On the Impact of Deploying Optical Transport Networks Using Disaggregated Line Systems

João Santos, Nelson Costa, and João Pedro

***Abstract*—Based on fundamental software-defined networking principles, disaggregated solutions have recently been proposed for optical transport networks. The first solution of such type takes the form of disaggregated line systems, which allow network operators to build networks using add/drop multiplexers from multiple vendors. In addition, these line systems allow any specification-compliant optical transponder to be freely connected, independent of their manufacturer. By removing the single-vendor dependency from line systems, traditional business models, based on vertically integrated solutions, are challenged and need to be rethought. Furthermore, competition between vendors is expected to increase, leading to higher innovation and differentiation. However, the development of interoperable line systems sharing a common set of specifications and capabilities may only be able to deliver suboptimal optical transmission performances when compared with proprietary solutions where line systems are fine-tuned. Hence, this paper evaluates the routing performance between disaggregated and proprietary optical line systems. Network simulations are carried out considering two different topologies with single- and multi-domain proprietary deployments. The results obtained show that while proprietary line systems keep the capability of achieving the best optical performance, disaggregated solutions cannot be ignored since they have the potential to reduce the optical–electrical–optical interface count with respect to multivendor deployments while still guaranteeing minimal demand blocking.**

***Index Terms*—Network disaggregation; Optical line systems; Software-defined networking.**

I. INTRODUCTION

The increasing popularity of cloud-based applications and quadruple-play services is leading to substantial traffic growth that requires continuous investment from network operators in their optical transport infrastructure. In order to protect their investment with future-proof solutions, network operators are looking for novel network paradigms [1,2] as alternatives to traditional vertically integrated solutions. Recently, architectures based on software-defined networking (SDN) have emerged as candidates for operating more agile networks and overcome the dependencies caused by vendor lock-in. SDN promotes separation between control and data planes, focusing on software programmability to automate many operations currently driven by manual actions. Thus, by shifting the location of most of the control logic currently residing in the network elements, the hardware can be simplified and turned into a commodity across the industry. Following this path, network operators will gain access to virtualized network functions, which will shorten service deployment time, potentially boosting operational expenditure (OPEX) savings. If the optical hardware does become (even if partially) commoditized, further savings regarding capital expenditures (CAPEX) [3] may also be attained.

However, the actual state of the optical market is still far from fulfilling this SDN vision. Some effort has been placed in developing vendor-owned software controllers, third-party network orchestrators, and standardized northbound/southbound interfaces. Such developments have as an ultimate objective to enable an open line system [4], also referred to as a disaggregated line system (DLS), where optical hardware from multiple vendors can be interconnected and controlled centrally by a single common control plane. One of the recent initiatives to achieve this goal is the Open ROADM consortium, which aims for a disaggregated photonic layer, first targeting the less challenging (performance-wise) metropolitan area networks. This multisource agreement [5] covers pluggable optics, transponders, and reconfigurable optical add/drop multiplexers (ROADMs) with the definition of interfaces to support service provisioning, performance monitoring, and alarms. With a disaggregated photonic layer designed under the agreement guidelines, equipment from multiple vendors can be freely interconnected without compromising functionality. The Telecom Infra Project (TIP) is another initiative where operators, suppliers, developers, etc., are cooperating to change the traditional network deployments to disaggregated ones [6].

While the introduction of disaggregated optical platforms is expected to push for equipment commoditization and generate new business models, there is still some uncertainty regarding the performance of such systems and their applicability to networks with more stringent optical performance requirements. Hence, the objective of this paper is to compare the deployment of proprietary (closed) line

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J. Santos (e-mail: joao.m.santos@coriant.com), N. Costa, and J. Pedro are with Coriant Portugal, Rua Irmãos Siemens, 1-1A, 2720-093 Amadora, Portugal.

J. Pedro is also with Instituto de Telecomunicações, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal.

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systems (PLSs) with DLSs. The analysis is done considering two large-size transport networks and, for PLS, both single- and multidomain deployment scenarios are studied. Uniform traffic patterns are considered (a realistic traffic pattern is also applied in one network) and multidomain scenarios are built using distinct clustering techniques. The results obtained show that disaggregated solutions can greatly reduce the number of required optical–electrical–optical (OEO) conversions in comparison to multidomain PLS networks without compromising the amount of traffic demands successfully routed in the network. Regarding single-domain networks, DLSs tend to require more optical signal regenerators. However, and as expected, the increase in the number of required optical signal regenerators with respect to PLS is highly dependent on the optical performance penalty induced by DLS.

This paper is structured as follows. Section II introduces SDN and disaggregation concepts, mainly focusing on their impact in optical networking. Section III describes the deployment scenarios considered in our study and introduces the physical model used to evaluate optical performance for both DLS and PLS. Section IV shows an extensive set of results for the two network topologies evaluated in this work. Finally, the main conclusions of this work are outlined in Section V.

II. SOFTWARE-DEFINED NETWORKING AND NETWORK DISAGGREGATION

A. *Software-Defined Networking*

As illustrated in Fig. 1, the SDN architecture is based on three distinct tiers: network elements, controllers, and applications. Compared to current networking solutions, these three tiers can be roughly mapped to data, control, and management planes, respectively. By definition, SDN is technology (packet, circuit, etc.) and medium (wireless, optical, etc.) agnostic. At the bottom tier of the architecture lies the hardware responsible for transmission, switching, monitoring, and other functions requiring data signal processing. Importantly, these nodes are exempt from distributed operations that require higher computation capacity and broader knowledge of neighboring nodes, such as calculation of routing paths (e.g., to forward packets) or configuration of forwarding tables (e.g., to switch virtual local area network flows). This smaller set of functions leads to simpler and cheaper equipment. Furthermore, this equipment can be turned into a commodity if the functions are standard-compliant or based on other industry-wide agreements. However, it should be possible to invoke the equipment functions via standardized application programming interfaces (APIs), e.g., OpenFlow [7] and OpenConfig [8]. In SDN, API standardization plays the key role of breaking vertically integrated systems and allowing network operators to decide, with more granularity, which solution in the market better fits their needs.

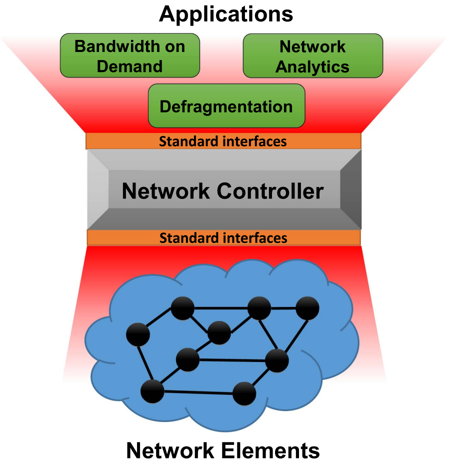

Fig. 1. Multitiered architecture of software-defined networking.

The central element of the SDN architecture is the network controller, which can communicate with the network equipment, in the southbound direction, and with the applications, in the northbound direction, while acting as a translator between both. As an example, transport API (T-API) [9] has recently been proposed as a controller northbound for carrier networks. The controller needs to fulfill basic requirements, such as i) keep updated information about the state of the network and existing services; ii) create new services, for which path computation capabilities are typically necessary; iii) provision and monitor the state of the services, which may eventually require the support of a wide set of southbound APIs; iv) apply service policies that allow fast reaction to changes in network conditions, e.g., service restoration in the case of degraded quality of service; and v) network topology virtualization to allow client segmentation at the northbound level. In a multilayer network containing individual controllers dedicated to specific technologies (e.g., packet or optical) or domains, coordination is ensured by a higher-level controller, also known as an orchestrator.

Finally, at the top tier of the SDN architecture lie the software applications. These software applications embody and execute a set of workflows that explore the functional capabilities in the controller and network elements. As such, network operators will use the set of applications that better fit their needs. For instance, complex analytical procedures, advanced network management operations [10], or emulation of functions previously running in the network hardware [11] can be programmed as SDN applications.

B. *Multilayer Network Orchestration Scenarios and Trade-Offs*

There is currently a clear evolution taking place in the context of multilayer network orchestration [2]. The control architectures depicted in Fig. 2 display the several stages of this evolution. Figure 2(a) shows a traditional orchestration scheme that relies on manual-intensive operations from technical support staff to handle multiple

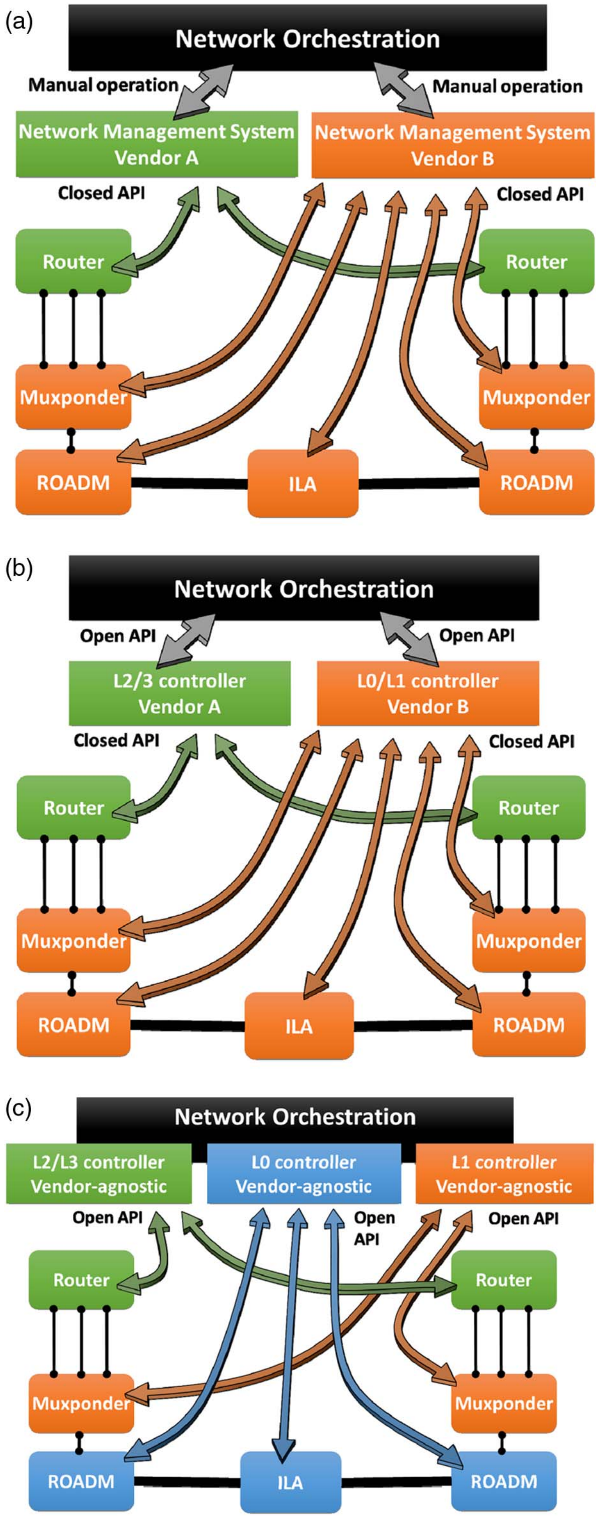

Fig. 2. Transport network control paradigms: vertically integrated system with (a) manual and (b) automated orchestration; (c) disaggregated system with automated orchestration.

management tools provided by the plethora of equipment vendors. For the network operator, this solution has several drawbacks. First, and due to the human-driven interactions with different tools, the service creation process may require several days or even weeks. Moreover, network operators are typically organized in separated planning departments, each one responsible for specific network layers. For multilayer services requiring coordination between different departments, further delays may be introduced. The second issue is related to vendor lock-in, which applies not only to the equipment but also to the management software. When the network operator acquires equipment from a given vendor, it must also include the respective management tools to provide fault, configuration, accounting, performance, and security (FCAPS) functionalities. Due to the proprietary nature of the interfaces between the management system and the equipment, the network operator always needs to use specific vendor tools for the everyday tasks. In addition, due to its design, optical equipment is not interoperable, i.e., a line system from vendor A does not communicate with a line system from vendor B. The same occurs for optical sources (transponders, etc.). Thus, any desire to augment the network capacity can only be satisfied by the same vendor that manufactured the equipment already installed, reducing the negotiation power of the network operator in future acquisitions. This type of solution, which includes software tools and equipment, is commonly labeled as vertically integrated.

Figure 2(b) shows a recent evolution [12] from the architecture depicted in Fig. 2(a). In this case, the management tools are replaced by vendor-developed software controllers that incorporate many of the FCAPS functionalities. The main differentiator in this case is in the controller functions that may now be invoked via open/standard APIs. This small change is very relevant because it enables the automation of many operations currently driven by distributed manual processes, i.e., it enables machine-to-machine workflows. Through the APIs, the network operator will be able to transversely communicate with SDN controllers from different vendors and introduce programmable workflows for the whole network at the orchestration level. Despite guaranteeing virtualized functions, reduced service deployment times, and OPEX savings, this architecture still fails to fulfill the ultimate SDN promise by preserving hardware opacity under the vendor controller and keeping vendor lock-in. In order to evolve to the next stage, open interfaces must be extended down to the physical equipment.

Figure 2(c) shows a disaggregated system with automatic orchestration. In this case, network operators have direct access to the physical equipment. This feature allows network operators to increase vendor diversity, which fosters innovation and competition, ultimately lowering CAPEX [3] and enabling new business models. The recently formed Open ROADM consortium is pursuing this approach. However, it should be highlighted that the optical layer will only become fully vendor-agnostic once interoperable coherent optics without major optical performance penalties are commercially available [13]. In this case, network operators have freedom on both control and data planes, meaning that they are able to seamlessly mix different hardware/software vendors within and between both planes.

C. Network Disaggregation in Optical Networks

The fundamental goal of disaggregation is to split functionalities currently integrated into monolithic solutions. With this separation, each functionality can be adjusted and optimized independently (e.g., updated with state-of-the-art technology). The data center environment is a recent disaggregation example where storage, networking, and computation functions were divided into independent functional blocks. Interestingly, the underlying objectives of disaggregation closely resemble SDN in the sense that it enables separating hardware and software, which also decouples their respective development cycles. The first disaggregation activities taking place in the optical sector [5] focus on separating hardware blocks and creating specific functions to be controlled via software. Three independent hardware blocks were established: pluggable optics, transponders, and ROADMs. Each physical block is expected to provide an API to allow provisioning of services and collection of alarms and performance monitoring information. The specific attributes of these APIs are well defined and guarantee that a common set of controller primitives can be employed to interact with equipment from different vendors.

As identified in Ref. [4] and compared with traditional vertically integrated PLS platforms, DLS can potentially boost competition and innovation between vendors. However, by choosing to combine different parts (equipment) together as a network, the network operator will need to act as a system integrator (or find someone who fills this gap). Typical networking issues, such as interoperability, troubleshooting, accurate performance modeling, and end-to-end service provisioning, must be efficiently solved to avoid turning DLS deployments into unmanageable endeavors.

III. PHOTONIC LAYER PROPERTIES FOR DLS AND PLS

As depicted in Fig. 3, three distinct scenarios are evaluated in this work. Figures 3(a) and 3(b) represent single- and multidomain PLS networks, respectively. Within the vendor domain, the network is assumed to be fully optimized for the proprietary optical interfaces. In a multidomain network, careful geographical segmentation allows fully transparent wavelength services between sites located in the same domain. However, in the absence of line side interoperability, any demand that needs to traverse at least two domains undergoes OEO conversion at a border site because signal handover at a border site has to be done via the (interoperable) client side, which requires using two line interfaces. Conversely, in Fig. 3(c), a DLS network allows ROADMs from multiple vendors to freely mix without imposing network domain segmentation. Transponders from different vendors can be directly connected to DLS ROADMs. However, note that interoperability between transponders from different vendors is outside the scope of this work.

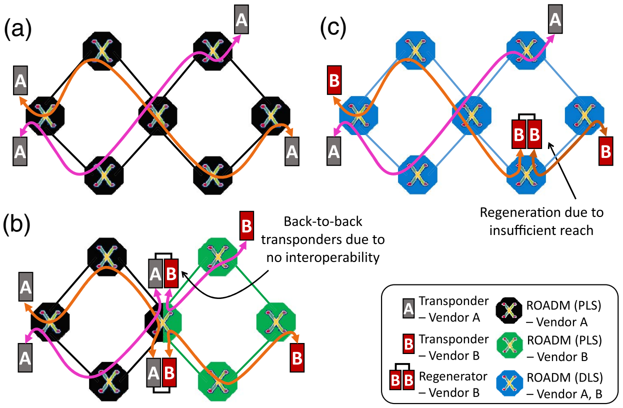

Fig. 3. Networking scenarios: (a) single-vendor PLS, (b) multivendor PLS, (c) multivendor DLS.

Aligned with [4], only the transmission of coherently detected modulation formats is considered in this work. In this case, optical dispersion compensation modules can be removed from the network and, therefore, the quality of transmission of each lightpath can be assessed quite accurately using the Gaussian noise (GN) approach for fiber nonlinearities. The GN model main assumption is that, in dispersion uncompensated transmission systems where nonlinear interference (NLI) caused by the Kerr effect is relatively small, the NLI can be modeled as additive Gaussian noise that is statistically independent of signal and amplified spontaneous emission (ASE) noise [14], originating in optical amplifiers. Using the GN model, the impact of optical fiber transmission effects on the "equivalent" optical signal-to-noise ratio (OSNR) can be modeled as [14]

$$\mathrm{OSNR}_{\mathrm{eq}} = \frac{P_{\mathrm{Tx}}}{P_{\mathrm{ASE}} + P_{\mathrm{NLI}}}, \tag{1}$$

where P_{Tx} is the optical signal average power level, P_{ASE} is the ASE noise power, and P_{NLI} is the NLI contribution to noise. Assuming incoherent noise accumulation along a lightpath, the total "equivalent" OSNR, $\mathrm{OSNR}_{\mathrm{tot,eq}}$, of a lightpath is given by

$$\frac{1}{\mathrm{OSNR}_{\mathrm{tot,eq}}} = \frac{1}{\mathrm{OSNR}_{\mathrm{add}}} + \sum_{i=1}^{S} \frac{1}{\mathrm{OSNR}_{\mathrm{eq},i}} + (N_{\mathrm{ROADM}} - 2)\frac{1}{\mathrm{OSNR}_{\mathrm{psth}}} + \frac{1}{\mathrm{OSNR}_{\mathrm{drop}}}, \tag{2}$$

where $\mathrm{OSNR}_{\mathrm{add}}$, $\mathrm{OSNR}_{\mathrm{psth}}$, and $\mathrm{OSNR}_{\mathrm{drop}}$ are the OSNRs at the add, pass-through and drop ROADMs, respectively, while S and N_{ROADM} are the number of fiber spans and ROADMs in the lightpath, respectively. $\mathrm{OSNR}_{\mathrm{eq},i}$ is the "equivalent" OSNR of fiber span i.

The quality of transmission of each lightpath is evaluated by calculating its residual margin (RM) defined as the difference between the available OSNR and the required OSNR for a given signal quality in back-to-back (B2B), $\mathrm{OSNR}_{\mathrm{B2B}}$. In order to cope with additional transmission effects and to guarantee that the system operates correctly during the full network lifecycle, an additional system margin (Margin) is also considered. Therefore, the final RM is given by

$$\mathrm{RM} = \mathrm{OSNR}_{\mathrm{tot,eq}} - \mathrm{OSNR}_{\mathrm{B2B}} - \mathrm{Margin}. \tag{3}$$

The system margin results from several contributions. The impact of aging, power ripple along the transmission bandwidth, and polarization-dependent losses is taken into account by considering a fixed system margin of 0.05 dB every time an optical amplifier or ROADM is traversed by a lightpath:

$$\mathrm{Margin}_{\mathrm{fixed}} = 0.05 \times (N_{\mathrm{OLAs}} + N_{\mathrm{ROADMs}}), \tag{4}$$

where N_{OLAs} is the total number of optical amplifiers in the lightpath. Additionally, ROADMs perform optical filtering of the transmitted signal. While traversing a small number of ROADMs usually imposes only negligible bandwidth limitations, traversing a cascade of ROADMs may be quite detrimental. Thus, an additional filtering penalty is added to the system margin, resulting in

$$\mathrm{Margin} = \mathrm{Margin}_{\mathrm{fixed}} + \mathrm{Filt}_{\mathrm{pen}}. \tag{5}$$

The filtering penalty is modeled in this work as presented in Ref. [15]. The power launched into each optical fiber is optimized in order to maximize the “equivalent” OSNR, following the local optimization for a global optimization approach [16]. The fiber spans are composed of SSMF and LEAF, modeled as indicated in Table I. A power level of 1 dBm is set at each ROADM input by a preamplifier. The optical signal is attenuated by 15 dB in the add and drop ROADMs and by 18 dB in the pass-through ROADMs. The noise figure (NF) of optical amplifiers is modeled as dependent on the span loss. For a total span loss up to 15 dB, the NF is set to 7 dB; for total span loss higher than 25 dB, the NF is set to 5 dB; and linear interpolation is used to estimate the NF for the intermediate span losses. The OSNR measured in the B2B configuration for the modulation format under analysis in this work is shown in Table II.

The impact of network disaggregation is evaluated by changing two parameters: the optical power level at the input of each fiber span and by considering an additional system penalty [13]. The optical power level at the input of each fiber span is either optimized with the objective of maximizing the “equivalent” OSNR, which models the case of networks where the network operator has detailed information about each network element (PLS scenario), or is set to a fixed level of 0 dBm. A power level of 0 dBm is not necessarily the optimum one but should still lead to good compromise between linear and nonlinear transmission effects when the modulation format and fiber types considered in this work are used and, therefore, may be set when there is only limited information about the operation of the network elements (DLS scenario). Another limitation in DLS scenarios is the more challenging optimization of power levels of the individual lightpaths at the output of each network element, which leads to increased impact of power ripple on the system performance. This effect is modeled in this work by adding a penalty, Sys_{pen}, of up to 3 dB, to the system margin (in case of the DLS scenario).

TABLE I
OPTICAL FIBER PARAMETERS

Fiber Type	Attenuation Parameter [dB/km]	Dispersion Parameter [ps/nm/km]	Nonlinear Coefficient [1/W/km]
SSMF	0.21	17	1.3
LEAF	0.22	3.8	1.5

TABLE II
REQUIRED OSNR IN B2B

Modulation Format	QPSK
$\mathrm{OSNR}_{\mathrm{B2B}}$ [dB]	12
Bit rate [Gb/s]	100

IV. RESULTS AND DISCUSSION

In order to assess the potential benefit of the disaggregated photonic layer in backbone DWDM networks, a set of 100 GbE/OTU4 services is generated and routed in the reference topologies described in Table III. Each network node is based on a ROADM architecture with Route&Select (R&S) in the express layer and colorless add/drop banks. For each node pair exchanging traffic, the k shortest distance routing paths are precomputed. The traffic load is varied from 3 Tbps to around 100 Tbps and, for each load value, 100 independent traffic traces are generated based on a uniform distribution and, for the Sparkle network, also based on one traffic matrix provided in the context of the IDEALIST EU project [17]. Services are ordered by decreasing distance (on their shortest path) and routed sequentially through the path that minimizes the number of required OEO conversions. First-fit wavelength assignment is enforced and 96 wavelength channels per link are assumed.

As depicted in Figs. 4 and 5, a multivendor scenario is considered for each network with two or three domains (DOM = 2 or 3, respectively). The nodes composing each domain are determined using clustering techniques [18,19]. The employed algorithms are based on hierarchical single-linkage clustering, where the similarity between clusters (i.e., the probability of merging the clusters) is defined by the neighboring nodes. The algorithm starts by considering each node of the network as an individual cluster. The objective of the algorithm is then to reach a given number of clusters (two or three, in this work) with the constraint of only merging clusters if at least one link exists in-between (thus ensuring accessibility to all nodes). The similarity,

TABLE III
TOPOLOGY PROPERTIES

Network	Node Count	Average Node Degree	Average Link Distance [km]
Sparkle	49	2.8	392
Japan	48	3.4	154

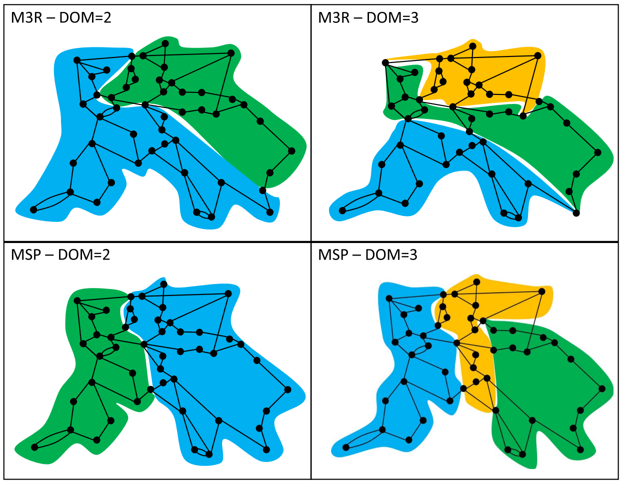

Fig. 4. Clustering for Sparkle topology using MSP and M3R for two and three domains.

which stands for a measurable affinity between neighbor network nodes from different clusters, is employed to guide the clustering procedure using one of the two following functions: minimum shortest-path distance (MSP) or minimum regenerator count (M3R) over the shortest path. While the former option first merges cluster pairs denoting the minimum shortest-path distance, the latter gives preference to the cluster pair whose nodes require the minimum number of regenerators to be interconnected. Note that these clustering techniques are purely topological and applied before doing any demand routing. The actual traffic distribution is not taken into account. Although both similarity functions are based on the shortest path, the use of distinct metrics (either distance or regenerator count) is shown to produce clusters with different compositions.

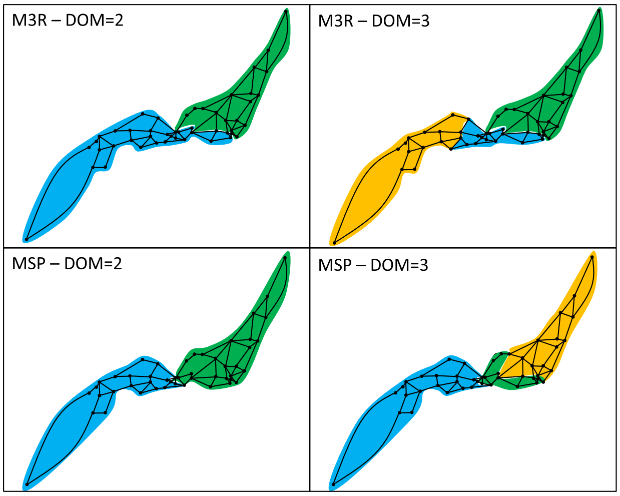

Fig. 5. Clustering for Japan topology using MSP and M3R for two and three domains.

A. Demand Blocking

Figure 6(a), which plots the average demand blocking ratio in the Sparkle network for IDEALIST-based traffic distribution and multiple values for the number of shortest paths, shows that the usage of a DLS or a PLS (even with several domains) results in similar blocking ratios. The small differences are mainly observed for multidomain PLSs, which occasionally exhibit higher blocking ratios. This result is a consequence of the routing algorithm that is employed in this work. Indeed, due to the need to place an OEO conversion whenever two domains are traversed, the routing algorithm avoids as much as possible using paths that traverse different clusters. Thus, longer paths in terms of number of links are often chosen, which ultimately lead to faster exhaustion of the available network resources. The results obtained when considering a uniform traffic distribution in the Sparkle network are similar to the ones exhibited in Fig. 6(a) and, therefore, are not shown in this work.

The demand blocking ratio for the Japan network when considering a uniform traffic distribution is presented in Fig. 6(b). In conformity with the Sparkle network, the different network scenarios (DLS and PLS) show very similar demand blocking ratios. Interestingly, and this is also the case for the Sparkle network, the capability to successfully route demands (without being blocked) is highly sensitive on considering just the shortest path or multiple ones (route diversity). However, augmenting k from 3 to 6 does not necessarily lead to a relevant reduction of the blocking ratio. This effect is especially evident in the Japan topology.

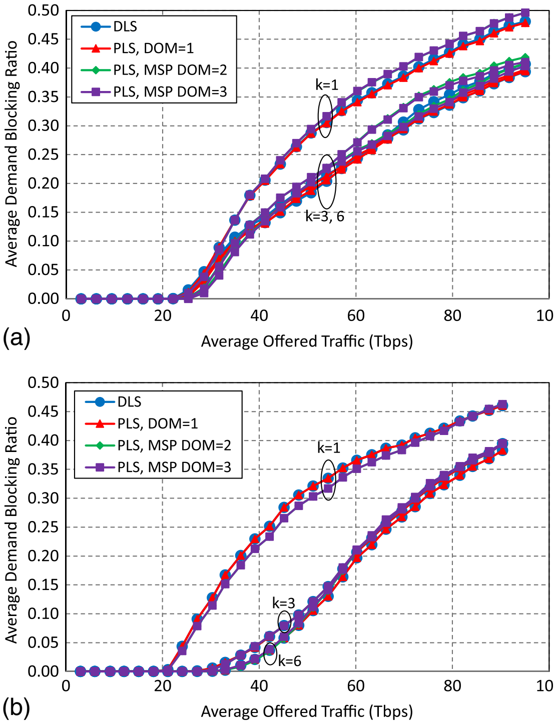

Fig. 6. Demand blocking for (a) Sparkle and (b) Japan network topologies with MSP clustering.

It is important to highlight that the success of the clustering techniques is also dependent on k, which will be demonstrated in the following subsection.

B. OEO Interfaces

The number of interfaces for OEO conversions (transponders, optical signal regenerators, etc.) is typically the largest contributor to the network CAPEX. Figure 7 shows the average OEO interface count as a function of the network load when considering different Sys_{pen} values in the Sparkle network (both traffic distributions are considered). With a system penalty of 0 dB, DLS has similar performance to single-vendor PLS as the only source of degradation results from setting a fixed power level at the input of each fiber span instead of optimizing it. Increasing the system penalty leads to augmenting the OEO interface count, as expected. In multidomain PLS scenarios, the OEO interface count also increases as a consequence of enforcing optical signal regeneration when a demand traverses a domain. In fact, compared with a $Sys_{pen} = 3$ dB in DLS, the worst result is always attained with a PLS network operating with three domains, which suggests that multidomain networking (even with optimized clustering techniques) is quite disadvantageous from an OEO interface count point-of-view. Keep in mind that, if the line system is kept proprietary, the multidomain deployments may still be improved by introducing interoperable optical interfaces. However, this interoperability will also come at a cost of optical performance. Notably, even for a system penalty of 3 dB, the number of interfaces in DLS is 30% and 13% smaller than the triple-vendor scenarios for IDEALIST-based and uniform traffic distributions, respectively.

The OEO interface count for the Japan network topology, depicted in Fig. 8, provides a more comprehensive outcome. Indeed, when compared with Sparkle, the average link distance in the Japan network is shorter and, therefore, optical signal regeneration is not so often required, even when considering DLS with the highest system penalty. For this reason, and since OEO conversion is enforced when different domains are traversed, even if no optical signal regeneration would be needed otherwise, DLS is able to reduce the number of required OEO interfaces in more than 93% when compared to multidomain PLS. This trend, although with less expressive differences, was also previously identified in Ref. [20].

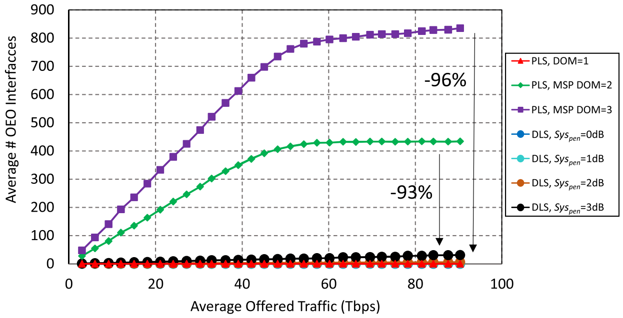

Fig. 8. Number of line interfaces for OEO in Japan network topology with a uniform traffic pattern for $k = 6$ and different values of Sys_{pen} in DLS.

In general, the obtained results indicate that the application of DLS is topology dependent. In the cases where optical signal regeneration is only seldom needed, e.g., metropolitan and some regional area networks, the introduction of DLS is very competitive with respect to multidomain deployments. On the other hand, if the network needs to resort to optical signal regeneration more often (as is many times the case in long-haul networks), the optical signal performance degradation caused by DLS may be quite relevant, leading to a considerable increase in OEO interface count. Therefore, the advantage of DLS over multidomain deployments is much smaller and the best approach to follow may not be straightforward.

A comparison between the two clustering techniques employed in this work is depicted in Fig. 9 for Sparkle and Japan network topologies. Identical blocking probabilities are obtained when using both clustering techniques. As already mentioned, there is a clear dependency of the number of required OEO interfaces with the route diversity k. Indeed, increasing the number of routing options also results in an increase in the number of required OEO interfaces. This result may seem counterintuitive, as enabling a higher number of routing options should keep or even

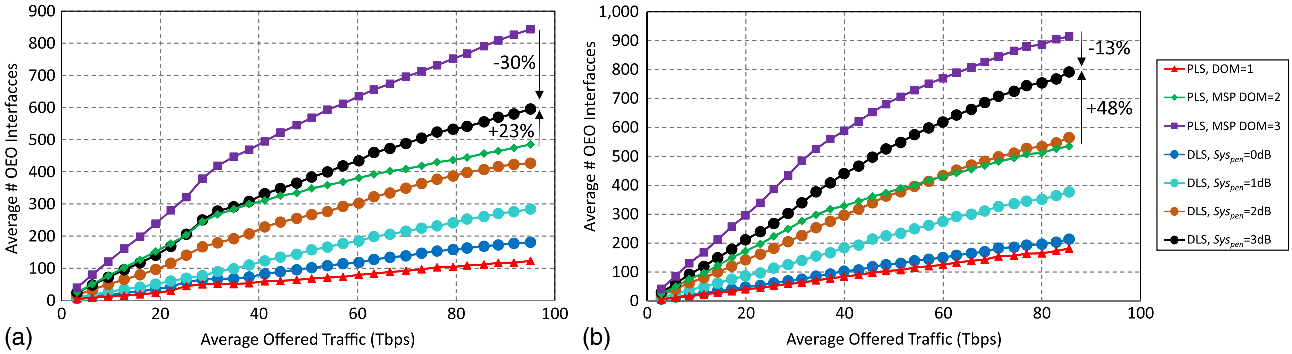

Fig. 7. Number of line interfaces for OEO conversion in Sparkle network topology with (a) IDEALIST-specific and (b) uniform traffic patterns for $k = 6$ and considering different values of Sys_{pen} in DLS.

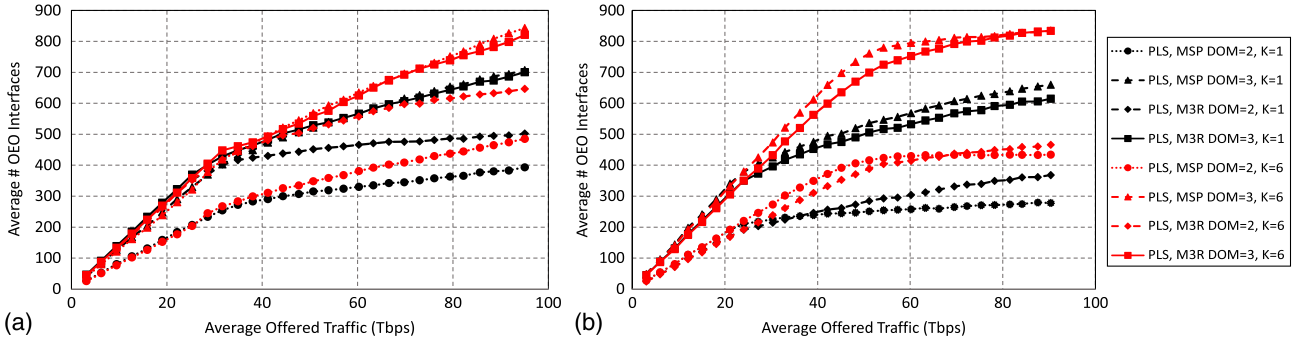

Fig. 9. Comparison of line interfaces for OEO between MSP and M3R in (a) Sparkle and (b) Japan network topologies. The IDEALIST traffic pattern is assumed for the Sparkle network.

reduce the number of required OEO interfaces. However, as shown in Fig. 6, increasing the number of routing options also reduces the blocking probability which, therefore, materializes in more deployed services and leads to an increase in the required OEO interfaces.

Figure 9 also shows that, for two domains, MSP offers the lowest OEO interface count in both the Sparkle and Japan network topologies. However, the differences with M3R are more significant in the Sparkle network. Regarding the use of three domains, the two clustering options lead to similar results, with M3R showing only a slight advantage in the Japan network. In the specific case of the Sparkle network, applying the uniform traffic distribution does not lead to substantial differences with respect to the IDEALIST one. However, the main outcome from Fig. 9 is highlighting the importance of strategically building the domains. After employing distinct clustering algorithms, it becomes evident that the selection of nodes composing each domain can greatly impact the routing performance, namely, in terms of OEO usage.

V. CONCLUSION

The concept of network disaggregation is tightly coupled with the adoption of a SDN-like architecture in the optical networking ecosystem. In this context, the main objective of this work was to analyze the potential of disaggregated optical line systems versus proprietary line systems. Considering that the design of disaggregated platforms is not fully optimized (as in proprietary systems), differentiation was introduced by degrading the optical transmission performance. Different levels of degradation were assumed to assess the impact of using optical components with different degrees of mismatch. Different network scenarios were also devised to enable the comparison between conventional single- and multidomain deployments and the prospective disaggregated systems. The simulation results produced with multiple topologies, different traffic distributions, and domains defined by distinct clustering techniques, showed that disaggregated systems can be very competitive. Indeed, the obtained results demonstrated that demand blocking is not affected by DLS but may be slightly increased in multidomain networks. Regarding the need for OEO interfaces, it is shown that, in general, the benefits derived from disaggregation are topology dependent. In topologies where the use of optical signal regeneration is seldom needed, the introduction of disaggregation offers a cost-effective alternative to multidomain deployments. On the other hand, if the topology is prone to more optical signal regeneration, the performance penalties induced by disaggregated platforms will limit the OEO interface savings. Nonetheless, the outlook for disaggregated line systems remains very positive when compared against multidomain networks. Regarding single-domain scenarios, attractiveness of disaggregated platforms depends on if they are able to outweigh (through OPEX savings or access to more competitive pricing) the introduction of additional OEO interfaces for optical signal regeneration.

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