in the pay-as-you-grow license model for the S-BVTs, but savings are also obtained thanks to the no-need for grey optics and lighter IP routers in the HL3s (IP offloading). Again, while traffic increases by 15% each year, CAPEX increases 7.8% and 7.4% for the two classical IP over WDM with grooming and bypassing respectively. The PASSION solution only increases CAPEX at a rate of 4% in this scenario of 15% traffic annual growth.

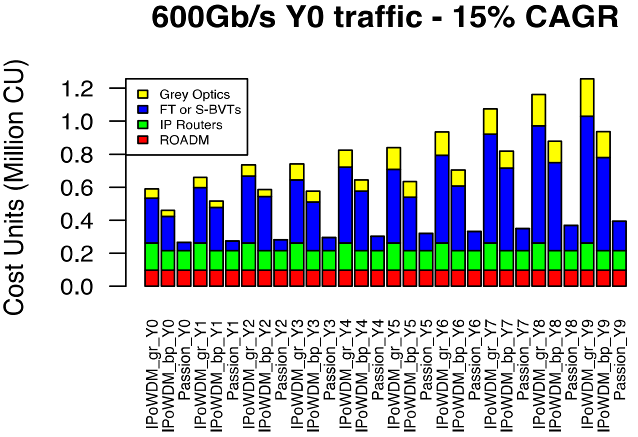

Figure 7. Scenario #2: 600Gb/s Y0 traffic per HL4 *and*

In conclusion, the PASSION architecture is feasible from a techno-economic perspective as it achieves the objective of 40% CAPEX reductions to justify a technology shift from the classic paradigm. Also, it shows scalability in terms of moderate cost increase per year for different traffic growth cases (15% and 40% CAGR). In outline, from the operator perspective, the cost-effective ultra-broadband transport and expansion in a large MAN with dynamic capacity adaptation and HL3 IP off-loading can yield savings of tens of 10Tb/s routers per big city. However, the saving in FTs, both in downlink and uplink, at HL3 is very high. From the vendor perspective, the impact of the solution is high: tens of HL3s per large city. The cost reduction of IP equipment does not justify the investment in PASSION S-BVTs per-se, but the saving in FTs does. 40% CAPEX reduction achieved. Great scalability with moderate cost increase when traffic grows is also in favor of this solution, particularly, considering potential future massive deployment.

III. USE CASE 2: SHARED PROTECTION MEC

As the authors of [4] claim, introducing datacenter capabilities at all MAN nodes may increase the CAPEX network total cost by 30-50% in addition to the high OPEX costs of powering and maintaining the edge data centers. Thus, the deployment of MEC (Multi-Access Edge Computing) nodes needs to be carefully decided based on the expected return of investment from new application services.

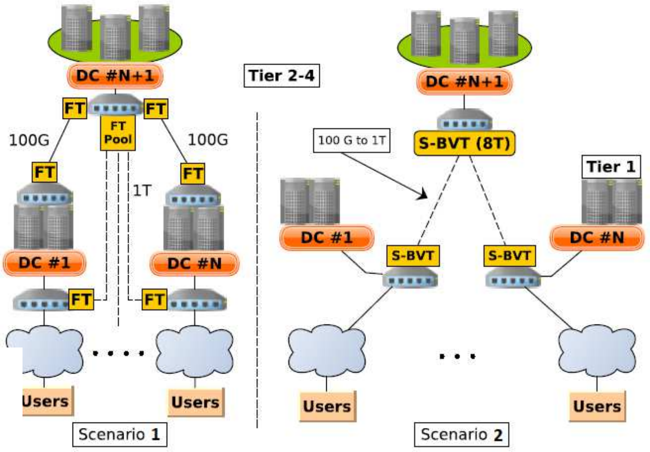

Figure 6. Architectures for dynamic restoration.

ne of the technologies providing ultra-low latency services r 5G at the application layer is edge computing. The ›ssibilities of placement of the primary and backup ›mputing resources opened by state-of-the-art advanced ‹ceable bandwidth-variable transceivers (S-BVT) deserve a ›reful study, not only in terms of latency but also in terms of ›st. In other words, there is a tradeoff between latency, cost, ıd power consumption. If the latency budget can be met via ›ntralized/mixed centralized-edge processing rather than ing only a pure edge option, a lot of resources may be saved, and edge computing becomes more affordable to operators. The margin for the distribution strategy to be adopted depends on the latency budget of the edge application. In [5] we analyzed two strategies from the perspective of computation resources consumption when the delay budget permits to choose: overflow over a paired same-level Data Center (DC) and overflow over a centralized site. We showed that a proper distribution of computing resources in the centralized overflow together with S-BVT high-speed transmission can outperform the costs of a distributed strategy, requiring fewer resources and much smaller DCs in central offices. Namely, for the same target blocking probability of 10^{-6}, the total saving percentage achieved in terms of hardware resources for edge computing tasks is 8%. Consequently, the savings in terms of computation elements can be also translated into a reduction of the power consumption.

In [6] we studied the optical interconnection of CDN caches with S-BVTs from the perspective of availability. We compared several approaches to implement this scenario with dynamic circuits, considering both inter-cache and backup traffic with fixed transceivers featuring both permanent and switched optical circuits, and with the Tb/s sliceable bandwidth-variable transceivers. Consider the two dynamic restoration scenarios depicted in Figure 7. In scenario 1, each Tier1 local data center has a backup on a central data center (Tier 2-4) using independent dynamic connections based on fixed transceivers. The main drawback of this approach is the number of optical circuits and transceivers that are needed. On the other hand, Scenario 2 implements the connections from the local data centers to the centralized data center using S-BVT technologies. This demands the use of less transceivers and optical circuits. In addition, extra bandwidth can be flexibly added when needed. The number of IT resources for each scenario is computed using Eq.1, taken from [4] where N is the number of local data centers and M is the number of resources needed in the centralized, high tier data center.

$$P_{NoSevice} = P_{Failure_{T1}}[P_{Failure_{T4}} \sum_{i=M+1}^{N} \binom{N}{i} P^{i}_{Failure_{T1}} (1 - P_{Failure_{T1}})^{N-i} (1 - P_{Failure_{T4}})]$$

The caches for these contents can be accessed via the local data centers, as well as in through higher hierarchical level servers for redundancy and for the content not available in the local data centers. Table I shows the number of needed transceivers and IT resources needed to comply with service availabilities at Tier 1 (99.67% availability) and Tier 4 (99.99% availability) data centers, in a target use case where the local data centers serve 70,000 active subscribers of IPTV contents, demanding 15 Mb/s for 4k video.

TABLE II. RESOURCE COMPARISON

		Scenario 1	Scenario 2
Number IT Resources		43	43
Number of fixed transceivers	**100G**	80	-
	1Tbps	43	
S-BVTs	**2Tbps**	-	40
	8Tbps		1

Even though the number of IT resources is the same in both scenarios, the one supported by the S-BVT uses fewer transceivers. This is due to the fact that the dynamicity of the S-BVT better leverages the benefits of statistical multiplexing. Also, note that the wavelength occupancy is fixed in scenario 1 and proportional to the traffic load in scenario 2, which enables the efficient (re)use of bandwidth in the S-BVT scenario.

IV. USE CASE 3: ULTRA LOW LATENCY B2B SERVICES

Currently, most B2B (Business to Business) inter-factory applications are typically transported over multiservice IP networks using Segment Routing or L3/L2 VPNs with QoS requirements (latency, bandwidth, packet loss) for different applications. This is the typical infrastructure that operators offer with the aim of paying off the deployments by overlaying several services in the same network. However, ultra-low latency applications (e.g., real-time connectivity for industrial robots) cannot be served in this way and require dedicated fiber deployments with very high costs and long activation times. The S-BVT based backhaul architecture aims to solve this problem by enabling simultaneous transport of different traffic profiles from ultra-low latency industrial applications to non-time sensitive residential traffic.

According to the network scheme shown in Figure 8, a Telco operator could offer dedicated optical subcarriers from different locations (e.g., factories and teleworkers residences) towards a central control node. E2E optical transmission provides ultra-low latency over a Telco multiservice infrastructure avoiding the extra costs of deploying or renting a dedicated fiber infrastructure. Furthermore, the use of an S-BVT in the central node would enable a simpler integration of new remote locations. Let us compare two different strategies already mentioned in this study. The first one is the IP over WDM strategy with Fixed Transponders and optical bypassing at the HL3 nodes (IPoWDM_bp). The second one is the PASSION solution with S-BVTs with 50Gb/s lambda granularity and optical-bypassing at the HL3 nodes. In Figure 5, note that the cost of the equipment for each one of these solutions, assuming a reference topology with 6 HL1/2, 33 HL3 and 380 HL4, are 0.41 million Cost Units (CU) and 0.22 million CU, respectively. The costs are normalized taking the

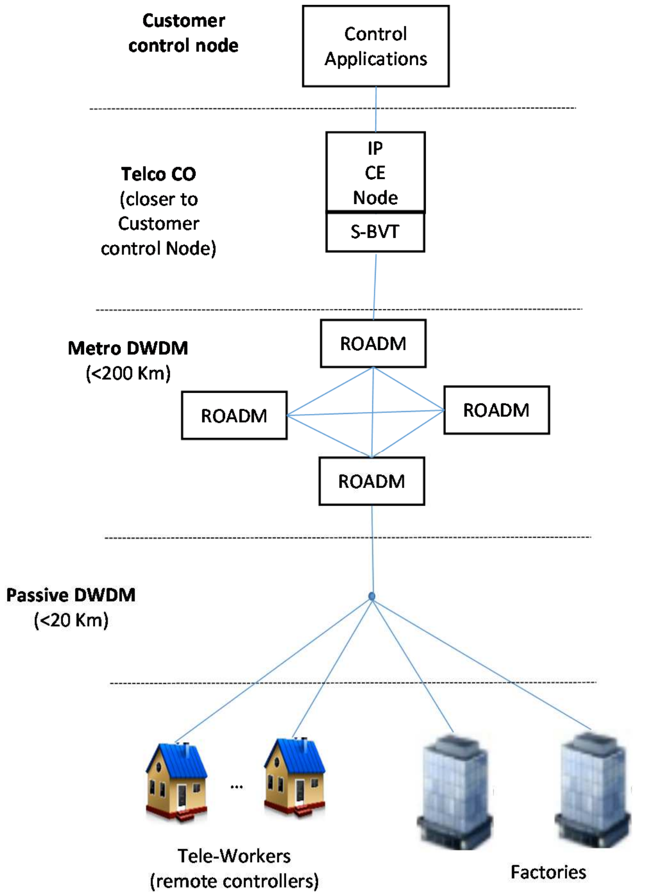

Figure 8. Ultra-Low latency B2B for industrial robot control.

cost of a 10G grey interface as reference. These costs give us an approximation of the cost per node as $\frac{0{,}41\cdot 10^{6} CU}{(6+33+380)\, nodes} = 978\, CU$ per node for the IPoWDM_bp scenario and a cost of $\frac{0{,}22\cdot 10^{6} CU}{(6+33+380)\, nodes} = 525\, CU$ per node for the PASSION scenario. Additionally, according to Telefonica experience on fibre deployments in Europe, we can assume that the cost of deploying optic fiber (trench, duct, and fiber itself) is around 540 CU per kilometer. Table III summarizes the cost of two alternatives: 1) Dedicated fibre infrastructure using IPoDWDM point to point links and 2) Ultra Low Latency B2B Telco service based on SBVT PASSION technology over existing fibre infrastructure. First alternative including the total cost of the fiber deployment for 2 km connections between nodes, while the second option is sharing this cost among 32 customers. Different number of nodes in the Metro networks are also considered. For the sake of the example, for 4 nodes in the MAN network the cost of the equipment in the IPoWDM_bp is given by $4 \cdot 978$ CU, and the cost of the fiber deployment for a complete mesh of 4 nodes with 2 Km connections is given by $\binom{4}{2} \cdot 2\, km \cdot 540$ CU.

	Scenario	**Cost of equipment (CU)**	**Cost of fiber (CU)**	**Total cost (CU)**
4 nodes	**Dedicated dark fibre based on IPoDWDM**	4·978	6·2·540	10392
	B2B Telco service based on PASSION	4·525	6·2·540/32	2302
10 nodes	**Dedicated dark fibre based on IPoDWDM**	10·978	45·2·540	58380
	B2B Telco service based on PASSION	10·525	45·2·540/32	6768
25 nodes	**Dedicated dark fibre based on IPoDWDM**	25·978	300·2·540	348450
	B2B Telco service based on PASSION	25·525	300·2·540/32	23250

TABLE III. COST COMPARISON OF B2B SCENARIOS

Note how the overall cost of the Ultra-Low Latency B2B Telco solution could be more than 90% lower than deploying a dedicated fibre infrastructure.

V. CONCLUSIONS

This work analyzes three different use cases for optical grooming in 5G networks. Use case I (IP and Optical Optimization) demonstrates that the use of SBVTs as grooming alternative in metro scenarios can achieve CAPEX savings of 50% per year versus current IP over WDM. Use Case II (Shared Protection MEC) concludes S-BVTs are key devices to improve backup MEC scalability in terms of IT resources (virtual machines, storage, etc.) and transceivers, thanks to their capability to adapt to the actual traffic demand and to obtain multiplexing gains at the optical layer. Finally, Use Case 3 (Ultra Low Latency B2B services) presents a new Telco service enabled by metro networks with optical grooming capabilities.

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REFERENCES

[1] J.P. Fernandez-Palacios, Victor Lopez, Beatriz de la Cruz, Ori Gerstel, Nicola Sambo and Emilio Riccardi, Chapter 7 "Sliceable Bandwidth Variable Transponders", Elastic Optical Networks, 2016, ISBN 978-3-319-30174-7.

[2] EU passion project: Photonic technologies for progrAmmable transmission and switching modular systems based on Scalable Spectrum/space aggregation for future agIle high capacity metrO Networks (EU H2020 KET Project). Scuola Superiore Sant'Anna. URL: http://www.passion-project.eu.

[3] D. Larrabeiti, G.Otero, J. Fernández-Palacios, N. Serrano, V. López, WP2 Deliverable 2.1: Definition of use cases and requirements for network, systems and subsystems. PASSION Project H2020-ICT-30-2017.

[4] J. A. Hernández, M. Quagliotti and L. Serra, "On the cloudification of Metropolitan Area Networks: impact on cost and energy consumption," *2021 IEEE 7th International Conference on Network Softwarization (NetSoft)*, 2021, pp. 330-338, doi: 10.1109/NetSoft51509.2021.9492662.

[5] G. Otero Pérez, D. Larrabeiti, J.A. Hernández, J. P. Fernández Palacios, V. López, M. Svaluto Moreolo, and J. M. Fabrega. "Strategies to Scale Edge Computing throughout the MAN with Optical Networking Technologies". IEEE Photonics Society, 22th International Conference on Transparent Optical Networks (ICTON), Bari, Italy, July 2020.

[6] G. Otero, D. Larrabeiti, J. A. Hernández, P. Reviriego, J. P. Fernández Palacios, V. López, M. Svaluto Moreolo, R. Martínez, and J. M. Fabrega. "Optical Interconnection of CDN Caches with Tb/s Sliceable Bandwidth-Variable Transceivers featuring Dynamic Restoration". European Conference on Networks and Communications (EuCNC), Valencia, Spain, 2019.

[7] M. A. Pisarda et al. "All-optical Aggregation and Distribution of Traffic inLarge Metropolitan Area Networks using multi-Tb/sS-BVTs" in *Journal of Optical Communications and Networking*, vol. 14, no. 5, pp. 316-326, May 2022, doi: 10.1364/JOCN.448115.