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## Deliverable D6.2

# Automation and Orchestration of Services in the GÉANT Community

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### Abstract

This document reports on a survey of Orchestration, Automation and Virtualisation (OAV) practices in the GÉANT and NREN community, on follow-up community events, and presents a brief OAV market analysis. It concludes by proposing future steps for the WP6 Task 2 team.

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## Executive Summary

Orchestration, automation and virtualisation (OAV) have become key enablers for service providers to facilitate faster, agile and more economical infrastructure and service development, deployment and provisioning. Adopting OAV principles allows organisations to make smarter use of their resources, including physical and virtual hardware and software, thus facilitating the digital transformation process.

The GÉANT and NREN community have been on this path for several years. Even though organisations are at different stages of their journey, for most of them the motivation for their work originated from an organisational perspective, focusing on the improvements within their own domains. Therefore, today, most of the work known so far is single-domain and domain-specific.

With the aim to maximise the benefits of the project endeavour, the team formed within the *Network Services Evolution and Development* task (Task 2) of the GN4-3 project's *Network Technologies and Services Development* work package (WP6) started its work on OAV with a survey among GÉANT project partners.

The OAV survey was designed to elicit the OAV work already undertaken, the platforms being built upon, current and future OAV use cases, the challenges being faced by the NRENs, and input on how the NRENs felt the GÉANT project could help them on their OAV journey. The survey showed a strong need within the community for collaboration and exchange of knowledge and expertise, rather than the development of a particular software solution. After the completion of the survey, the work of the project team continued with the community building and collaboration sessions at community events, bringing together experts from different parts of the world to present their work, use cases, results and challenges.

This document presents the activities and the results that the Task 2 team has achieved, starting with the OAV survey and the subsequent community events designed to stimulate discussion and build consensus on strategies and next steps. In addition to the survey results and the conclusions drawn from the community sessions, this document provides a brief market analysis related to the OAV topics and concludes with the planned future work for the team in the *Network Services Evolution and Development* task.

## 1 Introduction

The area of orchestration, automation and virtualisation (OAV) is becoming increasingly important for network operators as they strive to deliver robust, efficient and flexible infrastructure and services in a responsive manner for an ever more diverse and demanding set of users and applications. In this respect, the adoption of OAV principles is as important to the NRENs in the GÉANT community and R&E institutions world-wide as it is for the large commercial communications service providers (CSPs) and content providers. The growing trend of the research, development and implementation of OAV techniques, methodologies, tools and systems is visible in the documented work of individual organisations, in the commercial or open-source market and in patents that are being filed.

Inputs received during the GN4-3 project preparation phase showed that there is interest in the community in working on OAV. It was already known that the path, the experience and expertise levels among project partners vary, and that the OAV work is mostly directed at single-domain cases, though the specific details of the progress of each NREN were not so well known. Therefore, rather than focusing on specific OAV details, it would be more important to determine a common strategy and take steps in that direction.

At the start of GN4-3, it was therefore felt that the most effective way forward would be to have a period of consensus building, in which the project would seek to determine a common strategy for NRENs, and from there agree next steps, with the goal of allowing the benefits of OAV to be applied in a hardware-agnostic, multi-domain approach. While the NRENs may have different implementations, organisational processes and systems, it would be desirable to have some common approach for future multi-domain interoperability.

With the aim to maximise the benefits of the project endeavour, the Network Services Evolution and Development task (Task 2) of the GN4-3 project's Network Technologies and Services Development work package (WP6) created a team of 12 people (working part-time on the project) from eight countries' NRENs and their third parties to learn more about the current status of OAV in the community, and to focus the work to enhance the overall OAV maturity level in the community.

The team acknowledges the OAV work from the previous generations of GÉANT projects (see Section 2). As a starting point for their work, the team created and conducted a survey of GÉANT project partners to elicit the ongoing OAV work, platforms, use cases, challenges and plans. The survey results are given in Section 3.

As a direct follow-up of the survey feedback that more dissemination and collaboration activities are needed, the team has initiated a series of events with the aim to bring together the community around OAV topics, provide the possibility for OAV-active organisations to share their knowledge and expertise and for the Task 2 team to present its work. The first of the events was a specific strategic network services workshop held in Amsterdam in May 2019, which was then followed by a number of community events, in particular TNC 2019 in June and the 17th Service and Technology Forum in July. The summary of the events is provided in Section 4.

Section 5 undertakes a market analysis of OAV in the context of patents, an overview of a selection of commercial service providers and vendor products, open source tools and initiatives.

Section 6 summarises the conclusions, and presents the future work planned within WP6 Task 2 team.

## 2 The GÉANT Project's OAV Work

Work on OAV has spanned several generations of the GÉANT project, in the area of e-infrastructure integration, Service Provider Architecture (SPA), the GÉANT Testbeds Service, Network Management as a Service (NMaaS), and perfSONAR, to name just some examples. This section presents a brief summary of the work carried out during the GN4-2 project, concluding with the current project phase, which follows up on the findings of the previous projects and continues the work on its objectives.

### 2.1 Integration with Other e-Infrastructures

Aware of the need of the NRENs to provide operational excellence in the advanced services and infrastructure offering within and alongside the service provider environment, Task 3 of the Joint Research Activity 1 (JRA1), Network Infrastructure Evolution, worked on modelling the integration of different e-infrastructures from the perspective of transport services, optimisation, automation and orchestration of multi-domain business processes. In addition to network transport services for e-infrastructures, Task 3 defined a framework for systems and processes, from the perspective of the infrastructure, service, operational and business aspects to facilitate effective end-to-end intra-domain service delivery.

The Task delivered a proof of concept of the end-to-end multi-domain order management and service delivery of MS Azure ExpressRoute connectivity services, exploring in their work connectivity services from the GÉANT portfolio (GÉANT MD-VPN service portfolio, including EVPN technologies, the GÉANT Open Cloud Exchange (gOCX)) and SDN technologies through the end-to-end multi-domain operational alignment at the data plane. Additional focus was on integration of operational and business processes through service fulfilment, as well as the need for the automation and orchestration for as many functions and process elements as possible, basing their work on standards and industry best practices [D7.2] [D7.5]. The solution is largely compliant with the TM Forum Framework [TMFFx] Information Framework (SID) and Open APIs [TMFOpenAPIs], and the Metro Ethernet Forum (MEF) Lifecycle Service Orchestration [MEFLSO]. It is using eduGAIN for authentication, and KeyCloak and Organisation Information Service (OIS) for authorisation.

### 2.2 Service Provider Architecture

The Service Provider Architecture (SPA) [D8.5], [D8.11] was a first attempt to deliver a model that demonstrates how available services and user or business operations can be brought together under the implementation of one holistic framework. The study was based on technology-agnostic,

abstracted service models and firmly aligned with the TM Forum Framework [TMFFx]. The work started with an emphasis on fulfilment and assurance operations procedures, and evaluated the associated processes for common business support systems (BSS) and operations support systems (OSS) in a prototype project called 'ELINE'. The ELINE provides its customers a service comparable to the Ethernet Private Line (EPL) [EPL] as defined by the Metro Ethernet Forum (MEF) [MEF].

The Consolidated Connection Service (CCS, now renamed to General Connection Service, GCS, as described below) served as an example and all service implementation aspects and transition processes were investigated. This also included service performance verification and monitoring. ELINE was based on NSI-compatible code of the OpenNSA/NSI code repository [OpenNSA] [NSI] and followed best practices and standards such as set by the MEF [MEF], TM Forum (TMF) [TMF], Open Grid Forum (OGF), International Telecommunication Union (ITU), Institute of Electrical and Electronics Engineers (IEEE) and Internet Engineering Task Force (IETF).

## 2.3 General Connection Service (GCS) (formerly CCS)

GCS is based on a technology-agnostic service abstraction assuming the NSI abstraction of a network connection where a connection is a logical link between two locations over which data is transported unmodified from ingress to egress [D8.8]. During GN4-2, the Ethernet-framed transport service was implemented and allowed Ethernet frames to be transported over MPLS, OTN or spectrum-based infrastructures. A connection can be reserved, allocated, released and cancelled according to a schedule. The reservation process was applied recursively to multi-domain path segments using the NSI protocol and served as a service planning or orchestrating agent.

In a first pilot GCS was configured to serve the GÉANT Testbeds Service (GTS), i.e. GTS was the first client or user of GCS and relied on GCS for the automatic provisioning of its virtual circuits or link objects. In a second pilot (the ELINE project) GCS was integrated with the service provider architecture of GN4-2.

## 2.4 GÉANT Testbeds Service

The GÉANT Testbeds Service [GTS], [D8.9], was initially developed to allow researchers to set up individual testbed environments in an automated fashion. GTS is based on the concept of a Generalised Virtualisation Model (GVM) which allows networks to be sliced in an abstracted way where abstracted virtualised objects called resources can be defined, instantiated and arranged to create application-specific insulated networks. The virtualisation of service objects in GTS allows the automation of resource provisioning: users can construct network environments using virtual building blocks via a web-page and the GTS software-based resource manager then coordinates and orchestrates the setup of the virtual network environments. Available resource building blocks in GTS are currently Virtual Machines (VMs), Virtual Circuits (VCs), Virtual SDN switches (which are mapped to completely virtualised hardware switch instances (VSIs) and Bare Metal Servers (BMSs)).

GTS allows the integration of any type of resource for automatic provisioning and integration into the system such as science instruments (e.g. radio telescopes, gene sequencers, etc.), licensed mobile

spectrum or sensors, as long as there is a Resource Control Agent (RCA) software module available that configures and maps the virtual service object to the underlying infrastructure. The concept of abstract service objects extends to fine grained functional capabilities such as traffic handlers (rate shapers, policers, load balancers, filters, IDS functions, etc.) in the emerging field of network function virtualisation (NFV).

## 2.5 Network Management as a Service

Network Management as a Service [[NMaaS](#)] [[D8.7](#)], simplifies domain network management by providing the infrastructure and a portfolio of network management applications via a cloud-based, multi-tenant and secure network management system. NMaaS consists of the NMaaS platform, a portal (web-based user interface) and the set of integrated containerised applications that can be deployed through the portal, with the support to users provided for using the infrastructure as well as for integrating new end-user applications into the platform. The NMaaS platform consists of the virtualised network and cloud infrastructure resources based on Docker [[Docker](#)] and Kubernetes, and the establishment of a data communication network (DCN) for communication between the tool and the equipment is realised as a virtual private network (VPN).

Through the trusted one-stop shop for application deployment, users deploy selected tools in a separately orchestrated automatic manner on a per-user, securely instantiated cloud infrastructure, tailoring the application variable to 90% of the user needs. The deployment process is very fast and straightforward for the user as it incorporates standard application packaging, configuration conventions, and DCN access models thus reducing the amount of information required from the user (for service/tool configuration) to a minimum. NMaaS is, for now, geared toward network management tools, however, the platform is suitable for all types of tools.

## 2.6 perfSONAR

The Performance focused Service Oriented Network monitoring ARchitecture (perfSONAR) [[perfSONAR](#)], [[pSGHUB](#)] is an open-source, modular and flexible software product for active network performance monitoring. With its history dating back to 2000, it is currently being developed jointly by ESnet, Internet2, Indiana University, the University of Michigan and the GÉANT project. perfSONAR enables network engineers to run IPv4 and IPv6 active probes measuring throughput, packet loss, delay, jitter and other performance metrics across multiple domains. To date, there are more than 2000 perfSONAR nodes installed worldwide [[pSMAP](#)].

The proliferation of virtual network environments, together with an ever-increasing use of perfSONAR thanks to small and inexpensive hardware, has triggered the need for automated nodes management. Improved orchestration and automation are now provided through perfSONAR supported Ansible roles and playbooks that speed up and ease the installation, configuration and maintenance of deployments [[pSAUT](#)]. This is of particular interest to NOC and PERT engineers that manage numerous perfSONAR instances in a single domain, but also in multi-domain use-cases like the Performance Measurement Platform (PMP) run by the GÉANT project [[pSGN](#)].

In parallel to this OA work, perfSONAR has evolved to enable end-to-end active performance monitoring through and for virtual networks. Measurements can now be performed from a single perfSONAR node through multiple layer 2 or layer 3 virtual circuits, thus accommodating the growing deployments of single or multi-domain virtual private networks [[pSDI4R](#)].

## 2.7 Network Services Evolution and Development Task Objectives

In the current GÉANT project, GN4-3, Task 2 of WP6 focuses on network services from the perspectives of their underlying technology, possibilities for automation, orchestration and virtualisation, their business and operational processes, single- and multi-domain aspects, and single- and multi-partner operability.

The key objectives for the task from the project description are to:

- Consult with the community (and international collaborators) to establish and maintain consensus on a direction for interoperable (virtualised) network service orchestration and automation, which will then drive the further work of Task 2.
- Identify existing and/or develop new software components and APIs needed to enable single and/or multi-domain service orchestration and partner interoperability, for agreed use cases.
- Foster partner interoperability by piloting enhanced/new technology-agnostic service platform components, based on interoperable standards in a multi-domain environment.

To address these objectives, it was first necessary to understand the "lie of the land" for OAV adoption in the community. So, at an early stage, the Task 2 team created a survey on OAV which was distributed to the GÉANT project partners, to learn more about their current and planned work and strategies. Section 3 provides a summary of the survey results.

## 3 Survey on OAV in the GÉANT Community

To begin the consensus building process described above, the natural first step was to initiate a survey to learn more about the current status and plans of NRENs in the GÉANT community for adopting and implementing OAV principles.

The survey, given in Appendix A, was developed to complement the topics covered by the GÉANT NREN Compendium [[GNCOM](#)], with the purpose to:

- Learn about the strategy and actions of each NREN related to network and service orchestration, automation and virtualisation (OAV).
- Explore if there are common use cases, ideas, needs and issues in the community in the areas of automation, orchestration and virtualisation.
- Recognise possible areas of collaboration both amongst NRENs and between NRENs and GÉANT.
- Determine and recommend possible future work within WP6 of the GN4-3 project that could be of benefit to as many partners as possible for identified use cases.

The survey contained 35 questions and was organised into five areas:

1. Existing OSS/BSS platforms
2. Current OAV use cases
3. Challenges in adopting OAV
4. Future OAV use cases
5. How GÉANT might help the NRENs

The survey was issued via the GÉANT Partner Relations team to the APM (STF) representatives of each NREN, and copied to the NREN GA contacts. The response rate was good, with the survey being completed over a period of around 4 weeks by senior managers of 31 organisations. The responding organisations were ACOnet, AMRES, ARNES, ASNET-AM, BELNET, CARNET, CESNET, CYNET, DFN, EENet-HITSA, FUNET, GARR, GÉANT, GRENA, GRNET, HEAnet, Jisc, KIFU, LITNET, MARNET, MREN, NORDUnet, PSNC, RASH, RedIRIS, RENAM, RESTENA, SUNET, SURFnet, SWITCH and URAN. The survey results are summarised in the following sections, and can also be found on the wiki [[OAVSurvey](#)].

## 3.1 Existing Network and Services Platforms

The purpose of this section was to find out about typical platforms used by NRENs, including the composition of OSS/BSS systems, the use of standard practices, data models and APIs.

From the responses shown in Figure 3.1, it can be seen that the majority of NRENs do not have a fully integrated OSS/BSS solution. A significant proportion (around half) do not operate an OSS/BSS platform or, if they do, it contains only a few of the necessary components. Of those operating an OSS/BSS, around 37% claim to have some automation capability.

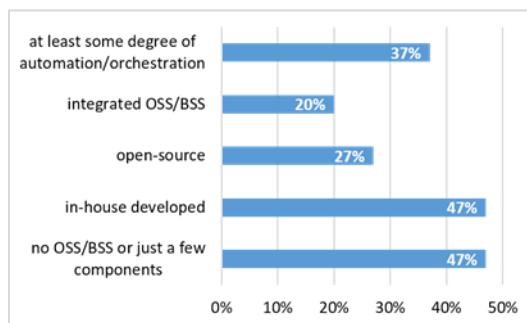


Figure 3.1: OSS/BSS Composition

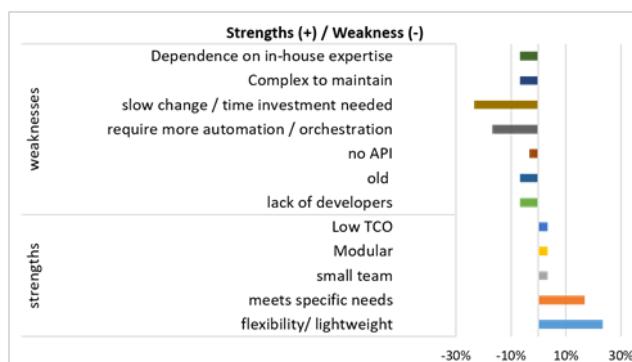


Figure 3.2: OSS/BSS Strengths and Weaknesses

There is a large variety of components in use, with many being somewhat old and not OAV focused. OTRS, Ansible, Cacti, and JIRA were mentioned multiple times.

Regarding the strengths and weaknesses of their existing systems, responders considered their main strengths to be that they are flexible, well understood and perform the job they are tasked to do. Regarding weaknesses, many NRENs reported that they are slow to change/adapt to the need for more automation. Several times a lack of resources was cited as the main reason for this (see Figure 3.2).

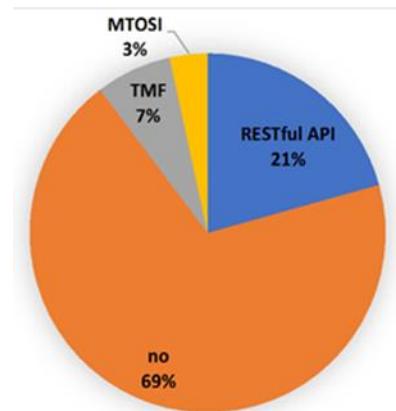


Figure 3.3: Use of Standard APIs

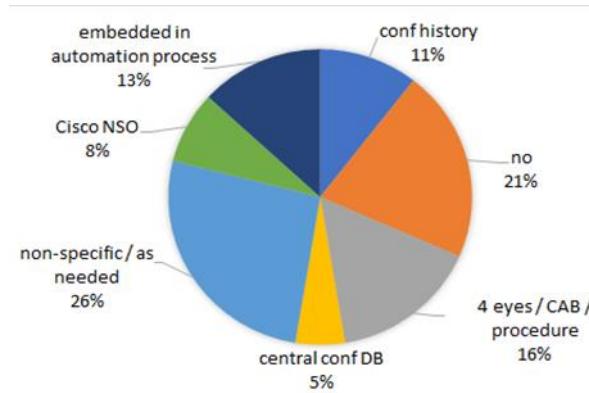


Figure 3.4: Configuration Control and Management Policies

Regarding the use of standard data models and APIs, the majority of NRENs (64%) reported that they are not using data models. Those that do only use them partially and use proprietary models (21%). The remaining 15% are using proprietary data models.

Similarly, 69% of NRENs are not using APIs (see Figure 3.3). Where APIs are employed, RESTful APIs are the most used (21%), while only a few standard APIs are used (TMF 7%, MTOSI 3%).

Only a few NRENs (13%) reported that their configuration control and management policies are embedded in their automation systems (shown in Figure 3.4). Other responses indicated a variety of methods including configuration histories, databases and non-specific bespoke methods. A fairly large number of NRENs (21%) reported having no policies at all.

## 3.2 Current OAV Use Cases and Services

The objective of this section was to explore existing OAV approaches to deploying and supporting services. More than half of the interviewed organisations have some form of OAV in production: 17 organisations have implemented some form of automation, 14 virtualisation and 4 orchestration (see

Figure 3.5). Automation is in test or development in 7 organisations, orchestration and/or virtualisation in 5 (see Figure 3.6).

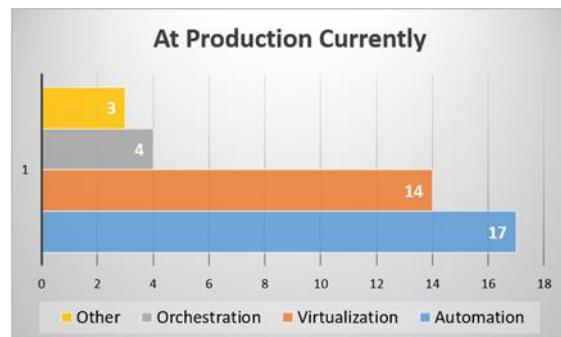


Figure 3.5: OAV in Production

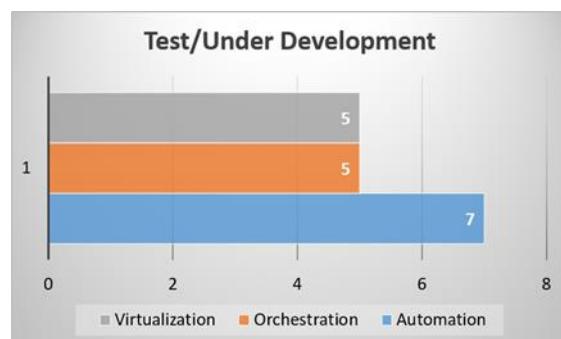


Figure 3.6: OAV in Test/Development

Responses show that 60% do not have or, at least, do not mention any strategy concerning OAV at the production/development stage.

The use cases that were reported as implemented first are:

- Virtual resource allocation, hardware consolidation
- Monitoring, alerting, checks, configuration, automatic provisioning, BGP peering policies, services based on IP/MPLS layer
- Intelligent management of systems.

Among survey participants, the most popular tools and software are:

- Kubernetes and Cisco NSO for Orchestration
- Ansible for automation
- VMware and Xen for virtualisation
- OpenStack for cloud solution on OAV

In addition, 43% list use of in-house software and 40% said that they use open-source software (see Figure 3.7).



Figure 3.7: OAV Software in Production

Most of the interviewed organisations (73%) have not implemented any inter-domain orchestration or automation. The remaining 27% stated that their multi-domain OA use cases include MD-VPN, DDoS, OpenNSA, bandwidth-on-demand provisioning, multi-cloud deployment and automation.

From the provided options, most organisations have indicated configuration integrity, problem troubleshooting and SOC enhancements as their top priorities (see Figure 3.8).

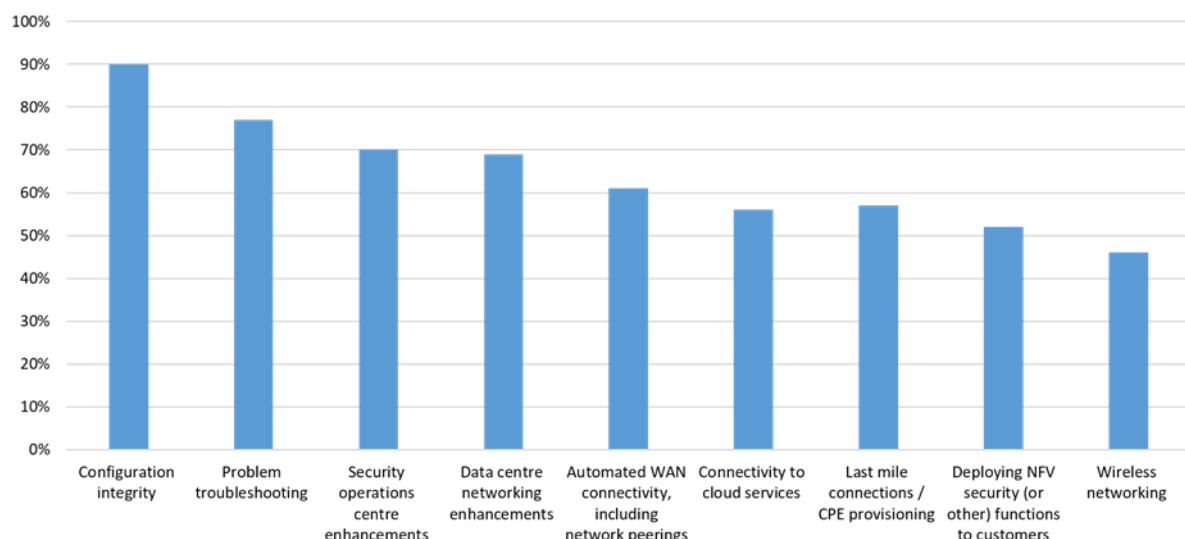


Figure 3.8: OAV Use cases priorities

Multi-domain use cases are of interest to 30% of the organisations, out of which:

- 42% are interested in use cases between their organisation and end-institutions or campuses, such as managed CPE service delivery, VPN, monitoring, firewall, DDoS, Federated Identity Management/SSO, VoIP and WiFi as a service.
- 35% are interested in use cases between their NREN and GÉANT, such as MD-VPN, the GÉANT Testbeds Service (GTS), connecting to research projects/cloud, FoD, DDoS, AAI, monitoring, exchange of operational stats and events.
- 23% are interested in use cases between their NREN and a cloud provider, for example global connectivity, any direct access services, ANA, CAE1, GNA and support for big science users/mirror sites.

Of the virtual services, NRENs offer VPN, virtual machines, VRFs and virtual circuits.

### 3.3 OAV Priorities and Challenge

The surveyed organisations reported a wide array of operational priorities. Some are interested in speed- and economy related improvements, such as faster delivery time, automation of duties, fewer field trips, reduced manual labour, better efficiency and less repetition. Related is a desire for a reduction of human error, with improved configuration consistency and integrity. Other popular themes were a single point of truth and capabilities for service bundling, service unification and offering more services. Monitoring, alerting, telemetry and troubleshooting were also commonly mentioned operational priorities. Some NRENs have concerns related to the support of outdated equipment and hardware-agnostic operations. Further priorities mentioned were service redundancy, cybersecurity, continuous upgrades, wider connectivity, automated maintenance notification, resource sharing and standardised interfaces.

A majority of NRENs indicated that network operations and maintenance (e.g. automatic monitoring, ticketing, fault analysis, management), network connections, hardware independent or technology-agnostic control of the network, consistent network elements updates and large control plane updates verification (e.g. improved accuracy and reduced errors), and network security (e.g. firewalls, VPNs, T&I) are the service areas where OAV is most likely to be applied in the short-term future.

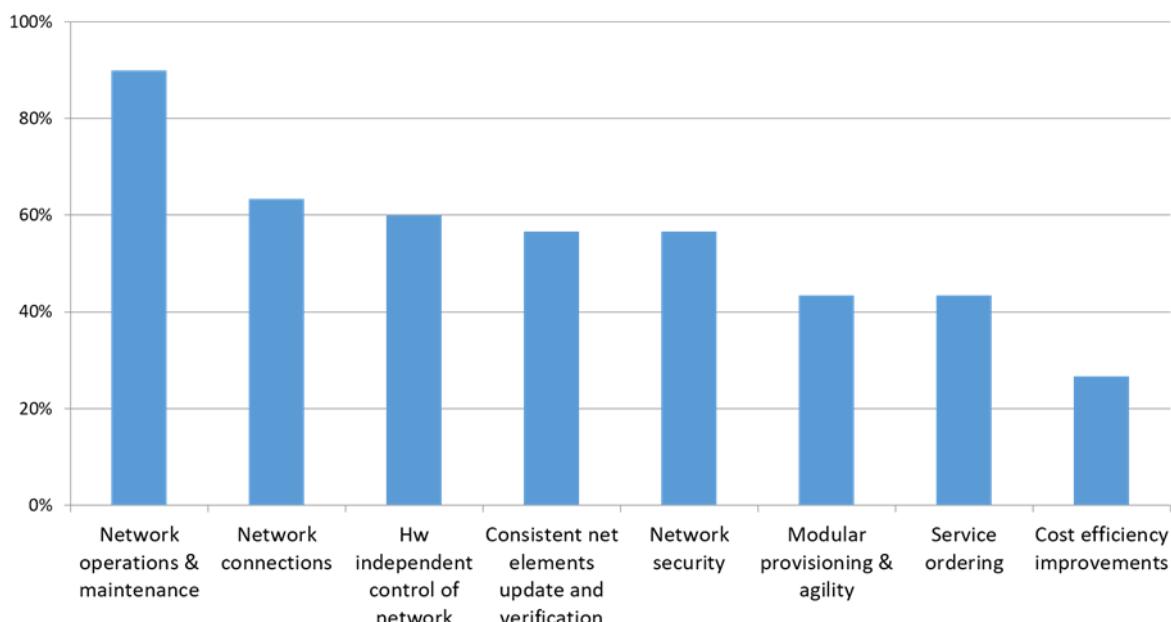


Figure 3.9: OAV Service Areas in 2-year plans

Modular network provisioning and agility, and service ordering were indicated as likely to be applied by a significant number of NRENs (close to half of the responses), while cost efficiency improvements (e.g. Green IT, a federated shared infrastructure) interest only a minority of NRENs, as presented in Figure 3.9.

Most of the interviewed organisations (70%) reported challenges in their OAV work. Most of them were clearly related to a lack of human resources, in particular developers and DevOps personnel. A key challenge for most organisations is a lack of personnel in general, as well as a lack of people who can combine software and network skills. These are seen as the right skills for approaching orchestration, automation and virtualisation. They also mentioned various technical considerations, including inter-workings and integration of different network components, equipment with no virtualisation support and vendor support considerations.

Concerns regarding the network engineering or NOC teams around increased automation are mentioned by 57% of the NRENs. The more widely reported concerns relate to the risk of automating failures due to mistakes, having inadequate software, reduced troubleshooting capabilities, and lack of ability to provide the flexibility required by tailor-made services. However, these concerns are mostly not considered to be blockers.

When asked about the tools for ensuring automation robustness, correctness or verification, 60% of the organisations reported that they do not use tools or that they do not plan to use tools. The remaining 40% reported using a number of tools, of which Gitlab CI/CD and telemetry tools are mentioned more frequently. However, none of the tools were singled out by all respondents.

### 3.4 Future OAV Use Cases and Services

NRENs are aware of the challenges and advantages of orchestration, automation and virtualisation solutions but the survey has shown that there are different priorities and requirements, and thus different expectations and plans. Moreover, some NRENs are more experienced with OAV, while others have just started their journey.

The positive observation is that a majority of 77% has short-term plans for OAV use cases and services within the next two years. Examples of such plans include:

- Managing data centre networks.
- Campus local networks and their upstream connections.
- Managing self-service for security ACLs.
- Last mile connections.
- WiFi management.
- Automating all fault management processes, problem troubleshooting, traffic analysis, report generation.
- Piloting of new service provisioning (e.g. on optical layer via programmable interfaces).
- Increased automation on monitoring systems.
- NFV adoption (WAN virtualisation, edge services virtualisation, automation of NFV firewalls).
- Orchestrated service delivery.
- Network and cloud services bundling integrated with AAI.
- Inter-domain optical provisioning.
- Consistent network elements updates and large control plane updates verification, e.g., improved accuracy and reduced errors.
- Cost efficiency improvements, e.g., green IT, federated shared infrastructure, etc.
- Automated security.

Beyond the next two years, fewer NRENs (57%) have plans, while the remaining 43% reported that they have no long-term plans. The plans that are mentioned are less specific and detailed, and some of them include pilot orchestration which covers multiple layers like routing and optical systems, and automating the provision of all customer services (automate all appropriate OSS/BSS processes from service ordering through to delivery and maintenance).

Analysing the future OAV use cases and services that were mentioned in the plans, it is clear that at the moment automation is of more interest and a higher priority than orchestration, but that the introduction of orchestration techniques will be the next stage of service evolution. This is also reflected by the responses in the earlier section that said the majority of NRENs began their OAV adoption with automation.

Only 46% of the respondents have indicated that they have some plans to implement inter-domain OA. The work of the majority is primarily focused on their own domains. The inter-domain use-cases of interest that were mentioned are - inter-domain circuit provisioning, DDoS mitigation, and the use of multi-domain connectivity services such as MD-VPN service orchestration or automation or NSI protocol.

A wide majority of respondents (80%) would in principle allow changes to their network configuration based on requests originated in another organisation, be that GÉANT, an NREN, a campus, or some other organisation. However, prerequisite is the existence of strong AAI, agreed policies, processes and procedures. A strong message from NRENs is the need for federated AAI (53%), around 27% of them suggesting to use the eduGAIN service. It has been expressed that reusing existing tools, building on them, and extending them to handle authorisation should satisfy the wider community.

The survey results show that NRENs want to use standards for interoperability. If their resources are not equipped with standardised APIs, there is a wide acceptance (70%) to use wrappers around existing service endpoints to facilitate interoperability with third parties (other NRENs, etc.).

Last but not least, the survey asked about the disaggregation from the physical hardware layer.

Most NRENs (66%) observe and to some extent have investigated disaggregation trends and solutions, including white boxes with separate Network Operating Systems (Figure 3.10). Disaggregation is not considered in the backbone, but more for edge and data-centre use cases. For some the deployment in production is not very certain because of recent network infrastructure investments. Some consider the maturity level of disaggregation not sufficient to replace traditional network infrastructure. The remaining 24% either did not reply to this question or did not report any activity in this area.

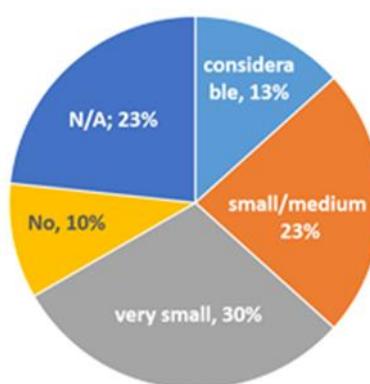


Figure 3.10: Disaggregation from physical hardware layer

## 3.5 The GÉANT Community and the GÉANT Project's Role

This section explored how the GÉANT community and the GÉANT project could help NRENs in terms of OAV and or OSS/BSS collaboration and knowledge exchange, inter- or intra-domain service piloting, provisioning and delivery.

Participants were asked if they collaborate with other NRENs on OAV topics, and if so what the use cases are. Over half of the NRENs expressed their interest in collaborating (48%), 4% would collaborate if there is a clear end-user or NREN requirement for it, while 45% said that they do not have a need for collaboration and 3% did not respond to this question. SURFnet, GRNET, HEAnet and ESnet were mentioned the most as the organisations that are active and have expertise in OAV, while 41% either said that they do not know about other work in the community or did not reply.

When asked how they see a possible involvement of the GÉANT project in their OAV journey, NRENs outlined five of the provided areas, as illustrated in Figure 3.11.

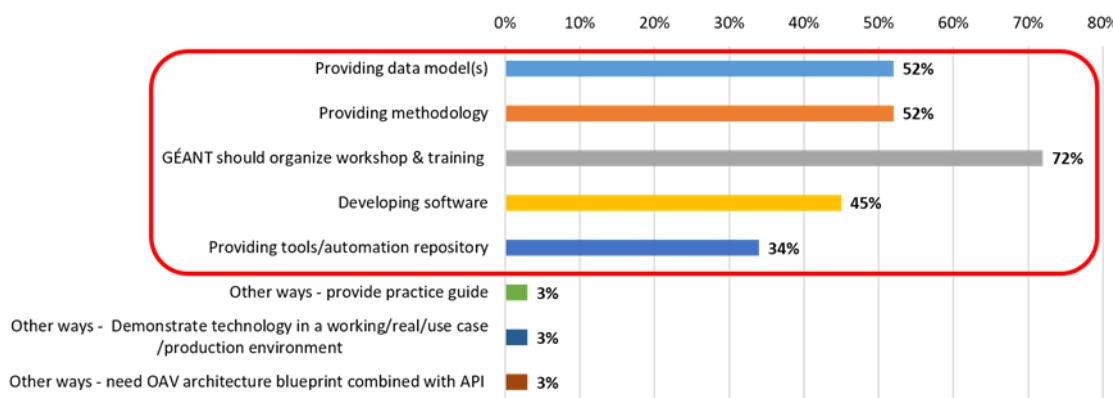


Figure 3.11: Interest in GÉANT assistance

The most important support is seen to be the organisation of workshops and training, then assistance with providing data models and methodologies for automation and orchestration. NRENs are also interested in receiving help with developing software and in the provision of a tools/automation repository. Suggestions included also providing a best practice guide and technology demonstrations in a working, real use case production environment. A minority of NRENs said they need an OAV architecture blueprint, including exposed APIs.

When asked about taking part in a pilot use case involving automatic inter-domain network or service orchestration with full or partial control given to other parties over their network slice, 45% of the respondents replied that they would be interested in participating in such a pilot, while 38% were not.

Exploring how likely NRENs are to use a full OSS/BSS turn-key solution provided by a third party (such as a system integrator, a commercial OSS/BSS suite or GÉANT), the survey results showed that only 24% of the respondents are considering such turn-key solutions (see Figure 3.12). The key issues in this area could be the speed of deployment, support, compatibility and specific NRENs' needs. To overcome these issues, a coordination layer/solution for a third-party OSS/BSS would be appreciated, which can sit on top of the OSS/BSS with a comprehensive view over all available resources and services.

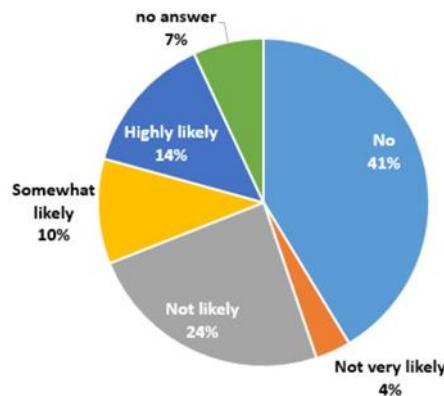


Figure 3.12: Interest in full OSS/BSS turn-key solutions provided by a third party

## 3.6 Key Survey Findings

The survey participants have shown a high level of interest in OAV. The benefits of adopting OAV in NRENs are very similar to those seen by commercial CSPs or content providers and includes:

- Faster service delivery / reduced delivery time.
- Enables and supports better infrastructure scaling
- Reduced human error and manual work.
- Lower service delivery costs.
- Better reporting.
- Increased efficiency.
- Ensured and increased configuration uniformity and consistency.

NRENs are at different stages of their OAV journey. While some are quite advanced, most have not started any significant work yet, and have little or no OAV capability. Therefore, there is plenty of scope for greater collaboration and knowledge sharing / exchange between NRENs, particularly as some common pain points can be recognised, such as:

- Lack of manpower - in number, required skills and expertise.
- Coping with priorities - existing systems vs. new development, continuous operations vs. new development.
- Maintaining CI/CD in a production environment.
- Integrating changes in the production brownfield of existing systems.
- Time management - split between operations and R&D.
- Cost - additional people, additional software, software replacement.
- Limitations of proprietary solutions.

There is a wide variety of components and systems being used by NRENs. These are mostly OSS, with rather fewer BSS, and very little OSS-BSS integration (whether proprietary, in-house or open source). Further, there is no obvious common single direction or best practice for OAV, and currently little use of standard data models and APIs that facilitate OAV.

The initial focus should be on improving intra-domain capabilities for NRENs, thus “raising the bar” across the community. A wide variety of use cases were reported. Connectivity services were of very broad interest to most if not all NRENs (including GCS and MD-VPN), with configuration integrity ranking highest of the application areas, followed by problem troubleshooting and security operations centre enhancements. While most NRENs do not yet have inter-domain OAV, NRENs were mostly interested in the following cross-domain use-cases: NREN and a campus (42%), NREN-GÉANT (35%) and then NREN-cloud (23%). Interestingly, some 80% of NRENs would be willing to allow changes to their configurations resulting from requests initiated in other domains, assuming the agreed policies, procedures, authentication and authorisation are in place.

Finally, there is plenty of scope for greater collaboration and knowledge sharing / exchange between NRENs. The survey showed that around 50% of the NRENs do not speak to other NRENs about their OAV work. That may be because some have not yet started their journey, but it is an indication that knowledge exchange should be fostered and encouraged, and that this should be an important part of the future plans for WP6.

## 4 OAV: GÉANT Community Discussions

The OAV NREN survey provided an excellent baseline of the position of NRENs with respect to their current OAV adoption and their future plans and use cases. The results highlight common areas of interest in the NRENs, and potential areas of at least broad consensus, but these can only be confirmed by further discussion with and between the NRENs.

Acting upon the survey outputs on the need for collaboration, discussion and sharing of knowledge and expertise, WP6 Task 2 has attended several events for different user groups, to present the survey results and initiate the dialog and the consensus-building process on OAV topics:

- GÉANT GN4-3 Future Service Strategy Workshop, Amsterdam, 9-10 May 2019 [[FSSW](#)]
- TNC 2019, Tallinn, 16-20 June 2019 [[TNC19](#)]
- 17th Service and Technology Forum, Dublin, 3-4 July 2019 [[17STF](#)]

The outcomes of these events are presented in more detail in the following sections.

### 4.1 GÉANT GN4-3 Future Service Strategy Workshop

The GN4-3 Future Service Strategy Workshop was held in Amsterdam on 9-10 May 2019, with the aim of bringing together senior decision makers within the NREN community to discuss strategy in two areas: OAV and cloud services [[FSSW](#)].

The OAV day, organised by WP6 and the Partner Relations team, was attended by around 70 people, both in person and remotely. After setting the context for the event, the GÉANT OAV work is presented in [[GÉANTOAV](#)]. In the case of the GÉANT network, the two presented use cases address internal needs:

- For automation of the existing testbed that replicates the production GÉANT network in order to increase efficiency and enhance quality assurance.
- For orchestration in the disaggregated network to manage complexity and provide flexibility in infrastructure and service provisioning and assurance.

In the case of external-facing service orchestration, more information should be gathered to understand the user requirements.

The survey results were presented next, and further discussion followed on both the future NREN strategy for OAV and the immediate next steps that should be taken in support of that strategy. A number of points of general agreement were reached, many of them confirming the survey results:

- There is a high level of interest in working on OAV.
- OAV implementation is lagging behind interest.
- It is clear that there is scope for increased adoption of OAV within the NREN community.
- Automation is currently the most important aspect of OAV for the NRENs, and the most common tool being used is Ansible. NRENs are currently looking for the best places to start automation, and will address orchestration as their experience with automation grows.
- There is no “one size fits all” solution; attempting to enforce such a thing would not be productive. Rather, there is interest in defining a reference architecture, or identifying architectural “building blocks” where the focus is on APIs and interfaces, examples of data modelling, methodologies, etc.
- With some NRENs having already made inroads into OAV, knowledge exchange should be maximised without “reinventing wheels”.
- The common pain point issues identified in the survey demonstrate the need for collaboration within the community and an increase of knowledge exchange.
- The survey responses and discussions showed a variety of terminology used by the NRENs. A common language would facilitate better understanding and knowledge exchange.
- It is important to focus on use cases. Those around connectivity services and configuration integrity are considered good starting points.
- The current NREN focus is more on providing their own services, rather than brokering services from other service providers.
- There is no real interest in the project developing a new OSS/BSS platform.
- It is important to identify actions an NREN can take to maximise its future ability to have systems that are interoperable with other NRENs and GÉANT.
- Value, uptake and sustainability are important considerations and inputs for the OAV work.

These points are taken as an input for the future work items in Task 2. One such item is to work on the terminology that can be used as a reference document for future collaboration within the community. The purpose of such a document is not to become the one and only source of truth or ultimate dictionary, but rather to specify the main terms and their interpretation as it will be used by the Task 2 team in their future community and consensus building work. A second work item should address the need for stronger collaboration and opportunities for knowledge sharing. Therefore, Task 2 has initiated discussion at the following two events - TNC 2019 and the 17th STF. Additional future work items are given in Section 6.

## 4.2 TNC 2019: OAV Side Meeting

A side meeting (BoF) session with a focus on OAV was organised by WP6 for TNC19 in Tallinn, June 20, 2019 [[TNC19OAVBoF](#)]. Unlike the Future Service Strategy Workshop, which was organised for invited GÉANT project partners' senior managers, the TNC side meeting was open to all interested in the topic - on site or via videoconference.

The OAV BoF session also extended the European focus to include international viewpoints from NRENs outside the European community. Speakers were invited from ESnet, Internet2 (both USA), and AARNet (Australia) to share approaches to OAV outside Europe, and to foster future discussion and collaboration. The European speakers for the BoF were invited from organisations recognised as active in OAV adoption, i.e., HEAnet, GRNET, SURFnet, CARNet and GÉANT. Discussion was encouraged throughout the whole session, invoking feedback on all presentations, the survey results and the overall OAV topics.

Similarly to the survey and the Service Strategy workshop, it was concluded that OAV work is very much organisation-specific and that most of the work is focused on intra-domain topics.

More than sharing the solutions, benefit can be seen in sharing the information about the use cases, lessons learned, knowledge and experience. Developed code might be consulted and adapted rather than adopted as is. It is also recognised that the OAV work first requires changes in thinking, and then in the organisation. However, with consistent, persistent and incremental work along clear long-term and short-term goals, the results will be valuable and visible. It was also noted, that the OAV question is not how much it costs, but how much might be lost if the opportunity is missed and ignored. The need for further collaboration and organisation of similar events is again highlighted.

## 4.3 17th STF: OAV Discussion

The outcomes of the survey results, the Service Strategy Workshop and TNC BoF were presented at the GÉANT Service and Technology Forum (STF) in Dublin. STF participants are NREN representatives appointed by their NREN as Access Port Managers (APMs) and responsible for the collaboration with the GÉANT organisation on connectivity services to the GÉANT network. APMs are mostly technical people, some of whom are also at senior management level, and the topics at the STF meetings were therefore mostly focused on technical, with some organisational or business topics.

The 17th STF was attended by 38 NREN representatives. The purpose of the Task 2 team's participation in the OAV topic was not just to inform the group about their work and current status, but also to provoke further discussion and gather feedback from this very important user group.

The conversations addressed the experience and common topics from the organisations that are well advanced on their OAV journey (as per the survey and the TNC discussions), and their view that some see this as very hard, while for some it is achievable. It was also remarked that OAV requires a change in thinking and the approach to work, to effect a shift towards automating repetitive, routine manual actions, and that this might be easier achieved by creating a separate engineering team that would

work on the OAV tasks while the established network engineering team continues work on daily production management.

The discussions broadly confirmed the findings of the survey, the workshop and STF audience. The outputs were in line with the suggestions for future work around knowledge sharing and exchange. It was clear that encouraging and facilitating more discussion, and sharing experiences and best practices is highly desirable. The point made at both previous meetings regarding helping NRENs take action to maximise their future interoperability with other NRENs' systems was made again.

## 5 OAV Market Analysis

Even though many of the NRENs<sup>1</sup> users have higher demands than regular users and, in some cases, even extreme demands regarding the design and specifications of network and services operations, service delivery and user expectation management does not differ that much from the commercial world. Both user groups expect a high level of professionalism, availability, reliability, resiliency and redundancy from all services, with a simple, one-stop-shop-based and near-immediate service provisioning and delivery.

Commercial, open-source and R&E development, service and equipment portfolios are interlaced. In all cases, the best solutions are made only with skilled and knowledgeable design and engineering. Most solutions in production are customised to the needs of particular companies, their business drivers, internal organisations and also organisational, cultural and other legacy factors. Very often, all of this is reflected in their OSS, BSS and Network Management Systems (NMS).

Numerous sources of state-of-the-art development of technologies, products and tools exist and it would not be possible to address all of them, nor is it the intention of this document to do so. This section provides a brief introduction to some commercial and open-source tools, techniques and methods that were either explicitly mentioned in the survey, or are used in the OAV implementations reported within the GÉANT community.

The market analysis starts with a review of patents, since they tend to pave the way for future product developments and are thus an indicator of near-future trends, even if they are not already a part of the products.

### 5.1 OAV-Related Patents

As a part of the market analysis, OAV-related patents that were granted in recent years were examined to identify trends. The analysis was done with the help of the PatentsView tool [[PATENTSVIEW](#)], a platform that offers US Patent and Trademark Office (USPTO) data for research purposes. This comprises patent data from 1976 up to March 12, 2019 and, although based on patents recorded in the U.S., this includes patents from inventors and patent-owning entities (assignees) from 200 locations in Europe and Asia (as of 2013). The data for this document was retrieved on 26 July 2019, investigating all patents that were granted (not just filed) and the search was based on exact match

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<sup>1</sup> Although these data do not constitute the official USPTO record, they are supported by the USPTO Office of the Chief Economist, with additional support from the US Department of Agriculture (USDA). “The PatentsView initiative was established in 2012 and is a collaboration between USPTO, US Department of Agriculture (USDA), the Center for the Science of Science and Innovation Policy, New York University, the University of California at Berkeley, Twin Arch Technologies, and Periscope.” ([\[PATENTSVIEW\]](#) “About” link).

phrases. A variety of phrases was evaluated with emphasis on network OAV and the following sections provide more detail.

Investigating the phrases "network virtualization" and "virtual network", the term "network virtualization" appeared in 70 patent titles as exact match since 1976, and 67 patents with this phrase were granted since 2010 (the UK-English "virtualisation" form did not appear). The term "virtual network" appeared 376 times in patent titles since 1976, and a total of 294 of these patents were granted since 2010. Figure 5.1 shows a clear increase of the patents and suggests continued interest and focus by inventors, assignees and companies.

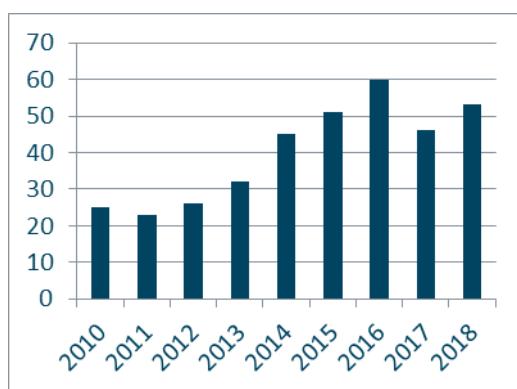


Figure 5.1: Number of patent titles using "network virtualization" or "virtual network"

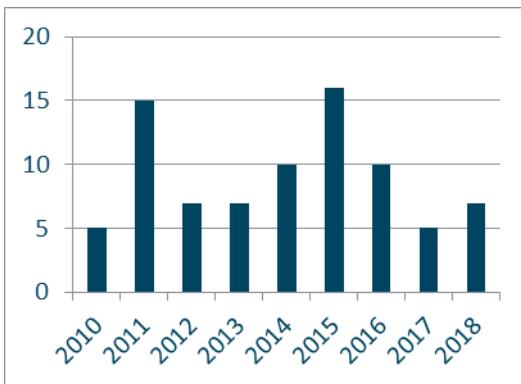


Figure 5.2: Number of patent titles using "network automation" or "automatic/automated network"

In the context of automation, the phrases "network automation", "automated network" and "automatic network" were used for the search of exact matches in patent titles. Since 1976, a total of 125 patents with these terms were granted (network automation (1), automated network (53), automatic network (71)); 82 of these patents fall into the time span from 2010 – 2019, see Figure 5.2.

The terms "network orchestration", "orchestrated network" and "orchestration" were considered in the database retrievals. The results showed that only 7 patents were granted using these exact phrases as a part of the patent title (network orchestration (6), orchestrated network (1)). The earliest the term "network orchestration" appeared was in 2016 ("orchestrated network" appeared in a patent granted in 2018), see Figure 5.3.

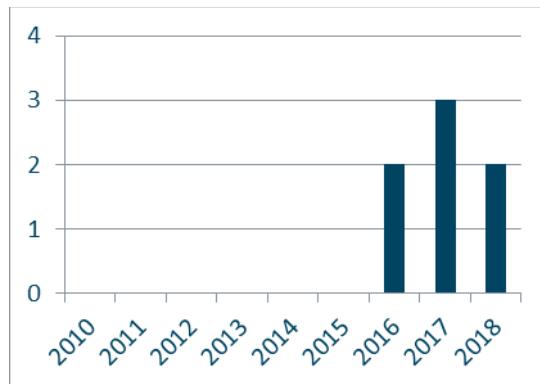


Figure 5.3: Number of patent titles using “network orchestration” or “orchestrated network”

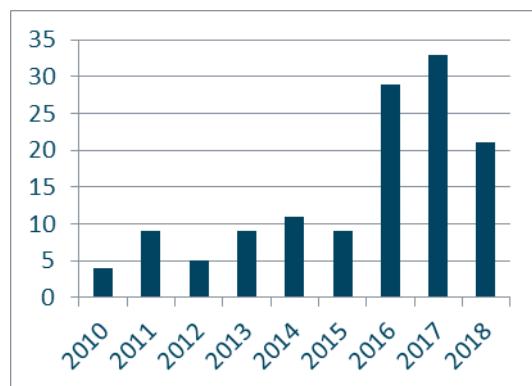


Figure 5.4: Number of patent titles using “orchestration”

A retrieval of the general term “orchestration” yielded 136 patents since 1976, see Figure 5.4; 130 of those were granted since 2010.

As the process from filing to granting a patent can last several years, the study shows that work on OAV related topics has been increasing for a number of years and that vendors can be expected to use these patents in upcoming products, systems and services. Starting in 2014, a strong increase can be observed in patents related to virtualisation. Interest in orchestration seems to have a strong focus since 2016. The data is very much dependent on the terms that were used in the searches, as exact match phrases were used in the investigation.

In almost all phrase retrievals a drop of matches can be observed in 2018. This seems to suggest that the PatentViews tool may not have all patent data available for 2018, although the authors claim that their data reflects information up to March 12, 2019. At the same time, none of the retrievals produced any patent for 2019, which also seems to suggest a possible lag of patent information becoming available.

However, the examination shows that a clear increase in OAV related patents from 2010 to 2017 (leaving the years 2018 – 2019 for future investigation). The categories for patents in the area of “network virtualization” and “virtual network” show the majority of patents concentrating on general methods and processing, followed by security related issues such as isolation of instances and the configuration of network components or routing.

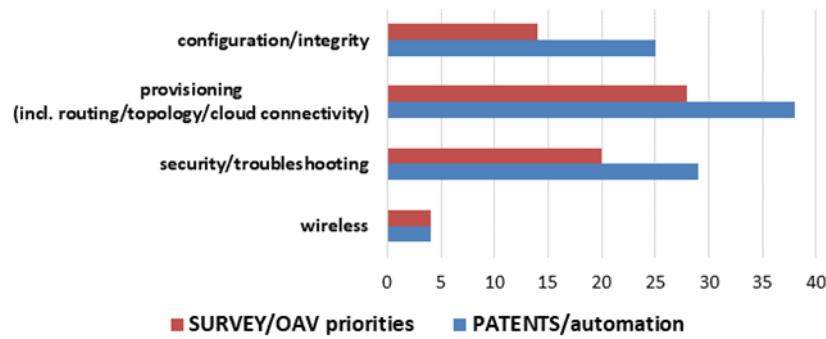


Figure 5.5: Comparison of OAV focus in patents and in OAV survey (based on patent titles containing “automated/automatic network” or “network automation” for patents granted between 2010-2018)

Patents in the area of “network automation”, “automatic network” and “automated network” focus on configuration/integrity, automatic provisioning of network connectivity as well as on security and troubleshooting (see Figure 5.5), which is very much in line with the priorities for OAV that the NRENs reported in the survey.

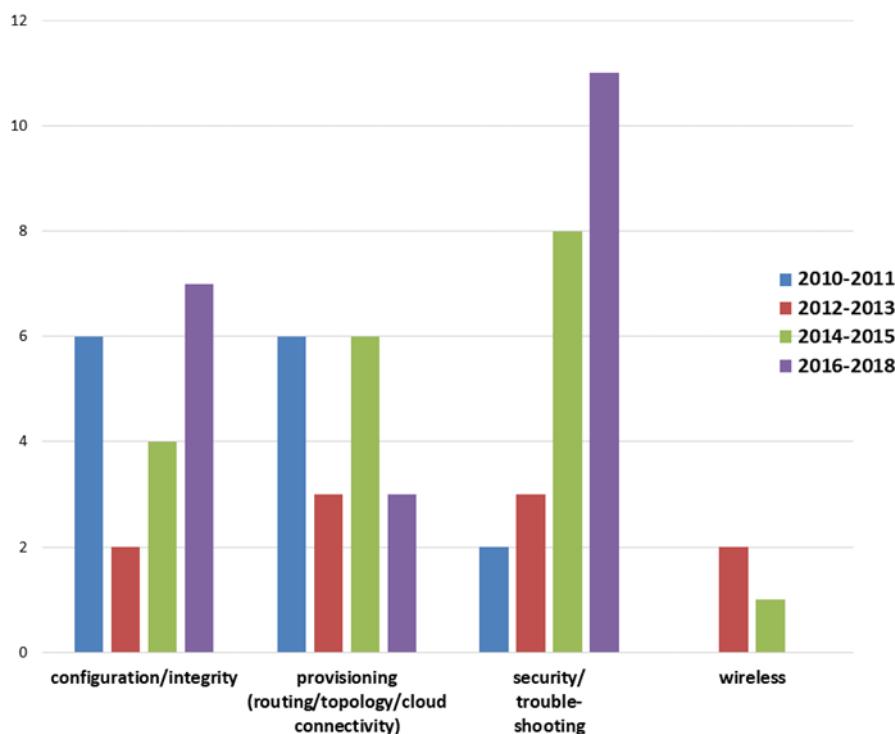


Figure 5.6: Patent titles related to focus areas in recent time intervals (based on patent titles containing “automated/automatic network” or “network automation” for patents granted between 2010-2018)

Figure 5.6 shows that interest increased especially for network automation in the contexts of configuration integrity and security/troubleshooting in recent years. Patents in connection with network orchestration show interest in general method and processing, but also routing and network orchestration for data centres.

These findings indicate that there will be more development in these areas that will probably include some of novelties described by the patents and will thus shape the future steps in both commercial and NREN organisations.

## 5.2 OAV in Commercial Environments

The motivation of commercial Communication Service Providers (CSPs) for OAV is very similar to that of NRENs: they both want to speed up the process of digital transformation, enhance agility in business and operational processes, optimise the costs and the use of available resources. They want to decrease the time for service delivery, and the amount of time required for manual work, thus hoping to reduce the number of human errors while at the same time increasing configuration uniformity and consistency, and improving and enhancing reporting.

As per available sources [[AUTOJ](#)], the challenges that commercial CSPs and NRENs face are very similar and relate to, for example:

- Manpower and skills.
- The adoption of DevOps and CI/CD paradigms.
- The standardisation of service definition and architecture elements based on data models and templates.
- The prioritisation of design and development time and tasks vs. production management.
- Heterogenous equipment and OSS/BSS components.

In the commercial world, further complexity exists where companies go through mergers and acquisitions, which is not that frequent in the R&E world. Even though commercial companies have some advantages over NRENs, in that they can more easily compete for skilled and experienced individuals and quickly employ additional people when needed, this still does not guarantee staff retention and the efficiency, effectiveness and expertise of available staff.

The path towards orchestrations, automation and virtualisation that is taken for OAV is also similar for the commercial and NREN organisations. Virtualisation of infrastructure resources is well represented at interconnectivity and equipment levels, thus impacting the network and application services.

There are four areas that could be the focus for automation (and orchestration) [[AUTOJ](#)]:

- One single function.
- Domain-specific - where a domain might be determined per process, service, set of equipment, vendor type or some other entity.
- End-to-end, with a clear definition and distinction of each end.
- Cross-domain (including inter-domain and multi-domain).

CSPs are developing their networks in the direction of Intent-Based Networking (IBN) where operations and management are orchestrated through the incorporation of machine learning and artificial intelligence, with the projection that by 2024 more than 65% of enterprise companies will

have IBN deployed in some form. It is expected that the global aggregate IBN market will reach 4.1 billion USD by 2024 and that by that time just network automation and orchestration for IBN will reach nearly 490 million USD [[GIBNM](#)].

In the area of network automation and orchestration (NAO) products and services, 17 major vendors were leading the 7.4 billion USD market in 2017 [[NEPS](#)]. The majority of 87% is for element and network management systems development (EMS/NMS), with a visible trend of the shift towards network controls and orchestration (NCO) segment which includes WAN SDN, network orchestration and virtual infrastructure management (VIM) sub-segments. The document estimates that the market will grow by over 80% by 2022. The top five network equipment providers (NEP) which stand out in the area of EMS/NMS development are Huawei, Nokia, Ericsson, Cisco and ZTE [[NAOMS](#)].

Most of the earlier NFV deployments started as domain-specific, focused either on a specific service, a "virtual-box", vIMS and vEPC or enterprise vCPE/SD-WAN deployments. Through domain-orchestration-based deployments, some companies like AT&T and Telefónica are transitioning towards full, platform-based, multi-domain and multi-use case NFV/SDN orchestration.

### 5.2.1 Commercial OAV Products

Cisco with its NSO product keeps the role of NCO leader, thanks to their WAN configuration and NFV/SDN platform capabilities [[SDNO](#)]. Other relevant vendors are Ciena, with its Blue Planet Intelligent Automation Platform for packet-optical transport, Samsung in the area of LTE and 5G mobile infrastructure, Juniper, with IP/optical gear, Contrail and Northstar with WAN SDN and NFV products, and Fujitsu with Virtuora and their packet-optical transport software products.

More information is provided in this section for Cisco NSO and Ciena BluePlanet solutions, based on the results of the OAV survey and the number of times these tools and solutions were mentioned, combined with the information from the SDX Central next-gen OSS and LSO report [[NGOSS](#)].

#### Cisco Network Services Orchestrator (NSO)

The Cisco Network Services Orchestrator [[CSNO](#)], [[NSOBA](#)] provides a platform for the orchestration and the full end-to-end lifecycle automation of physical or virtual network services. NSO can access and administer all elements in all network devices that participate in a service, and program their configuration along an end-to-end path, including bridging the different domains, different vendors, traditional or SDN management interfaces, different OSS or NFV orchestrator systems [[LSA](#)].

NSO uses a standardised YANG modelling language to describe a service, then maps the service to the YANG device models, including also non-YANG devices, and thus provides the basis for automation of device configuration. The usage of YANG modelling provides NSO with a single but network-wide interface for any network device or service, physical or virtual, including multi-vendor or multi-domain environments. With Cisco Elastic Services Controller (ESC), NSO can also be used for virtual applications management. NSO can be used for service assurance and fulfilment processes and can interoperate with third party and open-source OSS/BSS components such as order management, customer portals and event management alarm and fault as a part of the end-to-end service orchestration.

## Ciena Blue Planet

Ciena Blue Planet (CBP) is a microservices-based, modular software suite that enables the automation and orchestration of network services, from design to creation, delivery and assurance. It helps in simplifying the adoption of SDN and NFV, across physical and virtual domains [[BPS](#)], [[BPSS](#)]. Based on open-source technologies, model-driven templates and container-based microservices, CBP can be used for Multi-Domain Service Orchestration (MDSO), NFV orchestration, commercial-grade ONOS and WAN automation, SD-WAN, connectivity to clouds, edge computing and virtualisation, virtualised managed services, virtualised Customer Premises Equipment (vCPE), Bandwidth on Demand (BoD), and others.

Ciena's Blue Orbit ecosystem, a part of the Blue Planet services, represents also the DevOps Exchange Community and DevOps Toolkit where resources and ideas can be shared to foster stronger collaboration between partners. With the use of Ciena's Blue Planet Intelligent Automation Platform [[BPIAM](#)] orchestration, policy and advanced analytics and APIs can be linked to the business processes whose execution can then be triggered automatically.

## 5.3 Open-Source OAV Initiatives

Open-source initiatives are carefully observed and used by both commercial and non-commercial companies. In order to achieve higher levels of automation in "self-driving" networks and sufficient freedom for the required systems' customisation, commercial CSPs are working towards building their own solutions based on open-source platforms, methods and technologies.

There are a number of tools, software products and also methodologies that originate in the open-source world but impact highly on the everyday operations of many different types of organisations. Some of them, like NetDevOps and CI/CD will be briefly referenced in this section, followed by brief references to the most popular open-source tools such as Ansible, Git, Jenkins and initiatives like OSM and ONAP.

### 5.3.1 DevOps / NetDevOps

With the first OAV initiatives it became clear that the previous division of responsibilities into network engineers, developers and operations teams is no longer sustainable, as the digital transformation requires knowledge of all three areas of the infrastructure and service lifecycles. Apart from knowledge and skills, a change in the culture and working methodologies towards more agile work and stronger collaboration is needed. All of this led to the creation of DevOps, or NetDevOps [[NetDevOps](#)], which are sometimes referred to as a discipline, methodology, collaboration or feedback [[DEVOPS](#)].

Some of the more popular DevOps practices include [[NDOCP](#)]:

- Automate everything to avoid any manual provisioning, configuration or performance monitoring, to detect and resolve any issues or errors and remove bottlenecks.
- Enhance configuration management with the use of continuous configuration automation (CCA) elements such as Ansible playbooks, JSON, XML or YAML.

- Treat monitoring as a testing tool in order to be able to act quickly.
- Move towards streaming telemetry solutions with near real-time access to structured data and be able to process the data upon their arrival and act immediately.
- Structure the data based on standard data models to be able to collaborate and interconnect easily and quickly with different systems.
- Drive continuous improvement - evaluating and enhancing practices, processes, tools, environments and source code.
- Enhance and stimulate communication and collaboration among network architects, developers and operations teams.

DevOps / NetDevOps is changing the culture of organisations. It speeds up and shortens the process from design, development, testing and release to the final deployment of a newer software version. It brings service creators and end-users closer together, thus intensifying their collaboration towards a faster break up or towards longer-term satisfaction and trust. DevOps are usually mentioned together with the CI/CD.

### 5.3.2 Continuous Integration, Delivery and Deployment

Continuous Integration, Continuous Delivery (CI/CD) and Continuous Deployment are new methods that are introduced and used by DevOps [[ACIDD](#)], [[CN](#)], having been taken from the software development industry where they are now widely accepted and adopted practices.

Continuous Integration implies merging the work of all individual code-contributing developers into a common repository, which speeds up and eases the preparation of the next software release. The code is tested through creating a build and running tests against the build, thus trying to control these continuing incremental development steps.

While CI automates a testing process, Continuous Delivery automates the software release process. It thus extends the CI process and requires a higher degree of automation with each step of build deployments for the release of a new software version.

Continuous Deployment reaches further towards the end-user by enabling the automatic upgrade of the software to the newest version that has successfully passed all the stages of the delivery to the production pipeline.

Test-driven development (TDD), automated acceptance testing and continuous integration are structural elements of Continuous Deployment. The implementation of the CI pipeline includes the following architectural steps:

- Use of a modern version control system (VCS) to manage environment configurations, e.g. Git.
- Use of a CI orchestration engine to build and test components, such as Jenkins and Ansible for process automation.
- Integration of the CI orchestration engine with life cycle management tools, e.g. JIRA.
- Communication of feedback by providing reports.

CI is a valuable tool to assess the readiness of a service, the impact that system-level changes might have on the service, and the overall compactness and compatibility of the service components. During this process, every change must be well tested and must have fast rollback capability to a known state, either a good or a failed controlled release, such as canary (slow roll out to a small subset of users) and blue/green (two parallel deployments: previous vs. new version) deployment capabilities [[NetDevOps](#)].

### 5.3.3 Infrastructure as Code

Infrastructure as code (IaC) is a process for managing and provisioning infrastructure elements structure and configuration through descriptive, machine-readable definition files. This concept became useful and important for cloud infrastructure and can be (though it is not wide-spread yet) extended to data centres, campus or WAN networks and other infrastructure segments. IaC is applicable for physical equipment such as bare-metal servers, storage, switches and routers as well as for the virtual machines or other resources [[ASA](#)]. The resource definitions can be managed through a version control system and are usually stored in source control repositories. These definitions are more declarative than an exact device configuration and include the information about the applications that are using these resources, and are suitable for a wider deployment by an infrastructure deployment tool, such as Terraform by Hashicorp [[TERRA](#)]. The Infrastructure as Code concept applied on network infrastructure is referred to as Network as Code (NaC).

Three main principles of Network as Code are described in [[NAC](#)]:

- Store network configurations in a source control (e.g. Git) repository history along with details such as who made the changes, when the change was made and why.
- Source control is the single source of truth – each environment can be constructed in the same way using the same configuration definitions with minimum variations.
- Deploy configurations with programmatic, if possible standardised, APIs to enable easier and wider-scale interoperability, interconnectivity, transferability and consistency.

NaC is seen as an integral part of the adoption of NetDevOps.

### 5.3.4 OAV Tools

There are a lot of tools on the market that can support a continuous integration, deployment and delivery pipeline. A few of the most popular tools that were also mentioned very frequently in the OAV survey are presented in this document - Git [[GIT](#)], Jenkins [[JNKNS](#)], YAML Lint [[YAMLL](#)] and Ansible [[ANSIBLE](#)], [[ANS](#)].

**Git** is a free open-source distributed system for source code control management, suitable to coordinate work among a group of programmers. It supports change tracking, version control, distributed non-linear workflows and includes specific visualisation and navigation tools. It supports continuous integration process and speeds up the release process. It is usually used for code commit, integration of new code with the code base and pull to a CI build server.

**Jenkins** is a free open-source CI build server that is used for checking and validating new commit versions, and providing feedback about the pass or fail exit condition. It can be used to automate different types of tasks related to different pipeline stages, such as building, testing, delivering or deploying software.

**YAML** Lint is a simple validator of a YAML syntax, which also checks for any unnecessary repetition, spaces, indentations or line length.

**Ansible** is a simple automation and orchestration engine based on Python, which is often used for infrastructure or service provisioning, management or deployment in clouds, campus, WAN or multi-domain scenarios. Ansible is frequently used together with Jenkins in the CI/CD process [[AJCICD](#)] in a way that its Playbooks and roles are reused for provisioning, while Jenkins serves as process orchestrator. Ansible can connect with multiple devices simultaneously via API or SSH, using YAML syntax to define individual states and can be used as an orchestrator for sequences of API operations.

## 5.4 OAV Standardisation Efforts and Projects

The multitude of different hardware and software, infrastructure and services, vendor and open-source solutions driven by the business need for digital transformation, forces the need for interconnectivity and interoperability of any possible combination. The easiest way to achieve this is via standards. In the OAV area, standardisation is primarily sought for data models and interfaces.

There are several organisations that are driving standardisation work in the area of OAV. This is summarised well in Network service orchestration: A survey [[OSNSO](#)], including an overview of research projects and individual research initiatives. Even though the primary focus of this paper is orchestration, it is readily extendable and fully relevant to the areas of automation and virtualisation.

The same document also considers the difference between single-domain and multi-domain orchestration which is very relevant to the GÉANT service area. Unlike a single-domain orchestrator that can reach, manage and control all given resources within the same administration domain, the orchestrator of one domain in a multi-domain environment does not know about the systems and resources in another domain. Because of such complexity, multi-domain scenarios have a stronger need for standardisation of the systems, models and interfaces. Several multi-domain orchestrators are mentioned, such as T-NOVA [[TeNOR](#)], Open Network Automation Platform - ONAP [[ONAP](#)], [[ONAPA](#)], [[ONAPD](#)] and Escape [[ESCAPE](#)].

Single-domain orchestrators are much more represented on the market and referenced in existing solutions. The European Telecommunications Standards Institute (ETSI) has developed reference architectural frameworks to support NFV management and orchestration [[NFV](#)] and provided a single-domain network service orchestrator Open Source Management and Orchestration (MANO) [[OSM](#)], [[OSMSF](#)], [[OSMOB](#)] which is suitable for the management of physical as well as virtual resources.

ETSI Open Source MANO (OSM) is described at a functional level and does not specify any particular technology or implementation solution, but is often referenced for using SDN and NFV architectural frameworks. It specifies a number of interfaces for NFV Infrastructures (NFVI) and Virtual Infrastructure Managers (VIMs), such as OpenStack, VMware vCloud Director, Amazon Web Services

(AWS), and OpenVIM, and GÉANT's DynPaC [[DynPaC](#)] that allows on-demand setup of communication circuits between data-centres in different domains.

Most of the implementation solutions are tied to a particular environment, and even though they all include similar technologies related to connectivity services, network, system or end-user applications, the combination of the implemented infrastructure, systems, tools and products make one combination almost unique. Still, many of them use one or more of the tools or technologies mentioned in this document. Some of the implementation solutions are Cloudify Documentation Center [[Cloudify](#)], Gohan Simple and unified cloud service architecture [[Gohan](#)], Open Baton framework [[Open Baton](#)], Tacker [[Tacker](#)], X-MANO [[X-MANO](#)], and XOS Overview [[XOS](#)].

Taking into consideration the results of the OAV survey of GÉANT project participants (mostly European national and research network organisations), the feedback received from three community meetings and the market analysis, it is evident that there are some common strategies that are driving the transformation of digital infrastructure and services, supported by an increasingly large but still limited set of prominent tools. At the moment, these strategies or proven algorithms might not be directly visible and transparent, but they may become so with time and with an increasing number of successful use case implementations.

The WP6 Task 2 work aims to identify and help share successful strategies and examples of best practices from the GÉANT community. By supporting the required uptake of orchestration, automation and virtualisation principles, and facilitating various knowledge-sharing activities, the team aims to raise the overall level of OAV adoption in the community. The future work planned by the WP6 Task 2 team is presented in Section 6.

## 6 Future Work

After the initial survey and the follow-up OAV-related community events, the Network Services Evolution and Development Task will continue its work in the area of orchestration, automation and virtualisation through collaboration with the community. Initial work will start with two specific activities: focus groups and knowledge sharing/exchange.

WP6T2 will set up and chair small focus groups to explore specific topics and their relevance to our community, to discuss and document best practices, and to help promote specific OAV technologies. The topics are yet to be determined, as are the organisations that will participate in the focus groups. Potential areas of interest - as indicated by the survey - include defining a common OAV terminology and documenting a “reference architecture / framework” that will identify common interfaces and the necessary building blocks. The terminology and the architecture will be used as a reference, to foster better understanding of the work from different organisations and teams. The reference architecture / framework is not intended to replace the existing work of any organisation, but rather to help organisations think about maximising opportunities for future interoperability, and to provide a practical “blueprint” that could be followed by organisations just starting out on their OAV journeys. The focus groups will prioritise use case(s) of interest to multiple NRENs, to maximise the contribution to the overall GÉANT strategy, rather than seeking to solve specific use cases for only one NREN.

Even though no specific use cases are recognised to be of interest to all NRENs and the level of automation, orchestration or virtualisation clearly varies between the NRENs, there are a few groups of NRENs with similar use cases that might be explored. This work will draw on appropriate expertise from the project and the community to better develop the community’s knowledge and understanding of OAV for those use cases, possibly leading to future pilots.

The work so far has shown a community need for knowledge sharing and exchange, with the aim to increase the levels of collaboration and information exchange between the NRENs. The team is looking into the following potential areas for its knowledge exchange work:

Holding online InfoShares for technical subjects, by members of the community as well as external experts for different user groups with different levels of technical, managerial and business focus.

Providing a tools repository where NRENs can share their orchestration and automation scripts, tools, templates, etc.

Maintaining wiki pages with an open access for all, similar in spirit to a SIG/TF Wiki area. The wiki would point to InfoShares, the repository, other events, common terminology, examples of good practice in the community, etc.

Through its work, the team will explore whether there is a common strategy for the project partners and then use these findings to continue the work with the users in line with that strategy, towards the overall progress of orchestration, automation and virtualisation in the GÉANT community.

Even if the work might not be directed to solve the particular use case of any particular organisation, increasing the exchange of knowledge and experience, working on the models, architecture and interfaces, tools and solutions may help the organisations and their NetDevOps teams to draw from these sources into their own specifics, situations and needs, in so doing "raising the bar" for OAV across many organisations.

The results of the focus groups and knowledge exchange will be continuously disseminated through the project and through the proposed OAV wiki, and reported in future WP6 deliverables.

## 7 Conclusions

The Network Services Evolution and Development task in the Network Technologies and Services Development Work Package (WP6) of the GN4-3 project aims to support interoperability and coordination of the instantiation of network services, within a single- and/or across different technological or partner domains. It also aims to support automated service deployment, aligning with business and/or operational processes. Such an aim has at its heart the work on automation, orchestration and virtualisation that is needed for the most effective network infrastructure and service provisioning and delivery. A team has been created in Task 2 to support the exploration of the OAV needs and potential work for the community.

Starting from the OAV work in previous generations of the GÉANT project, the team has initiated a survey to determine the "lie of the land" in OAV adoption in the community, and to look for the best way for Task 2 to contribute to and support the community. The survey has shown significant interest and a lot of existing work in NRENs in the area of OAV, and also shown that at the moment no specific additional software development provided by the GÉANT project could help the NRENs, since their OAV work is tailored to specific systems and processes. Therefore, the Task 2 team is continuing its work towards contributions to the community through knowledge sharing and exchange, and through focus groups, starting with its first workshop, TNC sessions and presentations. The information gathering has also been extended with the market analysis that covers solutions from commercial and open-source environments, standardisation efforts and implementations. This market analysis serves as a starting point for further research in the OAV area, knowing that any of the sources might serve a different purpose for different organisations, use cases or levels of maturity but all in the direction of the further improvement and progress of any orchestration, automation or virtualisation efforts.

It can be concluded that there is no single and quick solution that will lead to the overall and total automation and orchestration of network services. However, when completed in line with the determined short- and long-term organisational goals and processes, even small steps make a difference. The selection of tools can differ, and the selection of starting points can differ too. There is no ultimate recipe where to start or when to stop, or an ultimate path that everybody should follow, even with the help and use of standards and best practices. It is important to start, to define the final long term and short term goal, to take consistent steps, no matter how small they may be, to achieve quick wins, to stay persistent and consistent with the strategy, service templates and common approach to the engineering of automated processes towards the multi-domain/global orchestration. And then the results will be visible.

The Task 2 team's future work is defined to address the inputs from the community and to be based on the findings from the survey and market analysis. The team will work to organise and contribute to the knowledge sharing and exchange, and to organise focus groups around specific topics of NREN interest, as this approach is seen by the community to be of greater benefit than a specific software

development. The future work will continue to explore, learn and take advantage of all the differences and dissimilarities of the Task 2 multi-domain team, gathering contributions and inputs from their own organisations, through collaboration with other organisations in their NRENs, countries, communities and also through collaboration with the global R&E network community.

## Appendix A GN4-3 WP6T2 Questionnaire: Automation and orchestration in NRENs

### A.1 Introduction

This survey has been sent through GÉANT’s Partner Relations team to NRENs to be filled in by their senior network engineers. The responses provided should reflect the opinion of the NREN, not the personal views of the person filling in the survey.

The questions were coordinated by the Network Technologies and Services Development Work Package (WP6) of the GÉANT GN4-3 project. Please complete the survey by April 17, 2019 and email it to: [gn4-3-wp6-wpls@lists.geant.org](mailto:gn4-3-wp6-wpls@lists.geant.org) or submit online via survey monkey at <https://www.surveymonkey.com/r/OAV-in-NRENs>.

The survey was developed to complement the topics covered by the GÉANT NREN Compendium (see <https://compendium.geant.org/>).

The purpose of this survey is to:

- learn about the strategy and actions of each NREN related to network and service orchestration, automation and virtualisation (OAV);
- explore if there are common use cases, ideas, needs and issues in the community in the areas of automation, orchestration and virtualisation;
- recognise possible areas of collaboration both amongst NRENs and between NRENs and GÉANT;
- determine and recommend possible future work within Work Package 6 (WP6) of the GÉANT GN4-3 project that could be of benefit to as many partners as possible for identified use case(s).

For all questions that have free-text boxes please feel free to provide any additional explanation and information that we did not explicitly ask and you find relevant, including any potential requirements or prerequisites related to your answer. There is also a free text box at the end of the survey for you to add any extra comments.

All the information provided will be analysed to determine potential future work items for WP6. A summary of the findings will be presented for information and discussion at the “GN4-3 Future Service Strategy Workshop” in Amsterdam on 9/10 May 2019.

We may also initiate further more specific investigations, e.g., focus groups or expert discussion groups, on certain topics based on the survey findings, or we may wish to follow up with specific respondents about specific answers they have given. Hence we have asked for the contact details of the person(s) in each NREN completing the survey.

## A.2 I. Information about the NREN

Please provide the following information:

- \* **1. Name of your National Research and Education Network (NREN):**
- \* **2. Your name and role (person or persons completing the survey)**
- 3. We would like to contact you in case of any additional questions. If you agree, please provide contact details.**

\* Any personal data (your name, role and contact details) provided would be used only for the purpose of this survey data gathering and analysis on the basis of your consent which will be provided upon your fulfilment of the aforementioned data and will not be disclosed outside of the team working on this consensus building initiative in the project in any part of the process. The data controller of your data is GÉANT Association and you can find GÉANT's privacy notice here: <https://www.geant.org/privacy-notice/Pages/GEANT-Privacy-Notice.aspx>.

## A.3 II. Your Existing Network and Services Platform

We would like to understand the current status of the systems that underpin your network deployment, so that we know more about the platform upon which you are building or could build future services using Orchestration, Automation and Virtualisation (OAV) principles.

- 4. What elements are your network’s OSS (Operations Support System) and BSS (Business Support System) comprised of? What do you see as strengths and weaknesses of your OSS and BSS systems?**
- 5. Does your organisation employ a data model such as the TM Forum Information Framework (SID), the DMTF Common Information Model (CIM), (IETF) YANG models, or something similar? If so, which one(s)?**
- 6. Does your organisation follow the practices of any related process models, guidelines, standards or best practices such as TM Forum, MEF, IETF, ITIL or ISO 27000? If yes, which?**
- 7. Do you or your organisation participate in / contribute to any standardisation communities or network operator fora related to automation? If so, which ones and why?**

**8. Do you use standard APIs for interoperation between your OSS and BSS components? If so, please provide examples.**

**9. What policies do you have today to control and manage changes to your network device configurations?**

**10. Do you have a networking / network services testbed within your organisation? Does it support evaluation and testing of orchestration, automation and virtualisation approaches? If so, please explain how.**

## A.4 III. Your Current OAV Use Cases and Services

In this section, we would like to explore any existing applications of OAV approaches to deploying and supporting services within your network.

**11. What orchestration, automation, and/or virtualisation work is taking place in your organisation? For each of these work areas, please state whether it is in the strategy, development or production stage.**

**12. Of the above areas, which did you choose to implement first, and why?**

**13. Which software are you using for orchestration, automation, and virtualisation? Please include any open source tool(s), in-house software, commercial off-the-shelf software, third party bespoke systems, etc.**

**14. Have you implemented any inter-domain orchestration or automation? If yes, please give more details.**

**15. How would you rate the priority of the following orchestration, automation and virtualisation use cases (please choose all that apply and specify as many details as you find appropriate):**

	none	low	medium	high	critical
Automated WAN connectivity, including network peerings					
Connectivity to cloud services					
Last mile connections / CPE provisioning					
Wireless networking					
Data centre networking enhancements					
Problem troubleshooting					

Configuration integrity				
Security operations centre enhancements				
Deploying NFV security (or other) functions to customers				

Do you have any other use cases? Please specify

**16. Please describe multi-domain OAV use cases of interest to you that include:**

- a) An institution / campus and your NREN
- b) Your NREN and GÉANT
- c) Your NREN and a cloud provider

**17. Does your NREN offer or use virtualised services such as VPNs, VRFs, virtual circuits, virtual machines, or other type of abstracted overlays or slicing? If so, please list these.**

## A.5 IV. Your OAV Challenges and Priorities

In this section we are trying to understand your organisation's priorities but also the challenges you face in meeting those priorities, in the context of OAV.

**18. What are the main operational priorities you are working on and major pain points you are trying to solve within your operational processes?**

**19. Do you face particular challenges in widening your orchestration, automation and virtualisation work? If so, please describe these.**

**20. Please indicate whether you plan to apply OAV principles to the following service areas in the next two years, and if so give example(s) for each:**

- a) Hardware independent or technology agnostic control of the network
- b) Modular network provisioning and agility
- c) Network operations and maintenance, e.g., automatic monitoring, ticketing, fault analysis, management, etc.
- d) Consistent network elements updates and large control plane updates verification, e.g., improved accuracy and reduced errors
- e) Network connections
- f) Service ordering

- g) Cost efficiency improvements, e.g., green IT, federated shared infrastructure, etc.
- h) Network security, e.g., firewalls, VPNs, T&I, etc
- i) Other areas? Please specify.

**21. What kind of skills do you consider that people in your organisation should have to approach orchestration, automation and virtualization? Do you consider that people in your organisation have the right skills? If not, what is missing?**

**22. Does your network engineering / Network Operations Centre (NOC) team have specific concerns around a movement towards increased automation? If so, what are they?**

**23. Which tools do you use or plan to use to ensure your automation platform is robust and will operate correctly, and that changes applied can be appropriately verified?**

## A.6 V. Your Future OAV Use Cases and Services

We would like to understand your plans and priorities for future use cases / services which would benefit from automation. Identifying NRENs that have made progress in one area may help other NRENs starting out in that area.

**24. What plans do you have a) within the next two years, and b) beyond that timeframe for your future use of orchestration, automation and virtualisation?**

a) within the next two years:

b) beyond that timeframe:

**25. Do you plan to implement any inter-domain orchestration or automation in the future? If yes, please describe.**

**26. What is your view on allowing changes to your network configuration based on requests originated in another organisation, be that GÉANT, an NREN, a campus, or some other organisation?**

**27. What authentication and authorisation infrastructure do you believe is required to establish appropriate authorisation policy for handling service requests from your own network or for requests originated in another organisation, be that GÉANT, an NREN, a campus, or some other organisation?**

**28. If you do not use standardised APIs, would you be open to putting a “wrapper” around existing service endpoints to facilitate interoperability with third parties (other NRENs, etc.)?**

**29. What level of disaggregation from the physical hardware layer would you like to achieve in your organisation in the next 2-4 years, (e.g., through the deployment of white boxes with separate Network Operating Systems, etc.)?**

## A.7 VI. How can the GÉANT Community / the GÉANT Project help you?

This survey is seeking to build consensus around use cases for OAV within the GÉANT and NREN community, and to identify future work in WP6 that can deliver the maximum benefit and best value for that community.

**30. Do you collaborate with GÉANT or other NRENs on network and service orchestration and automation? If so, for what scenarios or use cases?**

**31. Are there NRENs who you consider to be good examples of best OAV practice? Who? Why?**

**32. How can the GÉANT project assist you in your journey towards greater automation and orchestration of your services? Which of the following would you find useful:**

- a) providing data model(s)
- b) providing methodology
- c) providing training (please specify the topic)
- d) developing software (please specify which)
- e) providing a tool(s) / automation repository
- f) or other ways (please specify):

**33. Would you consider taking part in a pilot use case involving automatic inter-domain network or service orchestration with full/partial control given to other parties over your network slice? If yes, is there a particular pilot use case that would be of most interest to you?**

**34. How likely is your NREN to use a full OSS/BSS turn-key solution provided by a third party, e.g., a system integrator, a commercial OSS/BSS suite or GÉANT?**

## A.8 VII. Concluding Comments

This section allows you to add any other comments or information you think is relevant to the survey and its goals.

**35. Please enter any additional comments or suggestions you may have:**

**Thank you very much for taking the time to fill in the survey!!!**

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# Glossary

<b>AAI</b>	Authentication and Authorisation Infrastructure
<b>API</b>	Application Programming Interface
<b>APM</b>	Access Port Manager
<b>AWS</b>	Amazon Web Services
<b>BMS</b>	Bare Metal Server
<b>BoF</b>	Birds-of-a-Feather
<b>BSS</b>	Business Support System
<b>CBP</b>	Ciena Blue Planet
<b>CCS</b>	Consolidated Connection Service
<b>CD</b>	Continuous Deployment
<b>CI</b>	Continuous Integration
<b>CSP</b>	Communications Service Provider
<b>DCN</b>	Data Communication Network
<b>EMS</b>	Element Management System
<b>EPL</b>	Ethernet Private Line
<b>ESC</b>	Elastic Services Controller
<b>ETSI</b>	European Telecommunications Standards Institute
<b>EVPN</b>	Ethernet Virtual Private Network
<b>GA</b>	GÉANT General Assembly
<b>GCS</b>	General Connection Service
<b>gOCX</b>	GÉANT Open Cloud Exchange
<b>GTS</b>	GÉANT Testbeds Service
<b>GVM</b>	Generalised Virtualisation Model
<b>IaC</b>	Infrastructure as Code
<b>IBN</b>	Intent-Based Networking
<b>IDS</b>	Intrusion Detection System
<b>IEEE</b>	Institute of Electrical and Electronics Engineers
<b>IETF</b>	Internet Engineering Task Force
<b>ITU</b>	International Telecommunication Union
<b>JRA</b>	Joint Research Activity
<b>MANO</b>	Management and Orchestration
<b>MD-VPN</b>	Multi-Domain Virtual Private Network
<b>MDSO</b>	Multi-Domain Service Orchestration
<b>MEF</b>	Metro Ethernet Forum
<b>MPLS</b>	Multi-Protocol Label Switching
<b>MS</b>	Microsoft
<b>NaC</b>	Network as Code

<b>NAO</b>	Network Automation and Orchestration
<b>NCO</b>	Network Controls and Orchestration
<b>NEP</b>	Network Equipment Providers
<b>NFV</b>	Network Function Virtualisation
<b>NMaaS</b>	Network Management as a Service
<b>NMS</b>	Network Management System
<b>NOC</b>	Network Operations Centre
<b>NREN</b>	National Research and Education Network
<b>NSA</b>	Network Service Agent
<b>NSI</b>	Network Service Interface
<b>OAV</b>	Orchestration, automation and virtualisation
<b>OGF</b>	Open Grid Forum
<b>ONAP</b>	Open Network Automation Platform
<b>OSM</b>	Open Source MANO
<b>OSS</b>	Operations Support System
<b>OTN</b>	Optical Transport Network
<b>perfSONAR</b>	Performance focused Service Oriented Network monitoring ARchitecture
<b>PERT</b>	Performance Enhancement and Response Team
<b>PMP</b>	Performance Measurement Platform
<b>R&amp;D</b>	Research and Development
<b>RCA</b>	Resource Control Agent
<b>SDN</b>	Software Defined Network
<b>SPA</b>	Service Provider Architecture
<b>STF</b>	Service and Technology Forum
<b>R&amp;E</b>	Research & Education
<b>TDD</b>	Test-Driven Development
<b>TMF</b>	TM Forum
<b>TNC</b>	The Networking Conference
<b>USD</b>	US Dollar
<b>VC</b>	Virtual Circuit
<b>VCS</b>	Version Control System
<b>VIM</b>	Virtual Infrastructure Management
<b>VM</b>	Virtual Machine
<b>VPN</b>	Virtual Private Network
<b>VSI</b>	Virtual Switch Instance
<b>WAN</b>	Wide Area Network
<b>WP</b>	Work Package