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CARNET OAV Architecture Analysis

Abstract
The document analyses the mapping of the CARNET architecture to the TM Forum's Open Digital Architecture aiming to provide a standardised view of the components and implementations of orchestration, automation and virtualisation within the NRENs.

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Executive Summary

Analysing NREN architectures from an orchestration, automation and virtualisation (OAV) point of view using a common reference architecture helps align efforts, and find similarities in the way different functionalities and components are implemented, which in turn facilitates potential collaboration between organisations and future interoperability. In pursuit of this goal, the GN4-3 *Network Technologies and Services Development* Work Package (WP6), *Network Services Evolution & Development* task (T2) selected the TM Forum Open Digital Architecture (ODA) as a reference blueprint architecture that can be used for such cross-comparison. The rationale for that choice is described in Deliverable D6.6 *Transforming Services with Orchestration and Automation* [D6.6].

The WP6T2 team is working with NRENs to perform such mappings. In this document the team reports on an analysis of the different functional aspects of the CARNET network management system architecture, and how their components map to the ODA reference model. The mapping highlights the main characteristics and capabilities of the current CARNET network architecture, and how they fit into the main functional domains of ODA. The analysis was carried out by the network architects supported by the WP6T2 team.

1   Introduction

The purpose of this document is to analyse the components of CARNET's network management system architecture, focusing on the Orchestration, Automation and Virtualisation (OAV) aspects of its implementation, and how these map to the TM Forum Open Digital Architecture. The NREN community can use this analysis to compare their own components and approaches with those of CARNET, and may find similarities which 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.

The Croatian Academic and Research NETwork – CARNET – is a public institution operating within the Ministry of Science and Education in the field of Information and Communication Technology and its application in education [CAN]. The CARNET network is a private network connecting both the academic, scientific and research community of the Republic of Croatia, and the primary and secondary education system institutions. CARNET also connects government sites and almost all health institutions in Croatia - hospitals, health centers, Croatian health insurance fund and others. The CARNET network covers more than 5000 locations, enabling a highly distributed community, especially when considering that this includes over 718 islands on the Croatian coast. CARNET's mission is to provide reliable information flows for both the remote online education and the exchange of health-related data.

The main activities carried out by CARNET are focused on three key areas: internet service provisioning, information society development, and education for the new era [CNW].

CARNET was founded in 1991, and was the first Internet Service Provider in Croatia. Services such as helpdesk, file storage, and online education courses were provided from the very beginning. The CARNET Computer Emergency Response Team (CERT) was also established in the early years, transforming in 2007 into the Croatian National CERT.

The CARNET network has grown constantly over the years to keep pace with increasing user demands. Today, the CARNET IP/MPLS core has 4 regional PoPs, 19 county network PoPs, and 2 data centre sites.

In order to support a high-quality education experience, CARNET not only helps education providers to broadcast courses and events online, but also instituted its own "train the trainers" (later e-Mentors) programme that is in charge of building a community of CARNET trainers. The e-learning focus started in 2004 when the CARNET education center Edupoint [AEP] decided to strategically move to online delivery. Online courses are offered via the established E-learning academy.

Starting in 2005, schools were connected to the CARNET network, and hosting services were offered to both primary and secondary schools. The schools on the islands have been connected via the e-Islands project since 2007, with CARNET providing broadband internet and video conferencing systems. This is when the CARNET Portal for Schools for teachers, students, parents, and schools was first launched. Most of the schools today use Loomen, the CARNET Content Management System (CMS) based on Moodle [PSS]. In addition, CARNET hosts a portal for the exchange of school textbooks, and has also been involved in the creation of the first Croatian online encyclopedia. Via the CERT, content filtering is also provided for more than 555,000 students in primary and secondary schools. CARNET is also responsible for the State final examination portal, first established in 2008. Today, the Edu.hr portal provides a central access point to all CARNET education services [EDU]. The latest addition to the educational services family managed by CARNET is the MOOC courses portal [MOOC].

In addition to e-education services, CARNET also provides services for the Research and Education (R&E) community such as the CARNET Cruncher service that provides its members remote access to supercomputing facilities [CNS].

In 2007 CARNET established an integrated help desk for all CARNET users by merging the Customer Support Helpdesk (previously managed by the University Computing Centre) and the Helpdesk for Customer Support for the primary/secondary education system.

CARNET is also in charge of all activities related to the Croatian top-level domain .hr, including the administration of free secondary and tertiary domains. Payable domains are registered using authorised registrars.

To help CARNET system engineers with their daily activities, CARNET provides a number of "sys" services [SYS]. This includes services such as sys.backup (for secure remote data archiving), sys.monitor (for remote web monitoring using Icinga2), and sys.virtual (a virtual provider for small organisations, managed by CARNET).

The CARNET Trusted Certificate Service (TCS) is provided via a portal and is provided to all CARNET members [CERT].

The current focus of the network and service evolution is on the continuous upgrade of e-schools services, and the deployment of a 100 Gbps network within the Croatian Science and Education Cloud (HR-ZOO) project [ZOO].

CARNET's OAV architecture analysis has been conducted using the TM Forum Open Digital Architecture (ODA) [ODA] functional blocks as a reference point. The TM Forum ODA is promoted as a blueprint for new digital industry architectures, and the rationale for its selection as a reference model by the GN4-3 WP6T2 team is given in Deliverable D6.6 *Transforming Services with Orchestration and Automation* [D6.6]. The whole set of ODA documentation provides common terminology, a minimum set of core design principles, and groups of decoupled functionalities. Together they 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 that of 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 1.1).
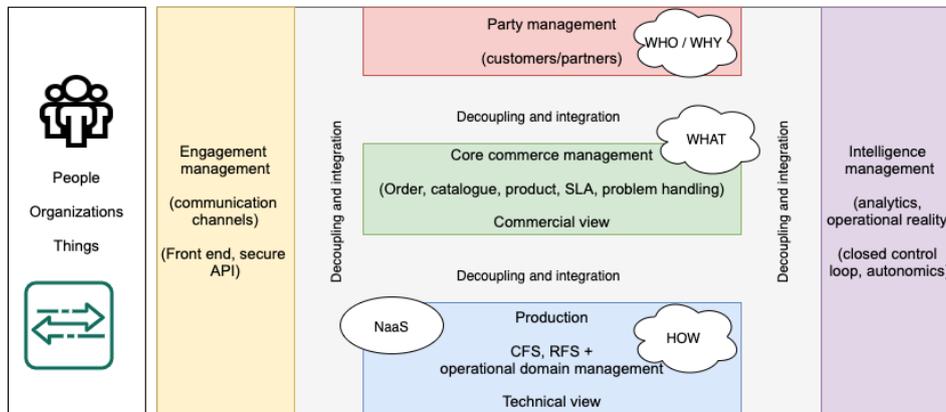
Figure 1.1: The TM Forum ODA functional architecture

In a nutshell:

- the **Engagement Management** functional block focuses on the engagement with the end-users (people and systems) that can interact via multiple channels.
- the **Party Management** functional block handles the processes that are related to all parties that interact with the organisation, and defines their roles and relationships.
- the **Intelligence Management** functional block is in charge of 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, and manages the product lifecycle.
- 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

In recent years CARNET has seen huge growth in the number of connected locations - to the point where its network now serves over 5,000 sites. This number includes many schools that need to be managed, with over 1,300 LANs, more than 8,000 LAN switches, and 35,000 Wi-Fi Access Points. However, the number of engineers available to work in this field is extremely small when considering the highly distributed scenario, and number of end-sites and devices. In addition, there is a plethora of educational services that need to be provided by CARNET on top of the network that are put into place [DMS]. As a result, CARNET as an organisation is facing scalability challenges that can only be addressed by the implementation of OAV principles.

The main principle that drives the evolution of service management in the NREN is the identification of repeatable tasks and their automation using scripting. This eliminates the need for all network engineers to acquire the expertise to handle each specific vendor equipment - which is of great interest to the NREN because its network is built using equipment sourced from multiple manufacturers.

To support this evolution, CARNET engineers have developed a Network Operations Centre (NOC) portal that provides access to a variety of NOC Tools, i.e. tools that are developed internally by CARNET or clean/adapted open source tools that are used in the day-to-day activities of the NOC engineers.

The CARNET network management goal is to use these tools to consistently:

- Configure devices / troubleshoot device configuration (device descriptions & locations, root cause analysis).
- Document changes.
- Enable straightforward configuration of devices and services for new (unskilled) engineers.

CARNET has developed LAN Cloud Management**,** an in-house network management solution for school networks (which are predominantly wireless)-. Using this solution, the network provisioning and monitoring can be done remotely, via an API. This provides a vendor-agnostic perspective to school admins, and a remote global admin access to the CARNET NOC [ESC][NMM]. The admin tools in this case include topology visualisation, network behaviour analysis, security with unified threat management, mobile device management, etc. CARNET is developing a self-care portal for school admins. This will enable efficient and proactive troubleshooting via passive and active monitoring. The main aim of the solution is to move all of the complexity into the private CARNET cloud that will provide security, centralised management, and granular visibility of each client, user, and application. The technical support for this solution will be provided using a three-tier system. The first tier is the

e-School technician, the second tier is the CARNET Helpdesk, and the third is the CARNET NOC. The e-services that will be provided include AAI@EduHR, LMS, CMS, e-Class register, CARNET fi (simplified authentication), GDPR360 (for user master data management), Mobile Device Management MDM, and Enterprise Resource Planning.

2.2 Mapping to ODA Functional Architecture

When put into context of the TM Forum ODA functional representation, the CARNET Network Management System (NMS) architecture components can be represented as in Figure 2.1. The grey boxes in the diagram represent CARNET network management system architecture components, and their placement within the ODA functional blocks is defined based on their main functionalities. If the components provide complex multifaceted functionalities, they are broken down into sub-components which are placed in the respective functional block (e.g. membership database).
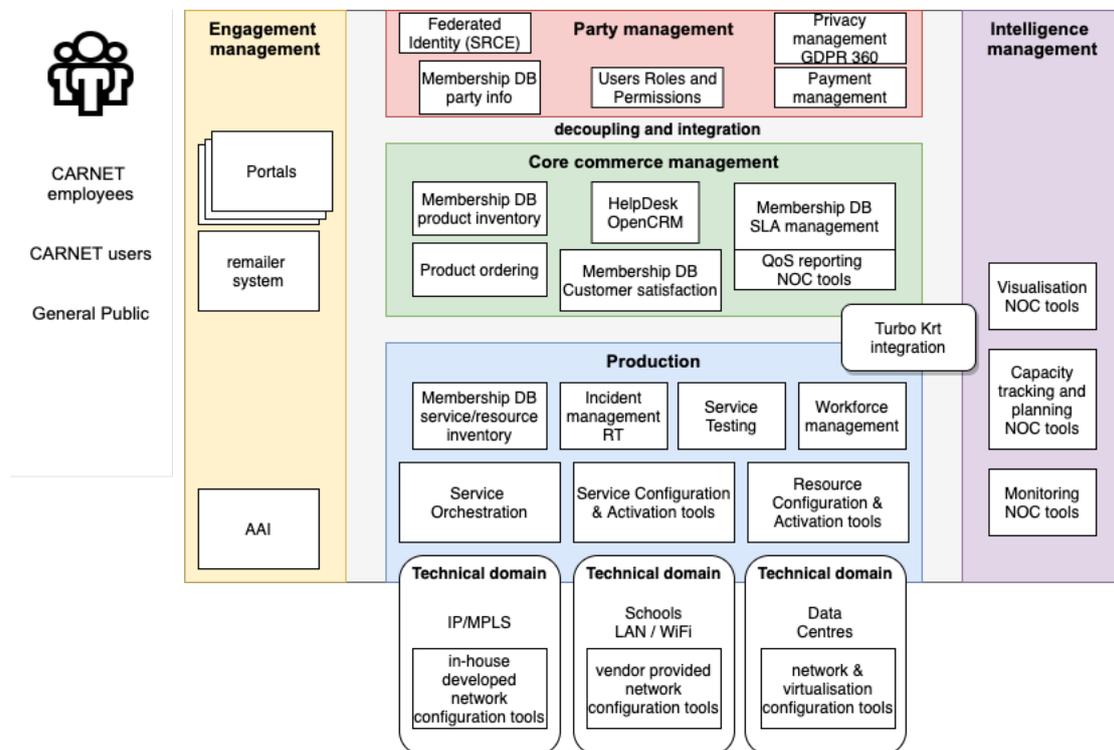
Figure 2.1: CARNET NMS components mapped to the TM Forum ODA

2.2.1 Engagement Management

A number of web portals offer access to the different services provided by CARNET. Information about most of the main services related to connectivity, internet service, training, collaboration, and security services are made available via the main CARNET web page. It then branches to different access portals depending on the service type such as https://domene.hr/, https://certifikati.carnet.hr/, https://meduza.carnet.hr/, etc. In addition to the main website, there are a number of social media channels that are used by the NREN to highlight its activities and available services.

For CARNET member institutions that have already subscribed to the main connectivity services, the Membership portal provides all institution-specific information. Through the portal, institutions can view the status of their services, order additional services, access service monitoring tools, report and track problems (by creating a problem ticket), access all agreements and service-related documentation, and provide feedback.

The schools' and school-related educational services are provided via a second set of portals including the government-supported **e-Citizens** system, on whose behalf CARNET manages the mToken application for generating one-time passwords. The educational portals that can be accessed by students, parents, teachers and schools include e-Dnevnik [DNE], Loomen [LOO], e-lektire [ELE], Skole [SKOLE], e-Laboratorij [LAB], Nikola Tesla distance learning [TESLA], CMS, Sigma, Delta, etc.

System admins and technicians in institutions that collaborate with CARNET can also access the **sys portal** that provides them with training resources, tools and services used in their daily activities.

Figure 2.2: CARNET NOC portal

For CARNET employees, a special set of management portals has been developed. The CARNET NOC portal (see Figure 2.2) acts as a gateway to all network-related management tools. The NOC portal includes links to:

- CARNET "Turbo Krt tool"
- Network Weather map
- Active/passive monitoring tools
- Vendor integration tools (ex. Cisco prime tool)
- Reporting, antiDDoS, and visualisation tools
- The trouble ticketing system
- NOC rosters and current responsibilities (people management)
- Basic overviews of current events in the core network

All portals are integrated with authentication and authorisation mechanisms (AAI), including role management to control access to services. The AAI interfaces are connected to the information about users, identities, roles, and rights that is stored in the Party Management blocks. Based on this information the portals provide a corresponding level of access to the underlying systems.

In addition to using the different available portals to order and manage active services, users can also send requests via e-mail using the remailer system component. Each mail raises a ticket in the ticketing system that can be used to track the order through to fulfilment.

2.2.2 Party Management

The main information about CARNET customers is stored in the Membership database (DB). This is accessible to CARNET employees with different levels of access rights, and to the CARNET customers, i.e. the CARNET institution members who can view and manage only the information related to them or their institution.

From a TM Forum Party Management point of view, the Membership DB (see Figure 2.3) stores information such as:

- institution name and address
- type of affiliation to CARNET
- contact person in the institution (head of office, legal office contact, technical contact)
- participation in active CARNET projects

It also stores the billing information for permanent links which is then used for payment management. The Membership DB also tracks all active CARNET projects (such as e-Islands, e-Schools, etc.), and their partners.

The level of access is managed through user roles and associated permissions. There are 14 different types of users defined (see [USR] for an example) and the CARNET web site provides information about the availability of each service to each type of user [IHA].

Federated identity in the Party management block refers to AAI@EduHR - the national federated identity provider (IdP) which is managed by the University Computing Centre, SRCE [AAI].

CARNET has also implemented the **GDPR360** solution that manages the personal data of all users to ensure GDPR compliance. This solution enables the implementation of user-based privacy management for all services the user is subscribed to. Other GDPR-related considerations are related to the overarching organisation-level knowledge base that is built within Intelligence Management.

2.2.3 Core Commerce Management

The main products offered by CARNET include network connectivity, a number of top-level services (such as hosting, communication and collaboration, and computer security), and a wide variety of digital education services. These are offered to primary and secondary schools, universities, and the general public.

Početna	Ustanove	Adrese	Osobe	NOC	Izvještaji		Odjava

[*] Damir Regvart

Ustanova:

ID	Naziv	Adresa	Mjesto	Članstvo	IP range	hostname	RT	
1187	Gimnazija Karlovac	RAKOVAC 2	47000 Karlovac		[A] 172.16.217.152 / 30 [R] 31.147.211.192 / 27 [A] 31.147.211.192 / 27	**MZOS-SS-KA-GIMKA-1** **Krt** Konf Log Zenoss Ping NetFlow Shell Serial Grafana **mCN** VizL1 Obavijest Smetnja Parametri RT → [Otvori Otvoreni Svi]	#1037	Host

Linkovi kojima je 'Gimnazija Karlovac' točka B   Prikaži neaktivne linkove | Popis ustanova | dodaj link

Naziv linka	Ustanova B	Ustanova A	Vlasnik veze	Eki	Tip veze	Brzina veze	Dat. spajanja Dat.odspajanja	
	Gimnazija Karlovac RAKOVAC 2 / 47000 Karlovac	Trgovačko-ugostiteljska škola Karlovac STJEPANA RADIĆA 8 / 47000 Karlovac	Taormina		svjetlovod (EKV)	1 Gb/s	24.06.2015	

ODF oznaka točke A/poz. niti	ODF oznaka točke B/poz. niti	ID veze	Problem prijavljuje	QoS	Username/pwd/br. priključka	Tehnologija
/11,12	/1,2	352	CARNET		//	

Kontakt osobe:

ID	Djelatnik	OIB	Titula	Funkcija	Telefon	e-mail	Napomena
1069				administrator resursa e-Dnevnik administrator	tel i fax: mobitel:		kontakt@gimnazija-karlovac.hr
10661			prof.	stručnjak za tehničku podršku	mobitel:		
11502				administrator imenika	tel i fax:		
11503				ravnatelj	fiksni: mobitel		
12412				e-Škole koordinator	mobitel: fiksni: +		

Popis bivših djelatnika

SZK DOKUMENTI za ustanovu 'Gimnazija Karlovac'   (Arhiva)

ID	Datum	Naziv	Vrsta	Ur. broj	Klasa	Dodao
12626	2019-02-23	DGU snimak – kućni broj 2	ulazni			23.02.2019 16:16
11605	2018-07-16	Imenovanje administratora imenika	ulazni			17.07.2018 14:19
11496	2018-05-28	Imenovanje administratora imenika	ulazni			29.05.2018 13:42
7943	2015-09-14	Imenovanje administratora imenika	ulazni			14.09.2015 16:02
7816	2015-06-23	Zahtjev za uključenje u e-Dnevnik sustav	ulazni			23.06.2015 16:02
6100	2013-11-29	Zahtjev za uključenje u e-Dnevnik sustav	ulazni			29.11.2013 16:21
5766	2013-08-30	Dopis - Obavijest o otkazu ADSL-a	izlazni			30.08.2013 16:36
5596	2013-06-06	Fotografije komunikacijskog ormara	ulazni			06.06.2013 15:22
5276	2013-03-19	Tehnički podaci potrebni za spajanje ustanove na CARNet mrežu	ulazni			19.03.2013 12:34
5017	2012-12-21	Zahtjev za e-Dnevnik	ulazni			23.01.2013 12:09
3925	2011-04-13	Arhiva	ulazni			13.04.2011 11:56

Broj dokumenata: 11

Projekti i usluge:

ID	Naziv projekta	ID	Naziv usluge	ID	Ostalo
6	e-Škole prijavljeni	2	e-Dnevnik		
9	Učionice budućnosti	13	Realizirana suradnja		
11	MS WiFi projekt				
23	e-Škole projekt (II. faza)				
28	4.slot - e-Škole: projektiranje				
41	4.slot - e-Škole: pasiva				
54	e-Škole Aktiva: FAZA 2				

Figure 2.3: Institution information and related links in the Membership DB

While the CARNET website acts as a product catalogue (listing all available services, as discussed in Section 2.2.1) many of the services (especially the educational ones) have their own portals. For the network connectivity services and related top-level services, the main product catalogue and inventory is the Membership DB. It lists all active services for each institution, and provides the means for each institution to order new additional services if necessary.

The Membership DB provides a general view of the health of each active service and links to the Service Level Agreements (SLAs) that define the Quality of Service (QoS) parameters for these services. It also provides links to high-level reporting on service performance, and integrates with the NOC reporting and visualisation tools.

Membership DB also provides access to the yearly customer satisfaction questionnaires that need to be filled out by each institution. Using this system, the institutions can also report problems by creating a ticket that will automatically be sent out to the first-level support help desk, which uses OpenCRM to track tickets.

2.2.4 Production

CARNET uses several components and tools to manage production services. Most of these are developed in-house, but CARNET also adapts open-source tool sets and tools provided by equipment vendors.

The main inventory information is stored in the Membership DB. This stores all basic network information, for example:

- IPv4 address space assigned to institutions
- type of network connection and speed
- network operator and contract for last mile connection
- CPE hostname

The Membership DB also helps engineers to manage more advanced network information such as IPv4 and IPv6 allocation management.

All service-related incidents are tracked in the Request Tracker ticketing system [RTS] which manages escalations to second level of alarms that originate from the help desk, and all NOC-issued alarms. The monitoring information gathered via Zenoss is used to trigger open/close incident tickets.

CARNET's NOC engineers work is scheduled using a 24/7 roster. A minimum of four NOC engineers are on duty during work hours. Two of them support the implementation of the e-schools project, while one is assigned to field work. During non-working hours and weekends, there is always at least one NOC engineer on standby for the main network services/backbone. Incident alarms are sent as SMS notifications to the engineer on duty.

In addition to the NOC team, the Network department also has:

- a team in charge of the network services, core and monitoring tools development.
- a team responsible for the procurement of access links to the CARNET networks via the telco providers.

- a specialised e-schools implementation project team that is working in the core network and the datacenters, passive LAN, active LAN, and application monitoring.

Excel sheets hosted in the cloud are used for roster management of all teams based on a two months cycle.

Most of the automation and orchestration activities in CARNET are focused on the service and resource configuration, and activation procedures. These are implemented with the help of the NOC portal management tools. The **Turbo Krt** tool plays the role of integration component, gathering and processing information from multiple components.

CARNET Turbo Krt Tool

CARNET developed an in-house tool called Turbo Krt (Turbo Digger in Croatian) to provide a high-level view of the network, and to promote fast troubleshooting (see Figure 2.4). It collects and presents all important information from different databases, and cross-compares this data with a number of active monitoring tools (Zenoss, NetFlow, syslog, network topology), and the Membership DB. It also integrates information from sources external to CARNET such as information from the power company regarding electricity outages.

Figure 2.4: CARNET NOC portal – Turbo Krt tool

Turbo Krt is also used as a search engine for hostname, IP address, and related representation information (see Figure 2.5). Turbo Krt is able to dynamically create a summary page that contains a number of shortcuts in the form of URL/API links for a more detailed NOC engineer view of a link or institution.

This detailed view provides information about the current link status, syslog information, topology, and detailed network information (such as VLAN ID, network type, and link speed). Turbo Krt is also integrated with the CARNET trouble ticketing system. In the detailed institution view, all links to other tools are auto-generated so that engineers do not have to search for links/institutions in other tools while troubleshooting.
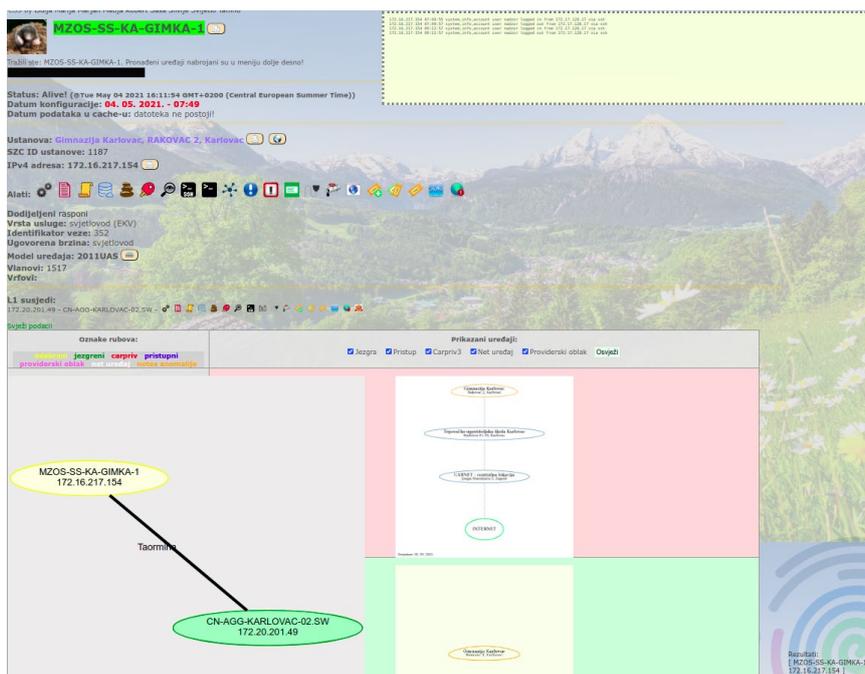
Figure 2.5: Turbo Krt detailed view

Service Orchestration

Within the CARNET NOC, special attention is given to the automation and orchestration [TNC] of several important actions including:

- Implementation of the antiDDoS service – the service blackholes' destination address for a specified time span, based on a set of triggers such as NetFlow analysis results, link thresholds, predictive thresholds, and triggers from antiDDoS boxes.
- VRF creation – auto-generation of configuration changes that can then be applied via MegaConf (another NOC tool) or manually.
- QoS management – auto-generation of configuration changes that can be applied via MegaConf or manually. The automated configuration of QoS is based on the time of the day (e.g. limiting system backup services during daytime).

Other examples of service orchestration implementation include the management of wireless and wired LANs in the schools using APIs. This effort is work in progress, and is part of the latest project for e-schools that is currently being rolled out [ICTS].

2.2.5 Technical Domains

CARNET's operational domain can be divided into three broad technical domains that focus on different aspects of the NREN's activities:

- **IP/MPLS in the core network** – this technical domain is the main focus of the CARNET NOC team, and, for the management of the specific activities for this domain, mostly in-house network configuration tools are used in combination with available open-source software tools. For the purposes of configuration creation and active configuration change, CARNET is

using in-house developed tools (such as MegaConf, MegaTool, MultiTK, MultiTO) that utilise Netconf/SSH or API management:

- ○ MegaCONF – global configuration change for a large set of devices.
- ○ MegaTool – for execution of certain actions on groups of the devices (such as getting NMAP information, grabbing telco provider IDs), checking IP interface status, etc.
- ○ MultiTK – a specialised provisioning tool for Mikrotik equipment.
- ○ MultiTO – "Multi ticket opener" – changes are tracked using the trouble ticketing system in CARNET, so this tool enables changes that affect many ticket instances at once. For example, the change of a last mile telco operator in a single area can affect 100 schools in that area. With this tool, 1 click equals 100 solved changes.

- **Schools LAN and WiFi for the e-schools connectivity and services** – for the purposes of management of the wired and wireless networks within the primary and secondary schools, a set of vendor-provided tools are used [ICT]. These include Cisco (Meraki and Cisco Prime), Fortinet devices (Fortimanager), and Aruba Airwave.

- **Datacentres** – The virtualisation layer in the CARNET data centres is implemented using OKD which is a distribution of Kubernetes that is optimised for continuous application development and for multi-tenant deployments [OKD]. OKD is actually an open-source version of RedHat's OpenShift. This is a Platform-As-Service solution where Docker containers are orchestrated using Kubernetes. The communication between pods is done by establishing a pod network which is configured using OpenShift SDN. For automation purposes, Ansible playbooks are used to define the cloud-hosted infrastructure, and to apply any post-provisioning configuration. Good automation and orchestration practices are of great importance for this technical domain due to the lack of resources, and the continuously growing demand for services (mostly regarding the e-schools projects).

2.2.6 Intelligence Management

Within the Intelligence Management functional block there are a number of CARNET components that focus on gathering different types of information from multiple sources and visualising it using customised visualisation tools.

These tools include:

- Monitoring with Zenoss (SNMP, alarm trigger, performance, link/interface threshold)
- Netflow information (NFSEN)
- Network weather map
- Grafana with Influx DB integration for performance management

A number of different performance-reporting tools are used for capacity tracking and planning, where the focus is on identifying both under-utilisation and over-utilisation of links.

CARNET has developed a predictive, threshold-based system for link monitoring. If the institution or backbone link is utilising more bandwidth than a learned baseline, an alarm is shown in the NOC console).

In the e-schools realm, the CARNET Delta service focuses on learning analytics and educational data mining [DELTA] [CDE]. The goal of this service is to improve the decision-making and policy-making processes by supporting the CARNET NOC with relevant information, as well as improve overall learning outcomes. The learning analytics architecture is designed to store logs from all e-school-related services in an Oracle-based data lake (centralised repositories that store structured and unstructured data at any scale). The data lake is then accessed by an enterprise data warehouse system that performs business intelligence (DW/BI). The results from the analytics are presented through the service portal. In the future development of the e-schools project, the service will be augmented with machine learning and related artificial intelligence algorithms for deep insight analytics and predictions.

3 Conclusions

CARNET provides a large number of services, and manages related requirements from its vast community of users. Network users demand an efficient and effective approach to service management that can scale easily.

Having faced a rapid growth in locations and traffic, CARNET has leaned heavily on automation and orchestration opportunities to be able to produce solutions that are highly reliable and scalable in times of great demand. CARNET engineers have embraced the golden rule of automation - by focusing on automating repetitive daily tasks, engineers become more efficient, freeing them up to focus on more complex issues.

The analysis of the components used for service management in all ODA functional blocks show that, for most of the network and service management activities, CARNET has decided to either use a large set of tools developed in-house or customise existing open-source solutions. The main component that provides functionalities across several ODA functional domains is the **Membership DB** which is the heart of the system. **Turbo Krt** is the main integration tool that provides collated information, and exports context information to a number of monitoring and troubleshooting tools.

The OKD solution for hosting services provides an agile platform for rapid application development - while the network devices' automated configuration scripts are accelerating the process of network management in the backbone and school LANs. The implementation of the **e-schools** project is founded on the main OAV principles as a means to achieve nationwide scalability and transform the Croatian Research and Education landscape into a fully digital platform.

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Glossary

AAI	Authentication and Authorisation Infrastructure
API	Application Programming Interface
BI	Business Intelligence
CERT	Computer Emergency Response Team
CLI	Command Line Interface
CMS	Content Management System
CPE	Customer Premise Equipment
DB	Database
DDoS	Dynamic Denial of Service
DNS	Domain Name System
DW	Data Warehouse
GDPR	General Data Protection Regulation
IdP	Identity Provider
IP	Internet Protocol
IX	Internet Exchange
LAN	Local Area Network
LMS	Learning Management System
MDM	Mobile Device Management
ML	Machine Learning
MOOC	Massive Open Online Courses
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
PoP	Point of Presence
QoS	Quality of Service
SDN	Software Defined Network
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SMS	Short Message Service
SNMP	Simple Network Management Protocol
SSH	Secure Shell
R&E	Research and Education
TCS	Trusted Certificate Service
URL	Uniform Resource Locator
VLAN	Virtual LAN

VLE	Virtual Learning Environment
VRF	Virtual Routing and Forwarding
VoIP	Voice over IP
WP	Work Package