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Deliverable DJ1.3.2: Architecture Considerations for Federated Backbone Networks Study

The Federated PoP

Deliverable DJ1.3.2

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Abstract

This deliverable considers all aspects of establishing a federated Point of Presence (PoP). A federated PoP is a site where several networks such as NREN and GÉANT are collocated to offer services in a joint manner. The main motivations for a federated PoP are an extended reach of connectivity services and cost savings. In order to achieve these benefits several challenges have to be solved, in particular concerning the joint operation of the federated PoP in terms of management and monitoring.

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Executive Summary

The objective of GN3 Joint Research Activity 1 Future Network, Task 3 Federated Network Architectures (JRA1 T3) is to investigate how to optimise the use of network resources and find practical ways to stitch together services from equipment originating in multiple domains while maintaining a high quality of service. It also includes ensuring services can be provisioned quickly while keeping operational costs low. Such aims present challenges to Layer 1 (L1), L2 and L3 network architectures, control planes and management systems as well as the network's administrative and organisational set up. Meeting these aims and challenges is key to the success of the European NRENs and of GÉANT.

This report is the result of the work done in the second year of the GN3 project as a follow-up to the study of architecture considerations for federated backbone networks carried out in Year 1, which was documented in Deliverable DJ1.3.1 [DJ131]. The future work and recommendations for test cases identified in that deliverable were distilled to the aim of defining and describing a "Federated Point of Presence". T3 defines a Federated Point of Presence (federated PoP or F-PoP) as a site where several networks are collocated to offer connectivity services in a joint manner. To do so, network operations are carried out in accordance with collaborative agreements and it is possible for equipment to be used by several networks. The key benefits of a federated PoP are improved services and reduced costs; the main challenges include operational management, technological differences, and agreeing a cost model. This report addresses the requirements for establishing a federated PoP, and considers the technological issues involved. It discusses the connectivity services available in a federated PoP and the operational aspects in terms of practical approaches and advice.

There are a number of key issues that influence whether and how a federated PoP should be established. The key criteria for identifying potential F-PoP candidates include network architecture, traffic, infrastructure availability, cost, resiliency, and services. Crucially, a new architecture involving federated PoPs must be able to support at least the same level of service provision as the current infrastructure, and preferably improve upon it, as well as deliver added value and/or cost benefits as a result of cooperation and sharing. These considerations are addressed in Section 2.

The technological issues involved in establishing a federated PoP relate to connecting members at L1, L2 and L3. Taking into account the current technologies used by networks, the minimum F-PoP configuration option is optical equipment only. Other potential configuration scenarios include optical plus switching and / or routing equipment. These variations are discussed in Section 3, with a series of figures showing examples of different configuration options.

The report's discussion of services in a Federated PoP (Section 4) focuses on GÉANT-related connectivity services, both those currently available or those planned for the foreseeable future. All services are built on top of Dense Wavelength Division Multiplexing (DWDM) equipment from multi-vendor environments and alien wave technology. The section discusses practical approaches to realising the services, including the role of tools developed or used in the GÉANT community.

Sharing resources by several parties in a federated PoP imposes additional requirements on the operation and maintenance of the PoP. Prerequisite for the successful operation of a federated PoP are signed agreements between the host and an individual member, and agreed operational procedures. Added value can be achieved by close collaboration based on the common interests of F-PoP members. Indeed, this added value represents one of the main reasons for establishing a federated PoP. Section 5 makes recommendations as to what the agreements and procedures should cover to facilitate close collaboration, and introduces a communication model for F-PoP operation that is based on the federated architecture work carried out in Y1. It offers practical advice on maintenance and monitoring, again highlighting the potential role of tools developed or used in the GÉANT community to optimise the operation of the federated PoP.

The motivation for creating a federated PoP is the possibility of offering improved connectivity services in a multi-domain manner and of achieving a cost reduction in comparison to having separate PoPs run by different NRENs in the same city. This report discusses the conditions under which it can be particularly beneficial to establish a federated PoP, and the many aspects that should be considered. However, the opportunities for testing, demonstrating and validating research scenarios such as federated networking have until now been limited. JRA1's plans for Y3 include developing a detailed proof of concept of a Multi-Domain Junction Test Facility, which will be used by T3 for evaluating all aspects of the federated PoP. The Facility may also benefit a number of other GN3 Activities and Tasks, particularly those to which T3's work is closely related, to the advancement of the areas of common interest as well as their individual objectives. The proof of concept work will help to identify any further aspects and considerations that should be taken into account when setting up a federated PoP, in addition to those described in this report, including particular problem areas, and to identify more solutions to the issues raised here. It will also allow T3 to confirm the extent to which the federated PoP will deliver the expected benefits of improved services and cost reductions, and help to meet the aims and challenges key to the success of the European NRENs and of GÉANT.

1 Introduction

1.1 Background

The objective of GN3 Joint Research Activity 1 Future Network, Task 3 Federated Network Architectures (JRA1 T3) is to investigate how to optimise the use of network resources and find practical ways to stitch together services from equipment originating in multiple domains while maintaining a high quality of service. It also includes ensuring services can be provisioned quickly while keeping operational costs low. Such aims present challenges to Layer 1 (L1), L2 and L3 network architectures, control planes and management systems as well as the network's administrative and organisational set up. Meeting these aims and challenges is key to the success of the European NRENs and of GÉANT.

In Year 1, JRA1 T3 carried out a study of architecture considerations for federated backbone networks, which was documented in Deliverable DJ1.3.1 [DJ131]. In Year 2, as a follow-up to that work, the Task has applied the results to developing the concept of a "Federated Point of Presence".

T3 defines a Federated Point of Presence (federated PoP or F-PoP) as a site where several networks are collocated to offer connectivity services in a joint manner. To do so, network operations are carried out in accordance with collaborative agreements and it is possible for equipment to be used by several networks.

For a fuller discussion of the concept of federation, including examples of its realisation in a number of large-scale projects within the GÉANT user community, please see [DJ131]. While there may be alternative possible models, the scope of JRA1 T3's work, as defined in the Technical Annex, is to study federation. The results of the work will confirm the extent to which federation can deliver the expected benefits and so demonstrate its appropriateness as a proposed approach for GÉANT.

1.2 In this Document

The remainder of this Introduction covers the benefits and challenges of federated networks, identifies the three entities involved in a federated PoP, provides examples of federated PoPs, and summarises the relations between the work carried out by JRA1 T3 and other GN3 Activities and Tasks.

Section 2 addresses the requirements for establishing a federated PoP, and presents an economic analysis.

Section 3 considers technological issues, presents generic configuration options – optical, switching and IP routing – and gives examples.

Section 4 outlines the connectivity services available in a federated PoP based on Dense Wavelength Division Multiplexing (DWDM) equipment, switches and routers, while Section 5 addresses operational aspects including cooperation agreements, procedures, communication models, and maintenance and monitoring.

Section 6 offers a summary of the report and an assessment of the federated PoP work.

1.3 Benefits and Challenges of Federated Networks

This section identifies the key benefits and challenges of federated networks, as described in the research paper *"Building federated research networks in Europe"* written by the Task members for the TERENA Network Conference 2010 [BFRN].

The key benefits are:

- Improved services for multi-domain projects by offering enhanced service resilience and also by simplifying the support structures from the user perspective.
- Reduction of capital expenditure and costs of leased circuits for the networks participating in the federation. As these costs dominate the total cost of wide-area core networks such as GÉANT, major reduction of the overall cost is possible.

The main challenges are:

- Management challenges: interconnecting networks through federation requires tight collaboration in network operation. Processes for fault handling, configuration, accounting, performance monitoring, quality of service (QoS), and security management have to be coordinated.
- Technological differences and missing standards: while collaboration at the IP level is based on well-known shared standards, there is a large heterogeneity at the level(s) below IP. Every network has implemented an individual realisation of technologies such as native Ethernet, Ethernet over Multi-Protocol Label Switching (EoMPLS) or Synchronous Digital Hierarchy (SDH). This creates difficulties when a multi-domain link has to be provisioned and further complicates operational collaboration.
- Unified user view: users should experience the federated network as a single network and be unaware of the collaboration within the federation. A unified service desk has to be provided.
- Cost model: federating a network at the European level involves serious costs. It is therefore necessary to agree on a cost-sharing model and also a pricing model for the services on the federated network. The model must take into account how partners are remunerated for the resources they contribute to the federation. This problem has not yet been satisfactorily solved even in the context of cross-border fibre (CBF).

1.4 Entities Involved in a FederatedPoP

From an organisational point of view, a federated PoP involves three entities: F-PoP owner, host and member.

- **F-PoP owner** – provides physical space for the federated PoP (e.g. room and rack space) and is responsible for maintaining the physical space and conditions (such as temperature, humidity, power supply and uninterruptible power supply (UPS), etc.). Premises for a federated PoP may, but do not have to be provided by an NREN, in which case the owner can be referred to as the “home NREN”. The F-PoP owner may, but does not have to, participate in the traffic exchange and services that are provided in the federated PoP. If the F-PoP owner participates in the F-PoP services, then the owner is also an F-PoP host.
- **F-PoP host** – if the F-PoP owner does not participate in the F-PoP services, then the party that both participates in the F-PoP services and takes a coordinating, liaison role between the members and the owner is called the F-PoP host. The F-PoP host may, but does not have to be from the same building, city or country as the F-PoP owner. The most important aspect of the F-PoP host entity is this dual role: coordinating the maintenance of the premises and participating in the F-PoP services.
- **F-PoP member** – is a party interested in interconnecting with the federated PoP, and may also be known as a “guest network”. F-PoP members establish a physical connection in the F-PoP and provide the required hardware. However, it is also important to define traffic exchange between the entities within a federated PoP.

  (Section 3.1 additionally distinguishes between an active F-PoP member, with equipment installed in the federated PoP, and a passive F-PoP member that is only present in the F-PoP with a leased line or a fibre connected to the equipment of another member. Section 3.1 also introduces four member types based on the technology they use: lightweight (i.e. optical), switching, routing and full service.)

For the purposes of communication, Section 5.2.1 proposes a further role, that of F-PoP operator, which can be taken by any of the entities.

1.4.1 Responsibilities

The entities differ in their responsibilities, as summarised in Table 1.1 below.

Area	Responsibility		
	Owner	Host	Member
F-PoP premises	Maintain and operate		Comply with the rules of the host
Hosting services	–	Provide	–
Other services (such as those described in Section 4)	–	Provide and/or use a service	Provide and/or use a service

Table 1.1: Technological configuration options of a federated PoP member

1.5 Examples of a Federated PoP

One example of a federated PoP is a PoP in an NREN that connects to the GÉANT network and which also accepts a link for another NREN's connection to GÉANT. In such a case, three entities can be distinguished: the home NREN (or F-PoP owner) that is providing the physical space for the PoP; DANTE as one F-PoP member, because connectivity to the GÉANT network is enabled; and the second NREN as a second member of the federated PoP.

A similar example, which can be referred to as a multi-domain PoP, is any Internet Exchange Point (IXP) where several Internet Service Providers (ISPs) meet at the same point (i.e. the home / owner location) and some or all of them exchange traffic using connections established within the PoP.

Federated PoPs and multi-domain PoPs are similar in that they share the same elements – one host and at least one member – and both need contracts covering the physical placement of the equipment, interconnection and traffic exchange. The difference might be in the level of interaction and cooperation between the individual entities in any federated network architecture model layer: the infrastructure, operations and/or services layer [DJ131].

1.6 Relations with Other GN3 Activities

The work carried out by JRA1 T3 and described in this deliverable relates to several other Activities and Tasks in the GN3 project. These relations are identified in the appropriate sections of the report. In addition, an overview is given here.

Within JRA1, Task 1 (JRA1 T1) and Task 2 (JRA1 T2) are investigating the development of technologies used for constructing networks (carrier class transport network technologies, and photonic switching and experimental photonic facilities respectively). These investigations are important for considering which kinds of technical possibilities are realistic for building a federated PoP. For example, they will help determine whether it can be assumed that interoperability based on alien wavelengths is going to be reliable enough for regularly offered services to be built on top of it. JRA1 Task 4 (JRA1 T4) is investigating virtualisation techniques. These are relevant for hardware savings, and may mean that some NRENs participating in the federated PoP operate virtual equipment instead of physical devices. This is particularly relevant for routers.

With regard to JRA2 Multi-Domain Network Service Research, there is only a loose relation. JRA2, in particular Task 1 Control and Management, are investigating future management concepts and evaluating management frameworks for this purpose. These management frameworks should, in the future, be applied to managing an F-PoP. The challenge faced by JRA2 T1 is that most existing frameworks are not designed for a multi-domain environment and only give recommendations for managing a single-domain environment.

SA1 Network Build and Operations deal with the management of the GÉANT network. This work has to be seen in context with JRA1 T1 and T2 to get a view on current and future technologies for constructing networks and therefore also federated PoPs. In addition, SA1's investigations identify practical decisions that have to be made. This has an influence of what can be regarded as realistic technological options. Reciprocally, JRA1 T3's output can be taken into account in further GÉANT network architecture planning.

SA2 deal with multi-domain network connectivity services. SA2 Task 1 Multi-Domain Network Connectivity Services Development specifies these services in collaboration with the other Tasks, whose focus is to contribute certain aspects (e.g. operations, monitoring, security, tools). These services are very relevant for Task 3's work, since they have to be evaluated to determine which can be offered via a federated PoP.

There is no relation between the F-PoP work and JRA3 Multi-Domain User Application Research, SA3 Multi-Domain User Applications or SA4 Software Governance.

2 Requirements for Establishing a Federated PoP

Establishing a federated PoP involves introducing changes into the overall network architecture in order to deliver benefits in terms of lower costs and/or better utilisation of the infrastructure. Crucially, changes to the network topology that may be introduced by establishing a federated PoP should not have a negative effect on the operation and overall performance of the current network infrastructure. Establishing a federated PoP – in the GÉANT network, for example – should therefore be preceded by a careful analysis of all advantages and disadvantages; potential drawbacks like the creation of bottlenecks or a reduction in the overall resiliency of the network should be identified and avoided through careful planning. Another prerequisite is to draw up agreements between participating parties defining all aspects of F-PoP operation.

The key issues influencing whether and how one or more federated PoPs should be established are discussed in detail in the following sub-sections.

2.1 Selection Criteria

To identify potential candidates for federated PoPs a careful analysis of current architectures is needed and a number of factors important for the proper functioning of a network involving a federated PoP must be assessed (e.g. amount of traffic that will be crossing the federated PoP, backup routes, etc.). A new architecture involving federated PoPs must be able to support at least the same level of service provision as the current infrastructure, and preferably improve upon it.

Long-term as well as short-term effects should be carefully considered. In the short term, the new architecture should have a positive impact on network optimisation and lower costs. In the long term it should allow the flexible extension of the GÉANT network and be compatible with any planned or potential future upgrades and development.

The most important aspects to consider are listed below and described in the following sub-sections.

- Current and future network architecture.
- Traffic flows and traffic behaviour.
- Availability of the infrastructure (network equipment, fibre).

- Cost.
- Resiliency requirements.
- Services to be offered.

In general, the two main ways of identifying potential candidates for federated PoPs are, first, to identify a location where at least two networks are or can be easily connected, and second, by thorough analysis of the overall network architecture to identify the best opportunities for network optimisation.

2.1.1 Network Architecture and Traffic

The first step in identifying potential nodes should be the analysis of current GÉANT and NREN architectures and of the traffic within these networks. Analysis of network traffic will help to identify (or to confirm) the location of the main nodes in the network, while analysis of GÉANT and NREN architectures can provide useful information regarding possible improvements such as the geographic (re)location of points where at least two networks meet each other. Such analysis should be based on current data, but should also take into account trends and planned or potential developments in order to produce proposals that are valid for the network in the future.

The current GÉANT architecture consists of several types of nodes: core PoPs that are on the GÉANT fibre cloud and use Dense Wavelength Division Multiplexing (DWDM) / Next-Generation (NG)-SDH/IP platforms, and a set of PoPs that are off the GÉANT fibre cloud and use leased wavelengths. Taking into account access to services, PoPs can also be divided into GÉANT PoPs that have access to all services, GÉANT PoPs that do not have access to the GÉANT Plus platform, GÉANT "routerless" PoPs, and NREN PoPs connected to remote GÉANT PoPs. Extensive information on the current GÉANT architecture and a description of GÉANT PoP capabilities can be found in Section 2.1 of *"Deliverable DS1.1.1,2: Final GÉANT Architecture"* [DS111].

Taking the architecture of NRENs into consideration, a potential location for a federated PoP could be a city where at least two networks have their equipment or fibre so that interconnection is possible (or already takes place). This is a simple example; more complicated cases, such as when an NREN has a presence in two different cities and a federated PoP might therefore be created in one of these cities, should also be taken into account, provided there is reasonable justification (either economic or technical) for making changes to the network.

In each case, the demand for each type of service should be assessed in order to determine the required capabilities and features of the federated PoP. Both current architecture and potential future requirements should be taken into account. Those capabilities and requirements impose further requirements on the technical realisation of the connection by requiring specific functionality from the hardware.

Other factors affecting the choice of location include the availability of commercial services, private peering and IXPs.

2.1.2 Infrastructure Availability

Infrastructure availability is a significant factor in planning potential changes in the network topology of GÉANT and NRENs. It includes the availability of networking hardware and, more important, the availability of fibres that could be used for providing connectivity to the federated PoP. While lack of networking hardware shouldn't be a big obstacle, the availability of fibres is one of the key factors influencing the successful creation of a federated PoP.

Options for providing the connections include:

- Installation of fibre to connect to federated PoP in existing cable ducts.
- Use of managed services run on the existing fibre network infrastructure.
- Use of available dark fibre which could be used for providing connectivity.

Of these options, availability of dark fibre infrastructure on routes to a federated PoP would deliver the biggest benefit, as it offers the potential to support a large number of services by installing the appropriate hardware. International fibre connections should be taken into account, with special attention to cross-border fibre (CBF) connections, which may be very useful for interconnecting to a federated PoP.

On the other hand, serving several networks in a single federated PoP imposes high requirements on the networking hardware that will be used in that PoP. It is foreseen that 40 Gbps and 100 Gbps interfaces may be available in GÉANT in the future for some subscribers (with plans to provide 40 Gbps interfaces for NRENs subscribing to GÉANT IP at more than 10 Gbps [DS111]). Where one PoP serves several NRENs, the volume of aggregated traffic may be high, so robust devices will be needed.

2.1.3 Cost

Typically, one of the main goals for establishing a federated PoP is to reduce the overall cost for GÉANT and NRENs. The overall cost of establishing a federated PoP is therefore another key factor that must be taken into account. The overall cost includes the cost of equipment, fibres, maintenance and operation, and in most cases should be lower compared to the architecture without federated PoPs. A more detailed analysis of cost issues is given in Section 2.2.

2.1.4 Resiliency

Introducing a federated PoP should not have a negative impact on network resilience. Care should be taken when designing and planning to ensure that the federated PoP does not create a single point of failure for several NREN networks; backup routes for each network connected to a federated PoP should be in place to provide connectivity in case of F-PoP failure. Since the impact on network resiliency of a federated PoP may be different for each participating network, it is necessary to define conditions for each network which should be met when introducing changes in the network architecture. Taking into account connectivity services offered in the GÉANT Service Area, it is important to assure resiliency for the joint network at least at the same level as in the architecture not involving federated PoPs. Additionally, individual NRENs may also try to increase resiliency, e.g. by considering alternative routes to the federated PoP.

When designing the federated PoP, protection and redundancy for the network should be taken into consideration, at the level of redundant F-PoP, redundant fibre cable paths, redundant power supply as well as redundant equipment. For that purpose, a risk-cost-benefit analysis should be performed, because additional redundancy for the sake of stronger resiliency introduces additional costs. These additional costs have to be justified in relation to the resiliency gain.

2.1.5 Service Portfolio

A federated PoP should allow access to all services requested by users from participating networks. A good candidate for a federated PoP is a node that is already capable of providing access to GÉANT services. The current and future GÉANT service portfolio includes the following set of network services [GSWWW, DS1322] (see also Section 4 *Connectivity Services in a Federated PoP* on page 23):

- IP Service.
- GÉANT Plus Service providing access to point-to-point circuits.
- GÉANT Lambda Service providing transparent wavelengths between two NRENs across the GÉANT network.

Two new services are being defined in SA2 T1:

- Static Dedicated Wavelength Service – a multi-domain, end-to-end, point-to-point connectivity service for data transport based on dedicated wavelengths in the participating domains.
- Bandwidth-on-Demand Service – a multi-domain, end-to-end, point-to-point connectivity service for data transport using Ethernet technology allowing specific amounts of bandwidth to be reserved on demand.

Changes in the architecture of the network should not limit the overall usability of any of these services. This implies that a federated PoP should support all of the services that are required by the connected networks. The potential to support all of the connectivity services that are part of the GÉANT Service Area (as defined in SA2 T1) should be considered.

Depending on the type of services that need to be supported there are several options for the technical realisation of a federated PoP. More information about support of services in a federated PoP is given in Section 4, while technological issues related to different kinds of federated PoPs is given in Section 3.

2.2 Economic Analysis

This section discusses the economic aspects of a federated PoP, divided into capital and operational expenditure, briefly considers the financial benefits of cooperation, gives examples of cost-based considerations, and outlines areas to be studied in Y3.

2.2.1 Capital Expenditure

Capital expenditure (CAPEX) includes:

- Initial installation: room, cooling, electricity, IT hardware (DWDM, routers and switches), fibre links, local connections inside the rooms.
- Effort needed: planning, ordering, installation, testing, deployment.

The cost of building a federated PoP depends greatly on the readiness of the selected site. A feasible solution would be to choose an existing NREN PoP, because the NREN will have already examined and reviewed the premises as part of their procurement process. A public collocation or server hosting room is also feasible, especially if it is located near fibre cross-connect sites. Both alternatives offer the possibility of utilising the existing services by contracting, which is beneficial both financially and in terms of effort.

If the federated PoP has to be established as a greenfield project, the capital expenditure will rise, because of the following factors:

1. Fitting the physical room: the room may be lacking fundamental structures, e.g. secure routers and racks, which need to be fixed.
2. Environment control: this includes air conditioning, fire-protection systems and security systems.
3. Room cabling: the IT systems need to be interconnected inside the rooms. In addition, the room needs to be connected to the local metropolitan area fibre optical networks.
4. Actual equipment used for networking: DWDM equipment, routers or switches.

Establishing the federated PoP requires effort. The effort needed depends on the initial situation. The main labour-intensive cost items are:

1. Planning of the installation and setup.
2. Procurement and ordering of the necessary materials, devices and connections.
3. Installation and construction work on-site and with the related systems.
4. Testing of the room and the new systems.
5. Deployment into production use.

The greenfield approach may be justified in some cases, for example where the operational phase expenditure can be reduced by higher initial investment. The expected lifetime of a federated PoP is long, which means that the operational phase cost will dominate in the final analysis. In addition, high-quality installation work means less and shorter maintenance problems in the long run. The electrical power consumption of the selected hardware will accumulate during the operational phase, which supports the promoting of green technology.

The cost structure should have a significant advance payment component to cover both room fitting and planning for overall optimisation.

2.2.2 Operational Expenditure

Operational expenditure (OPEX) includes:

- Local field service for minor operational tasks, e.g. patch cabling, etc.
- Field service operations for IT hardware maintenance and expansions.
- IT hardware maintenance fees.
- Spare-part management.
- Electricity bill.
- Room-usage fees.
- Fees for maintaining the room services (as listed in Section 2.2.1).
- Effort needed: operations, monitoring, fault repairs, etc.

The operational expenditure depends on the selected method and means of establishing the federated PoP. There may be possibilities for achieving savings as a result of competition between vendors.

2.2.3 Benefits of Cooperation

The capital expenditure could be shared between the participating NRENs as the principal funding strategy. This strategy can be most easily used in the PoP setup phase. Options for achieving added value and/or savings based on sharing include:

- Hardware: This has an impact on both capital and operational expenditure. The most straightforward application is sharing the fibre infrastructure, panels and ducts. Networking devices can also be shared, either logically or physically. Logical sharing can be performed with, for example, virtual LANs or virtual routers. The sharing can be taken to the chassis level, if two NRENs agree to install interface cards in the same device; this can arise if, for example, both parties are using same hardware vendor.
- The physical space: Procurement of the room can be undertaken jointly, which offers a better chance of finding optimal sites, e.g. near IXs or major collocation sites. The closer equipment vicinity will result in shorter fibre lengths and easier cross-connecting possibilities.
- Inter-NREN services: The ease of interconnecting makes it possible for NRENs to provide services to one another. This lowers the cost of some of the existing NREN services, e.g. lightpaths to neighbouring countries. Establishing a federated PoP may enable innovative international research and education projects in fields not seen so far.

2.2.4 Cost-Based Considerations

For the federated PoP to deliver both enhanced service resilience (understood in this context to mean general robustness and reliability in combination with the ability to maintain service levels in the event of failure and/or sub-optimal conditions) and a reduction in overall costs, it’s realistic to assume that other aspects might need to be compromised or lost. Again, risk-cost-benefit analysis will be required to assess specific situations and options. For example:

- Building a federated PoP means adding an extra facility into the European network infrastructure, besides the existing GÉANT and other available services. Both the existence of a federated PoP and the set of services provided through the PoP should be considered when the cost analysis is applied.

  Federated PoPs can offer L1 and L2 services for specific purposes and in regions where to add them to a GÉANT PoP would be more expensive and they would be less likely to be available at short notice. In this example, the actual cost of the additional service is less than the estimated cost of upgrading the GÉANT PoP. The compromise is that the set of services is limited to L1 or to L1 and L2.
- In rural areas, the services can be delivered by a combination of owned equipment and leased lines. The introduction of a federated PoP operated by the local NRENs or their affiliates can improve both the level of services and overall long-term costs. In this case, federation also includes the local organisations that participate in the regional infrastructure, among whom there is a lot of interest in realising such financial advantages. As in the first example, the high bandwidth but limited services (L1 or L1/L2 rather than the ability to offer a general L3 set of services) is the possible compromise.
- A federated PoP offers the option to add a regional bypass for GÉANT-related connectivity and operations, which can be attractive in terms of availability and performance. It offers this option more cost-effectively than can be achieved by a specific extra link or dedicated service. (The actual cost effectiveness will be determined as a result of planned Y3 work.)

2.2.5 Areas for Study in Y3

Areas that have been identified for study in Y3 to help develop the cost/benefit analysis include:

- Relative significance of collocation fees. Investigate a possible relationship between collocation fees and connectivity costs with regard to total GÉANT cost (e.g. that collocation fees increase in relative significance as connectivity costs decrease) and its effect.
- Collocation cost models. Study collocation cost models to identify factors affecting potential cost savings, e.g. extent to which costs scale with the number of rack footprints and electric breaker sizes.
- Virtual slices vs individual hardware. Compare costs and benefits of sharing hardware through virtualisation versus using individual hardware.
- Commercial premises vs NREN premises. Obtain statistics on how many of the NREN PoPs are in commercial telehouses and compare costs and benefits of commercial vs NREN ownership of premises.

3 Technological Issues Related to Establishing a Federated PoP

3.1 Configuration Options

From a technical perspective, a federated PoP consists of one or more NRENs, and possibly GÉANT, collocating their equipment. The federated PoP is not under the authority of, or managed by, a single administrative entity. Therefore the boundaries within a federated PoP have to be defined in terms of both technical and non-technical management. The concept of the federated PoP introduces cost savings by sharing hardware between its members.

A federated PoP offers only those services that the connected parties have agreed on, and multiple or even mixed configurations of services between members are possible. We can distinguish between an active F-PoP member, with equipment installed in the federated PoP, and a passive F-PoP member that is only present in the federated PoP with a leased line or a fibre connected to the equipment of another member. Taking into account the current technologies used by networks, the type of equipment installed in the federated PoP will be optical, switching and/or routing, depending on the needs of the F-PoP members. Table 3.1 below shows different configuration options for a federated PoP where at least two different networks, of member types ranging from lightweight to full service, are present.

Technology / Equipment	Member Type				Key
	Lightweight	Switching	Routing	Full Service	
Optical	●	●	●	●	● Available – Not present
Switching	–	●	–	●	
IP Routing	–	–	●	●	

Table 3.1: Technological configuration options for a federated PoP

The table shows that the minimum configuration option is a federated PoP whose members have optical equipment only. In other configuration scenarios there may be members who also have either switching or routing equipment. In addition there may be members who support all technologies (full-service members who have optical, switching and IP routing equipment).

3.1.1 Optical

In the configuration scenarios shown in Table 3.1, optical hardware forms the basis of the federated PoP. Optical technology is widely used and it will certainly be present at the federated PoP. In a typical scenario, every member will have equipment from a different vendor, so the wavelengths will need to be converted to the electrical level and members will connect with each other through a specific transponder. This client interface will be SDH, Ethernet or Optical Transport Network (OTN), and the wavelength will end inside the domain of each member. Occasionally, two members may have equipment from the same vendor. In this case, power-level settings, wavelength frequencies and other parameters should be agreed in advance, and the wavelength would be configured in pass-through between the two members. In a very unusual case – e.g. when NRENs use hardware from the same vendor – the optical equipment could be shared by several members.

3.1.1.1 *Alien Waves*

The Dense Wavelength Division Multiplexing (DWDM) equipment must allow optical pass-through so that the signal is not converted to the electrical level. This can be achieved when the same DWDM vendor is used in the involved domains, so that there is only one DWDM hardware instance in the federated PoP. Otherwise, the DWDM has to be able to transport alien wavelengths. See *"Deliverable DJ1.2.1: State-of-the-Art Photonic Switching Technologies"* [DJ121] for further information on alien waves.

3.1.2 Switching

Switching in a federated PoP typically relies on Ethernet or OTN.

In the case of Ethernet switching, an F-PoP member can use either native Ethernet or Ethernet in its Carrier Class version (sometimes called Carrier Ethernet, but this is not a standard term) to connect to other member(s). The Carrier Class version includes additional features, such as Ethernet Operations, Administration and Maintenance (OAM) or Ethernet QoS, to allow traffic engineering and protection and restoration, as well as to support multi-domain services. Interoperability issues between different vendors are not expected when using plain Ethernet. In the case of Carrier Ethernet, Ethernet OAM and Ethernet QoS are emerging features and are being standardised by the Metro Ethernet Forum (MEF) and Institute of Electrical and Electronics Engineers (IEEE) (e.g. 802.1ag, MEF E-LMI TechSpec or MEF16 [IEEE802.1ag, MEF E-LMI TechSpec, MEF16]). The standards are supposed to be implemented by many equipment vendors, but, as with every new technology deployed in a production network, interoperability issues are expected. A detailed explanation of these features can be found in the deliverable *"DJ1.1.1: Transport Network Technologies Study"* [DJ111] from JRA1 T1.

OTN switching, on the other hand, is a technology developed several years ago and currently widely deployed. It allows the transparent transport of a client signal. The client is able to see what was transmitted, and troubleshooting is made easier. OTN also includes management features. For further information, please refer to [DS111].

3.1.3 IP Routing

Finally, due to the different needs of the F-PoP members, the IP layer may be present in the federated PoP. One or more routers may be installed.

One possibility is to make use of virtualisation technologies to slice the physical router into several virtual routers, one slice for each participating network. One domain then has to volunteer to monitor the physical router as well as its own virtual slice, while the other domains would only manage their own virtual slices. As mentioned in Section 2.2.3 above, this could be an interesting approach because of the potential cost savings.

Another option is for each member wanting to establish IP routing to install its own router in the federated PoP and then to connect with the others.

From a technical point-of-view there could be difficulties realising the policies of the domains involved, e.g. Border Gateway Protocol (BGP) routing policies, so rules and procedures should be defined.

3.2 Technical Examples of a Federated PoP

The following figures show examples of the different configuration options for a federated PoP.

Figure 3.1 and Figure 3.2 show a scenario in which different members interconnect with each other via optical equipment. All members are using equipment from different vendors in their respective networks. Figure 3.2 shows an alien wave between NREN A and NREN B. This wavelength is not converted to the electrical level when traversing the federated PoP.

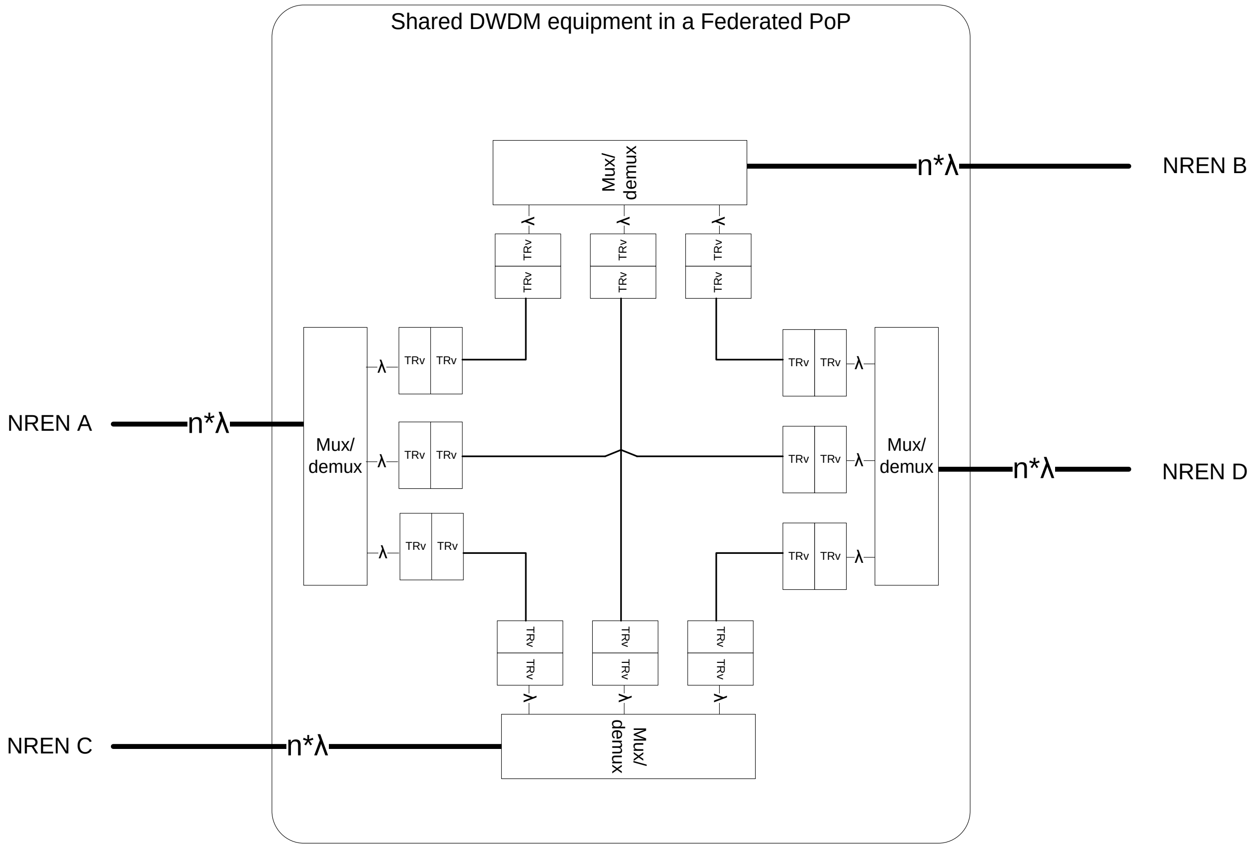

Figure 3.1: Lightweight federated PoP (optical equipment only) with 4 parties

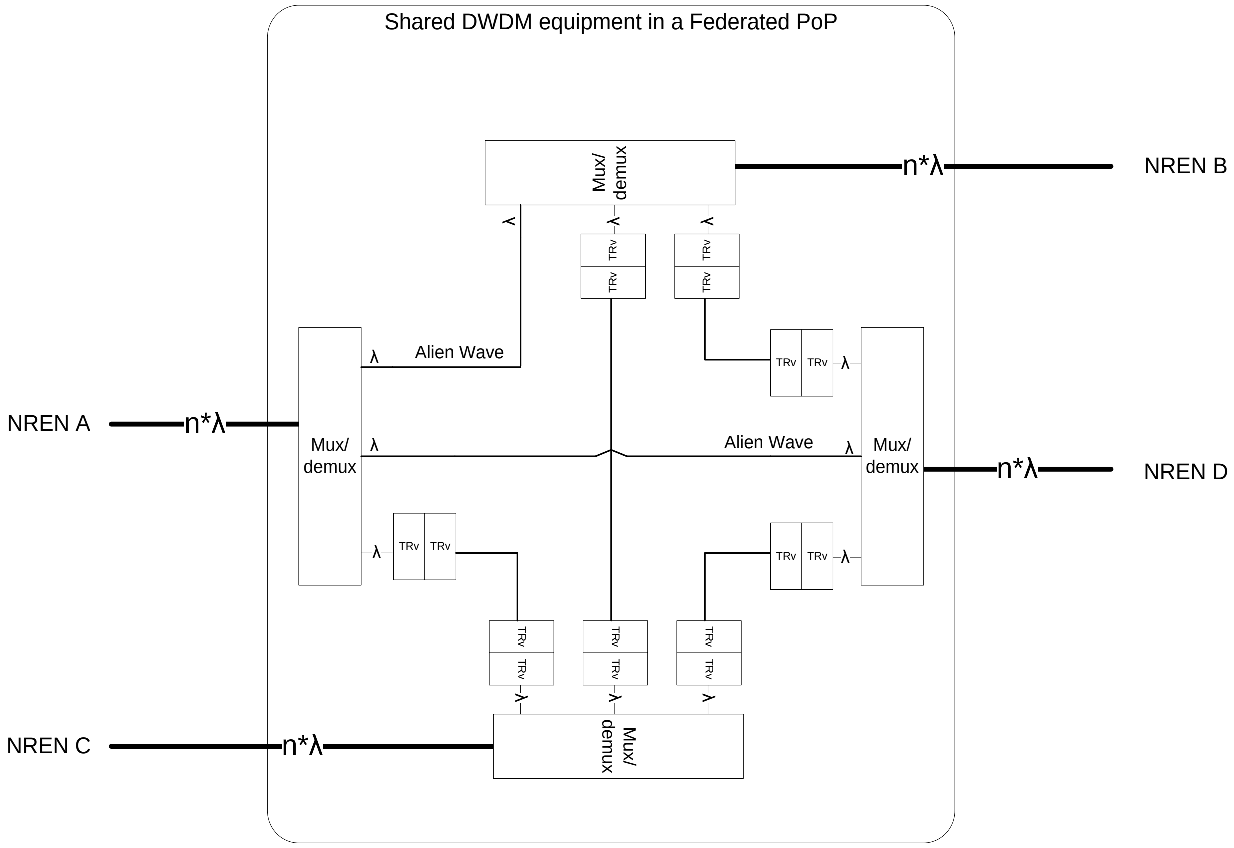

Figure 3.2: Lightweight federated PoP (optical equipment only plus alien wave) with 4 parties

Figure 3.3 and Figure 3.4 show different scenarios in which the members connect with each other via switching or routing equipment, based on all NRENs entering the federated PoP through their own DWDM equipment.

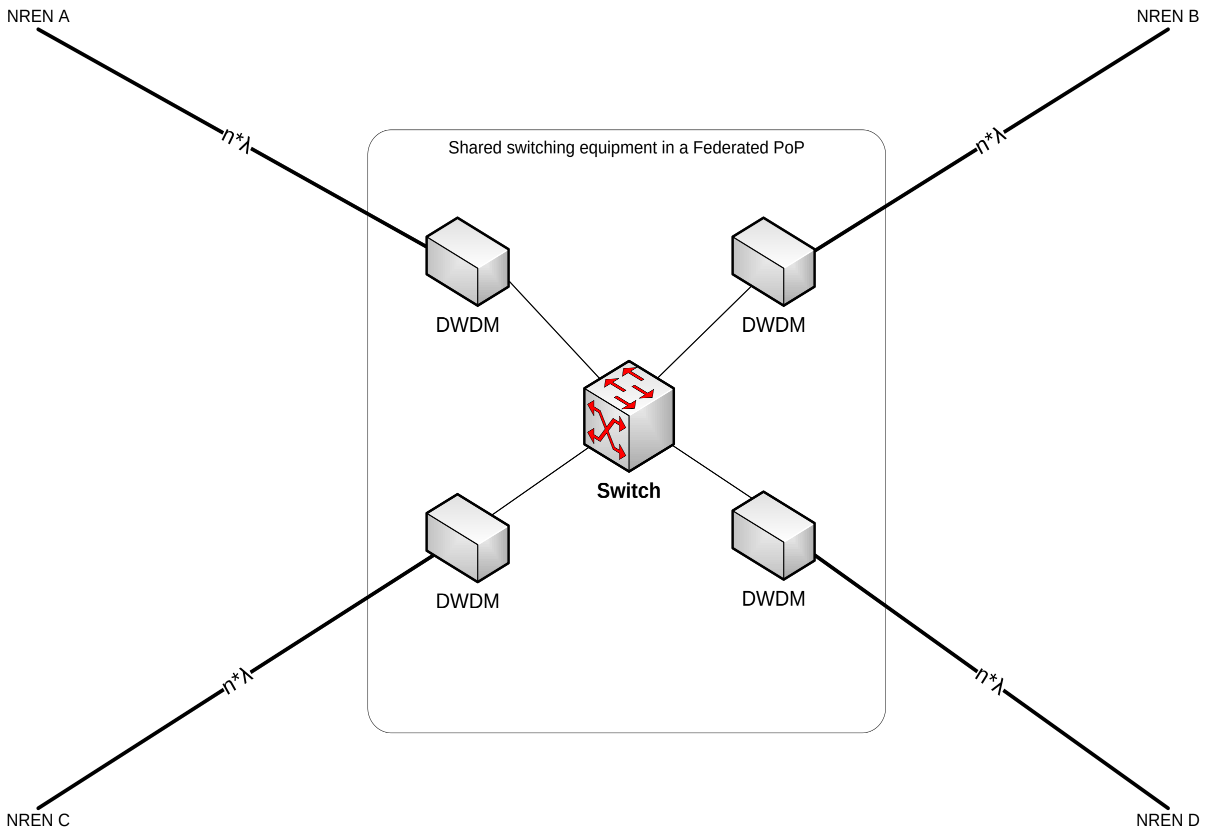

Figure 3.3: Switching federated PoP (optical and switching equipment) with 4 parties

Figure 3.3 represents a switch shared by all four NRENs, thereby reducing costs for all the entities entering the federated PoP. A less cost-effective option is to have additional switches in the federated PoP – e.g. due to the fact that two NRENs already have switches installed inside the location. When the federated PoP switches OTN, a dedicated piece of switching hardware might not be needed, as OTN switching could be performed within the optical equipment.

In addition to using owned optical equipment, it is possible that one of the NRENs comes into the PoP with a managed service, and directly connects to the switch.

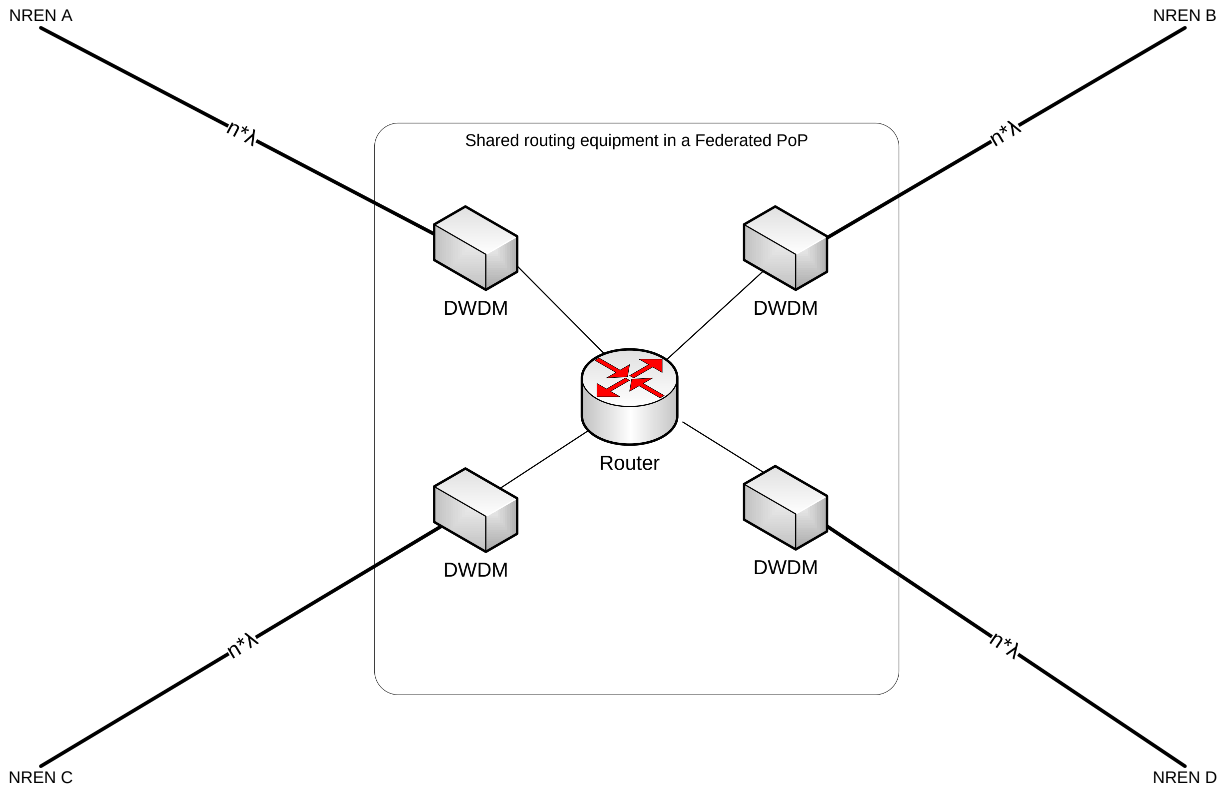

Figure 3.4: Routing federated PoP (optical and routing equipment) with 4 parties

Figure 3.4 depicts the routing scenario, based on a shared router within the federated PoP. Having more than one router in the routing federated PoP is possible; however, from a cost perspective it is not recommendeded.

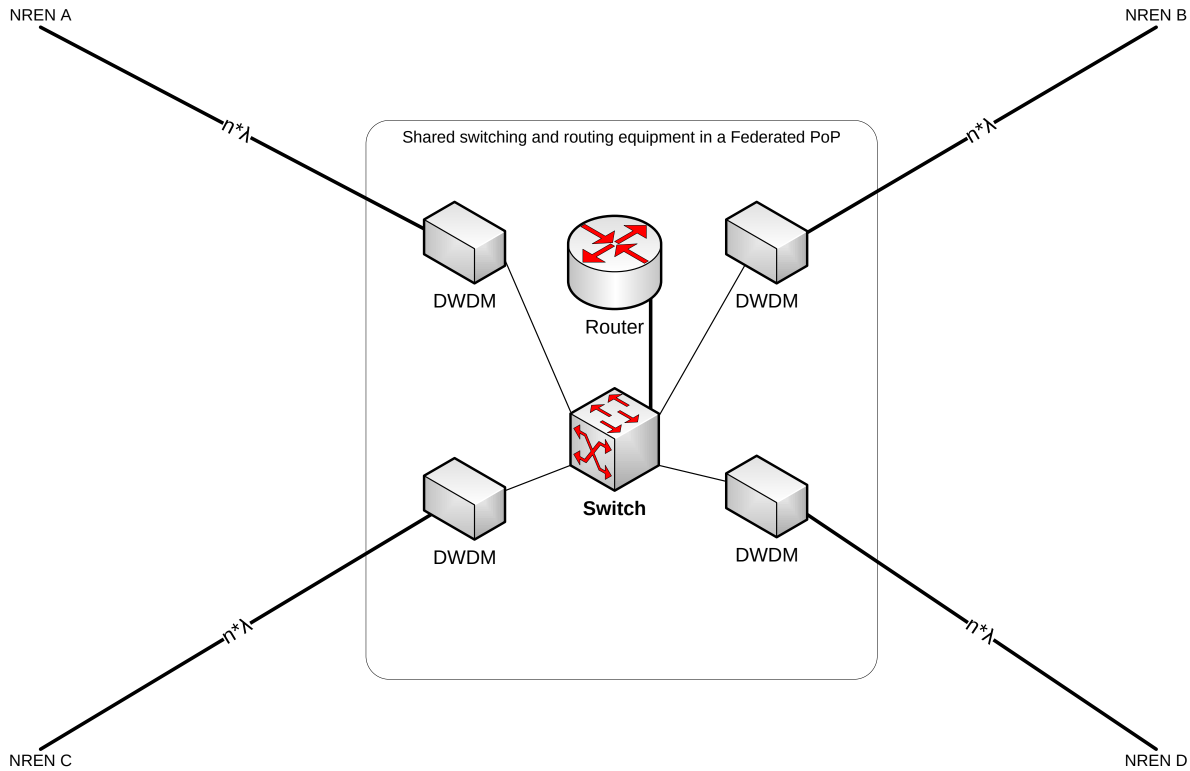

Figure 3.5: Full service federated PoP (optical, switching and routing equipment) with 4 parties

Figure 3.5 provides an example of what a full-service federated PoP might look like. Note that although the optical options from Figure 3.1 and Figure 3.2 have not been drawn, such combined services are possible inside the federated PoP.

4 Connectivity Services in a Federated PoP

The federation of a PoP is only reasonable if connectivity services are jointly offered. All connectivity services existing in each of the domains should be investigated for extension towards the other domains by using the federated PoP.

This section considers only GÉANT-related connectivity services, either those currently available or those planned for the foreseeable future. (In the work leading up to this deliverable, however, Task 3 has investigated other services too.) The section is ordered by the devices necessary to provide the services.

4.1 Services Based on DWDM Equipment

Since DWDM equipment is the common platform in the federated PoP, services based on this technology only can be regarded as a minimum of what a federated PoP can offer. It applies to all F-PoP member types, as explained in Section 3. This situation is depicted in details in Figure 3.1 and Figure 3.2 in Section 3, but DWDM equipment is also present in Figure 3.3, Figure 3.4 and Figure 3.5.

4.1.1 GÉANT Lambda Service

The GÉANT Lambda service [GSWWW, DS1322] provides dedicated wavelengths between PoPs of the GÉANT network. End users have to be connected by their local NRENs to the GÉANT PoPs in order to access the service. If GÉANT is part of a federated PoP, this service can be enabled.

4.1.2 Static Dedicated Wavelength Service

The Static Dedicated Wavelength Service has been specified by SA2 T1 in two documents: *"Service Level Specification"* and *"Infrastructure and Operational Level Agreement"* (these documents have not yet been finalised and so are currently unavailable as publicly accessible reference sources). It can be regarded as a multi-domain extension of the GÉANT Lambda Service. The service deals with so called multi-domain end-to-end (E2E) links. These links start in one domain, potentially cross intermediate domains, and end in another domain. Within each domain they are realised as dedicated wavelengths, while they are stitched together at domain borders by linking the layer 2 technologies used (e.g. Ethernet, SDH or OTN).

In the realisation inside the federated PoP, two cases have to be distinguished: If the optical hardware is shared, then the realisation is simple because an optical pass-through is possible without performing an add/drop. If different DWDM systems are involved, the traffic needs to be converted to the electrical level and then the framing on layer 2 has to be stitched together.

For running the Static Dedicated Wavelength Service the tool I-SHARe (Information Sharing across Heterogeneous Administrative Regions) is very important. It is used to manage contact information and technical interface data about all the domains involved and to keep track of the progress of operational procedures [DJ131, ISHARE].

4.2 Services Based on Switches

In the following paragraphs it is assumed that switching functionalities are realised by dedicated switching hardware. This is relevant for the “switching-only” and “full-service” member types of a federated PoP. If the DWDM hardware used includes switching functionality, then the following services can be realised by just using the DWDM hardware. Configurations where switches are included are shown in Figure 3.4 and Figure 3.5 in Section 3.

4.2.1 GÉANT Plus Service

The GÉANT Plus Service [GSWWW, DS1322] allows SDH-based connections ranging from 155 Mbps to 10 Gbps. It is realised via additional SDH devices within the GÉANT PoPs. As for the GÉANT Lambda Service, end users need to reach a GÉANT PoP via their local NRENs in order to benefit from the service.

4.2.2 Static Sub-Wavelength Service

Although GÉANT does not offer a standard Static Sub-Wavelength Service today, the service can be considered as providing a multi-domain variant of the GÉANT Plus Service using the federated PoP. This means that a certain capacity is reserved for the user end-to-end, which requires a stitching of the technologies being used by the involved domains.

While the Static Dedicated Wavelength Service has been fully specified and is ready for use, the Static Sub-Wavelength Service has not been specified yet. However, the changes required to support it are relatively easy to address, so such a service can be detailed in several months. There is only uncertainty about the user demand for it.

4.2.3 Bandwidth-on-Demand Service

The static services described above require manual intervention to establish each end-user connection. The aim of the Bandwidth-on-Demand Service defined by SA2 T1 is to realise this in an automated manner using software signalling techniques. For the signalling, a common protocol, the Inter-Domain Controller (IDC) protocol, has been defined. It has been implemented by the GÉANT AutoBAHN software (Automated Bandwidth Allocation across Heterogeneous Networks) [AutoBAHN] and in ESnet's OSCARS (On-Demand Secure Circuits and Advance Reservation System) [OSCARS]. The level on which the software signalling happens is the same as for the Static Sub-Wavelength Service. This way of realising the connection is desirable from the users' and operators' point of view, but requires some effort to set up the service. Here again the stitching of technologies plays an important role.

In summer 2011 a prototype phase for the service will be carried out where bandwidth-on-demand (BoD) connections are established between NREN Network Operations Centres (NOCs). Later it will be decided how to extend the service in the direction of the end users.

As a support tool for the BoD service the common Network Information Service (cNIS) [CNIS] is important. It contains the topology of a domain that is used for constructing the BoD path through the network.

4.3 Services Based on Routers

When routers are installed at a federated PoP, IP services can be realised. This is relevant for the "router-only" and "full-service" member types of a federated PoP. Since these services are well-established as multi-domain services there is no need to differentiate between GÉANT-only and multi-domain variants. Configurations where routers are included are shown in Figure 3.4 and Figure 3.5 in Section 3.

4.3.1 IP Service

IP services are offered today in GÉANT [GSWWW, DS132] and all NRENs. It is therefore highly desirable that IP communication from the federated PoP is realised into all connected networks.

From a technical point of view there is a difficulty with realising the policies of the domains involved, e.g. BGP routing policies. One possibility is to make use of virtualisation technologies to slice the physical router into several virtual routers, one for each participating network. One domain then has to volunteer to monitor the physical router as well as its own virtual slice, while the other domains would only manage their own virtual slices.

In addition to the IP Service, the establishment of Multi-Protocol Label Switching (MPLS) tunnels over the federated PoP can be considered. However, the use of MPLS as a single-domain technology is quite limited, so the demand for these tunnels in a multi-domain environment is expected to be even more limited.

5 Operation of a Federated PoP

Sharing resources by several parties in a federated PoP imposes additional requirements on the operation and maintenance of the PoP. Prerequisite for the successful operation of a federated PoP are signed agreements between the host and an individual member, and agreed operational procedures. Added value can be achieved by close collaboration based on the common interests of F-PoP members. This added value represents one of the main reasons for establishing a federated PoP. Common interests can be found in infrastructure sharing and joint use of cabling, equipment (DWDM, Ethernet/IP switching or IP routing equipment), as well as human resources. Collaboration is also necessary in activities related to F-PoP operation, monitoring and maintenance. The benefits from collaboration and resource sharing include cost reduction, while the synergy that is created can bring to light new joint projects. The operation of a federated PoP can be supported by existing GÉANT tools and services. An analysis of GÉANT-related tools that might be used to support F-PoP operations can be found in *"Deliverable DJ1.3.1: Architecture Considerations for Federated Backbone Networks Study"* [DJ131]. The establishment and operation of a federated PoP must allow management of all layers of the federated network architecture model proposed in deliverable DJ1.3.1. This means that general rules for establishing the federated PoP, as well as operational procedures allowing management of services and infrastructure, should be defined.

5.1 Agreements for Establishing a Federated PoP

For successful operation of a federated PoP it is important for all parties to define, agree and sign an agreement of cooperation. Such an agreement should at least define issues such as:

- Subject of contract, such as the type of PoP, with all component elements.
- Ownership of individual elements.
- Financial obligations, if any.
- Usage rules for F-PoP premises for F-PoP members.
- Individual responsibilities, as well as clear demarcation lines between them.

In addition, each pair of members that are exchanging traffic should also agree (for example, through a formal contract) individual responsibilities and demarcation points.

The F-PoP host defines admission rules for the federated PoP i.e. who is allowed to become an F-PoP member. (Where the F-PoP host is not the F-PoP owner, such rules should be compatible with any internal rules defined by the F-PoP owner). However, traffic exchange between individual members within the federated PoP depends upon the members themselves, and does not have to be determined or influenced by the F-PoP host. A similar rule applies to the services that can be provided to or used by the F-PoP member. One member can participate in all services, or in some of them. Terms of use and participation for each F-PoP member have to be agreed with the service owner (the party that is responsible for the service).

In the case of a GÉANT federated PoP, each NREN will have to formalise its relationship with DANTE in order to be able to connect to the GÉANT network. With regard to services that are provided jointly by several parties, operations level agreements related to those services should be signed by all involved F-PoP members.

In the case of an IXP, the home party signs an agreement with the individual Service Provider (SP) regarding terms and conditions of F-PoP admission, and individual SPs have to reach agreement (with or without formal contract) regarding traffic exchange.

5.2 Operational Procedures

Once the federated PoP has been established, all involved parties have to be aware of the rules and procedures that must be followed in order to be able to successfully provide or receive a service. Some of them are unilaterally defined (for example, procedures for admittance to the F-PoP premises, including guidelines on how to behave in the premises, fire protection and avoidance procedures and so on), and some of them can be bi-laterally or even multi-laterally defined (for example, procedures that cover interconnectivity issues, alarms regarding network maintenance and others).

Each F-PoP party – host or individual member – will probably have some or all of those documents already. The only change in the case of a federated PoP is that those documents should be adapted and shared with another party that is participating in the federated PoP.

The set of operational procedures should, as a minimum, cover the following:

- Admittance to the F-PoP premises – who can access the F-PoP premises when, why and how.
- Maintenance of F-PoP premises – rules, roles and responsibilities for each party.
- Establishment of new components – new cabling, equipment or connections.
- Scheduled maintenance – timeframe, information channels and forms (sms, email, phone, contact numbers and addresses).
- Unscheduled maintenance – information channels and forms, possible exceptions to regular situations (for example, admittance to F-PoP premises, if not covered elsewhere).
- Connection termination – when, how, individual steps by relevant member, information channels and forms, and so on.
- Operational databases and infrastructure best practice – standards and procedures to ensure that operational databases describing the installations (rack locations, slots, distribution frames, patch cables, etc.) accurately reflect the reality, and that the NOC's infrastructure conventions are complied with in the build.

For each F-PoP member, such procedures regarding the federated PoP should be harmonised with internal procedures. For example, an F-PoP member should not commit to maintenance-window hours that are outside its employees' normal working hours. Additional procedures can introduce extra overheads and administrative work. It is therefore of vital importance to align F-PoP processes with individual F-PoP member processes as much as possible.

A network's operational productivity depends to a significant degree on the standardisation and uniformity of its PoPs, which typically follow a common building plan. Since that plan will vary from network to network, the advantage of uniformity could be lost in a federated PoP for all networks except the F-PoP owner or host. The federated PoP's standards and procedures should acknowledge this, and try to minimise or mitigate the impact.

5.2.1 Communication Model for F-PoP Operation

For the successful operation of a federated PoP, it would be useful for one member to take a coordinating role in relation to all F-PoP members. Although it may seem logical for the F-PoP host or home NREN to take such a role, the F-PoP parties can elect another member to coordinate all the actions needed for successful operation of the federated PoP. In the case of GÉANT, either the home NREN or DANTE could take the role. However, in situations where the F-PoP host is not the owner of the F-PoP premises, it is the role of the F-PoP host to coordinate activities with the owner of the F-PoP premises.

It is recommended that this coordinating function be carried out through the role of "F-PoP operator". One way that communication can then be performed is through the F-PoP operator, as shown in Figure 5.1. Each F-PoP member will state their needs, or direct their announcements, through the F-PoP operator, who will further distribute these to other members, or solve the issue, as appropriate.

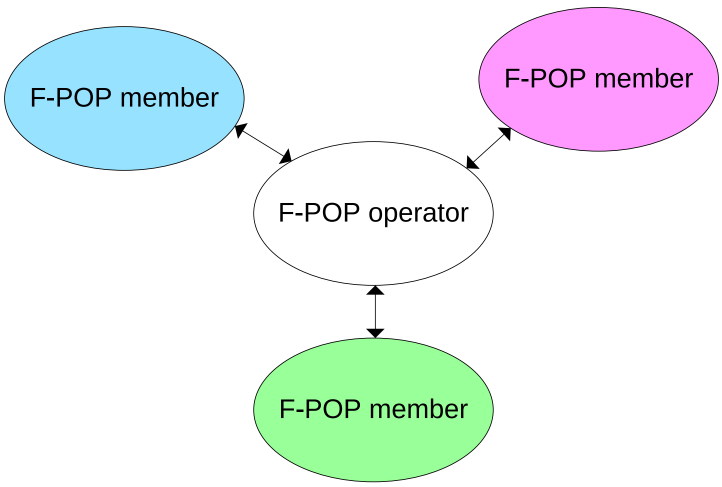

Figure 5.1: Communication model for operations in the F-PoP – F-PoP operator

Such a model corresponds to the federated network architecture Model A [DJ131], in which all communication is performed through the management layer.

As stated above, the F-PoP operator may, but does not have to be from the F-PoP host party. Figure 5.2 below shows the variant communication model for situations where the F-PoP host a) is not the owner of the F-PoP premises but takes a coordinating role towards the owner, and b) does not take the role of the F-PoP operator.

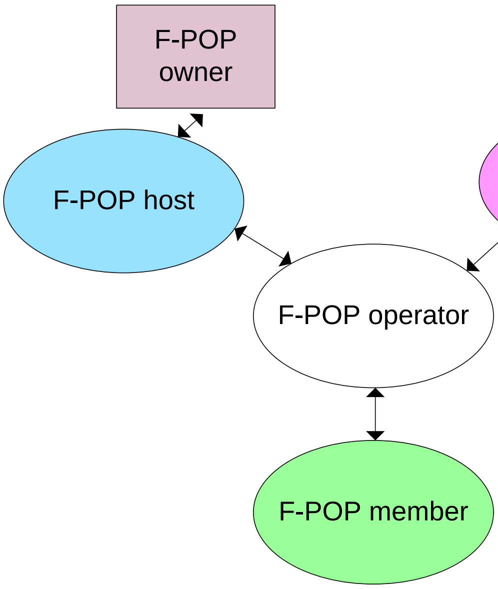

Figure 5.2: Communication model example with the F-PoP host and F-PoP owner

Another approach is to form an F-PoP operating team, consisting of individual F-PoP member representatives, and to include a coordinator for this team (selected either from the F-PoP coordinating member or from the F-PoP operating team), as shown in Figure 5.3. In this case, all communication will be performed through such a team (through mailing lists and/or collaboration tools). A similar model is being proposed for the operation of the Bandwidth-on-Demand Service currently being defined in SA2 T1, where support teams located in each NREN collaborate to operate joint support services and create virtual teams (e.g. joint service desk).

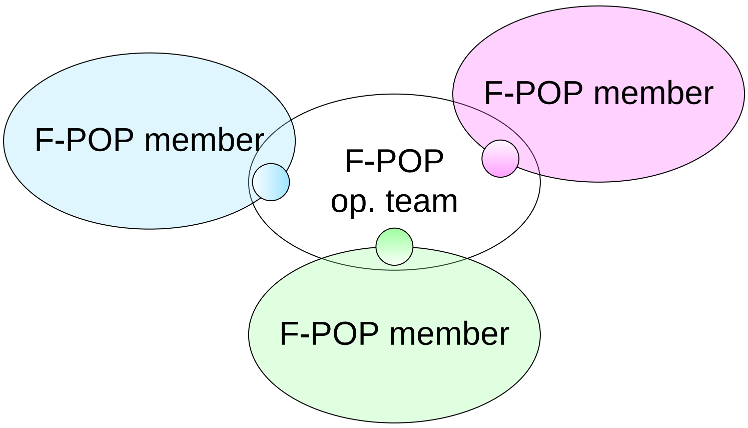

Figure 5.3: Communication model for operations in the F-PoP – F-PoP operating team

This model corresponds better to the federated network architecture Model B [DJ131], which assumes multiple communication channels for the sake of faster and more efficient operation.

The first approach can be useful when the federated PoP is being established and where the F-PoP host, acting also as F-PoP operator, serves as a single point of contact for new F-PoP members. However, since collaboration and joint services are the main characteristics that distinguish the federated PoP from a multi-domain PoP, it is expected that the second approach will bring more benefits and bring the federated PoP closer to its goals.

In the case of the GÉANT network, each NREN selects one or two representatives to the Access Port Manager (APM) team, which is coordinated by DANTE. For the purpose of a federated PoP, the APMs can, but do not have to, act as the F-PoP representative of an individual F-PoP member.

In the case of provisioning services using GÉANT tools, communication between parties is determined by and specific to the tool (e.g. in the operation of the Bandwidth-on-Demand Service, AutoBAHN instances communicate directly with each other). However, when special intervention is needed from the F-PoP owner, one of the above communication models can also be used to send a notification from a particular F-PoP member to the F-PoP owner. As mentioned above (see Section 4), GÉANT tools that could potentially also be used in a federated PoP to provide services are: iSHARE [ISHARE], cNIS [CNIS], and AutoBAHN [AutoBAHN].

The multi-domain nature of the connectivity services that can be jointly provided by the F-PoP participants makes it important to have clear demarcation points. F-PoP equipment that can be shared by several participants will have to be assigned to the domain of one of the parties (and agreed among the sharing F-PoP participants). Alternatively, it could be a separate domain, but that introduces additional overheads related to the operation of such a domain, which could increase the overall cost of the federated PoP.

5.3 Maintenance and Monitoring

Maintenance of the federated PoP includes maintenance of the physical location, individual members' cabling and equipment, and the infrastructure services that are provided over the physical infrastructure.

Maintenance of the F-PoP premises should be defined within the operational procedures, probably by the host. It is possible that individual F-PoP members will be able to influence minor changes to those procedures. However, there is unlikely to be scope for them to influence bigger and/or frequent changes. This is because an existing PoP that is to become a federated PoP will probably already have maintenance rules in place, based on physical and environmental conditions on the one hand and PoP requirements on the other, which will not permit significant changes.

Maintenance of individual members' cabling and equipment can be done in two ways: each F-PoP member can be responsible for the management and maintenance of its own property, or some or all of the members can engage a proxy to perform those tasks for them. The role of proxy can be taken by the host, or by one of the F-PoP members. In the case of a proxy, all parties will have to agree on costs as well as rules and the responsibilities of each party.

Regarding the maintenance process, a distinction should be made between planned maintenance (with the definition and announcement to other parties of scheduled maintenance time and windows) and unplanned maintenance. Unplanned maintenance is not desirable, but is unfortunately unavoidable for any production network. In the case of unscheduled maintenance, special care should be taken in defining communication channels and points of contact for all parties.

5.3.1 Monitoring

Monitoring of a federated PoP includes monitoring all the physical components of each individual party. It is likely that each party will already have its own monitoring system. In the case of joint use of installations, equipment and services, it is highly recommended to have information about the infrastructure elements within the domains of other F-PoP members. For this purpose, interfaces between individual monitoring systems should be defined, in order to exchange important information between members. The challenges presented by the realisation of such interfaces will depend on the structure and openness of individual monitoring solutions, as well as on F-PoP members' company policies.

During the GN2 project, the development of a new tool suite for multi-domain monitoring was started. This tool suite, called perfSONAR (Performance Service-Oriented Network Monitoring Architecture) [perfSONAR], is used to build an infrastructure for network performance monitoring. Its development and implementation within GN3 is covered by SA2.

More precisely, of the perfSONAR services and visualisation tools, the following ones are interesting. For monitoring instances of the Static Dedicated Wavelength Service, the End-to-End Monitoring System (E2EMon) tool is relevant because it gives a view on E2E links by composing information from each DWDM management system involved. The tool can be extended in the future to deal with sub-wavelength services, including both the static and dynamic ones. If the federated PoP includes IP routing, then several other perfSONAR services become relevant, such as the Round Robin Database Measurement Archive (RRD MA) to monitor link utilisation, interface errors and output drops. Furthermore, a HADES Active Delay Evaluation System (HADES) measurement box can be put into the federated PoP to enable active measurements from and to the PoP in order to measure delay, jitter, packet loss, trace routes and available bandwidth. Concerning visualisation, the federated PoP should be included in installations of the customer network management application WebCNM, a network weathermap tool offered in addition to perfSONAR. For troubleshooting in the context of the federated PoP and the services run on it, perfsonarUI is highly relevant. This tool directly accesses the perfSONAR tool to display measurement results.

Although perfSONAR was developed with the intention of solving, or helping to solve, end-to-end performance problems on paths crossing several networks, implementation just within the federated PoP can be useful to understanding other domains' crucial F-PoP elements. Such a tool might also be appropriate for use in IXP cases, involving at least next-hop neighbouring devices within the federated PoP.

The experiences and tools of eduPERT, developed within the GN2 project, can be very useful for the effective and efficient operation of the federated PoP, for finding and correcting performance problems either within the federated PoP or for issues that originate or end in any part of the network that passes through the federated

PoP or affect parties that are members of the federated PoP. More information about eduPERT findings, tools and experiences can be found on the eduPERT website [eduPERT], as well as in deliverable DJ1.3.1 [DJ131].

Multi-domain monitoring can be installed and used by F-PoP members to give added value to the F-PoP operation. It is also desirable to explore and realise the potential (if any) for integrating the multi-domain monitoring tool with the existing network monitoring system of an F-PoP member. Such integration is important in order to make the operation of an individual F-PoP member more efficient. Otherwise, having two separate monitoring systems to maintain, operate and monitor might add overheads to their everyday operations.

6 Conclusions

This deliverable has discussed the concept of establishing a federated PoP from a comprehensive set of aspects. The motivation for considering the creation of federated PoPs is the possibility of offering connectivity services in a multi-domain manner via the federated PoP and of achieving a cost reduction in comparison to having separate PoPs run by different NRENs in the same city. The details of the motivation have been examined, to show under which conditions it can be particularly beneficial to establish a federated PoP.

When a federated PoP is planned, there are many possibilities for constructing it. Usually each NREN participates at a federated PoP with its own DWDM equipment. It is certainly also possible that two or more NRENs share DWDM equipment, or that an NREN connects to the federated PoP via a managed service without an owned DWDM device on site. Furthermore, switching and routing equipment can be installed at the federated PoP in a shared or separate manner. These hardware-related decisions are strongly related to the services that can be realised via the federated PoP. In particular, the realisation of newly defined multi-domain connectivity services by SA2 T1 plays an important role here.

The discussion on services in this deliverable has been limited to connectivity services. In addition, the federated PoP could also contain servers for application hosting. For example, a Domain Name System (DNS) server could be operated in a joint manner. It is useful to consider running such servers as virtual servers (e.g. via VMware [VMWARE]).

The operational aspects of running the federated PoP are potentially complex, particularly in terms of management and monitoring. It has to be taken into account that each participating domain has its own operational procedures and tools. Collaboration is therefore not straightforward, and care is required when defining the operational framework to ensure that the federated PoP does not have a negative effect on operation and overall performance compared with the previous network infrastructure.

The JRA1 T3 members have not yet applied these considerations to a concrete use case, which was suggested in the Technical Annex as an optional element of this deliverable. Several scenarios have been discussed as potential candidates throughout Y2. However, the situations where federated PoPs may be applicable have been at too early a stage to base a use case on them. JRA1's plans for Y3 include developing a detailed proof of concept of a Multi-Domain Junction Test Facility in a realistic case, which will be used by T3 for evaluating all aspects of the federated PoP. The case under evaluation should provide an example of a multi-domain architecture involving GÉANT and a limited number of NRENs interconnected via cross-border fibre. The proposal to engineer a Test Facility built as a Federated Dynamic Optical Light Exchange has been approved by the GN3 management team; the Facility will benefit a number of other GN3 Activities in addition to

JRA1 (for whom it will be of benefit to all four Tasks), particularly those such as SA1, SA2, JRA2 and JRA1 T4 to which T3's work is closely related, to the advancement of the areas of common interest as well as their individual objectives. The architecture and functionalities of the Test Facility will be discussed and agreed with the SA1 Activity before implementation.

The proof of concept work will help to identify any further aspects and considerations that should be taken into account when setting up a federated PoP, in addition to those described in this report, including particular problem areas, and to identify more solutions to the issues raised here. It will also allow T3 to confirm the extent to which the federated PoP will deliver the expected benefits of improved services and cost reductions, and help to meet the aims and challenges key to the success of the European NRENs and of GÉANT.

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Glossary

APM	Access Port Manager
AutoBAHN	Automated Bandwidth Allocation across Heterogeneous Networks
BGP	Border Gateway Protocol
BoD	Bandwidth on Demand
CAPEX	Capital Expenditure
CBF	Cross-Border Fibre
cNIS	Common Network Information Service
DNS	Domain Name System
DWDM	Dense Wavelength Division Multiplexing
E-LMI	Ethernet Local Management Interface
E2E	End-to-End
E2EMon	End-to-End Monitoring System
EoMPLS	Ethernet over Multi-Protocol Label Switching
F-PoP	Federated Point of Presence
GN3	The current GÉANT project
HADES	HADES Active Delay Evaluation System
IDC	Inter-Domain Controller
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
I-SHARe	Information Sharing across Heterogeneous Administrative Regions
ISP	Internet Service Provider
IXP	Internet Exchange Point
JRA	Joint Research Activity
JRA1	GN3 JRA 1 Future Network
JRA1 T1	JRA1 Task 1 Carrier Class Transport Network Technologies
JRA1 T2	JRA1 Task 2 Photonic Switching and Experimental Photonic Facilities
JRA1 T3	JRA1 Task 3 Federated Network Architectures
JRA2	GN3 JRA 2 Multi-Domain Network Service Research
JRA2 T1	JRA2 Task 1 Control and Management
JRA2 T3	JRA2 Task 3 Monitoring
JRA3	GN3 JRA 3 Multi-Domain User Application Research
L1	Layer 1
L2	Layer 2
LAN	Local Area Network
MEF	Metro Ethernet Forum

MPLS	Multi-Protocol Label Switching
NOC	Network Operations Centre
NREN	National Research and Education Network
OAM	Operations, Administration and Maintenance
OPEX	Operational Expenditure
OSCARs	On-Demand Secure Circuits and Advance Reservation System
OTN	Optical Transport Network
perfSONAR	Performance Service-Orientated Network Monitoring Architecture
PERT	Performance Enhancement Response Team
PoP	Point of Presence
QoS	Quality of Service
RRD MA	Round Robin Database Measurement Archive
SA	Service Activity
SA1	GN3 SA1 Network Build and Operations
SA2	GN3 SA 2 Multi-Domain Network Connectivity Services
SA2 T1	SA2 Task 1 Multi-Domain Network Connectivity Services Development
SA2 T2	SA 2 Task 2 Multi-Domain Service Coordination & Operations
SA2 T3	SA 2Task 3 Monitoring and Performance
SA3	GN3 Service Activity 3 Multi-Domain User Applications
SA4	GN3 Service Activity 4 Software Governance
SDH	Synchronous Digital Hierarchy
SLA	Service Level Agreement
SP	Service Provider
TNC2010	TERENA Network Conference 2010
UI	User Interface
UPS	Uninterruptible Power Supply
WebCNM	Web Customer Network Management