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Network Monitoring Solutions

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Abstract

This deliverable provides an update of the status of the network monitoring services in production under GN5-2 Work Package 6 Task 3, Monitoring (WP6 T3) as of M18 (June 2026), along with a review of other ongoing activities undertaken as part of GN5-2 WP6.

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Executive Summary

The Monitoring task (Task 3) of the Network Development work package (WP6) in GÉANT's GN5-2 project is responsible for three production network monitoring services – Argus, perfSONAR and TimeMap. Additionally, WP6 Task 3 is engaged in exploring the analysis of Performance Measurement Platform (PMP) data, applying the TimeMap architecture to the monitoring of the GÉANT Core Time and Frequency Network (C-TFN) that is now being deployed, and participating in the new MetrANOVA Consortium initiative aimed at the controlled sharing of monitoring data between organisations. All the above services are targeted at the GÉANT community at large.

This deliverable presents an update on the status of the WP6 Task 3 network monitoring service portfolio as of June 2026, 18 months into the GN5-2 project that began in January 2025, together with ongoing work and new initiatives underway in Period 2 of GN5-2 by WP6 Task 3. The document finds that all the production services are on target to meet or exceed their key performance indicators (KPIs) by the end of GN5-2. Overall, the portfolio of network management and monitoring services continues to fulfil GÉANT's objective of ensuring that the services it offers are current, effective, address real NREN demands and are well used.

1 Introduction

In the GN5-2 project's Network Development work package (WP6), Task 3 Monitoring (T3) works on further developing and evolving network monitoring and management tools and services for the GÉANT community.

Three production-level services are supported by the WP6 T3 team at the time of writing this document:

- **Argus** – An open-source, alarm aggregation and correlation tool that enables Network Operations Centres (NOCs) and service desks to aggregate incidents and planned events from multiple monitoring applications into a single, unified dashboard and notification system.
- **perfSONAR** – Consists of two sub-activities:
  - The perfSONAR International Project, involving development and user support of the perfSONAR software for active network performance monitoring within an international collaboration between GÉANT, ESnet, Internet2, Indiana University, RNP and the University of Michigan.
  - The perfSONAR Consultancy and Expertise service provided to the GÉANT community, including operating a mesh of perfSONAR test points provided by organisations from the GÉANT community and running a perfSONAR central data archive with its visualisation dashboards.
- **TimeMap** – A tool that collects and visualises latency and jitter measurements over the GÉANT backbone network, helping to verify network anomalies and performance issues.

In parallel with this operation and development work, the WP6 T3 teams also seek new monitoring opportunities by building on the experience gained over recent years and closely listening to the R&E community's needs and demands via user and satisfaction surveys, infoshares and face-to-face events, while being aware of the process of network evolution. Areas under consideration and investigation, with new solutions being proposed, include:

- Very high-speed monitoring
- Technical requirements of networked musical performances with geographically distributed performers
- Network or routing micro-disruptions
- Automated anomaly detection and troubleshooting
- Sharing of monitoring data
- Monitoring of new types of networks

This document presents a snapshot of the status of the WP6 T3 network management and monitoring services as of June 2026, 18 months into the GN5-2 project. Section 2 describes the

services in production, covering users, uptake and usage, KPIs, and activities; Section 3 details the additional initiatives where WP6 T3 is leveraging its knowledge and expertise to explore and provide new monitoring tools, platforms and processes; Section 4 outlines the conclusions, including the direction of WP6 T3's future work.

2 Services in Production

This section describes the current status of the WP6 T3 services currently in production, namely:

- Argus
- perfSONAR
- TimeMap

For each service, it provides a high-level description; information on users, uptake and usage; the status of KPIs; and a description of recent and ongoing activities.

2.1 Argus

Argus [1] is an open-source tool for NOCs and service centres to aggregate incidents from all their monitoring applications into a single, unified dashboard and notification system. Most NOCs will, out of necessity, use a myriad of applications to monitor their infrastructure and services. In turn, they need to contend with manually managing notification profiles and monitoring dashboards in each individual application. Argus mitigates these scenarios by providing the NOC with a singular overview of actionable incidents, and by providing a single point of access to notification configuration and visualisation. Argus does not provide a monitoring service itself; it is lightweight by design, focusing on one thing: managing the alarms of the underlying monitoring applications in use.

Argus is agnostic about the details of each monitoring application, instead providing a REST Application Programming Interface (API) to report new incidents, and to search, fetch or update the status of previously registered incidents. Glue services – software pieces giving access to other applications' alarms or data – already exist for several source applications, and more can be easily written using the documented API and/or existing API client libraries for Python. Incidents are associated with a source application and can be tagged with arbitrary metadata from that source application, including URLs to drill down into incident details.

Metadata can be used to make custom incident filters, which can be applied both in the dashboard user interface (UI) and in notification profiles. Mechanisms also exist to add acknowledgements to incidents and to link incidents with tickets in the NOC's ticketing application. The data model even supports registering inter-relationships between incidents, a functionality leveraged when correlating incidents. Planned maintenance events can also be listed in Argus, allowing further correlation with incidents. Notifications via email, SMS and the messaging platforms Microsoft Teams and Slack are supported, and the inclusion of additional media is planned, such as Telegram, Matrix and Discord via Apprise [2]. The Argus development roadmap can be found on the WP6 Wiki [3].

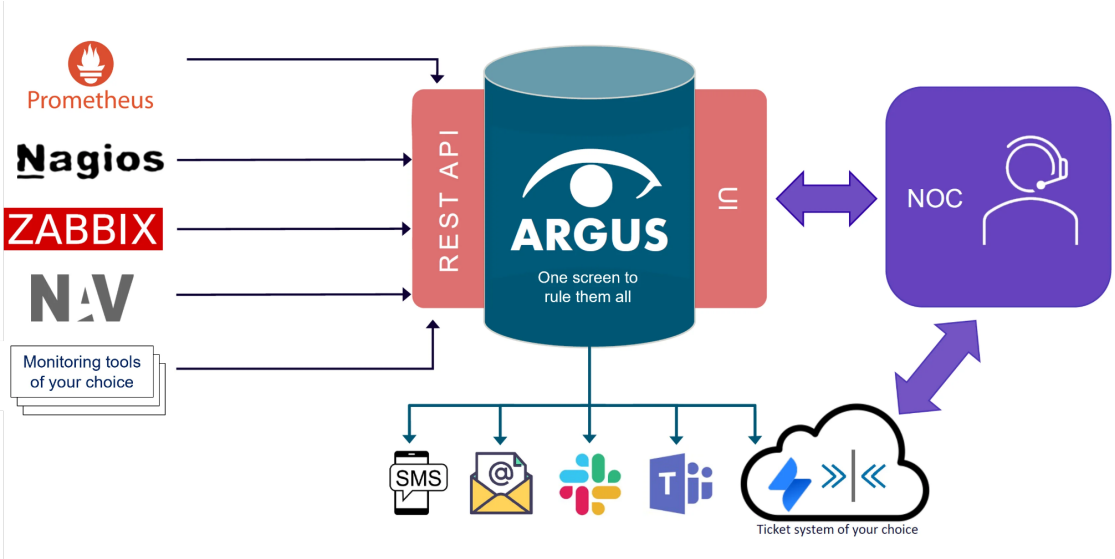

Figure 2.1 The Argus architecture

Argus provides federated login. Users can sort and filter the alarms in their personal view and can set up flexible, personal alarm notification profiles. Argus has proven useful in providing a distinct interface between individual product teams and an organisation's NOC when it comes to defining which monitoring alerts should be handled by the NOC, and which ones the product teams will handle themselves.

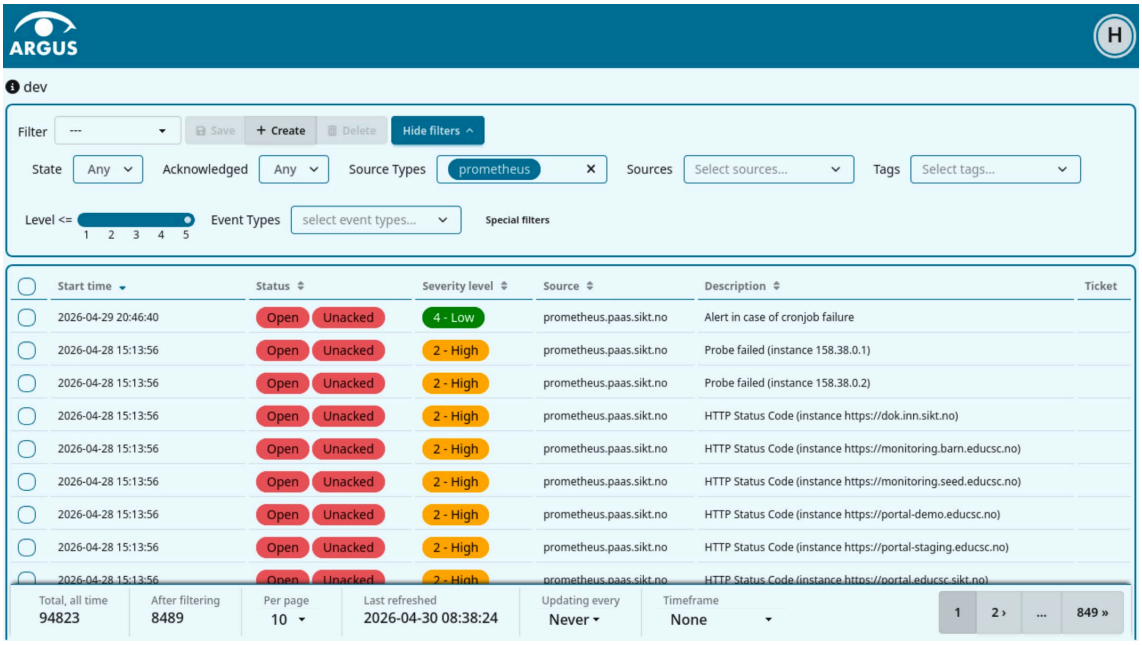

Figure 2.2 The main Argus UI screen, listing the different events received by the system with their statuses and other useful information, along with the filtering panel at the top of the screen

Argus is open source and is mainly developed by resources from Sikt (the Norwegian NREN) supported by the GN5-2 project, with 25 PM allocated to Sikt in WP6 T3 over the project lifecycle, plus between 6-12 PM per year contributed externally by Sikt. It is available on GitHub [4] for installation free of charge.

2.1.1 Users, Uptake and Usage

Argus's target users are personnel at an NREN's/organisation's NOC or service desk. Argus is also an important tool for L2 and L3 system/network engineers, who can use it to set up their personal alarm profiles. Argus is in production at four NRENs: Sikt, SUNET (Swedish NREN), REANNZ (New Zealand's NREN), and RHnet (Icelandic NREN), along with the GÉANT NOC. A pilot instance has been installed by DeiC (Danish NREN) and some contacts are currently underway with DFN (German NREN) and SURF (Dutch NREN), which have expressed interest in deploying Argus. The other Nordic NRENs have also communicated interest in deploying Argus as part of a wider NORDUnet effort. Argus has additionally been deployed at the University of Agder (Norway) and at the University of Helsinki (Finland).

Sikt has collaborated with SUNET to implement glue services for Nagios [5] and Zino [6], which are now available and documented on GitHub [7][8]. Docker images and user documentation have been updated, and a live demo site is now available for prospective users [9].

2.1.2 Key Performance Indicators

The key performance indicators for Argus are shown below. Commitment from the Argus team to meet users' requirements resulted in a high number of feature releases and dissemination events, exceeding the two relevant KPIs. This work is projected to result in new installations and reach or exceed the remaining KPI target by the end of GN5-2.

KPI	Baseline (start of GN5-2)	Target (end of GN5-2)	Measured (end of June 2026)
Number of feature releases per year	9	3	10
Number of new or renewed installations and assistance requests per year	2	10	8
Number of dissemination events per year	4	5	8

Table 2.1 Argus KPI measured for the period 1 January 2025 to 30 June 2026

2.1.3 Activities

Argus 2.0 and a total of 10 feature releases have been distributed so far in GN5-2. The main improvements include:

- A fully rewritten frontend using htmx [10] (replacing React [11])
- Improved user-friendliness
- Simplified installation
- Enhanced workflow customisation
- An upgraded API
- Improved scalability (asynchronous handling of incoming events)
- Support for planned maintenance

Furthermore, the team addressed the feedback received during GN5-1 by simplifying the installation and adding more glue services.

Since the beginning of the GN5-2 project, eight presentations of Argus have taken place at the following events:

- FOSDEM 2025, as part of the GÉANT services portfolio, January 2025, Brussels, Belgium [12]
- Community Hub at TNC25, as part of the GÉANT NOC deployment, June 2025, Brighton, United Kingdom [13]
- NORDUnet Community Workshop, together with the GÉANT NOC deployment, September 2025, Copenhagen, Denmark [14]
- 24th Special Interest Group on Network Operations Centres (SIG-NOC), April 2026, Utrecht, Netherlands [15]
- Djangocon Europe in April 2026, Athens, Greece [16]
- 5th European perfSONAR Users Workshop, May 2026, Paris, France [17]
- Community Hub at TNC26, as part of the WP6 T3 portfolio, June 2026, Helsinki, Finland [18]

Lastly, a promotional video was created and published on the Argus landing page in March 2026 [1].

2.2 perfSONAR

perfSONAR is an open-source, modular and flexible architecture for active network performance monitoring. Installations worldwide provide a view of network performance across multiple domains, allowing NOC engineers to seamlessly analyse and diagnose network behaviours across an entire end-to-end path.

The tools available in the perfSONAR suite perform active IPv4 and IPv6 measurements of throughput, packet loss, delays, jitter, HTTP and DNS response times, and record network route and path changes. Measurement Points (MPs) installed independently on selected network paths can be orchestrated and used together within a single organisation or between multiple partners. A lookup service lists all publicly available MPs, thus making the MPs – their status and measurements – visible outside of their own domain. This gives stakeholders from external domains the opportunity to perform measurements, subject to permissions being given, thus creating a multi-domain monitoring environment. The perfSONAR suite contains all necessary tools for setting up a successful performance-monitoring architecture, including “meshes” of tests between nodes in a single community of interest and visualisation of the results as a red-amber-green dashboard or measurement graphs.

perfSONAR version 5.2 was released in June 2025 (M6 of GN5-2), and focused primarily on internal dependency upgrades (such as Grafana, OpenSearch, and Ubuntu 24 support) without major feature changes. The upcoming version 5.3, due for release before the end of GN5-2, introduces structural tool changes and new user-facing configuration utilities, with WP6 T3 directly contributing to support for Microdep and pSGUI.

The perfSONAR toolkit has been developed with a layered architecture, decoupling the different components for easier long-term maintenance and allowing for different perfSONAR bundles to be deployed independently, as shown in the following figure.

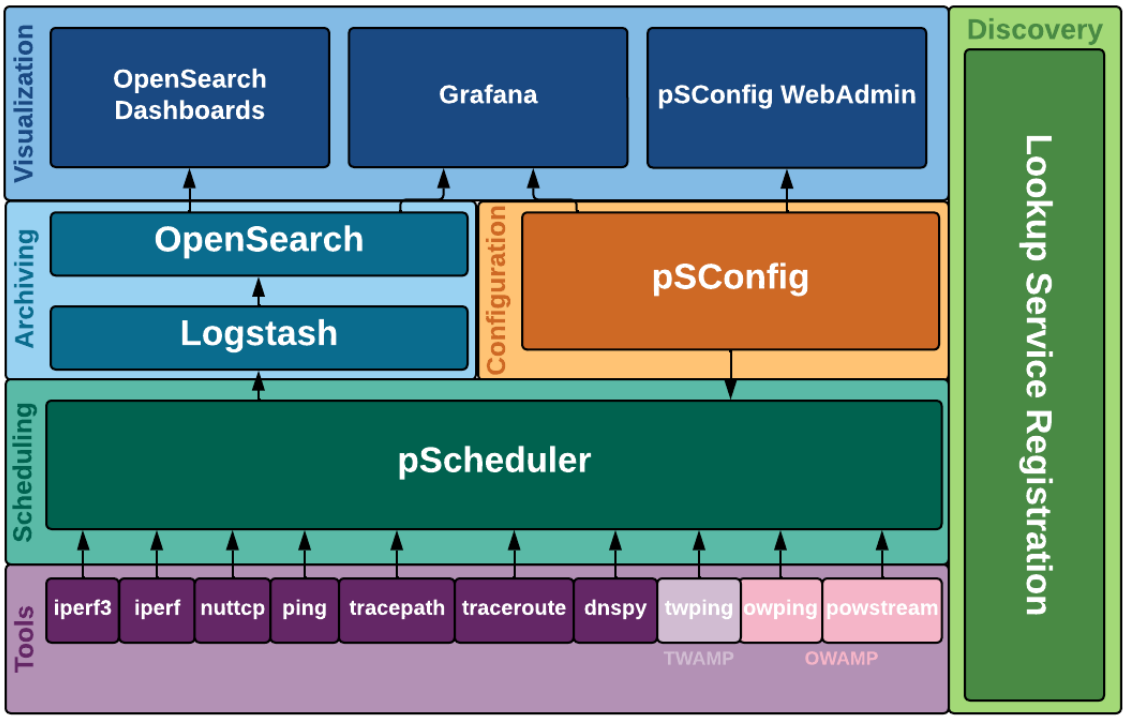

Figure 2.3 The perfSONAR architecture

In GN5-2, the perfSONAR service is divided into two sub-activities:

- GÉANT participation in the perfSONAR International Project, an international collaboration with ESnet, Internet2, Indiana University, RNP and the University of Michigan.
- The perfSONAR Consultancy and Expertise service provided to the GÉANT community.

perfSONAR International Project

The global perfSONAR team develops, maintains, distributes and provides support for all the different perfSONAR software that are installed and used on numerous Research and Education (R&E) networks around the world to perform active measurements and monitor network performance.

Several information sources and support options are available for perfSONAR:

- Main website [19]
- Installation and usage documentation [20]
- YouTube channel [21]
- Developers' resources are available on GitHub [22]
- GN5-2 project contributions and related work are listed on the GÉANT wiki [23]
- Support requests can be submitted through the global user mailing list [24] or the dedicated GÉANT Slack channels [25]

perfSONAR Consultancy and Expertise

The perfSONAR Consultancy and Expertise sub-task aims to provide support and disseminate knowledge about perfSONAR usage for the GÉANT community. It offers four different activity types:

- Helping to ensure that designed measurement architectures and infrastructures based on perfSONAR fit the performance-monitoring and measurement needs of the requesting party.
- Providing specific training and running workshops on perfSONAR deployment, use and best practices.
- Providing extra support to assist GÉANT and NRENs with deploying and operating perfSONAR, as requested.
- Maintaining and operating a set of perfSONAR services useful to the global perfSONAR community and to GÉANT-area perfSONAR users in particular.

As part of this set of services, the Consultancy and Expertise sub-activity operates the Performance Measurement Platform (PMP) mesh of perfSONAR test points that are provided by organisations from the GÉANT community, and a central server which hosts a perfSONAR archive and some related visualisation dashboards. As PMP has achieved its intended purpose – i.e., showcasing a lightweight, low-cost deployment model to allow NRENs to accurately monitor the performance of the GÉANT backbone from the perspective of end-users – PMP is no longer a service by itself as of the end of the reporting period. However, most of its infrastructure remains operational under the perfSONAR service as a means of evaluating and testing perfSONAR development and data collection for the GÉANT community. User support continues unchanged now as part of the perfSONAR Consultancy and Expertise service. More information about these changes can be found on the GÉANT website [26].

Contact details for perfSONAR Consultancy and Expertise are available on the GÉANT wiki [27] and the team can be reached directly via email at perfsonar@lists.geant.org.

2.2.1 Users, Uptake and Usage

perfSONAR International Project

Active network measurements are useful to network engineers, system administrators, research communities, researchers and students. perfSONAR users include:

- Organisations (e.g., universities, GÉANT NRENs and the GÉANT organisation) that want to provide active network measurement capabilities to their users, or to any collaborating organisation's users (enabling multi-domain measurement capabilities).
- Organisations that want to perform active measurements within their own domain or any other perfSONAR-enabled domain.
- Research communities that undertake data-intensive science, need to move large volumes of data between sites, and want to have telemetry on network characteristics.
- Individual users who want to monitor end-to-end performance or performance on particular links of interest.
- Network researchers and students interested in developing or monitoring and assessing the performance of new high-speed networks, technologies and protocols.

perfSONAR users are located worldwide and form the global perfSONAR community. The map in the following Figure 2.3 shows a global subset of perfSONAR nodes registered in the central Lookup Service [28]. As of June 2026, in addition to around 2,500 public nodes running more than 10,000 services, there are also several private installations implemented worldwide.

Figure 2.4 perfSONAR installations worldwide as of June 2026, taken from the Lookup Service dashboard [28]

There are more than 500 perfSONAR deployments in European countries including Armenia, Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Moldova, Montenegro,

Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Sweden, Switzerland, the United Kingdom and Ukraine.

perfSONAR Consultancy and Expertise

Target users of this service are teams and individuals from the GÉANT community. Since active network measurements and performance monitoring require specific, advanced knowledge, users are mostly from NOCs, the NRENs' constituencies, or cross-domain projects in which they might participate. However, the service's availability is not limited to a specific user group.

2.2.2 Key Performance Indicators

The perfSONAR International Project KPI is detailed in the following table.

KPI	Baseline (start of GN5-2)	Target (end of GN5-2)	Measured (end of June 2026)
Number of major perfSONAR releases	2	2	1

Table 2.2 perfSONAR International Project KPI for the period 1 January 2025 to 30 June 2026

The last major perfSONAR release, 5.2, was issued in June 2025, with subsequent bug-fix releases 5.2.1 to 5.2.5, from July 2025 to June 2026. With release 5.3 currently being finalised, the KPI is on target to be met by the end of GN5-2.

The perfSONAR Consultancy and Expertise KPI tracks the number of requests for consultancy fulfilled by the team during the reporting period, as shown in the following table. The team expects the KPI target to be met by the end of GN5-2 due to demand for further consultancies over the coming period.

KPI	Baseline (start of GN5-2)	Target (end of GN5-2)	Measured (end of June 2026)
Number of consultancies fulfilled	8	8	5

Table 2.3 perfSONAR Consultancy and Expertise KPI for the period 1 January 2025 to 30 June 2026

2.2.3 Activities

perfSONAR International Project

The work of the global perfSONAR team is currently focused on providing support for the most recent version 5.2 and preparing the next major release of perfSONAR, version 5.3, which will bring a new pSConfig user interface and some new visualisations and ways to look at measurement data. The GÉANT perfSONAR team is contributing by building, testing and fixing all Debian/Ubuntu packages, integrating the Microdep [29] and psGUI tools, and testing and debugging perfSONAR 5.2 and the other latest releases.

The team is responsible for providing the Debian build, distribution, and testing infrastructure in line with the latest Debian and Ubuntu standards. Efforts to strengthen the automated testing

framework (autopkgtest) advanced significantly by the end of the reporting period, including an improved reporting UI and Linux Containers (LXC) support. An updated version of the perfSONAR testpoint image is now provided through nmaas vNOC [30], and work on the perfSONAR archive image is nearing completion. Using those images together makes it possible to deploy a mesh of perfSONAR measurement points and their associated archive and visualisation dashboards inside this nmaas vNOC platform, thereby providing users with an easy-to-use mechanism to test-drive or learn perfSONAR and its different components.

The GÉANT perfSONAR team also provides user support on the global users mailing list and on the different Slack channels. Queries are mostly related to upgrades of existing installations and feedback about new perfSONAR releases or, in the case of new users, regarding the perfSONAR installation and setup process.

Another development activity performed by the GÉANT perfSONAR team is the maintenance and improvement of the Lookup Service dashboards that list and document all perfSONAR public installations worldwide. This service is provided thanks to a Grafana instance running on the nmaas vNOC infrastructure. It is regularly updated to the latest Grafana version [31] to stay current and improve the user experience, such as by adding new filtering capabilities, for example.

The GÉANT perfSONAR team also co-chairs training and documentation activities. Within the perfSONAR International Project, it coordinates and performs tasks relating to updating and providing users with proper documentation for every new perfSONAR release, alongside maintaining training resources including the perfSONAR web pages and YouTube channel [21].

The perfSONAR software suite was presented at the following events during the reporting period:

- FOSDEM 2025, as part of the GÉANT services portfolio, January 2025, Brussels, Belgium [12]
- 34th Services and Technology Forum (STF), February 2025, Dublin, Ireland [32]
- Network Performance and Monitoring Workshop, April 2025, Prague, Czechia [33]
- RIPE-SEE 13, April 2025, Sofia, Bulgaria [34]
- Community Hub, Exchange Theatre and during the EUMETSAT meeting at TNC25, June 2025, Brighton, United Kingdom [35][36]
- Jisc Networkshop, June 2025, Nottingham, United Kingdom [37]
- 23rd SIG-NOC, October 2025, Barcelona, Spain [38]
- TechEX25, with a perfSONAR tutorial, December 2025, Denver, USA [39]
- 5th European perfSONAR Users Workshop, May 2026, Paris, France [17]
- Network Latency BoF [40] and the Community Hub [18] at TNC26, June 2026, Helsinki, Finland

At TNC25 in June 2025, the 20th anniversary of perfSONAR was celebrated with small marketing items distributed to attendees at the GÉANT booth and after the given presentations.

At TechEX25, a perfSONAR tutorial workshop was jointly organised by the six partners of the international collaboration.

A joint perfSONAR and MetrANOVA face-to-face developers meeting was organised by the team and hosted at Jisc offices in London in March 2026. MetrANOVA [41] is a new set of software and an architecture designed to facilitate controlled data sharing while preserving digital sovereignty. It is created and will be distributed by a group of contributing organisations, one of which is the GÉANT project through WP6T3. Currently under development, MetrANOVA's essential capabilities are collecting and storing metadata, network flow information, network device metrics and other network-related data; providing customisable dashboards with advanced network visualisations; and allowing the definition and enforcement of data-sharing policies. Development of MetrANOVA is focused on scalability and stability, employing modern packaging ready for container-based deployments while ensuring sensible configuration management.

perfSONAR Consultancy and Expertise

During the reporting period, the perfSONAR Consultancy and Expertise service has provided support to:

- GÉANT Association, for monitoring of the EuroHPC network and carrying out tests at very high speed (400 Gbps and up to 1 Tbps).
- Worldwide LHC Computing Grid (WLCG) and GridPP, the UK's representation in the WLCG, to run 100-Gbps, IPv6-only measurements on their network.
- ASIERA (Irish NREN), to renew their perfSONAR public deployment. This culminated in the organisation of a perfSONAR training session in December 2025 [42].
- RENATER, to renew their perfSONAR internal deployment via the use of containers, along with hosting a dedicated RENATER's Users meeting the day before the 5th European perfSONAR User Workshop in May 2026.

The GÉANT perfSONAR team also organised the 5th European perfSONAR User Workshop itself, a two-day event that brought together perfSONAR user and developer communities to explore use cases for the toolkit, share best practices, and discuss future features and the perfSONAR development roadmap. The workshop was held on 6–7 May 2026 and was hosted by RENATER in Paris, France [17].

As noted previously, the team also operates the PMP mesh of perfSONAR test points. This provides the ability to gather all of the resulting performance measurement data with the help of contributing NRENs. Using this data, the team has developed machine-learning scripts to analyse the network performance metrics to spot anomalies and alert network operators. A first production-level deployment of those scripts was achieved during the reporting period, with the resulting analysis published as a white paper [43]. The paper shows that direct histogram-based learning can successfully detect both transient anomalies and sustained distribution shifts, highlighting its potential for real-time network monitoring.

2.3 TimeMap

TimeMap is an open-source monitoring system dedicated to supporting real-time networked applications requiring low-latency and low-jitter network transport. It collects per-segment latency and jitter measurements on a network backbone using two-way active measurement protocol (TWAMP) probes and provides an interactive visualisation of the measurement data through the TimeMap dashboards, as illustrated in Figure 2.5 below. The system is implemented using Telegraf [44], InfluxDB [45], and Grafana [31].

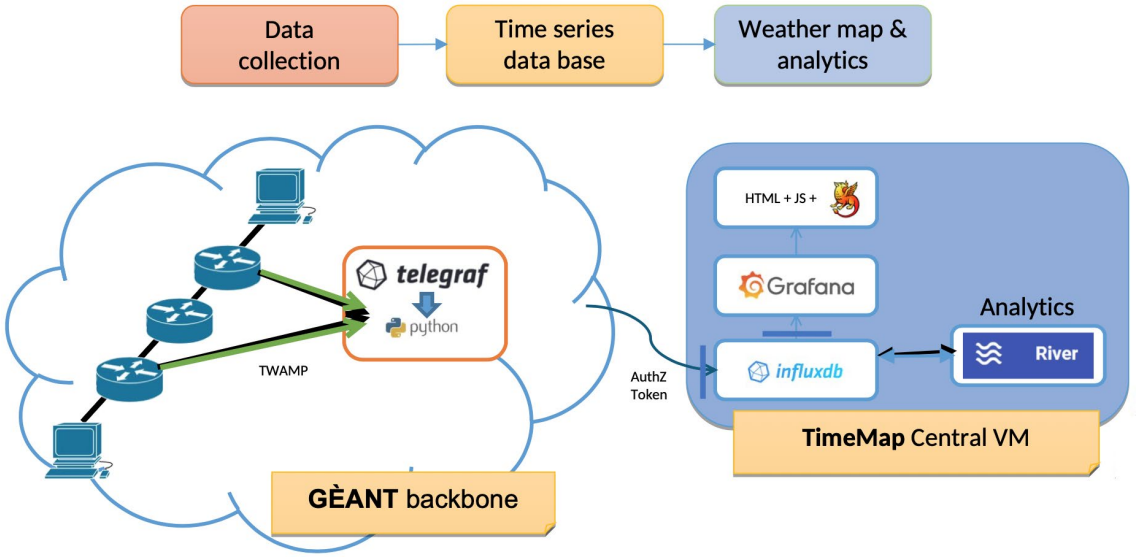

Figure 2.5 The TimeMap architecture

TimeMap is designed to help debug issues for real-time services such as (but not limited to) the LoLa audio-visual streaming application used by performing-arts communities [46], as it can identify activities on the backbone that affect latency and jitter parameters. Any real-time service over a network can benefit from TimeMap monitoring.

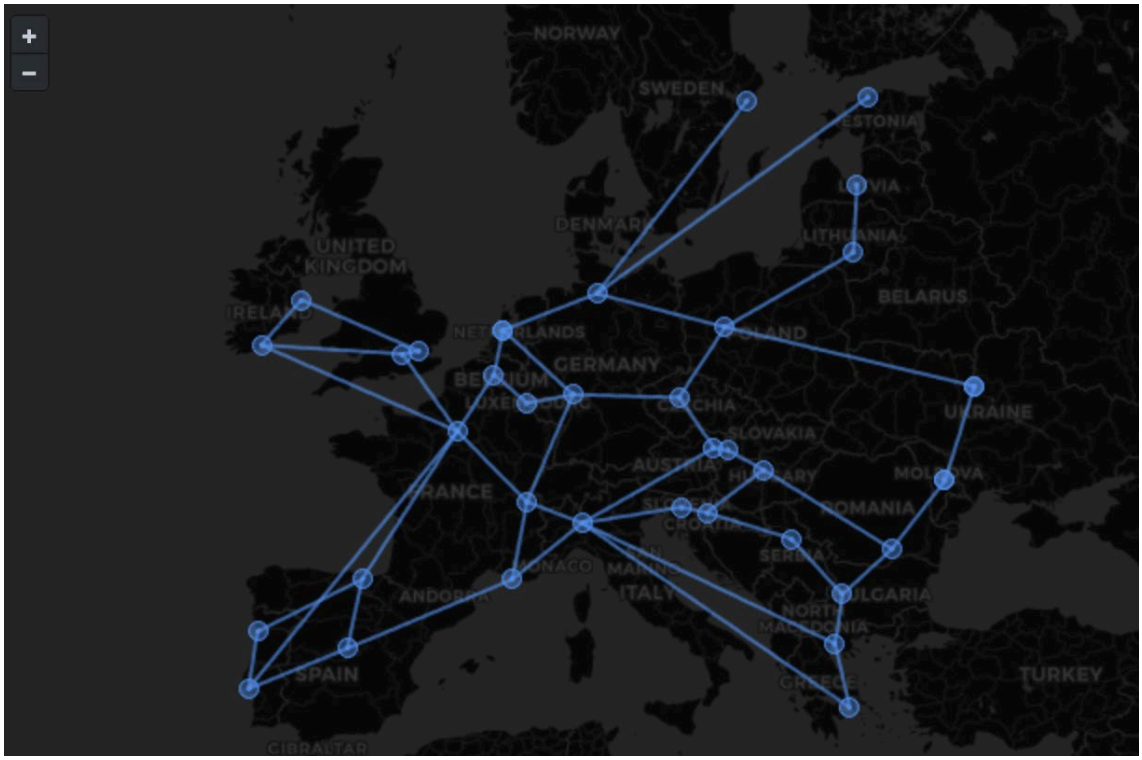

Figure 2.6 The geomap landing page showing the GÉANT backbone topology

TimeMap was created with two specific objectives: to use measurement tools included in the existing equipment to remove the need to deploy extra hardware (i.e., a zero-footprint monitoring solution), and to make the service as easy as possible to deploy inside an NREN's backbone network. To achieve these objectives, TimeMap is based on microservices, which can readily be adapted for deployment in the network of any NREN interested in having access to detailed latency and jitter measurements and visualisations.

GÉANT's TimeMap deployment is available online [47], where it is accessible via eduGAIN federated login. The documented code has been published, together with a user guide and an admin guide, on the GÉANT GitLab [48]. TimeMap is now also used to monitor the characteristics of Time and Frequency Networks (TFNs), first applied to the pilot link between PCSS (the Polish NREN) and Physikalisch-Technische Bundesanstalt (PTB, the German National Metrology Institute (NMI)) with the intention of expanding to other network segments as they are connected.

2.3.1 Users, Uptake and Usage

In GN5-2 the TimeMap team provided assistance to the organisations already using TimeMap (CSUC/RedIRIS, FCCN, GARR and GÉANT), and to Jisc for a new TimeMap installation in the core of their network.

In addition, the TimeMap team focused on improving the reliability of data collection from GÉANT backbone network devices, and on collecting data from the C-TFN pilot link and the other networks that will interconnect. It is noted that data from the C-TFN will be acquired from

multiple different sources and organisations, most likely using equipment from different vendors. Therefore, the data collection scripts are being adapted to work with diverse time and frequency equipment. Collaboration to this end is ongoing with the Royal Observatory of Belgium and with REFIMEVE (French metrological research infrastructure) and RENATER (the French NREN).

2.3.2 Key Performance Indicators

TimeMap's KPIs are detailed in the following table.

KPI	Baseline (start of GN5-2)	Target (end of GN5-2)	Measured (end of June 2026)
Number of feature releases per year	1	5	4
Number of new or renewed installations and assistance requests	2	10	6
Number of dissemination events per year	1	10	7

Table 2.4 TimeMap KPIs measured for the period 1 January 2025 to 30 June 2026

With other dissemination activities already planned for the end of 2026, and continued interest in TimeMap from different networking teams, these KPIs are on target to be met by the end of GN5-2.

2.3.3 Activities

TimeMap is now collecting data from the Nokia routers newly installed as part of the infrastructure upgrades to the GÉANT backbone completed in June 2026 [49]. Crucially, TimeMap still remains fully compatible with the previous-generation Juniper devices where they are still in use. This allows TWAMP measurements to be run between both types of devices where applicable. TimeMap's polling mechanism has also been improved, and data gaps have been resolved.

TFN monitoring has been made possible via greater abstraction in the architecture and the use of data-export workflows via n8n, an AI-based workflow automation tool, which meets the NMI requirement for the ability to export raw data [50]. Discussion is ongoing with partners including the Royal Observatory of Belgium and REFIMEVE to explore TFN device-monitoring collaborations, as well as with the European Association of National Metrology Institutes (EURAMET) representatives, with the help of GÉANT and GARR, to discuss options for monitoring White Rabbit deployments[1] with TimeMap.

[1] White Rabbit is an open-source technology developed at CERN, used for high-precision synchronisation of clocks across fibre-optic cables.

Dissemination activities included presentations at:

- The 2nd TFN Special Interest Group (SIG-TFN) meeting, February 2025, Ispra, Italy [51]
- Jisc Networkshop, June 2025, Nottingham, United Kingdom [37]
- CARNET Users Conference, November 2025, Rovinj, Croatia [52]
- TechEX 25 in December 2025, Denver, USA [39]
- 5th European perfSONAR Users Workshop, May 2025, Paris, France [17]
- The Community Hub at TNC26 as part of the WP6 T3 portfolio, June 2026, Helsinki, Finland [18]
- Jisc Networkshop, June 2026, Nottingham, United Kingdom [37]
- The 3rd TFN Special Interest Group (SIG-TFN) meeting, June 2026, Brussels, Belgium [53]

3 Beyond Service Development

Alongside the three production services presented above, WP6 T3, Monitoring, also works on network monitoring more broadly, seeking to respond to the needs of NOC engineers and to find opportunities to observe and monitor R&E networks in novel, useful ways. As part of this effort, WP6 T3 provides its expertise and knowledge to the GÉANT community through:

- Advice on deployment and configuration of monitoring software and tools
- Testing for reliable performance of very high-speed links
- Verifying network performance for real-time and time-sensitive applications such as networked musical performances
- Developing automated data analysis for faster detection of anomalies
- Enabling data sharing between organisations
- Researching new and innovative ways to monitor networks

This section examines the various activities under this umbrella carried out by the WP6 T3 teams during the reporting period.

3.1 High-Speed Monitoring

Jointly with the GÉANT Network team, during the reporting period WP6 T3 explored tools and strategies to test very high-capacity links, from 400 Gbps up to 1.2 Tbps. For new use cases, such as those arising from the European High-Performance Computing (EuroHPC) monitoring requirements, measuring the bandwidth available on the provided links is essential. Meeting these requirements necessitates choosing the right tools and fine-tuning network interface cards, the network stack and the different buffers to send and receive packets. To this end, the perfSONAR platform was chosen as the performance monitoring solution for the EuroHPC HyperConnectivity project [54] due to its positioning as the only community-developed, vendor-agnostic, end-to-end active network performance measurement platform.

The usual iperf2 and iperf3 tools were used, owing to their integration into the perfSONAR platform, but new tools such as qperf [55] and perftest [56] were also explored, opening up the possibility of testing throughput with the RDMA protocol. Testing was carried out initially in lab conditions, back-to-back between servers to validate the setup, before progressing to the real network once conditions were in place to prevent disruption of production traffic. Speeds of more than 1 Tbps were reached from a single machine, therefore meeting the requirements of the EuroHPC HyperConnectivity project.

3.2 Networked Musical Performances

Networked musical performances are musical acts performed by participants across different geographical locations, sometimes located hundreds or thousands of kilometres apart. For such performances to be possible, the artists or performers need to be connected reliably with the lowest latency possible and with minimal variation in delay (i.e., jitter). Measuring and monitoring these metrics is key to enable such performances between conservatoires and music institutes across the world.

WP6 T3 provides tools and processes to accurately measure latency and jitter on specific network segments as well as end-to-end. By using both the TWAMP probes in a TimeMap deployment and the regularly scheduled latency measurements done with perfSONAR, an accurate view of the latency on the networks involved in a musical performance can be obtained. The team working on this topic will showcase its findings at events in the future and a best-practice guide for network and IT teams at conservatoires and music institutes is being written for wider publication.

3.3 Micro-Disruptions with Microdep

When configuration changes happen in a network or some automatic rerouting takes place, a few packets might get lost or re-ordered. In the case of latency-sensitive or bandwidth-demanding applications, spotting those micro-disruptions helps network operators provide the best possible service to users. Microdep [29] is a tool designed for that purpose, being developed and deployed by Sikt, the Norwegian NREN, for some years now.

At its heart, Microdep uses a steady stream of very small packets to probe the network at regular intervals, a functionality provided by protocols like OWAMP and TWAMP, which are very well supported by perfSONAR. It follows, therefore, that integrating Microdep within perfSONAR would help users of both tools and lower the cost of maintenance in the long term, and work on this is underway. This is another area where the expertise and knowledge of WP6 T3 and the perfSONAR team is key to widening network performance-monitoring capacities for all users. Microdep will be part of perfSONAR version 5.3 due for release later in 2026.

3.4 Automated Anomaly Detection and Troubleshooting

Network operators are interested in spotting anomalies in network-monitoring datasets, as these often indicate something unusual happening on the network: an incident, a change of configuration or conditions – in short, something that needs to be looked at. Having tools that can automate detecting anomalies and filter out the false positives is thus very valuable to network operators.

TimeMap includes an automated anomaly-detection function based on statistical analysis of monitoring data. If anything deviates from the norm of past measurements, it can be labelled and surfaced to the operator directly via latency and jitter plots. The perfSONAR data collected

as part of PMP operation has also been analysed for deviations in latency distribution using an unsupervised machine-learning technique. The GN5-2 WP6 white paper *Anomaly Detection in perfSONAR Data Using Autoencoders*, published in July 2026, presents the results of this analysis and its automation [43].

Argus, which pulls together events from different monitoring platforms, is also a tool with a high potential for automating network troubleshooting. The data model used internally has been devised for this purpose, and a correlation engine is being designed to help operators make better and easier sense of the different alarms and events.

These various techniques and approaches hold further potential, and this is an active research area of focus for the WP6 T3 teams.

3.5 Controlled Data Sharing with MetrANOVA

Operators troubleshooting issues in R&E networks often reach a point where, to understand an end-to-end problem, monitoring data obtained on other networks would be very useful. Gaining access to such data can be challenging due to regulatory, organisational or technical constraints. MetrANOVA [41] aims to solve this problem, both at the technical level and with easily definable and verifiable data-sharing policies.

MetrANOVA is currently under development by a group of partner organisations. An initial version of a data normalisation pipeline and a high-efficiency backend storage system is already available. There is a clear demand for a solution in this field, as shown by the feedback received after the presentations and demos carried out by the team at various events in 2025 and 2026, including TNC, multiple Special Interest Groups (SIGs) and infoshares. WP6 T3 brings its expertise to the global MetrANOVA collaboration, in terms of both the technical stack and the discussions on solutions for sharing sensitive data.

3.6 TimeMap for Time & Frequency Networks

The TimeMap architecture was designed from the ground up to be flexible and adaptable to the diverse network environments, equipment, and ways of working of the R&E community. As such, TimeMap can easily be adapted to new network types, as was done in the TFN pilot in collaboration with WP6 T1. The proof of concept produced by WP6 T3 quickly turned into a prototype collecting data from different equipment and networks, laying the foundations for a single-pane-of-glass solution presenting key metrics and comparisons of time and frequency parameters.

4 Conclusions

This document presented an overview of the status, as of June 2026 (M18 of GN5-2), of the three production services managed by WP6 Task 3 – Argus, perfSONAR and TimeMap – along with advancements and innovations in the areas of high-speed network monitoring, real-time applications such as networked musical performances, micro-disruption monitoring, automated anomaly detection, data sharing, and TFN monitoring.

perfSONAR is a very robust and well-established platform relied on by many R&E organisations and NOCs, with public deployments still growing worldwide. Upcoming features like Microdep and psGUI are meaningful contributions from the GÉANT project to the international perfSONAR collaboration. TimeMap, with its lightweight and flexible architecture, demonstrates its continued utility by being easily adapted to monitor TFNs. Argus delivers value to users via easy customisation to suit different needs and ways of working, while having a robust, yet versatile data model and an increasing number of 'glue' services allowing the connection of many different network-management tools.

These services are developed jointly by the GÉANT project and contributing member NRENs, along with partner organisations like ESnet, Indiana University, Internet2, RNP, Texas Advanced Computing Center and the University of Michigan in a collaborative effort, pooling resources for maximum efficiency. Concerted approaches like these are a clear asset to the GÉANT project and members while also being beneficial to the wider R&E community.

The research areas under investigation by WP6 T3 continue to show potential, as demonstrated by the various collaborations in which the teams are participating and the feedback received at the numerous meetings and presentations.

Based on community feedback and team efforts to track the state of the art in network monitoring, the following areas are the focus of WP6 T3's future work:

- Continuing to develop a deep understanding of throughput measurements at very high speed, which is key to supporting projects such as the EuroHPC network.
- Ascertaining the technical demands of real-time networking applications and provide guidance to networked musical performance support teams.
- Providing NOCs with sought-after automated anomaly detection and troubleshooting capabilities, such as those developed within TimeMap and the machine-learning research on perfSONAR data.
- Sharing network-monitoring data with control and confidence via normalised processes and data formats, particularly via MetrANOVA, to respond to clear demand from the R&E sector.
- Exploring monitoring of new types of networks, building on the adaptation of TimeMap for TFN monitoring.

All production-level services under WP6 T3 are on target to meet or exceed their KPIs by the end of the GN5-2 project. User adoption is stable or even keeps on growing where the possibility exists. The portfolio of network-monitoring services, curated for quality and reliability, continues to provide utility and value to the GÉANT members and the wider R&E community. The active research underway demonstrates the capabilities of WP6 T3 to deliver innovative and purposeful solutions qualitatively and efficiently.

Acronyms

AI	Artificial Intelligence
API	Application Programming Interface
C-TFN	GÉANT Core Time and Frequency Network
EURAMET	European Association of National Metrology Institutes
EuroHPC	European High-Performance Computing
KPI	Key Performance Indicator
LXC	Linux Containers
MP	Measurement Point
NMI	National Metrology Institute
NOC	Network Operations Centre
OWAMP	One-Way Active Measurement Protocol
PMP	Performance Measurement Platform
PTB	Physikalisch-Technische Bundesanstalt (the German National Metrology Institute)
R&E	Research and Education
RDMA	Remote Direct Memory Access
SIG	Special Interest Group
SIG-NOC	Special Interest Group on Network Operations Centres
T3	Task 3
TACC	Texas Advanced Computing Center
TNC	Terabit Networking Conference
TFN	Time and Frequency Network
TWAMP	Two-Way Active Measurement Protocol
UI	User Interface
WLCG	Worldwide LHC Computing Grid
WP6	Work Package 6, Network Development

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