Optical Spectrum as a Service in Multi-Operator Environments: Challenges and Enabling Technologies for Transparent Optical Overlay Networks

Kaida Kaeval[1], Klaus Grobe[2], Jörg-Peter Elbers[2]
[1] Tallinn University of Technology, Tallinn, Estonia
[2] Adtran, Martinsried, Germany
kaida.kaeval@taltech.ee

Abstract: This work reflects the challenges, intermediate solutions, and outlooks on the wide-scale implementation of Optical Spectrum as a Service in live multi-operator network environments.

1. Introduction

According to an operator study published in [1], leasing out an optical spectrum instead of a leased capacity in a Dense Wavelength Division Multiplexing (DWDM) networks is an appealing, but also challenging, prospect for telecommunications operators worldwide. In the spectrum leasing use case, often referred to as Optical Spectrum as a Service (OSaaS), the leasing party is granted access to the provider`s DWDM spectrum via a dedicated add/drop port in the multi-degree Reconfigurable Optical Add/Drop Multiplexer (ROADM), or a selection of consecutive wavelength ports in the fixed-grid filter. When the spectrum is available in consecutive network domains, OSaaS avoids signal regeneration at domain borders and uses just one transceiver pair, located at the connection end points. This provides multiple benefits: in addition to increased availability and decreased latency due to a reduced number of transceivers, it creates attractive economic benefits like reduced CAPEX requirements during service set-up. It also reduces energy consumption and personnel requirements during operations [1]. Furthermore, with the European Commission`s Net Zero initiative in mind to minimize the $CO_2$ footprint by 2050 to net zero [2], OsaaS helps to achieve reduced $CO_2$ and electronic waste production. However, allowing third-party signals to enter the provider`s DWDM network may pose a threat to the integrity of interconnected networks when the power spectral density of the signals varies from pre-agreed parameters. A well-tested solution to solve such non-compliance is to use Software Defined Networking (SDN)-based solutions [3-5] to monitor and control the third-party equipment in the disaggregated networks. However, while the approach is applicable for single-operator and partnership-based network environments, it is usually avoided in multi-operator scenarios, where management and control of the equipment is considered a business-critical matter. A perfect example of such network environment with conflicting expectations on sharing the management and control data can be illustrated based on the national networks in Europe, which are interconnected at the country borders, but operated by different operators.

This work reflects the challenges, intermediate solutions, and future outlooks on a path to wide-scale implementations of Optical Spectrum as a Service in multi-domain, multi-operator environments.

2. Challenges in enabling Optical Spectrum as a Service in the live networks

Regardless of how appealing the benefits of OSaaS are, the operation of OSaaS in a multi-operator environment, characterized by reduced visibility, monitoring capabilities, and limited access to management and control functions, comprises many challenges. To guarantee the interworking and signal integrity between the domains, a set of interworking functions is required:

- receive filtering to ensure signals are transmitted only inside the assigned spectrum of the OSaaS,
- fast shutdown of (certain rogue) signals,
- signal policing functions as per power spectral density (PSD) or total power, required amplification or power suppression of the OSaaS spectrums as per next domain rule sets and thresholds,
- amplified spontaneous emission (ASE) noise or dummy channel insertion for amplifier control/balancing.

Furthermore, compatibility with contractual agreements (threshold compliance, availability, and service level agreement) must be calculated and reported per end-to-end service and each interconnected domain. In multi-operator environments with restrictions to share management and control data, dedicated hardware in front of each domain can provide a clear demarcation point. Depending on the selected hardware, one or more interworking functions from the list can be implemented in an autonomous operation manner, without the manual reconfiguration requirements. Table 1 presents some of the readily available hardware options for OsaaS interconnect as well as a new, standalone, vendor-, domain- and infrastructure-independent Network Domain Interface Device (NeDID) [6].

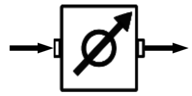
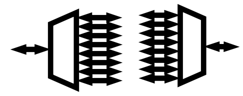
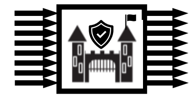
Solution	VOA with constant output 	A dedicated ROADM degree 	Network Domain Interface Device 
Filtering	No	Yes	Yes
Fast shutdown of signals	No, but constant power output available	No	Yes
Signal policing functions: **a) PSD-based levelling** **b) P_{TOT}-based levelling** **c) Amplification** **d) Automated adjustments to next domain rule set**	 No Yes No No	 Depends on hardware Yes Depends on hardware No	 Yes Yes Yes Yes
Add port for ASE, or channel probing	No	Yes, when additional degree available	Yes
Compatibility calculations and reporting	No, but telemetry data usually available	No, but telemetry data usually available	Yes
Extras/benefits	Simplicity of the solution, available today	Simplicity of the solution, available today	Routing, highly scalable

Table 1 Challenges and enabling technologies for Optical Spectrum as a Service policing functions

The first solution in the table uses a variable optical attenuator (VOA) in front of the OSaaS domain. The solution is most effective in the case of a single wavelength, as it is not capable of filtering or maintaining the PSD of the bundled signals. As there is no visibility or control over the transmitted spectrum, except for total power, the solution requires manual intervention, if the OSaaS end-user changes the number, or symbol rate of the active channels, or automated signal power adjustments happen in the Open Line System (OLS). Depending on the magnitude of changes, this may require a maintenance window and close cooperation between all involved operators on the end-to-end route.

The second solution in the table uses a set of dedicated ROADM modules with integrated Wavelength Selective Switches (WSS) and amplifiers to drop wavelengths from domain A and add them to domain B. The ROADM modules may be different for operators, and the internal set-up of each device defines the capabilities of the solution. Until the ROADM technology is LCoS, the hardware can flexibly police any OSaaS configuration [1]. However, to fully benefit from the solution, the proprietary software of the ROADM devices may need modifications. For example, PSD-based leveling can be mimicked, if the media channels configured in the WSS use the smallest increments provided by the module, and not the original channel spacing within the OSaaS. As importantly, leveling adjustments must be carried out continuously, as confirming the 99.999% signal parameter compatibility requires tracking the parameters with less than 0.86-second increments. That may use a significant amount of data within the management channel and/or be complicated by the limitations of the built-in hardware.

The last solution in the table is the dedicated Network Domain Interface Device (NeDID). This device is based on N:M WSS and is designed to carry out all the required interworking functions for enabling OSaaS in multi-operator environments. The NeDID device concept comprises per-port policing functions, following the pre-agreed rulesets from the next domain resource provider. The device has N inputs and M output ports which are completely vendor-, domain- and infrastructure-independent. It provides interworking functions, such as continuous monitoring, policing, and adjustment of the signals according to the preset thresholds of the next domain and calculating the signal compatibility and service level agreement performance. The device also provides an add-port for a channel probing-based option to characterize the spectral resources. The NeDID can be operated by one of the interconnected operators, or by an operator, independent from the interconnected domains. In the latter use case, the NeDID acts as a broker of the interconnected spectral resources and enables a new networking model, a Transparent Optical Overlay Network.

3. Transparent Optical Overlay Network

If two or more NeDIDs are managed by a single operator, a Transparent Optical Overlay Network, illustrated in Fig. 1, can be established. According to the OSaaS survey conducted in [1], 56 % of the participating operators would be willing to share their spectrum resources with a third-party or wholesale retailer if the signal handover would be

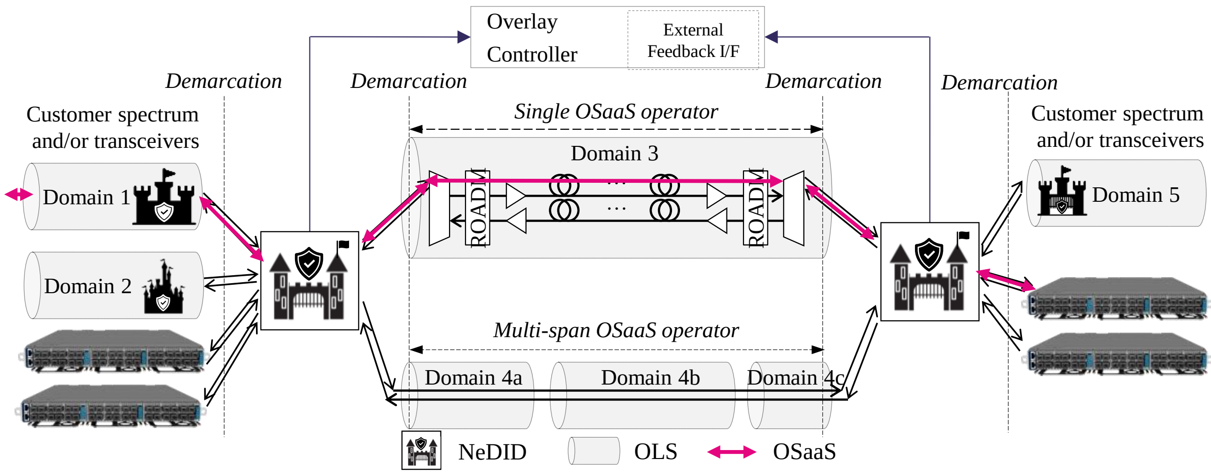


Fig. 1 The concept of transparent optical overlay networks

implemented safely and control over the network would remain at the sole hands of the resource owner. A consortium-based business model can be used with two or more interested partners with a common goal of selling an end-to-end spectrum. Alternatively, a wholesale carrier model can be used, where the wholesale carrier buys the available resources from different operators and operates the transparent optical overlay network on top of the available resources. Regardless of the operation model, the optical resource providers are responsible for keeping the OLS performance as stable as possible, but it is the NeDID operator who is responsible for blocking out the rouge signals, suppressing fast power transients, adjusting the power levels of the signals for next domain, and calculating the available resources' compatibility to the contractual service level agreement documentation.

As a physical demarcation point between interconnected network domains, the NeDID collects necessary telemetry data from multiple input and output ports, adjusts the signal parameters as per rule set, and calculates service level agreement (SLA) compatibility. Selected viewer or access rights about the NeDID configurations and streaming telemetry outputs can be shared with any interconnected domain provider or end-to-end OSaaS end-user, using domain- or service-related restrictions. This brings significant value through the reduction of time and effort spent on fault localization, contributing to shorter service repair times and higher end-to-end availability in multi-operator environments.

4. Conclusion

Optical Spectrum as a Service has become an attractive service model for customers demanding high capacity and flexible network resources. In this work, we have discussed the challenges, intermediate solutions, and outlooks on the implementation of Optical Spectrum as a Service in live multi-domain, multi-operator network environments. We have compared some of the readily available solutions on the market and introduced a new, standalone, vendor-, domain- and infrastructure-independent Network Domain Interface Device (NeDID). Finally, we have shared insights into the new networking concept, called Transparent Optical Overlay networks, which together with the NeDID as the potential to simplify monitoring, fault localization and reporting of the interconnected network resources and end-to-end services in the multi-operator environments.

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References

[1] K. Kaeval, "Optical Spectrum Services in Open Disaggregated Transport Networks", Doctoral thesis, Tallinn University of Technology, 2023
[2] European Commission, 2050 long-term climate strategy, [available online, last accessed November 13th, 2023], https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en
[3] O.G. De Dios, et al., "First demonstration of multi-vendor and multi-domain EON with S-BVT and control interoperability over Pan-European testbed", ECOC, pp. 1-3. 2015
[4] A. Aguado, et al., "Dynamic virtual network reconfiguration over SDN orchestrated multitechnology optical transport domains," JLT, 34(8), pp.1933-1938, 2016.
[5] Y. Li, et al., 2017. "tSDX: enabling impairment-aware all-optical inter-domain exchange," JLT, 36(1), pp.142-154.
[6] K. Kaeval, et al., Adva Optical Networking SE, 2023. Method and apparatus for providing end-to-end optical spectrum services over multiple transparent optical network domains. U.S. Patent Application 18/075,405.