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Milestone M7.2 (M38)
SCS Service Definition

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Abstract
This document defines a reference model and service definition for the Spectrum Connection Service (SCS) to be offered in the GÉANT Association and NREN networks.

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1 Introduction

1.1 Historical Context

In the previous GN4-2 project, the JRA1-T1 group investigated a service to carry a single Alien Wavelength (AW) called “Alien Wave Service” [AW-CBF-SS]. This service was defined as follows:

An AW Service is the service provided by a network provider which carries a customer’s optical signals with minimal loss of fidelity. The customer’s optical signal remains in the optical domain for the entire length of the service. The service may introduce some degradation of the optical signal to noise ratio (OSNR) or add non-linear effects, however these effects will remain within the level of performance agreed by the AW service provider. Similarly, the user has an obligation to keep the light injected into the AW service within the bounds agreed.

At the time that this definition was written the GÉANT network did not incorporate the ROADMs needed to deliver such a service, however many NRENs (National Research & Education Networks) did have this capability, hence were able to carry AWs.

Based on lessons learnt in GN4-1 and GN4-2, the technical disruption brought in by Open Line Systems (OLS), the widespread use of Alien Wavelengths through the NRENs [GN4-1-R1] and increased vendor support, GÉANT Association and the NRENs plan to leverage the new equipment’s technical capabilities to add a Spectrum Connection Service (SCS) to the GÉANT service portfolio.

In GN4-3, GÉANT will replace their existing Infinera DWDM/OTN equipment with new equipment that supports Open Line System (OLS) and FlexGrid capabilities. This upgrade will be rolled out starting in 2020 and will be completed by the end of 2022.

The new Spectrum Connection Service will go beyond an Alien Wavelength service and will expand capability to support multiple wavelengths. The service will be called a ‘spectrum’ service specifically to highlight the fact that GÉANT will make available a slice of optical spectrum (analogous to radio spectrum) to customers to add new wavelengths as-and-when they need the capacity.

In order to make this a spectrum service available to all European research and education institutions, GÉANT and the NRENs must coordinate in defining a new service and associated reference model.

1.2 Objective of this Document

The objective of this document is to define a reference model and service definition for the Spectrum Connection Service (SCS) to be offered in the GÉANT Association and NREN networks. The service definition will define the SCS terminology, interfaces, APIs and information workflows for a set of use cases. It will also be used by the NRENs to provide Spectrum Connection Services within their national R&E communities.

This document also aims to define the capabilities of the SCS service.

2 Spectrum Connectivity Service Reference Model

2.1 Spectrum Service Concept

The Spectrum Connection Service will go beyond a simple Alien Wavelength service and will support multiple wavelengths over a single slice of spectrum. There are several differences between the SCS and an AW service. With the introduction of FlexGrid combined with ROADM route-and-select capabilities, a channel can be varied to offer amounts of spectrum larger than the traditional 50GHz. This innovation is what has made the Spectrum service possible. The two service types are disambiguated below:

AW service

- An AW service is defined as a single source launched into a fixed ITU-T grid – traditionally this has typically been 50GHz. The user signal may be a single or dual-carrier wavelength.
- The AW service includes optical gain adjustment. The optical loss/gain along the path is monitored and the power levels are adjusted either automatically in the ILA equipment (or manually in older equipment) to keep them optimum for the amplifiers. This is relatively simple for the AW service as only one source is present. The optical power of the AW launched onto the fibre is adjusted to keep the power level consistent with the remainder of the C-band wavelengths.
- AW services require the user to constrain the optical parameters of the client signal to ensure that the service works correctly with other optical services on the link. For example, the optical power level should not be changed suddenly during operation.

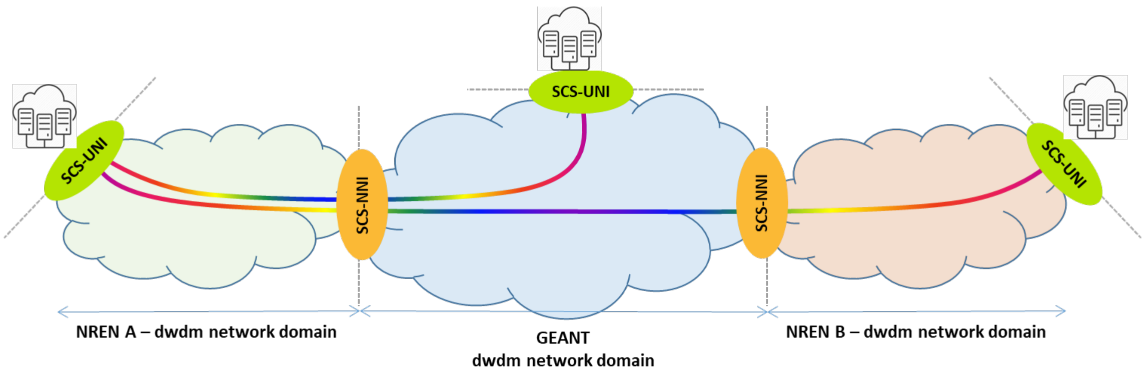
Spectrum service

- The user can inject multiple optical services onto spectrum via a single port on a DWDM system.
- The provider of the Spectrum Service provides access to a part of the spectrum in the optical line system. The DWDM system may be based on fixed filters such as 100GHz or can use FlexGrid to divide the optical spectrum into 'slices' which are typically multiples of 12.5GHz.
- A spectrum service is often offered as contiguous spectrum for ease of operation.
- Current vendor implementations have limited capabilities in optical power monitoring and control for spectrum services. For this reason, optical power management practices for spectrum services will require special agreements between spectrum provider and customer. For example, an agreement not to change optical power levels without prior agreement.
- AW services are a sub-set of spectrum services.

2.2 Connectivity Reference Model

Figure 2.1 shows the relationship between the services that transit the GÉANT and NREN networks. Two service interfaces are defined, these are:

- **SCS-UNI –** The Spectrum Connection Service User-Network Interface. This interface defines the 'end' of the SCS service region. Beyond this SCS-UNI is the customer's network which is outside the region controlled by the SCS service.
- **SCS-NNI –** The Spectrum Connection Service Network-Network Interface. This interface defines the boundary between two networks that are participating in the SCS service. Metadata relating to the service may be transferred between NREN service providers interconnected at the SCS-NNI. This includes, for example, service name, service owner, service spectral width, target optical power levels, etc.



SCS-UNI: Spectrum User-Network Interface

SCS-NNI: Spectrum Network-Network Interface

Figure 2.1: Reference model for SCS optical connectivity

The actors involved in the SCS service are:

- The spectrum service users:
  - Own the equipment behind the SCS-UNI, including the optical device generating the optical signals. This will typically be a coloured coherent optical interface on a switch/router or transponder equipment.
  - Transmit their optical signal to the service providers over the SCS-UNI.
- The spectrum service providers:
  - Own and operate the optical infrastructure and the DWDM line system in their domain.
  - Interact through SCS-UNI with spectrum consumers and through SCS-NNI with the other spectrum providers.

2.3 Management Interface Reference Model

The management of the multi-domain spectrum service is still under consideration. Each NREN will have their own local NMS (Network Management System) and the end-user will also have at a minimum a local management interface e.g. CLI or craft terminal to manage their transponder, as shown in the figure below.

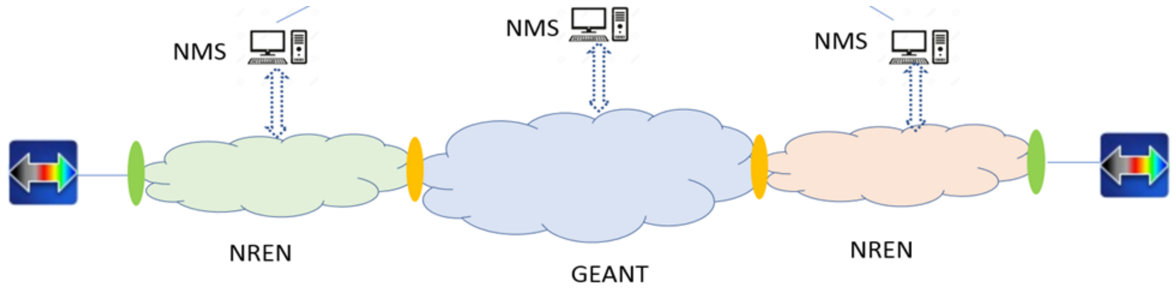


Figure 2.2: Reference model for the management interfaces

A range of options for the end-to-end management of the SCS service are considered in section 6.

3 Spectrum Connectivity Service

3.1 Service Objectives and Privacy

The goal of this spectrum connection service definition is to allow service providers to build a single or multi-domain (i.e. that transits multiple NRENs) service that operates without regeneration between two sites connected to the R&E network.

The spectrum service will allow users to transmit an optical signal over a slice of the spectrum between two endpoints in a secure way.

Security and Privacy are disambiguated as follows:

- ***Security*** means not only that the typical security measures for network services have been taken (inventory of all the components carrying the signal, labelling, monitoring of intermediate interfaces,…) but also that setup is done in such a way as to ensure that the signal from one user cannot harm any other users who are using neighbouring parts of the spectrum. For example, optical power management of a non-allocated part of the spectrum should mitigate interferences between users' signals.
- ***Privacy*** is also an important subject to consider when designing a Spectrum Connectivity Service. Privacy, in this context, provides certainty that, at the receive side, the signal cannot be received by any other neighbouring users on the spectrum. To guarantee this, specific technology is needed (Route and Select, Fixed filters). (Refer to 4.3.1 User-Network Interface (SCS-UNI))

3.2 Service Prerequisites

There are several prerequisites that the community of NRENs and service users should be able to satisfy to comply with the SCS reference model.

Service providers must satisfy requirements to be able to deliver a 'minimum viable product'. These define a set of minimum skills and level of technical maturity enabling service providers to provide a basic level of information for service implementation, operation and troubleshooting.

In addition, requirements are set out for service users defining the necessary skills and technical maturity needed for them to provide minimum information for service operation.

The service provider may include constraints such as setting a limit on the proportion of the spectrum that can be used for providing spectrum services to third parties.

The full detailed requirements for users and the NREN delivering the Spectrum Service are set out in Appendix D. In general, an NREN needs to have a DWDM system that can carry alien waves or alien spectrum. They also need to provide procedures and tools to predict the performance of the spectrum service.

These prerequisites relate both to the procedures that need to be in place and the domain infrastructure allowing to perform monitoring, control and provision of the service. Automation is not necessary but should be a goal for the future.

A checklist for NRENs /GÉANT to be eligible to participate in the SCS community can be found in Appendix D

3.3 Service Quality Targets

Spectrum Service Quality Targets (SQTs) may be influenced by the maturity of communication between service providers and users. The specific SQT items will be agreed at the time of service implementation. Quality targets may include, but are not limited to, the following items:

Service quality target item	Example value
NOC response time	60 minutes
Time to repair a fibre cut	24 hours
Time to repair an equipment hardware failure	12 hours
Time to implement service change	48 hours

Table 3.1: Service quality targets – example

Following pilot tests, all parties will define and agree to achievable service quality targets.

3.4 Service Workflows

The workflows described in the following sections are the recommended procedures for SCS implementation, monitoring, service upgrade and fault recovery.

3.4.1 Service Implementation Workflow

This service implementation workflow, shown in Figure 3.1, lists the steps necessary to initiate, plan and test a spectrum service. The workflow is complete once the service starts:

1. Define endpoints, required spectrum slice, maximal latency and distance.
2. Evaluate possible routes for spectrum service by service providers.
3. Model service parameters and required power levels.
4. Agree on the pilot implementation between all parties.

5. Evaluate the results of pilot implementation.
6. Agree to the SLAs for spectrum service.
7. Start the spectrum service.

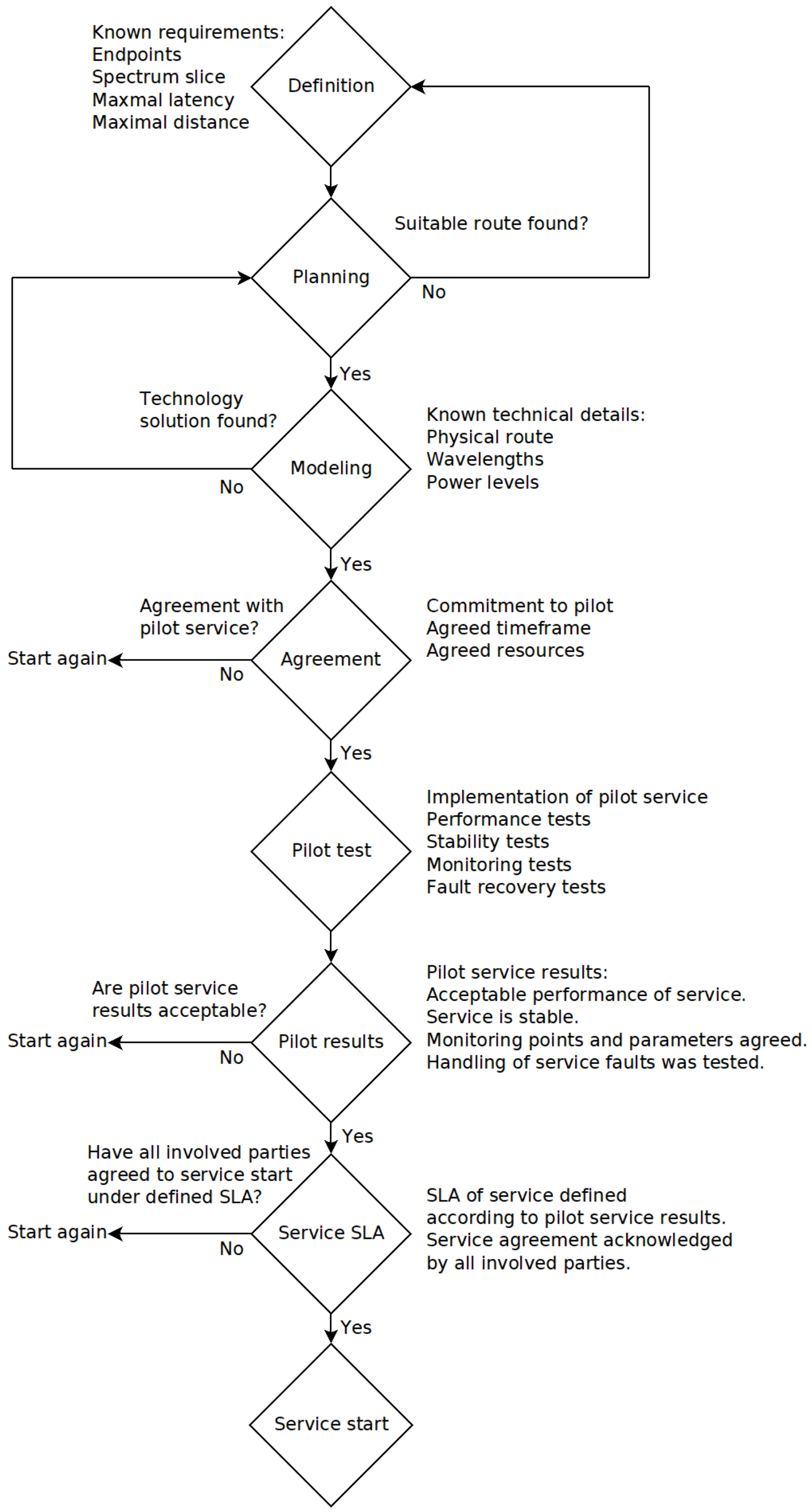


Figure 3.1: Service implementation workflow

3.4.2 Service Monitoring Workflow

This service monitoring workflow includes the steps necessary to establish and operate spectrum service monitoring up to the start of the service.

1. The SCS user provides monitoring parameters (Table 4.1) to the SCS provider in an agreed way and format. Detailed information about frequency and monitoring parameters is provided as part of the SCS agreement.
2. The SCS provider aggregates monitoring parameters from users and its own optical infrastructure to assess SCS performance.
3. The SCS provides performance indicators to its users at a frequency and to an extent defined by the SCS agreement.
4. The monitoring data is retained by the NRENs for an agreed length of time.

3.4.3 Service Changes Workflow

The service changes workflow, shown in Figure 3.2, includes the steps necessary to upgrade the SCS spectrum and path parameters specifically.

1. The SCS user decides the changed parameters and provides them to the SCS provider.
2. The SCS provider assesses the changed parameters and possible scenarios and proceeds as described in paragraph 3.4.1.
3. Should the SCS user change technology or parameters from their current technology, they shall notify the SCS provider's NOC about the changes at least 24 hours ahead before implementation.

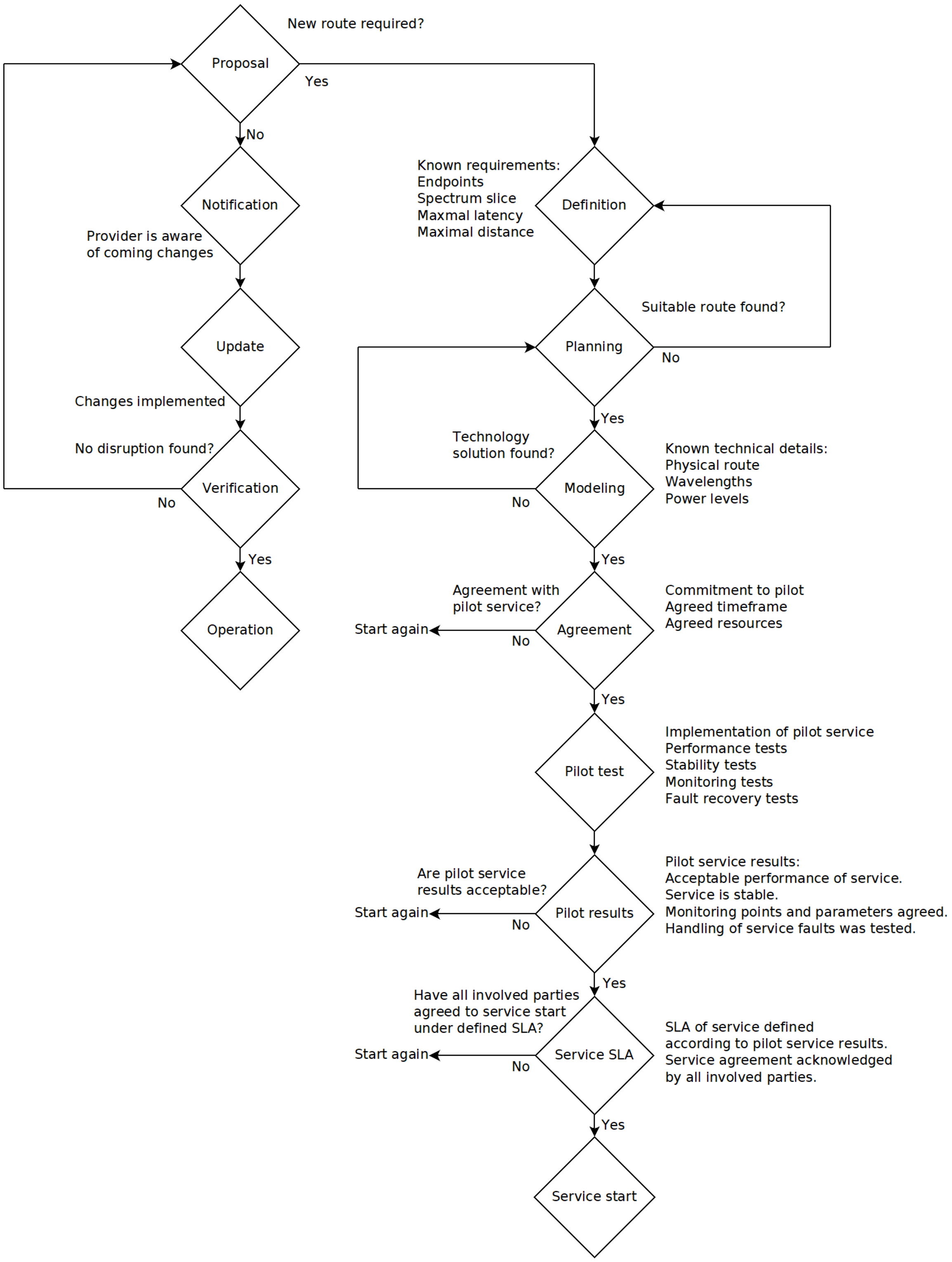


Figure 3.2: Service upgrade workflow

3.4.4 Service Recovery Workflow

The service recovery workflow, shown in Figure 3.3, includes the steps necessary to recover the service after a fault.

1. The SCS user immediately notifies the SCS provider about a fault in their service. Note that on occasion an NREN may identify a fault before they are notified of it by the SCS user.
2. The SCS provider will evaluate the monitoring parameters history and identify possible sources of the fault.
3. The SCS provider will immediately notify the SCS user about the estimated time it will take to recover the service.
4. The SCS provider and SCS user will work together to recover the SCS service.
5. The SCS provider will notify the SCS user as soon as the SCS service is recovered.

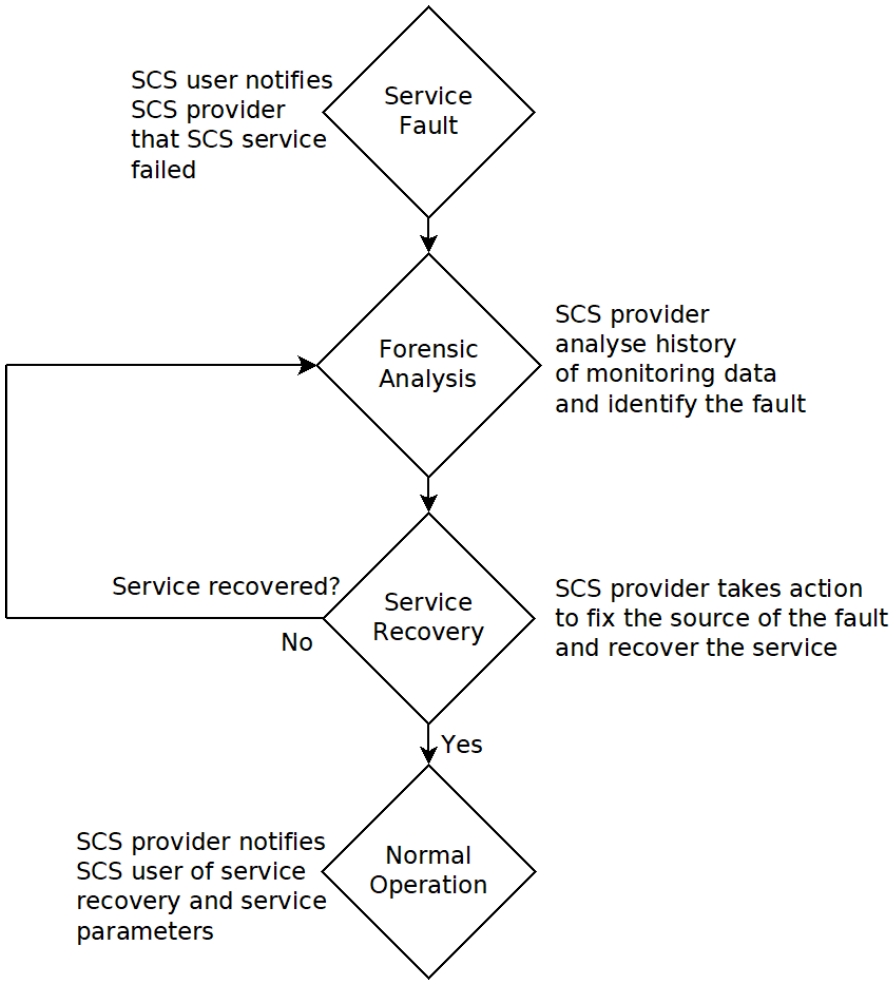


Figure 3.3: Service recovery workflow

3.5 SCS Roadmap

The service roadmap is summarised in Table 3.2. In the final Service Definition, this section will be included on the SCS wiki page.

Release	Description	Date
1.0	The initial release of SCS	Q1 2022
	Analysis of optical multi-domain monitoring including proof of concept	GN5
2.0	Other releases or features	GN5

Table 3.2: SCS roadmap

4 Optical Transport Infrastructure for SCS Services

4.1 Optical Transport – Overview

When designing an SCS service, it is essential to **determine the optical performance of a given transport infrastructure when routing a given optical signal**. The figure of merit for a transport infrastructure can be summarised using parameters such as the OSNR/GSNR value.

Such a figure of merit is a useful indicator of the expected performance of the optical channel. By adopting a standard figure of merit, the community can easily predict end-to-end optical performance when the service transits multiple NREN providers.

It is proposed that for the SCS service a common route planning and simulation tool (for example TIP GNPy), could be adopted. The alternative would be to ask each SCS provider to declare the figure of merit of their own infrastructure, using simulation tools and/or on their own planning tool, if available, or based on the average OSNR of optical signals on the same path. The advantage of having a common tool would be in terms of homogeneity of the value obtained for the figure of merit over the different domains.

In some circumstances, several paths might be available to carry the signal within a single domain. By default, the local SCS provider will be responsible for the choice of the best path in their network.

4.2 Optical Properties of the SCS Service

To characterise an optical transport infrastructure using a route planning and simulation tool, it is necessary to share data about the system. This data allows the SCS provider to estimate the performance attainable for a given pair of transponders, under given constraints of baud rate, modulation, spectrum utilisation etc.

Table 4.1 shows the set of optical transport infrastructure properties that have an impact on the OSNR of the optical signal travelling over the infrastructure itself. All SCS providers should share this data with other SCS providers to allow the optical performance of the offered path to be evaluated. The data listed constitutes information needed at the simulation tool to estimate the figure of merit.

The main parameters that should be provided to the spectrum users by the OLS provider are: quarantined OSNR between endpoints, needed TX power per given AW channels, delivered RX power to any given AW channels, and available spectrum per channel (channel width). Other parameters should be optional.

Per span properties	Units
Fibre type	
Distance	km
Fibre loss	dB
Amplifiers type	
Per node-to-node properties	
WSS or Fixed OADM (insertion loss)	
Per optical domain properties	km
Amplification spacing	
Repair margin (EOL margin)	
DCM type	
Adaptation layer (demarcation point penalties)	
Existing optical signals properties	
Existing channel type	
Wavelength/channel plan	
TX launch power of existing transponders	
Optical power level	
Figure of merit	
OSNR value	If known by any method (describe the method).

Table 4.1: Information required for each optical domain to perform the service design

See section 6.1.1 for further discussion on monitoring these parameters.

The TIP project, in the OOPT group, is working on a Physical Simulation Environment (PSE) to develop an open-source multi-vendor tool for optical network planning. The group is currently still actively developing the GNPY tool, which will make it possible to plan routes and network capacity and to simulate network conditions.

4.3 Interconnection Points

The interconnection points in the reference model mark the transition between two optical domains and it is important that the GÉANT community agrees on a common interconnect technology and methodology. In the following paragraphs, relevant interconnection schemas are listed and the main properties for each are highlighted. The schemas below address both SCS-UNI and SCS-NNI. The aim is to lay out a common understanding and wording regarding possible and feasible interconnection strategies. This list is not intended to be exhaustive.

4.3.1 User-Network Interface (SCS-UNI)

The SCS-UNI defines how and where the Spectrum Consumer device is interconnected to the Optical Transport infrastructure operated by the Spectrum Provider. That interface defines where the Optical Source devices are interconnected to the OLS and represents the service demarcation point from an administrative perspective. Features and functionalities available to the SCS user also depend on how and where this interface is implemented.

Considering current optical network platforms and technologies two main possibilities are available:

- Add/Drop section based.
- N-degree ROADM based.

Add/Drop Section

The SCS user device is interconnected through the Add/Drop section of the node of the optical transport platform in the SCS Provider domain. To consider a wide range of possibilities, the main Add/Drop structures are listed in Figure 4.1.

Add/Drop Types:

- Coloured
- Colourless (C)
- Coloured Directionless
- Colourless Directionless (CD)
- Colourless Directionless Contentionless (CDC)

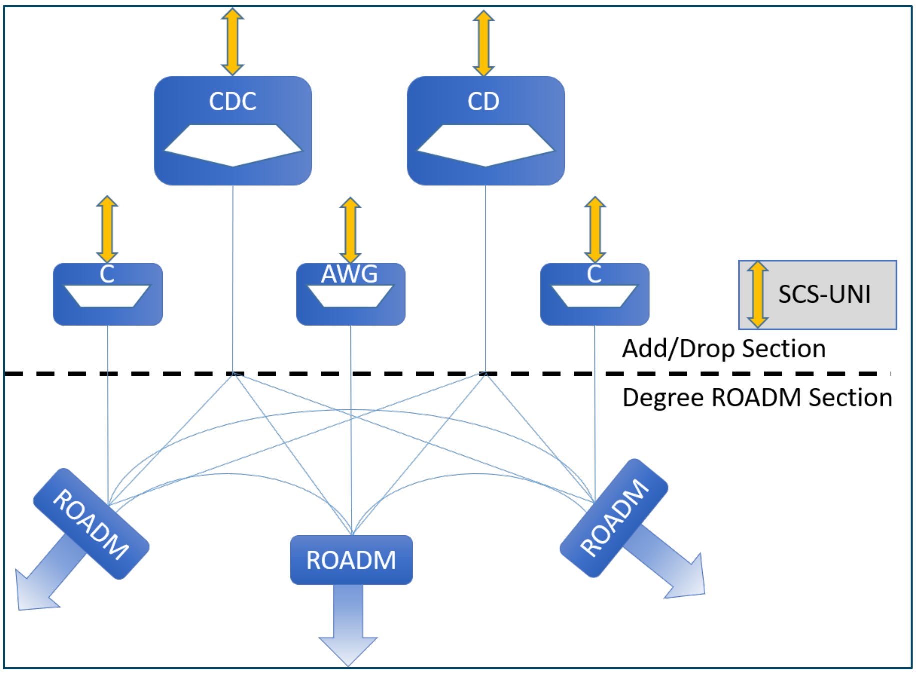


Figure 4.1: SCS-UNI Add/Drop section interconnection points

The main features of the various Add/Drop types are listed in the following table.

	Grid	Spectrum limitations	Reconfigurable Routing/Restoration	Privacy issues
Coloured Directioned	Fixed	50/75/100 GHz	NO	NO
Colourless (C)	Flex-compatible	NO	NO	YES
Coloured Directionless	Fixed	50/75/100 GHz	YES	NO
Colourless Directionless (CD)	Flex-compatible	NO	YES	POSSIBLE
Colourless Directionless Contentionless (CDC)	Flex-compatible	NO	YES	POSSIBLE

Table 4.2: Add/Drop section UNI main features

FlexGrid compatibility depends on the particular implementation and the underlying ROADM structure and technology.

This kind of interconnection can in principle benefit from the native signal facilities in terms of amplification, equalisation and service management. In particular, the currently available Management and Control planes are expected to be able to support such a setup.

N-degree ROADM Section

It is possible to define the SCS-UNI directly as a degree port in the ROADM structure according to the schema reported in Figure 4.2.

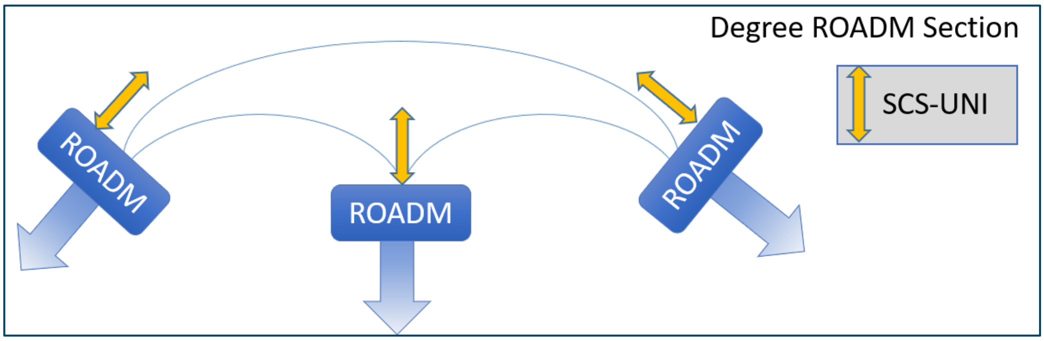


Figure 4.2: SCS-UNI N-degree ROADM section interconnection points

The SCS-UNI directly interconnected to the degree is coupled with the specific direction of the ROADM. Restoration or rerouting is not possible in this case. This specific set-up depends on the ROADM technology. Broadcast and Select ROADMs deliver the full C-Band into the outgoing direction of the interface, meaning that the entire C-Band is seen by the receiving interface of the user. This clearly implies severe privacy issues. Route and Select structures can therefore be used to filter out the undesired C-Band portions, delivering only the agreed slice of the spectrum.

This setup is different from the native spectrum arrangement, so it will not be possible to achieve benefits in terms of equalisation, power balancing, and OAM. The Control and Management plane would have to rely on a reduced set of features.

4.3.2 Network-Network Interface (SCS-NNI)

The SCS-NNI defines how optical transport infrastructure can be interconnected in different administrative domains and heterogeneous platforms in order to exchange optical signals.

As in the SCS-UNI case, SCS-NNI can be implemented as an interconnection through the Add/Drop section or directly through the Degree ROADM section.

Add/Drop to Add/Drop

SCS providers (optical transport infrastructure operators) are interconnected through the Add/Drop section (Figure 4.3). The specific implementation of the node (Colourless, Directionless, CDC, etc.) and the Add/Drop section impacts the functionalities of these interconnections. Please refer to 4.3.1 above for the Add/Drop section characterisation.

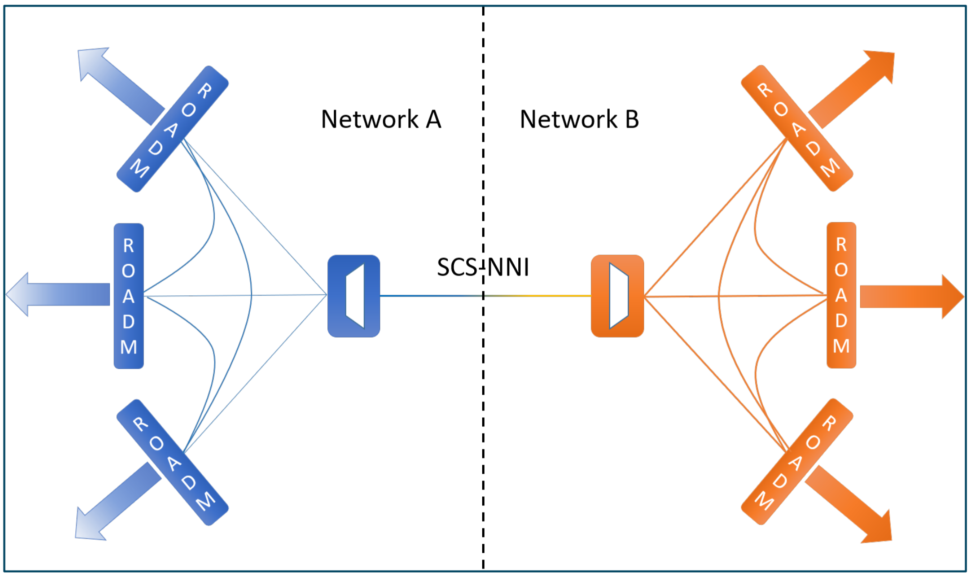


Figure 4.3: SCS-NNI Add/Drop to Add/Drop interconnection

ROADM to ROADM

In this case, SCS providers are interconnected directly through the line port of a dedicated ROADM in the node, as shown in Figure 4.4.

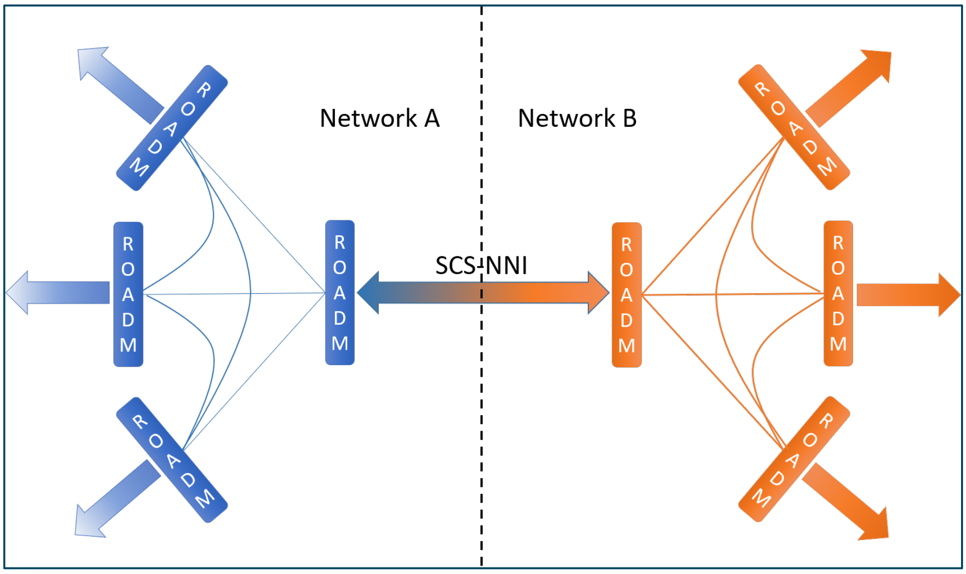


Figure 4.4: SCS-NNI ROADM to ROADM interconnection

This arrangement can benefit from the WSSs present in both nodes, and each network provider can both independently select the correct portion of the spectrum to offer and autonomously perform equalisation and power balancing.

This setup is different from the native spectrum arrangement so the Control and Management plane will operate with a reduced set of features.

4.3.3 Adaptation Function

To establish an SCS service, the transition between optical domains for a given optical signal must be able to be transmitted with the minimum penalty through the next domain without any possibility of compromising the correct functioning of the latter. To guarantee this, each interconnection point must be equipped with the following functions:

- Amplification
- Attenuation
- Policer
- Monitoring
- Privacy assurance

Amplification and attenuation are needed to adjust the alien signal power (single or multiple carrier signals) according to the hosting domain needs, in order to correctly equalise the spectrum. A policer is needed to react to misconfiguration that could be potentially dangerous for the hosting network. Monitoring tools are needed to check and to troubleshoot the operation of the service. Finally, regarding the privacy issue, it is important to ensure that only the expected optical signals are injected in the appropriate domain.

Although the adaptation layer is by its very nature a neutral element between two domains, it is important that there should be agreement as to who is responsible for managing each of its functions, which must be present on at least one of the domains.

4.4 Spectrum Planning

When planning an SCS service, the main questions that must be answered relate to:

- Existence of an available path between the two endpoints.
- Availability of suitable common capabilities among domains spectrum portion.
- Availability of tool to switch off /adjust to optical power according to the needs of each optical domain.
- Availability of monitoring tools to check and control the signals.
- A strategy to establish an SCS connection should start by considering as possible candidates:
    - The path with the fewest optical domains transited.
    - The shortest physical path.
    - Availability of a common spectrum portion suitable for the signal (50–100GHz or flex portion).
    - Availability of tools to control the power.

Among the possible candidate connections, the best choice will be the one which has the highest OSNR. For ease of allocation of spectrum, it is recommended that GÉANT reserve a portion of its network's spectrum for use by the SCS services. Knowledge of this spectrum range will allow NRENs to plan and reserve that same portion of the spectrum free in their own networks.

5 User Optical Requirements

This section describes the characteristics of the device at UNI that receives and transmits the optical signal from the transmission line. From the perspective of the Spectrum Connection Service, this is the device that generates the optical signal that is launched to the spectrum slice:

- The user must be present in (or able to reach) a GÉANT or NREN site that supports the SCS service.
- The user must be able to state their service requirements: bandwidth, latency, diversity etc. These user requirements are to be communicated to the SCS service provider through the mechanism described in section 3.4.
- The optical signal must conform to the requirements set out below.

5.1 Optical Source Device Overview

Currently several solutions to generate and receive optical signals are on offer by vendors. These can be categorised by network architecture as integrated or disaggregated.

In traditional monolithic DWDM systems, the optical interface is integrated horizontally with the transmission solution. A transponder maps the client site interface with the optical signal travelling on the line system one to one, and a muxponder aggregates several client signals to one single line optical channel. This integrated DWDM solution enables OTN switching capabilities using a device called a Switchponder.

In the so-called vertical integrated architecture, the optical interface is part of layer 2 or layer 3 equipment and can be an embedded interface or, more often, a pluggable device. The pluggable transponders can be proprietary or merchant modules. Two different technologies are currently available for this: the ACO (Analog Coherent Optics) where the DSP (Digital Signal Processor) is outside the module and the DCO (Digital Coherent Optics) where it is included in the transceiver module.

The disaggregated architecture includes a dedicated standalone element, the DCI [GN4-2-R1] which provides optical interfaces through a line system that also offers monitoring, management and control functionalities. These typically small elements, normally consisting of 1 or 2 rack units and having low power consumption, have been optimised for use in the Data Centre. For DCIs both ACO and DCO embedded or pluggable solutions are additionally available.

5.2 Optical Interface Device Properties

To define a stable and effective service model, one of the key elements to be agreed is the minimum set of capabilities and properties of the optical interface devices. This section sets out a minimum set of commonly agreed on features and list of desirable properties for the SCS user equipment that the SCS provider needs to agree in advance with the SCS user to serve the spectrum needed. This set of requirements and parameters is shown in Table 5.1 below.

Parameter	Definition	Note	Type of Requirements
DWDM Frequency Grid	Fixed/Flex	Frequency Grid (e.g. 50GHz – fixed grid, 12.5 GHz slice – flex grid) – ITU-T G694.1	Optional (O)
Number of channels in the Spectrum Slice	In case of multiple channels planned for the spectrum service, define the number of channels and their high-level arrangements (e.g. guard band)		Mandatory (M)
Line Rate	Bit rate @ the line interface (Gbps)		M
Baud Rate	Symbol rate @ the line interface (Gbaud)		M
Line Modulation	Line coding modulation (e.g. DP-QPSK)	Indicate modulation supported and the modulation designated for the proposed connection	O
Frame Format	OTN or equivalent frame format	e.g. OTU4 or Proprietary framing	O
Spectral Width	Spectral width for the designated service	(GHz)	M
TX power range	Power range for the transmitting interface (dBm)	Indicate supported working range and reference value	O
TX power centre frequency	Details of the channel central frequency. [191.35–196.1] THz		M
Min transmitter OSNR	OSNR at the receiver side (dB)	Vendor Specs as for a transmitter side OSA qualification of the interface	O
Roll-off factor	Pulse shape characterisation to evaluate Inter Symbols Interference		O
Chromatic Dispersion Tolerance	Max Chromatic dispersion at the receiver to operate without errors (ps/nm)		O

Parameter	Definition	Note	Type of Requirements
RX power range	RX power range for selected channel (dBm)		O
RX power range whole spectrum	RX power range in case of multiple channels (dBm)	In case of multiple channels received on the RX port from the Add/Drop section	O
Receiver OSNR tolerance	Minimum OSNR to operate without errors (dB)	Back-to-back min OSNR with the designated FEC	O
RX input power damage threshold	Max power at the receiver to operate without damage (dBm)		M
State of polarisation tracking features	Speed of polarisation tracking (Mrad/s) or general features	In order to understand if aerial fibres can be allowed along the path	O

Table 5.1: Optical Interface device properties

6 Monitoring Management of the Spectrum Connection Service

This chapter describes the monitoring and management aspects of Spectrum Connection Services (single-source and multi-source alien services).

6.1 Requirements for Spectrum Service Monitoring and Management

Provision of a spectrum service involves the creation of a spectrum tunnel through a provider's OLS between two endpoints. The SCS provider should have the ability to monitor the spectrum services and have in place the required mechanisms to enable them to police and shape the channel. These mechanisms are necessary to protect the OLS against interruptions caused by AWs. An overview of the spectrum services parameters which should be configured and monitored can be found in section 3 and Table 5.1.

Delivering a spectrum service brings many technical and economic advantages, but also some complexities at the operational level which must be taken care of and handled correctly. To do this, the optical and digital operational parameters that should be monitored by parties involved in the service provisioning chain must be identified. To do this, the point in the spectrum service delivery chain at which the operation parameters required to monitor, report and handle events regardless of their severity can be collected must be located.

In the SCS services, unlike in the native-generated light source services, all digital processing will be done on third-party transponders. This means that some QoS-parameters of importance for monitoring which reside at Electrical domain (digital level) will not be directly accessible by the spectrum service provider. So the spectrum service provider will be more or less blind to the quality of services delivered and unable to trace and allocate the source of a failure event unless the spectrum service user provides them with the necessary information needed to perform end-to-end monitoring.

From the user perspective, tracing the wavelength through OLS and knowing its condition while passing through OLS-NEs (Optical Line Systems Network Elements) is not possible. This can be solved if the service provider gives the user the monitoring information in real time.

In general, the SCS provisioning and monitoring process is divided into three phases:

1. Planning and pre-provisioning phase
2. Provisioning phase
3. Operation and monitoring phase

6.1.1 Monitoring in the Planning and Pre-Provisioning Phase

The spectrum service provider should deliver the following parameters to the user:

- **End-to-end OSNR value:** This is one of the most important pieces of information the user needs to estimate the achievable capacity between the service endpoints. It is the responsibility of the service provider to maintain the specified OSNR throughout the service period. The OSNR delivered indicates the quality of the optical path and can be used to price the service provided. The total OSNR can be calculated directly by formula or planning tools, or experimentally measured. The existing wavelength services running between the same endpoints can be used to give a good indication of what the expected OSNR could be on the new services. It is recommended that the spectrum/wavelength user choose capacity and modulation formats which give a 2dB OSNR margin.
- **Required central frequency and spectrum width comply with the ITU-T as follows:** The service provider should provide the central frequency with a reference to 193.1THz (1552.52nm). “193.1 + n × wavelength_spacing” where n is a positive or negative integer including 0 and wavelength_spacing is the OLS ability to provide wavelength steps. If the step is 25GHz the equation above becomes “193.1 + n × 0,025” (According to the ITU-T G.694.1). If the service is a spectrum with more than one wavelength the length of wavelength spacing should be used to calculate the central frequencies of each wavelength/carrier.
- **Preferred Roll-off and Pre-emphasis weight:** Where the spectrum service provider demands specific values for Roll-off and Pre-emphasis weight, this should be specified. Most DCI NEs can tune these values. Roll-off essentially controls the width of the spectrum and Pre-emphasis weight controls to which extent the TX lowpass characteristic is compensated.
- **TX and RX:** The spectrum service provider should specify the required TX value from the laser source on DCI or similar user devices (on dBm) and delivered power level (RX) to the user device (RX on user device e.g. DCI). In most cases, the user devices are co-located with the OLS-NE (SCS-UNI level). If not, the power budget for the access fibre part should be taken into account.

6.1.2 Monitoring in the Provisioning Phase

The provisioning phase involves both the service provider and the user. After physical connection, the SCS-UNI port at the service provider side is usually in blocking mode (i.e. light transmission is suppressed). The user should tune wavelength and optical power on the source according to the spectrum service provider’s requirements. The spectrum service provider will then open the port after verifying that the conditions above have been fulfilled.

6.1.3 Operation and Post-Provisioning Phase

The Optical line system (OLS) should have the necessary functionality to fully control the SCS-UNI provider port. It should be able to do the following:

- Drop only the agreed spectrum at the SCS-UNI port.
- Allow only the agreed spectrum from the user at the SCS-UNI port and block the rest of the spectrum. Also, the OLS should not forward this portion of spectrum onto any other SCS-UNI

ports belonging to other users (privacy aspect). This implies that broadcast and select ROADM architectures should not be used at add/drop ports used by the spectrum service.

- The OLS should be able to react fast and tune (attenuate or boost) the optical power level at the ingress point to the target level which the OLS is expecting. The extra OSNR margin (2dB, as per requirement in the previous section) will help to combat the sudden power changes.

As mentioned above, the split of monitoring capabilities between spectrum service provider and user makes the operation of the spectrum service slightly more challenging. Procedures and tools will therefore need to be agreed on to merge the split monitoring capabilities into an integrated function. This can be done in several ways. One simple method could be to introduce real-time monitoring of QoS-parameters and then push this data onto a central database which is accessible from both the service provider domain and the user domain. The parameters which should be available on such a database are:

- Provided by user (per port):
  - Actual TX and RX on DCI (user side at SCS-UNI)
  - Actual OSNR and Q-factor
  - Central frequency
  - Symbol rate
  - Modulation format
  - BER
  - BBE, SES, ES
  - CD and DGD
  - Delay
- Provided by service provider (per port and direction):
  - RX and TX on provider side at SCS-UNI
  - Any other additional parameters are optional
- Alarm management:
  - Notifications of events such as fibre cut or RAMAN pump failure, that affect the users' wavelengths.

6.2 GÉANT-SURF case study

This section describes how monitoring is achieved in an existing spectrum service.

6.2.1 Introduction

SURF (previously SURFnet) provide GÉANT with a share of the optical spectrum provisioned over SURF's DWDM systems between Amsterdam and Hamburg. GÉANT has access to a single super-channel consisting of 10 channels on the 50GHz grid of SURF's DWDM system and add/drop facility for the purpose of transporting up to 500Gbps of research and education-related data.

As SURF operates the fibre link, the demarcation points of the service are the SURF ODFs in Amsterdam and the NORDUnet ODF (arranged by SURF) in the meet-me room in Hamburg. This is represented in Figure 6.1 as the 'SURFnet service area'.

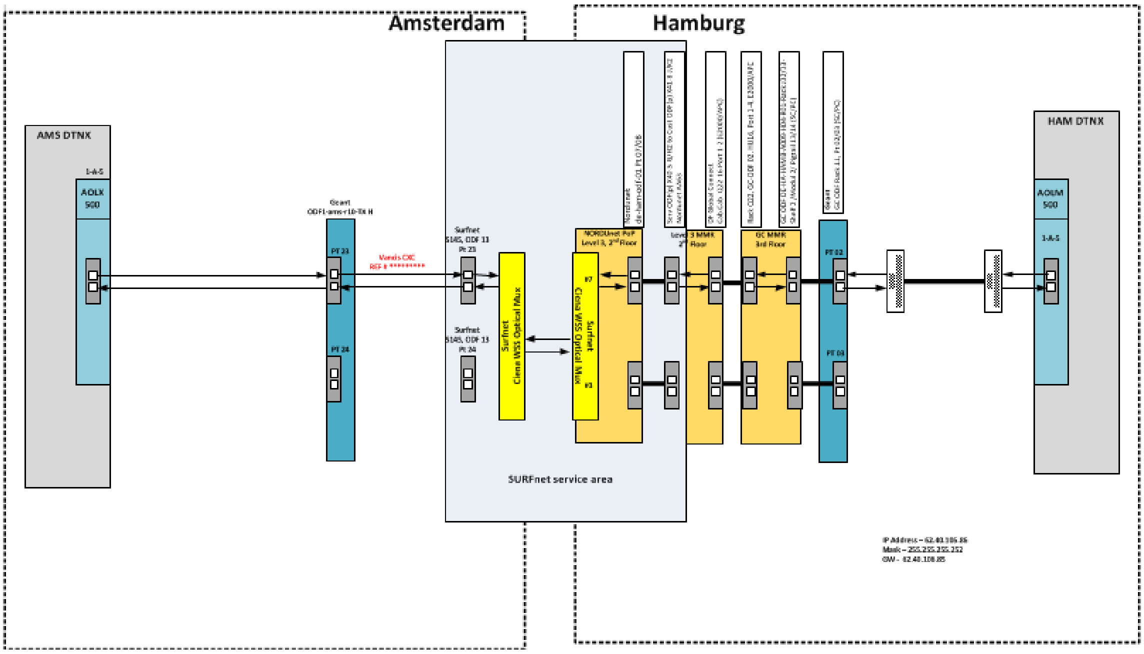
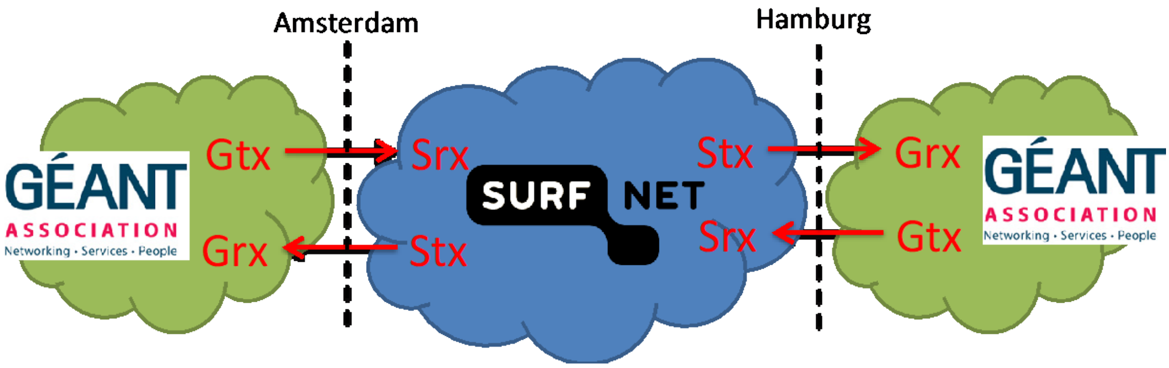


Figure 6.1: Ams-Ham case study

6.2.2 Responsibility Matrix

The demarcations for responsibilities between GÉANT and SURF are as follows:

- At Amsterdam two monitoring points: SURF (Stx) -> GÉANT (Grx) and GÉANT (Gtx) -> SURF (Srx).
- At Hamburg two monitoring points: SURF (Stx) -> GÉANT (Grx) and GÉANT (Gtx) -> SURF (Srx).
- Both (N)RENs monitor their partner's egress point. (i.e. the signal received from the partner).
- Both (N)RENs monitor their own egress point. (i.e. the signal transmitted to the partner).



Partner	SURF	GÉANT
Monitoring point Srx van (Gtx->Srx)	x	
Monitoring point Stx van (Stx->Grx)	x	
Monitoring point Grx van (Stx->Grx)		x
Monitoring point Gtx van (Gtx->Srx)		x
Informing about problems in (G -> S)		x
Informing about problems in (S -> G)	x	

Figure 6.2: Ams-Ham responsibility matrix

6.2.3 Monitoring of the Spectrum Connection Service

GÉANT does not have the visibility of the OSC for the Alien Wave spectrum provided by SURF. Instead, GÉANT relies on their own NMS reporting alarms (Pre-FEC BER Errors, Power levels) generated by the line cards below thresholds at the time of an incident. When an alarm is detected it is reported to SURF to be investigated further. Sample alerts on the Infinera DNA Transmission kit at the GÉANT Line Card end include:

- OPR Out of Range – Low
- Optical Loss of Signal – Payload

6.3 SCS Monitoring & Management Solutions

Monitoring of the Spectrum Connection Service in a multi-domain environment has no specific use case, therefore the community needs to agree on a common way to perform monitoring. Work has been done in the past to deliver multi-domain monitoring solutions such as CMon. These solutions have been difficult to maintain due to the work needed by all participants to keep the tool updated.

The variety of NMSs used by NRENs makes the situation more difficult; each system can provide different quantities and types of data which should be standardised if the aim is to build a homogenous monitoring solution. Finally, NRENs are free to implement their own policy to access/share sensitive data from their systems, so any consensus solution will require discussions between NRENs to be held.

However, there are some options (listed below) which could be used for SCS monitoring purposes.

6.3.1 Use Dedicated Account in NRENs' NMS

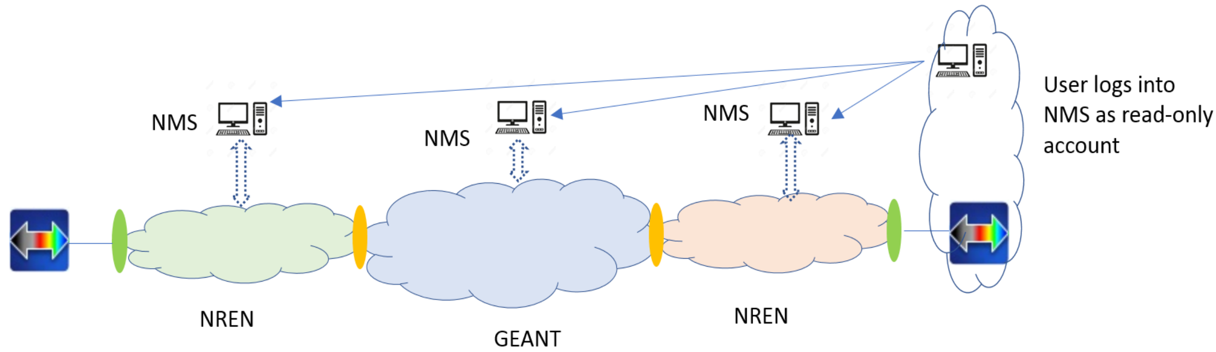


Figure 6.3: Dedicated account for users

The first and easiest option is to make use of a read-only account from an NREN's WDM monitoring system. The SCS NOC or any centralised monitoring team could access the remote WDM system to check a given AW connection's operability. In this case, the NRENs would have to agree to create this type of read-only account but, as this can imply a security issue, implementing restricted (but sufficient) access for such an account is a must.

6.3.2 Implement a Centralised Dashboard

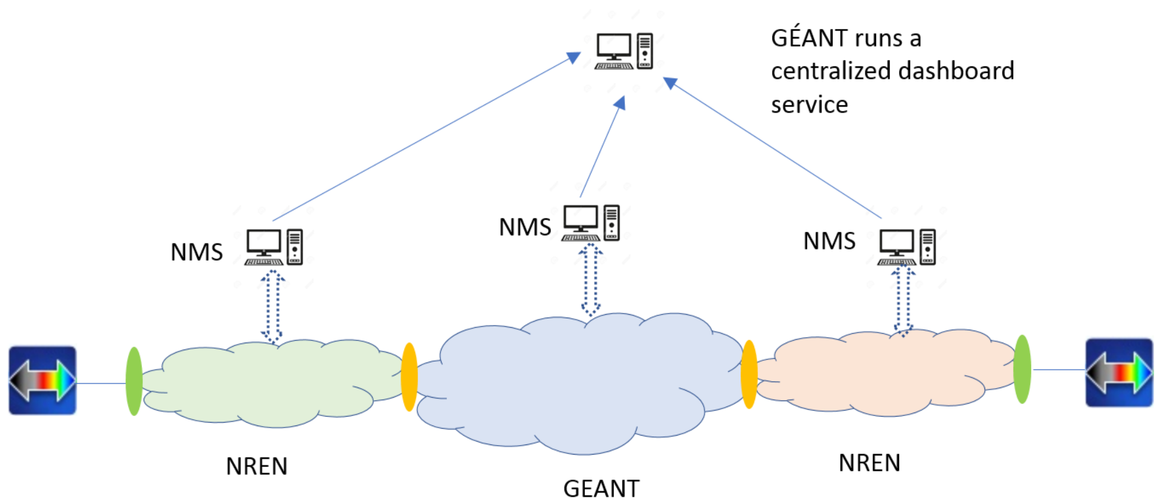


Figure 6.4: Centralised dashboard

Implementing a centralised dashboard removes the need to access the remote WDM system but does require an established connection over which to send or give access to raw monitoring data, which can be displayed on the special dashboard as an umbrella solution to present aggregated data.

There are two different methods to implement this feature:

- **Host network (NREN) uploads data to central server**
  In this case it is necessary to build a standardised communication channel (API) which can be used for sending data to a centralised server which collects, aggregates and displays all the information.
- **Central server collects data directly from WDM management system (OLS)**
  This solution shares some aspects with the one presented in section 6.3.1, including a similar security issue, but only requires one system user per NREN for collecting data. Furthermore, the whole process is automated.

Uploaded or collected data must fulfil the mandatory parameters described in Table 5.1: Optical Interface device properties.

6.3.3 Use a Special Orchestrator

The most complex solution in terms of difficulty of implementation is to build an orchestrator that is suitable for each NREN. The feasibility of this solution depends on having available standardised API interfaces from heterogeneous WDM monitoring systems.

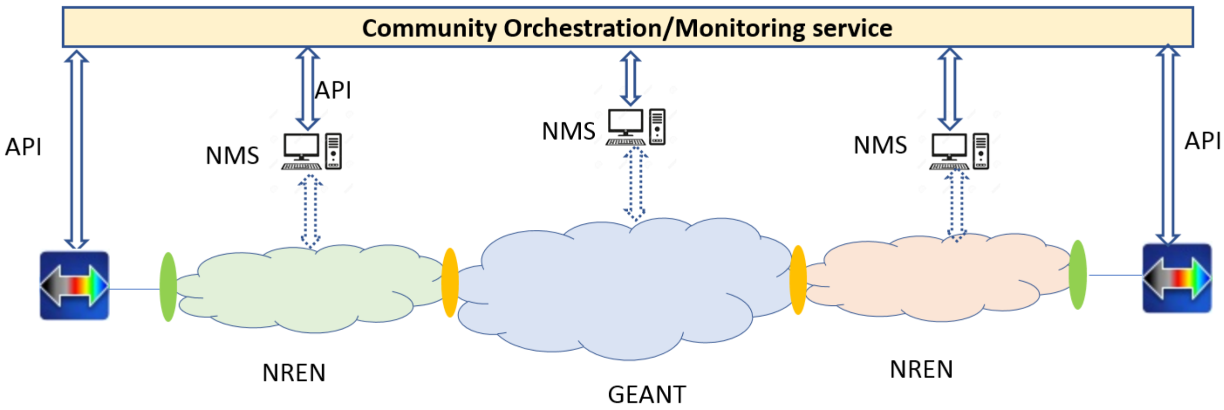


Figure 6.5: Specialised orchestrator

A well-designed orchestrator should be able to automatically control each AW between NRENs and will also collect data to support daily network operations (for example monitoring). Docker-based systems (such as Swarm or Kubernetes) should be taken into consideration, to be expanded using an appropriate network module.

An operative Spectrum Connection Service requires an appropriate management and control system to handle spectrum-related issues such as:

- Allocating (reserve) end-to-end spectrum for new connection(s).
- Modifying or deleting existing spectrum.
- Setting existing spectrum parameters.

These management actions can be carried out either through manual coordination (agreement via email, messaging service, phone calls and implementation in each domain using the available tools using the local NOC's provisioning system) or using an umbrella management/orchestration system.

It is expected that among users in the R&E community requests for a spectrum service will be few and the average service duration long, typically six months or greater. For this reason, owing to the cost and effort involved, the second option of developing a software solution to operate an umbrella management/orchestration system is not considered suitable.

Therefore, to ensure that manual service provisioning can be carried out efficiently, tools such as web-based service templates should be developed to expedite the creation of new service instances.

6.4 SLA Definition

The SLA will be developed based on experience in piloting the service and once the project has a better understanding of the customer's needs.

Appendix A Use case Collection

A.1 Data Centres Interconnection by Spectrum Connectivity Service

The use case described in this section concerns the use of the SCS to create an interconnection between the HEP Tier 1 CNAF and the HEP Tier 0 CERN.

A.1.1 Actors

- CERN as DC facility
- GÉANT
- GARR
- CNAF as DC facility

A.1.2 Description: CNAF-CERN Use Case

Based on the GÉANT Spectrum Connectivity Service it is proposed to establish an interconnection at high bandwidth capacity between the two High Energy Physics Data Centre sites: CERN (Geneva, Switzerland) and CNAF (Bologna, Italy). The optical link is a multi-domain interconnection between the two Data Centre end-sites, GÉANT and the Italian NREN, GARR.

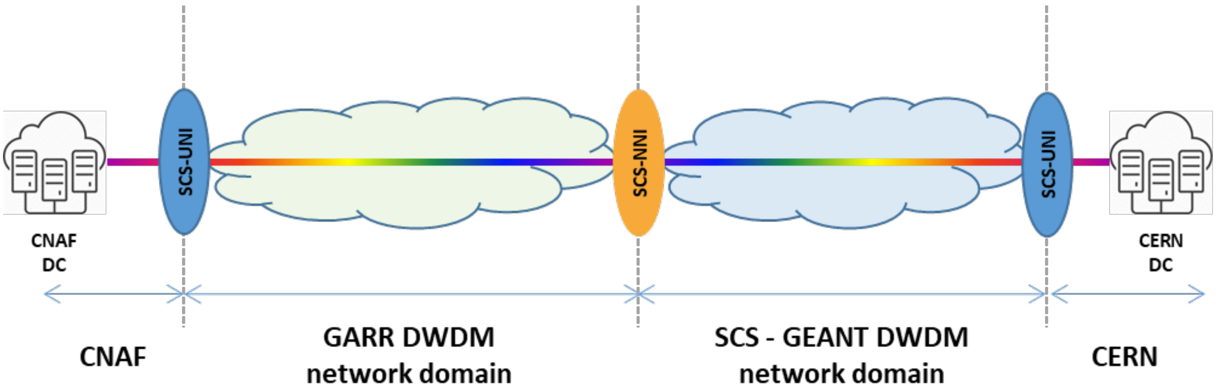


Figure A.1: CERN-CNAF use case

The two photonic transport infrastructures, GÉANT and GARR, must fulfil the minimum performance requirements as defined by the SCS and must have an SCS-NNI interface to enable the seamless interoperation of the two optical domains. Similarly, at the boundary between GARR and the end-sites, the SCS-UNI must allow the transit of the optical signal from the end-site device to the transport infrastructure.

In each end-site, DCI boxes must be installed to generate the optical signal. According to the SCS reference model, mechanisms must be in place to enable the provision, management and monitoring of the connectivity services.

A.1.3 Demarcation Points

The demarcation points are:

- SCS-UNI: CERN - GÉANT
- SCS-NNI: GÉANT – GARR (MIL GÉANT PoP)
- SCS-UNI: GARR – CNAF

A.1.4 Photonic Layer

Currently, both photonic layers, in the GÉANT and GARR domains, are being upgraded. The upgrades of both the infrastructures and the use case operational phase are to be completed at approximately the same time, so there is no risk associated to them. Furthermore, since the tenders for the procurement of the new photonic infrastructure are ongoing, there is time to propose and hopefully obtain the features needed for the new SCS.

A.1.5 Path Details

The total path length is around 1000km. The characteristics of the path will be defined in accordance with the reference model once the final values of the optical parameters become available.

A.1.6 User Optical Device

The plan is to deploy a pair of DCI boxes in CERN and CNAF to transmit an optical signal with a capacity of multiples of 100Gbps in a channel with spectral width of 100GHz (to be agreed with the third parties). In addition, guard bands may be required. Since the path length is estimated to be about 1000km, the only modulation required is expected to be DP-QPSK, but tests should be carried out to study different modulation options. A solution that requires 3R regeneration along the path is not recommended, however it might be a possibility to consider.

A.1.7 Actors Engagement

If all the above conditions are met, user engagement can begin.

A.1.8 Use Case Goals

Testing of:

- SCS-NNI
- SCS-UNI
- OLS simulation tools
- Provisioning capabilities through NBI
- Monitoring capabilities
- Troubleshooting scenarios.

A.2 PRG-POZ – Use Case

A spectrum sharing solution is requested to interconnect precise time and ultra-stable frequency distribution centres in Prague and Poznan (including national approximations of UTC) over CESNET and PIONEER networks or the GÉANT network. Additionally, the connection will support interconnection of the Prague and Poznan GOLE (Global Optical Lightpath Exchange) nodes.

Prerequisites

- Spectrum slice or Alien Wavelengths along Prague-Poznan path
- DWDM networks with AW or spectrum slice capability
- Monitoring demarcation point at borders of NRENs

End Points

- Prague (CESNET) and Poznan (PIONEER)

Administrative demarcation points

- Cieszyn (CZ-PL borders)

Distance

- 1326km

Expected modulation

- CW for ultra-stable frequency
- Low-frequency OOK or proprietary for precise time
- DP-QPSK or QAM for connection of GOLEs

Channels requested

- 50GHz for ultra-stable frequency
- 50GHz for precise time (preferably with 50GHz guard bands)
- 100GHz for data

A.3 PRG-AMS – Use Case

This spectrum sharing solution is sought to interconnect the Prague and Amsterdam GOLE nodes. The line rate is expected to start at 200Gbps and upgrade to 400Gbps in 2022.

Prerequisites

- Alien Wavelength along Prague-Amsterdam path
- DWDM networks with AW or spectrum slice capability
- Monitoring demarcation point at network collocation

End Points

- Prague (CESNET) and Amsterdam (GÉANT)

Administrative demarcation points

- Prague (co-located network PoP)

Distance

- 1200km (estimated)

Expected modulation

- DP-QPSK or QAM for data

Channels requested

- 100GHz for data

A.4 PRG-FRA – Use Case

Spectrum sharing is requested to interconnect precise time and ultra-stable frequency distribution centres in Prague and Frankfurt over CESNET and GÉANT networks.

Prerequisites

- Alien Wavelength along Praha/Brno-Frankfurt path
- DWDM networks with AW or spectrum slice capability
- Monitoring demarcation point at network collocation

End Points

- Praha/Brno (CESNET) and Frankfurt (GÉANT)

Administrative demarcation points

- Prague (network PoP)

Distance

- 1200km (estimated)

Expected modulation

- CW for ultra-stable frequency
- Low-frequency OOK or proprietary for precise time

Channels requested

- 50GHz for precise time (possibly bidirectional, may require 50GHz guard-bands)
- 50GHz for ultra-stable frequency

Appendix B Data Exchange Parameters for Alien Wave Provisioning

Parameter	Unit	Optional/ Mandatory	Comment
Test required	Yes/No	Mandatory	Provider indicates if a test is required to check impact or verify parameters that are not known or cannot be supplied
Min. Input power of a wave	dBm	Mandatory	Provider needs a certain input power to make equalisation possible without excessive attenuation of other waves
Max. Input power on a port	dBm	Mandatory	Provider can only perform limited attenuation on an input port or a wavelength
Typ. Input power of a wave	dBm	Mandatory	Provider indicates a preferred input power for a wave.
Min. Drop power of a wave	dBm	Mandatory	Provider must indicate the min. drop power that customer may expect
Max. Drop power of a wave	dBm	Mandatory	Provider must indicate the min. drop power that customer may expect
Typ. Drop power of a wave	dBm	Mandatory	Provider must indicate the typical drop power that customer may expect
Allowed power drift on add port	dB	Mandatory	Power drift that is allowed before provider sees alarm
Expected power drift on drop port.	dB	Mandatory	Most drop ports assume that any power in a power range that meets transceiver specs is OK as long as it does not fluctuate. Within the range slow drift is perfectly acceptable.
Switching of alien wave allowed	Yes/No	Optional	Indicates if a customer is allowed to switch power. Power changes usually occur either as orchestrated when waves are added/deleted or in case of a failure. Photonic systems may not be robust against frequent power flaps.
Number of waves allowed on add port	#	Mandatory	On some ports it may not be possible to add or drop multiple waves, even if the ports are filtered because port power is measured and used by the control software
Number of waves allowed on drop port	#	Optional	Some receivers that deploy broadcast and select can handle power from other waves on the same receiver. This is not trivial as the DWDM receiver design must support this
Centre Wavelengths / Frequencies	nm/THz	Mandatory	Wavelength and Frequencies must match the wavelength plan of the provider in case of multiple providers or CBFs the list will include the corresponding free waves

Parameter	Unit	Optional/ Mandatory	Comment
Bandwidth per wave	GHz	Mandatory	Provider must know how much bandwidth is requested. Customer must know the bandwidth that can be allocated.
Low Wavelength / Frequency	THz	Mandatory	In case of FlexGrid
High wavelength / Frequency	THz	Mandatory	In case of FlexGrid
Number of tributary waves	#	Optional	This is required to assess the total power in case of FlexGrid systems.
Launch power per section	dBm	Optional	Provider must protect other waves
Out-of-band ASE (Broadband) acceptable on add	Yes/No	Optional	In case AWs are inserted and are not filtered per wave, ASE may seep through onto other waves in the system.
Demarcation points	-	Optional	Address / Floor / Room / Cage / Rack / ODF / port etc. Type of connector
Chromatic Dispersion	ps/nm	Optional	Total chromatic dispersion measured at a specified wavelength.
PMD	ps DGD	Optional	Including maximum and minimum observed
OSNR	dB	Optional	OSNR at the output of the link
FEC	[]	Mandatory	FEC rate of reference transceiver. Can be used instead of OSNR under the assumption that OSNR is gaussian and no linearities are present.
Fibre Type		Mandatory	Type of fibre such as SSMF, SMF28, SiCore
Modulation classes supported / forbidden		Mandatory	Provider indicates modulation classes he accepts or excludes such as ASK/NRZ
Length of the link	Km	Mandatory	Length of the link
Number of EDFAs	#	Optional	Number of EDFAs
Longest span length	Km	Optional	
Average span length	Km	Optional	
Total attenuation in fibre	dB	Optional	
Total attenuation in non-fibre (pads, ROADMs etc.)	dB	Optional	
Figure of Merit	[]	Optional	The sum of all (from dB to a.u. converted) gains needed on all EDFAs to compensate losses, final drop span excluded
Number of ROADMs	#	Optional	Indicates the number of filtering ROADMs in the path. (This may be needed by customer to verify if the DWDM TRX can be used)

Appendix C Spectrum Channel Testing Methodology

1. The spectrum channel should be provisioned as specified by the customer.
2. With no GÉANT optical source connected to the channel, measure the power of the integrated optical noise over the channel with the resolution bandwidth set to 0.1 nm.
3. Next, connect the transponder at each end of the link, set the frequency, modulation power as needed and optimise for lowest pre-FEC BER.
4. Measure the power of the integrated optical signal over the channel with the resolution bandwidth set to 0.1 nm.

The OSNR is the ratio of the two measurements.

Appendix D Eligibility Checklist for NRENs/GÉANT for Participation in the SCS Community

Participants must be able to support the Specific requirements as listed below:

Requirements for service users

- The service user **must** be able to give service providers information online about performance parameters they expect from the service. (i.e. OSNR, BER, latency, diversity).
- The service user's devices **must** comply with the optical signal threshold and boundaries defined by the SCS service provider.
- The service user **must** be able to establish a communication channel to service providers NOCs.
- The service user **must** agree to notify the service provider before changing any optical parameters such as power levels or frequency.

Requirements for service providers (NRENs/GÉANT)

- The NREN **must** have a DWDM system that is capable of carrying alien waves or alien spectrum.
- The NREN **must** be able to provide procedures and tools to predict the performance of the spectrum service; This may be an optical planning tool provided by the NREN's equipment vendor, or an optical modelling tool such as TIP's GNPY.
- The NREN **must** have sufficient spare optical spectrum on their system for the duration of the service requested by the customer and must agree to reserve that spectrum for the customer.
- The NREN should indicate which nodes in their network are available to participate in the SCS service.
- The NREN **must** be able to set a TX optical power level target on their ROADMs to hand over at the SCS-NNI.
- The NREN **must** have the procedures and tools to support monitoring of the end-to-end service. The level of monitoring is to be agreed between SCS participants.
- The NREN **must** have the procedures and tools in place to optimise the end-to-end optical performance of the multi-domain service. This could be either automated tools or an optical engineer with relevant skills to optimise service performance.
- The NREN **must** be able to provide online optical power and spectrum reporting of the spectrum service.

References

[AW-CBF-SS] *AW, CBF and Spectrum Sharing Definitions*, GN4-2 JRA1 T1, 2017 https://intranet.geant.org/gn4/2/Activities/JRA1/Shared%20Documents/GN4-2_JRA1-T1-AW-CBF-SS.docx?Web=1 *(resource available to project participants only)*

[GN4-1-R1] https://www.geant.org/Projects/GEANT_Project_GN4-1/Documents/D13-2_Blueprint-of-Services-and-Research-Plan-for-Future-Work.pdf#search=Deliverable%20D13%2E2%20Blueprint%20of%20Services%20and%20Research%20Plan%20for%20Future%20Work

[GN4-2-R1] https://intranet.geant.org/gn4/ecreview/GN4_2P2/BackgroundDocs/GN4-2_White-Paper_DisaggregatedSystems.pdf *(resource available to project participants only)*

Glossary

ACO	Analog Coherent Optics
AW	Alien wavelength. The optical signal generated by the user equipment
API	Application Programming Interface
ASE	Amplified spontaneous emission
BBE	Background Block Error
BER	Bit Error Rate
C	Colourless (Add/Drop)
CD	Colourless Directionless (Add/Drop)
CD	Chromatic Dispersion
CDC	Colourless Directionless Contentionless (Add/Drop)
CLI	Command line interface
CW	Carrier Wave – i.e. unmodulated light
dB	Decibel
dBm	Decibel-milliwatt
DCI	Data Centre Interconnect
DCO	Digital Coherent Optics
DGD	Differential group delay
DP-QPSK	Dual-polarisation quadrature phase shift keying
DSP	Digital Signal Processor
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium-Doped Fibre Amplifier
ES	Errored Second
FEC	Forward Error Correction
FlexGrid	An ITU-T DWDM standard for providing a flexible slice of optical spectrum
GÉANT	Europe's provider of R&E networking
Gbps	Gigabits per second
GHz	Gigahertz
GOLE	Global Optical Lightpath Exchange
ITU-T	International Telecommunication Union, Telecommunication Standardisation Sector
Mrad/s	Milliradian per second
NBI	Northbound Interface

NE	Network Element
NMS	Network Management System
NNI	Network-Network Interface
NOC	Network Operations Centre
NREN	National Research and Education Network
ODF	Optical Distribution Frame
OLS	Open Line System
OOK	On-Off Keying
OPR	Optical Power
OSA	Open System Adapter
OSC	Optical Supervisory Channel
OSNR	Optical Signal to Noise Ratio. A ratio of signal to noise measured in dB
OSS	Operational Support System(s)
OTN	Optical Transmission Network ITU-T standard
PoP	Point of Presence
PSE	Physical Simulation Environment
QAM	Quadrature amplitude modulation
RX	Receive
SCS	Spectrum Connection Service
SCS-NNI	Spectrum Connection Service Network-Network Interface
SCS-UNI	Spectrum Connection Service User-Network Interface
Service Provider	Also referred to as the SCS provider. The NREN or GÉANT who provides the spectrum service to the user
Service User	Also referred to as the SCS user. The research or education user who consumes the spectrum service
SLA	Service-level agreement
SES	Severely Errored Second
Spectrum	A proportion of the optical spectrum on a DWDM transmission system that is allocated to a user in an SCS
SQT	Service Quality Target
THz	Terahertz
TRX	Transceiver
TX	Transmit
UNI	User-Network Interface
WDM	Wavelength Division Multiplexing
WSS	Wavelength Selective Switch