The New Dawn of Network Architecture

Summary of GN3 JRA1 Future Network year 1 achievements and results, including a possible outlook for a future NREN and GÉANT architecture

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Abstract

The first year of the GÉANT3 project has identified topics that JRA1 consider to be important for the research community in order to realize a visionary GÉANT and NREN future network to support future networking. Some might even say it represents a new dawn for backbone transport, switching and routing technologies. This report provides an overview JRA1 T1 Carrier Class Transport Network Technologies are presenting the initial findings of a study of Carrier Class Transport Network Technologies (CCTNT). JRA1 T2 State-of-the-Art Photonic Switching Technologies, investigates state-of-the-art and emerging optical networking technologies in order to determine how GÉANT and the NRENs can develop their networks to meet future demands. JRA1 Task 3 Federated Network Architectures are conducting an investigation into network federation, i.e. sharing resources among multiple independent networks. JRA1 T4 Current and Potential Uses of Virtualisation are presenting the results of an initial comparative study of existing infrastructure virtualisation technologies and frameworks. The discussion then turns to current technologies and architectural trends, covering both single- and multi-domain network architectures. Leading to a discussion about Optical Transport Networking and next generation OTN, which is the new big thing in backbone transmission evolution. Building on the topics discussed, the “new dawn of network architectures” are presented covering single- and multi-domain network architectures. The report closes by arguing for a potential future GÉANT Network Architecture, which also encompasses the potential of a federated network infrastructure.
2 Introduction

Leveraging network assets to deliver a compelling array of innovative services to the National Research and Education Network (NREN) community and ensure a superior user experience requires optimisation of the network infrastructure. An all-optical network infrastructure is one or even two decades out on the horizon.

Right now there is a shift towards creating a converged backbone of high-leverage networks which will optimise optics and IP in a cohesive fashion. The trend is towards a closer integration of IP, packet and Time-Division Multiplexing (TDM) technologies together with an optical transport network, offering significant opportunities for reducing costs and increasing network efficiency.

This report provides a summary of current GN3 Joint Research Activity 1 Future Network (JRA1) Tasks and their respective deliverables, which address:

- Carrier Class Transport Network Technologies.
- Photonic Switching and Experimental Photonic Facilities.
- Federated Network Architectures.
- Current and Potential Uses of Virtualisation.

The focus then turns to current technologies and architectural trends, covering both single- and multi-domain network architectures.

This leads to a discussion about Next-Generation Optical Transport Networking (NG-OTN) as a re-emerging transport architecture in the transmission layer. It has become clear that OTN will be a major focus area in the digital and analogue backbone transmission evolution for both the commercial and NREN community.

Building on the topics previously discussed, the "new dawn of network architectures" are presented in detail, again covering both single- and multi-domain network architectures.

The paper closes by projecting the new architecture approach towards federated network architectures.
3 Carrier Class Transport Network Technologies

This section is a summary of the JRA1 Task 1 Carrier Class Transport Network Technologies deliverable [DJ1.1.1] presenting the initial findings of a study of different transport network technologies that meet the criteria of Carrier Class and that fall within the scope of JRA1 T1 as a research activity, i.e. they are either new technologies, or new developments in well-established technologies.

It defines Carrier Class Transport Network Technologies (CCTNTs) and establishes their background:

- their evolution from Plesio-synchronous Digital Hierarchy (PDH) through Synchronous Optical Networking / Synchronous Digital Hierarchy (SONET/SDH) and Optical Transport Networking (OTN) to next-generation networking;

- the challenge presented by data traffic and by the National Research and Education Networks’ (NREns’) environment and experience;

- the benefits and motivations for using CCTNT;
  
  - the key concepts and requirements
  
  - data traffic, functionality (especially Quality of Service (QoS) Control plane protocols such as Generalised Multi-Protocol Label Switching (GMPLS))

  - research networking

  - cost – that qualify a transport network technology as Carrier Class.

It then outlines the ways in which a set of representative technologies deliver those requirements, and reports on their standardisation status.

JRA1 T1 has defined CCTNTs as technologies designed to provide transport for network services and protocols. Carrier Class denotes that the technologies are extremely reliable, support a wide range of speeds up to the current industry maximum, and are well-tested and proven in their capabilities.

A transport network technology must meet the following criteria to qualify as a CCTNT:
• Effectively support diverse types of traffic such as the elastic traffic of data applications and time-sensitive multimedia traffic.
• Effectively support all popular customer services such as Internet access, Virtual Private Networks (VPNs), Voice over IP (VoIP), IPTV and others.
• Be manageable by providing diverse and feature-rich Operations, Administration and Management (OAM) functionality.
• Be reliable by providing resilience and fast restoration for transport connections.
• Be scalable to support numerous customer connections through a carrier network.
• Be able to provide Quality of Service (QoS) and bandwidth guarantees when necessary.
• Provide separation of customer and provider networks in terms of operation and configuration parameters such as address spaces, connection IDs and others.
• Be cost-effective. This is a major requirement for service providers. Network costs are extremely high and a good argument for service providers to change their legacy technologies is the ability to provide better and more flexible services at the same or, if possible, lower cost.
• Deliver high bandwidth and performance up to the current industry limit (i.e. up to 40 G today and up to 100 G in the nearest future).
• Conform to the appropriate standards.
• Be multi-protocol. A CCTNT should be capable of transporting any kind of customer traffic and so should support different if not all existing protocols.

Taking into account these criteria, the technologies considered are the following.

3.1 OTN and Next-Generation OTN (NG-OTN)

DJ1.1.1 provides a detailed study of OTN, covering its origins and evolution; architecture and features, particularly those that qualify it as a CCTNT.

The challenge is to address the delay sensitivities of data networking whilst utilising an OAM-rich architecture – all at ultra-high capacity. In these ways, NG-OTN symbolises not only new technology and architectural design, but also an entirely new approach to transport networking.
NG-OTN is the newest concept of converged core transport architecture, designed more for Ethernet than for telecommunications traffic, and formed of a collection of OTN standards initially written a decade ago – but being renewed by the ITU-T Study Group 15 (SG15) and to develop this technology, with input from other standards bodies. The outcome should make NG-OTN more flexible and realise its potential.

3.2 Ethernet

Ethernet as a transport technology has existed for many years. However, it was lacking some of the functionality necessary to qualify as Carrier Class. DJ1.1.1 describes recent developments in the Ethernet standards that address some of these deficiencies, namely Ethernet OAM, Ethernet QoS and high-speed Ethernet (40 GE and 100 GE).

3.3 Layer 2 Routing

The term Layer 2 Routing denotes routing protocols that are designed specifically for Layer 2 devices such as Ethernet switches. The design principles of well-known Layer 3 routing protocols (L3 being the network layer with which routing protocols are usually associated but to which they are not, in fact, exclusively bound) such as Open Shortest Path First (OSPF) or Intermediate System to Intermediate System (IS-IS) do not require major changes to work with Ethernet switches. However, the details of the protocol, for example, the format of addresses carried in routing protocol advertisements, do have to change. There are currently several initiatives that aim to develop the Layer 2 Routing protocol:

- Provider Link State Bridges (PLSB): the proprietary routing protocol from Nortel.
- Shortest Path Bridging (SPB): from the IEEE. There are two different flavours of SPB: SPB VID (SPBV) and SPB MAC (SPBM).
- Transparent Interconnection of Lots of Links (TRILL): from the IETF.

DJ1.1.1 focuses on SPBM, since it is the only protocol aimed at PBB/PBB-TE technologies, which have many more features of a Carrier Class network transport technology than plain Ethernet, at which SPBV and TRILL are aimed. It describes the design principles of SPBM, briefly considers each of the focus areas, including ongoing standardisation by the IEEE and offers observations on maturity and competition.

3.4 Synchronous Ethernet

Synchronous Ethernet is a new standard defined by ITU-T for the distribution of accurate frequency over Ethernet ports and links by the very precise control of the bit rate of an Ethernet link. DJ1.1.1 provides an introduction to Synchronous Ethernet, covering ITU-T terminology, frequency synchronisation versus time synchronisation, the concept and uses of accurate frequency, benefits and possible problems as well as features. It also explains why this technology has been presented as a CCTNT and not just as a feature of traditional Ethernet. Its status as a CCTNT is, however, still a subject of debate.
3.5 **Ethernet over Multi-Protocol Label Switching (EoMPLS)**

Ethernet over IP/MPLS (Internet Protocol/Multi-Protocol Label Switching) is one of the technologies that can be used to transport Ethernet frames over a provider’s backbone network. Although MPLS is said to be complex, it is also popular in big providers’ networks and over the years of its deployment it has proved its reliability and scalability. DJ1.1.1 provides information on developments that have occurred during recent years, particularly those defined by the Metro Ethernet Forum (MEF), in order to turn EoMPLS into a CCTNT, including the implementation of Virtual Private Wire Service (VPWS), Virtual Private LAN Service (VPLS) and Virtual Private Multicast Service (VPMS), improvements in OAM functionality, protection and restoration, and multicasting.

3.6 **Multi-Protocol Label Switching Transport Profile (MPLS-TP)**

MPLS-TP is a profile of IP/MPLS designed to meet transport network operational requirements. It takes key elements from IP/MPLS such as MPLS / Pseudowire Emulation Edge to Edge (PWE3) architecture and forwarding mechanisms, and, optionally, GMPLS control plane, and provides additional functionality such as performance monitoring, OAM, Tandem Connection Monitoring (TCM), protection switching and ring protection. DJ1.1.1 presents the background to MPLS-TP, including its evolution from its initial form to the ITU-T's development of T-MPLS, describes its characteristics and requirements, architecture and main capabilities, and tries to provide a snapshot of the ongoing standardisation work being carried out by a joint ITU-T and IETF working team.

3.7 **Provider Backbone Bridge Traffic Engineering (PBB-TE)**

Provider Backbone Bridge Traffic Engineering (PBB-TE) is the third (and latest) standard developed by the IEEE with the aim of giving providers a Layer 2 carrier-grade transport based on classical Ethernet, a.k.a. Carrier Ethernet Transport (CET). The first two technologies of the CET family are Provider Bridges (PB) and Provider Backbone Bridges (PBB). As PBB-TE re-uses some features of PB and especially of PBB, DJ1.1.1 provides a brief description of these technologies before describing the features, capabilities and limitations of PBB-TE itself, and offering observations on its maturity, competitors and applicability.

3.8 **Industry Focus Areas**

One of the current focus areas for the parties involved in developing these technologies is the implementation of features that were present in legacy technologies but which are missing, either completely or partly, from the most recent technologies. Such features include OAM functionality, protection and restoration mechanisms, and the possibility to operate with or without the control plane. Other focus areas are cost-effectiveness, environmental impact, and the integration of all the technologies within seamless network architecture, there being a marked design tendency towards convergence, cross-layer capability and flat networks. For these reasons, the study’s assessment of most of the technologies has focused on the following areas. (Some of the
technologies did not fit precisely into this structure because of their different features, degree of maturity, and amount of available documentation or extent of standardisation.)

- Features:
  - Quality of Service (QoS).
  - Protection and restoration.
  - Operations, Administration and Maintenance (OAM).
  - Multicasting.
  - Control plane protocols (including GMPLS).
  - Multi-domain services.
  - Standards.
  - Scalability and manageability.
- Applications.
- Cost-effectiveness.
- Standardisation.

3.9 Summary

DJ1.1.1 ends with a summary comparison of the CCTNTs’ functionality, and concludes that, in the opinion of the JRA1 Task 1 team, all of the technologies described in the document are of potential interest to the research networking community. It is the intention that the report [DJ1.1.1] will help the community to understand the strengths and weaknesses of each one. DJ1.1.1 does not single out any of the technologies as “the best”, does not create any ranking of the available technologies, and does not provide any simple tips for selecting a technology.

Instead, it provides information about them all and allows the reader to decide which one is the best for their network. The question of which technology is the most suitable for future networks is not addressed as the answer depends on each NREN’s particular needs, which in turn depend on many factors such as type of organisation, type of services delivered, skill set of the operations staff, legacy network and services, etc. However, it is expected that this report [DJ1.1.1] will provide the information necessary to help organisations select the most appropriate technology, given their respective needs.

The study focuses on new technologies, or new aspects and improvements of mature technologies, many of which are still in the process of being developed and standardised. It is likely that some of the information it presents will change in future, or new information become available that could have been of major relevance to the study. DJ1.1.1 therefore provides only a snapshot of the current situation, with indications of where the technologies are heading; it is anticipated that any additions or changes will be reflected in JRA1 Task 1’s future work.
Photonic Switching and Experimental Photonic Facilities

This section is a summary of the JRA1 Task 2 Photonic Switching and Experimental Photonic Facilities deliverable [DJ1.2.1] investigating state-of-the-art and emerging optical networking technologies in order to determine how GÉANT and the NRENs can develop their networks to meet future demands.

During the last decade, NRENs have built and are continuing to build their own Dense Wavelength Division Multiplexing (DWDM) networks in order to meet the increasing demands of their users for dedicated, high-capacity and high-quality services. In order to address both capacity and quality issues, optical networking technologies have been and are the first choice for building a robust and scalable transport network.

Since there are many principles of optical signal amplification, the overview of optical networking technologies concentrates on the four generally used types: rare-earth doped fibre, semiconductor, Raman and parametric. DJ1.2.1’s survey of photonic fibre switches considers whole fibre capacity and the switching of bands rather than the switching of individual wavelengths, and addresses the principles of photonic switching rather than the construction principles of switching networks. The discussion of wavelength counts and bands covers:

- The successively defined transmission windows.
- The broadening transmission spectrum.
- Capacities.
- Wavelength Division Multiplexing (WDM) grids and channel-, frequency- and wavelength-calculation formulae.
- Increasing the wavelength count (by increasing the number of channels and/or increasing the bandwidth for each channel).
DJ1.2.1’s study of Optical Add/Drop Multiplexers (OADMs) addresses the adding or dropping of wavelength channels (lambdas) in WDM systems using either automated lambda processing or simple optical filter devices offering static add/drop capability, together with tunable filters, Photonic Integrated Circuits (PICs) and Optical-to-Electrical-to-Optical (OEO) conversion. DJ1.2.1 also discusses transponders, the main transmitting and receiving devices for optical transmission systems, covering 10 G, 40 G and 100+ G technology reviews; regeneration techniques; Forward Error Correction (FEC); and the basic modulation methods and formats behind signal coding. In addition it also considers the use of alien wavelengths via DWDM systems in the context of Cross-Border Fibre (CBF).

Circuit switching based on wavelength granularity is well established in optical networks, but the need for high-performance switching of finer granularities is driving Optical Packet Switches (OPS) and Optical Burst Switching (OBS), two of the optical processing techniques investigated by JRA1 Task 2 and reported in DJ1.1.1. OPS provides the finest switching granularity; OBS combines the best characteristics of coarse-grained optical wavelength switching and fine-grained optical packet switching, while avoiding their deficiencies. In addition it also considers light-trails, which can be considered as an alternative optical transport technology (OBT variant) able to broker the bandwidth between multiple nodes on the same wavelength.

DJ1.2.1 also discusses circuit-switching networks, where data is delivered through a dedicated pipe between the source and destination in the network. The granularity of the circuit and the circuit’s life-time are the two main parameters that can be used to classify different types of circuit-switched network (SCN) into a Synchronous Digital Hierarchy (SDH) network and a Dynamic Switched Network (DSN).

The discussion includes Hybrid Network Architecture, which combines the best of packet- and circuit-switched worlds, and the two types of all-optical wavelength conversion, which are one of the main building blocks for creating wavelength-convertible networks.

Multi-domain networks feature in the study because the absence of geographical boundaries in scientific research means that isolated innovation in the provision of network services – in the area of lambda-networking, for example – does not make sense. International, inter-domain connections are therefore essential. Within this context, the use of alien (or foreign) wavelengths via DWDM systems from different vendors is an appealing concept. However, there is a variety of challenges that complicate the application of alien wavelengths in multi-domain DWDM networks, particularly system performance, interoperability testing and Operations, Administration, Maintenance and Provisioning (OAM&P).

DJ1.2.1 goes on to address impairment-aware control plane considerations, including the main standardisation efforts for control plane architectures, protocols and interfaces, and the initial contribution towards impairment-aware (IA) control plane solutions. It discusses impairments on transparent optical networks, such as:

- Polarisation Mode Dispersion (PMD).
- Amplifier Spontaneous Emission (ASE).
- Polarisation-Dependent Loss (PDL).
- Chromatic Dispersion (CD).
- Crosstalk (XT).
- Non-linear impairments and other impairment considerations.
It also discusses monitoring solutions that can be used to provide real-time optical impairment information to IA control planes, particularly those based on the sampling of optical signals. In addition, it addresses impairment-aware control plane considerations and requirements, covering different optical network contexts (based on the criteria of accuracy required and constraints imposed) and types of architecture.

DJ1.2.1 concludes that the best prospects for fundamentally improving the optimisation of available network bandwidth lie in the all-optical solution for optical packet nodes, which inherently have to be more energy efficient and data-format transparent. The developments of dynamically switched lightpaths and dynamic provisioning in general have a central role to play in the NREN community. The main obstacle will be how to implement these technologies on existing infrastructure in a multi-domain environment, with impairment-aware technology in optical networks a key driver to the solution.

Research and development of 40 G, 100 G and 100+ G transmission are in progress, including field trials to identify suitable modulation formats for transmission, although the trade-off between system performance and complexity (mainly of the receiver) has still to be analysed. Certain trends are discernible, such as a technology shift from direct detection to coherent detection in order to achieve higher channel capacity and an increase in the importance of using Digital Signal Processing (DSP). Other trends are not expected to become general among vendors, e.g. an increase in spectral efficiency through the utilisation of transmission bands other than C and L or through denser spacing of the individual channels.

JRA1 Task 2 is planning future work including 40 G and 100 G testing with advanced modulation formats; further study and practical results of multi-domain alien waves carried over CBFs; and research into GMPLS-controlled optical networks with and without impairment awareness.
5 Federated Network Architectures

Federating networks means to share resources among multiple independent networks in order to optimise the use of those resources, improve the quality of network-based services, and/or reduce costs.

This section is a summary of the JRA1 Task 3 Federated Network Architectures deliverable [DJ1.3.1] which is investigating network federation. The results are of value and relevance not only to GÉANT and European NRENs but also to any special-purpose network and core networks in general.

DJ1.3.1 starts with a definition of federation and other key terms relating to federated networks, together with a clarification of the scope of the study. After outlining the benefits and challenges of federation, the user demand for federated networks is assessed based on an analysis of current and future large-scale projects requiring international data transmission.

DJ1.3.1 then describes and assesses a selection of existing GN3 tools and services that could serve as building blocks for federated networks. This leads into an introduction to architecture models for building federated networks. The models propose layered architectures that are deliberately generic in order to be applicable to many scenarios. DJ1.3.1 then describes the proposed GN3-related test cases by which the models will be verified and refined in future work.

The potential benefits of federation include cost savings, support for multi-domain services and improved user experience. The main challenges relate to the management, technological differences, missing standards, cost model and the federation-independent presentation of services.

The current large-scale projects analysed to assess user needs for federated networks included the Large Hadron Collider Optical Private Network (LHCOPN), Electronic Very Long Baseline Interferometry (e-VLBI), Enabling Grids for E-Science – Croatia (EGEE-III), and Distributed European Infrastructure for Supercomputing Applications (DEISA 2). Some of the future projects that will come under the European Strategy Forum on Research Infrastructures (ESFRI) umbrella were also included in the analysis. The key parameters for federated networks are geographic location, topology, type of end-to-end connection, data requirements, operations and services (i.e. work-flow and procedures, quality of service, performance monitoring and security) and cost model.

The existing GN3 resources, tools and services that were assessed for their potential usefulness for building a federated network were NREN networks, operational tools and supporting services, administration and procedures, and end-user services. The networks of 5 NRENs representative of European research infrastructures (DFN, PIONIER, RedIRIS, SURFnet and CARNet) were analysed for topology, coverage, utilisation and development. Particular attention was paid to three cross-border fibre (CBF) initiatives. The
operational tools and supporting services assessed included those for performance troubleshooting (eduPERT), measurement support (perfSONAR), automated bandwidth provisioning (AutoBAHN, AMPS) and information storage (I-SHARE, c-NIS). The administrative and procedural principles, requirements and best practices considered include information sharing, agreements, collaboration between network operations centres, an operations model and a governance structure. The key points relating to end-user services concern how the services are composed and offered, i.e. whether by direct aggregation of similar services in the partners’ networks or as a layer on top of the core network components provided by the federation partners; each method has fundamental implications for the network design.

The generic federated network architecture models, defined as a result of analysing current and future large-scale projects and existing GN3 resources, tools and services, are composed of three main layers: Infrastructure, Operations and Service. The lower, Infrastructure Layer consists of network infrastructure elements (the NRENs in the case of GÉANT); the middle, Operations Layer consists of the tools and support services (also known as intra-federated services) that are needed to provide support for services that are offered to end users (e.g. perfSONAR, AutoBAHN); the top, Service Layer contains the end-user services themselves. Elements within the same layer may be inter-related. Elements in the Service Layer are not permitted to interact directly with the Infrastructure Layer, but must go through elements of the Operations Layer.

The two variant models, A and B, reflect the two ways communication is performed within and between the layers, with Model A being the simpler, restricting communication between neighbouring layers to the management component of each layer, and Model B being more complex, allowing direct relationships between individual elements in adjoining layers. While Model B is potentially the more scalable, it risks increasing the overhead, reducing robustness, and duplication.
Future work will verify and refine the models by applying them to GN3-related test cases. One approach is to analyse the building blocks and relationships of an existing collaboration from the perspective of the proposed federation model. A second approach is to analyse the implications of making a change in the federation, and which model is better suited to the new situation. The test cases proposed are the GÉANT network itself (with use cases including using CBF for GÉANT PoP-to-PoP connections, using CBF as an element in regional links, a federated GÉANT PoP and remote IP backup with CBF) and LHC Tier1-to-Tier2 connections. In addition, the federated models presented here will be compared with other models from the literature, e.g. those defined by the TM Forum, and with those used or proposed by other GN3 service or joint research activities.
6 Current and Potential Uses of Virtualisation

In the context of network and computing infrastructure, virtualisation is the creation of a virtual version of a physical resource (e.g. network, router, switch, optical device or computing server), based on an abstract model of that resource and often achieved by partitioning (slicing) and/or aggregation. A virtual infrastructure is a set of virtual resources interconnected together and managed by a single administrative entity.

This section is a summary of the JRA1 Task 4 Current and Potential Uses of Virtualisation deliverable [DJ1.4.1] which aims to investigate potential uses and benefits of infrastructure virtualisation services for the GÉANT and NREN communities. It proposes a multi-layer, multi-domain and multi-technology virtualisation architecture suitable for NREN requirements, based on tools and software that have already been developed or are currently under development within the European research community.

DJ1.4.1 starts by presenting a comprehensive comparative study of existing major activities, research projects and technologies addressing infrastructure virtualisation. The projects considered include European projects (FEDERICA, MANTICORE, Phosphorous, 4WARD), US projects (GENI, PlanetLab/VINI/OneLab), a Japanese project (AKARI) and a commercial cloud project (Amazon virtualisation). All the projects include infrastructure virtualisation at national and/or international level and some of them involve National Research and Education Networks (NRENs) and international connectivity. The study tries to provide a consistently structured assessment of different projects addressing the following points:
Current and Potential Uses of Virtualisation

- Overview of the project and its objective.
- A definition of infrastructure virtualisation as understood by the project as well as an architectural overview of its virtualisation approach.
- User community.
- Overview of existing features and implementation of virtualisation for Layer 1, Layer 2, Layer 3 and computing resources.
- Multi-domain support of the virtualisation technology.
- Testbed implementation and availability.
- Current status and roadmap.

JRA1 Task 4 concludes that the European research community, helped by the drive and commitment of the NRENs, has managed to achieve significant progress on infrastructure virtualisation technologies through projects such as FEDERICA, MANTICORE and Phosphorus. These projects are complementary and, combined together, they can provide virtualisation of Layer 1, Layer 2 and Layer 3 networks as well as computing resources. Any proposal for GÉANT virtualisation services should therefore build on the developments and achievements of these projects.

DJ1.4.1 also presents the results of an initial study of NRENs’ requirements for using infrastructure virtualisation technologies in the near future. The analysis reported here focuses on the requirements of three NRENs only. This is a pilot analysis; its results are expected to create the foundation and framework for a more comprehensive study to be carried out during 2010 covering as many NRENs as possible, as well as GÉANT. To carry out the requirements survey, a questionnaire was prepared in four sections as follows:

- Existing use of virtualisation technologies and services.
- Other potential applications.
- Areas of specific or strategic interest for application of virtualisation.
- Risk analysis.

The results provide a summary of how different NRENs plan to use virtualisation over the coming 1-3 years, their experiences so far, and their views on the cooperative use of virtualisation in GÉANT. They also indicate the existence of a unanimous requirement for virtualisation by NRENs, with each stressing a different aspect of virtualisation and related services, i.e. Layer 1, Layer 2, Layer 3 and computing virtualisation.

The current virtualisation technologies resulting from the projects mentioned above are still in their research and development stage. It is therefore not realistic to propose a specific solution to the NREN and GÉANT community. DJ1.4.1 doesn’t aim to promote a specific solution or framework for a technological proof of concept for GÉANT virtualisation services. Instead, it aims to propose a solution for integrating and interworking existing virtualisation mechanisms and solutions at different layers, leaving the choice of suitable virtualisation technologies to individual NRENs, while enabling them to offer multi-domain, multi-layer and multi-technology virtualisation services.

DJ1.4.1 proposes an initial, multi-layer and multi-domain infrastructure virtualisation mechanism based on a combination of solutions and tools developed by relevant EU projects, namely FEDERICA, MANTICORE and Phosphorus. Without reinventing the wheel, the proposition is to integrate existing Layer 1, Layer 2, Layer 3 and computing virtualisation tools both horizontally and vertically.
Finally, DJ1.4.1 outlines a plan for a pilot prototype implementation and verification of the proposed integrated virtualisation service mechanism. Because of time and resource limitations within JRA1 Task 4, the prototype implementation and proof of concept will be carried out on a very small scale using existing resources within Task 4 participants’ facilities. Two virtualisation frameworks and two small-scale testbeds have been selected for prototype implementation and proof of concept testing: the University of Essex Layer 1 testbed (small scale) deploying Phosphorus (User Controlled Lightpath Provisioning (UCLP)) and the HEANET Layer 3 testbed (small scale) deploying MANTICORE.

Network virtualisation is a relatively new concept. As with any innovation, there will undoubtedly be some aspects, both benefits and problems, which only emerge over time. Evaluating the advantages, disadvantages and risks of virtualisation compared to traditional operation, particularly with regard to security, will therefore form a key part of future JRA1 T4 work. At this stage in the development lifecycle, however, the majority agree on the benefits and necessity of network virtualisation, as demonstrated by the EU projects reviewed by JRA1 Task 4, none of which has so far reported significant drawbacks.
7 Current Common Network Infrastructures

7.1 Current Network Technologies

A snapshot of current dominating network technologies reveals a set of technologies that have been in use for some time – some, like SDH/Sonet and Ethernet, have even been in operation for two decades – but are still serving the telecommunication business. The current technologies are, starting from the top:

![Technologies of Today]

The most intelligent, and therefore also the most heavily processing-dependent technology is IP; processing demand decreases as you move down the list. The processing element has a large impact on the cost per bit. Therefore the overall cost per bit per technology also decreases as you move down the list.

Bandwidth per subscriber increases faster than power per bandwidth decreases. This is not environmentally and economically sustainable. Technology improvements and system-design optimisation alone will not solve the problem but part of the solution could be using the lowest possible network layer. Nevertheless, power consumption will rise significantly in electronic-based network components.

Looking more specifically at the network components, routers have by far the worst power profile and will dominate the overall power profile, while photonic components will help limit the overall power profile although that the use of more DSP intensive control in photonic slowly increases the power consumption.

Although the photonic layer has the lowest carbon footprint, it must be subjected to developments and enhancements in order to reduce the power-consumption cost, resulting in a smaller interface carbon footprint.
7.2 **Current Network Architecture**

During the last decade, NRENs have built and are continuing to build their own DWDM networks using fibre optic infrastructures. On top of the DWDM network, NRENs have typically added a multi-service switching platform capable of handling packet and TDM traffic flows. The network infrastructure is then commonly equipped with a distributed mesh IP layer. However, some NRENs have started to centralise the IP core and move the IP intelligence to the edge of the IP network.

This type of network infrastructure is fragmented, without any utilisation of the cross-layer function palette, thereby making each layer a domain of its own. End-to-end services are stitched vertically and horizontally through each layer, making the use of network resources inefficient.

The diversity of control plane solutions for each layer is making automated network and service provisioning a nightmare, forcing bandwidth-on-demand solutions like AutoBAHN and Dynamic Resource Allocation Controller (DRAC) to develop technology proxies for each layer and adjust the source code each time a new node is added.

The diversity of control plane solutions has also led to a diversity of network management systems (NMSs), making operations problematic and inefficient. This in turn has led to internal diversity within network organisations, which have established separate IP and Transmission Departments, each with dedicated skill sets. The communication barrier between these departments has also been distinctly problematic: often when an IP engineer said A, this was understood by a transmission engineer as B, and then the reply would be understood by the IP engineer as C and chaos was the result.

7.3 **Current Multi-Domain Architecture**

A multi-domain environment is a set of individual domains agreeing on a set of common service offering in conjunction with their individual services palette
Interconnecting two or multiple domains at strategic junctions is typically treated as a service handover to a black box, where the originating domain can't ensure performance or even monitor the signal when it passes to another domain. The technology used for carrying the traffic can be diverse from network to network, making the deployment and provisioning process extremely tedious and difficult. In addition, an end-to-end Service Level Agreement (SLA) is difficult to agree and to implement and, during operation, almost impossible to honour.

The actual handover is typically done via back-to-back client interfaces interconnected by patch fibre arrangements. A change request would generate a truck roll with a lead time of a couple of hours or in worst case 2-3 days. If additional interfaces were needed, that would generate equipment orders and a truck roll with a lead time of 12 – 16 weeks.
8 Next-Generation OTN

This section are giving some highlights about OTN and NG-OTN which are seen as the future dominant technology in the digital and analogue backbone transmission evolution for both the commercial and NREN community, providing support for a wide range of TDM, packet and IP narrowband and broadband services.

8.1 Optical Transport Network

The OTN architecture concept was developed by the ITU-T initially a decade ago, to build upon the SDH and DWDM experience and provide bit rate efficiency, resiliency and management at high capacity. OTN therefore looks a lot like SONET/SDH in structure, with less overhead and more management features.

It is a common misconception that OTN is just SDH with a few insignificant changes. Although the multiplexing structure and terminology look the same, the changes in OTN have a great impact on its use in, for example, a multi-vendor, multi-domain environment. OTN was created to be a carrier technology, which is why emphasis was put on enhancing transparency, reach, scalability and monitoring of signals carried over large distances and through several administrative and vendor domains. All these are issues that the NREN community is currently struggling to solve.

The advantages of OTN compared to SDH are mainly related to the introduction of the following changes:

- **Transparent Client Signals:**
  In OTN the Optical Channel Payload Unit-k (OPUk) container is defined to include the entire SONET/SDH and Ethernet signal, including associated overhead bytes, which is why no modification of the overhead is required when transporting through OTN. This allows the end user to view exactly what was transmitted at the far end and decreases the complexity of troubleshooting as transport and client protocols aren't the same technology. OTN uses asynchronous mapping and demapping of client signals, which is another reason why OTN is timing transparent.

- **Better Forward Error Correction:**
  OTN has increased the number of bytes reserved for Forward Error Correction (FEC), allowing a theoretical improvement of the Signal-to-Noise Ratio (SNR) by 6.2 dB. This improvement can be used to enhance the optical systems in the following areas:
○ Increase the reach of optical systems by increasing span length or increasing the number of spans.
○ Increase the number of channels in the optical systems, as the required power theoretical has been lowered 6.2 dB, thus also reducing the non-linear effects, which are dependent on the total power in the system.
○ The increased power budget can ease the introduction of transparent optical network elements, which can’t be introduced without a penalty. These elements include OADMs, Photonic Cross Connects (PXC), splitters, etc., which are fundamental for the evolution from point-to-point optical networks to meshed ones.
○ The FEC part of OTN has been utilised on the line side of DWDM transponders for at least the last 5 years, allowing a significant increase in reach/capacity.

- Better scalability:
The old transport technologies like SONET/SDH were created to carry voice circuits, which is why the granularity was very dense – down to 1.5 Mb/s. OTN is designed to carry a payload of greater bulk, which is why the granularity is coarser and the multiplexing structure less complicated.

- Tandem Connection Monitoring:
The introduction of additional Tandem Connection Monitoring (TCM) combined with the decoupling of transport and payload protocols allow a significant improvement in monitoring signals that are transported through several administrative domains, e.g. a meshed NREN topology where the signals are transported through several other NRENs before reaching the end users.

  In a multi-domain scenario – “a classic carrier’s carrier scenario” where the originating domain can’t ensure performance or even monitor the signal when it passes to another domain – TCM introduces a performance monitoring layer between line and path monitoring allowing each involved network to be monitored, thus reducing the complexity of troubleshooting as performance data is accessible for each individual part of the route.

Finally, a major drawback with regards to SDH is that a lot of capacity during packet transport is wasted in overhead and stuffing, which can also create delays in the transmission, leading to problems for the end application, especially if it is designed for asynchronous, bursty communications behavior. This over-complexity is probably one of the reasons why the evolution of SDH has stopped at STM 256 (40 Gbps).

OTN’s G.709 interface to the photonic layer is becoming more important as high bit rate creates more concerns over optical impairments and their effect on signal integrity and spectral efficiency in Long Haul system design. OTN has the ability to transport, monitor and provision TDM, packet and IP traffic directly onto DWDM wavelengths at ultra-high capacity.
The requirements for optical transmission monitoring at high capacity are far more stringent, because the small pulse widths and higher light intensity required for high-capacity transmission cause exponential increases in optical effects and signal sensitivity to noise, problems to which OTN offers solutions in the form of ever more enhanced error correction and signal processing capability.

OTN has all the capabilities required to monitor, manage, and control each client signal transported on a particular wavelength in the network. In this way, OTN adds operations, administration and maintenance (OAM), and provisioning and troubleshooting functionality to optical carriers.

OTN provides the network management functionality of SDH and SONET, but on a per-wavelength basis. A digital wrapper, which is flexible in terms of frame size and allows multiple existing frames of data to be wrapped together into a single entity, enables more efficient management through a lesser amount of overhead in a multi-wavelength system. The OTN specification includes framing conventions, non-intrusive performance monitoring, error control, rate adaption, multiplexing mechanisms, ring protection, and network restoration mechanisms operating on a per-wavelength basis.

The OTN technology architecture is being further defined as capacity increases, as service focus becomes more data-centric, and as multi-domain monitoring and provisioning become more important. This development is known as Next-Generation OTN, and its definition is currently being led by Study Group 15 in the ITU-T.

### 8.2 Next-Generation Optical Transport Network

Next-Generation OTN is a development of the OTN standard described above, maintaining the SDH-like OAM functionalities, with added development that enables more efficient mapping of and support for data signals such as Ethernet and IP. This transformation is what has been called the Packet Optical Evolution or the Packet Optical Transport Service (P-OTS), with OTN as the carrier for packet services such as MPLS-TP, PBB-TE, Synchronous and Connection-Oriented Ethernet, or IP/MPLS.

The transmission of IP and Carrier-Grade Ethernet over WDM networking was normally requiring end-to-end circuit monitoring, management and protection functions that were previously provided by the SDH network are
now being implemented on the WDM layer network; this removes a layer from the transport infrastructure and achieves better bit-transfer efficiency.

On the optical layer, development of functions such as wavelength configuration, automatic power balancing and optical-layer performance monitoring can help to reduce operational expenditures in a time of decreased technology-enabling finance. On the digital layer, technological and architectural convergence is a major factor in transport networking: metro networks merge more and more with long-haul optical transmission networks, again with reduced cost as a key motivation.

Therefore, in the absence of SDH at the high end of backbone capacity, with the merger of Access and Core Transport planning, and given the advent of all-optical and multi-domain networking, a new transport technology is required.

Next-Generation OTN proffers a solution to the converged transparent transport of TDM, packet and IP-based services and goes beyond point-to-point wavelength services by implementing a more flexible architecture based on Optical Channel Data Units (ODU), including ODU-k, ODU-0 and sub-0, ODU-ne and ODU-flex.

This promises improvements to service-layer networking efficiency, protection and restoration functions, scalability and flexibility.

This next generation of optical networking will develop the transmission layer from a static networking medium to become an intelligent dynamic transport network infrastructure supporting high-capacity multiplexed applications over multi-domains, which in fact is the “Next Big Thing” for networking.
The New Dawn of Network Architectures

WDM, TDM and packet-oriented network layers are undergoing a critical transition in which the networks are migrating from static legacy-based transport networks to dynamic, intelligent next-generation transport networks. The future network strives towards a converged backbone solution, changing the game for the NRENs by having higher integration between the different layers to give a single entity with common visibility, provisioning, and protection schema.

The driving force behind this transition is the need to improve operational efficiency and to deploy more cost-effective transport networks than yesterday’s network infrastructures. More precisely, there is a growing demand for more bandwidth, faster provisioning, and a more enhanced set of service functionality. Furthermore, the transport technology is also evolving to support migration towards IP and transport convergence. This is caused by advancements in transport technologies and protocols that have made available a new generation of equipment that features a high degree of functional integration and is capable of supporting an embedded intelligent control plane.

All this can be seen as “the new dawn of network architectures”.

Digital and analogue OTN is seen as the future dominant technology for the future network backbone architecture, whereas other Carrier Class packet technologies like MPLS-TP, PBT and Carrier-Grade Ethernet will be more suited for metro and regional networks.

The use of packet and OTN switches combined with a meshed DWDM infrastructure could be the most compelling solution for building the future network infrastructure. DWDM is seen as the future flexible glue for the entire network from metro to core, utilising the fibre infrastructure in an optimal way. Such an infrastructure will be future-proof, reliable, flexible, scalable and provide a sustainable carbon footprint without compromising cost efficiency.
For multi-domain interworking the use of OTN switches for interconnecting domains and providing intelligent add/drop capabilities looks very promising. In addition it enhances the operational and cost efficiency in utilising cross-border fibre capacity when it comes to provisioning, protection and maintenance by reducing the need for manual intervention. It turns a multi-domain junction into a dynamic adaptive switching bridge.

Intelligent control plane technologies are the glue that will help realise a vision of multi-vendor, multi-carrier and multi-regional interoperable networking that supports end-to-end connection services on a global scale.

As a part of the future GÉANT and NREN network architecture, it is evident that vertical intelligent control plane network integration will play a significant role in providing converged network architecture with common visibility, enabling automatic provisioning and distributed restoration and protection schema. However the control plane must still support abnormalities for each layer.

### 9.1 Future Network Architecture

Designing and planning a future network architecture can be done in many ways. Typical starting points could be the need for upgrading an existing network or starting from scratch in a green-field scenario. Both scenarios are dependent on legacy experience political aspects, financial limitations and the expected service spectrum.

The following section describes a generalised architecture based on a dark fibre infrastructure, JRA1’s intermediate results and the author’s interpretation of the general technology evolution.

#### 9.1.1 Backbone Architecture

The architectural layout of the backbone should be based on a combined mesh- and ring-structured DWDM. Each Point of Presence (PoP) should encompass advanced flexible Tuneable ROADMs (T-ROADMs) with a channel count greater than 72, and include a client traffic transparency rating from 10 Gbps to 100 Gbps. The system should be enabled for increasing capacity granularity e.g. 400 Gbps and 1 Tbps, without the need for additional major hardware upgrade or other technical limitations of the network solution. The solution should compensate for optical system impairments like generated by optical components and the dark-fiber systems.

In order to achieve fibre optic resiliency and to support the overall restoration topology, the T-ROADM should as a minimum have 2 branches into the network. The overall network should require strategically placed Re-amplifying, Reshaping, Retiming (3R) generation in order to cope with resiliency and restoration.

NG-OTN switches, or T-ROADMs with NG-OTN switching capability, should likewise be deployed in each PoP handling IP, packet and TDM traffic flows. The NG-OTN switching capacity should be in the range of terabit and should have a client traffic transparency rating from 1 Gbps to 100 Gbps.

The T-ROADMs and the NG-OTN switches solution should have a GMPLS control plane for any traffic pipe WDM, TDM or packet providing automated network and service provisioning. Resiliency should be provided, e.g. 1+1, N+1 protection schemes including priority-based dynamic protection and restoration. In addition, provision should be made for distributed restoration, using vertical integration across WDM, TDM and packet-oriented layers.
The T-ROADMs and the NG-OTN switches solution should have carrier-class OAM capabilities very similar to SDH (e.g. continuity, connectivity and quality checks; remote indications; performance monitoring parameters), with a special emphasis on the tandem connection concept for “carrier’s carrier” services.

The trend towards centralising the IP backbone will continue, with an increase in the routing capacity. The core routers will be transformed into or be replaced by terabit carrier-class core routers with flexible interfaces in the 10 G+ to 100 G range. The interfaces should have deep packet buffers suitable for supporting high-performance wide-area data transfers and oversubscription. The interfaces should have the potential for a smooth integration into the underlying transmission, limiting the need for additional OEO conversion.

The core routers should as a minimum support most common types of IP operation protocols, IPv4 and IPv6, including virtualised operation and routers. The number of routes in the Forward Information Base (FIB) should be greater than 1 million.

The core routers should mainly handle IP transit and IP peering traffic flows. In conjunction with the core routers, smaller IP switch routers should handle all IP intelligence, including traffic grooming coming from the access and metro networks, meaning that these switch routers should have a scalable solution for establishing common L2 and L3 services.

All routers should have a GMPLS control plane interworking vertically with the transport layers, providing automated network and service provisioning including activation of resiliency and priority-based distributed dynamic protection and restoration using vertical integration across the WDM, TDM and packet-oriented layers.

In that way, the IP connectivity resiliency could support even stronger than today by the transport layer utilising the vertical intelligent control plane providing a <50 msec. switch over time.

The general architecture outlined above would enable dynamic adaptive switching ranging from 100% packet-oriented to 100% circuit-oriented.

**9.1.2 Metro/Regional Architecture**

The architectural model for metro and regional networks follows the same vision as the backbone, but slightly reduced in respect of capacity and granularity, leading to a more extensive use of packet switching instead of NG-OTN switching in order to achieve an even finer granularity, and the use of more intelligent CCTNTs such as MPLS-TP, PBB-TE and Carrier Grade Ethernet.

The architecture will still be based on a combined mesh and ring-structured Long Haul DWDM network where each PoP encompasses T-ROADMs with the same functionality as the T-ROADMs used in the backbone network.

Packet-based switches will reside next to the T-ROADMs with a switching capacity in the range of 0.5 terabit and should have a client traffic transparency rating from 100 Mbps to 10 Gbps in order to handle IP, packet and TDM traffic flows. NG-OTN switches will be strategically placed in the network and, over time, when capacity increases, will take over the packet switch functionality.
The T-ROADMs, packet switches and NG-OTN switches solution should have a similar GMPLS control plane as described for the backbone, handling provisioning, resiliency, protection, and restoration in the same way. The same applies to the OAM component.

The IP metro and regional architecture will again be similar to the backbone but with slightly reduced capacity and granularity. The IP intelligence is still moved to the edge of the network.

All routers should have a similar GMPLS control plane interworking vertically with the transport layers as described in 9.1.1 Backbone Architecture. There will still be a trade-off between the use of protection mechanisms in the transport layer and the traditional IP protection mechanism.

The metro and regional architecture will also enable dynamic adaptive switching in the same range as for the backbone: from 100% packet-oriented to 100% circuit-oriented.

### 9.1.3 Multi-Domain Network Architecture

A multi-domain environment is a set of individual domains agreeing on a set of common service offerings in conjunction with their individual services palettes. Assuming these domains follow the architectural approach described above, the natural interconnection mechanism would be OTN switches or, in special cases, an alien wavelength service (typically where the counterpart domains were using the same DWDM platform).

In scenarios where multiple domains reach the same junction, the full potential benefit of OTN switches would be realized, turning this junction into a dynamic adaptive switching bridge.

### 9.1.4 Management Plane

The management system should be a Fault, Configuration, Accounting, Performance and Security (FCAPS) system and should manage all network elements and contain a network planning tool. It is not expected that one system will fit all network elements, but it is expected that there will a much tighter bond between each system. The network management systems (NMSs) should have open northbound and southbound interfaces. They should also support event correlation, service provisioning and activation, including the possibility of dynamic provisioning in combination with control plane protocols and resource applications. In addition, they should support automatical device and logical topology discovery.

The management solution should ideally be built on a lightweight hardware configuration with built-in resiliency for all process and hardware components. The interconnection between the management system and the network should be based on IP communication.
9.2 Federated Network Architecture

The GÉANT network is the pan-European communication infrastructure serving Europe’s research and education community and is co-funded by European NRENs and the EC. The GÉANT network is operated by DANTE Limited, based in Cambridge in the UK. For further information see www.dante.org.

The GÉANT project advances all aspects of European research and education networking. This encompasses the network itself, a range of network support and access services for users, initiatives to address the digital divide of research and education networking around Europe, and technological research to ensure GÉANT continues to be at the forefront of networking on a global scale.

The GÉANT network is seen by many as a federated network or as an instance of federation. However, looking at the network itself there is very limited federation involved.

The GÉANT backbone interconnects 34 European NRENs and further provides connectivity to similar research and education networks in other parts of the world. The backbone is constructed and operated by DANTE. Today the GÉANT backbone consists of connectivity based on a mixture of leased dark fibre links lit using a carrier-class DWDM system operated by DANTE and managed circuit services provided by commercial service providers.

The term federation applies to GÉANT mainly in relation to the governance and funding aspect, not to the network itself. Presently there is limited federated use of NREN network infrastructure parts or virtual circuits.

This section looks at a future architectural model which could be used in selected parts of the GÉANT network as a replacement of the current network model – to be more precise, in areas where NREN has well-established DWDM infrastructures.

At first glance, utilising multiple network domain resources might be seen as the most cost-effective way of providing a set of generalised network services. However, there is much more to it than that, as described by [DJ1.3.1].

The scope of this section is to provide a network architecture description related to the network equipment and fibre infrastructure. It is assumed that, as a minimum, each domain has a DWDM infrastructure reaching to the domain border or the network demarcation points between the domains.

As mentioned above, OTN switches were seen as a very promising solution for multi-domain interconnections, providing intelligent add/drop capabilities and enhanced utilisation of cross-border fibre capacity – in total, turning a multi-domain junction into a dynamic adaptive switching bridge.
In order to combine network resources effectively, therefore, OTN switches should be deployed in the demarcation points between domains. Each domain could then connect to these OTN switches with wavelengths originating from their own OTN and packet-switching layer. This means that the architecture would require individual domains to provide the transport layer for the multi-domain network and the service refinement to be done by the OTN-switching overlay. As a mandatory requirement the transport layer should be OTN-based, passing through all the domains in order to monitor, manage, and control each channel end-to-end.

The federated IP infrastructure should be based on strategically deployed core routers in close proximity to globally recognised Internet Exchange Points (IXPs). The underlying DWDM and OTN federated infrastructure should groom the IP traffic coming from the individual domains and facilitate IP peering and IP transit traffic flows towards external Internet service providers making the overall IP traffic cost lower compared to the individual domains’ achievable IP cost rates.

The control and management of the OTN switches and the IP core routers could be done in a federated way with a legal entity undertaking the overall coordination and operation. This entity could then again subcontract control and operation to multiple Network Operations Centres (NOCs) sharing a common set of operation tools.

The future GÉANT network could be a combination of the current network model, updated in accordance with the backbone architecture outlined in Section 9.1.1 and the federated approached outlined in this section.

In principle it could be said that GÉANT is moving towards a leased line architecture (NREN OTN-provided transport layer) with a set of high-end OTN switches and core routers (owned and managed by GÉANT).

JRA1 is currently in the process of identifying a feasible test case for interconnecting multiple domains via one or several domains in order to test and evaluate not only the features of OTN but also the federated network architecture approach outlined in this section.
Summary

The first year of the GÉANT3 project has identified topics that JRA1 consider to be important for the research community in order to realize a visionary GÉANT and NREN future network to support future networking. This report has presented what some might even say would represent a new dawn for backbone transport, switching and routing technologies.

This report has provided an overview of:

- JRA1 T1 Carrier Class Transport Network Technologies presenting the initial findings of a study of Carrier Class Transport Network Technologies (CCTNT). It identifies the key concepts and functionalities that define a transport network technology as Carrier Class, and outlines the ways in which a set of representative technologies (selected because they meet the criteria of Carrier Class and fall within the scope of JRA1 T1 as a research activity) deliver them.

- JRA1 T2 State-of-the-Art Photonic Switching Technologies is investigating state-of-the-art and emerging optical networking technologies in order to determine how GÉANT and the NRENs can develop their networks to meet future demands. It gives an overview of optical networking technologies, investigates optical processing techniques, presents a study of Operations, Administration, Maintenance and Provisioning (OAM&P) for multi-vendor/multi-domain scenarios, and addresses impairment-aware control plane considerations.

- JRA1 Task 3 Federated Network Architectures deliverable are conducting an investigation into network federation, i.e. sharing resources among multiple independent networks. It defines key terms, benefits and challenges; assesses user demand for federated networks based on an analysis of current and future large-scale projects; evaluates existing GN3 resources, tools and services that can serve as building blocks for federated networks; introduces a set of generic federated network architecture models; and describes the GN3-related test cases by which the models will be verified and refined.

- JRA1 T4 Current and Potential Uses of Virtualisation presents the results of an initial comparative study of existing infrastructure virtualisation technologies and frameworks. It also presents the results of an initial analysis of NRENs' requirements for using infrastructure virtualisation technologies in the near future. Furthermore, this deliverable defines virtualisation services within the context of GÉANT and proposes an approach for their implementation within GÉANT and associated NREN infrastructures. Finally, it provides a plan for proof of concept and validation of the proposed virtualisation approach over a small testbed.
This report then provides an overview of current technologies and architectural trends, covering both single- and multi-domain network architectures.

Leading to a discussion about Optical Transport Networking and next generation OTN, which is the new big thing in backbone transmission evolution. Building on the topics discussed, the “new dawn of network architectures” are presented covering single- and multi-domain network architectures.

The report closes by arguing for a potential future GÉANT Network Architecture, which also encompasses the potential of a federated network infrastructure.

As a follow-up to the studies summarized in this report, the JRA1 team is implementing a series of tests to verify the most important features of the technologies and approaches described. The tests will produce a further set of information and advice for the research networking community – this time based on real experiments.
References

All public GN3 deliverables are available from the Deliverables area of the project website: http://www.geant.net/Media_Centre/Media_Library/Pages/Deliverables.aspx.

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## Glossary

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<tr>
<td>3R</td>
<td>Reamplifying, Reshaping, Retiming</td>
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<td>AMPS</td>
<td>Advance Multi-domain Provisioning System</td>
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<td>ASE</td>
<td>Amplifier Spontaneous Emission</td>
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<td>AutoBAHN</td>
<td>Automated Bandwidth Allocation across Heterogeneous Networks</td>
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<td>CBF</td>
<td>Cross-Border Fibre</td>
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<td>CCTNT</td>
<td>Carrier Class Transport Network Technologies</td>
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<td>CD</td>
<td>Chromatic Dispersion</td>
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<td>CET</td>
<td>Carrier Ethernet Transport</td>
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<td>cNIS</td>
<td>Common Network Information Service</td>
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<td>DEISA2</td>
<td>Distributed European Infrastructure for Supercomputing Applications</td>
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<td>DJ1.1.1</td>
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<tr>
<td>DRAC</td>
<td>Dynamic Resource Allocation Controller</td>
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<td>DSN</td>
<td>Dynamic Switched Network</td>
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<td>DSP</td>
<td>Digital Signal Processing</td>
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<td>DWDM</td>
<td>Dense Wavelength Division Multiplexing</td>
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<td>EGEE</td>
<td>Enabling Grids for E-Science</td>
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<td>EoMPLS</td>
<td>Ethernet over Multi-Protocol Label Switching</td>
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<td>ESFRI</td>
<td>European Strategy Forum on Research Infrastructures</td>
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<td>e-VLBI</td>
<td>Electronic Very Long Baseline Interferometry</td>
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<td>FCAPS</td>
<td>Fault, Configuration, Accounting, Performance and Security</td>
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<td>FEC</td>
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<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IS-IS</td>
<td>Intermediate System to Intermediate System</td>
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<tr>
<td>I-SHARe</td>
<td>Information Sharing across Heterogeneous Administrative Regions</td>
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<tr>
<td>ITU-T</td>
<td>International Telecommunication Union – Telecommunication Standardisation Sector</td>
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<tr>
<td>IXP</td>
<td>Internet Exchange Point</td>
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<tr>
<td>JRA1</td>
<td>GN3 Joint Research Activity 1 Future Network</td>
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<tr>
<td>Term</td>
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<td>JRA1 T1</td>
<td>JRA1 Task 1 Carrier Class Transport Network Technologies</td>
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<td>JRA1 T4</td>
<td>JRA1 Task 4 Current and Future Uses of Virtualisation</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LHCOPN</td>
<td>Large Hadron Collider Optical Private Network</td>
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<tr>
<td>MEF</td>
<td>Metro Ethernet Forum</td>
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<tr>
<td>MPLS</td>
<td>Multi-Protocol Label Switching</td>
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<tr>
<td>MPLS-TP</td>
<td>Transport Profile</td>
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<tr>
<td>NG-OTN</td>
<td>Next-Generation Optical Transport Networking</td>
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<tr>
<td>NMS</td>
<td>Network Management Systems</td>
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<tr>
<td>NOC</td>
<td>Network Operations Centre</td>
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<tr>
<td>NREN</td>
<td>National Research and Education Network</td>
</tr>
<tr>
<td>OADM</td>
<td>Optical Add/Drop Multiplexer</td>
</tr>
<tr>
<td>OAM</td>
<td>Operations, Administration and Management</td>
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<td>OAM&amp;P</td>
<td>Operations, Administration, Maintenance and Provisioning</td>
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<tr>
<td>OBS</td>
<td>Optical Burst Switching</td>
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<td>ODU</td>
<td>Optical Channel Data Units</td>
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<td>OEO</td>
<td>Optical-to-Electrical-to-Optical</td>
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<td>OPUk</td>
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<td>OSPF</td>
<td>Open Shortest Path First</td>
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<tr>
<td>OTN</td>
<td>Optical Transport Networking</td>
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<tr>
<td>PB</td>
<td>Provider Bridges</td>
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<tr>
<td>PBB</td>
<td>Provider Backbone Bridges</td>
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<tr>
<td>PBB-TE</td>
<td>Provider Backbone Bridge Traffic Engineering</td>
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<td>PBOT</td>
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<td>PDH</td>
<td>Plesio-synchronous Digital Hierarchy</td>
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<tr>
<td>PDL</td>
<td>Polarisation-Dependent Loss</td>
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<tr>
<td>perfSONAR</td>
<td>Performance Service-Orientated Network-Monitoring Architecture</td>
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<tr>
<td>PIC</td>
<td>Photonic Integrated Circuit</td>
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<tr>
<td>PLSB</td>
<td>Provider Link State Bridges</td>
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<tr>
<td>PMD</td>
<td>Polarisation Mode Dispersion</td>
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<tr>
<td>P-OTS</td>
<td>Packet Optical Transport Service</td>
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<tr>
<td>PoP</td>
<td>Point of Presence</td>
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<td>PWE3</td>
<td>Pseudowire Emulation Edge to Edge</td>
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<td>PXC</td>
<td>Photonic Cross Connect</td>
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<td>QoS</td>
<td>Quality of Service</td>
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<td>ROADM</td>
<td>Reconfigurable Optical Add/Drop Multiplexer</td>
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<tr>
<td>SCN</td>
<td>Circuit-Switched Network</td>
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<td>SG15</td>
<td>ITU-T Study Group 15</td>
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<td>SLA</td>
<td>Service Level Agreement</td>
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### Glossary

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<thead>
<tr>
<th>Acronym</th>
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<tr>
<td>SNR</td>
<td>Signal-to-Noise Ratio</td>
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<td>SONET</td>
<td>Synchronous Optical Networking</td>
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<td>SPB</td>
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<td>SPB MAC</td>
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<td>TCM</td>
<td>Tandem Connection Monitoring</td>
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<td>Time-Division Multiplexing</td>
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<td>Tuneable ROADM</td>
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<td>TRILL</td>
<td>Transparent Interconnection of Lots of Links</td>
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<td>UCLP</td>
<td>User Controlled Lightpath Provisioning</td>
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<td>Voice over IP</td>
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