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A techno-economic study of optical network disaggregation employing Open-Source Software business models for Metropolitan Area Networks

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***Abstract*—This work provides a techno-economic evaluation of optical WDM disaggregation architectures in the context of Metropolitan Area Networks. The study compares two optical disaggregation options (partial vs. total) against the legacy benchmark where optical equipment is subject to vendor lock-in, as it is deployed in most networks today. We show that emerging open-source software projects within the Software-Defined Networking (SDN) ecosystem can potentially yield significant cost savings for medium- and large-size network operators, while they can introduce extra flexibility and agility to network operations and service deployments.**

***Index Terms*—Optical WDM Disaggregation; Open-Source Software Models; Techno-Economics.**

I. Introduction

OPEN-source software (OSS) has proven itself over the years both as a feasible de-facto standard for software (SW) development and a successful business case for companies willing to provide support and extra features on top of it. OSS was originally proposed in the 1980s as a free software movement against proprietary software, but today has become a whole business ecosystem with successful case examples like Red Hat, Java, MySQL, etc. As a matter of fact, Red Hat announced in 2018 a net income of 384 Million US dollars.

OSS benefits from having a large community of software developers providing support and producing new updated versions featuring security, reliability and stability. This way, companies avoid reinventing the wheel and receive the best of both worlds: transparent technology with the support and features of commercial software. Following the Red Hat example, Linux Red Hat accounts for around 100 Million lines of code (LOC), a quantity that shows the number of software developers and time devoted to producing newer versions with ever-increasing functionalities.

In this like, large companies like Google, Facebook or Microsoft have gone to a "bare metal" model where they acquire hardware directly from the original design manufacturers of hardware (HW) and adapts existing free OSS customized "in-house" on attempts to reduce both capital and operational expenditures (CapEx and OpEx) [1]. This trend has arrived at the telecommunications arena, where a number of telecommunications operators (aka telcos) are advocating for optical network disaggregation which promises to enable freedom of choice without vendor lock-in while gaining business agility, service delivery and operations efficiency [2], [3], [4], [6].

Thanks to the rise of the Software Defined Networking (SDN) paradigm, a large number of SDN-based open-source projects have appeared in the last decade, ranging from Network Operating Systems and SDN controllers (i.e. Cumulus, ONOS [7], Opendaylight, to broader scope projects developed around such SDN frameworks (i.e. CORD [10] and VOLTHA. The Central Office Rearchitected as Datacenter (CORD) aims at bringing datacenter and cloud agility closer to the users while VOLTHA focuses on creating hardware abstraction for broadband access equipment, providing a common, vendor agnostic, control and management system for a set of white-box and vendor-specific hardware devices for Passive Optical Networks (PONs).

OSS not only covers SDN controllers and controller frameworks but also reference implementations of Networks Function Virtualization (NFV) Management and Orchestration (MANO) software stack aligned with ETSI NFV interfaces such as Open Source Mano (OSM), or full network automation systems like the Open Network Automation Platforms (ONAP), a comprehensive platform for real-time, policy-driven orchestration and automation of physical and virtual network functions for service deployment automation. Additionally, a large number of open source libraries (with different licensing models) are also available covering several building blocks in a complete software stack, supporting SSH connections, the NETCONF protocol, YANG model parsing, enabling the implementation of NETCONF servers and software agents (see, for example NETOPEER2).

According to [3], "the term optical disaggregation involves all the operational models in which telcos are actively involved in the design, assembly, testing and life-cycle management of the WDM transport systems (WDM-sys)" deployed in their networks. This implies that different optical functionalities, traditionally integrated into a single device and interconnected by a back panel, are now performed by different boxes, interconnected by external cables. Furthermore, the introduction to the market of disaggregated optical HW from some vendors

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along with the rise of OSS initiatives, implementation and multi-source agreements as well as open and standard data models (such as OpenROADM or OpenConfig), enables a wide range of disaggregation options in the WDM domain with considerable potential cost savings.

However, a full optical WDM disaggregation is challenging since the network operator must ensure both horizontal and vertical interoperability, at the data plane level among different boxes, and at the control plane level towards a common controller and management tool(s). In this regard, this article analyzes the pros and cons of different levels of disaggregation, namely partial and full, and provides a techno-economic study of the two options against the legacy mono-vendor aggregated optical network. Techno-economic evaluations conducted on real Metropolitan Area Networks (MAN) in the context of EU H2020 Metro-haul project shows that disaggregation can provide important CapEx savings, especially for medium to large-size operators.

Thus, the remainder of this paper is organized as follows: Section II overviews the architectural options for optical WDM disaggregation and the HW, SW and Integration cost model used in Section V, which analyzes the cost breakdown of each solution as a function of network size. Finally, Section VI concludes this work with its main findings and conclusions.

II. Optical disaggregation architectures

Following [3], we consider in our analysis two different options for optical WDM disaggregation: (1) an intermediate partially disaggregated vs (2) a more radical fully disaggregated optical network.

To understand the differences between them, consider Fig. 1 where a classical aggregated optical WDMnetwork is depicted (top) along with the fully disaggregated (medium) and partially disaggregated (bottom) cases. Essentially, the optical layer is composed of two domains: the “Digital-to-WDM adaption layer” (DtoWDM) and the “WDM Analogue transport layer” (A-WDM). The DtoWDM part comprises the hardware equipment in charge of the adaptation of digital client signals to analogue “media channels” of the A-WDM domain. The A-WDM domain involves those functions related with the transport of such analogue “media channels”, namely add-drop, switching, multiplexing, amplification, equalization, etc. The main optical Network Elements (O-NEs) in the former domain comprise the Transponders (TP), Muxponders (MP) and Switchponders (SP); in the A-WDM domain, these are Multi-Degree Reconfigurable Optical Add-Drop Multiplexers (MD-ROADMs), Line Terminals (LTs), Multiplexers (MUX) and optical In-Line Amplifiers (ILAs).

In the classical *fully aggregated (or Monovendor)* legacy case, which shall be used as a benchmark, both A-WDM and DtoWDM equipment are provided by the same vendor, including control and management sub-systems at a network level (NMS), planning and design tools and often full operational support during the entire life-cycle of the product. An open and possibly standard North-Bound Interface (NBI) can be provided towards a higher level controller or orchestrator, which may also control the packet layer, enabling end-to-end management and service provisioning. In such a vendor lock-in case, the supplier performs the system integration activity. This process includes all the interoperability issues among the network elements and between the O-NEs and the proprietary controller of the optical layer.

In the *partially disaggregated (or open line system) model*, a single vendor provides the A-WDM part, including its HW and SW and network-wise control/management sub-systems (NMS) or SDN controller. However, different vendors may provide the DtoWDM-related O-NEs. The definition of a ”standard” interface at the border (Single Wavelength Interface - SWI) guarantees the interoperability between the A-WDM and the DtoWDM domains. Some of the advantages of the aggregated solution are maintained: in particular the control loops necessary to tune the analog parameters and optimize the optical transmission can still be performed in a proprietary way by the A-WDM vendor. The interoperability issues at the data plane level are limited to the borders between the A-WDM and DtoWDM domains, while at the control plane level the integration of the two domains is regarded as being under a single WDM transport controller (see [3] for a detailed discussion).

Finally, the *fully/totally disaggregated* option represents the case where different vendors provide both the DtoWDM and the A-WDM domains and NMS or SDN controller. To ensure data plane interoperability in this scenario, the interface between different hardware boxes belonging to the A-WDM domain, here named Multi Wavelength Interface (MWI) following the OpenROADM terminology, must also be compliant to a standard definition. Moreover, the WDM controller, in charge of managing all the issues related to analog optical transmission in a multi-vendor environment, must be necessarily vendor-agnostic. Therefore, the South-Bound Interface (SBI) between the controller and the different vendors’ O-NEs must also be compliant to a (set of) standards and/or open data models (see again [3] for a detailed discussion).

For a fair comparison between the three options, all three cases are assumed to be able to deliver the same services in terms of type, QoS fulfillment and carried traffic volumes. To this end, the condition of a mature market is assumed, namely all parts for the three options, HW and SW, are considered to have reached a stable release during system integration (i.e., no troubleshooting effort over and above that required in standard conditions). Also, all standards for interoperability are assumed to be available and implemented in commercial products.

III. Open-Source Software cost models and integration cost

Following [5], it is estimated that the HW cost itself of a packet switch represents about 50% of the total cost, thus the remaining half typically belongs to the Operating System license and SW. Thus, in a disaggregated network model, telcos could potentially purchase optical white boxes with a potentially significant discount, rely on OSS and only pay the cost of extra SW features for the SDN agents of each NE and the SDN controller. Such SW may be developed in-house or externally, opening new business opportunities to third parties.

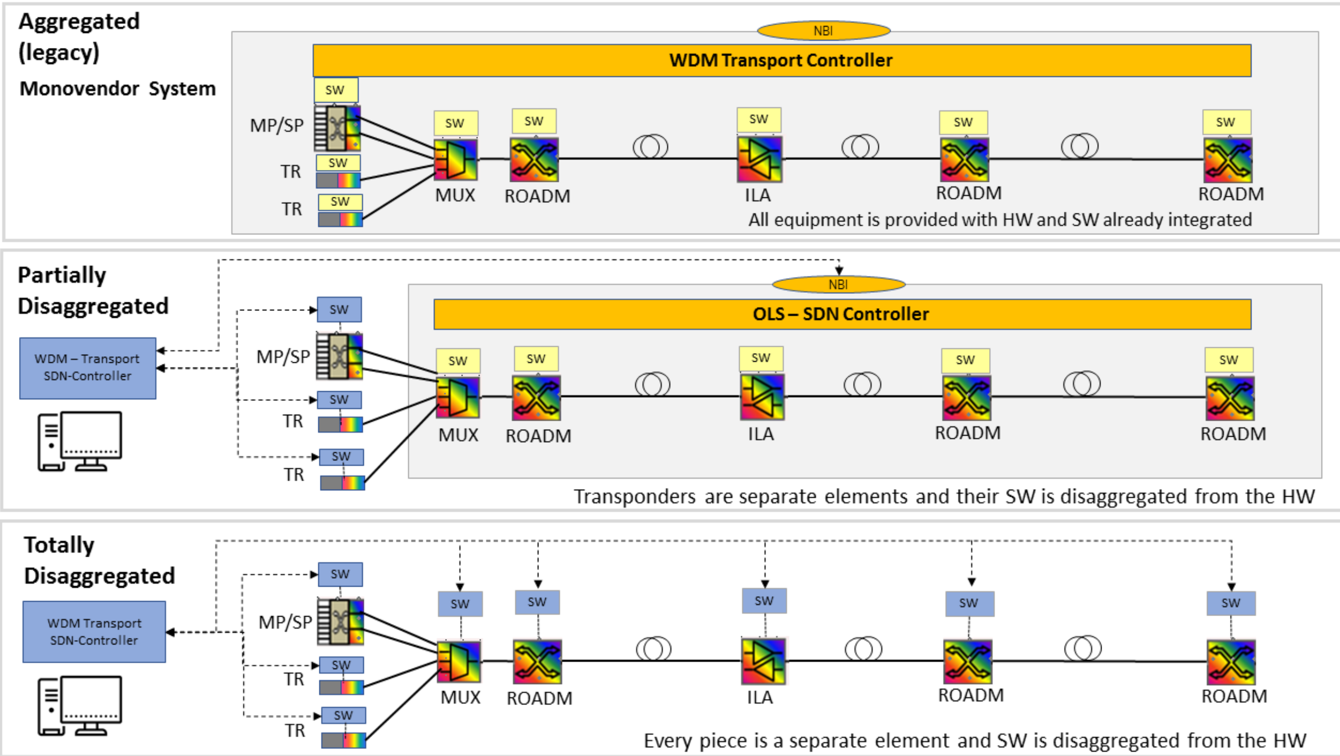

Fig. 1. Optical WDM disaggregation architectures (on blue boxes SW components in charge of the telco or a third part).

Indeed, existing OSS initiatives in the SDN context for WDM transport are gaining momentum and expected to reach maturity in the short to medium term. For example, the Open and Disaggregated Transport Network (ODTN) project [11] is an operator-led initiative to build data center interconnects using disaggregated optical equipment, open and common standards, and OSS. ODTN extends the ONOS framework with a controlling application supporting Transport API photonic media layer north bound interfaces (NBI) and provides drivers for the NETCONF-based control of transceivers and terminal devices using the OpenConfig device model as well as the OpenROADM model. At the O-NE level, Conf-D and netopeer software have been successfully used to implement agents for OpenConfig devices (like Bandwidth-Variable Transponders) and OpenROADM prototypes [12].

In our cost model, we shall measure the amount of SW development in terms of the number of lines of code (LOC) to develop all the extra features needed to reach the same functionalities as in a legacy benchmark network. We further assume that SW developers write programs at an average pace of 4 LOC per hour, a number which includes all the software life-cycle, namely requirements, design, coding, documentation, validation, operation and support. This number is in line with the authors of [8], who conducted an extensive study on software projects employing different programming methodologies and languages, finding an estimated range between 325 and 750 LOC per month (translates into 2 - 4.3 LOC/h).

Integration cost, which is particularly hard to predict even in the benchmark aggregated architecture, is expected to play an important role in deciding in favour of one disaggregation architecture or another. Integration accounts for the effort devoted to lab testing, product validation and in-field verification of equipment and control SW (agents on equipment and network-wise SDN controller), including troubleshooting due to incompatibility issues (both HW and SW) that may occur during network operations.

IV. Cost parameters and model

Table I overviews the different costs for the two disaggregated models along with the legacy benchmark. In the table, all costs are normalized to an individual Cost Unit (CU) metric chosen to be equal to the cost of a 10G Transponder. Concerning SW, it results that 1 CU also corresponds to 200 lines of SW code (i.e. 50 hours of work of a specialized SW developer at 0.02 CU per work hour).

	Legacy	Partial Agg	Fully Disagg
HW A-WDM			
ROADM degree	2.5	2.5	1.50
ROADM A/D	3.1	3.1	1.86
ILA	1.3	1.3	0.78
HW DtoWDM			
10G Transponder	1	0.75	0.75
10x10G Muxponder	7.6	5.7	5.7
100G Transponder	6.8	5.1	5.1
SW Agents A-WDM	-	-	1500
SW Agents DtoWDM	-	1000	1000
SW Controller	206 -	604	500
Integration	217	564	1629

TABLE I
Hardware, Software and Integration costs in normalized CU for 125 MAN nodes.

1) Comments on HW costs: In the case of the aggregated mono-vendor option (benchmark), equipment SW is developed within the integrated solution and its cost is included in the HW cost. Equipment vendors may benefit from an economy of scale if large quantities of equipment are provided to a variety of telco customers. Thus, the model considers a discount of 3% at every doubling of the volume of equipment purchased. The same percentage of discount on volume is applied also to disaggregated options. Table I shows the reference cost values for the supply of 125 metro nodes.

In both disaggregated options, a discounted price for the ”bare metal” HW cost is applied with respect to the benchmark since the equipment application SW is developed separately. In particular, our estimates suggest that both disaggregated options could potentially benefit from 25% discount regarding DtoWDM HW, and another 40% for A-WDM HW in the fully disaggregated case only.

We assume that the bare metal HW offers low-level interfaces that can be consumed by layers and software components (a.k.a. device programmability). Indeed, we assume that the SW agents of A-WDM equipment are significantly more complex, since they have to coordinate O-NEs made of multiple sub-system blades, that is why they are expected to obtain a larger discount factor (40%) in a disaggregated scenario.

2) Comments on SW costs: In the aggregated mono-vedor case the SW agent cost is included in the HW cost while for the SDN controller the cost is assumed equal to a fixed percentage (5%) of the whole HW cost. In both dissagregated options, SW agents of O-NEs are assumed to rely on the availability of mature SDN-based OSS projects, for instance SW developed within the framework of a standardization body like the OpenROADM Multi-Source Agreement (MSA). However, such OSS often requires additional development for the customization required by the specific network implementation. The cost of SW customization is shared among a limited number of items of equipment of the same telco. Thus, the SW cost figures provided in Table I for both O-NE SW agents and SDN controller refer to a total cost amount of SW development regardless of the number of equipment on which such SW is installed. For the Partially disaggregated option only, the SW overall controller cost include both the development of the network controller and the OLS SDN controller (Fig. 1) evaluated as fixed percentage of A-WDM hardware (5% applied, as for aggregated HW). Clearly large operators will benefit from disaggregation more than smaller ones since the custom software is developed once and used multiple times. The SW costs of Table I refer to the case of 125 Metro nodes supply which is the smallest scenario here considered. Besides, large networks typically have more heterogeneous equipment than smaller ones.

The individual SW values for the two disaggregation options are based on a simple model that takes into account the estimated LoC for each SW agent and SDN controller, multiplied by the hourly cost of a SW engineer and its average productivity. In particular, for the implementation of OpenConfig or OpenROADM SW agents, using either the OSS netopeer framework or Cisco ConfD (the latter may have restrictions for commercial purposes) a basic Proof-of-Concept can be implemented in around 2,000 LoC. A feature set agent can go up to 10,000 LoC, while having most SW features should require approximately 20,000 LoC. We estimate that adding quality control, error control, and ”professional” set ups (i.e. going from a Proof-of-Concept to a real implementation) would require between 25,000 and 50,000 LoC, i.e. 125 to 250 normalized CUs. The table shows a pessimistic case of four different SW agents for DtoWDM and six ones for A-WDM equipment (i.e. 4x250 and 6x250 CUs respectively).

Concerning the SW implementation of the SDN controller, ONOS is assumed as the main reference framework. Since ONOS lacks of any kind of specific support for disaggregated optical networks and includes only a reduced set of device management features, a basic proof-of-concept may require around 9,000 LoC for the controller ”application”, which implements the main service orchestration logic. Then, drivers for both OpenConfig and OpenROADM devices need to be implemented, which is a basic set, accounting for another 10,000 LoC, namely 20,000 total for a prototype. Again, we should further apply a corrective factor or 5 to 10 times for professional-like SDN controller SW. Thus, we estimate that a carrier class SDN controller may go up to 100,000 LoC (i.e. 500 CUs).

3) Comments on Integration: Finally, integration costs need also be included in the model, including HW and SW testing, debugging and troubleshooting in a network context and post-deployment support. This is the most critical point, especially for disaggregated architectures which integrate a multitude of different HW and SW items, each of them potentially from different providers.

In the case of partially and fully disaggregated options, integration is made under the assumption that all equipment items, HW, SW and controller, respond to well-defined specifications, hopefully, issued by standardization bodies. The model used to obtain values in Table I and results presented in Fig. 2 and Fig. **??** assumes that integration cost is the sum of two components: network-wise and element-to-element integration.

The first contribution involves the network integration itself and the associated troubleshooting required both in legacy and disaggregated options. Its associated cost depends less than linearly on the number of nodes involved in the integration, but with a higher impact for more disaggregated networks.

The second contribution, i.e. element-to-element integration, deals with the interoperability tests required to be conducted on every pair of O-NEs from different vendors. This integration cost is proportional to the squared of nodes since each equipment type must be checked against each other. This portion of integration cost is not included in the legacy benchmark architecture since this compatibility assessment is not required at the telco, and is more significant for fully disaggregated than for the partially disaggregated architecture.

Thus, the larger and more disaggregated a telco network is, the higher should be its integration cost. Numbers for integration cost in Table I have been computed for a 125 MAN node telco, assuming ten types of equipment parts to be integrated (four DtoWDM and six A-WDM HW components).

V. Evaluation and results

In the following economic evaluation, we have considered typical Metro networks made of ROADMs connected in a weakly meshed topology and traffic requirements in line with the early/mid-term 5G deployment, i.e. each MAN node drops about 300 Gb/s traffic to the MAN (in line with the forecasts of [13]). The MAN topologies used for the evaluations have the following parameters [9]:

- Avg. number of degrees per node: 2.8
- Avg. number of A/D units per node: 1.2
- Avg number of ILA per link: 0.05
- Avg number of tributary 10G per node: 4
- Avg number of 10x10G muxponder per node: 1.5
- Avg number of 100G per node: 1

Thus, taking into account the above Metro network scenario, the average cost for a legacy benchmark node is 2.8x2.5+1.2x3.1+(0.05x2.8x1.3)/2=10.8 CU. Similarly, the cost of the DtoWDM part is: (4x1+1.5x7.6+1x6.8) = 22.2 CU. Thus, the DtoWDM cost represents approximately two thirds of the total cost of the node, on average for the legacy benchmark architecture.

Using the above parameters together with the cost numbers of Table I, we obtain the results of Fig. 2. This figure overviews the three architectures as a function of the number of MAN nodes. As shown, the experiment spans small regional telcos with hundreds of nodes to large continental telcos with tens of thousands of nodes. As a rule of thumb, a telco network comprises approximately one MAN node per 10,000 subscribers.

As shown, disaggregated solutions may provide interesting cost savings for telco sizes above 1,000 nodes, while it is definitely more expensive for regional ones.

Figs. 3, 4 and 5 shows the individual cost breakdown for the cases of 250, 1,000 and 16,000 Metro nodes. These three cases identify approximately small, medium and large (continental or global) operators, respectively. The cost breakdown includes the following parts:

- Equipment HW, namely A-WDM (blue) and DtoWDM (green).
- SW development, i.e. OS and SDN control SW (orange) and equip. SW agents (yellow)
- Integration (red)

As shown, for small operators, the cost of SW development and integration does not compensate HW savings, yielding that legacy solutions are cheaper than disaggregated ones. However, large telcos clearly benefit from sharing the cost of SW development among a large number of nodes. Interestingly, mid-size telcos (few thousand nodes) show the case where partial disaggregation is the cheapest solution since it offers a trade-off between cost savings in DtoWDM equipment and acceptable integration costs concerning legacy and fully disaggregation options.

In conclusion, it is true that disaggregated architectures potentially offer significant cost savings in HW but the cost of integration and SW development needs to be taken into account and possibly does not pay off for small telcos.

VI. Wrap-up and discussion

Optical disaggregation is possible thanks to the ever-increasing efforts devoted by SW developers on open-source software projects. We foresee SDN-based solutions both as a requirement and enabler for optical WDM disaggregation in the near future.

Adopting the disaggregation paradigm in the optical WDM layer is expected to create an ecosystem of competitiveness with significant benefits in terms of Capex and Opex savings; but more importantly SDN is also expected to further introduce flexibility and agile network operations and service deployments.

As shown in this study, optical disaggregation makes sense for medium size and specially large operators with thousands of metro nodes since the cost of SW development and integration represents a large portion of the total cost for small telcos.

In the partial disaggregation model, the effort demanded of the telecommunications operator related to system integration is very limited compared to the potential cost savings in the DtoWDM HW domain. This represents a good compromise in the short-medium term, when the standardization activities of MSAs like OpenROADM and OpenConfig, regarding both data plane interoperability and open Yang models for the control plane, are still under development and their implementation by equipment vendors is still in a preliminary stage.

Furthermore, the greater benefit of the partial disaggregation solution depends on the fact that the life-cycle of DtoWDM boxes is generally much shorter than that of the OLS (A-WDM), as technology innovation evolves much faster for the transponders and muxponders than for the optical switches and ROADMs. So the possibility to preserve the infrastructural investment made in the A-WDM domain, while following the technology evolution in the DtoWDM domain, is expected to enable significant savings for telecom operators during the lifetime of their optical networks.

Finally, the fully disaggregated model is by far much more challenging than the partial model in terms of system integration. For these reasons, the adoption of this model is not likely to become feasible in the near future, and its possible subsequent success will strongly depend on the availability and maturity of standards capable of ensuring horizontal and vertical interoperability.

In conclusion, this work has shown that telcos have a business opportunity concerning the migration of their optical WDM systems to disaggregated models based on Open-Source SW projects, where the operator may have only to deploy and existing mature open-source SW and build extra functionalities on top of it (about several thousands of LOC). The cost of integration (its level of uncertainty) and the maturity of the ecosystem (interoperability agreements and standards) are however points of attention to which an operator should look for a comprehensive and conscious choice.

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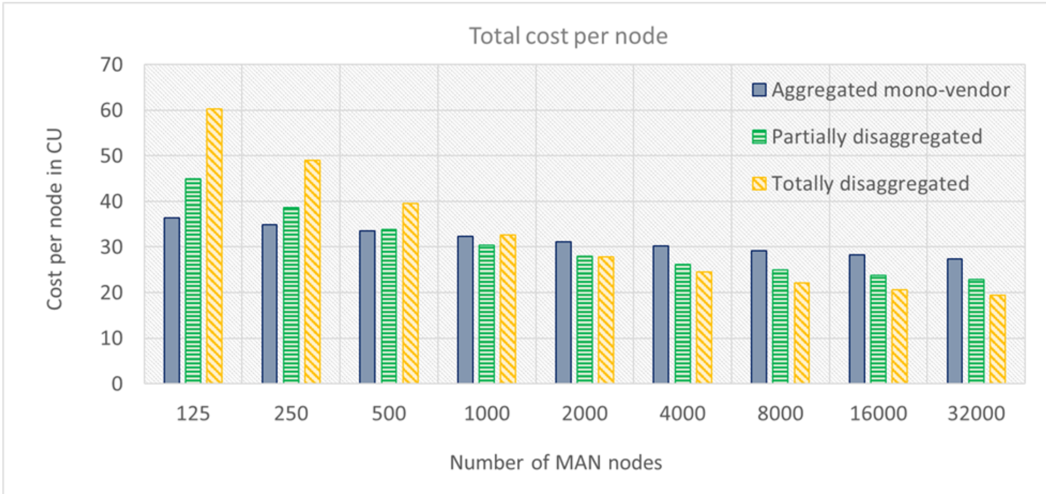

Fig. 2. Total cost per node for the aggregated and disaggregated options as a function of number of MAN nodes to be deployed.

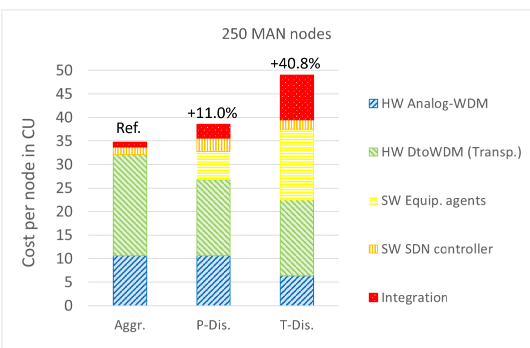

Fig. 3. Cost breakdown for the three disaggregation options (Aggr.= Aggregated Legacy, P-Dis. = Partially Disaggregated, T-Dis. = Totally Disaggregated) for 250 MAN nodes.

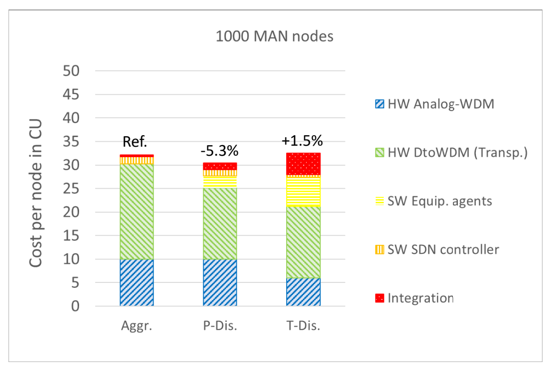

Fig. 4. Cost breakdown for the three disaggregation options (Aggr.= Aggregated Legacy, P-Dis. = Partially Disaggregated, T-Dis. = Totally Disaggregated) for 1000 MAN nodes.

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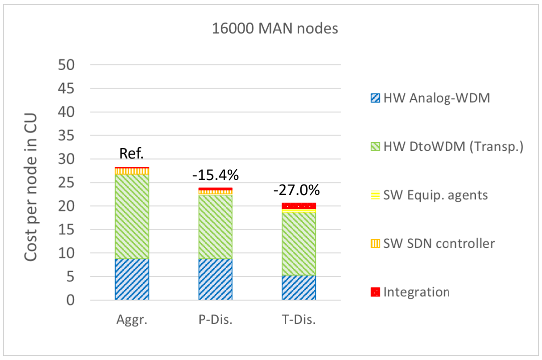

Fig. 5. Cost breakdown for the three disaggregation options (Aggr.= Aggregated Legacy, P-Dis. = Partially Disaggregated, T-Dis. = Totally Disaggregated) for 16000 MAN nodes.

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