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GARR OAV Architecture Analysis

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Authors: Fabio Farina (GARR); Alessandro Inzerilli (GARR), Lidija Jakovčić (CARNET), Maria Isabel Gandía (CSUC/RedIRIS), Ivana Golub (PSNC), Pavle Vuletić (AMRES)

Abstract

This document analyses the mapping of the GARR architecture to the TM Forum's Open Digital Architecture (ODA), aiming to provide a standardised view of the components and implementations of orchestration, automation and virtualisation within the National Research and Education Network (NREN).

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Executive Summary

Analysing National Research and Education Network (NREN) architectures from an Orchestration, Automation and Virtualisation (OAV) perspective using a common reference architecture helps align efforts between NRENs and uncovers similarities in the way different functionalities and components are implemented, which in turn facilitates potential collaboration and future interoperability between organisations.

TM Forum Open Digital Architecture (ODA) [1] is being used as a reference model to map several architectures in the GÉANT project. Mapping the architectures to a single blueprint makes cross-comparisons easier and helps organisations working on digital transformation. A reference architecture like ODA supports the transition from traditional modes of organisation based on manual work and procedures to a model where services/products are automatically provisioned and orchestrated.

GARR operates Italy's national ultra-broadband network for the Research and Education (R&E) sector, providing high-capacity connectivity and advanced services to support scientific collaboration and institutional activities. The infrastructure spans approximately 20,000 km of optical fibre, interconnects over 1,000 sites, and integrates with global research networks to enable distributed computing and data-intensive workflows. Its design prioritises performance, reliability, and interoperability across diverse academic and research domains.

The next-generation platform, GARR-T, constitutes a substantial architectural evolution from the previous GARR-X network. It introduces a tenfold increase in backbone capacity, reaching 40 Tbps. GARR-T also offers advanced functionalities such as spectrum sharing, optical path provisioning, and quantum key distribution, future-proofing the network.

To better understand the structure and capabilities of the GARR-T network's central pillars of observability and programmability, which constitute the main logical building blocks for this next-generation GARR backbone, an analysis was conducted by mapping this system to TM Forum's ODA using the key ODA functional blocks of Engagement Management, Party Management, Core Commerce Management, Production, and Intelligence Management.

Each block was analysed in terms of its components, technologies, and user-facing services, finding that GARR-T's architecture emphasises automation and reliability through advanced monitoring and orchestration systems. Processes traditionally requiring manual intervention have been replaced by event-driven models, ensuring dynamic adaptability and operational efficiency. The network leverages containerised microservices and distributed mini data centres to streamline service delivery, offering virtualised features like firewalls and intrusion detection systems for institutions with limited resources. These innovations position GARR-T as a foundational platform for emerging scientific collaboration models, such as geographically distributed data lakes.

1 Introduction

GARR is the ultra-broadband network dedicated to the Italian R&E community. Its main objective is to provide high-performance connectivity and to develop new services for the daily activities of researchers, professors and students as well as for international collaboration. To aid its mission of meeting the specific requirements of the education, research and culture community, GARR also designs custom network solutions and services.

The GARR network is an extensive digital infrastructure of around 20,000 km of optical fibre covering the entire national territory of Italy and supporting high transmission capacity (up to 200 Gbps) on both download and upload streams. The network reaches about 3 million users and connects more than 1,000 sites, most of which are public institutions (research institutes, universities, research hospitals, cultural institutes, libraries, museums, schools). The network is interconnected with international research networks and the worldwide Internet to enable any researcher to exchange digital data and content and use scientific computing resources and cloud-based applications, regardless of their geographic location.

The GARR network is designed and managed by Consortium GARR, a non-profit association founded under the auspices of the Italian Ministry of University and Research. Consortium members include CNR, ENEA, CRUI Foundation, INAF, INFN, INGV, Italian public universities, Scientific Research Hospitals (IRCCS) and animal health and food safety Institutes (IZS) [2].

GARR has always been an integral part of GÉANT, the pan-European R&E network, the management of which it collaborates on with the other European NREN members. GARR is also connected to the main global research networks and international bodies that develop and govern international infrastructures, such as the Internet Engineering Task Force (IETF), the Internet Society and e-IRG.

GARR-T: GARR's Next Generation Network

GARR-T, as in Terabit, is the name of the next-generation GARR network. It is an evolution of the production network with new, innovative features [3]. GARR-T is a cutting-edge network built around users' needs and designed to be future-proof. Key benefits include the ability to adapt over time, rapidly scaling up and growing the network in terms of capacity, capillarity and provided services. A new level of automation, enhanced reliability and measurability through advanced monitoring systems are GARR-T's key innovations.

The new network's aims are notable: 700 km of new fibre-optic sections are planned, accompanied by 42 optical Points of Presence (PoPs) over approximately 6,000 km of optical fibre and 9 new metropolitan PoPs (shown in Figure 1.1 and Figure 1.2). An additional 6 cities will gain a double PoP to ensure redundancy and increase reliability. The full infrastructure is 10 times more powerful than the previous GARR-X network: the backbone capacity is growing from 3.5 Tbps to 40 Tbps, while the aggregated access capacity increases from 2 to 10 Tbps (as shown in Figure 1.1).

The new network is built with two key components: the packet layer and the optical layer. During the migration from the previous GARR-X network to the current GARR-T network, the packet network underwent a complete renovation with the replacement of all network equipment. The architecture is based on the data centre model, i.e., with Spine and Leaf nodes for access aggregation and Edge nodes for end points at the user's premises. While ensuring uniformity and equal access to services, this model leverages the reach of the network, delivering optimal agility to smaller nodes with the greater impact (in terms of space and energy consumption) on core nodes only.

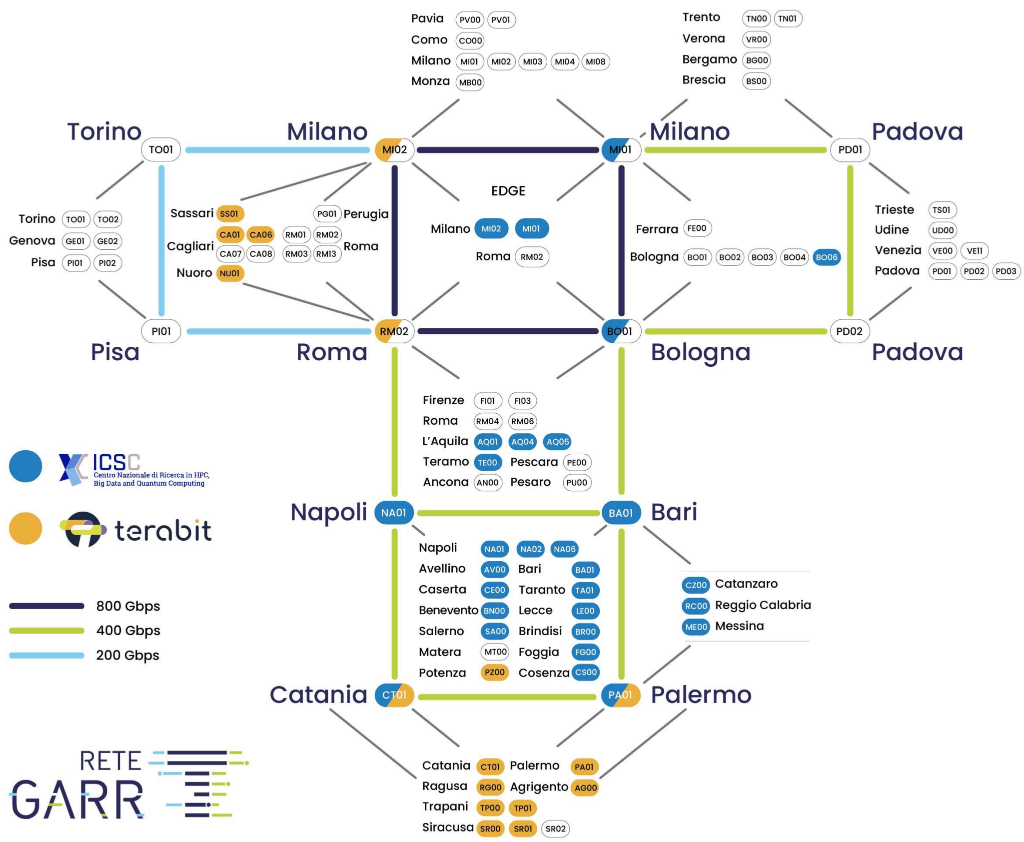

Figure 1.1: GARR-T backbone topology

The key features of GARR-T are the following:

- **A flexible, efficient and sustainable optical network**: The optical network features important innovations fostering flexibility, adaptability to user needs and the creation of new services. It is based on a partially disaggregated model, where fibre and devices are seen as different components whose combination produces the optical transport hardware infrastructure. This model ensures both efficiency and long-term sustainability, as it separates the lifecycles of the fibre and the equipment, allowing the network to be operated independently from any specific network equipment supplier, thus avoiding technological lock-in.

  This innovative model is implemented via an Open Line System (OLS) of optical fibres, supported by an advanced management and control software system. The result is an active infrastructure that is capable of routing any optical signal. The OLS technology allows the flexible management of the optical spectrum, enabling spectrum sharing and the development of innovative application offerings, such as time and frequency transport or Quantum Key Distribution (QKD).
- **New services**: The GARR-T network offers new services to users and empowers users to configure and manage them independently, according to their specific needs [4].
- **Distributed computing**: One of the most distinctive innovative services offered by GARR-T is Data Centre Interconnection, i.e., the geographical interconnection of data centres as if they were in one location, by using direct optical links. By leveraging the partially disaggregated model, connected sites can directly interface with the OLS and create a dedicated end-to-end optical channel. Thanks to the use of highly specialised and modular equipment, this feature can be offered at relatively low costs, allowing for savings in space and energy consumption. This service builds on the emerging “data lake” model for

large scientific collaborations, in which data access and management take place locally, while computing resources can be geographically distributed.

- **Optical paths and spectrum sharing**: GARR-T is designed in anticipation of the introduction of optical paths (light paths) and spectrum sharing features, seen as the glue for new applications and technical opportunities for users. These services will be key to seamless interconnection with international infrastructures, for example, by making a portion of the physical infrastructure available through spectrum access. Spectrum sharing is a key enabling factor in extending optical network functionalities in areas limited by economic and geographical constraints, as in the case of submarine cables [5].
- **Monitoring and automation for a more reliable network**: The introduction of automation mechanisms has made GARR-T network management more efficient, allowing the timely identification of potential malfunctions and immediate reconfiguration as required.
- **Automation is fundamental in the new network**: Processes that used to require human intervention have been completely revised via the adoption of an abstraction model that represents the network according to its functions and not the sum of its individual components. This is an event-driven model with the ability to adapt to constant change, similar to the intention-driven model adopted in the ICT and cloud worlds to automatically evolve services.
- **Streamlined service implementation for all needs**: A new feature of GARR-T is the streamlining and simplifying of service implementation. By leveraging a "containerised" approach to virtualisation, processes are broken down into many agile micro-services. GARR-T has a distributed cloud infrastructure to rely on, with mini data centres being implemented across the physical nodes of the network. These mini data centres will host both infrastructure support services (monitoring, security, AAI, analytics tools) and application services. Among the latter, we plan to offer virtualised network features, such as firewalls and Intrusion Detection Systems (IDSs), to support users with fewer resources or technical skills.

The GARR-T delivery project has formally been completed. However, GARR-T is designed as a foundational platform. Its architecture is based on core principles of openness, extensibility, and continuous evolution. As such, certain components of the GARR-T backbone continue to evolve over time. This ongoing development applies to both the hardware (devices) and software, including systems for monitoring, alerting, control, automation, and orchestration.

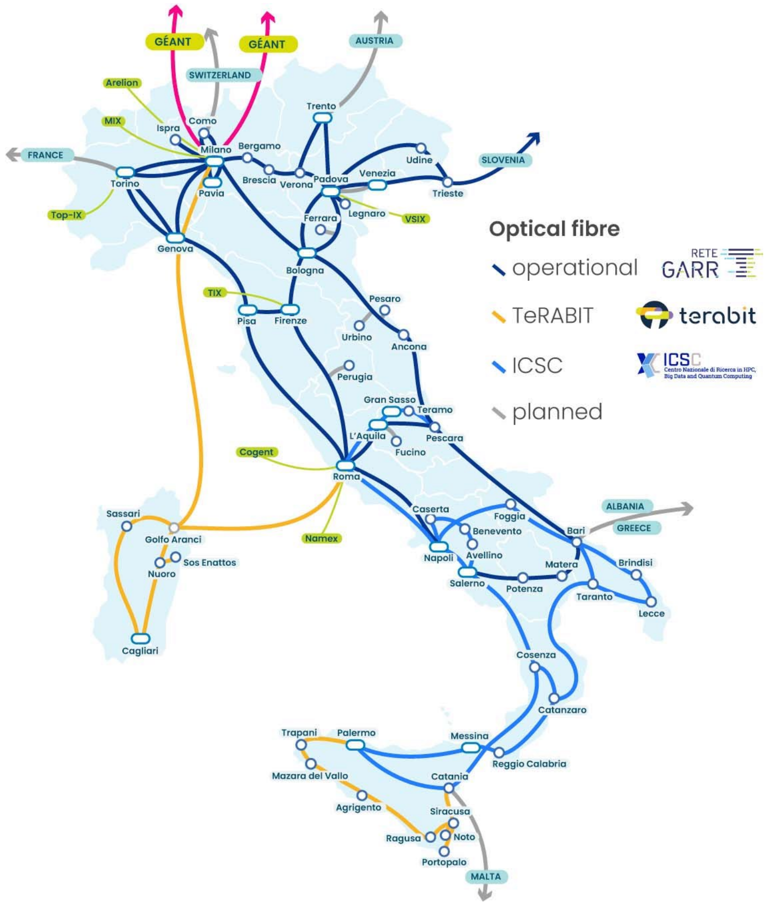

Figure 1.2: GARR-T map with planned extensions

TM Forum Open Digital Architecture

GARR's OAV architecture analysis has been conducted using the TM Forum Open Digital Architecture (ODA) functional blocks as its basis. The TM Forum ODA is intended as a blueprint for new digital industry architectures, and the rationale for its selection as a reference model by the Network eAcademy team of the Network Development work package (WP6) of the GN5-2 project is given in GN4-3 Deliverable D6.6 *Transforming Services with Orchestration and Automation* [6]. The ODA provides a common terminology, a minimum set of core design principles, and groups of decoupled functionalities. Together, these define the requirements for the implementation of an agile, model-driven service management architecture that incorporates orchestration and automated operations, as well as virtualised or hybrid environments.

The main idea behind ODA is the decoupling and integration of components, which enables independent choice of solutions for each component, while at the same time maintaining a unified overall approach that supports the full end-to-end service lifecycle (including interoperability). The high-level ODA functional architecture maps the main components by their capabilities into the ODA function blocks (see Figure 1.3).

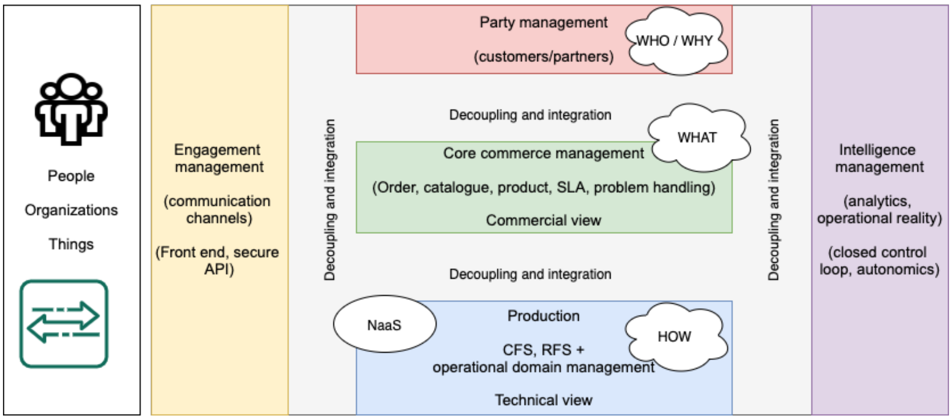

Figure 1.3: The TM Forum ODA functional architecture

In a nutshell:

- The **Engagement Management** functional block focuses on engagement with end-users (people and systems) that can interact via multiple channels.
- The **Party Management** functional block handles the processes related to all parties that interact with the organisation, and defines their roles and relationships.
- The **Intelligence Management** functional block covers the implementation of data analytics processes, and based on the analysis, provides closed control loops for full automation wherever possible.
- The **Core Commerce Management** functional block focuses on the placement of products and services to the customers, along with product lifecycle management.
- The **Production** functional block manages the delivery and lifecycle of all customer-facing and resource-facing services. These can be based on different technologies or might be a combination of multiple operational domains, including multi-domain services provided with the cooperation of other parties.

2 Architecture Analysis

This section outlines a high-level approach to GARR's OAV architecture analysis, followed by a mapping of individual operational systems to the blueprint architecture of TM Forum's ODA.

2.1 High-Level OAV Approach

The primary design criteria for the GARR-T backbone automation architecture are backward compatibility with pre-existing management systems and the adoption of a disaggregated modular approach for all components. The high-level goal for GARR-T is to create an environment for the development of a software platform capable of controlling all layers of the network in a harmonious and unified manner: optical spectrum, optical transport network, packet network, edge services, data centre and above-the-net application services.

To achieve this goal, an architecture was modelled with two primary pillars: **observability** and **programmability**.

- **Observability** refers to all the subsystems required to collect and represent the current state of the backbone and all its elements. This covers monitoring, analysis, alerting, inventories, discovery, and legacy information systems.
- **Programmability** refers to all the tools needed to automate equipment configuration. In addition, the programmability layer collects and persists the high-level intents specified by the Network Operations Centre (NOC) regarding the desired state of network services.

The link between the current network state extracted from the observability systems and the desired state in the programmability layer is a high-level central orchestration layer that is responsible for implementing reconciliation cycles for network divergences from what is specified.

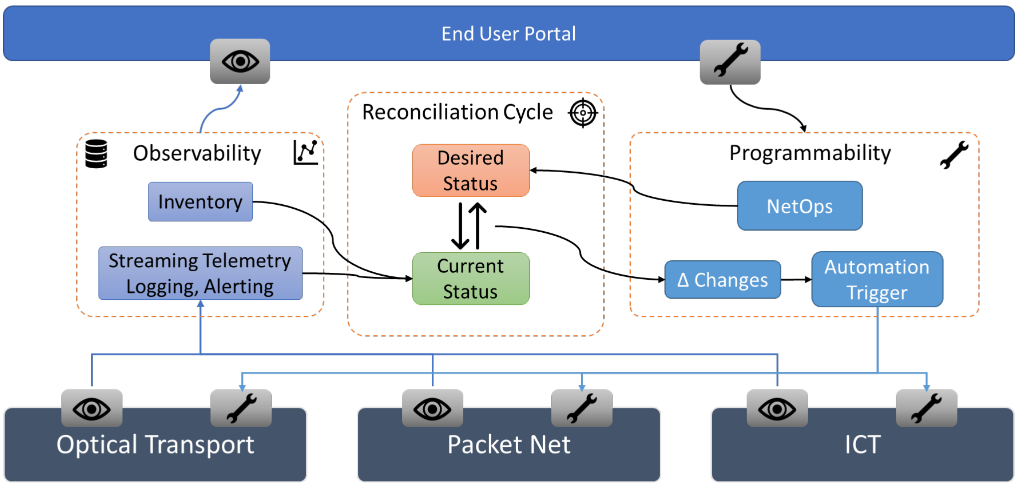

Figure 2.1: GARR-T automation architecture

2.2 Mapping to ODA Functional Architecture

When put into the context of the TM Forum's ODA functional representation, GARR's Network Management System (NMS) architecture components can be represented as in Figure 2.2. The grey boxes in the diagram represent GARR's NMS architecture components, and their placement within the ODA functional blocks is determined by their main functionalities.

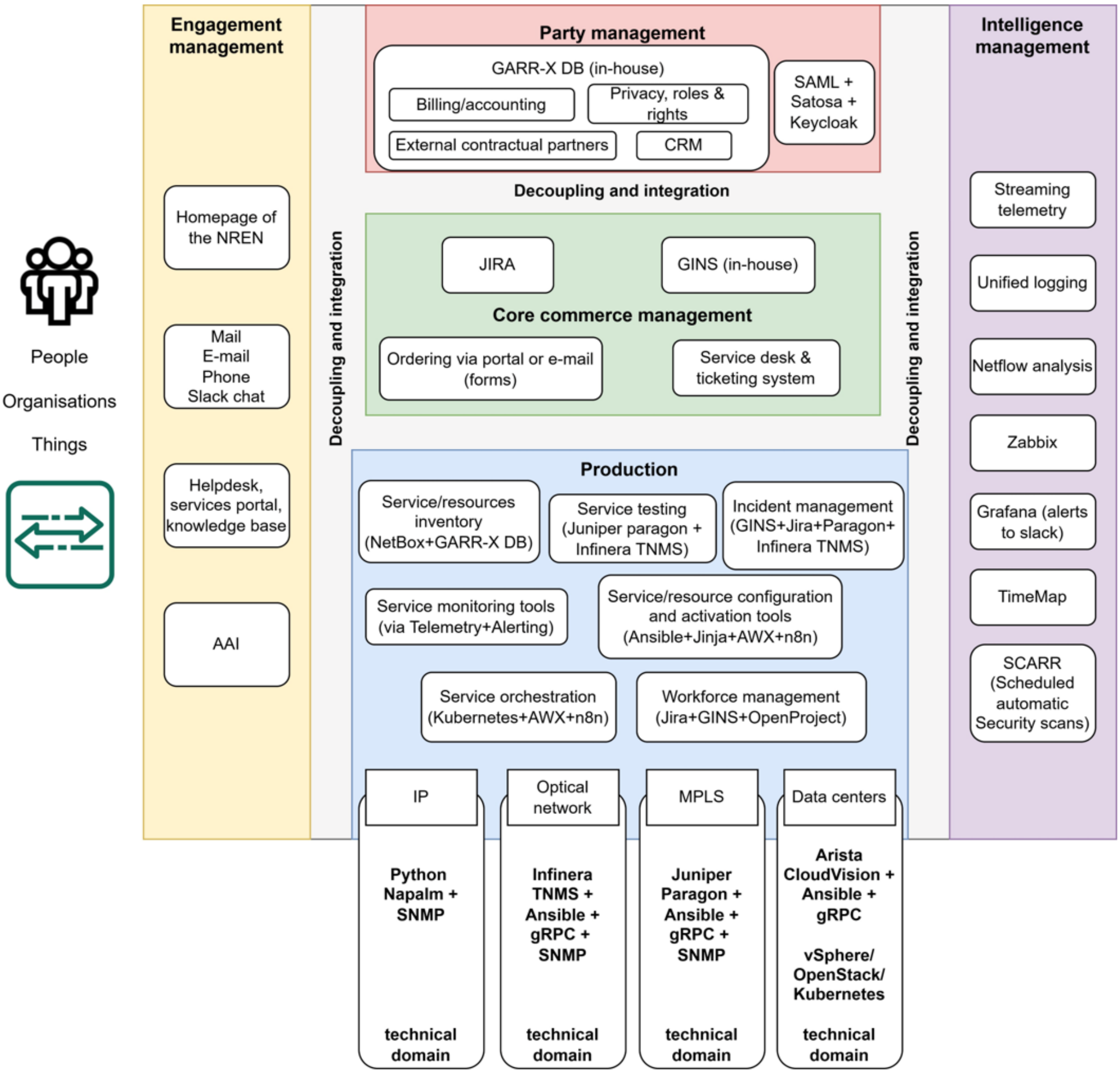

Figure 2.2: GARR's NMS components mapped to the TM Forum's ODA model

An analytical breakdown of each ODA functional block and the relevant GARR NMS components follows.

2.2.1 Engagement Management

GARR uses different tools to tackle the Engagement Management functional block, from traditional phone calls and e-mails to more advanced portals, chat and helpdesk tools. The functionalities of each tool are explained briefly below:

- **GARR home page** [7] – Used for the service portfolio.
- **E-mail** – Single point of contact for new requests.
- **Phone** – Serves as a means of emergency contact.
- **Slack** – Regular communication and alerts propagation.
- **Helpdesk and services portal** – These provide support ticket functionality, using both Jira and an in-house TTS solution.
- **Knowledge base** – Technical and operational documentation.
- **AAI** – Electronic identity system enabling R&E community members to access multiple services with their institutional credentials.

Engagement functions harmonise traditional channels with more recently introduced channels, such as the Slack communication app used for handling asynchronous notifications from alarm systems. Additional channels will be introduced in the near future, such as a user portal to aggregate and manage user requests for new services (subject to authorisation from the planning and operations groups). User permissions are established according to the authorisation criteria following federated authentication. GARR is working to decouple rule definition and evaluation processes from enforcement, aiming to make authorisation as similar as possible to what happens with federated authentication.

2.2.2 Party Management

Party Management is mainly handled using an in-house tool called **GARR-X DB**, which is used for billing, accounting, and managing relationships with external contractual partners. It is also used as a CRM. Most aspects of privacy, roles and rights in GARR-X DB are handled through IDEntity Management for federated access (IDEM), the Italian national Authentication and Authorisation Infrastructure (AAI) federation for R&E [8].

In recent years, GARR adopted OpenID Connect (OIDC) as the authentication protocol for new services. This has been harmonised with the SAML protocol for IDEM Federation support through the adoption of the **GARR Satosa Gateway** service, which serves as a proxy between SAML and OIDC federated authentication protocols to simplify and increase interoperabilty for GARR-operated services.

Moreover, richer authorisation models and custom attributes/claims implementation have been introduced by pairing **Satosa Gateway** with **Keycloak**. Users incoming from the Identity Federation are augmented, or filtered, with the additional information and rules set in **Keycloak**.

2.2.3 Core Commerce Management

GARR uses a variety of tools for core commerce management. Their functions are summarised below:

- **Jira** – Utilised to develop teams, make new service requests, and plan for network engineering activities. Requests are generally managed through multi-step workflows coordinated with Jira.
- **GINS** – A legacy monitoring platform developed by GARR.
- **Forms** – Via portal or e-mail.
- **Service Desk** and ticketing system.

New requests for services are managed through the Jira portal, triggered by an email or a direct ticket. After service delivery, services are managed through GINS, an in-house information system that keeps track of the service status. More recently, GINS functionalities are being migrated to GARR's new streaming telemetry stack, with related alerting features.

2.2.4 Production

GARR uses an extensive number of tools in the Production block, which is in turn divided into separate technical domains. The following are the main functions performed by GARR in the Production functional block, and the respective tools used, together with a brief explanation of their use cases:

- **Service/resources inventory** (NetBox + GARR-X DB) – Devices and components are automatically discovered. This tool is available to the NOC and is consumed by other services.
- **Service testing** (Juniper Paragon + Infinera TNMS) – Alerting on metrics and circuits provisioning. Used by the NOC.
- **Incident management** (GINS + Jira + Paragon + Infinera TNMS) – Used by the NOC and engineering.
- **Service monitoring tools** (via Telemetry + Grafana Alerting) – Used by the NOC and management (reporting); available to end-users. Dashboards and alerts are made available according to the role.
- **Service/resource configuration and activation tools** (Ansible + Jinja + AWX + n8n) – Used by the NOC for automating device configurations.
- **Service orchestration** (Kubernetes + AWX + n8n) – Used to run the central IT services in this bullet list.
- **Workforce management** (Jira + GINS + OpenProject) – Gantt and project management tools.

NetBox is used as an automatic inventory tool. A team of agents query the network layer controllers to fetch the current status of the optical network, the packet network, certain IT resources (servers, storage, VMs), and data centre network resources. Administrative information is integrated from GARR-X DB, an in-house-developed Business Support System (BSS). A number of features related to service provisioning and testing are delivered through vendor controllers. In most cases, signals and alerts coming from the controllers are integrated with additional data sources coming from GINS, GARR-X DB or NetBox. Continuous monitoring has been implemented by adopting Telegraf, Influx/Prometheus and ClickHouse as data lakes. Overall observability and alerting are delivered with Grafana. Service configuration automation is implemented through Ansible playbooks and Jinja configuration templates. Ansible playbooks are then automated using different service orchestrators: AWX, n8n or Kubernetes. Specific tools are chosen according to their suitability and convenience for the group operating the platforms and management software.

2.2.4.1 Technical Domains

GARR divides the Production functional block into several technical domains:

- **IP** (Python Napalm + SNMP + gNMI) – IP observability is achieved with SNMP and gNMI. Automation for devices without SDN controllers is done using the Python Napalm library.
- **Optical Network** (Infinera TNMS + gRPC + SNMP) – Optical network programmability is mediated with Infinera TNMS controller. Observability probes DCI and OLS devices using gRPC and SNMP.
- **MPLS** (Paragon + Ansible + gRPC + SNMP) – MPLS automation is done using both Juniper Paragon Pathfinder and Ansible custom-built recipes. Again, packet device monitoring uses gRPC and SNMP channels to observe the devices.
- **Data centres** (CloudVision + Ansible, vSphere/OpenStack/Kubernetes) – Data-centre automation involves Arista CloudVision and Ansible for automating local networking. vSphere, OpenStack and Kubernetes are used by DevOps teams to instantiate and manage IT resources.

Different GARR-T platform building blocks have different technical domains to implement the observability and programmability pillars. The design criterion is that every subsystem should be autonomous in the chosen technology. The northbound interactions should be normalised and as standard as possible to expose a coherent, uniform perspective to higher-level tools that work with a single representation of GARR-T.

The IP network uses the Python Napalm library to interact with devices that do not support a central controller (e.g., users' Customer-Premises Equipment (CPE) devices). To monitor these devices, SNMP is the preferred protocol. Optical network devices are observed through a combination of SNMP and gRPC probes run through Telegraf. Optical circuits and spectrum partitioning are controlled via Ansible playbooks that interact with the Infinera TNMS controller, or directly with the devices. The MPLS network is managed through several Ansible libraries developed both to manage the devices' lifecycle and to provision new services. MPLS observability is achieved through gRPC and SNMP collected by Telegraf probes, also integrating information channels exposed by the Paragon network controller. Finally, data-centre resources are programmed.

2.2.5 Intelligence Management

GARR uses a variety of tools for Intelligence Management:

- **Streaming Telemetry** – Delivers insights on the device metrics, trends and expected operating range, with alerts in case of deviation. Allows the correlation of events from different devices and different network layers (e.g., optical and packet events).
- **Unified Logging** – Collecting all logs in unified data lakes helps to correlate events and carry out root cause analysis as part of investigations.
- **NetFlow Analysis** – Enables analysis of common traffic patterns, emerging user communities and outliers, along with anomaly detection. This is a prerequisite, together with streaming telemetry, for enabling predictive maintenance.
- **Zabbix** – Used mainly as a source of intelligence for alerts related to data-centre resources.
- **Grafana** – (via alerts sent to Slack) – the main single pane of glass for all the dashboards and data exploration tasks.
- **TimeMap** – Deployed to measure specific metrics as part of GARR's monitoring architecture philosophy, which seeks to keep everything under observation. Used to monitor latency and jitter between the nodes of the backbone.
- **SCARR (Scheduled Automatic Security Scans)** – A custom-built service to automate parallel security scans based on OpenVAS over large networks' IPv4 and IPv6 pools. Used to assess the security risks of the public IPs exposed to the public internet.

The intelligence toolset in GARR-T builds on top of streaming telemetry. Notably, GARR opted for a unified, homogeneous approach to handling different monitoring streams. All the metrics collected from the different network devices are sent to a unique time-series database pool. The same is done for logs coming from different devices and software. All log entries are collected in a single data facility. This enables a simple approach to data normalisation and multi-layer correlation analysis. More recently, the same approach has been applied to the collection and analysis of NetFlow flows. All analyses are performed via a geo-replicated Grafana deployment that also handles raising alerts and propagating signals to specific Slack channels, notifying Ops teams when expected working constraints are not satisfied. Besides this telemetry stack, additional sources, like Zabbix, support the observability of auxiliary systems such as the IT resources running the telemetry itself.

3 Conclusions

GARR is the ultra-broadband network dedicated to the Italian R&E community. Its main objective is to provide high-performance connectivity and to develop innovative services for the daily activities of researchers, professors and students, as well as for international collaboration.

GARR-T is the new generation of the GARR network. It is an evolution of the production network, offering innovative features. GARR-T is a cutting-edge network built around the users' needs and designed to be future-proof, focusing mainly on a new level of automation to achieve enhanced reliability and measurability through advanced monitoring and analytics.

Using a common reference architecture to analyse GARR's architecture from an OAV perspective, like the framework provided by the TM ODA reference blueprint, is a way to align with other NRENs' efforts in finding commonalities in implementing different functionalities and components.

The architecture analysis found that GARR-T's automation stack relies on two architectural pillars: observability and programmability. Observability involves building a complete unified layer for collecting and analysing telemetry monitoring, logging and alerting. This is paired with the ability for continuous discovery and updating of the representation of the current status of the network. Programmability covers providing automation tools that allow the provisioning of resources at different network layers – optical transport, packet, and data centres – through a common approach. Resting on top of these two pillars, higher-order orchestrators take care of keeping the requested status of the network aligned with what is observed.

Glossary

AAI	Authentication and Authorisation Infrastructure
BSS	Business Support System
CPE	Customer-Premises Equipment
CRM	Customer Relationship Management
DB	Database
DCI	Data Centre Interconnect
GINS	GARR Integrated Networking Suite
gNMI	gRPC Network Management Interface
gRPC	Remote Procedure Call
IDEM	IDEntity Management
IDS	Intrusion Detection System
IETF	Internet Engineering Task Force
IP	Internet Protocol
MPLS	Multiprotocol Label Switching
NMS	Network Management System
NREN	National Research and Education Network
NOC	Network Operations Centre
OAV	Orchestration, Automation and Virtualisation
ODA	Open Digital Architecture
OIDC	OpenID Connect
OLS	Open Line System
PoP	Point of Presence
QKD	Quantum Key Distribution
R&E	Research and Education
SAML	Security Assertion Markup Language
SCARR	Scheduled Automatic Security Scans
SDN	Software Defined Network
SNMP	Simple Network Management Protocol
WP	Work Package

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