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MARnet OAV Architecture Analysis

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Abstract

This document maps MARnet's Operations and Business Support System (OSS/BSS) to the TM Forum's Open Digital Architecture (ODA) and analyses the mapping to provide a standardised view of the components and implementations of orchestration, automation and virtualisation within the NREN. It highlights MARnet's strategic alignment with contemporary digital architecture standards and emphasises the critical need for automation within MARnet's operations to meet the growing demands of education and research activities. The analysis also identifies opportunities for further enhancement of MARnet's intelligence management capabilities through advanced technologies like machine learning and AI-capable tools, positioning MARnet to proactively adapt to emerging technological trends.

Contents

Figures

Executive Summary

The Macedonian Academic Research Network (MARnet) serves as a vital link in the integration of Macedonian universities into the global academic network. Its mission includes providing network access to students and faculty members, managing the .mk domain, and fostering international collaboration. In order to be able to support that mission, MARnet developed and maintains an Operations and Business Support System (OSS/BSS) that also provides a safe and stable environment for any future services.

To better understand the structure and capabilities of MARnet's OSS/BSS, an analysis was conducted by mapping this system to the TM Forum's Open Digital Architecture (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, showcasing MARnet's focus on user engagement, efficient party management, product delivery, service provisioning, and data-driven insights. This approach provides valuable insights into the integration of advanced digital functionalities, such as orchestration, automation, and virtualisation (OAV), within MARnet's OSS/BSS.

MARnet's strategic goals include interconnecting educational institutions, introducing cutting-edge technologies, contributing to knowledge dissemination, and shaping national information society strategies. The analysis reveals that MARnet uses a mix of commercial, open source and in-house-customised tools in its working processes across the service lifecycle to achieve these goals. Specific highlights include well-established in-house portals and catalogues to facilitate clear communication and service visibility, and a customised LibreNMS system deployed for NOC monitoring, capacity tracking and planning.

The architecture analysis emphasises the need to continue building on MARnet's successful use of automation and orchestration to streamline operations due to limited personnel and a large user base. Future enhancements in the Intelligence Management block, including advanced analytics and AI tools for anomaly detection and trend analysis, are recommended to bolster predictive capabilities and meet evolving user needs. Overall, the architecture mapping demonstrates MARnet's forward-thinking approach to modern digital standards, operational efficiency, and user-centric services, positioning it as a leading force in advancing education and research connectivity in Macedonia.

1 Introduction

This document analyses the components of the MARnet Network Management System (NMS) architecture, focusing on the Orchestration, Automation and Virtualisation (OAV) aspects of its implementation and mapping these to the TM Forum's Open Digital Architecture (ODA). The National Research and Education Network (NREN) community can use this analysis to compare their own components and approaches with those of MARnet; they may find similarities that inspire them to work together on their journey towards OAV. This mapping is part of a set of mappings of different NREN management architectures against ODA, thus providing a common reference point and the means for a cross-NREN comparative analysis of components and approaches.

MARnet, the Macedonian NREN, was established in 1995 as a part of the Ss. Cyril and Methodius University (UKIM), Skopje, and registered as a legal entity in Macedonia in 2010. Its primary mission is twofold: firstly, to integrate the university into the broader European and global academic network, and secondly, to provide network access to both students and faculty members of the university.

The initial integration of the UKIM network into the global academic internet occurred in 1995 with the establishment of a 64Kbps VSAT satellite link to Vienna. With this successful connection of the UKIM computer network to the internet via the MARnet project, both the number of users and network utilisation saw manifold growth.

By the year 2000, the then-outdated satellite link was upgraded to a 512 Kbps international connection. Subsequently, in 2007, this capacity was further augmented to 68 Mbps. Presently, MARnet boasts 2x100 Gbps throughput (currently operated by MARnet at 10 Gbps due to technical limitations) via GÉANT. This robust connection serves the needs of a vast user base exceeding 60,000 individuals at academic and research institutions and encompasses all state universities in Macedonia, with plans to connect primary and secondary schools to the MARnet network in the future.

UKIM's Faculty of Computer Science and Engineering (FINKI) plays a key role within MARnet, not only in research, development and education, but also by being actively involved in the management and administration of MARnet's network resources. This includes overseeing network infrastructure, ensuring its security and reliability, and implementing emerging technologies to improve network performance.

MARnet plays a pivotal role in managing the top-level domain for Macedonia, denoted as .mk (and the Cyrillic version, .мкд). The Network Information Centre under MARnet is responsible for registering subdomains for various organisations and institutions within this domain. In keeping with the principle of hierarchical addressing, the primary server for administering and overseeing the Macedonian top-level domain .mk recognises both secondary and tertiary subdomains.

MARnet's OAV architecture analysis uses the TM Forum's Open Digital Architecture (ODA) [1] functional blocks as its basis. The 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 GN5-2 Work Package 6 (WP6) is given in GN4-3 deliverable D6.6 *Transforming Services with Orchestration and Automation* [2]. 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 an 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 shown in the following figure maps the main components by their capabilities into the ODA functional blocks.

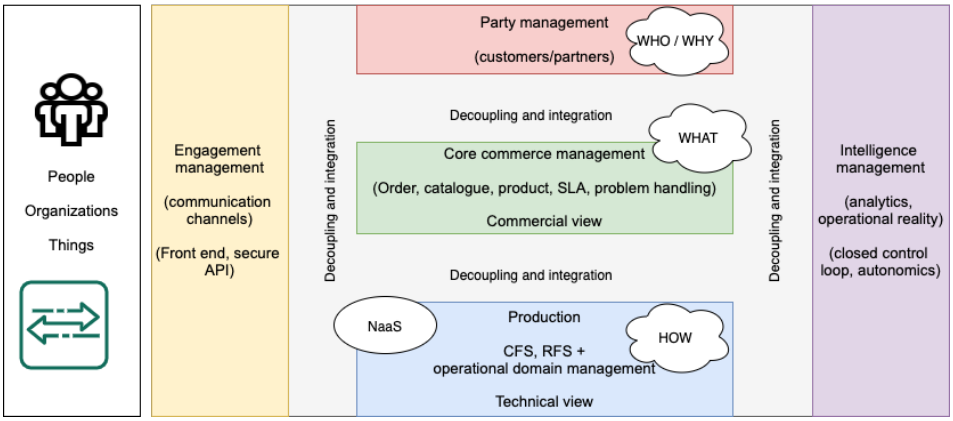

Figure 1.1: The TM Forum ODA functional architecture

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 that 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

2.1 High-Level OAV Approach

Recognising the significance of the practice established by GÉANT, MARnet aspires to achieve the following:

- Facilitate the interconnection of all research, higher education, and other educational institutions within Macedonia, fostering international links with high-speed internet access.
- Introduce, assess, and analyse novel services and cutting-edge network technologies, followed by subsequently implementing them effectively.
- Actively participate in relevant international collaborative initiatives and projects.
- Contribute to the generation and dissemination of knowledge.
- Engage in partnerships and collaborative efforts to shape strategies for the advancement of Macedonia's information society.

Currently, MARnet encompasses all state Universities: Ss. Cyril and Methodius University of Skopje, St. Clement of Ohrid University of Bitola, State University of Tetova, Goce Delcev University of Stip, Mother Theresa University and St. Paul the Apostle University of Information Science and Technology. In the future, it is planned that all primary and secondary schools will also be connected to the MARnet network.

In the context of OAV, MARnet's approach is grounded in the progressive integration of automated and software-defined processes into its operational environment. The current OAV framework relies on the use of Ansible-based automation for configuration and service deployment, OpenStack virtualisation for research and cloud-oriented workloads, and customised monitoring and management tools such as LibreNMS and NetBox for operational orchestration. These components are coordinated within an evolving architecture that follows the TM Forum's ODA principles of modularity and interoperability. The focus is on a gradual transition from manually operated systems to policy-driven and event-triggered automation, ensuring both reliability and scalability despite limited human resources. This automation-centric approach is particularly critical in the context of MARnet's limited human resources and large, diverse user base, where efficiency and reliability must be achieved through intelligent orchestration rather than manual intervention.

2.2 Mapping to ODA Functional Architecture

Put into the context of the TM Forum ODA functional representation, the MARnet Network Management System (NMS) architecture components can be represented as in Figure 2.1. The white boxes in the diagram represent MARnet NMS architecture components. Their placement within the coloured ODA functional blocks is determined by their main functionalities.

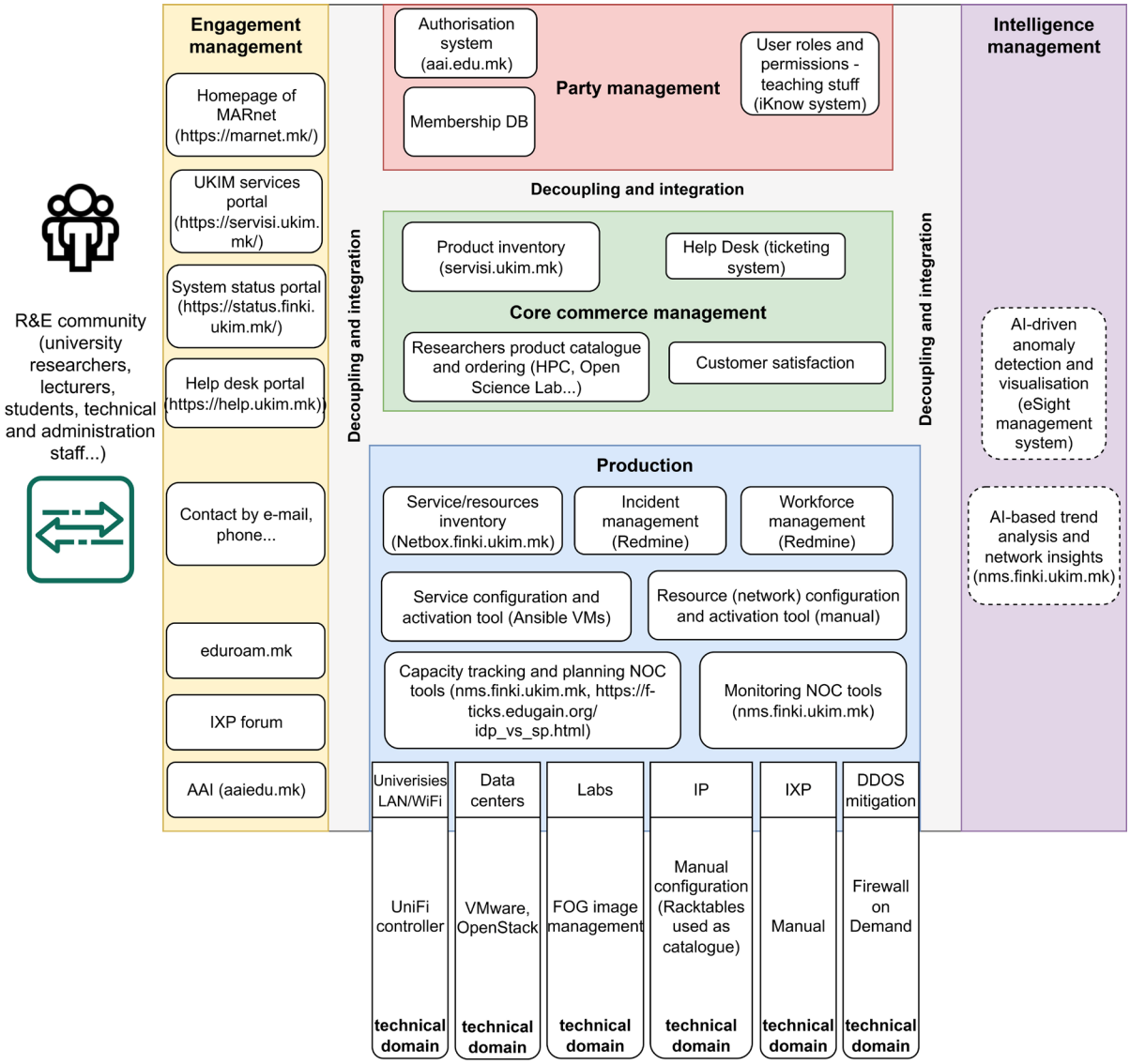

Figure 2.1: MARnet OSS/BSS system components mapped to the TM Forum ODA

2.2.1 Engagement Management

The Engagement Management functional block of the MARnet ODA mapping encompasses a set of online resources and communication channels that support engagement, interaction, and information dissemination. These elements facilitate effective communication and collaboration between MARnet, UKIM and its users within the academic and research community. These components include:

- **MARnet homepage** (https://marnet.mk/) – the primary online gateway and central website for MARnet, providing information and access to various resources. Users including researchers, academics, and other stakeholders visit this homepage to learn about MARnet's activities and access its services and resources.
- **UKIM services portal** (https://servisi.ukim.mk/) – a specialised online platform associated with UKIM. The portal offers a range of services and resources relevant to both the university and MARnet. These services comprise academic tools, administrative services, research resources, and more. The UKIM services portal integrates with MARnet's infrastructure and provides access to specific resources offered by the UKIM community through MARnet.
- **System status portal** (https://status.finki.ukim.mk/) – a dedicated website focused on providing real-time or near-real-time information about the status and performance of the UKIM/MARnet systems, networks and services. Users, including technical staff, administrators, and network operators, use this portal to monitor the health and availability of critical systems and services.
- **Help desk portal** (https://help.ukim.mk/ and http://help.finki.ukim.mk/kb/index.php) – intended to effectively address customer issues and enhance the utilisation of available products. It serves as a centralised platform where customers can submit their queries, problems, or requests, allowing support teams to promptly respond, troubleshoot, and provide solutions.
- **Contact by e-mail, phone** – this covers the various means of contacting MARnet for engagement, inquiries, support or collaboration.

Access to MARnet products is also facilitated through the implementation of eduroam, the Internet eXchange Point (IXP) forum, and the Macedonian Authentication and Authorisation Infrastructure (AAI) Federation:

- **eduroam** allows users (researchers, professors, students, staff) at eduroam-supporting institutions to connect to the internet through any institution globally that supports eduroam. The eduroam.mk site is a national portal, used by the administrators to facilitate eduroam management.
- The **IXP forum** serves as a platform where representatives of all national internet service providers connected to the IXP in Skopje [3] convene for regular meetings to exchange insights, best practices and experiences. These discussions aim to foster collaboration, enhance operational efficiency, and sustain the growth of the IXP system.
- **AAI** (https://aaiedu.mk/) – The Macedonian AAI Federation (AAIEDUMK) operates as part of MARnet and facilitates and simplifies the sharing of services across the whole federation. This is accomplished by using technologies to extend the scope of an (electronic) identity, issued by any member of the federation, to be valid across the whole federation. The Faculty of Computer Science and Engineering in Skopje is assigned as the Federation Operator.

2.2.2 Party Management

The Party Management functional block covers the management of customer-related information and relationships, as follows:

- **Authorisation system** – is crucial in defining roles and permissions for users within the research community. It ensures that users are granted appropriate access levels based on their roles.
- **Membership DB** – represents an Active Directory environment with Organisational Units (OUs) for each Faculty, as well as OUs for teachers and students within each Faculty. This database is used for all products available to users (https://servisi.ukim.mk/). There are different roles, such as teacher and student, that grant access to different products.
- **User roles and permissions** – the roles and permissions are primarily defined in a separate database called the iKnow system, which contains students' electronic records (http://finki.iknow.ukim.mk).

2.2.3 Core Commerce Management

One of the most important parts of the Core Commerce Management block is the **product inventory**, which in MARnet's case is available through different Web platforms, such as:

- **UKIM services portal** (https://servisi.ukim.mk/) – a specialised online platform maintained by Ss. Cyril and Methodius University (UKIM). This portal offers a range of services and resources relevant to both the university and MARnet.
- The **product catalogue** for researchers provides access to a range of advanced computing and data services, including reservation of High-Performance Computing (HPC) resources, self-service deployment of virtual machines and containers, and storage for research and educational purposes. Orders are placed by selecting products from the product catalogue (e.g., VM flavours or container images) and are either automatically provisioned according to established policies, or manually reviewed, particularly for services requiring project-based justification such as those offered by the HPC Competence Centre and the Open Science Lab. This product catalogue offers:
  - HPC resources of North Macedonia, coordinated via the national HPC Competence Centre [4].
  - Virtualised resources based on OpenStack [5].
  - Open science-related resources via the specialised Open Science Lab, including a national OpenStack cloud for self-managed virtual infrastructure, a GPGPU system for complex computations, and over 2 PB of centralised storage for large-scale research data [6].
  - Additionally, product-ordering functionality is available through the dedicated web portals of each service (e.g., HPC Competence Centre, Open Science Lab, and OpenStack).

Another important aspect is the **help desk** (customer support), responsible for addressing customer queries, resolving issues, and facilitating the use of products. The help desk backend uses the osTicket ticketing system, which is designed to streamline customer support processes by centralising incoming requests, inquiries and issues. It allows efficient management and tracking of customer interactions, prioritising of tasks based on urgency, assigning tickets to appropriate agents, and provision of timely responses and resolutions. This system helps improve customer satisfaction by ensuring consistent and organised support delivery while also enabling performance monitoring and reporting for continuous service improvement.

The last component in this block is **customer satisfaction**, which is dedicated to measuring and enhancing users' satisfaction with different products. This block is addressed through existing mechanisms such as the help desk (osTicket), which provides indirect indicators of user experience via tracked issues, resolution times, and recurring service requests. Additionally, usage patterns across platforms like the UKIM services portal and HPC catalogue offer insights into demand and user engagement.

2.2.4 Production

This functional block covers the processes and systems used by MARnet that enable the efficient creation, deployment, and delivery of products:

- **Network service and resource inventory management** – MARnet utilises a customised version of NetBox [7] (an example of the interface is shown in Figure 2.2).

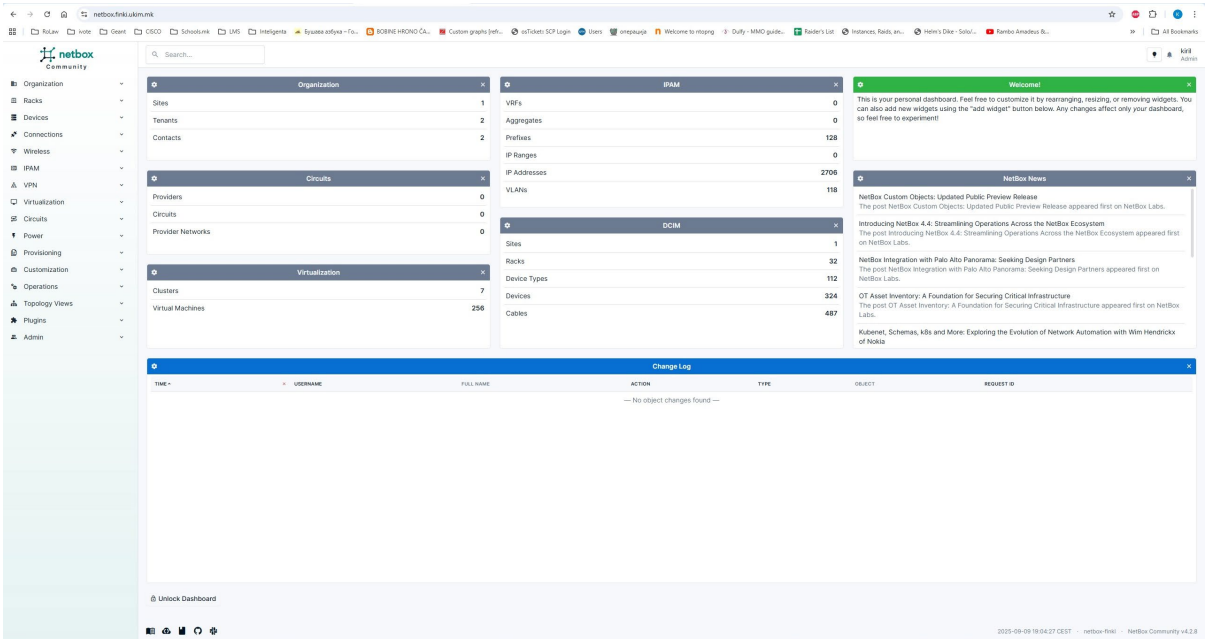

Figure 2.2: NetBox software used for service/resources inventory

- **Incident management and workforce management** – the Redmine software is used, with features configured to align with UKIM's specific workflows and requirements (as presented in Figure 2.3).

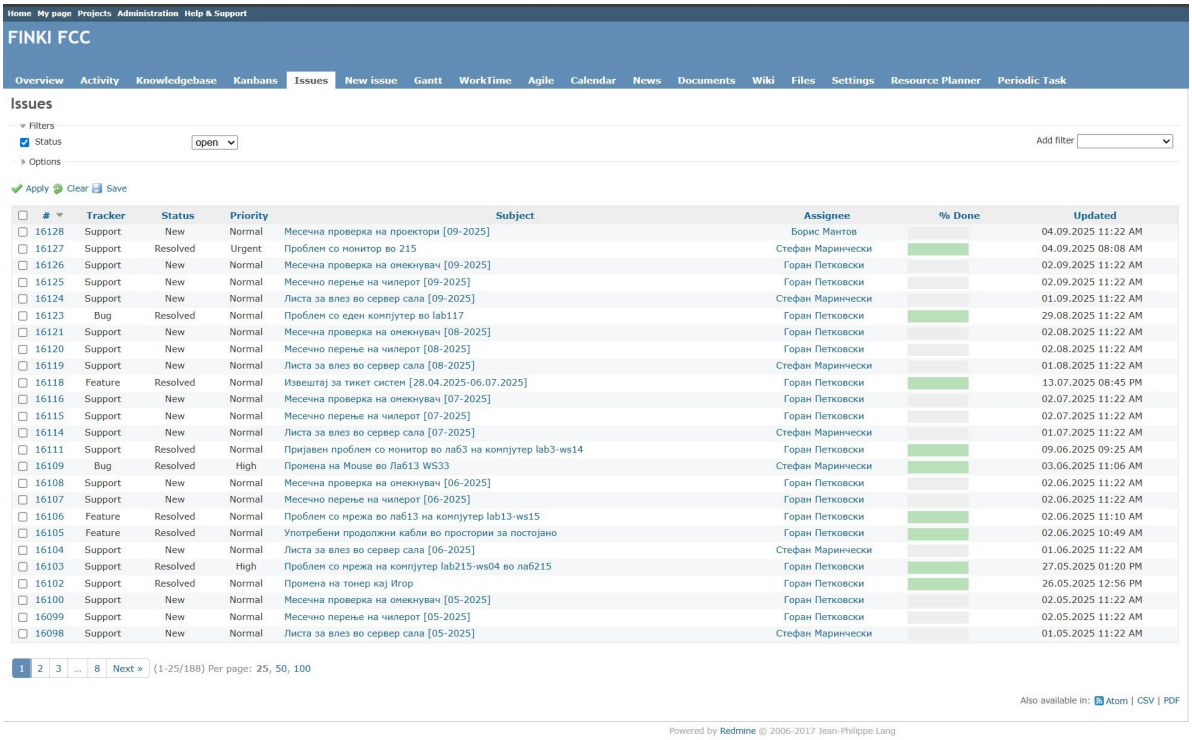

Figure 2.3: Redmine software used for incident and workforce management

- **Initial activation and base configuration of network devices** is done manually.
- **Configuration and activation of services across network devices** – Ansible VMs are used for the following tasks:
  - Define and enforce the desired state of servers and applications.
  - Automate the process of setting up new servers.
  - Patch operating systems and software on a large number of servers.
  - Automate the setup and configuration of monitoring tools and the collection of system and application logs.

- **NOC monitoring tool** – MARnet uses its nms.finki.ukim.mk system, a customised NMS based on the LibreNMS software [8]. An example of the dashboard interface is shown in Figure 2.4.

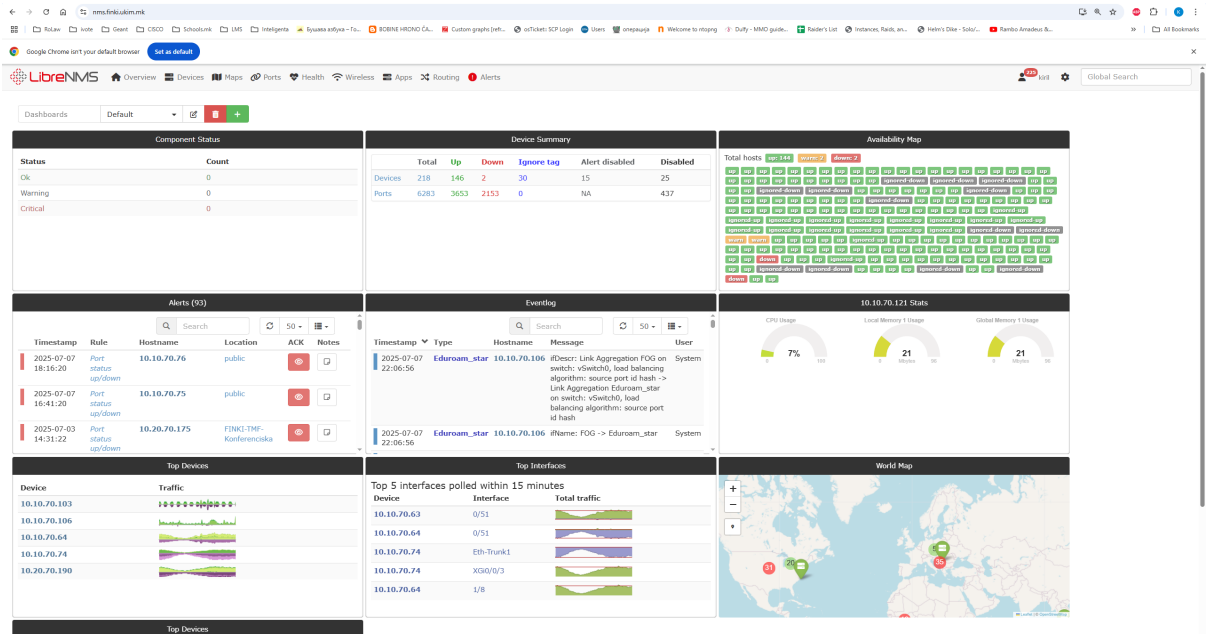

Figure 2.4: NMS used for monitoring purposes

- **Capacity tracking and planning NOC tools**:
  - MARnet uses the same nms.finki.ukim.mk system for NOC capacity tracking and planning as deployed for NOC monitoring.
  - AAIEDUMK is a participant in the F-ticks platform, an effort to collect usage information about the eduroam service [9].

Figure 2.5 offers an example of aggregated F-ticks data (aggregation unit is one minute).

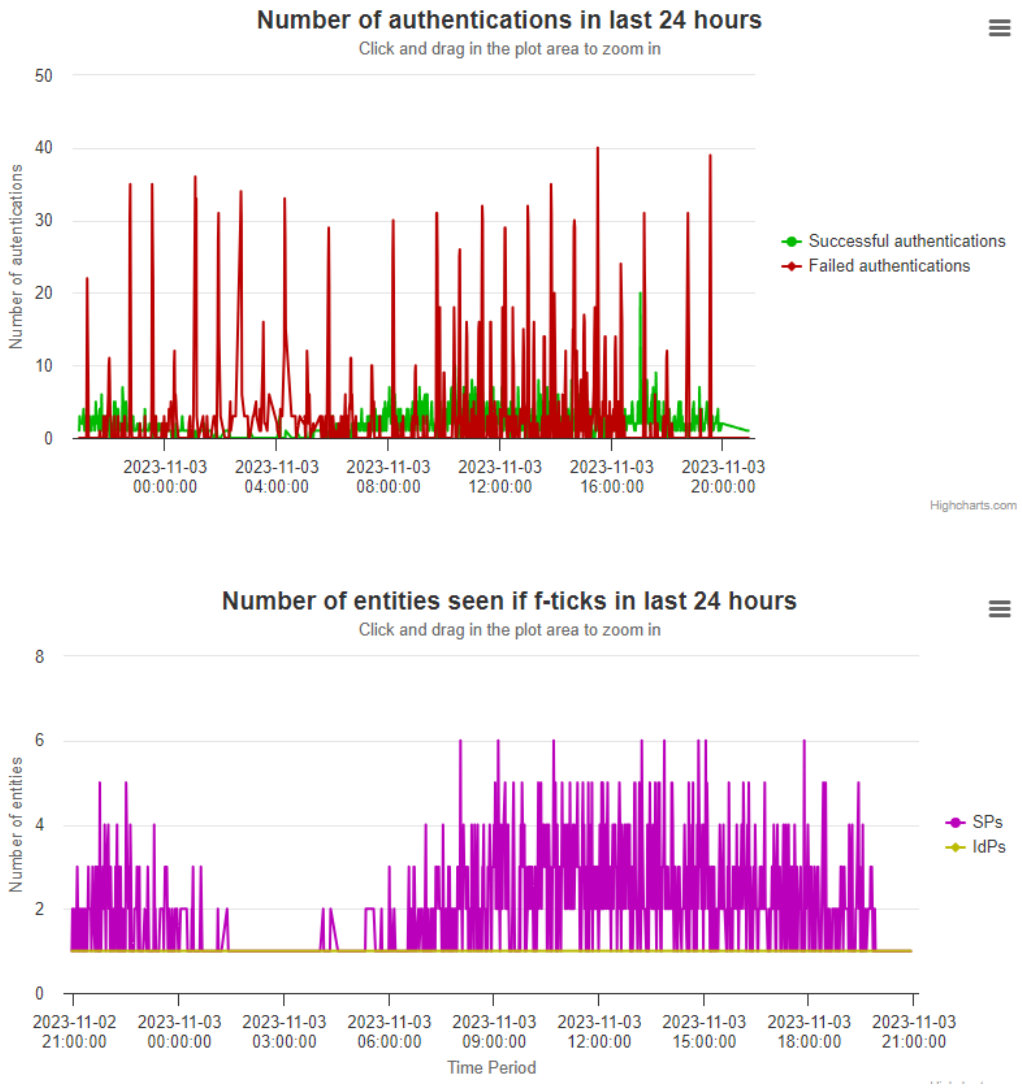

Figure 2.5: F-ticks data showing the number of authentications and number of entities seen in F-ticks over a given 24-hour period

An overview of successful logins for Identity Providers (IdPs) in the AAIEDUMK federation over a given 24-hour period is presented in Figure 2.6.

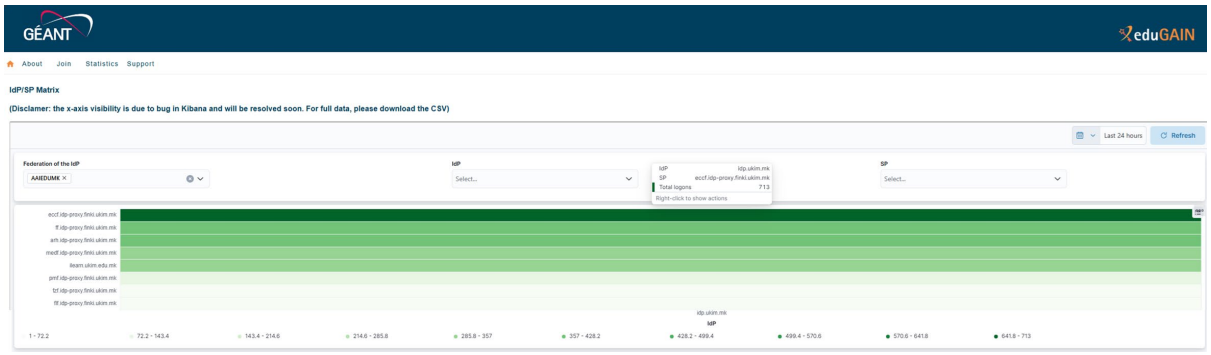

Figure 2.6: Number of successful logins for IdPs in AAIEDUMK over a 24-hour period

2.2.5 Technical Domains

Technical domains cover the key technologies, systems and infrastructure environments used to enable the provision of services, as follows:

- **Universities' LAN/WIFI** – A set of vendor-provided tools is used for wired and wireless network management within the universities. This includes UniFi Controller, a wireless network management software solution from Ubiquiti Networks.
- **Data centres** – This domain uses two different technologies: proprietary VMware and open-source OpenStack. All services are implemented using virtual machines:
  - VMware is mostly used for virtualising core services (e.g., Active Directory), application and database servers used for educational purposes, application and education projects, and commercial services.
  - OpenStack virtualisation is used for research purposes, with multiple flavours and operating systems.
- **Labs** – FOG Project image management is used to efficiently store, process and distribute images for university labs. It enables localised image handling, reducing latency and conserving bandwidth. It optimises resource utilisation, enhances security, and enables scalable image processing at the edge.
- **IP in the core network** – Most servers in the IP core network are configured manually where non-volatile IP addressing is required. In order to maintain persistent information on the many different VLANs and the IP addressing used in them, RackTables is used as a catalogue [10], as shown in Figure 2.7 on the following paghe. The Faculty of Computer Sciences and Engineering (FINKI) at UKIM is currently in the process of testing Ansible scripts for semi-automated IP configuration of network devices.

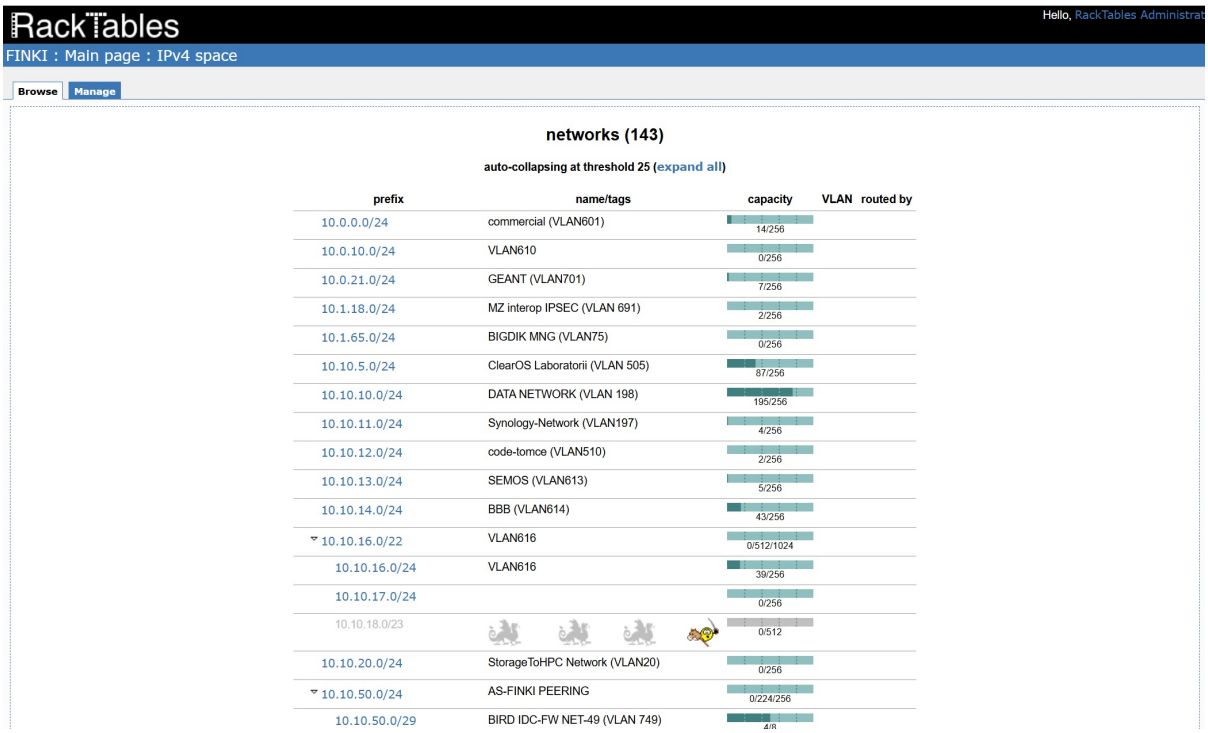

Figure 2.7: RackTables used as network resources catalogue

- **Internet eXchange Point (IXP) (ixp.mk)** – UKIM's FINKI hosts and runs the national IXP. This ensures that local traffic remains local, thereby improving latency, capacity and quality of service, making the internet more resilient and affordable.
- **Distributed Denial of Service (DDoS) attack mitigation** – MARnet relies on two complementary tools developed within the GÉANT community to enhance network resilience:
  - Firewall on Demand (FoD) [11], which allows real-time dynamic adjustment of firewall rules to block malicious traffic during ongoing DDoS attacks.
  - NeMo [12], an open-source NetFlow-based traffic analysis tool designed specifically for NRENs. It enables detection of DDoS and other traffic anomalies based on local flow data.

2.2.6 Intelligence Management

The Intelligence Management block focuses on collecting, analysing, and utilizing data to improve network performance and enhance the overall user experience. Currently, MARnet uses traditional software tools for data analytics, but the possibility of integrating AI is actively being explored.

The use of AI is being explored in the following two directions:

- **AI-driven anomaly detection and visualisation** – The NetEco software and eSight management system are currently used for visual monitoring and accessing historical data. In the future, this data can serve as the basis for AI-driven anomaly detection, both visually and analytically, allowing for faster identification of irregular patterns in network behaviour.

- **AI-based trend analysis and network insights** – In the future, further customisation of the NMS system [13] is planned to better exploit "intelligence", such as historical data and trend analysis, with the aim of generating insights into network performance trends to assist with capacity planning and optimisation efforts.

3 Conclusions

This analysis of MARnet's OAV architecture mapping highlights its strategic synchronisation with the TM Forum's Open Digital Architecture (ODA). This strategic alignment signifies MARnet's commitment to enhancing its network infrastructure, optimising operational workflows, and delivering cutting-edge services to its academic and research user base.

The integration of MARnet's network architecture with ODA's functional blocks highlights key areas of success for the NREN, including robust engagement management, streamlined party management, efficient core commerce operations, agile production processes, optimised technical domains, and data-driven intelligence management. The architecture mapping underlines the critical need for automation within MARnet's operations. With a limited workforce and a substantial user community comprising students, teachers, and researchers, automation is imperative to streamline processes, improve efficiency, and meet the growing demands of education and research activities.

The process of architecture mapping generated worthwhile insights into the potential for enhancing MARnet's Intelligence Management block in the future, building on the continuous evolution and refinement that MARnet envisions for its network architecture. MARnet has laid a solid foundation with data analytics, visualisation and capacity-planning tools. However, there is room for further improvement and integration of advanced technologies, such as machine learning and AI-capable tools, to bolster predictive analytics, anomaly detection and trend analysis. This strategically positions MARnet to adapt proactively to emerging technological trends and enhance its intelligence management capabilities to better serve the evolving needs of its academic and research community.

Glossary

AAI	Authentication and Authorisation Infrastructure
AAIEDUMK	Macedonian AAI Federation
BSS	Business Support System
DB	Database
DDoS	Distributed Denial of Service
FINKI	Faculty of Computer Science and Engineering at UKIM, Skopje
FoD	Firewall on Demand
HPC	High-Performance Computing
IdP	Identity Provider
IP	Internet Protocol
IXP	Internet eXchange Point
LAN	Local Area Network
MARnet	Macedonian Academic Research Network
NMS	Network Management System
NOC	Network Operations Centre
NREN	National Research and Education Network
OAV	Orchestration, Automation and Virtualisation
ODA	Open Digital Architecture
OSS	Operational Support System
OU	Organisational Unit
UKIM	Ss. Cyril and Methodius University of Skopje
VLAN	Virtual LAN
VM	Virtual Machine
WP	Work Package

References

[1] TM Forum, Open Digital Architecture (ODA): https://www.tmforum.org/oda/

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[3] Macedonian IXP: https://ixp.mk/

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[5] Product catalogue for virtualized resources based on OpenStack: https://openstack.finki.ukim.mk/ and https://cloud.hpc.mk/

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[11] Firewall on Demand (FoD): https://security.geant.org/firewall-on-demand/

[12] NeMo DDoS software: https://security.geant.org/nemo-ddos-software/

[13] NMS – See [8]