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Abstract

This document provides a summary of the Technology Task (Task 1) and Platform Task (Task 2) work within the Network Development Work Package (WP6) of the GN5-1 project.

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Executive Summary

This document summarises the work conducted as part of the Technology Task (Task 1) and Platform Task (Task 2) within the Network Development Work Package (WP6) of the GN5-1 project. It includes emerging technologies such as Router for Academia, Research and Education (RARE), quantum, optical time and frequency network, and fibre sensing. It also describes various platforms – Global Platform for Labs (GP4L), nmaas (formerly Network Management as a Service (NMaaS)), Service Provider Architecture (SPA) and the resource and service inventory management tool Maat – and how they can support National Research and Education Network (NRENs) in developing, providing and supporting their infrastructure, services and products.

1 Introduction

The evolution of network infrastructure, services and functionalities happens through evaluations, feasibility studies, investigations and deployment of emerging technologies and solutions. Some of these emerging technologies may lead to very useful services for the research and education (R&E) community, some might trigger additional research and development, but in any case, investigation of any new technologies and solutions requires clear use cases, thorough evaluation and investigation, and use of stable platforms and testing environments. From initial experiments, through pilots to production, technology evaluation needs to include different aspects such as operations, security, monitoring and management and it goes hand in hand with the development of new tools or supporting products helped by automation and orchestration.

The Network Development Work Package (WP6) of the GN5-1 project, through two of its Tasks – Technology (Task 1) and Platform (Task 2) – explores emerging technologies and provides platforms where new concepts and technologies can be tested, having in scope use cases relevant for the R&E community and in particular National Research and Education Networks (NRENs) – partners of the GN5-1 project. The objective is to prototype relevant emerging technologies, as long as they are grounded in practical use cases, and explore how these use-case implementations could be advanced to meaningful services, products or tools.

The aspect of training and dissemination also plays a huge role in this environment: learning opportunities are an essential component when it comes to emerging technologies and their acceptance within a community. Especially in a large community such as GÉANT, training and knowledge sharing help to establish a common understanding of general baselines, definitions and terminology. Common knowledge and reference frameworks also support the development of good policies for new services and a quick service uptake, and increases and simplifies opportunities for joint, multi-domain or cross-domain NREN collaboration.

This document describes the work conducted from the beginning of the GN5-1 project in January 2023 up until the end of March 2024 on the evaluation of emerging technologies in Task 1, and presents various platforms and tools developed in Task 2 and made available to the community to support collaboration, experimentation and network and service innovation.

Section 2 Network Technologies covers Router for Academia, Research and Education (RARE), quantum, optical time and frequency network, and fibre sensing. Section 3 Platforms describes Global Platform for Labs (GP4L), nmaas (formerly Network Management as a Service (NMaaS)), Service Provider Architecture (SPA) and the resource and service inventory management tool Maat. Section 4 offers overall conclusions and observations.

2 Network Technologies

The Technology Task explores emerging infrastructure technologies, their relevance and applicability for the NREN use cases and readiness and maturity for future operational services. The Task includes four areas of work: Router for Academia, Research and Education (RARE), quantum technologies, optical time and frequency networks (OTFN), and fibre sensing, investigating them from the perspective of the services they can offer, how cross-border challenges could be tackled, and how the development can be most beneficial in the support of the NREN community.

2.1 Router for Academia, Research and Education – RARE

RARE [RARE] is an open source routing operating system, developed for commodity hardware such as a white box switch. Available on low-cost hardware and being open source, RARE prevents vendor lock-in and helps reduce the digital divide. RARE is flexible in implementing ad hoc features and adapting new functionalities for specific use cases, making it suitable for R&E environments.

RARE uses FreeRTR [FreeRTR] as a control plane software. Initially, Tofino switches were used to deploy RARE/FreeRTR software. At first four and later five more of these switches were installed in the GÉANT network to form a Global Platform for Labs (GP4L, originally called GÉANT P4 Lab), described in Section 3.1.

The Programming Protocol-independent Packet Processors (P4) language is used for programming the data plane language of network devices, which may include programmable network interface cards, FPGAs, software switches and hardware ASICs. Interoperability tests are therefore of great interest. The RARE/FreeRTR team had the chance to be part of such tests at the European Advanced Networking Test Center (EANTC) in Berlin in March 2023 and were able to successfully show interoperability between RARE/FreeRTR and Juniper in a Border Gateway Protocol – Classful Transport (BGP-CT) [BGP-CT] demonstration. The results [BGP-CT_Results] were presented in Paris at the MPLS SD & AI Net World Congress 2023 in April [BGP-CT_Demo] (Figure 2.1).

Figure 2.1: RARE/FreeRTR listed as participant at the MPLS SD & AI Net World Congress 2023

With Intel announcing it is no longer developing Tofino switches based on the Barefoot Networks chipset [Intel Tofino], the RARE team focuses on the investigation of new hardware platforms such as Asterfusion switches [Asterfusion].

Starting from the already feature-rich operating system, the main focus during 2023 and 2024 is on the integration of specific use cases with the RARE platform. One such use case includes GÉANT Firewall on Demand (FoD) [GN FoD] and Network Monitoring (NeMo) [GN NeMo] for DDoS protection; a second use case focuses on the integration with the 5G User Plane Function (UPF).

FoD is a DDoS mitigation software developed for NREN Network Operations Centre (NOC) administrators to mitigate DDoS attacks through the GÉANT core towards their connected networks using FlowSpec rules they can control themselves without any need to contact the GÉANT NOC. The NeMo DDoS software is a tool for Netflow-based DDoS and traffic anomaly detection, analysis and mitigation. The first use case investigated how GÉANT services such as FoD and NeMo can be integrated with RARE/FreeRTR so that unwanted traffic can be mitigated by leveraging P4 data planes automated by BGP FlowSpec. In this use case, an automated solution is created based on Containerlab [Containerlab] that makes it easy for users to set up and simulate attack mitigation experiments in their networks.

This use case was shown in a two-part demo at the “Relying on RARE for DDoS Attack Protection” infoshare [RARE Infoshare]. The first part of the demonstration showed automated DDoS mitigation in a virtual network environment created by FreeRTR where an attacker host and a victim host interconnected with a BGP FlowSpec-capable FreeRTR BGP-peering with FoD. Two execution alternatives for automated FoD mitigation were shown, one based on Docker Compose [Docker Compose] and one based on Containerlab. In the second part of the demonstration, it was shown how the NeMo tool can be employed to complement FoD using NetFlow-based data for more advanced anomaly detection and how it can be integrated with FreeRTR for mitigation. The infoshare recording is available on the GÉANT YouTube channel [RARE Infoshare YT].

The second use case deploys the 5G User Plane Function (UPF) functionality in RARE/FreeRTR in an effort to separate this function from the 5G core implementation, and avoid strong dependency of 5G solutions on vendor-specific (and often expensive) equipment. The main function of UPF in 5G is the routing of traffic between the Radio Access Network (RAN) and other external networks. The RARE/FreeRTR use case not only offers the advantage that UPF packet processing can be offloaded for improved performance but also allows full control of traffic. The UPF implementation developed in the RARE/FreeRTR use case employs the Packet Forwarding Control Protocol (PFCP) to communicate with the 5G Session Management Function (SMF) that is responsible for monitoring and managing PDU sessions. Forwarding and tunnelling of user data is achieved with the GPRS Tunnelling Protocol (GTP) and its encapsulation/decapsulation. A presentation "Design and implementation of an open-source and production-ready 5G UPF on RARE/FreeRTR" has been accepted for the TNC24 conference in June 2024.

RARE/FreeRTR and use cases were presented worldwide at large venues such as the Asia Pacific Advanced Network (APAN) APAN55 and APAN56 meetings [APAN55], [APAN56], the 2023 Internet2 Technology Exchange [I2TE23] and TNC23 [TNC23]. RARE was also part of the WP6 Task 1 Milestone M6.2 event "Network Technologies Workshop" [M6.2_NTW].

A new documentation platform was developed with reference guides, installation guides and cookbooks and is available at [RARE_Docs_GN] and [RARE_Docs_GitHub]. A learning unit on RARE which includes a step-by-step installation guide is being developed to be part of the Network eAcademy [NeA]. As of September 2023, RARE has a new logo that was developed in collaboration with Work Package 2 (Figure 2.2).

Figure 2.2: New RARE logo

2.2 Quantum Technologies

The NRENs in the GÉANT community are currently exploring how to start up quantum-based infrastructures or testbeds, and how to incorporate quantum into their existing digital infrastructures, participating along the way in many quantum-related projects [EuroQCI], [OpenQkD], [QPSNC]. As the technology is still evolving and standards and recommendations are still being developed and published, and as the level of involvement and advancement in the field differs within the GÉANT community, information exchange and training are seen of great importance.

For information and knowledge sharing within the community, several different approaches were implemented including infoshares, wiki, a white paper with state-of-the-art information and also community involvement in an Open Quantum Group Meeting.

Three infoshares were conducted where Quantum Key Distribution (QKD) and Quantum technologies were featured: a first infoshare was entitled "Celebrating World Quantum Day" [QT_Infoshare_1] and took place on April 14, 2023 – the actual World Quantum Day – to highlight the importance of the topic and raise awareness within the GÉANT community. Nine NREN members presented their activities and projects related to quantum technologies. Through their short, lightning-talk-like presentations, the participants were able to learn about the current status of their activities, ongoing projects, could meet the NREN experts and get instructions on where to find more information.

A second infoshare called “Quantum Solutions” [QT_Infoshare_2] was organised on June 21, 2023. The event offered a platform for NRENs to hear about quantum products and solutions from 11 vendors.

Quantum technologies were also part of a third infoshare – the WP6 Task 1 Milestone M6.2 event entitled “Network Technologies Workshop” [M6.2_NTW] with a focus on ongoing standardisation work and standardisation roadmaps. Recordings of all infoshares are available via the respective event pages.

For further dissemination and community involvement, quantum-related topics and a quantum knowledge hub [QT_wiki] are included as a part of the Network Development (NETDEV) platform of WP6 [NETDEV_wiki]. This is where NRENs can find news such as the latest WP6 Task 1 quantum publications with links to published learning units and have access to a variety of quantum-related topics, for example newly added sections on quantum standardisation and quantum simulation.

A white paper, *QKD Concepts and Considerations* [QKDC&C_WP], was published on January 31, 2024 to support NRENs with a state-of-the-art document that discusses aspects of deployment and implementation of quantum key distribution networks, standardisation, hardware and interoperability issues as well as monitoring and operations. The white paper describes current QKD networks and how the challenge of implementing trusted nodes must be approached. It also highlights security challenges and considerations to show why hardware certification is still such an important topic.

To keep in touch with current issues that members of the community are facing, periodic Open Quantum Group Meetings are being held where NRENs have the opportunity to share news about their activities and can present topics in focus or possibilities for collaboration. Nine meetings have taken place in the reporting period, with the next scheduled for May 10, 2024.

As part of the GÉANT Network eAcademy a new track was started, called “Quantum Technology”, and learning units are being developed within the categories “Introduction to Quantum Algebra”, “Quantum Resources”, “Quantum Simulation”, “Quantum Communication” and “Standardisation”. Similar to the Network Automation track, a metro map was created in collaboration with WP2 (Figure 2.3), where each line represents one of these categories, with metro stations representing individual units within this category.

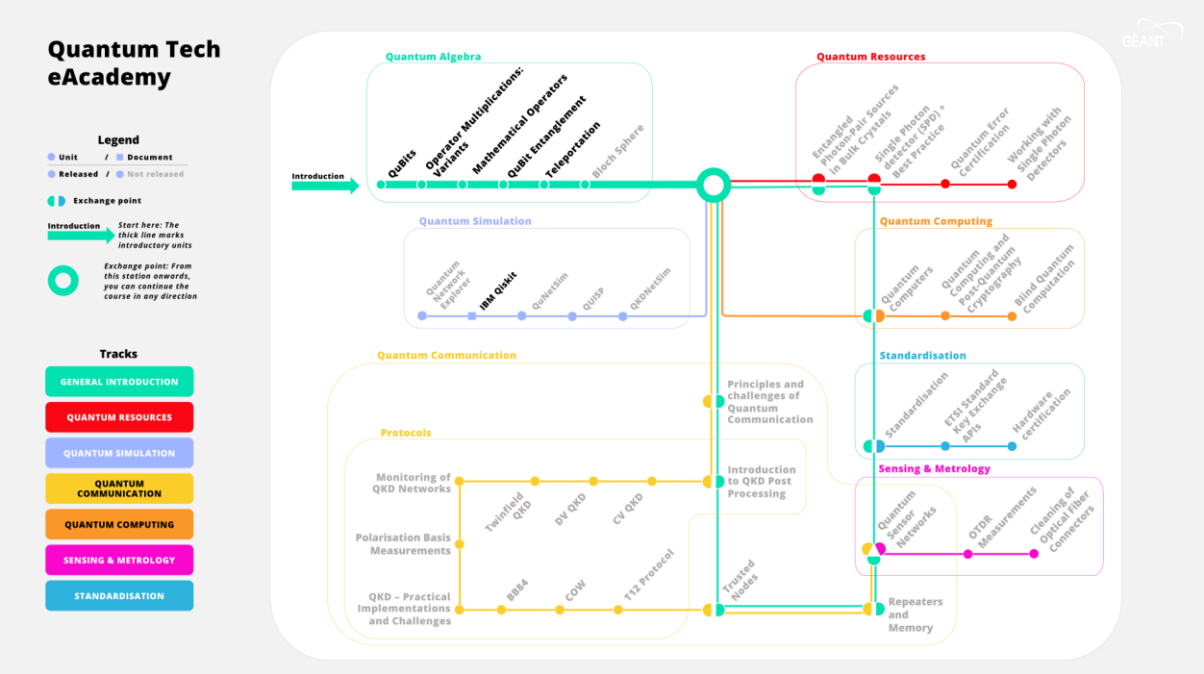

Figure 2.3: Quantum training metro map

For example, a green line takes the interested learner through a sequence of courses that provide an introduction to and understanding of general concepts related to quantum technologies. A Quantum Algebra class with five core learning units is part of this green introduction line, to help the learner understand the quantum concepts of entanglement and teleportation which constitute the foundation of quantum communication. The complete Quantum Algebra class comprises "QuBits" (a short teaser unit to introduce the world of QuBits), followed by the learning units "Operator Multiplication: Variants", "Mathematical Operators", "QuBit Entanglement" and "Teleportation", with an optional supplementary sixth learning unit "Bloch Sphere". An additional learning unit in the review pipeline that is also foreseen for the green introductory line is "Introduction to QKD Post Processing". More advanced courses currently under review are "ETSI Standard Key Exchange APIs" and "Entangled Photon-Pair Sources in Bulk Crystals".

2.3 Optical Time and Frequency Networks – OTFN

The third area of work in the Technology Task is related to optical time and frequency networks (OTFN), focusing on investigating options for possible services around high-performance ultra-precise time and ultra-stable frequency distribution. As described in *Distributing New Performant Time and Frequency Services over NREN Networks* [OTFN_NREN], only a few European NRENs have knowledge and experience in deploying and running OTFN, at the same time using different technical approaches and solutions. Given the growing interest from the NREN community and their local National Metrology Institutes (NMIs) as primary candidates for OTFN services, the work within WP6 Task 1 was in two directions: technical work on exploring possibilities for a Europe-wide network as a platform to provide OTFN services, and dissemination and knowledge exchange.

The exploratory work on a possible Europe-wide infrastructure with compatible cross-border services was run as an 8-month NETDEV incubator project [NETDEV_Inc], also building upon the outcomes of the recently completed CLONETS-DS project [CLONETS_DS]. The benefits of such a network include important objectives such as having a more reliable and accurate frequency distribution over fibre which could also serve as a backup for the Global Navigation Satellite System (GNSS) which is prone to jamming and spoofing attacks. This would also allow time comparisons by NMIs of UTC(k) references and frequency comparisons that would support the redefinition of the SI second aimed for by 2030. Other benefits include that highly accurate time stamp services could be made available and important fundamental research could be supported in areas such as quantum sensing, relativistic geodesy or astronomy.

The incubator project evaluated cost options, requirements and needs and narrowed the work to four topology options depending on the available budget. One of those options, Option A, is presented in Figure 2.4. With this option, the work on creating a pan-European time and frequency network continues even beyond this project phase, all based on the research and investigative activities in WP6 and towards a major new production service.

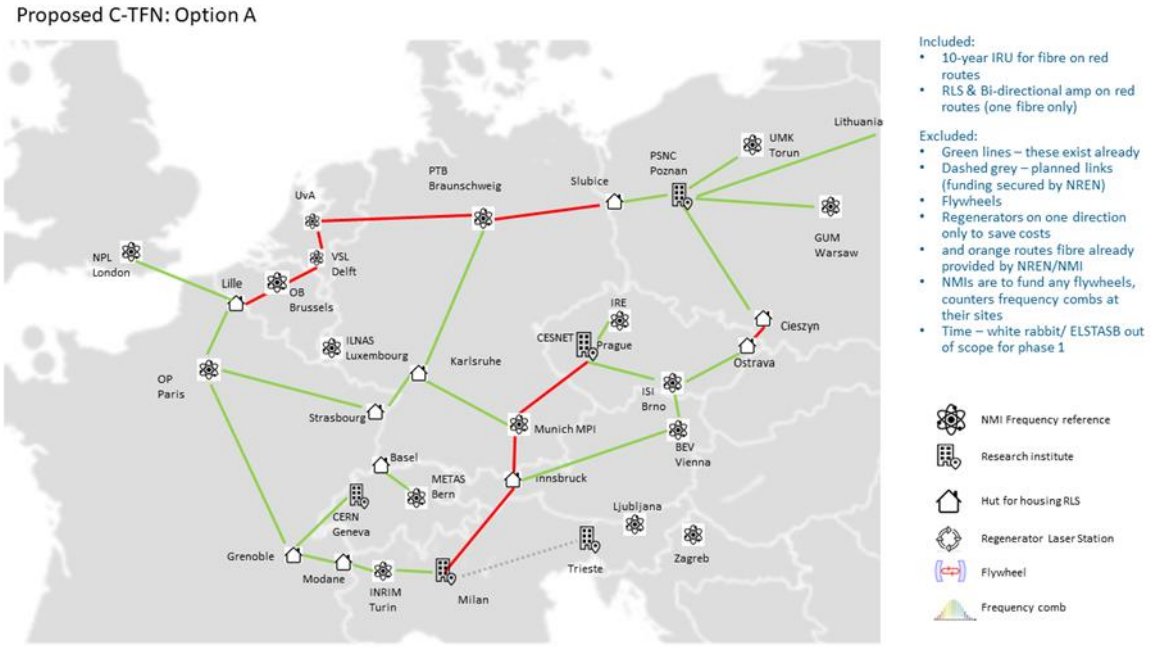

Figure 2.4: Topology Option A [OTFN_IncubatorReport]

The incubator study also looked at existing and planned NREN frequency services and their integration. A first pathfinder link (Figure 2.5) was identified between the Poznan Supercomputing and Networking Centre (PSNC) [PSNC] in Poznan, Poland, and the Physikalisch-Technische Bundesanstalt (PTB) [PTB] in Braunschweig, Germany.

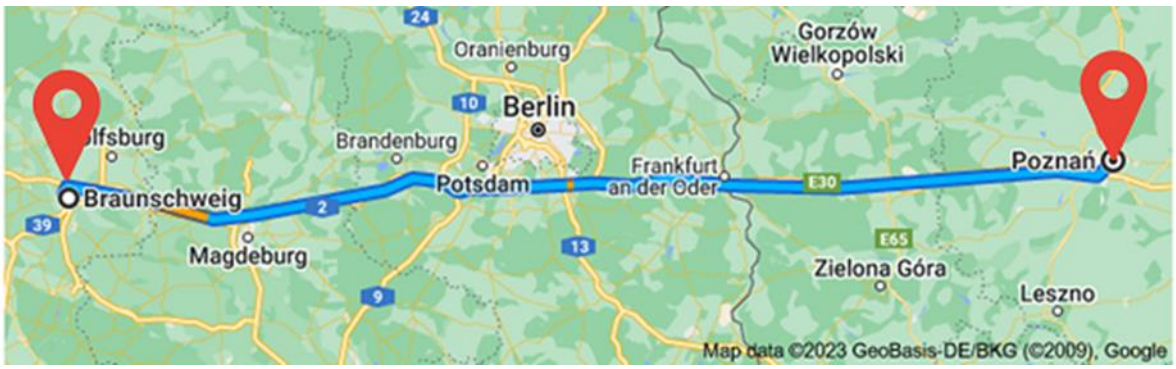

Figure 2.5: Pathfinder link [OTFN_IncubatorReport]

A discussion and planning meeting was held at CERN on February 7–8, 2024 involving both the NREN and NMI communities, with a focus on topology and the service roadmap. In several break-out sessions issues such as technical requirements, but also sustainability, business models and interconnect agreements were discussed. One major topic was the formation of a metrology community forum with representatives from both NMIs and the NREN community to ensure that time and frequency services can be addressed with the adequate expertise.

The incubator project recommends that both frequency and time services should be implemented (starting with frequency). The architecture of these services distinguishes between a time/frequency transfer layer and a time/frequency service layer (Figure 2.6). The transfer layer represents the infrastructure that is required to carry the services and includes infrastructure components and their operation and maintenance such as amplifiers, Regenerator Laser Station (RLS) equipment and the dark fibre. The service layer consists of all the devices and equipment needed to actually produce the time and frequency service. Components include

frequency combs, flywheels and also RLSs, as well as White Rabbit (WR) and Electronically Stabilised Fibre-Optic Time and Frequency Technology (ELSTAB) equipment.

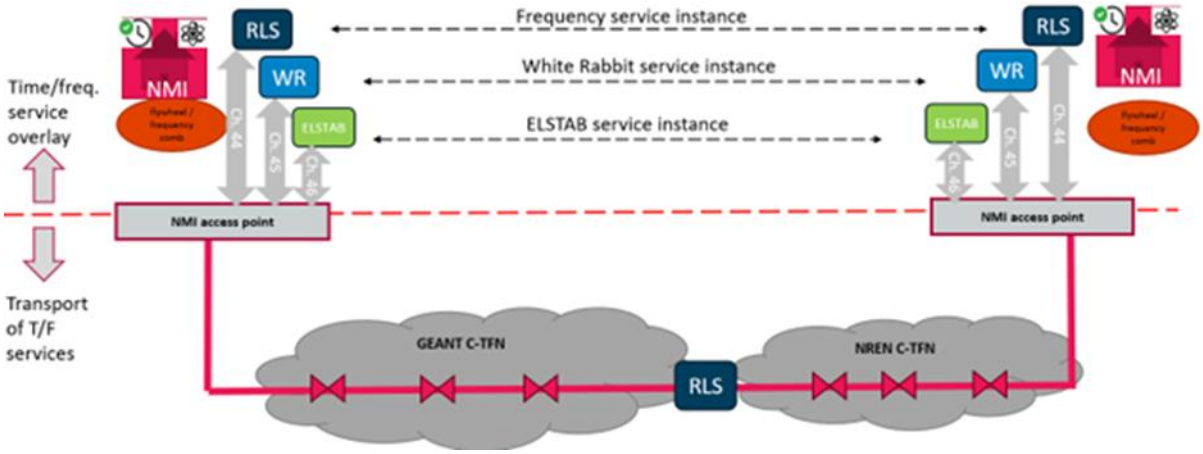

Figure 2.6: Time/frequency service and transport layer [OTFN_IncubatorReport]

In the OTFN subtask, investigations are underway to prepare adequate monitoring solutions for both transfer layer and service layer components, and a first monitoring pilot solution is being prepared for the pathfinder link. In order to have a very flexible solution it was decided to use TimeMap [TimeMap], currently employed for latency and jitter over the GÉANT network, and adapt it to the time/frequency infrastructure. TimeMap is implemented based on Telegraf, InfluxDB and Grafana and supports eduGAIN federated authentication. The monitoring solution is being developed in cooperation with the TimeMap team in the WP6 Monitoring Task (Task 3).

With the publication of "Optical Time & Frequency Activities in the GÉANT Project (Past & Future)" in *Proceedings of the 54th Annual Precise Time and Time Interval Systems and Applications Meeting*, January 23–26, 2023, Long Beach, CA [OTFN_GÉANT], a summary description was provided of the current European landscape of implemented technologies and the challenges that need to be overcome for cross-border links. More information on time and frequency services in Europe can be found in the OTFN NETDEV wiki under a new section called "TF Gateway" [OTFN_wiki_TFG]. Special information on monitoring and calibration of equipment can be found in the section "Monitoring and Calibration" [OTFN_wiki_M&C].

OTFN was also a topic in two infoshares: in the WP6 Task 1 Milestone M6.2 event "Network Technologies Workshop" [M6.2_NTW], various options and multi-domain solutions for optical time and frequency transfer in Europe were described. The second infoshare, held in January 2024 and called "PTP Operational Issues" [OTFN_Infoshare], focused on the deployment of the Precision Time Protocol (PTP): This was of great interest as more NRENs are moving from Network Time Protocol (NTP) to PTP as more applications and services require higher levels of accuracy and precision in networks.

A new track, "Time and Frequency Networks", was established as part of the Network eAcademy offering insight into general concepts for time and frequency services and information on specific technologies such as White Rabbit or ELSTAB. Four learning units are under review: three are related to general introductory concepts such as "Why Do We Need Precise Time?", "Introduction to Time and Frequency" and "Metrology Concepts for Time and Frequency". The fourth learning unit focuses on "Experiences with Setting Up a White Rabbit Network".

2.4 Fibre Sensing

Several GÉANT project partners recognised the need to evaluate the possible benefits and opportunities of using existing optical fibres as a sensing instrument to gather information about their network infrastructure and its surroundings. The gathered data might be valuable not only to network engineers in the context of network management and preventive maintenance, but also to researchers in the fields of seismology, oceanography or marine zoology. A project was proposed using the previously mentioned NETDEV incubator process, to explore whether there is a common interest from these NRENs for joint work and results sharing and, if yes, to identify possible immediate and future work within the community. The findings are documented in *Fibre Sensing Focus Group: Conclusions and Future Work* [FS_FGReport].

With fibre sensing, large amounts of data can be collected enabling monitoring of physical changes in the network that could point to security and operational issues, but also to disturbances and intrusions in the infrastructure. The extensive monitoring data through fibre sensing would also offer NRENs additional information about optical stability and could support time and frequency services that way. The incubator team identified several NREN roles in relation to fibre sensing technology: not all NRENs may decide to take on core sensing technology roles (NRENs with submarine cables may have more of an incentive to use fibre sensing for the detection and localisation of fibre cable faults); some NRENs may take on more strategic or operational roles.

Fibre sensing technology is based on the principles of optical time domain reflectometry (OTDR) where light pulses are injected into fibre. The receiver then measures the light backscattering. Scattering processes used for sensing include Brillouin scattering, Rayleigh scattering and optical interferometry. A very recent method is also state of polarisation (SoP), such as SoP sensitive Optical Time Domain Reflectometry (SoP-OTDR).

The evaluation of the incubator team outlined a three-part roadmap for the NREN community: short-term work on fibre sensing that would be conducted in 2024, followed by mid-term activities from 2025 through 2027, and finally a long-term objective from 2028 and beyond. The short-term investigation would focus on existing requirements, techniques and solutions, raising NREN awareness, contacting user groups and fostering collaboration, and roadmap planning in preparation for the mid-term activities. Special focus areas were identified, including data acquisition and visualisation as well as an analysis of the resources that would be needed for a service supporting a multi-domain R&E environment. Mid-term activities were divided into technical activities, user- and service-oriented activities, and activities supporting data management (including access policies and privacy and security issues). Mid-term activities are foreseen to be supported by a design study, experiments and field trials, and data management with proof of concept. Long-term activities have the goal of setting up a large-scale sensing network over the GÉANT and NREN infrastructure.

This short incubator project concluded with the aim to gather an extended team to start working on the objectives recognised as achievable in the short-term.

3 Platforms

The WP6 Task 2 team maintains and develops platforms that provide users with the functionalities to test new network technologies, manage and monitor network services, and automate and orchestrate network operations. Some of the work is a continuation of initiatives started in previous GNx projects – the development of the Global Platform for Labs (GP4L) programmable network infrastructure, the maintenance of production nmaas (formerly Network Management as a Service (NMaaS)) and Service Provider Architecture (SPA) services – in addition to the new activities, including the automation of network operations in the GP4L infrastructure, the design and pilot implementation of network service orchestration, and the development of the resource and service inventory management application called Maat.

The following subsections present the current status and the results achieved in each of those work areas.

3.1 Global Platform for Labs – GP4L

The Global Platform for Labs (GP4L) [GP4L] is an operational environment of programmable network switches established during the GN4-3 project [GN Projects] to evaluate and test an open source network operating system developed as a part of Router for Academia, Research and Education (RARE) [RARE].

GP4L is based on cost-effective network hardware, programmable at the silicon level using the Programming Protocol-independent Packet Processors (P4) language. Its first generation is based on the Edgecore Wedge 100BF-32X model. The key highlights of this model are 32 x 100GE QSFP28 ports with a switching capability up to 6.4 Tbps (4.7 Bpps).

Starting as GÉANT P4 Lab with four switches provided by the GN4-3 project and placed in Amsterdam, Frankfurt, Budapest and Poznan, it grew quickly by including switches from the partner R&E institutions (the community) that wanted to co-create a global infrastructure for experimenting with cutting-edge network technologies. Closer to the end of the GN4-3 project, GP4L was further expanded by two additional 400GE-capable (Edgecore AS9516-32) P4 switches placed in Geneva at CERN and connected to the Frankfurt P4 node.

Figure 3.1 below depicts the GP4L core nodes (belonging to GÉANT):

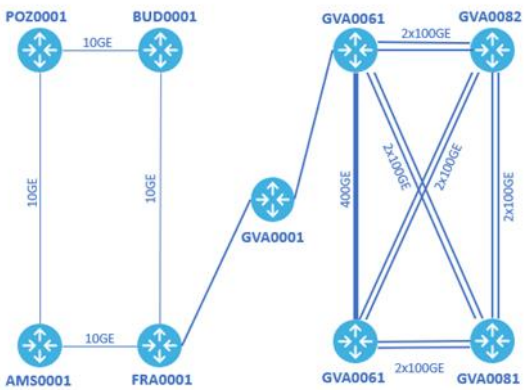

Figure 3.1: GÉANT nodes in GP4L

Through active dissemination, the interest in RARE and GP4L grew at the global level, with many organisations wanting to join GP4L and connect their nodes. Apart from the GÉANT nodes, the current GP4L also includes RARE nodes based on Asterfusion X312P-48Y-T and DPDK with a possibility to expand with other platforms such as FPGA or DPU hardware.

As at April 2024, GP4L connects 35 nodes belonging to various worldwide research and education institutions (see Figure 3.2), consisting of equipment purchased by the GÉANT project and the switches from the partner institutions (the community).

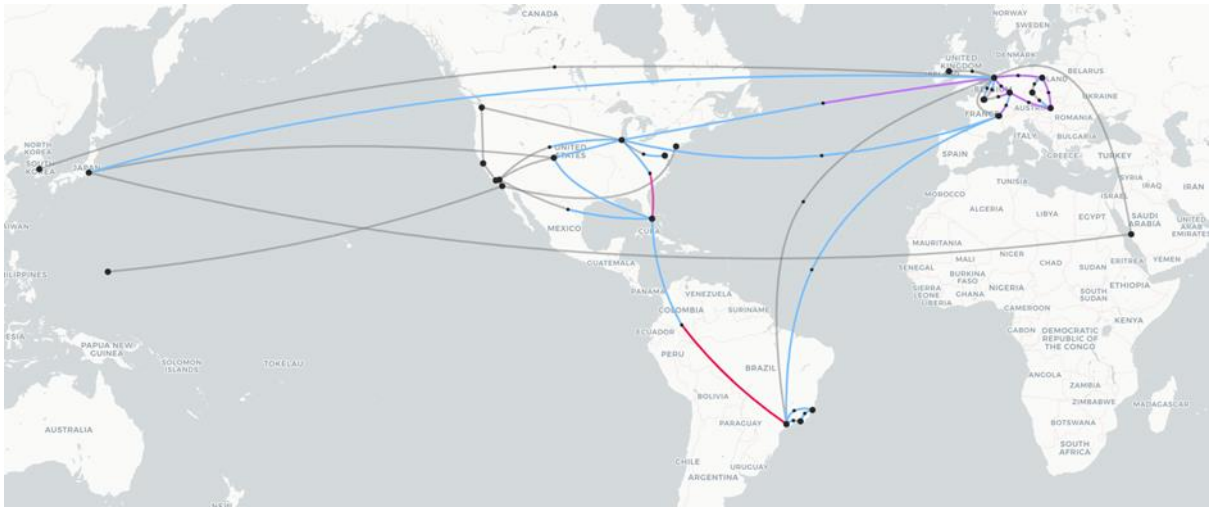

Figure 3.2: The GP4L global infrastructure in April 2024

Apart from maintenance and further extension of this programmable platform, the work on GP4L focuses on infrastructure advancement through automation, orchestration and virtualisation of network operations, in order to enhance operational efficiency through digital transformation. The objectives of this work are to:

- Transition towards a self-service approach, enabling end users to independently conduct experiments within the GP4L environment.
- Explore and showcase various automation and orchestration methodologies to benefit the broader GÉANT community.
- Offer a highly adaptable solution for interested parties, facilitating easy deployment and integration into existing infrastructures.

Several use cases are of interest: the digital twin concept, resource management, self-service reservation and service provisioning. Each of these is described below.

3.1.1 Digital Twin

As part of the work to automate network configuration, the GP4L team experimented with the concept of a "digital twin", which entails generating a virtual copy of the network infrastructure. This copy serves as a preparatory step for testing in a pre-production environment within a CI/CD workflow, before implementing changes in the production network configuration. Collaborating with Netreplica [Netreplica], the team utilised the nrx software [nrx], designed to export network topologies from NetBox [NetBox] (the inventory system used by GP4L for storing topologies) into the Containerlab [Containerlab] virtual environment. Containerlab allows the network infrastructure to be replicated in virtual form, connecting and configuring network devices as in a physical infrastructure. A digital twin was created for GP4L and is used to visualise the network topology of the

lab. Another digital twin was created for the PIONIER network [PIONIER] and it is used as one of the components of the development environment for testing the implementation of orchestrated service provisioning (see Section 3.1.4.

3.1.2 Resource Management

GP4L implements resource management automation using NetBox [NBDocs] as the network's single Source of Truth in which comprehensive information about GP4L devices is stored. Its REST API facilitates the management of stored information, while webhooks serve as notification hubs, relaying changes to relevant information based on user-defined event rules. In addition to NetBox, two other components for network tracking and management are used:

- Uptime Kuma [UTKDocs]: to monitor the health of all GP4L devices with a separately developed open source project offering a REST API for programmatically managing monitoring probes.
- Oxidized [OXDocs]: a network device configuration backup tool integrated with a Git repository. This integration supports an automated approach to tracking devices in Oxidized and retaining a history of configurations.

Camunda [CDocs] is used for orchestrating two end-to-end processes: one of adding a new active GP4L device in the NetBox [GP4L_OD_UC1], and another of processing parameter change or removal of a GP4L device in NetBox. [GP4L_OD_UC2] By implementing these processes, the multi-step process of maintaining consistent information across the GP4L network management has transformed into a single-step process: the network administrator needs to keep the NetBox information up to date, and the rest is propagated automatically.

3.1.3 Self-Service Reservation

A self-service reservation scenario allows users to specify the GP4L resources they require for their experiments using a self-service portal. Upon reservation creation, network administrators are notified of the usage request and can then decide whether to approve it. Approved reservations grant users access to the reserved resources during the defined reservation period. For this scenario, the suite of orchestrated network management components is expanded with three additional elements, all accessible through nmaas:

- LibreBooking [LBDocs], for user self-registration and reservation creation.
- Bastion [BDocs] server, built on Ubuntu, which facilitates VPN access to a designated device set via SSH.
- Apache Airflow [AFDocs] workflow engine, for the programmatic creation, scheduling, and monitoring of workflows.

High fidelity of the self-service reservation use case (that is, integrity to ensure the reservation is completed as per the initial requirement, robustness and reliability to ensure it can withstand the challenges of orchestration and automation of distributed resources and execution in such a complex environment) has been assured with additional processes defined in Camunda and executed daily to ensure that the information between LibreBooking and NetBox is always in sync. This use case is designed for extensibility, facilitating easy adoption by other entities for self-reservation capabilities. Further details are available at [GP4L_OD_UC3].

The self-service reservation solution is implemented for GP4L. It aims to replace the manual handling which is currently done by users who plan to run experiments on the GP4L infrastructure. In addition, the University of Murcia has shown interest in integrating this use case within their premises, aiming to manage researchers' access to their extensive lab resources.

A presentation on the reservation use case was given at the RIPE SEE 12 meeting in April 2024 in Greece [RIPE SEE12] and is scheduled for the TNC24 conference in June 2024 in France [TNC24].

3.1.4 Service Provisioning

In this scenario, GP4L is used as a platform for automated and orchestrated service provisioning for L2 services in the PIONIER network, in collaboration with and for the use case of the Polish NREN PSNC. Service provisioning implementation is based on TM Forum Order-to-Payment business processes definition, which encompasses all necessary steps: capturing customer orders, configuring and testing services, setting up monitoring, and fulfilling client orders, including usage tracking and billing as required.

By abstracting this process to define common steps in the service provisioning activities, and by envisioning a repository of processes, sub-processes, and elementary tasks, the goal is to provide a generalised, reusable method for orchestrating service provisioning as a collaborative blueprint that can be adopted by other NRENs.

Using the tools which are available on nmaas, this service provisioning approach and methodology is applied to develop workflows to provision example services in the PSNC network PIONIER such as L2 circuits. The approach and the current status of this work were presented at the 31st Service and Technology Forum meeting in April 2024 [STF31].

3.2 nmaas

nmaas is a multi-tenant platform for effortless, on-demand deployment of software tools and applications. (Formerly Network Management as a Service (NMaaS), the platform now supports more than just NMaaS and is being rebranded and redefined to reflect its expansion.) At its core, nmaas leverages a catalogue of containerised applications that can be deployed in an existing Kubernetes cluster. It allows each application instance to be tailored to the user's needs through a configuration process either at deployment time or at any point afterwards, while the application is running.

The platform includes three aspects:

- Providing, managing and maintaining the infrastructure of the self-service portal (Figure 3.3), platform and selected tools.
- Supporting users in using the platform and the offered tools in their individual contexts (e.g. for local network monitoring).
- Supporting users in contributing their software to the nmaas platform. The nmaas team decides which tool will be offered via the platform and supports contributors in providing their software via the platform.

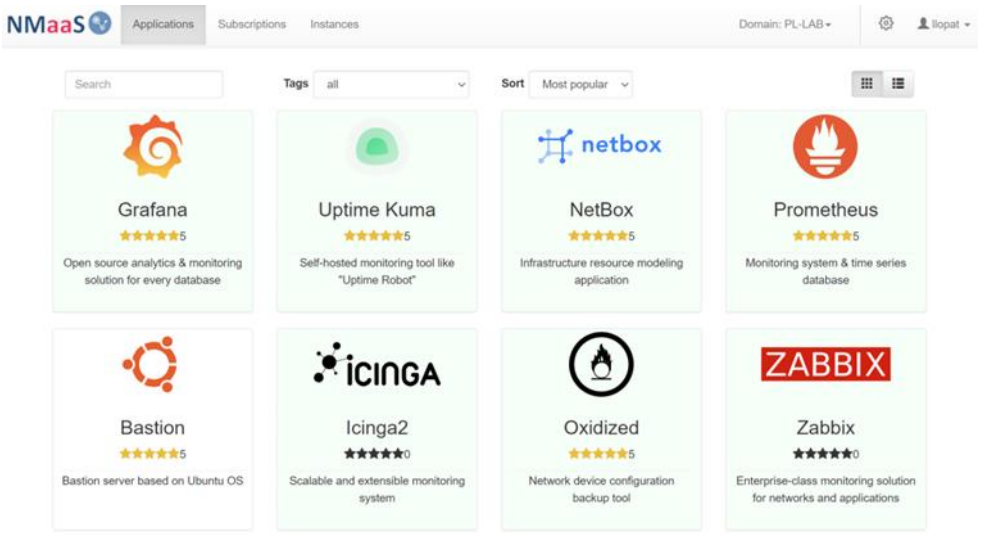

Figure 3.3: View of the nmaas portal

The GÉANT project offers nmaas in two forms:

- The nmaas software [nmaas GitLab] for organisations (usually NRENs) who wish to download and install an nmaas instance on their own infrastructure for their users, and providing support for those organisations.
- nmaas installations managed and operated by the WP6 Task 2 nmaas team.

Using a multi-tenant approach and software-based VPNs, each client organisation has private access to its isolated network management toolset running on a central nmaas instance. The nmaas user can create a containerised environment with pre-installed network management and monitoring tools, tailored for his/her own needs, securely separated from other users. In this way, users can focus on the management of the infrastructure they are responsible for, instead of taking care of the underlying platform itself.

Initially aimed at supporting National Research and Education Networks (NRENs) and their end-institutions in monitoring their infrastructures, nmaas offers an extensible catalogue of network management applications which can be deployed with just a few clicks either on the managed production instance operated by the GÉANT project, or on a self-hosted one deployed on the NREN's premises.

Lately, leveraging its capability of easy application deployment, a second use case has been developed for nmaas and it is starting to be used in the educational context as a Virtual Lab.

3.2.1 Virtual Labs

nmaas for Virtual Labs is a new nmaas use case aimed at educational communities. It leverages the existing nmaas functionality of on-demand application deployment and applies it in a learning context. This approach allows the nmaas platform to be further used in the process of both formal, supervised learning (such as university courses) and for informal and self-paced learning (MOOCs, short demos, tutorials). Examples of learning areas where nmaas for Virtual Labs can be applied include, but are not limited to:

- Cybersecurity – deployment of randomised, black-box container applications for studying common software vulnerabilities.

- Data analytics – offloading of resource-intensive workloads on a centralised and powerful computing infrastructure where the nmaas platform itself is deployed, through the deployment of relevant software tools for data analytics, simulations, and complex workflows.
- Web development – creation of personalised, portable development environments with all necessary supporting services included, such as web-based integrated development environments (IDEs), relational databases, message queues, application servers, etc.
- Devops – hands-on experience with popular continuous integration solutions hosted directly on top of nmaas, mitigating complex deployment operations or advanced configuration which might be challenging for novice users.

Two nmaas for Virtual Labs pilots have been organised for university courses at the Ss. Cyril and Methodius University in Skopje, North Macedonia, and were used as an opportunity to verify the new functionality in practice. The first pilot was dedicated to a cybersecurity course, where students were tasked with discovering and exploiting as many vulnerabilities as possible on a purposely vulnerable web application deployed on nmaas. In total, 45 students took part in this first pilot activity.

The experience from the first nmaas for Virtual Labs pilot was used by the team to define further enhancements to the use case, mostly focused around refining the visual presentation of the web components developed as part of the newly introduced features, as well as additional privileges to better fit virtual lab managers' role in the system. To this end, the second pilot centred on evaluating the improved virtual lab manager experience, and testing the previously untested bulk application deployment functionality. This pilot, also conducted at the Ss. Cyril and Methodius University in Skopje, North Macedonia, encompassed 30 students participating in an IT service management course. As previously, a total of 30 application deployments were performed, one for each participating student.

The nmaas for Virtual Labs use case was presented at the GÉANT infoshare "NMaaS Virtual Labs for Education" in November 2023 [nmaas Infoshare], the 2023 Internet2 Technology Exchange conference in the US in September 2023 [I2TE23], and the GÉANT Project Symposium in France in December 2023 [GN Symposium].

3.2.2 Platform Development

The nmaas software components are actively maintained and further enhanced with new features, improving the overall user experience and enabling support for additional use cases. During the last quarter of 2023, nmaas repositories were pushed to a newly created nmaas group on GÉANT's GitLab instance [nmaas GitLab]. In parallel, nmaas underwent a licence management process within the project which resulted in Apache Licence 2.0 being applied to all major nmaas components, and the entire solution is now fully open source. The nmaas team is now extensively using GitLab not only for source code management but also for collecting issues, release management and continuous integration in a public and transparent manner.

During 2023, three minor versions of nmaas were released, focusing on fixing issues and smaller enhancements. The major nmaas v1.6.0 version released in March 2024 included a number of new features implemented towards support of nmaas for Virtual Labs such as domain groups (containing one or more domains and specifying what applications are available for deployment by the users in given domains), bulk user account creation and domain setup, bulk application instances deployment and dedicated user role for virtual labs management. More details are provided in the release notes [nmaas V1.6.0 RN].

3.2.3 Service Maintenance

As part of the regular production service maintenance, the nmaas team is continuously engaged in multiple tasks such as: documentation updates, provisioning of new user domains on the nmaas production instance [nmaas Production], registering additional VPN profiles for new people to access existing domains, as well as user support.

A total of seven new customer domains were created on the official nmaas Virtual NOC instance along with 44 new client access VPN profiles. The catalogue of network management applications was further improved with new entries as well as version updates to existing ones. Additionally, major version upgrades were performed to a number of applications such as: renaming Inventory3 to Maat; extending the popular Uptime Kuma monitoring application with a third-party component; customising the existing Bastion application with a web interface for managing SSH keys developed by the nmaas team; migration to the use of the official Oxidized Docker image instead of a custom image maintained by the nmaas team. Minor version upgrades of smaller scope to existing catalogue applications are continuously performed by the nmaas team and are thus not explicitly mentioned.

Monitoring and maintenance tasks were continuously performed, supervising one production Virtual NOC instance [nmaas Production], one Virtual Labs trial instance [nmaas VLTrial], four development nmaas instances, various web, email and application servers supporting either the production nmaas instance or some of the development ones, analysing retroactively nmaas usage patterns, such as the number of newly deployed applications, the number of upgrades performed by users, instance load, etc. A continuous ongoing activity is monitoring for new version releases for the applications already integrated into the catalogue or some of the used supporting software.

Additionally, a new dedicated documentation website was set up [nmaasDocs], aggregating all of the previous content posted in various places across the Internet. Dedicated spaces were created for the nmaas for Virtual Labs use case [nmaas VLDocs], as well as for highlighting past dissemination activities [nmaas Presentations].

3.3 Service Provider Architecture – SPA

The Service Provider Architecture (SPA) [SPA] was designed as a blueprint for the implementation of a microservices-based modular digital service management platform that embodies the TM Forum Open Digital Architecture (ODA) guidelines and principles [ODA]. SPA enables transition from siloed monolithic solutions used for single service management to modular, flexible designs based on orchestration of independent functional components that are consistently used for all service management actions.

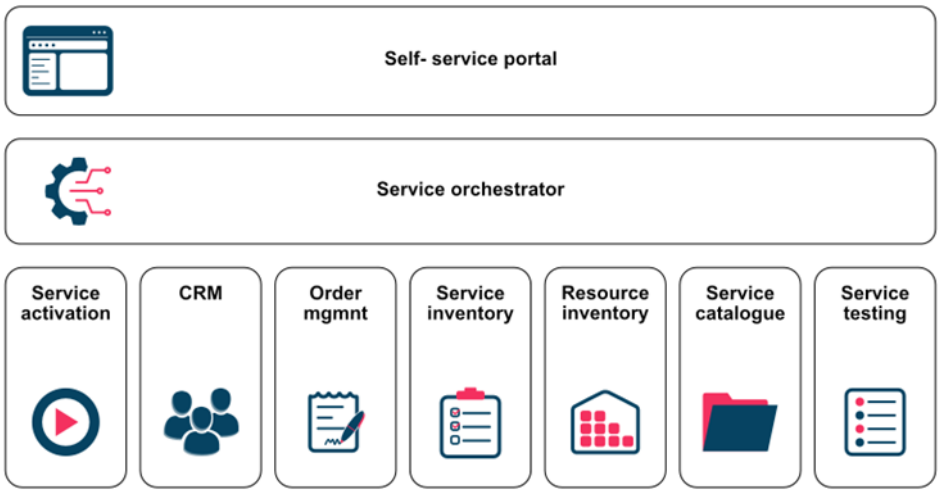

Figure 3.4: SPA architecture

The SPA architecture is presented in Figure 3.4, and its representation through the TM Forum Open Digital Architecture functional blocks is presented in Figure 3.5.

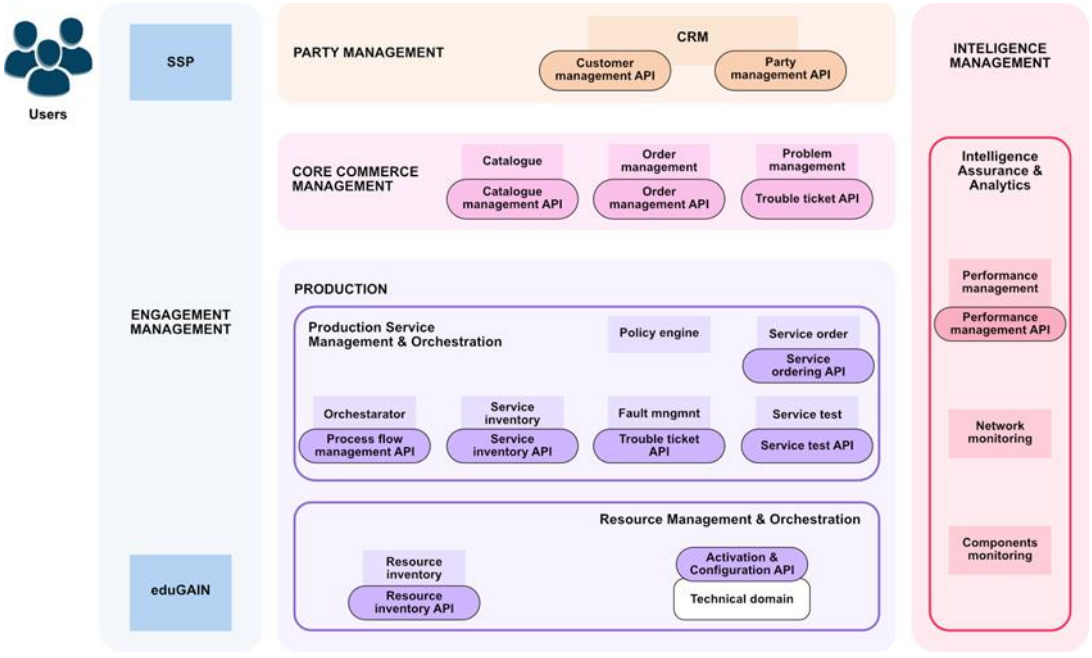

Figure 3.5: SPA architecture represented through the TM Forum Open Digital Architecture functional blocks

SPA was designed during the GN4-2 project and the work on it has continued in WP6 in GN4-3 and GN5-1. SPA is developed as a platform and for several years has been deployed as a management environment for the GÉANT Connection Service (GCS) managed by the GÉANT Operations team, which enables orchestrated and automated creation of L2 circuits across the GÉANT network using OpenNSA to deliver Microsoft Express Route circuits. With a slow retirement of the GCS service, the role of the SPA team is in supporting the GÉANT Operations team focusing mostly on software and infrastructure maintenance.

3.4 Maat

Maat is an application developed within the Platform Task and designed to manage resource and service information. Maat acts as a Source of Truth component in a network service orchestration and automation system and can easily and securely be integrated with other components using REST APIs and the authorisation protocol OAuth 2.0. The application is developed through collaboration with its users, based on the experience gained from the Service Provider Architecture platform and the GÉANT Connection Service (GCS). Maat's architecture, communication protocols and data models are aligned with TM Forum standards.

As a Source of Truth, the application stores the current and correct state of the network infrastructure and is the primary source of data for monitoring, configuration and other tasks in a network management system. The two implemented open REST APIs, called Resource Inventory Management and Service Inventory Management interfaces, allow data to be retrieved, deleted and updated, along with filtering and paging capabilities.

An important element of Maat is a flexible data model approach used to store resource and service data in a NoSQL database as JSON documents. The data definitions are placed in schema files so that the application can be configured to use different data models depending on the schemas used. By default, Maat uses the data model created by the TM Forum for the previously presented APIs, but it is possible to use multiple schemas and data definitions.

To enable security, Maat can be integrated with Keycloak (an open source identity and access management application [Keycloak]), which enables the REST protocol to be secured using the OAuth 2.0 standard (use of tokens to authenticate a user/client application that sends a request). In addition, Maat uses SSL to encrypt data transmission.

Maat is an application primarily intended to offer its Source of Truth functionality with exposed REST APIs as part of workflows that orchestrate network tools and serve to manage the lifecycle of network services, thus eliminating the need for manual, error-prone, tasks via the use of APIs. However, the Maat user should still be able to intervene in the database content or analyse it using an intuitive graphical interface. The application user interface is designed in collaboration with users to enable advanced search of resources and service instances.

Compared with NetBox – a popular Source of Truth tool often used within GÉANT community and featured in the GP4L resource management automation use case as a resource inventory (see Section 3.1.2) – Maat, with its flexible data model for services and a REST API for efficient integration, is suitable as both a resource and service inventory. Given that there are more tools that can serve as a resource inventory than as a service inventory, the focus of the work is on Maat's service inventory characteristics.

Maat was presented at the GNA-G Community meeting in February 2024 [GNA-G_VCs] and the 31st Service and Technology Forum [STF31] meeting in April 2024. More information and the source code are available at the Maat website [Maat].

4 Conclusions

This document has summarised the ongoing work within the Technology and Platform Tasks in the Network Development Work Package of the GN5-1 project. It has covered investigations and developments of technologies such as RARE, quantum and OTFN, including incubator work performed in areas such as OTFN and fibre sensing, that has aimed at sharing knowledge and best practices and focused on the approaches and areas of interest to the project participants and the community.

GP4L, nmaas, SPA and Maat offer more than just access to resources and implemented features. They provide opportunities to validate technologies and develop/test new solutions that can then be consulted, applied and/or implemented in any network. For instance, recent initiatives include orchestrating network operations within the GP4L infrastructure, implementing orchestrated network services utilising the Maat tool as a Single Source of Truth, creating virtual network twins for pre-production testing of configurations, and introducing a new educational Virtual Labs use case within the nmaas platform. The outcomes of these efforts are particularly relevant to NRENs, who assess the implemented solutions within their national networks. Additionally, it is worth noting that the Virtual Labs implementation is actively used for organising laboratory classes for students at Ss. Cyril and Methodius University in Skopje, North Macedonia. This helps explore the advancement and evolution of supporting technologies, tools and services at all their lifecycle stages, from early evaluation through deployment, production usage and later retirement.

Training and dissemination efforts will continue to accompany this work in all areas, highlighting topics that are identified by NRENs as essential and most sought-after.

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- GARR (FBK)
- GÉANT Association
- GRNET
- GRNET (ICCS)
- KIFÜ
- MARnet (UKIM)
- NORDUnet (DTU)
- NORDUnet (UNINETT)
- PSNC
- RedIRIS (UMU)
- RedIRIS (UPV/EHU)
- RENAM
- RENATER
- SURF (UvA)
- SWITCH
- UoB
- UoB (AMRES)

References

[AFDocs] https://airflow.apache.org/
[APAN55] https://apan55.apan.net/
[APAN56] https://apan56.apan.net/
[Asterfusion] https://cloudswit.ch/
[BDocs] https://docs.nmaas.eu/nmaas-applications/tutorials/bastion/
[BGP-CT] https://datatracker.ietf.org/doc/draft-ietf-idr-bgp-ct/
[BGP-CT_Demo] https://community.juniper.net/blogs/kaliraj-vairavakkalai/2023/05/22/bgp-ct-interop-demo-eantc2023
[BGP-CT_Results] https://eantc.de/wp-content/uploads/2023/04/EANTC-InteropTest2023-TestReport.pdf
[CDocs] https://camunda.com/
[CLONETS_DS] https://clonets-ds.eu
[Containerlab] https://containerlab.dev/
[Docker_Compose] https://docs.docker.com/compose/
[EuroQCI] https://digital-strategy.ec.europa.eu/en/policies/european-quantum-communication-infrastructure-euroqci
[FreeRTR] https://github.com/rare-freertr/freeRtr
[FS_FGReport] https://resources.geant.org/wp-content/uploads/2024/05/GN5-1_Fibre-Sensing-Focus-Group-Conclusions-and-Future-Work.pdf
[GN_FoD] https://security.geant.org/firewall-on-demand/
[GN_NeMo] https://security.geant.org/nemo-ddos-software/
[GN_Projects] https://GÉANT.org/projects/
[GN_Symposium] https://symposium.geant.org/
[GNA-G_VCs] https://www.gna-g.net/attend-a-meeting/gna-g-community-vcs-q1-2024/
[GP4L] https://wiki.geant.org/display/gp4l
[GP4L_OD_UC1] https://wiki.geant.org/display/gn43wp6/GP4L+Orchestration+Dev+-+Use+case+1
[GP4L_OD_UC2] https://wiki.geant.org/display/gn43wp6/GP4L+Orchestration+Dev+-+Use+case+2
[GP4L_OD_UC3] https://wiki.geant.org/display/gn43wp6/GP4L+Orchestration+Dev+-+Use+case+3
[I2TE23] https://internet2.edu/2023-internet2-technology-exchange/
[Intel_Tofino] https://www.intel.com/content/www/us/en/products/details/network-io/intelligent-fabric-processors/tofino.html
[Keycloak] https://www.keycloak.org/
[LBDocs] https://github.com/LibreBooking
[M6.2_NTW] https://events.geant.org/event/1404/
[Maat] https://GÉANT-netdev.gitlab-pages.pcss.pl/MaatDocs/ [login required]
[NBDocs] https://docs.netbox.dev/en/stable/
[NeA] https://wiki.geant.org/display/NETDEV/NeA
[NetBox] https://github.com/netbox-community/netbox
[NETDEV_Inc] https://wiki.geant.org/display/NETDEV/NETDEV+Incubator
[NETDEV_wiki] https://wiki.geant.org/display/NETDEV/
[Netreplica] https://netreplica.com/
[nmaasDocs] https://docs.nmaas.eu/
[nmaas_GitLab] https://gitlab.software.geant.org/nmaas
[nmaas_Infoshare] https://events.geant.org/event/1553/

[nmaas_Presentations] https://docs.nmaas.eu/nmaas-presentations/
[nmaas_Production] https://nmaas.eu
[nmaas_V1.6.0_RN] https://docs.nmaas.eu/release-notes/1.6.0/
[nmaas_VLDocs] https://docs.nmaas.eu/use-cases/virtual-lab/vlab-introduction/
[nmaas_VLTrial] https://vlab.dev.nmaas.eu
[nrx] https://github.com/netreplica/nrx
[ODA] https://www.tmforum.org/oda/
[OpenQkD] https://openqkd.eu/
[OTFN_GÉANT] https://www.ion.org/publications/abstract.cfm?articleID=18684
[OTFN_NREN] https://resources.geant.org/wp-content/uploads/2022/02/GN4-3_White-Paper_Time_and_Frequency.pdf
[OTFN_IncubatorReport] https://resources.geant.org/wp-content/uploads/2024/02/GN5-1_White-Paper_Core-TFN-Incubator-Final-Report_Public_Update.pdf
[OTFN_Infoshare] https://events.geant.org/event/1581/
[OTFN_wiki_M&C] https://wiki.geant.org/display/NETDEV/Monitoring+and+Calibration
[OTFN_wiki_TFG] https://wiki.geant.org/display/NETDEV/TF+Gateway
[OXDocs] https://github.com/ytti/oxidized
[PIONIER] https://pionier.net.pl/en/
[PSNC] https://www.psnc.pl/
[PTB] https://www.ptb.de/cms/
[QKDC&C_WP] https://resources.geant.org/wp-content/uploads/2024/02/GN5-1_White-Paper_QKD-Concepts-and-Considerations.pdf
[QPSNC] https://quantum.psnc.pl/en/
[QT_Infoshare_1] https://events.geant.org/event/1225/
[QT_Infoshare_2] https://events.geant.org/event/1427/
[QT_wiki] https://wiki.geant.org/display/NETDEV/QT
[RARE] https://wiki.geant.org/display/rare
[RARE_Docs_GN] https://docs.rare.geant.org/
[RARE_Docs_GitHub] https://github.com/GEANT/rare-docs
[RARE_Infoshare] https://events.geant.org/event/1567/
[RARE_Infoshare_YT] https://youtu.be/0rOTo1rh18w
[RIPE_SEE12] https://www.ripe.net/membership/meetings/regional-meetings/see/see-12/
[SPA] https://wiki.geant.org/display/NETDEV/SPA
[STF31] https://wiki.geant.org/display/APM/31st+STF+-+Brussels%2C+April+2024
[TimeMap] https://network.geant.org/timemap/
[TNC23] https://tnc23.geant.org/programme/
[TNC24] https://tnc24.geant.org/
[UTKDocs] https://github.com/louislam/uptime-kuma/wiki

Glossary

AI	Artificial Intelligence
APAN	Asia Pacific Advanced Network
API	Application Programming Interface
ASIC	Application-Specific Integrated Circuit
BGP-CT	Border Gateway Protocol – Classful Transport
C-TFN	Core Time/Frequency Network
CERN	European Organisation for Nuclear Research
CI/CD	Continuous Integration / Continuous Delivery
DDoS	Distributed Denial of Service
DPDK	Data Plane Development Kit
DPU	Data Processing Unit
DTU	Technical University of Denmark
EANTC	Europan Advanced Networking Test Centre
ELSTAB	Electronically Stabilised Fibre-Optic Time and Frequency Technology
ETSI	European Telecommunications Standards Institute
FAU	Friedrich Alexander University of Erlangen-Nürnberg
FBK	Bruno Kessler Foundation
FoD	Firewall on Demand
FPGA	Field Programmable Gate Array
GCS	GÉANT Connection Service
GNA-G	Global Network Advancement Group
GNSS	Global Navigation Satellite System
GP4L	Global Platform for Labs
GPRS	General Packet Radio Service
GTP	GPRS Tunnelling Protocol
ICCS	Institute of Communication and Computer Systems
IDE	Integrated Development Environment
IRU	Indefeasible Right of Use
JSON	JavaScript Object Notation
LRZ-BAdW	Leibniz Supercomputing Centre of the Bavarian Academy of Sciences and Humanities
Maat	A resource and service inventory management tool. Named after the Egyptian god who represents the concepts of truth, balance, order, harmony, law, morality, and justice.
MOOC	Massive Open Online Course
MPLS	Multiprotocol Label Switching
NeMo	Network Monitoring
NETDEV	Network Development
nmaas	network management as a service
NMI	National Metrology Institute
NOC	Network Operations Centre
NREN	National Research and Education Network
NTP	Network Time Protocol
ODA	Open Digital Architecture
OTFN	Optical Time and Frequency Networks
OTDR	Optical Time Domain Reflectometry

P4	Programming Protocol-independent Packet Processors
PDU	Packet Data Unit
PFCP	Packet Forwarding Control Protocol
PSNC	Poznan Supercomputing and Networking Centre
PTB	Physikalisch-Technische Bundesanstalt
PTP	Precision Time Protocol
QKD	Quantum Key Distribution
QSFP	Quad Small Form-factor Pluggable
R&E	Research and Education
RAN	Radio Access Network
REST	Representational State Transfer
RLS	Regenerator Laser Station
RARE	Router for Academia, Research and Education
RIPE	Réseaux IP Européens
SD	Software-Defined
SEE	South East Europe
SI	International System of Units
SMF	Session Management Function
SoP	State of Polarisation
SoP-OTDR	SoP sensitive Optical Time Domain Reflectometry
SPA	Service Provider Architecture
SSH	Secure Shell
SSL	Secure Sockets Layer
T/F	Time and Frequency
TNC	The Networking Conference
UKIM	Ss. Cyril and Methodius University in Skopje
UMU	University of Murcia
UoB	University of Belgrade
UPF	User Plane Function
UPV/EHU	Universidada del País Vasco / Euskal Herriko Unibertsit atea – University of the Basque Country
UTC	Coordinated Universal Time
UTC(k)	Physical realisations of UTC
UvA	University of Amsterdam
VPN	Virtual Private Network
WP	Work Package
WP2	Work Package 2 Marcomms, Events and Policy Engagement
WP6	Work Package 6 Network Development
WR	White Rabbit