Distributed Artificial Intelligence-driven open and programmable architecture for 6G networks

D5.2 Reports on integration and testbeds deployment in lab settings - Final

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Glossary of terms and abbreviations

Abbreviation / Term	Description
5GQI	5G QoS Identifier
AI	Artificial Intelligence
BDIx	Belief-Desire-Intention intelligent agents eXtended with ML capabilities
CLI	Command Line Interface
CSH	Computing and Storage Hub
CSP	Computing and Storage Powerhouse
CU	Control Unit
DU	Distributed Unit
E2E	End-to-End
eMBB	Enhanced Mobile BroadBand
GA	Grant Agreement
GEO	Geostationary
gNB	gNodeB
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet Protocol
KPI	Key Performance Indicator
KVI	Key Value Indicator
LEO	Low Earth Orbit
MANO	Management and Orchestration
MEC	Multi-Access Edge Computing
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
mMTC	Massive Machine-Type Communication
NSA	Non-Standalone
NTN	Non-Terrestrial Network

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O-RAN	OpenRAN
OVPN	OpenVPN
PoC	Proof-of-Concept
QoS	Quality of Service
rApp	Non-real time network automation
RAN	Radio Access Network
RIC	RAN Intelligent Controller
SA	Standalone
SDN	Software-Defined Networking
SLA	Service Level Agreement
SMO	Service Management & Orchestration
SNR	Signal Noise Ration
SSH	Secure Shell
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TN	Terrestrial Network
TSDB	TimeScale DataBase
UE	User Equipment
UE-VBS	UE-Virtual Base Station
URLLC	Ultra Reliable Low Latency Communication
VM	Virtual Machine
VPN	Virtual Private Network
WP	Work Package
XR	eXtended Reality

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Executive Summary

The final stage of the ADROIT6G project aims at integrating and validating the functionality and novel contributions of ADROIT6G framework, which are integrated within distinct Proof-of-Concepts (PoCs) experimentation. Three PoC implementations have continued to drive innovation: (i) holographic teaching, (ii) Industrial IoT leveraging TN or NTN, and (iii) collaborative robotics. Each PoC has progressed through testing and validation using an iterative methodology. Testing Cycle 1 focused on validating inter-block interactions and assessing preliminary Key Performance Indicators (KPIs). Testing Cycle 2 is actively underway, aimed at quantifying improvements in KPIs and KVIs compared to state-of-the-art, making use of the fully integrated ADROIT6G stack in coordination with each respective PoC application.

In this context, significant efforts towards integrating the ADROIT6G components within the architecture, with PoC applications and with respective testbed environments have been made. As after initial dry-runs in *Testing Cycle 1* ADROIT6G components addressed arising issues, component requirements also changed, along with intra-component interfaces and component-to-testbed interfaces. As a result, testbed environments have been upgraded to fit updated component requirements and component APIs have been adapted and extended to interact with a wider range of components and newer releases.

This deliverable outlines the status of all claimed integration activities, planned in the initial version of this deliverable (D5.1) for future PoC experimentation, as well as provides an update on testbed environments setup within *Testing Cycle 2*. It specifically focuses on addressing identified gaps and describing new integrations, interfaces, and improvements since the initial version. Section 2 iterates through four testbed environments and concisely outlines hardware, software and remote access changes made after *Testing Cycle 1* closure, followed by addressing other gaps identified in the initial WP5 phase. Section 3 presents integration efforts made for each PoC: initial integration, outlined in the previous version of this deliverable, is updated with deployment status and references to the intra-component API specification; additional integration is outlined as well as final deployment conceptual figures are provided per PoC.

This final deliverable version marks full readiness of component integration and testbed preparation for *Testing Cycle 2* KPI/KVI measurements and PoC testing. It sets the stage for future experimentation planning and final measurements, provided in the final deliverables of WP5 – D5.4 and D5.6, respectively.

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1 Introduction

ADROIT6G aims to validate and assess the readiness of its components within distinct Proof-of-Concepts (PoCs) of representative use cases: (i) holographic telepresence, (ii) Industrial IoT over TN or NTN, and (iii) collaborative robots. The integration, execution, and validation of the aforementioned PoCs will follow two sequential and iterative cycles of testing that are expected to facilitate the usage of the required ADROIT6G's components.

This deliverable serves as an iteration of the previous D5.1, placing particular emphasis on newly completed integration activities, enhanced interfaces, and the targeted closure of gaps identified in D5.1 and during the execution of *Testing Cycle 1*. It documents recent outcomes related to the deployment and advancement of testbed environments, improved integration of ADROIT6G components within these testbeds, and the evolution of PoC implementations. By incorporating lessons learned and addressing previously recognized challenges, this deliverable lays a stronger foundation for subsequent WP5 validation activities, ensuring greater cohesion and technical readiness of ADROIT6G components within the selected PoCs and testbeds.

This section introduces how the work presented in this final deliverable fits with the tasks of Work Package 5, Integration & Validation, and the project as a whole. The mapping of the tasks defined in the Grant Agreement (GA) of the project with the Sections of the deliverable is presented in Section 1.1. A recapitulation of the description and justification for mapping is provided for task T5.1. Section 1.2 covers the scope of the work presented in relation to the complete ADROIT6G architecture, as well as the objectives of the project.

1.1 Mapping ADROIT6G Outputs

This section presents the ADROIT6G's Grand Agreement (GA) commitments, as extracted from the formal deliverable and task description, with respect to their outputs and work to be performed, as described in Table 1.

Table 1: Adherence to ADROIT6G's GA Deliverable & Tasks Descriptions

ADROIT6G GA Component Title	ADROIT6G GA Component Outline	Respective Document Chapter(s)	Justification
DELIVERABLE			
D5.2: Reports on integration and testbeds deployment in lab settings – Final This deliverable reports on ADROIT6G components integration and testbeds deployment.			
TASKS			

Task 5.1: System integration and testbeds deployment	This task sets up the integration guidelines, coordinates and performs the actual integration and interconnecting of the developed architectural elements into a unified system, sets up the testbed environments including the relevant use case components (i.e., devices, emulators, simulators) and conducts dry-run testing to ensure the technical readiness of the ADROIT6G system as a whole prior to technology validation in the lab. A code repository including capabilities for continuous development will be provided. Testbeds for demonstrators or cross-partner developments are defined and integration tests are planned, specified, and performed. The testbed providers (ORO, EURE, ATH, EBOS, SIEMENS) will setup the data centre islands of their testbeds to host the various ADROIT6G elements. RAN emulators will be used to emulate the access part of the network. SIEMENS, CYENS and CAFA will develop appropriate emulators and traffic simulators to emulate in real time the different traffic conditions relevant to each use case application mimicking real-life scenarios. An open dataset will be produced that will include the values of SNR, modulation & coding scheme, traffic load, latency, packet error rate, and number of allocated radio resources at the vRAN; this dataset will be used to train the AI/ML models. (Output: D5.1, D5.2).	Section 2 & Section 3	This deliverable provides the final setup of the four testbeds used in ADROIT6G Testing Cycle 2 experimentation, including details about their hardware / software / remote access updates as well as gap elimination with respect to the PoC requirements and ADROIT6G system. Moreover, it provides a complete picture of all integration efforts carried out per PoC - intra-component integration, component-to-testbed integration and any other API extension necessary to ensure seamless ADROIT6G architecture deployment and validation in each PoC.

1.2 Deliverable Overview and Report Structure

1.2.1 Deliverable Scope

Table 2: Overview of PoCs and Testbed Facilities

PoC #	Title		Target testbed provider for Testing Cycle 1	Target testbed provider for Testing Cycle 2
PoC.1	Holographic Teaching (Immersive XR)		EBOS	ISI/ATH
PoC.2	Industrial IoT	2a Terrestrial 6G IIoT	EURE	EURE
		2b Rail Automation supported by NTNs	SIEMENS	SIEMENS
PoC.3	Collaborative Construction Robots (cobots)		ORO	ORO

Each PoC will deploy a layered testing practice to drive development, involving significant representative tests, verifications, and validations: *(i)* tests using specific use cases oriented for covering all service classes of specific vertical industries that are expected to be served by 6G technologies, and *(ii)* test, measurements, validation, and demonstration of the PoCs in lab settings. Continuous improvements will be achieved through feedback from PoC rollouts, providing the basis for information sharing, operation, learning and improvement, as shown in Figure 1-1.

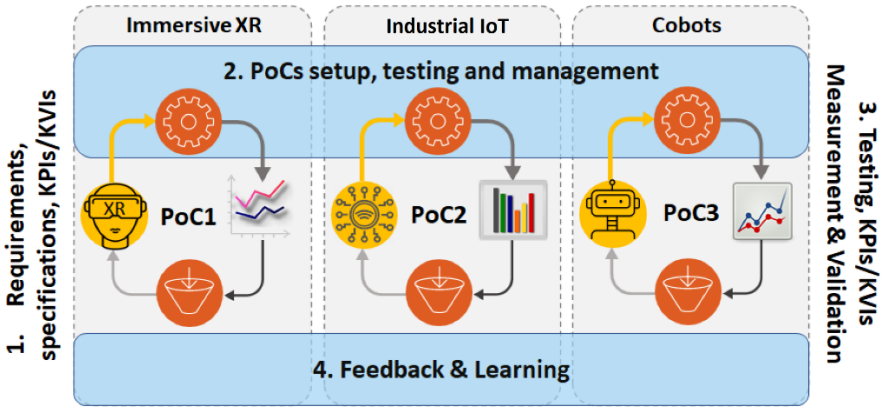

Figure 1-1: Integrated Testing and Evaluation Approach

This deliverable targets the first and (partially) second steps with the initial establishment and extension plans of the testbeds as well as a detailed specification of the PoCs. The remaining document is structured as follows:

- Section 2 provides a concise update on testbed environments, necessary after Testing Cycle 1 finalization.
- Section 3 presents per-PoC integration efforts, including both intra-component and component-to-testbed interfaces.
- Section 4 draws the main conclusions and analyses if all the aspects of planned efforts have been addressed to ensure successful Testing Cycle 2 run.

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1.2.2 Related ADROIT6G project objectives

The work presented directly contributes to the Project Technical Objectives given in Table 3.

Table 3: Project Objectives Related to the Work Presented in the Deliverable

Project Objective	Description
TO9	Integrate and demonstrate the potential and user value of ADROIT6G through relevant experimentation, testing, and validation of its innovations in PoCs in lab settings.

Table 4 provides a summary of the linkage to other project outputs, specific deliverables, and their respective contributions.

Table 4: Links to Other Project's Outputs / Work

WP #	Task #	Deliverable No related	Content
WP2	T2.1 & T2.2	D2.1 / D2.2/ D2.3	Analysis of the functional requirements from the use cases perspectives (including the definition of relevant KPIs and KVIs to be validated). Overall ADROIT6G architecture design, and identification the PoCs narrowed down from the representative use cases, and their final definition. Identification of ADROIT6G interfaces, including those for inter-component.
WP3	ALL	D3.2 / D3.3	Software and AI algorithmic components of ADROIT6G implementing energy efficient automated AI orchestration, multimodal generative models for scalable monitoring and secure data distribution, CrowdSourcing AI and AI algorithms for joint resource management.
WP4	ALL	D4.1 / D4.2	Software and algorithms for inter-domain slice and resource management with UE-VBS and non-terrestrial networks, multi-scale scale strategies for distributed closed loop automation, AI models, BDIx features selection and open, programmable data plane for multi-X domains.

1.2.3 Overview of the ADROIT6G Technological Components

The architecture overview of ADROIT6G is depicted in Figure 1-2. It comprises three main elements the AI-driven Management and Orchestration Framework, the Fully distributed and secure AI/ML Framework for CrowdSourcing AI Framework, the BDI- & AI-driven Unified & Open Control Operations Framework:

1. The AI-driven Management and Orchestration Framework implements the logic for the end-to-end, automated management of the inter-computing and inter-domain network infrastructure.

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It is pivotal for managing distributed applications and services across various infrastructures, extending from traditional cloud environments to the heterogeneous edge and the far edge/device layer.

2. The Fully distributed and secure AI/ML Framework for CrowdSourcing AI provides the AI mechanisms to assist the M&O and the control frameworks in their decisions. It represents a novel and forward-thinking approach to enhancing network operations, management, and service delivery using Artificial Intelligence (AI) and Machine Learning (ML).
3. The BDI- & AI-driven Unified & Open Control Operations Framework is responsible for the real-time and near-real-time close loops for the network automation. It coordinates the dynamic and inter-domain resource allocation in the short term, based on the current network condition and context-aware predictions.

From the technological domains point of view, the ADROIT6G architecture is expanded from the far-edge, edge, and towards the cloud domains:

1. The far-edge domain in the ADROIT6G framework refers to the outermost layer of the network infrastructure, focusing on the computing resources at the device level.
2. The edge domain in the ADROIT6G framework refers to the outermost layer of the network infrastructure, located at the edge of the network, near the end-user devices. This domain is also extended with computing capabilities on-board of satellites.
3. The cloud domain that allows the dynamic allocation of resources, while also ensures automate network operations.

More details about the ADROIT6G Network architecture can be found in previous deliverables of WP2, WP3, and WP4.

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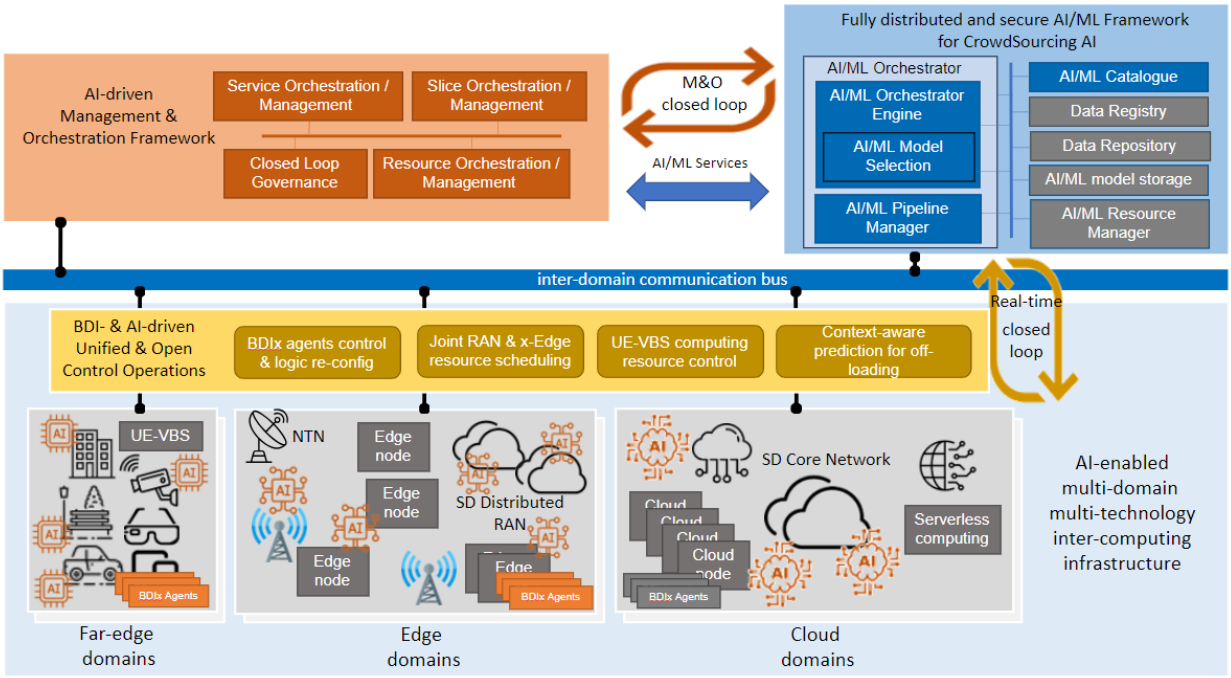

Figure 1-2: Overview of the ADROIT6G Network Architecture [D2.3]

2 Testbed Environments for the PoC Validation

Four testbed environments, partaking in the Testing Cycle 2, aim to validate innovations of ADROIT6G architecture, as well as bring four distinct PoC applications to benefit from the ADROIT6G deployment. Below, the final state updates, triggered by ADROIT6G component improvement, on the four established 5G testbeds are described. Specifically, testbed overview is reiterated, followed by software/hardware/remote access updates and technological gaps addressed specifically for each testbed-assigned PoC (see Table 2).

2.1 ISI/ATH Testbed Facility

2.1.1 Testbed Overview

The ISI Testbed, located in Patras, Greece, is managed by the Industrial Systems Institute (ISI) of the Athena Research Center. The facility provides an end-to-end Private 5G infrastructure with a cognitive compute continuum enabler combining Open Gateway Initiative standards with AI-driven orchestration for automated service deployment and resource management. The infrastructure comprises 4 physical servers (Intel Xeon/AMD Threadripper) with 112/224 cores, 704GB RAM, and 6 GPUs (2x H100, 3x RTX 6000 Ada, 1x RTX 4500 Ada) providing 328GB VRAM, 10.6TB NVMe storage, interconnected via a 100Gbps NVIDIA Spectrum-2 switch, plus edge nodes (x86 mini PCs, ARM Raspberry Pis).

Radio capabilities include two Amarisoft Callbox gNBs (Mini: 5G SA, 200/75 Mbps; Advanced: 5G SA/NSA, 3/2 Gbps) with UEs including smartphones, industrial CPE, and Raspberry Pi 4 devices with 5G HATs. The infrastructure uses IaC and GitOps principles (Ansible, Terraform, K3s), with each domain modeled as a K3s cluster. It integrates the SUNRISE-6G Operator Platform with CAMARA-compliant APIs for standardized network services and federated orchestration across partner testbeds, supporting network slicing, QoS management, and cognitive continuum orchestration with AI/ML-driven resource optimization.

2.1.2 Testbed Updates: Remote Access, Hardware and Software modifications

Hardware upgrades include the addition of a new physical server expanding compute capacity, two NVIDIA H100 GPUs providing enhanced AI/ML acceleration, and O-RAN-compliant CUs/DUs from Allbesmart integrated with Ericsson Radio Dot System, enabling disaggregated RAN architectures. Additional edge computing nodes (mini PCs and Raspberry Pi 4 devices) were deployed to strengthen the edge tier. Remote access operates through the GÉANT backbone with MD-VPN service and SSH access for partners. VPN integration via WireGuard/Headscale has been implemented for secure, identity-based networking. Security implements OAuth2 and JWT-based authentication with zero-trust principles.

Software enhancements include deployment of Open5GS Core alongside Amarisoft 5GC for flexible 5G core configurations, SUNRISE-6G Operator Platform integration with CAMARA-compliant APIs (QoS, latency, location, traffic influence), network slicing support with differentiated QoS profiles, enhanced Cognitive Continuum orchestration with AI/ML-driven Local Decision Agents (Deep Reinforcement

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Learning, Workload Prediction) for autonomous resource allocation, consolidated observability stack (Prometheus, Grafana, Jaeger, Kiali) with PostgreSQL telemetry storage, and MLOps deployment with MLflow, KServe, and NVIDIA Triton supporting TensorFlow, PyTorch, and ONNX for cloud and edge inference.

2.1.3 Gap Addressing of the PoC Requirements and/or ADROIT6G Platform

Gap 1: MLOps Stack deployment – in the initial phase of WP5 Testing Cycle 1, the ISI/ATH testbed lacked a fully deployed and operational MLOps environment to support the execution, lifecycle management, and federation of AI/ML workflows required by ADROIT6G AI-driven orchestration. During Testing Cycle 2, this gap has been fully addressed by deploying and integrating the global MLOps stack of the AI Federation Plane.

The deployment consists of two main functional components:

- **Model Registry & Artifact Management**, supporting versioning, secure storage, and retrieval of models and assets.
- **Model Experimentation & Serving**, enabling tracking, automated training workflows, and inference execution across cloud-edge environments.

The completed stack includes:

- **Argo Workflows** for workflow automation and distributed pipeline execution.
- **MLflow** for experiment tracking and model registry operations.
- **MinIO** as a unified storage backend for workflows and model artefacts.
- **Prometheus / Thanos** providing federated telemetry monitoring and analytics from testbed clusters.
- **KServe** for deployment and real-time serving of predictive and generative ML models at edge and cloud domains.

APIs enabling the federation of global and local stacks include commands for:

(i) Model retrieval and experiment intent submission
(ii) Dataset access
(iii) Inference execution

The stack now supports two operational user roles: Experimenters and Model Designers, ensuring streamlined onboarding, execution, and lifecycle automation of AI assets.

This enhancement enables:

- zero-touch AI/ML lifecycle governance

- cross-testbed model sharing and execution
- interoperability with Closed-Loop Governance policies
- seamless integration with PoC-1 holographic processing and PoC-2/3 models where required

The MLOps platform has been integrated into the ISI/ATH testbed 5G infrastructure, marking the successful closure of Gap 1 and ensuring readiness for KPI/KVI evaluation activities in Testing Cycle 2.

Figure 2-1: Example Deployment of an Argo Workflow

Gap 2: Lack of Edge Computing Validation Framework – in the initial phase of WP5 Testing Cycle 1, the ISI/ATH testbed did not provide a standardized validation environment to assess the execution and KPI performance of PoC-related workloads across the compute continuum. During Testing Cycle 2, this gap has been addressed with the deployment of an Edge Computing Validation Framework based on µBench. The validation framework enables automated execution and performance benchmarking of synthetic workloads. The framework integrates seamlessly with the consolidated observability stack — Prometheus, Grafana, Jaeger and Kiali — supporting real-time metrics collection, distributed tracing, and KPI aggregation to evaluate compute placement decisions under realistic traffic and load conditions.

This enhancement enables:

- objective measurement of latency, throughput, and resource-utilization KPIs
- repeatable benchmarking across edge and cloud execution environments
- dataset generation and closed-loop orchestration validation
- representative evaluation of workloads under multi-tier deployment

The edge validation platform is now integrated into the ISI/ATH 5G infrastructure, marking the successful closure of Gap 2 and ensuring readiness for KPI/KVI evaluation activities in Testing Cycle 2.

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2.2 EURE Testbed Facility

2.2.1 Testbed Overview

The EURE testbed, located at the SophiaTech Campus (EURE), is an advanced multi-x 5G/O-RAN facility that combines open-source (OAI) and commercial 5G components to support PoC-2a (Terrestrial 6G IIoT). It includes 5G SA Rel.16 RAN and Core, an ETSI MANO/O-RAN SMO stack in the form of K8s operators, and a full O-RAN RIC environment (near-RT and non-RT) for running xApps/rApps. The hardware side consists of 8 servers, O-RAN-compliant 7.2 RUs, an eCPRI split-8 RRH, n78 small cells (4x4 MIMO, 100 MHz), and a fronthaul switch with PTP support, enabling CU/DU/RU split deployments and vendor-agnostic experiments.

2.2.2 Testbed Updates: Remote Access, Hardware and Software modifications

Within ADROIT6G, the EURE setup has been consolidated as a “multi-RAN / multi-CN / multi-RU” playground and tightly coupled with the Trirematics SMO/non-RT RIC so that partners can automate E2E network-service deployments on Kubernetes. A unified data-lake (TSDB) with Grafana visualisation, plus an Nvidia GPU (≥32 GB) inside the SMO, was added to support AI/ML-driven xApps/rApps and online learning over real RAN metrics. Remote access is not enabled by default for security/operational reasons, but the testbed can expose a public IP or VPN endpoint on demand if partners need to run or validate PoC-2a components remotely.

2.2.3 Gap Addressing of the PoC Requirements and/or ADROIT6G Platform

Gap 1: Network infrastructure – Original gap: the PoC-2a networking details (number of functions, traffic patterns, KPIs to collect, scale of IIoT devices) were not yet instantiated on the EURE testbed. How we address it: we finalised the PoC-2a-specific topology on top of the existing multi-x infrastructure (8 servers + multi-RU + CU/DU splits) and aligned it with the traffic/KPI requirements from the use-case leaders. This turns the generic EURE 5G/O-RAN lab into a PoC-ready, high-capacity, time-synchronised testbed able to emulate large-scale IIoT and collect the required network-level KPIs.

Gap 2: xApp and rApp Development – Original gap: the PoC-oriented xApps/rApps were missing from the EURE testbed. How we address it: we develop and integrate PoC-2a-specific xApps (near-RT) and rApps (non-RT) on top of FlexRIC/SMO, using the testbed’s monitoring/data-lake and the on-board GPU to run more sophisticated AI/ML pipelines (policy enforcement, PRB/utilisation control, dynamic TDD, energy-aware optimisation). We also provide API/documentation sessions so partners can plug in their own apps.

Gap 3: Remote Accessibility – Original gap: no remote connection to the EURE testbed was available. How we address it: for now, local/on-site access is sufficient for PoC-2a integration, but, if partners require it, we can expose the cluster via a public IP or VPN with appropriate security rules to enable remote development, testing and data collection. This keeps the platform protected while still offering

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on-demand remote accessibility.

2.3 SIEMENS NTN Testbed Facility

2.3.1 Testbed Overview

The “Non-Terrestrial Networks and Non-Terrestrial Edge-Cloud Systems” (hereinafter referred as NTN testbed) facilitates the simulation and emulation of complex Non-Terrestrial Networks (NTNs), particularly satellite networks and satellite computing environments. To do so, it offers a hybrid compute and communication setup on mobile components, such as satellites and various application nodes, including industrial sites, trains, drones, and robots. Satellite connectivity is emulated to test conditions such as visibility, movement, delays, and packet losses. Real-world devices can work in conjunction with virtual devices (e.g. traffic-generating devices) to achieve high device density. In turn, the Satellite Computing layer is composed of containers or VMs on end-user devices and satellites, supported by industrial and open-source applications and monitoring tools.

The NTN testbed consists of several components: Emulation Software (e.g., satellite topologies, including their link and mobility models; as well as computing platform) and Hardware (e.g. access to real-world satellite systems), a Monitoring suite and Resource Orchestrator APIs for applications to be configured. A detailed description of the testbed has been provided in D5.1 [1].

2.3.2 Testbed Updates: Hardware / Software modifications and Remote Access

The hardware setup of the testbed has been updated a more powerful server blade, which is used for several purposes:

- it hosts the VMs to be used by the PoC-related partners, ensuring that these VMs have access the required computational resources and improved performance to host the ADROIT6G components.
- the increased capacity of the new server blade allows for the deployment of higher density network topologies. Namely, it supports scenarios in which every node within the network possesses its own dedicated computing resources. For example, this additional capacity was leveraged to extend the Kubernetes clusters used across different parts of the Proof of Concept (PoC), enabling more complex service orchestration and scaling.

In addition to the hardware improvements, software modifications were implemented, including updates to the NTN emulation platform with the latest developments, as well as upgrading the versions of the hypervisor and management tools. The NTN testbed APIs (including its internal Resource Orchestrator) were also extended in order to cope with existing and newer workflows required for the ADROIT6G platform integration in this PoC.

Furthermore, remote access processes have been enhanced, due to newer internal testbed policies:

1. remote connectivity for authorized users is facilitated through the OpenZiti solution, which is

an open-source zero trust networking platform designed to securely connect applications over any network by creating private, programmable, end-to-end encrypted connections that eliminate the need for traditional VPNs.

2. a dedicated sandbox environments have been created, enabling more flexibility for PoC partners to deploy and test their ADROIT6G components in isolation within the testbed. These sandboxes remain fully integrated with both the testbed and PoC-specific APIs, ensuring seamless interaction and data exchange.

Overall, these upgrades aimed at increasing the flexibility of collaborative development while maintaining a strong focus on security and operational reliability. A schematic diagram of the ADROIT6G environment within the NTN testbed is presented in Figure 2-2 (note that for security reasons, some connection details are omitted).

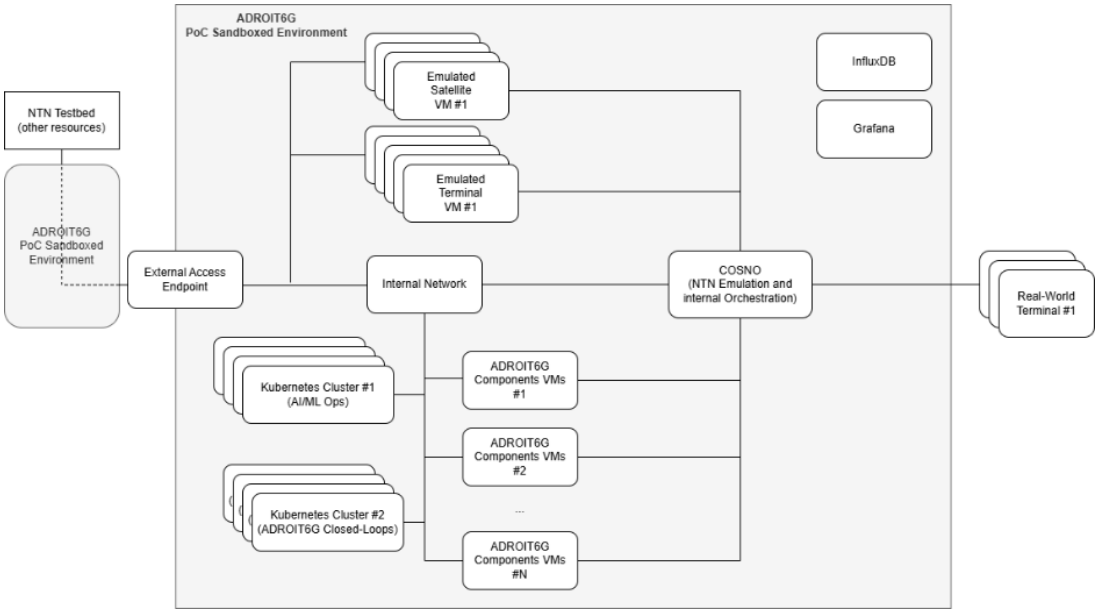

Figure 2-2: ADROIT6G PoC Sandboxed Environment overview within the NTN Testbed

2.3.3 Gap Addressing of the PoC Requirements and/or ADROIT6G Platform

Gap 1: Missing application migration API – the migration API has been developed within the testbed-local Resource Orchestration. This new API supports not only the migration of applications across different nodes or environments, but also handles the end-to-end lifecycle of applications, including automated instantiation and clean-up processes.

Gap 2: Mobile external devices adaptation – BDIx Agents have been successfully containerized, as a result, physical UEs are not required anymore and instead will be emulated within the NTN testbed. The Emulation framework ensures service quality settings and represents the real connection of a UE, thus not impacting the PoC measurements.

2.4 ORO Testbed Facility

2.4.1 Testbed Overview

The ORO Testbed is built on Orange Romania's 5G Laboratory infrastructure, distributed across Bucharest and Iasi Data Centers. It supports advanced 5G-enabled research and is the primary facility for the ADROIT6G PoC-3 use case (Collaborative Construction Robots). The Bucharest lab features a full 5G Standalone (SA) setup, including 5G RAN, Core, Edge Computing, and advanced Software Defined Networking (SDN). The Iasi lab hosts 5G SA RAN components. Both labs provide a comprehensive set of APIs for integration with upper-layer ADROIT6G components.

The ORO 5G Labs architecture is based on a virtualized network infrastructure supporting both NSA and SA 5G options. The RAN follows 3GPP Option 2, with gNBs connected to the 5G Core, supporting network slicing and differentiated QoS. The Bucharest lab uses general-purpose hardware for RAN, with commercial and open-source components, and includes an anechoic cage for high-demand testing. The transport network is split into three components: Bucharest and Iasi testbed networks, and E2E service configuration agents. Edge computing resources are shared between labs, with 25 servers providing significant compute, storage, and GPU resources.

Features, Capabilities, Services, and Innovations:

- **Network Slicing:** Supports multiple network slices (eMBB, URLLC) using 3GPP NSSAI parameters, with differentiated QoS and user profiles.
- **QoS Management:** Implements 3GPP 5GQI mapping for end-to-end service quality.
- **Virtualization:** Extensive use of OpenStack, Docker, Kubernetes, and OSM for flexible deployment of VNFs and applications.
- **Monitoring:** Advanced monitoring with Prometheus and Grafana for infrastructure, network, and device metrics, including energy consumption.
- **APIs:** Provides APIs for monitoring, slice management, orchestration, and big data analytics.
- **Performance:** High throughput (up to 1.6 Gbps DL), low latency (sub-4ms for URLLC), and support for a wide range of 5G devices and industrial routers.
- **Security:** Integrated security infrastructure with VPN support for remote access and inter-testbed connectivity.

The ORO Testbed is a state-of-the-art, virtualized, and highly programmable 5G research facility, supporting advanced network slicing, orchestration, monitoring, and integration with ADROIT6G innovations. It is well-equipped for validating demanding 6G use cases, particularly those requiring extreme URLLC and mMTC capabilities.

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2.4.2 Testbed Updates: Remote Access, Hardware and Software modifications

Recent updates to the ORO Testbed have significantly enhanced its capabilities, particularly in terms of remote accessibility and hardware resources. A secure VPN remote access system already in place has been updated and implemented, enabling research partners to connect to the testbed infrastructure from remote locations. This improvement facilitates collaborative experimentation and development, allowing partners to access, configure, and monitor testbed resources in real time, regardless of their physical location.

On the hardware front, the testbed now includes two high-performance servers equipped with NVIDIA L40 GPUs (48GB each), providing substantial computational power for AI-driven network functions and data-intensive 6G research. Additionally, the integration of one mmWave gNodeB and one standard gNodeB expands the testbed's radio access capabilities, supporting a broader range of 5G and pre-6G scenarios.

These hardware enhancements, combined with ongoing software modifications, ensure that the ORO Testbed remains at the forefront of validating advanced use cases, particularly those demanding extreme URLLC (Ultra-Reliable Low-Latency Communications) and mMTC (massive Machine-Type Communications) performance.

2.4.3 Gap Addressing of the PoC Requirements and/or ADROIT6G Platform

Gap 1: AI/ML orchestration – The AI/ML orchestration component has been fully integrated into the ORO Testbed. Solutions developed by our partners at NXW are now operational, enabling efficient deployment, operation, and classification of all ML models. This orchestration framework ensures seamless management of AI-driven functionalities across the testbed.

Gap 2: Zero-touch closed loop automation – Zero-touch closed loop automation capabilities have been successfully installed and tested. By leveraging the testbed's APIs and integrating the ADROIT6G Closed Loop Governance and AI-enabled closed loop functions from NXW, the ORO Testbed now supports advanced, fully automated network and service operations.

Gap 3: Advance Localization – The advanced indoor localization capability, essential for collaborative robotics in factory environments, is not implemented, in the testbed, due to lack of available physical devices, has a gap on the testing for advanced localization.

Gap 4: Network Infrastructure – Further testing is required to address the network infrastructure gap. Planned experiments will focus on special RAN/Core configurations and dedicated QCIs to achieve sub-millisecond latency, as well as the use of simulators to generate and analyze mMTC traffic loads. Conclusions will be drawn following these tests.

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3 PoCs Component Integration

As ADROIT6G PoCs require various components to interact with each other, specific components had to be interconnected on top of PoC-agnostic interconnection. This section outlines the status of interfaces, identified as required for successful test case runs, as well as specifies interfaces missing from previous deliverables.

3.1 PoC-1 – Holographic Teaching

PoC1 focuses on Holographic Teaching and how ADROIT6G's Zero-Touch M&O, BDIx-driven control, and Crowdsourcing AI enable real-time capture, transmission, processing, and rendering of high-quality 3D holographic content. Specifically, immersive XR workloads are managed and executed within the integrated ADROIT6G architecture to meet stringent throughput and latency targets.

3.1.1 Component deployment

In PoC1, the incorporation of the ADROIT6G architecture allows the uninterrupted recording, transmission, processing, and real-time display of high-quality 3D holographic content (point cloud data), utilizing 6G technology. The integration of the components and their communication protocols is summarized in the table below. The table reassesses the development state of components from an integration viewpoint and delineates the linkages among components along with their respective communication protocols. Only components necessitating further integration work are referenced. Table below outlines the status and additional details of ADROIT6G component deployment for PoC1 (Holographic Teaching).

Table 5: Components that Need to Work in Synergy to Achieve PoC-1 - deployment status

PoC Component	Models and Algorithms related to the component as per D3.2 and D4.1	Deployment Notes
AI-Driven Management & Orchestration Framework		
Closed-loop Governance (CLG)	Extends ETSI GS ZSM 009-2 concepts for deploying and overseeing zero-touch M&O closed loops (policy-driven monitors, analyzers, planners, and executors). The CLG provides the functionalities for sending policy updates, configuring and tracking BDIx agents residing on the devices, and collaborating with the UE-VBS Components	Containerized component deployed and instantiated on the testbed; policies configured for XR/QoE-centric loops.
Resource Orchestration & Management	End-to-end slice and resource management across far-edge/edge/cloud, including SLA-driven Adaptive Learning-Rate Federated	Containerized resource orchestrator deployed on the testbed Kubernetes cluster;

	Learning policies for slice-level resource provisioning over the computing continuum	exposes REST APIs towards UE-VBS/edge nodes.
Service/Slice Orchestration & Management	Enhanced service/application orchestration for real-time XR workloads; lifecycle, scaling, and placement across ADROIT6G architecture.	Installed with exposed ports for UI and APIs; services onboarded and lifecycle-managed.
Fully Distributed & Secure AI/ML Framework for CrowdSourcing AI		
AI/ML Pipeline Manager	Automation middleware leveraging/enhancing Prefect, Kubernetes, Seldon, KServe, and Istio for distributed training/serving pipelines. This component deploys and monitors pipelines for the generation of the models chosen by the AI/ML Orchestrator to fulfil the requirements set out by the model selection module in the PoC. It returns information on the performance and history of the deployed pipelines.	Containerized component installed; ports forwarded for UI; pipelines scheduled and monitored.
AI/ML Catalogue	Registry and artifact store leveraging MLflow and MinIO for automated tracking, registering, and retrieval of models in the AI/ML platform. This component is called by the model pipeline to track and register the development of the newly generated model and metadata to be deployed in the PoC. The catalogue stores the information necessary for the AI/ML Orchestrator engine to return the new model that meets the requirements set out by the model selection.	Catalogue deployed and populated with baseline and PoC1-specific models; access tokens configured.
UE side		
BDIx Agents	BDIx closed-loop functions (beliefs, desires, intentions, plan library); includes ANFIS-based policies and DAIS-style transmission/mode selection aligned to QoE targets.	Agents installed and instantiated with IPs assigned via emulation/testbed fabric; topology explorable via TCP; ports exposed for agent-to-agent messaging.

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BDI - & AI-driven Unified & Open Control Operations		
BDIx Agents Control & Logic Re-config (Real-Time Close Loop)	Real-time BDIx control logic that reconfigures beliefs, desires, and intentions of UE-side BDIx Agents; combines ANFIS-based decision policies and DAIS transmission-mode selection rules to adapt agent behaviour and link configurations to QoE/QoS targets.	Containerized controller service deployed in the control domain; exposes REST/TCP endpoints consumed by UE BDIx Agents; control policies loaded from the AI/ML Catalogue and updated via the AI/ML Orchestrator.
UE-VBS Computing Resource Control (Real-Time Close Loop)	UE-VBS control logic that promotes selected UEs to UE-Virtual Base Stations/Computing & Storage Powerhouses; BDIx-driven role-selection and resource-control policies decide when a UE becomes UE-VBS and how much compute/network capacity it offers to the CSP multi-hop topology.	Deployed as a containerised controller at the far-edge/edge; integrates with UE-side BDIx Agents over TCP/IP; provides configuration APIs for instantiating and updating UE-VBS roles used in offloading scenarios.

M&O Closed Loop Functions as well as AI/ML Orchestrator Engine/AI/ML Model Selection have been successfully developed, and could be deployed if needed, following the PoC1 experimental workflows specified in Deliverable D5.4, however, are not considered core components enabling the PoC1 scenarios. Similarly, Joint RAN & x-Edge Resource scheduling has been Validated in PoC-2a and PoC3 and is optional for core PoC1 experimental flow.

The following figure illustrated the software components deployed on the testbed mapping their interconnected functionalities.

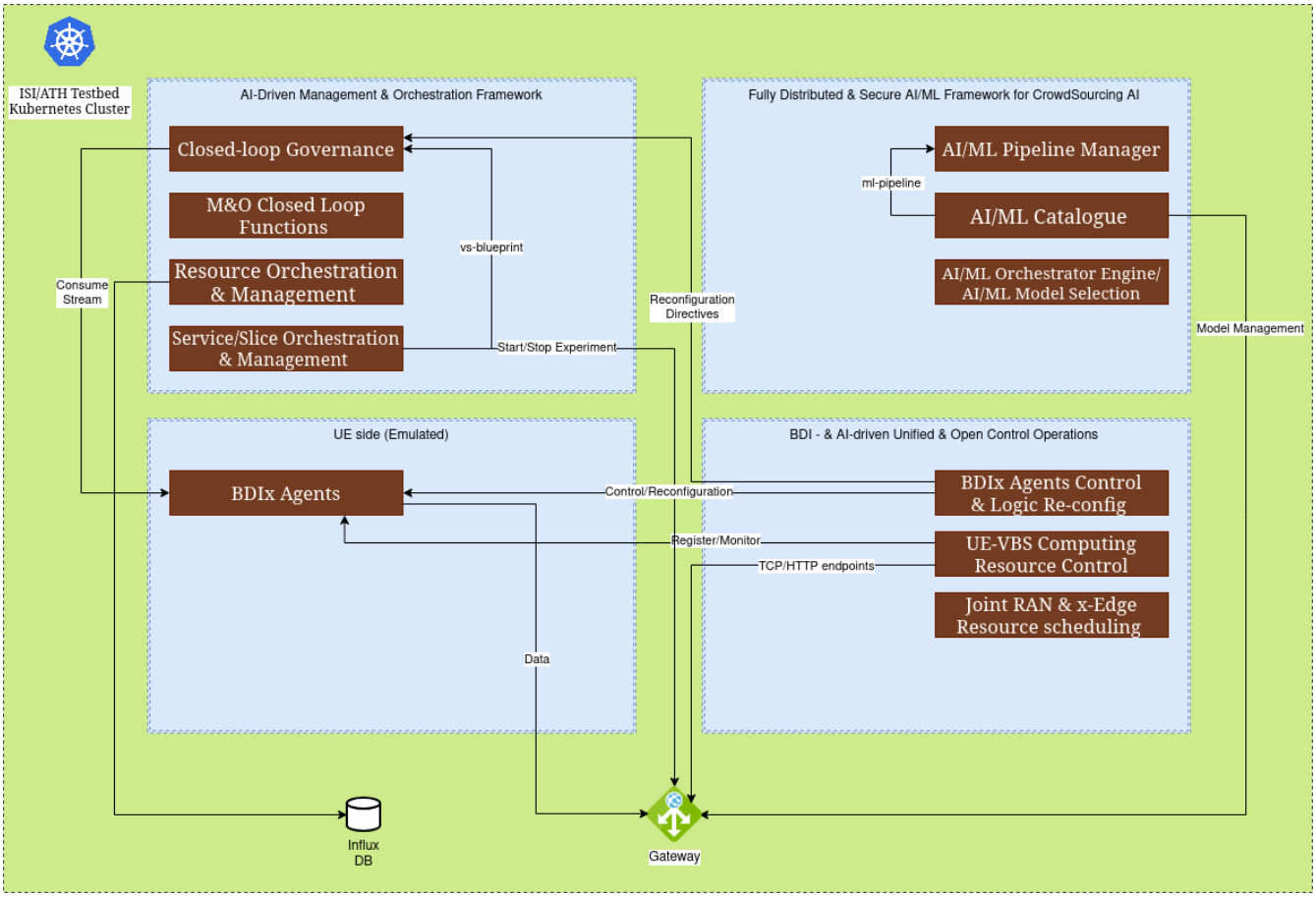

Figure 3-1: PoC1 components' final deployment on the ISI/ATH testbed

3.1.2 Technical Details of Additional Inter-Component Integration

D5.1 Table 23 outlines all interfaces planned for successful PoC1 execution. All of the interfaces claimed were successfully implemented. Table 6 lists references to implementation descriptions.

Table 6: PoC-1 components integration and communication.

Component	Communicates with	Status	Reference
AI-driven Management and Orchestration framework – Closed Loop Governance (CLG)	BDIx Agents	Completed	3.1.2.1
Service Orchestration / Management	CLG	Completed	D2.3 section 3.1
	Testbed	Completed	3.3.2.1

			(same APIs and features as PoC#2b)
Fully Distributed and secure AI/ML Framework for CrowdSourcing AI – AI/ML Pipeline Manager	AI/ML Catalogue	Completed	D2.3 section 3.2
	Testbed	Completed	3.3.2.2 (same APIs and features as PoC#2b)
	AI/ML Pipeline Manager	Completed	D2.3 section 3.2
Predictive Monitoring and SLA Offering Solutions	InfluxDB	Completed	3.1.2.3
	Testbed	Completed	3.1.2.3
UE side – BDIx Agents	CLG	Completed	3.1.2.1
	Testbed	Completed	3.1.2.1
BDI - & AI-driven Unified & Open Control Operations – BDIx Agents Control & Logic Re-config (Real-Time Closed Loop)	CLG	Completed	3.1.2.1
	BDIx Agents	Completed	D2.3 section 3.2
UE-VBS Computing Resource Control (Real-Time Closed Loop)	BDIx Agents	Completed	D2.3 secAtion 3.2
	UE-VBS Controller	Completed	D2.3 section 3.2
	Testbed	Completed	3.1.2.2

Intercomponent interactions are illustrated on the Figure 3-2.

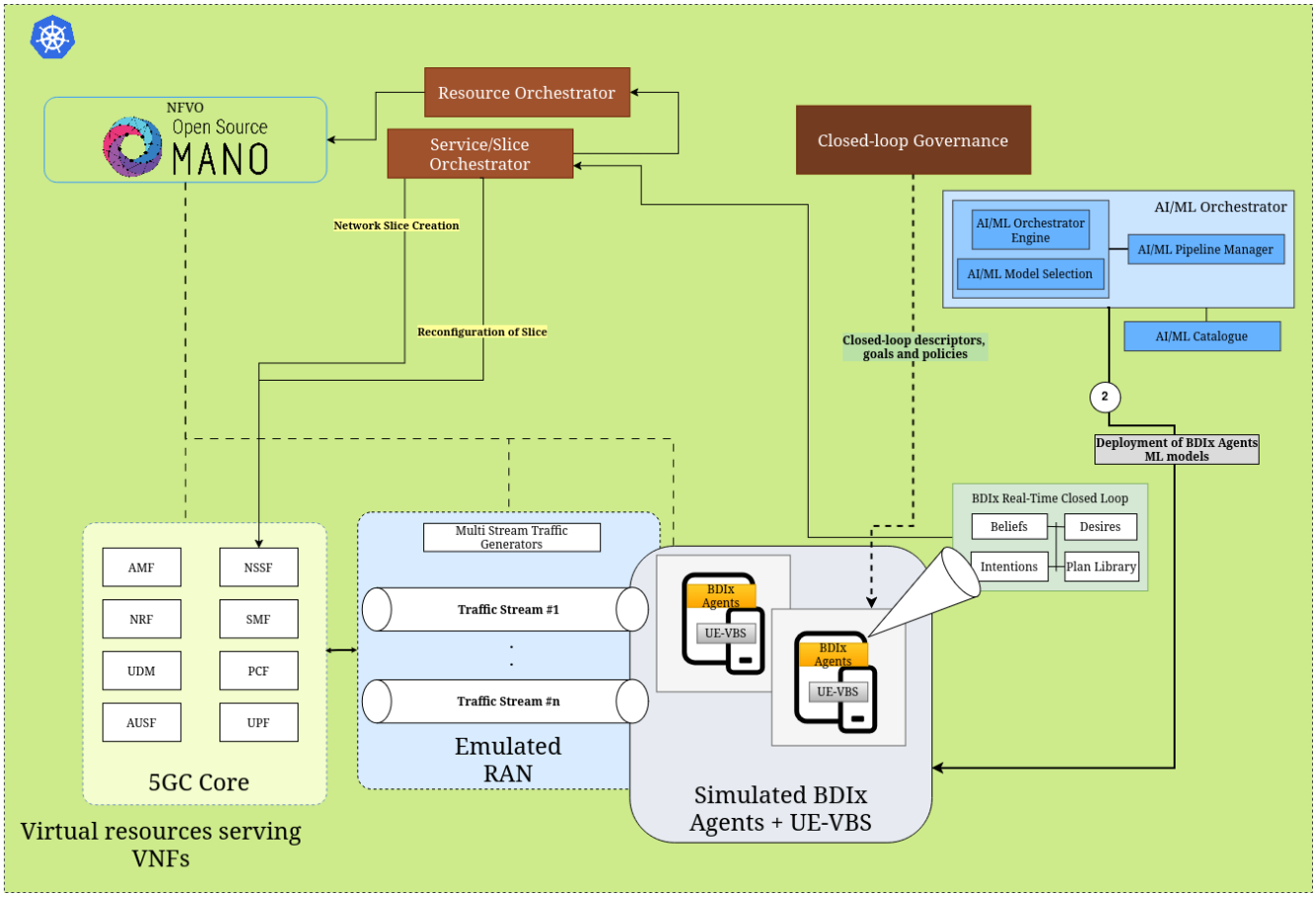

Figure 3-2: PoC1 components' interactions on the ISI/ATH testbed

3.1.2.1 Closed Loop Governance (CLG) & BDIx Agents

The Closed Loop Governance (CLG) is ADROIT6G's zero-touch governance layer that defines, deploys, and supervises ETSI-ZSM-aligned MAPE loops: it translates service intents into enforceable policies/guardrails, coordinates monitors–analyzers–planners–executors, and handles lifecycle controls (versioning, approvals, rollback) for safe automation. BDIx is an AI-driven control framework based on the Belief-Desire-Intention paradigm: agents maintain beliefs from live telemetry, optimize toward desires (e.g., SLA/QoE/energy goals), and commit intentions by selecting plans from a library to enact concrete network/application reconfigurations in real time. Building on these roles, the CLG and BDIx Agents were co-implemented by NXW and CYENS within the integrated ADROIT6G architecture for PoC-1: CLG instantiates policy-driven closed loops that subscribe to telemetry, evaluate KPI/SLA predictors, and issue reconfiguration directives; BDIx agents expose the plan library and actuate those directives as runtime changes. Both were containerized and deployed on the testbed with secure TCP/HTTP endpoint that make the UE consume the Holographic teaching streaming (as shown in Figure 3-3 and Figure 3-4) and clear north/southbound APIs; integration tests validated bi-directional signaling, CLG directives reaching BDIx actuators and feedback closing the loop that are resulting in a Completed status under representative XR traffic and slice reconfiguration scenarios.

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Figure 3-3 is created according to the context of holographic teaching. This interface is used to "push" the stream URL to the consuming device (the UE). The UE-VBS controller would call this POST endpoint, providing the URL of the holographic teaching stream. The agent running on the receiving end (e.g., the holographic-capable UE) will then use this URL to fetch the M3U8 playlist and begin streaming the content until it ends. API Endpoint Specification:

- Endpoint: Consume a Stream
- Controller: stream-controller
- HTTP Method: POST
- Path: /agent/stream/consume
- Description: "Consume an m3u8 stream until it ends."

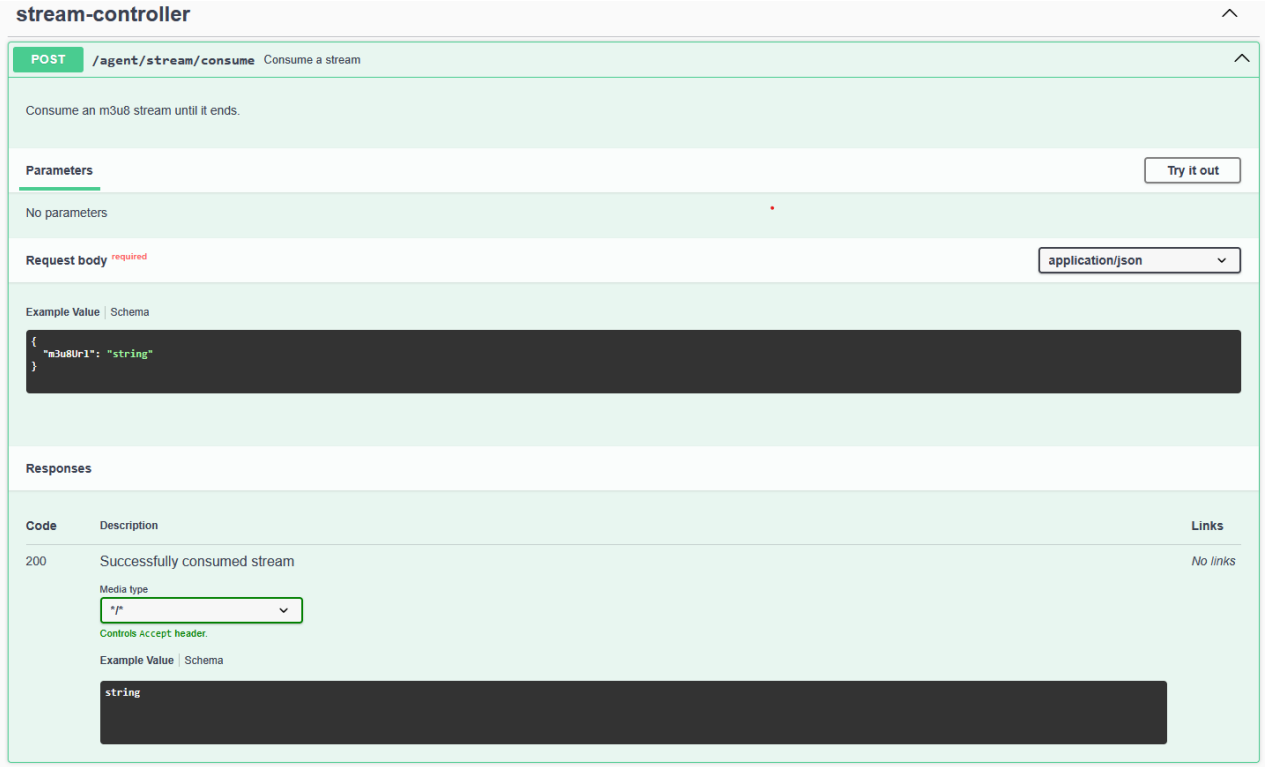

Figure 3-3: Stream Controller that, by sending the Rendering URL, the device initiates the streaming request and displays it to the UE

The descriptors of the closed-loop for the BDIx agents were managed through the Closed-Loop Catalogue, which provides endpoints to retrieve their data, as shown in Figure 3-4.

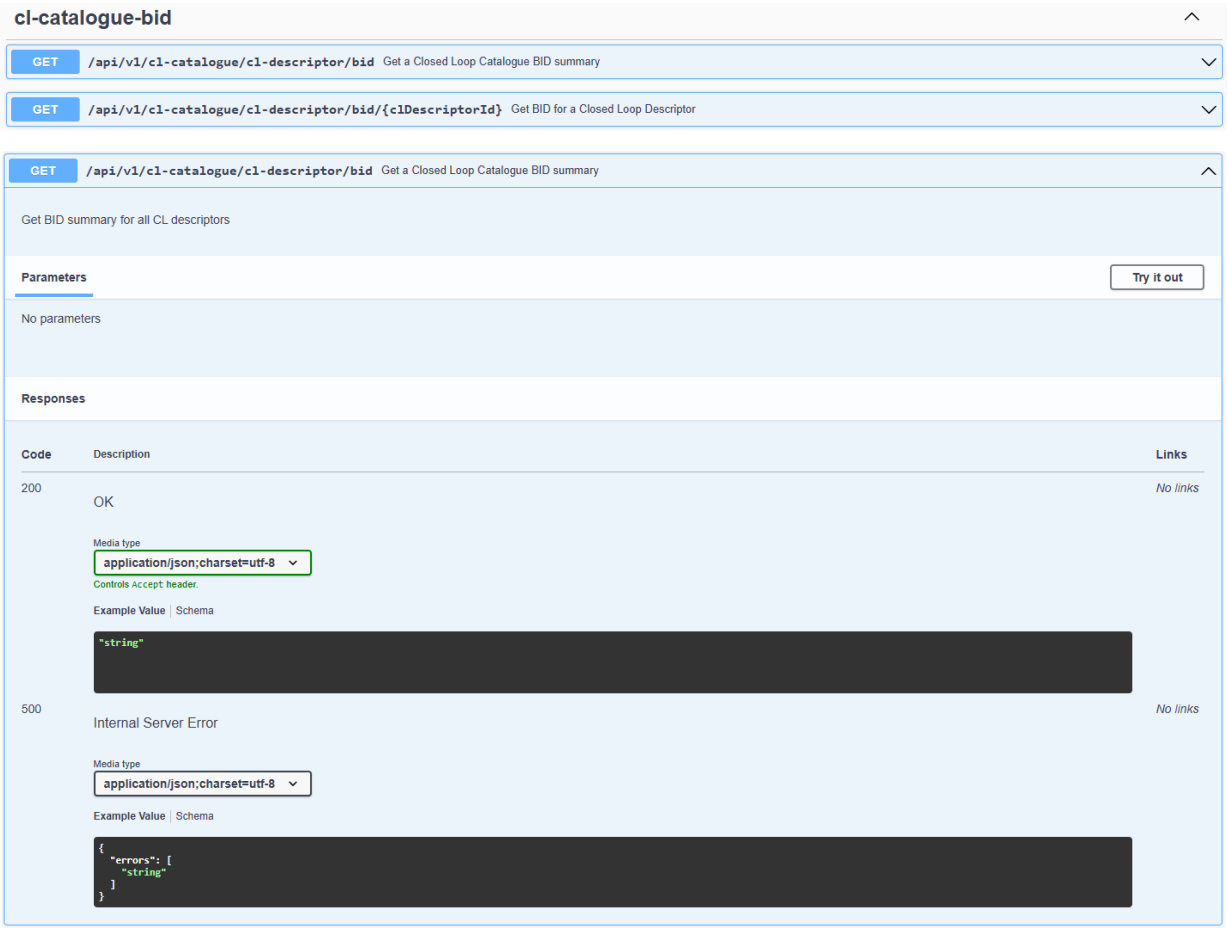

Figure 3-4: API endpoints for retrieval of BDIx Closed-Loop Descriptors

3.1.2.2 UE-VBS Computing Resource Control (Real-Time Closed Loop) at ISI/ATH Testbed

UE-VBS Computing Resource Control (Real-Time Closed Loop) is ADROIT6G's far-edge automation mechanism that realizes "open-resource" UE-VBS infrastructures directly on commercial UE devices: terminals can be dynamically configured to act as miniaturized base stations (mBSs), relay stations (RSs), or Computing & Storage Hubs (CSHs), exposing local radio, compute, and storage resources to nearby users and services. In close cooperation with CLG- and BDIx-driven policies, the UE-resident logic continuously collects device, network, and traffic telemetry (CPU load, battery, channel quality, queueing, SLA/QoE indicators), evaluates whether and where UE-VBS roles should be enabled, and commits intentions by switching roles, forming Virtual Data Tunnels, and instantiating "Computational & Storage Powerhouses" at the very edge in real time. The UE-VBS and BDIx components are containerized and deployed directly on UE devices and edge clusters, exposing secure TCP/HTTP endpoints and clear north/southbound APIs so that closed loops can steer UE-VBS formation, D2D/UE-

VBS mode switching, and slice-level reconfigurations while the ISI/ATH facility provides a full-stack 5G SA environment (Amarisoft 5GC/gNBs, Kubernetes-based MEC, Prometheus monitoring, and real 5G UEs) hosting the holographic teaching service and its supporting slices. Integration and validation campaigns (in synergy with the eBOS setup used in Testing Cycle 1 and its replication on the ISI/ATH infrastructure for Testing Cycle 2) confirmed bi-directional signalling, correct enforcement of CLG/BDIx directives on UE-VBS roles, and stable loop closure under representative XR traffic and slice reconfiguration scenarios, resulting in a Completed status for this functional block in PoC-1.

3.1.2.3 Predictive Monitoring and SLA Offering Solutions at ISI/ATH Testbed

Predictive Monitoring and SLA Control represents an ADROIT6G's cloud-native automation mechanism that augments the available services in 6G networks, contributing to the orchestration plane utilizing proactive intelligence, enabling forecast production for better prediction-driven resource scaling, and potentially can also be utilized in a series of processes across the entire service mesh. Built on the distributed monitoring infrastructure of ADROIT6G, the module ingests data to InfluxDB and generates forecasts for application microservices and series including mainly service-level indicators, while its use can be augmented to any type of time-series of the network, such as CPU/memory/IO pressure, network KPIs, traffic, queueing etc. — and uses these data streams to generate short-term predictions and mid-/long-term insights through advanced ML regressors and neural-network-based forecasting pipelines. A metrics predictor service to predict future values of resources based on their recent timeseries. There is also an InfluxDB service alongside for demo purposes to store and retrieve timeseries used for the predictor.

End-to-end validation activities conducted across Testing Cycle 1 - combining the tool and eBOS monitoring setups — verified bi-directional signalling and stable closure of the prediction-driven control loop under representative load surges, application traffic, holographic teaching services, and time-series provided. Tests confirmed that predictive insights generated by the ML models were reliably reported and monitored for users' actions and policies used by the testbeds for thresholds defined by the needs of the PoC. As a result, the Predictive Monitoring and SLA Offering Solution achieved a completed integration status for PoC-1, demonstrating the feasibility and impact of forecast-guided, multi-time-scale closed-loop automation. More specifically, the use of predictive models and orchestration actions can guarantee that the system ensures stable delivery of the holographic stream even during peak usage, mobility changes, or fluctuating channel conditions. This predictive resilience directly enhances the immersive quality of the holographic teaching session.

InfluxDB acted as a middleware for seamless data flow integration. The ISI/ATH Testbed database address and access tokens were embedded into the Predictive Monitoring and SLA Offering Solutions components, enabling them to function as clients and consume monitoring data. A real-time data

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stream was utilized by the models for inference purposes. The inference outputs, along with requested SLA violation rates, were retrieved through the native component API.

3.2 PoC-2a – Terrestrial 6G IIoT with extreme mMTC

PoC-2a focuses on the terrestrial 6G Industrial Internet of Things (IIoT) use-case where large numbers of industrial devices generate periodic and event-driven communication traffic (massive Machine-Type Communications - mMTC) when they collaborate in transport and assembly of the parts and in safety monitoring. The goal of this PoC is to validate the ability of the ADROIT6G components to manage distributed resources, orchestrate slices and services and maintain end-to-end performance under dynamic conditions.

3.2.1 Component deployment

To support the end-of-PoC validation of PoC-2a, this section introduces the set of ADROIT6G components that are actually deployed and expected to operate in synergy during Testing Cycle 2 (TC2) on the EURE/O-RAN testbed (TRL 4–5). Table 7 therefore focuses on the EURE baseline O-RAN stack (SMO/RIC with the required xApps/rApps) and the components that directly enable the targeted IIoT/mMTC scenario, namely the OULU federated learning model at rApp level (including the selected FL/quantization approach) and the real-time control loops provided by the BDIx agents and the UE-VBS computing resource control, together with the CAFA IIoT application driving periodic and event-driven traffic. Conversely, several components that were initially planned for PoC-2a—most notably NXW's "Fully Distributed and Secure AI/ML Framework for CrowdSourcing AI" (AI/ML Orchestrator/Model Selection, Pipeline Manager, Catalogue)—are not included in the present PoC-2a deployment, as their validation is already covered in PoC3 on a more suitable/higher-TRL setup following the testbed re-assignment (as reported in D5.3). This avoids duplication of validation effort while keeping PoC-2a coherent with the objectives of the EURE TRL 4–5 environment.

Table 7: Components that Need to Work in Synergy to Achieve PoC-2a - deployment status

PoC Component	Models and Algorithms related to the component as per D3.2 and D4.1	Deployment Notes
Fully distributed and secure AI/ML framework for CrowdSourcing AI		
ML model compression through Quantization	Federated Learning with Federated Averaging algorithm	The OULU FL model (FedAvg with quantization) is deployed and running at rApp level. TC2 validates its behaviour and performance impact under extreme mMTC traffic and dynamic network conditions, including interaction with the

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		control loops and the CAFA IIoT application.
BDI - & AI-driven Unified & Open Control Operations		
BDIx Agents Control & Logic Re-config (Real-Time Close Loop)	BDIx (Beliefs, Desires, Intentions, and Plan Library) as Real-time closed-loop Functions (D4.1), composed of: Adaptive neuro-fuzzy inference system (ANFIS) model/approach within BDIx framework (D4.1) and DAIS Transmission Mode Selection Algorithm under "Select the best Transmission Mode" Desire (D4.1)	BDIx agents are deployed and operational (validated in TC1). TC2 focuses on integration with the PoC-2a component chain (xApps/FL and application-driven traffic) and on verifying stable closed-loop decisions under dynamic conditions.
UE-VBS Computing Resource Control (Real-Time Close Loop)	UE-VBS Component functionality (i.e., mBS role)	UE-VBS resource control is deployed and operational (validated in TC1). TC2 validates coordinated actions with BDIx and rApp-level intelligence in the EURE/O-RAN testbed, targeting end-to-end performance stability for the IIoT/mMTC scenario.

Closed Loop Governance was initially considered for PoC-2a; however, following the testbed re-assignment and partner agreement to avoid duplicated validation, CLG is validated in PoC3 on the ORO testbed (see D5.3). Only the EURE O-RAN management stack (SMO) and related xApps/rApps are used. Service orchestration capabilities (beyond the EURE SMO baseline) are not deployed in PoC-2a, since these functions are validated in PoC3 with higher system maturity and broader multi-domain integration (see D5.3). PoC-2a relies on the EURE SMO for service/app lifecycle handling required by TC2. When it comes to end-to-end slice resource orchestration and the associated SLA-driven FL policy, these capabilities are validated in other PoCs (notably PoC2b/PoC3) where the full cross-domain slicing stack is available (see D5.3). PoC-2a uses the EURE RIC-side control for scenario-relevant resource actions.

The MERGE-based model selection/orchestration is validated in PoC3 following the DoA testbed adjustments and the transfer of the ORO testbed scope (see D5.3). It is intentionally excluded from PoC-2a TC2 to avoid duplication. Pipeline automation (Prefect/Kubernetes/Seldon/KServe/Istio-based) is validated in PoC3, where the end-to-end ML pipeline lifecycle is demonstrated (see D5.3), and is out

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of scope for PoC2a scenarios. Model tracking/catalogue functions (MLflow/MinIO-based) are validated in PoC3 as part of the consolidated AI/ML platform demonstration (see D5.3) as well.

The following figure illustrated the software components deployed on the testbed mapping their interconnected functionalities.

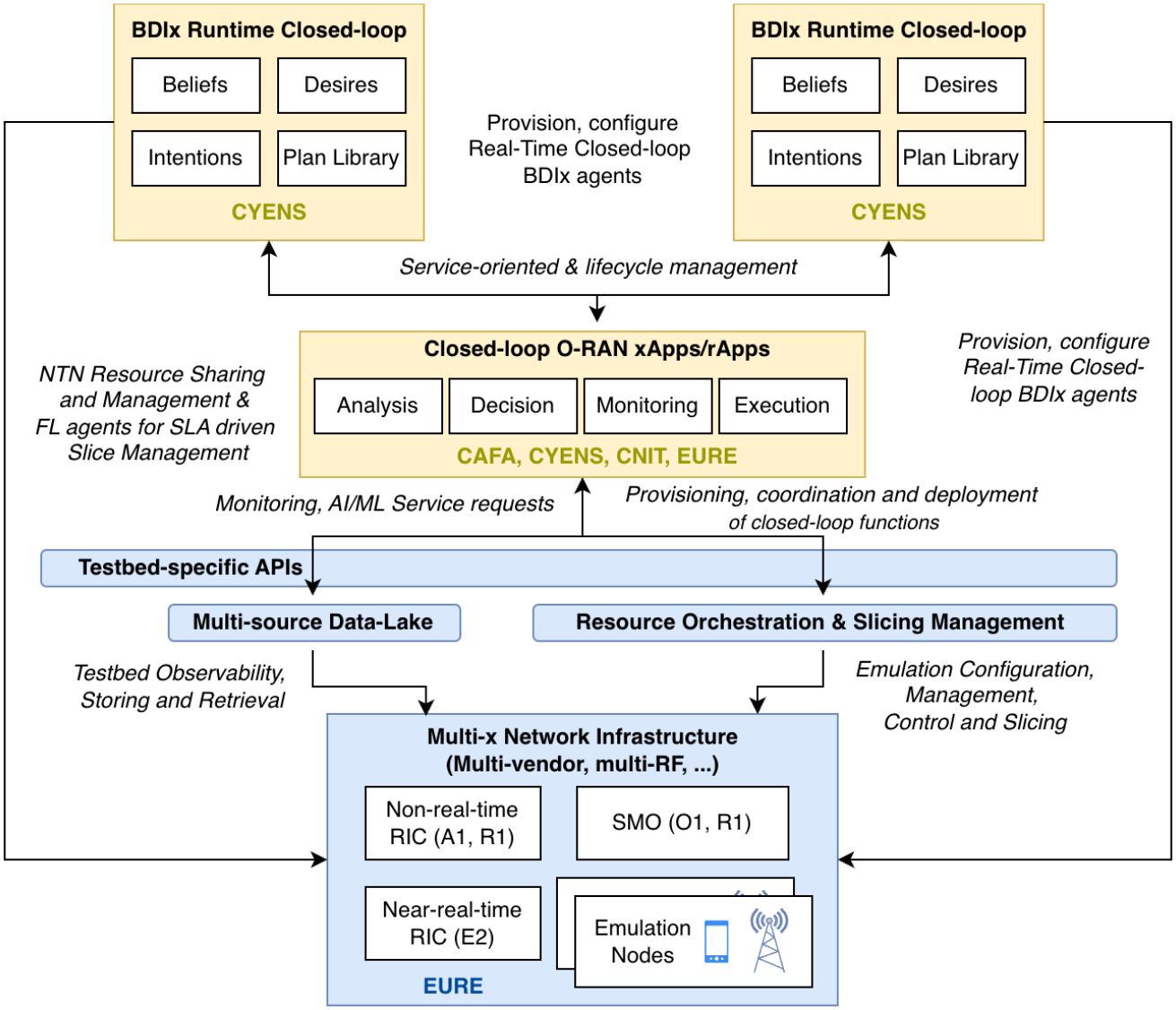

Figure 3-5: PoC2a components' final deployment on the EURE testbed

3.2.2 Technical Details of Additional Inter-Component Integration

This section specifies the inter-component communication and integration points required to execute the PoC-2a end-to-end scenario on the EURE/O-RAN testbed (TRL 4–5). Beyond listing which components are deployed, we document who talks to whom, through which interfaces/protocols, and what the integration status is for TC2. Table 8 summarizes the operational communication paths among the CAFA IIoT application, O-RAN xApps/rApps (including the OULU FL/quantization functions), and the

BDIx/UE-VBS real-time closed-loop controllers, as well as their interaction with the underlying Multi-X network infrastructure (SMO/RIC and emulation nodes). Components that were originally planned for PoC-2a but are validated in other PoCs (notably PoC3) following the testbed re-assignment and partner agreement to avoid duplication are explicitly marked as excluded and are therefore not part of the TC2 integration chain.

Table 8: PoC-2a components integration and communication.

Component	Communicates with	Status	Reference
AI-driven Management and Orchestration framework			
ML model compression through Quantization	Federated Learning with Federated Averaging algorithm	Completed	D5.1 section 3.2.2
UE side			
BDIx Agents	AgentSpeak/AgentACL/JASON/FIPA ACL (one of these agent languages), N1 Protocol, TCP/IP	Completed	D2.3 section 3.2
BDI - & AI-driven Unified & Open Control Operations			
BDIx Agents Control & Logic Re-config (Real-Time Close Loop)	BDIx Agents, TCP/IP	Completed	D2.3 section 3.2
UE-VBS Computing Resource Control (Real-Time Close Loop)	BDIx Agents, TCP/IP	Completed	D2.3 section 3.2

The following figure presents a UML component diagram of the **PoC-2a TC2 integration view**, highlighting the deployed components on the EURE/O-RAN testbed and the **interfaces used for inter-component communication**. The diagram focuses on (i) the **CAFA IIoT application** generating periodic and event-driven mMTC traffic, (ii) the **O-RAN closed-loop xApps/rApps** including the **OULU FL/quantization rApp**, and (iii) the **BDIx/UE-VBS real-time closed-loop controllers**, together with their interactions with the underlying **Multi-X network infrastructure** (SMO/RIC and emulation nodes). Communication links are annotated with the corresponding protocols and O-RAN interfaces (e.g., **A1/E2**, TCP/IP). Components marked as *excluded* are shown only for completeness and traceability, since they are validated in other PoCs and are not part of the PoC-2a TC2 integration chain.

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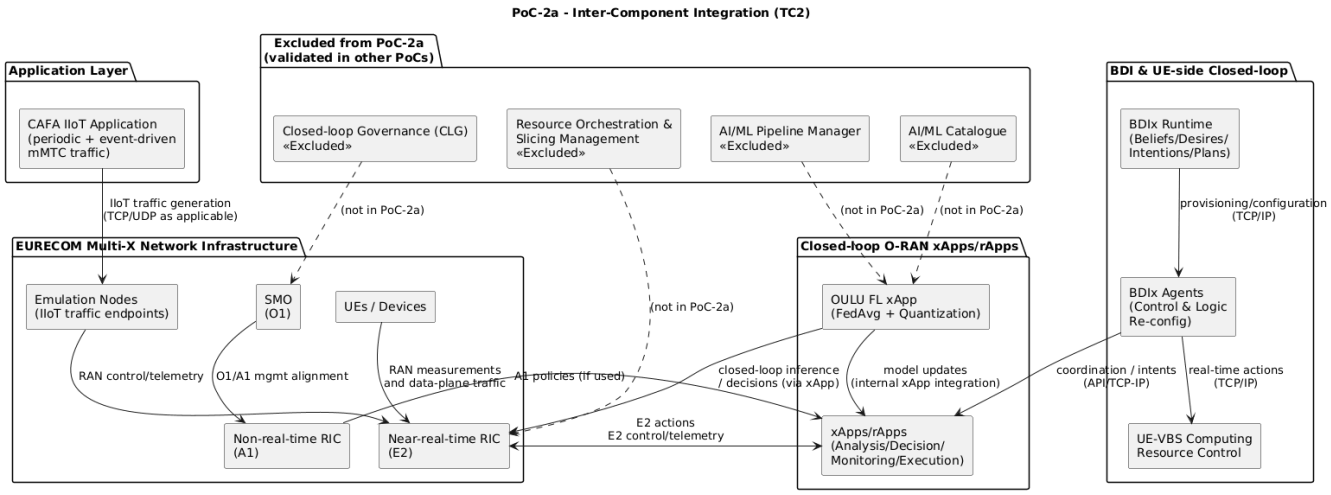

Figure 3-6: PoC2a components' interactions on the EURE testbed.

UML component diagram of PoC-2a TC2 integration, showing deployed components and their communication interfaces (A1/E2, TCP/IP), with excluded components shown for traceability only.

3.3 PoC-2b – Rail Automation Support by Non-Terrestrial Networks

In the following section, interfaces specific to PoC2b are outlined. PoC2b focuses on Railway Automation processes, and the role of emerging 6G technologies in reshaping the railway industry. In specific, basic railway operations are offloaded to the Non-Terrestrial network assets and managed within the integrated ADROIT6G architecture as equal far edge and cloud nodes.

3.3.1 Component deployment

Table 9 below outlines the status and additional details of ADROIT6G component deployment.

Table 9: Components that Need to Work in Synergy to Achieve PoC-2b - deployment status.

PoC Component	Models and Algorithms related to the component as per D3.2 and D4.1	Deployment Notes
AI-Driven Management & Orchestration Framework		
Closed-loop Governance (CLG)	Extends the concepts in ETSI GS ZSM 009-2 for deploying and overseeing M&O closed loop functions in zero-touch automation	Containerized component was deployed and instantiated on the testbed
Service Orchestration & Management	Enhanced capabilities for service and application components deployment and operation on top of NTN/satellite computing resources	Components of Service Orchestration and Management were installed on the testbed, as well as ports were exposed to access the UI

Fully Distributed and secure AI/ML Framework for CrowdSourcing AI		
AI/ML Orchestrator Engine / AI/ML Model Selection	**MERGE**: Meta-learning approach for Model selection, creation & adaptation	Component was deployed on external guest VMs and then pulled via other components.
AI/ML Pipeline Manager	Automation framework and middleware leveraging and enhancing SoTA solutions PREFECT, kubernetes, Seldon, kServe, and istio for the distributed, multi-domain deployment of training and model serving via pipelines	Containerized component was installed, ports were forwarded for the UI to be displayed
	SLA-driven Adaptive Learning Rate-based **Federated Learning** Policy for Slice-level Resource Provisioning	Containerized component was deployed on the testbed, and instantiated as server and clients in the emulation runtime
AI/ML Catalogue	Automation framework and middleware leveraging and enhancing SoTA solutions MLFlow and minio, for the automated tracking, registering, and retrieval of models in the AI/ML Platform	Component was deployed on external guest VMs and then pulled via other components.
	Predictive Monitoring and SLA Offering Solutions	Containerized component was deployed on the testbed, and instantiated in the emulation runtime
AI/ML Orchestrator Engine	ML model compression through Quantization for efficient and faster training using Collaborative Learning: **G-DNGAM and DIN algorithms** (D3.2)	Containerized component was deployed on the testbed, and instantiated as server and clients in the emulation runtime
BDI - & AI-driven Unified & Open Control Operations		

BDIx Agents Control & Logic Re-config **(Real-Time Close Loop)**	BDIx (Beliefs, Desires, Intentions, and Plan Library) as Real-time closed-loop Functions (D4.1), composed of: Adaptive neuro-fuzzy inference system (ANFIS) model/approach within BDIx framework (D4.1) and DAIS Transmission Mode Selection Algorithm under "Select the best Transmission Mode" Desire (D4.1)	Components themselves were installed and instantiated with ip addresses assigned through the Emulation framework. Topology can be explored via emulated tcp connections, as ports were correctly exposed to fascilitate agent-to-agent communication via emulation
UE-VBS Computing Resource Control **(Real-Time Close Loop)**	UE-VBS Component functionality (i.e., mBS)	Same as above.
Edge & Cloud & Far Edge Domains		
Non-Terrestrial Networks	Satellite Communication and Computing Framework Emulation	Part of the testbed
Computing capabilities within Non-Terrestrial Networks	Satellite Communication and Computing Framework Emulation	Part of the testbed

Figure 3-7 shows how the components are deployed in the testbed environment. Evidently, all components reside in the testbed, where AI-Driven management and orchestration is fully deployed on guest VMs, beside fractions of the AI/ML Framework for Croundsourcing AI. Other components, designed to be a part of the NTN emulation, e.g., BDIx Agents or Federated Learning agents, are deployed directly in the emulation environment. Importantly, BDI- & AI-driven Unified & Open Control Operations components can be also deployed on a physical mobile phone, as a result, on the diagram both options are shown.

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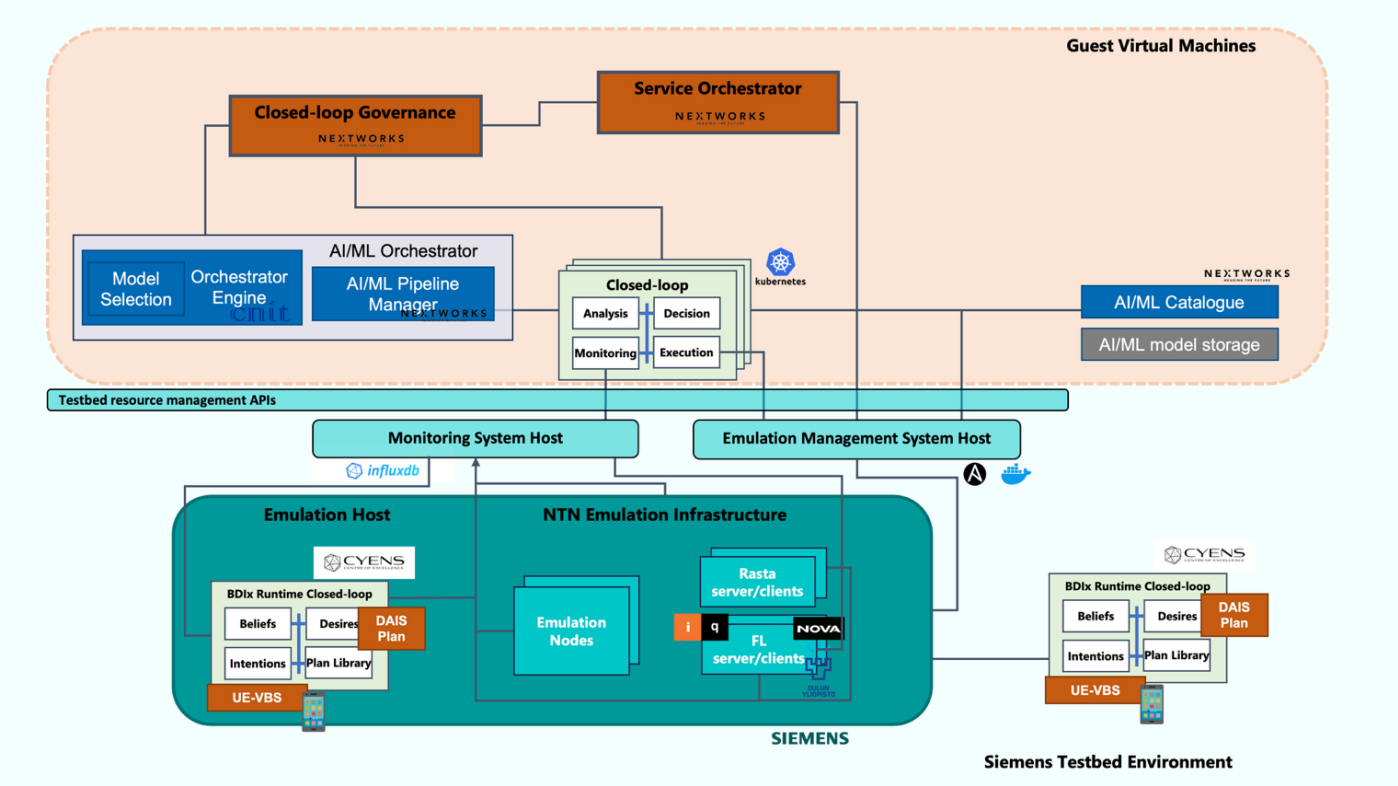

Figure 3-7: PoC2b components' final deployment on the Siemens testbed.

3.3.2 Technical Details of Additional Inter-Component Integration

D5.1 table 23 outlines all interfaces planned for successful PoC2b execution. All the interfaces claimed were successfully implemented, Table 10 lists references to implementation descriptions.

Table 10: PoC-2b components integration and communication.

Component	Communicates with	Status	Reference
AI-driven Management and Orchestration framework			
Closed Loop Governance (CLG)	BDIx Agents	Completed	3.1.2.1
Service Orchestration /Management	CLG	Completed	D2.3 section 3.1
	NTN Testbed	Completed	3.3.2.1
Fully Distributed and secure AI/ML Framework for CrowdSourcing AI			
AI/ML Pipeline Manager	AI/ML Catalogue	Completed	D2.3 section 3.2
	NTN Testbed	Completed	3.3.2.2

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AI/ML Catalogue	AI/ML Pipeline Manager	Completed	D2.3 section 3.2
Predictive Monitoring and SLA Offering Solutions	InfluxDB NTN Testbed	Completed	3.3.2.3
UE side			
BDIx Agents	CLG	Completed	3.1.2.1
	NTN Testbed	Completed	3.3.2.4
BDI - & AI-driven Unified & Open Control Operations			
BDIx Agents Control & Logic Re-config (Real-Time Close Loop)	CLG	Completed	3.1.2.1
	BDIx Agents	Completed	D2.3 section 3.3
UE-VBS Component (Real-Time Close Loop)	BDIx Agents	Completed	D2.3 section 3.3
	NTN Testbed	Completed	3.3.2.4

Intercomponent interactions are illustrated on the Figure 3-8. Logical flow here is combined with component placement, and every interface is illustrated with an arrow. Component-to-testbed interfaces fall into two categories – external and internal. External interfaces (e.g., SOM, Pipeline Manager) are routed through the resource management API – a standalone component, reachable without access to the emulation machine, as these requests from these components require resource management or allocation. On the other hand, internal interfaces (BDIx Agent, UE-VBS Component, Predictive Monitoring and SLA Offering Solutions) are for natively deployed components, where only emulation integration is required. These components can pull data or trigger simple resource management calls from native Emulation APIs.

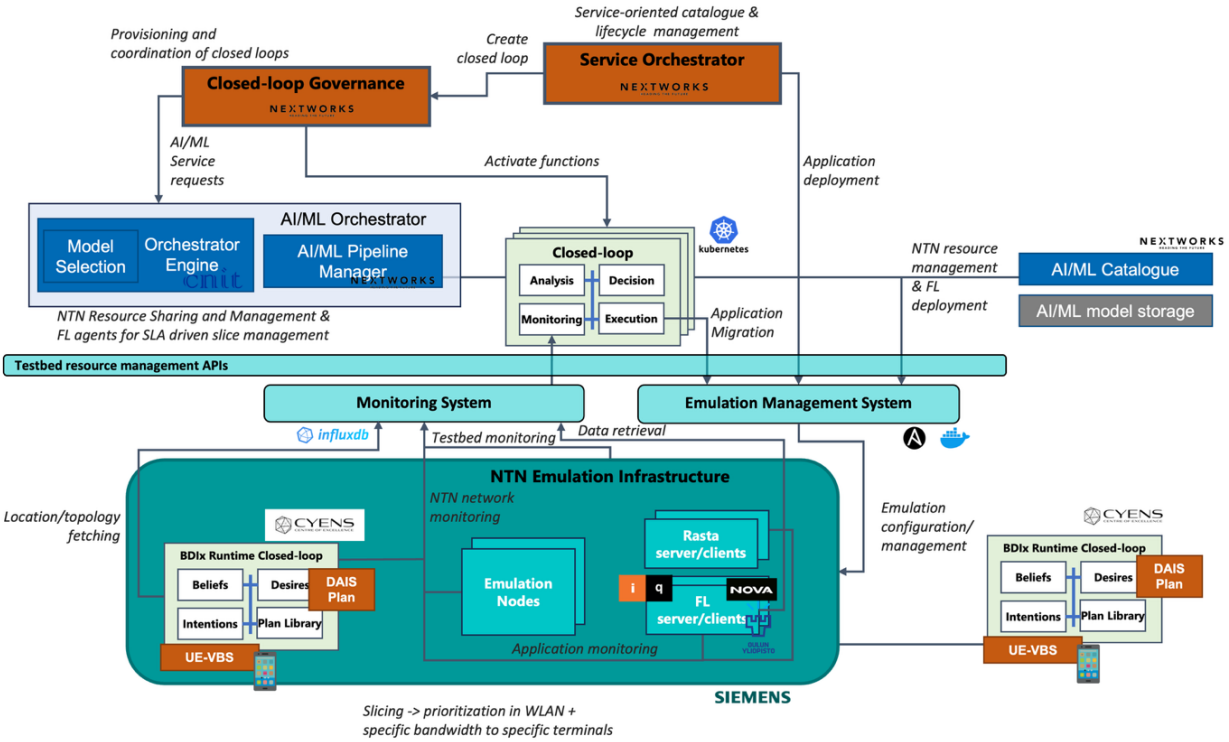
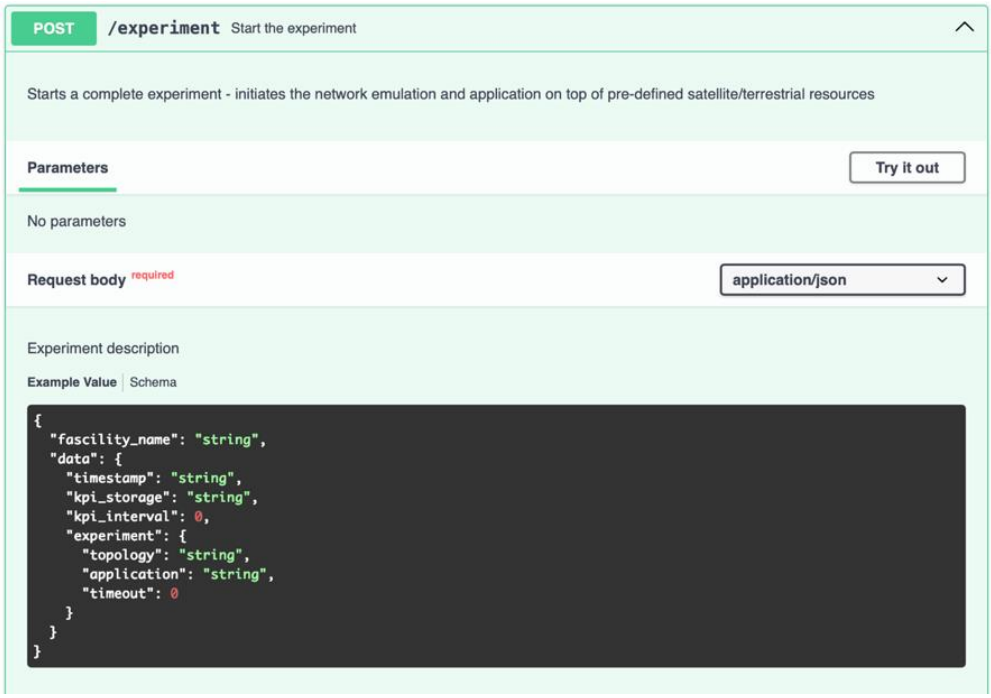
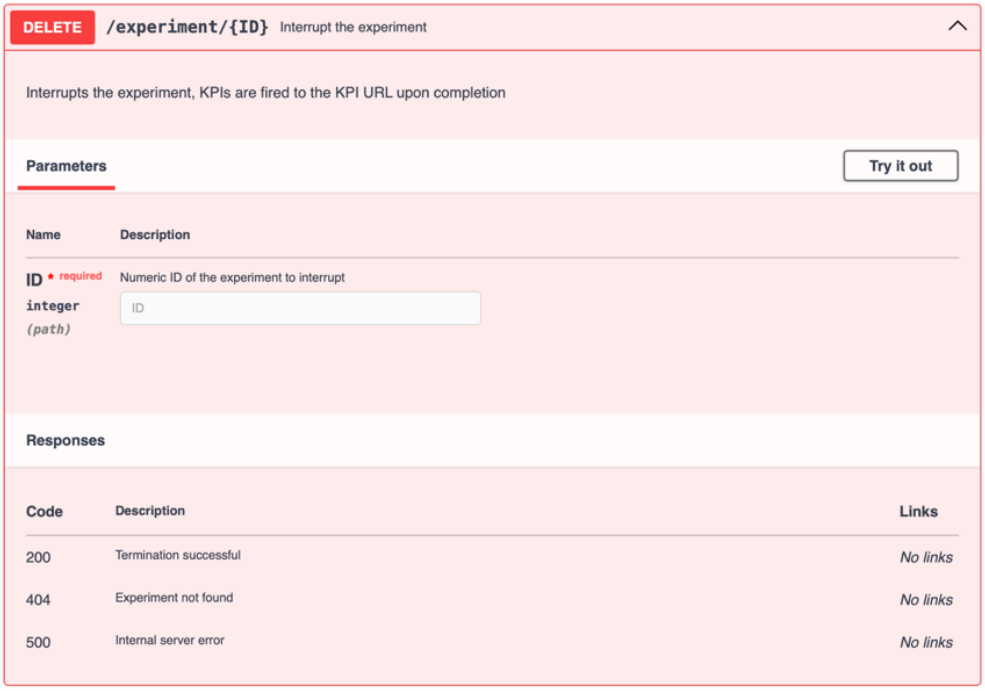


Figure 3-8: PoC2b components' interactions on the Siemens testbed.

3.3.2.1 Service Orchestration/Management & NTN Testbed

PoC application descriptors were provided to the SOM component to allow for instantiation and management of the application. From the testbed side, testbed-native Resource Orchestrator has been exposed and extended with PoC application exposed as a service. Figure 3-9 shows main endpoints used within ADROIT6G architecture – start and stop of the PoC application, and service handover API used for reactive changes in the PoC service deployment induced by other components (e.g., Predictive Monitoring and SLA Offering Solutions).


POST
/experiment
Start the experiment
Starts a complete experiment - initiates the network emulation and application on top of pre-defined satellite/terrestrial resources
Parameters
Try it out
No parameters
Request body
required
application/json
Experiment description
Example Value
Schema
{
"fascility_name": "string",
"data": {
"timestamp": "string",
"kpi_storage": "string",
"kpi_interval": 0,
"experiment": {
"topology": "string",
"application": "string",
"timeout": 0
}
}
}


DELETE
/experiment/{ID}
Interrupt the experiment
Interrupts the experiment, KPIs are fired to the KPI URL upon completion
Parameters
Try it out
Name
Description
ID
required
integer
(path)
Numeric ID of the experiment to interrupt
ID
Responses
Code
Description
Links
200
Termination successful
No links
404
Experiment not found
No links
500
Internal server error
No links

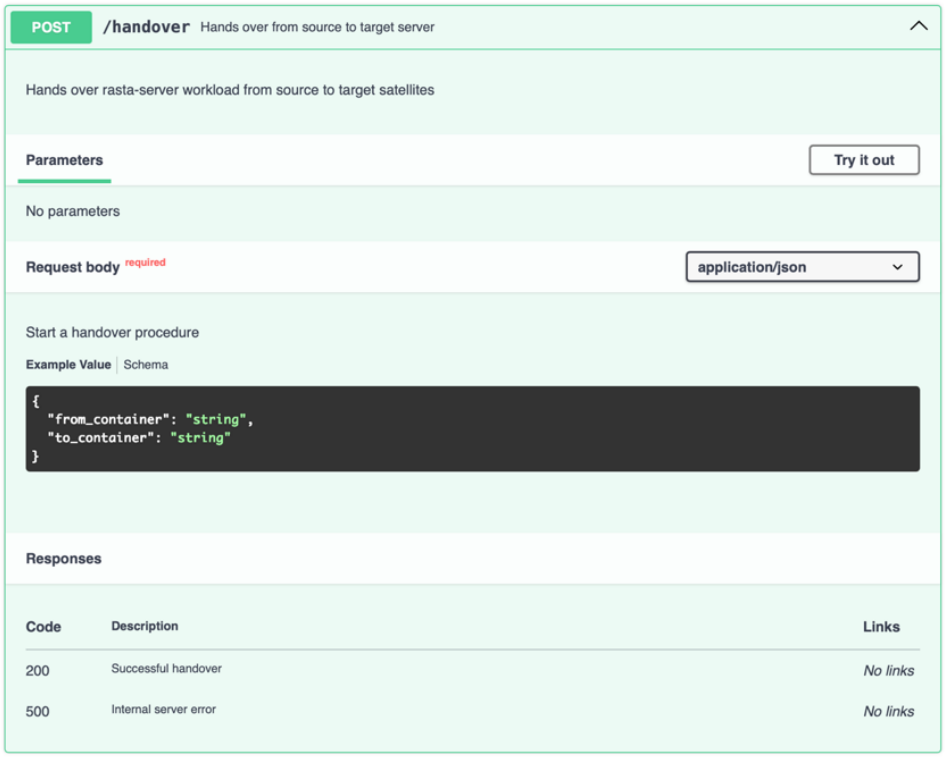
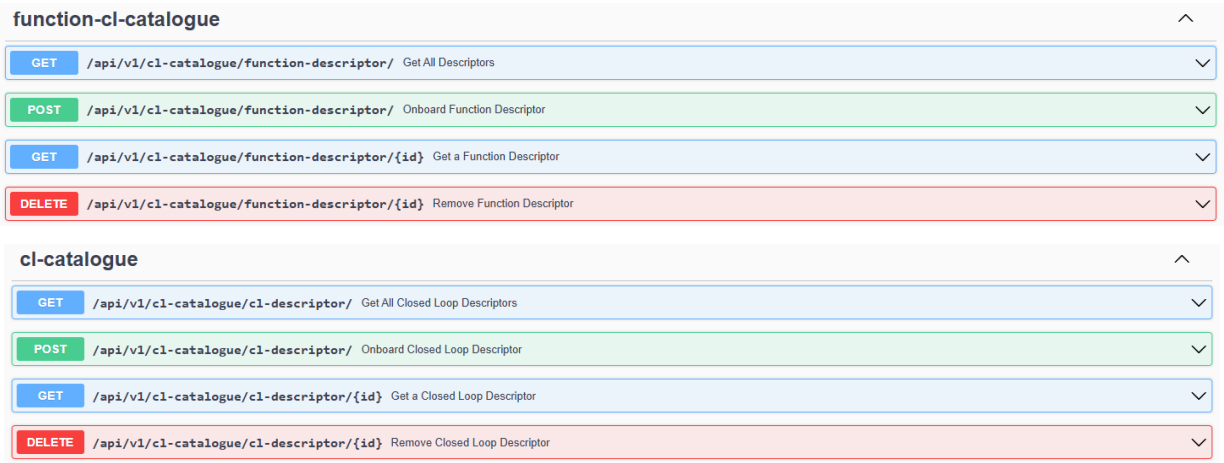
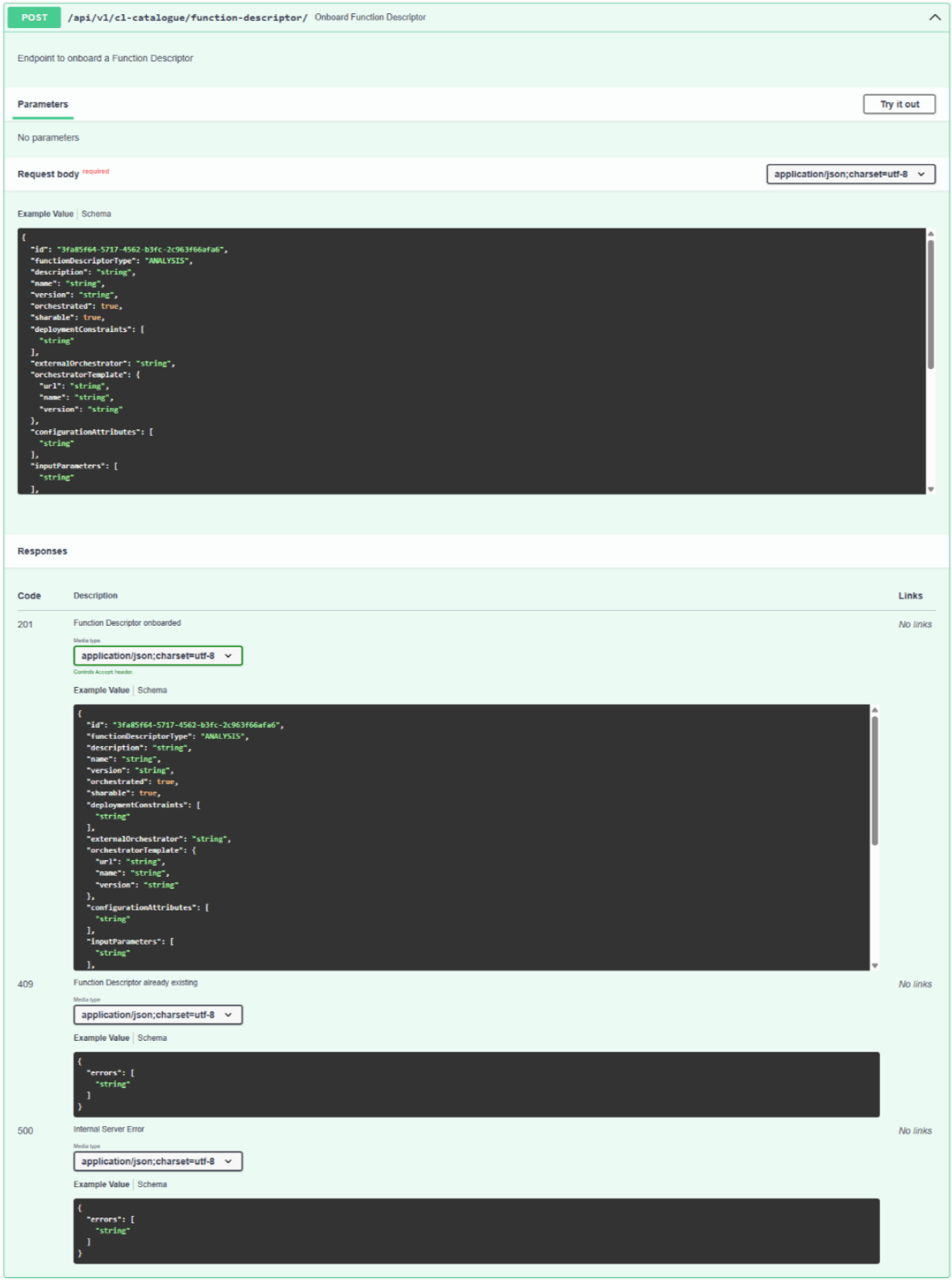


Figure 3-9: API specification of NTN Testbed to Service Orchestration and Management interface.

The descriptors of the closed-loops and their functions were stored in the Closed-Loop Catalogue, which allows to retrieve their info and delete them, too (Figure 3-10). A closed-loop function descriptor can be onboarded providing name, version and input/output parameters, together with other function-based info; a closed-loop descriptor is composed by the closed-loop functions and goals. The life-cycle of the closed-loop instance of the PoC, associated to the onboarded closed-loop descriptor, was managed through the Closed-Loop LCM (Figure 3-11): the instance can be created providing name, description, priority and the ID of the linked closed-loop descriptor , and then instantiated just providing the ID of the created instance.




POST
/api/v1/cl-catalogue/function-descriptor/
Onboard Function Descriptor
Endpoint to onboard a Function Descriptor
Parameters
Try it out
No parameters
Request body
required
application/json;charset=utf-8
Example Value
Schema
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"functionDescriptorType": "ANALYSIS",
"description": "string",
"name": "string",
"version": "string",
"orchestrated": true,
"sharable": true,
"deploymentConstraints": [
"string"
],
"externalOrchestrator": "string",
"orchestratorTemplate": {
"url": "string",
"name": "string",
"version": "string"
},
"configurationAttributes": [
"string"
],
"inputParameters": [
"string"
],
Responses
Code
Description
Links
201
Function Descriptor onboarded
No links
Media type
application/json;charset=utf-8
Controls Accept header.
Example Value
Schema
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"functionDescriptorType": "ANALYSIS",
"description": "string",
"name": "string",
"version": "string",
"orchestrated": true,
"sharable": true,
"deploymentConstraints": [
"string"
],
"externalOrchestrator": "string",
"orchestratorTemplate": {
"url": "string",
"name": "string",
"version": "string"
},
"configurationAttributes": [
"string"
],
"inputParameters": [
"string"
],
409
Function Descriptor already existing
No links
Media type
application/json;charset=utf-8
Example Value
Schema
{
"errors": [
"string"
]
}
500
Internal Server Error
No links
Media type
application/json;charset=utf-8
Example Value
Schema
{
"errors": [
"string"
]
}

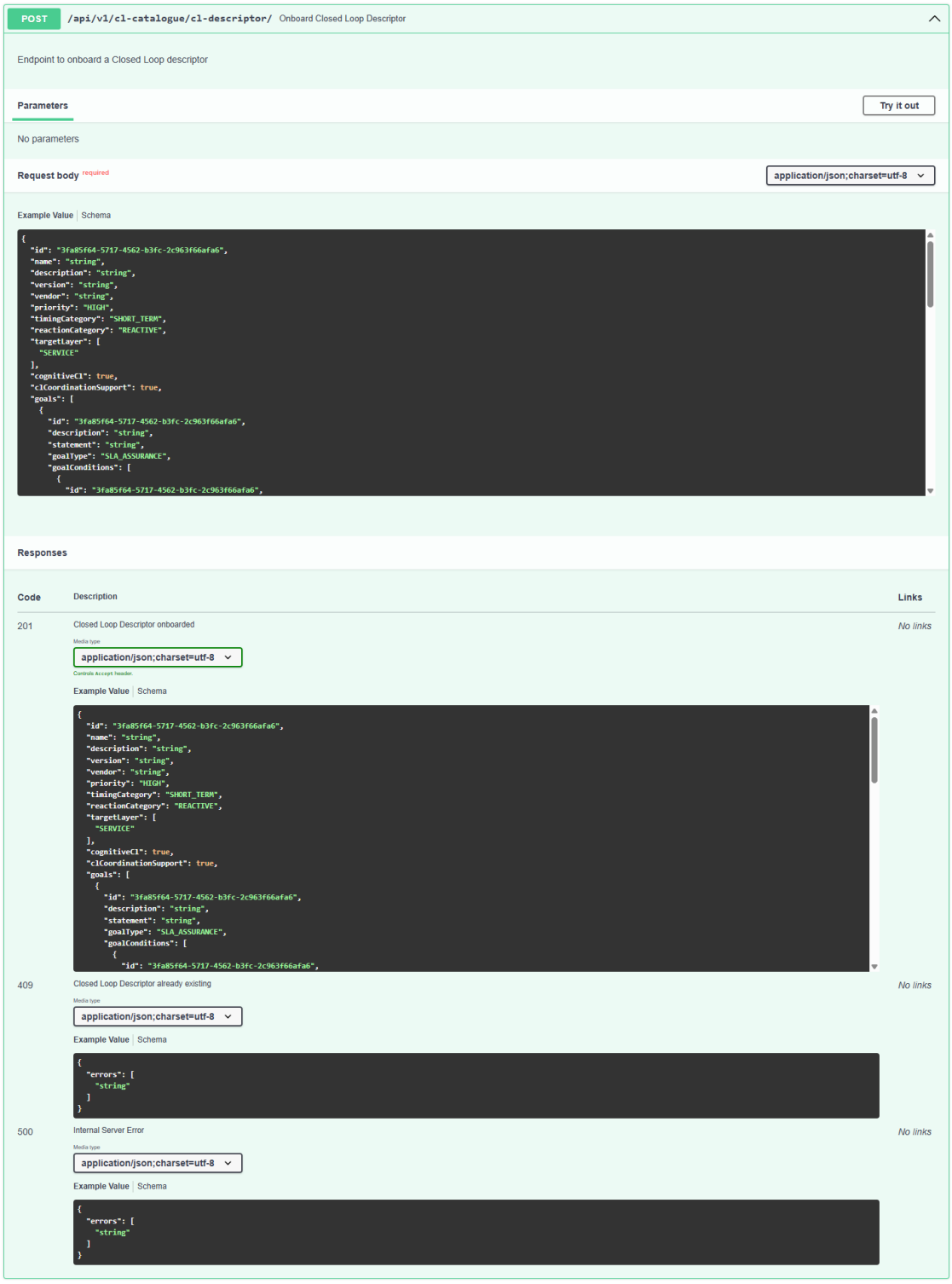
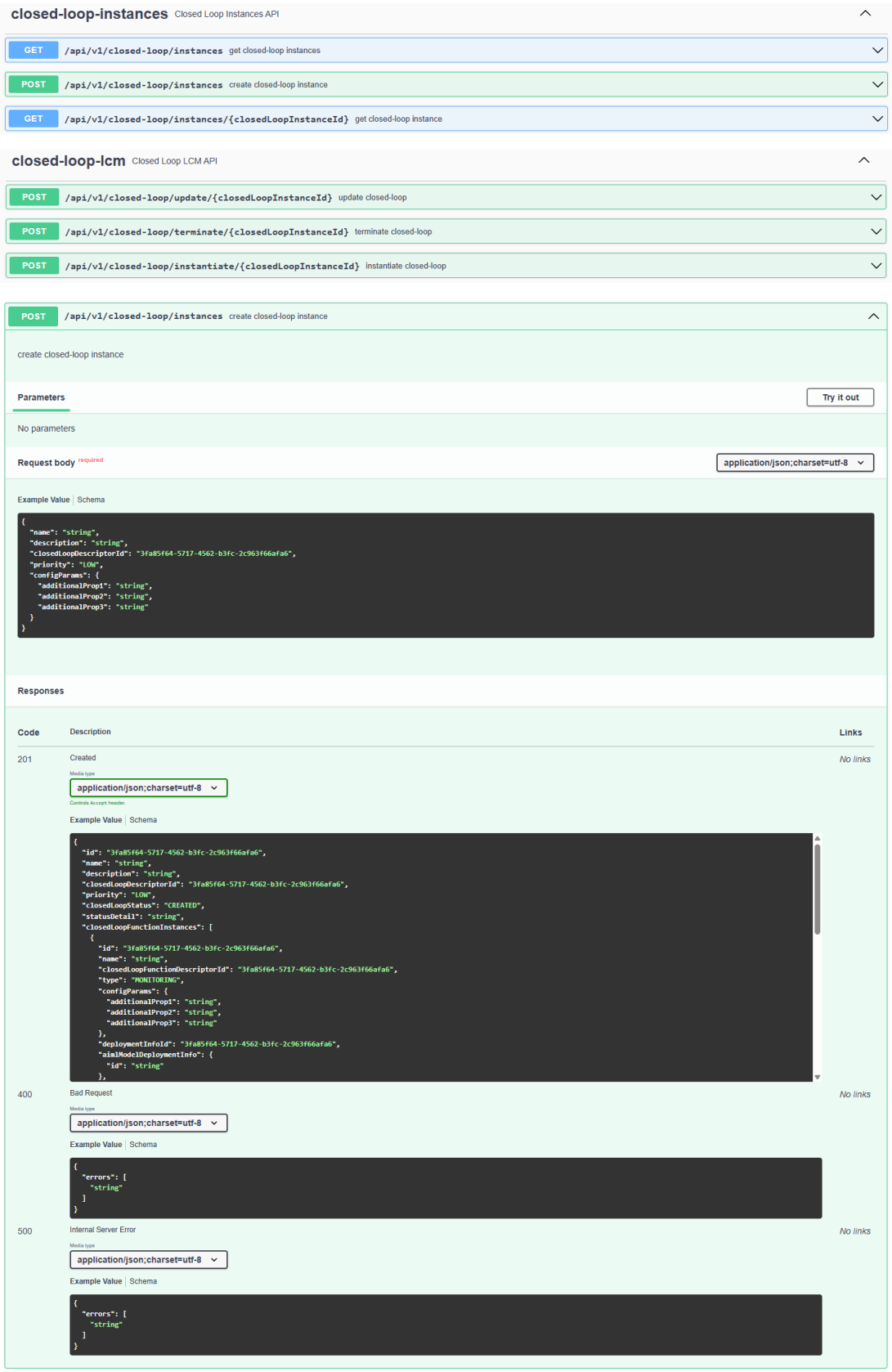


Figure 3-10: Closed-Loop Catalogue endpoints and API specification for onboarding new cl-function and closed-loop descriptors.


closed-loop-instances Closed Loop Instances API
GET /api/v1/closed-loop/instances get closed-loop instances
POST /api/v1/closed-loop/instances create closed-loop instance
GET /api/v1/closed-loop/instances/{closedLoopInstanceId} get closed-loop instance
closed-loop-lcm Closed Loop LCM API
POST /api/v1/closed-loop/update/{closedLoopInstanceId} update closed-loop
POST /api/v1/closed-loop/terminate/{closedLoopInstanceId} terminate closed-loop
POST /api/v1/closed-loop/instantiate/{closedLoopInstanceId} instantiate closed-loop
POST /api/v1/closed-loop/instances create closed-loop instance
create closed-loop instance
Parameters
Try it out
No parameters
Request body required
application/json;charset=utf-8
Example Value | Schema
{
"name": "string",
"description": "string",
"closedLoopDescriptorId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"priority": "LOW",
"configParams": {
"additionalProp1": "string",
"additionalProp2": "string",
"additionalProp3": "string"
}
}
Responses
Code
Description
Links
201
Created
No links
application/json;charset=utf-8
Example Value | Schema
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"name": "string",
"description": "string",
"closedLoopDescriptorId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"priority": "LOW",
"closedLoopStatus": "CREATED",
"statusDetail": "string",
"closedLoopFunctionInstances": [
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"name": "string",
"closedLoopFunctionDescriptorId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"type": "MONITORING",
"configParams": {
"additionalProp1": "string",
"additionalProp2": "string",
"additionalProp3": "string"
},
"deploymentInfoId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"aimlModelDeploymentInfo": {
"id": "string"
},
400
Bad Request
No links
application/json;charset=utf-8
Example Value | Schema
{
"errors": [
"string"
]
}
500
Internal Server Error
No links
application/json;charset=utf-8
Example Value | Schema
{
"errors": [
"string"
]
}

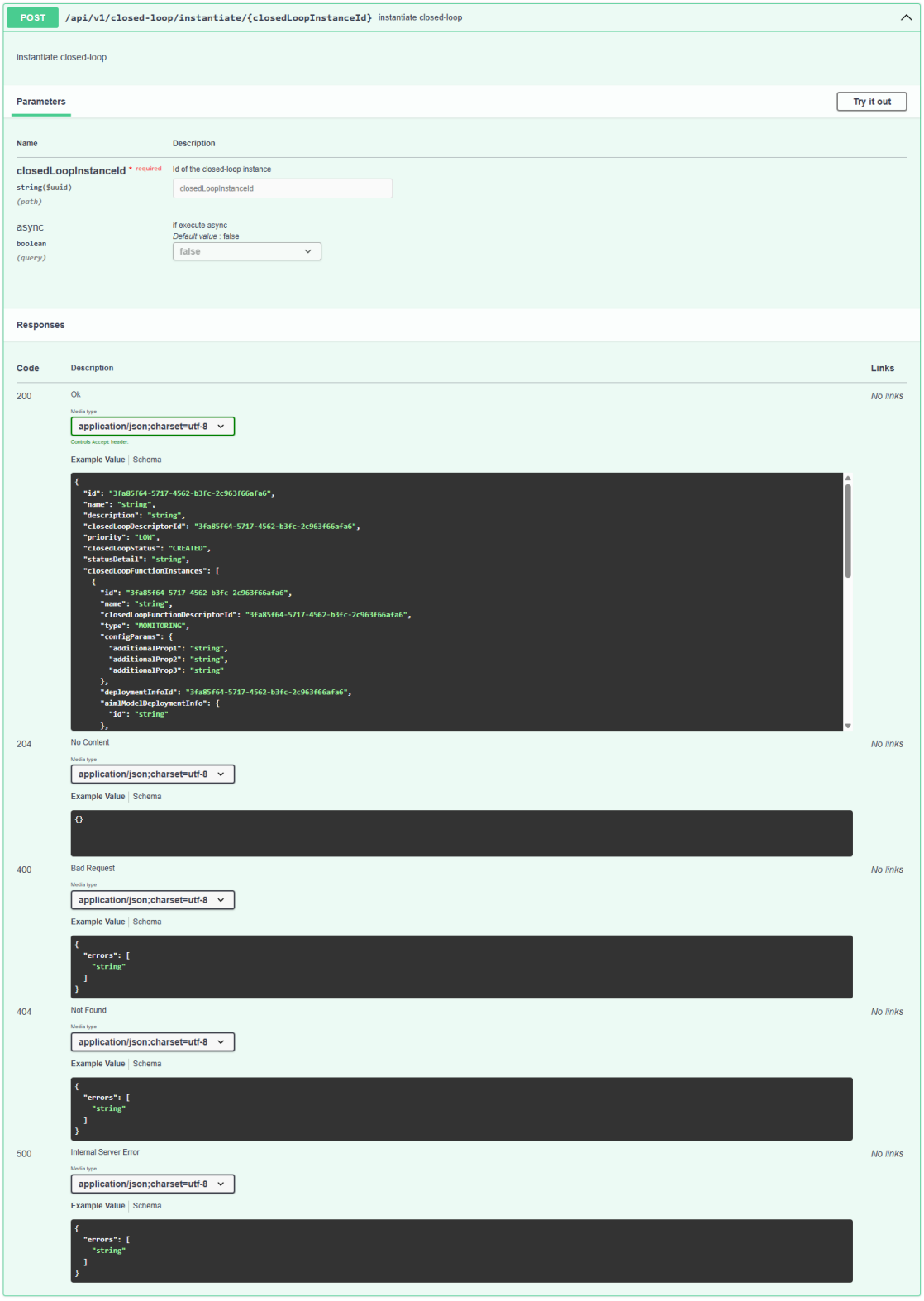
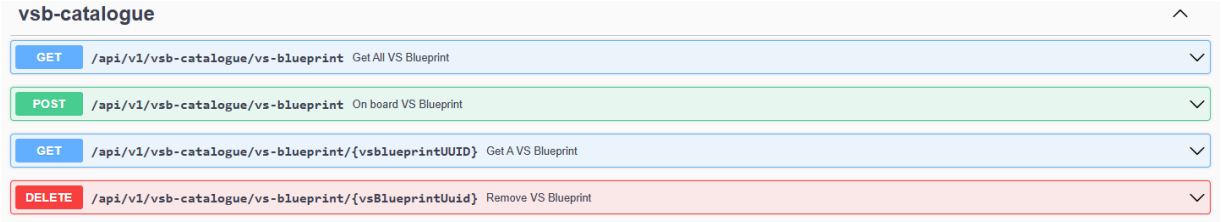


Figure 3-11: Closed-Loop LCM endpoints and API specification for creating and instantiating a closed-loop instance.

Vertical service blueprints were managed through the VSB Catalogue of the Service Orchestrator, which provides endpoints to onboard, retrieve and delete them, as shown in Figure 3-12. A blueprint can be onboarded providing name, version, list of components, list of endpoints, list of connectivity services and the associated closed-loop descriptor. The life-cycle of the service instance of the PoC, associated to the onboarded service blueprint, was managed through the Service LCM (Figure 3-13): the instance can be created providing name, description, the IDs of the linked blueprint and closed-loop descriptor and the list of service components instances; the created instance can then be instantiated by providing its ID. The instantiation of the service triggers also the instantiation of the closed-loop and the deployment of the closed-loop functions and the vertical applications on the Kubernetes cluster.



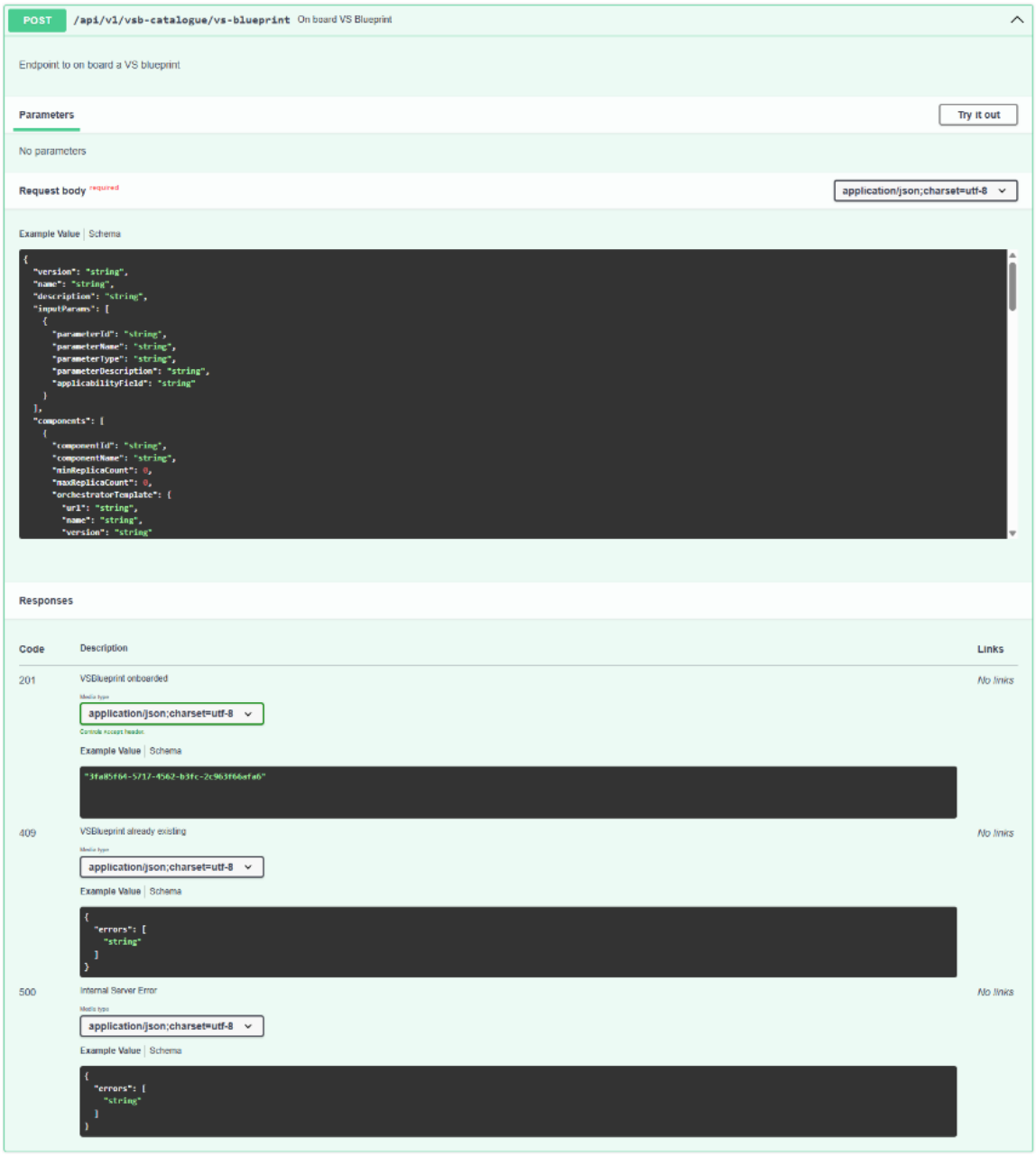
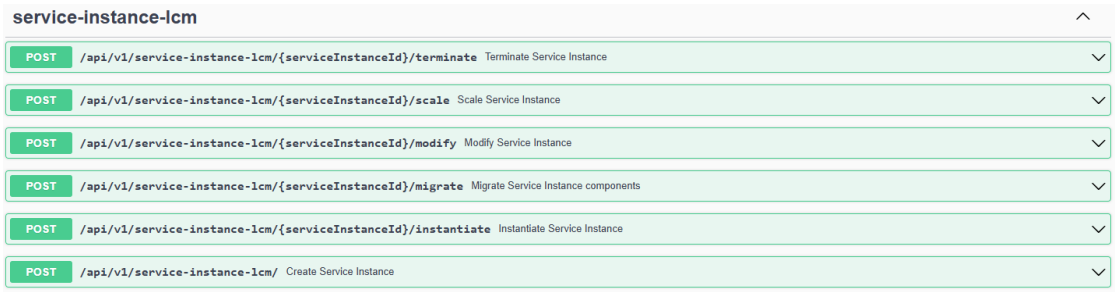
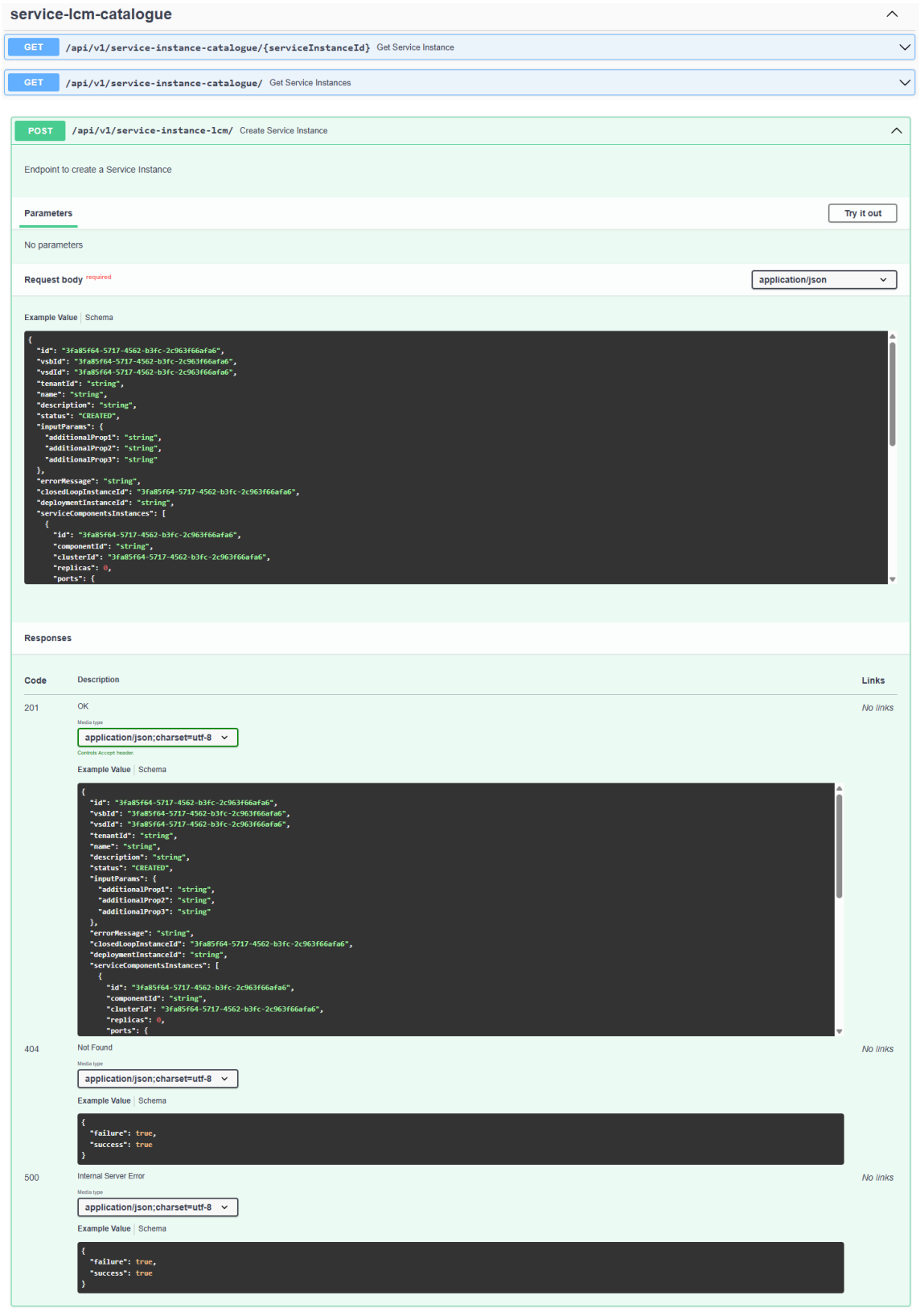


Figure 3-12: VSB Catalogue endpoints and API specification for onboarding new Vertical Service Blueprint.




service-lcm-catalogue
GET /api/v1/service-instance-catalogue/{serviceInstanceId} Get Service Instance
GET /api/v1/service-instance-catalogue/ Get Service Instances
POST /api/v1/service-instance-lcm/ Create Service Instance
Endpoint to create a Service Instance
Parameters
Try it out
No parameters
Request body required
application/json
Example Value | Schema
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"vsbId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"vsdId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"tenantId": "string",
"name": "string",
"description": "string",
"status": "CREATED",
"inputParams": {
"additionalProp1": "string",
"additionalProp2": "string",
"additionalProp3": "string"
},
"errorMessage": "string",
"closedLoopInstanceId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"deploymentInstanceId": "string",
"serviceComponentsInstances": [
{
"id": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"componentId": "string",
"clusterId": "3fa85f64-5717-4562-b3fc-2c963f66afa6",
"replicas": 0,
"ports": {
Responses
Code
Description
Links
201
OK
No links
Media type
application/json;charset=utf-8
Controls Accept header.
Example Value | Schema
404
Not Found
No links
application/json;charset=utf-8
Example Value | Schema
{
"failure": true,
"success": true
}
500
Internal Server Error
No links
application/json;charset=utf-8
Example Value | Schema

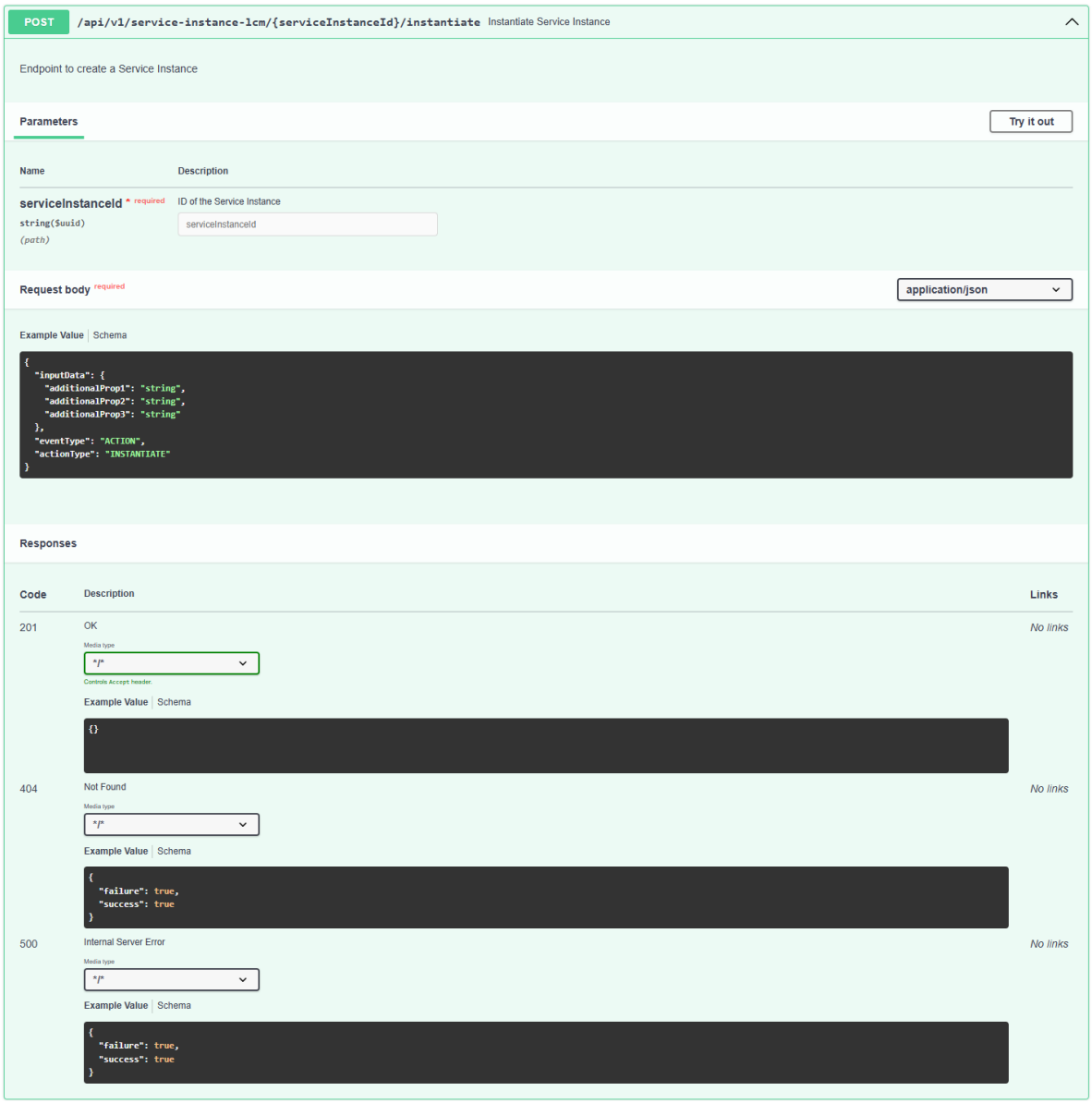


Figure 3-13: Service Instance LCM endpoints and API specification for creating and instantiating a service instance.

3.3.2.2 AI/ML Pipeline Manager & NTN Testbed

Emulation members had Kubernetes agents installed, which in turn allowed for their external management and AI/ML workload (federation) deployment via SOM web interface with already onboarded applications.

The AI/ML models used in the PoC were stored in the Model Catalogue, which provides endpoints for managing the model repository, as shown in Figure 3-14. New models can be uploaded via POST /mlops/models. The API also supports listing (GET /mlops/models), filtering/querying (POST /mlops/models/filter), downloading (GET /mlops/model/download), and deleting (DELETE

/mlops/model/delete) registered models. A model can be uploaded providing the model Name, its purpose as human-readable string, together with a .zip archive containing all required artifacts (class definition, training artifacts as the model weights, model requirements, model details metadata in JSON format, and model additional dependencies as a src.zip archive), as shown in Figure 3-15.

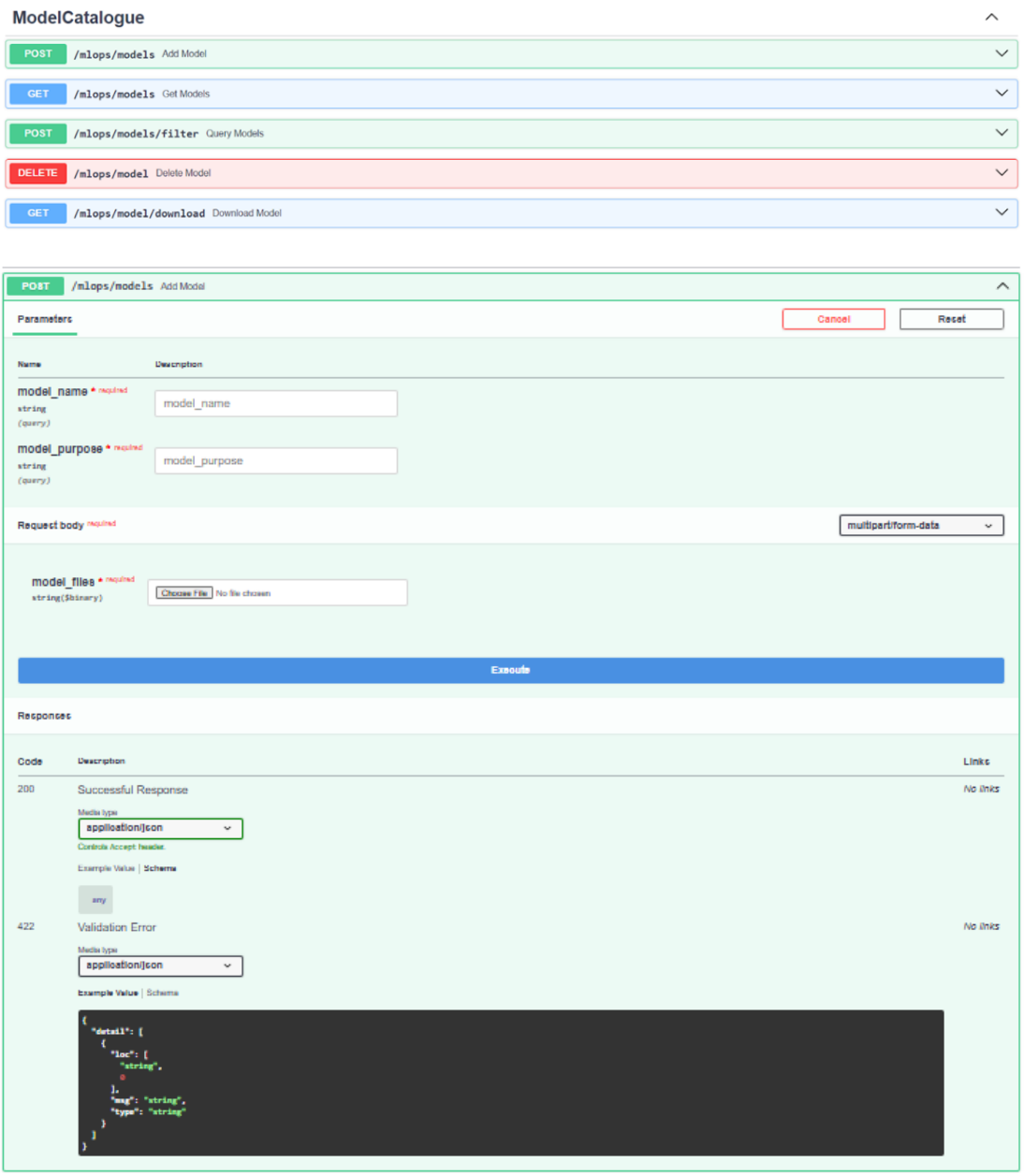


Figure 3-14: Model catalogue endpoints.

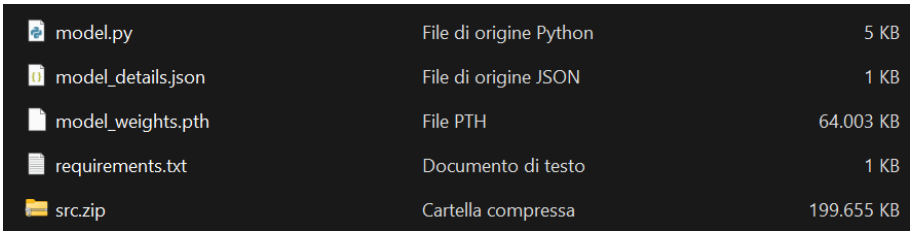
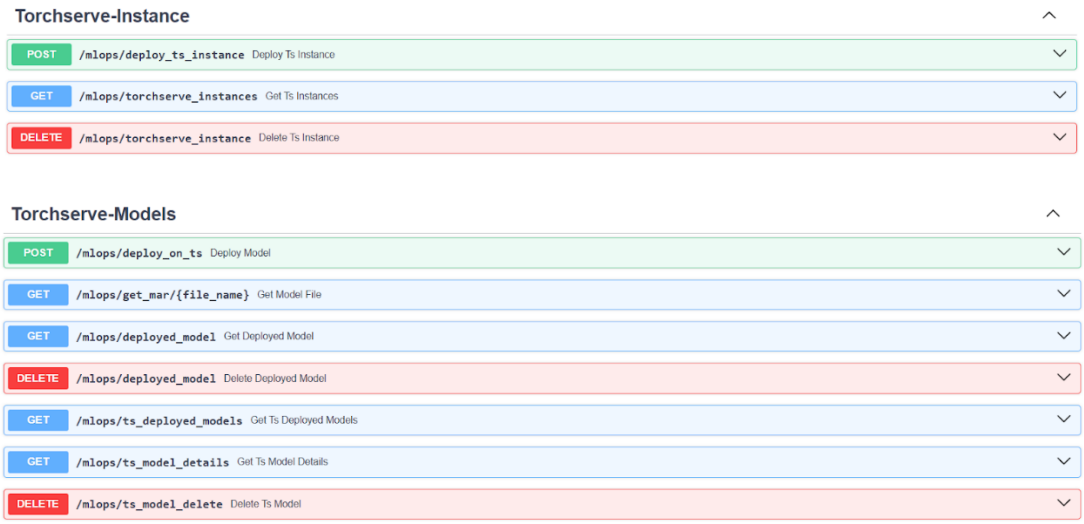


Figure 3-15: File structure for a sample model.

TorchServe [2] was used as inference server, which defines endpoints for deploying and managing TorchServe instances on Kubernetes nodes. Instances can be deployed (POST /mlops/deploy-ts-instance), listed (GET /mlops/torchserve-instances), and removed (DELETE /mlops/torchserve-instance), as shown in Figure 3-16. Each instance exposes management, inference, and metrics interfaces and can be configured with specific CPU/GPU resources and dependency requirements. TorchServe also provides endpoints for managing model deployments on TorchServe instances. Trained PyTorch models can be deployed to a running instance (POST /mlops/deploy-on-ts). The API supports listing deployed models (GET /mlops/ts-deployed-models), retrieving deployment details (GET /mlops/ts-model-details), and un-deploying models (DELETE /mlops/ts-model), as shown in Figure 3-16. A model can be deployed on a TS instance providing the model_id, the ts_instance_id, the name and version for the deployment, and the torchserve handler file together with additional files as model dependencies, and/or data-preprocessing scripts, as shown in Figure 3-16.



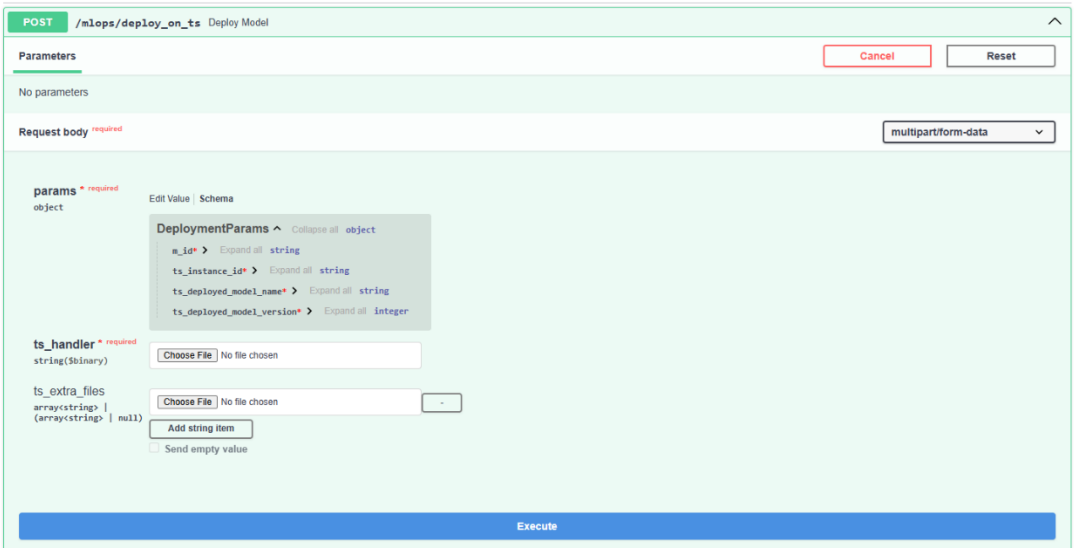


Figure 3-16: Inference server endpoints.

The underlying Kubernetes infrastructure can be investigated through the Infrastructure section of the API, which allows retrieval of node information (GET /mlops/nodes-info) and occupied ports (GET /mlops/occupied-ports), as well as management of worker deployments, including deployment (POST /mlops/deploy-worker), listing (GET /mlops/workers), and deletion (DELETE /mlops/worker), as shown in Figure 3-17.

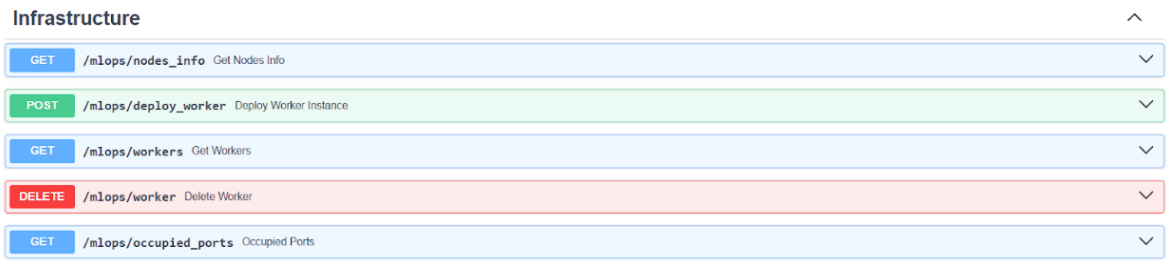


Figure 3-17: Infrastructure endpoints.

The Federation API is also provided, with endpoints for managing federated learning deployments, as shown in Figure 3-18. It supports deployment of new federations (POST /mlops/deploy-federation), listing all federations (GET /mlops/get-all-federations), retrieving specific federation details (GET /mlops/get-federation), and deletion of federation deployments (DELETE /mlops/delete-federation). Additionally, it enables model training across federated nodes (POST /mlops/fl-train). To deploy a new federation is needed to specify the name, the FL framework to be used, and the number of clients and servers that compose the federation.

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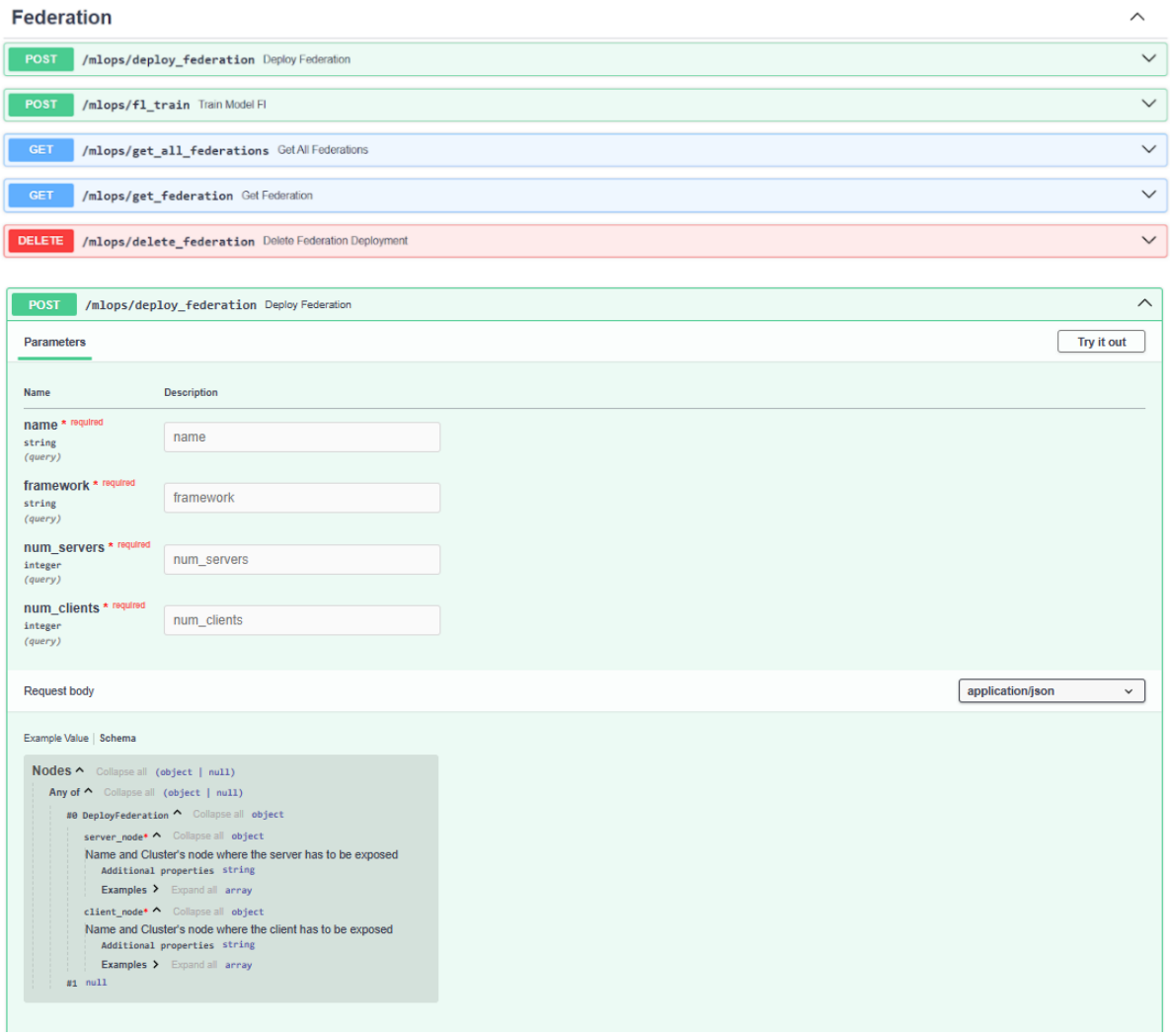

Figure 3-18: Federation endpoints.

3.3.2.3 Predictive Monitoring and SLA Offering Solutions & NTN Testbed

InfluxDB served as a mediator for data flow integration, NTN Testbed database address and access tokens were integrated into Predictive Monitoring and SLA Offering Solutions components to access as clients and consume monitoring data. Figure 3-19 shows a real-time data stream sample, used by the models for inference.

table mean	_measurement group string	_field group string	_value no group double	_start group dateTime:RFC3339	_stop group dateTime:RFC3339	_time no group dateTime:RFC3339	satellite_id group string
0	satellite_data	distance_time	13.99606656101422	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-12T06:16:00.000Z	100
0	satellite_data	distance_time	13.572387820825625	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-14T09:00:00.000Z	100
0	satellite_data	distance_time	13.039463065408377	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-16T11:44:00.000Z	100
1	satellite_data	distance_time	13.315228771640566	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-12T06:16:00.000Z	102
1	satellite_data	distance_time	13.386038219150217	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-14T09:00:00.000Z	102
1	satellite_data	distance_time	13.250271761765909	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-16T11:44:00.000Z	102
2	satellite_data	distance_time	13.471088733798611	2023-09-23T07:16:48.000Z	2025-10-23T07:16:48.179Z	2024-12-12T06:16:00.000Z	103

Figure 3-19: InfluxDB data model for the NTN Testbed to Predictive Monitoring and SLA Offering Solutions interface.

Inference results were pulled by the native component API, as well as requested SLA violation rates. Testbed adaptor then used inference information to adapt the PoC application deployment through testbed's native resource manager.

3.3.2.4 UE-VBS Component & BDIx Agents & NTN Testbed

Beliefs, including location and line-of-sight information, were first randomly generated and retrieved from a csv file on the shared memory. For Testing Cycle 2, dynamic information retrieval was performed via an http API by every UE individually. BDIx agents pulled their location and connectivity as a beliefs query on a timeout, configurable in the agent config file. The API for location fetching is shown on Figure 3-20.

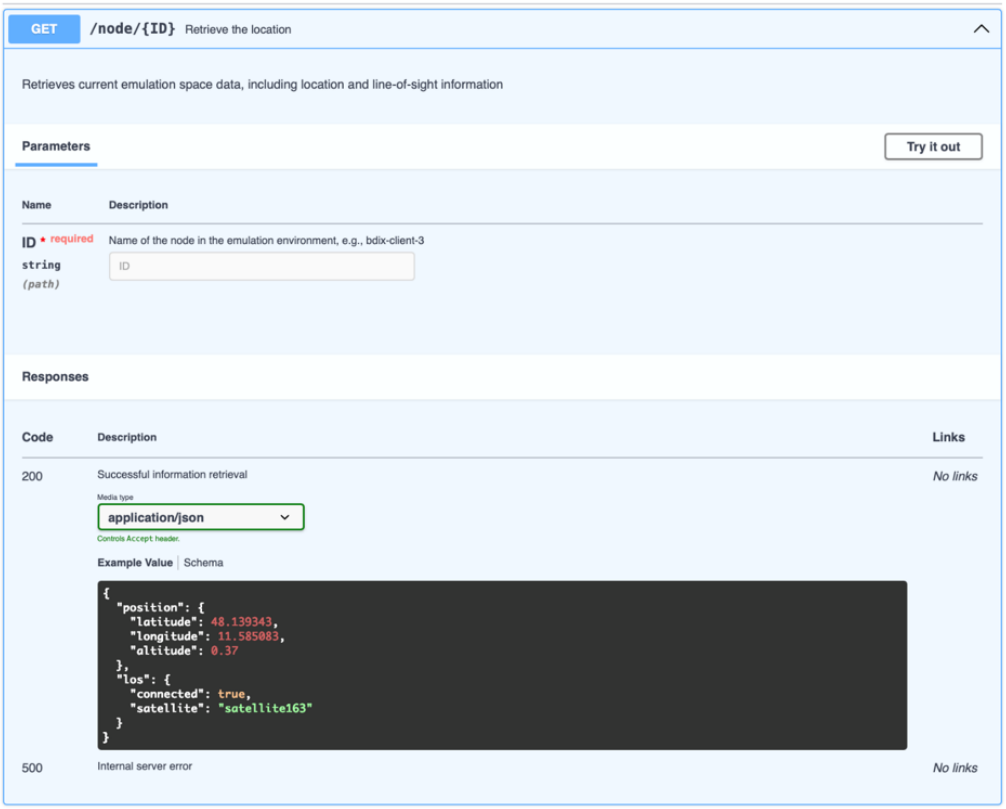

Figure 3-20: API specification for the NTN Testbed to UE-VBS Component & BDIx Agents interface

Upon successful belief loading, BDIx Agents then used emulation level information to form a topological connection tree of UE-VBS and relays. The resulting tree is exposed on an http endpoint (GET /uedata/tree) of topology module. Our testbed adaptor then fetched this endpoint periodically and used that data to create or delete emulation links between UEs. As a result, decisions of BDIx agents directly affected emulation environment topology.

3.4 PoC-3 – Collaborative Construction Robots

PoC-3 focuses on using 6G communication technology to automate modern construction sites by using mobile wheeled robots and aerial drones. A key innovation is the autonomous coordination between these robots and drones, enabled by 6G technology for precise communication and positioning. This coordination is crucial for synchronizing tasks like lifting, loading, and navigating, ensuring safety and efficiency.

3.4.1 Component deployment

The following table provides an overview of the key PoC3 components relevant for Testing Cycle 2. For each component, it lists the main models and algorithms implemented (as referenced in deliverables D3.2 and D4.1), along with the current deployment status and a brief description of its integration in the testbed. This summary clarifies which functionalities are already deployed and configured for

testing and identifies any components or features that are not included in the current PoC3 implementation.

Table 11: Components that Need to Work in Synergy to Achieve PoC-3 - deployment status

PoC Component	Models and Algorithms related to the component as per D3.2 and D4.1	Deployment Notes
AI-Driven Management & Orchestration Framework		
Closed-loop Governance (CLG)	Extends the concepts in ETSI GS ZSM 009-2 for deploying and overseeing M&O closed-loop functions in zero-touch automation	Containerized component was deployed on the testbed, configured and instantiated.
Service Orchestration & Management	Enhanced capabilities for service and application components deployment and operation on top of (extreme-edge)/edge/cloud computing continuum resources	Containerized component was deployed on the testbed, configured and instantiated.
BDI - & AI-driven Unified & Open Control Operations		
BDIx Agents Control & Logic Re-config (Real-Time Close Loop)	BDIx (Beliefs, Desires, Intentions, and Plan Library) as Real-time closed-loop Functions (D4.1), composed of: Adaptive neuro-fuzzy inference system (ANFIS) model/approach within BDIx framework (D4.1) and DAIS Transmission Mode Selection Algorithm under "Select the best Transmission Mode" Desire (D4.1)	Containerized component was deployed on the testbed, configured and instantiated.
UE-VBS Computing Resource Control (Real-Time Close Loop)	UE-VBS Component functionality (i.e., mBS)	Standalone component was deployed and configured in the testbed, in Windows environment, connected to other components in the testbed.
Joint RAN & x-Edge Resource scheduling	DFBNN-FL: Autonomous Radio Resource Management in D2D Communications Using	Not included in PoC3.

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	Federated Learning and Deep Feedback Neural Networks within the DAI Framework. It is an Energy-Efficient Edge Resource Management in Multi-User Goal-Oriented Communication(D3.2, D4.1)	

Figure 3-21 presents the final deployment diagram, outlining where the key PoC components are placed on the ORO testbed.

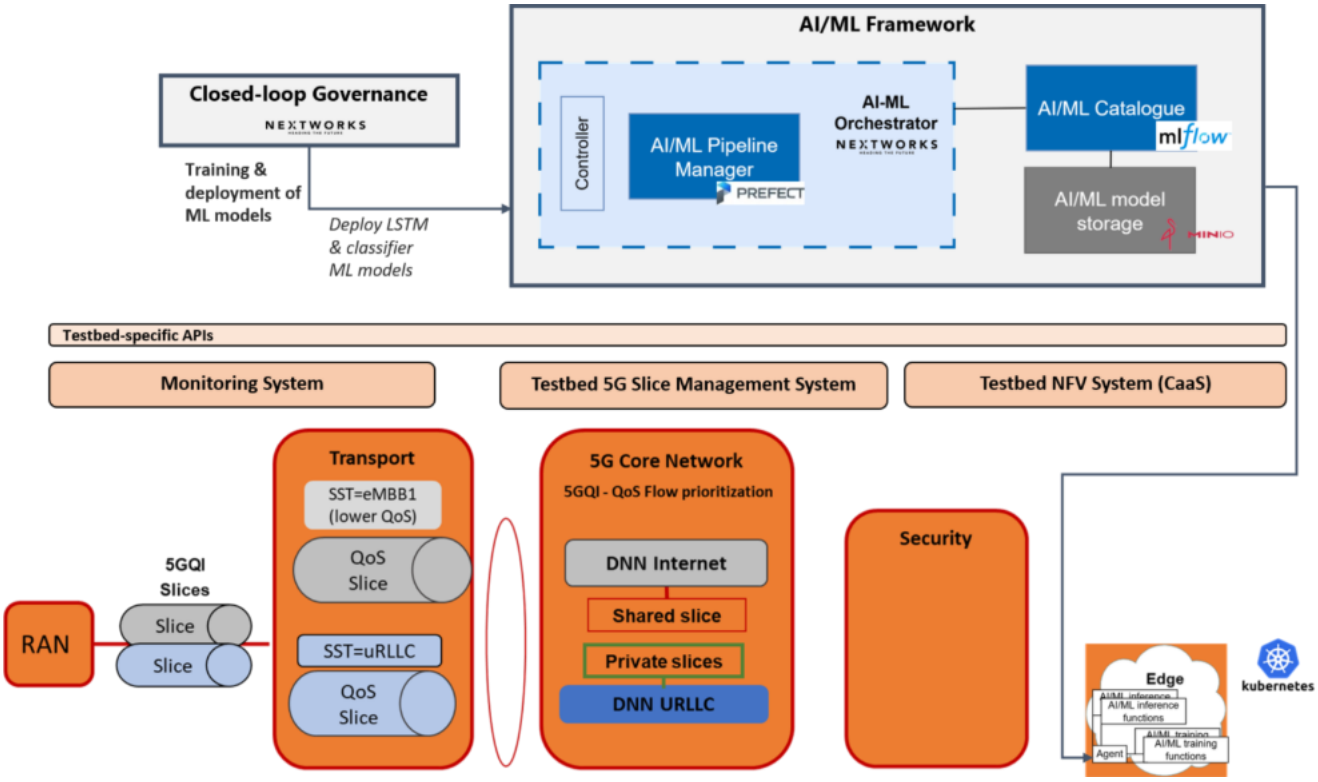

Figure 3-21: PoC3 components' final deployment on the ORO testbed.

3.4.2 Technical Details of Additional Inter-Component Integration

The table below outlines the technical integration details for key PoC3 components involved in Testing Cycle 2. It specifies which components communicate with each other, the interfaces or protocols used, and the actual status of each integration. References for relevant documentation sections are also provided. This summary highlights the maturity and readiness of inter-component communication, ensuring that all critical integrations are completed and aligned with the requirements for the ongoing testing activities.

Table 12: PoC-3 components integration and communication.

Component	Communicates with	Status	Reference
AI-driven Management and Orchestration framework			
Closed Loop Governance (CLG)	BDIx Agents through in-house MQTT	Completed	3.3.2.1 (same APIs and features as PoC#2b)
M&O Closed Loop Functions	Service/Resource/Slice Orchestrators	Completed	3.3.2.1 (same APIs and features as PoC#2b)
Resource Orchestration /Management	Edge (UE-VBS) nodes	Completed	3.4.2.1
Fully Distributed and secure AI/ML Framework for CrowdSourcing AI			
AI/ML Pipeline Manager	AI/ML Orchestrator (API), deployed containerized agents (API)	Completed	3.3.2.2 (same APIs and features as PoC#2b)
AI/ML Catalogue	AI/ML Orchestrator (API), deployed containerized (k8s) pipelines (API) Completed	Completed	3.3.2.2 (same APIs and features as PoC#2b)
UE side			
BDIx Agents	AgentSpeak/AgentACL/JASON/FIPA ACL (one of these agent languages), N1 Protocol	Completed	D2.3 section 3.3
Collaborative Robots	RADIO, EDGE	Completed	**Error! Reference source not found.**
BDI - & AI-driven Unified & Open Control Operations			
BDIx Agents Control	BDIx Agents	Completed	D2.3 section 3.3

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& Logic Re-config (Real-Time Close Loop)			
UE-VBS Computing Resource Control (Real-Time Close Loop)	BDIx Agents	Completed	D2.3 section 3.3

Intercomponent interactions are illustrated on the Figure 3-22.

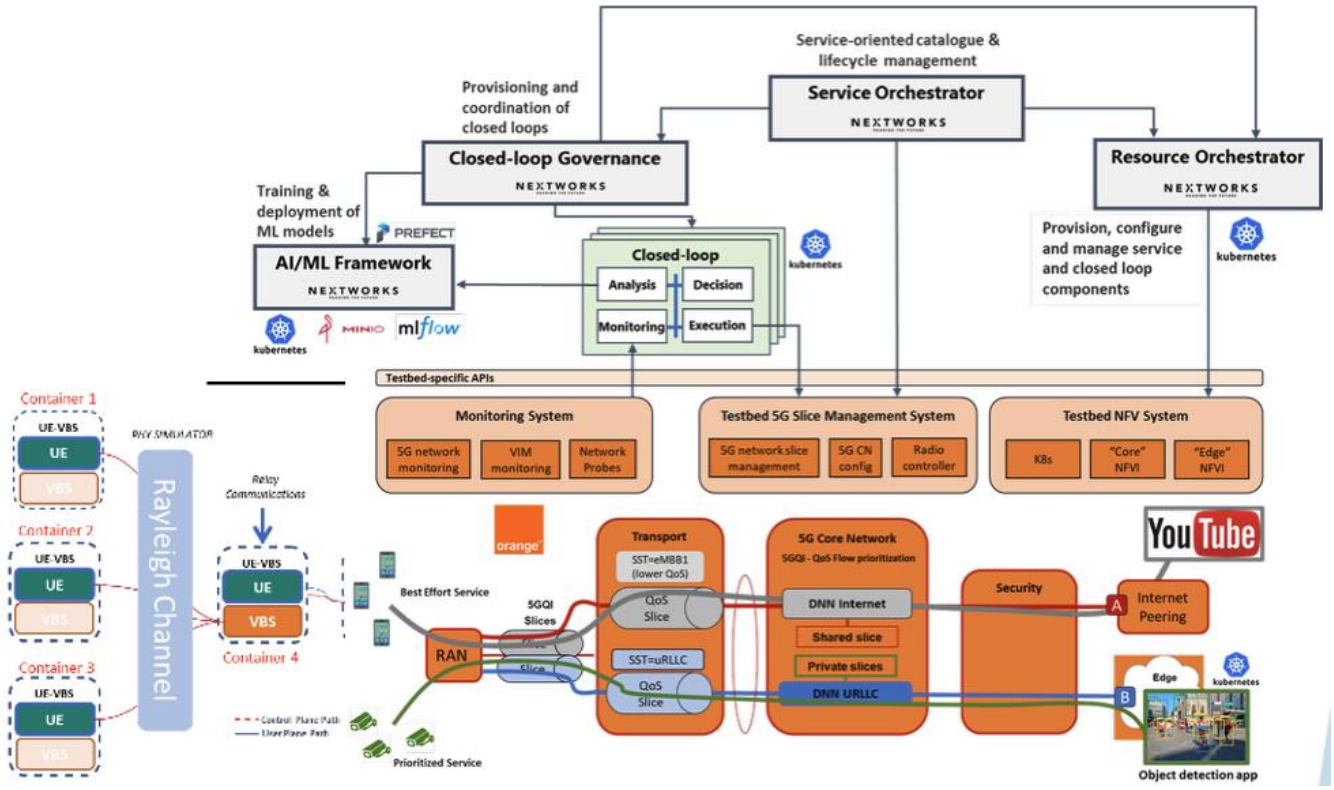


Figure 3-22: PoC3 components' interactions on the ORO testbed.

3.4.2.1 Resource Orchestration/Management & ORO Testbed

The computing resources where to deploy PoC services were managed through the Platform Manager and the Resource-Inventory of the Resource Orchestrator (Rec-Exec): the former provides endpoints to upload, remove and get information about Kubernetes platforms, as shown in Figure 3-23, the latter provides the same operations for Kubernetes clusters and nodes, as shown in Figure 3-24. A platform can be uploaded providing name and description, together with configuration, type and status of the platform (Figure 3-23); a cluster can be onboarded providing name, description and list of nodes that compose it (Figure 3-24).

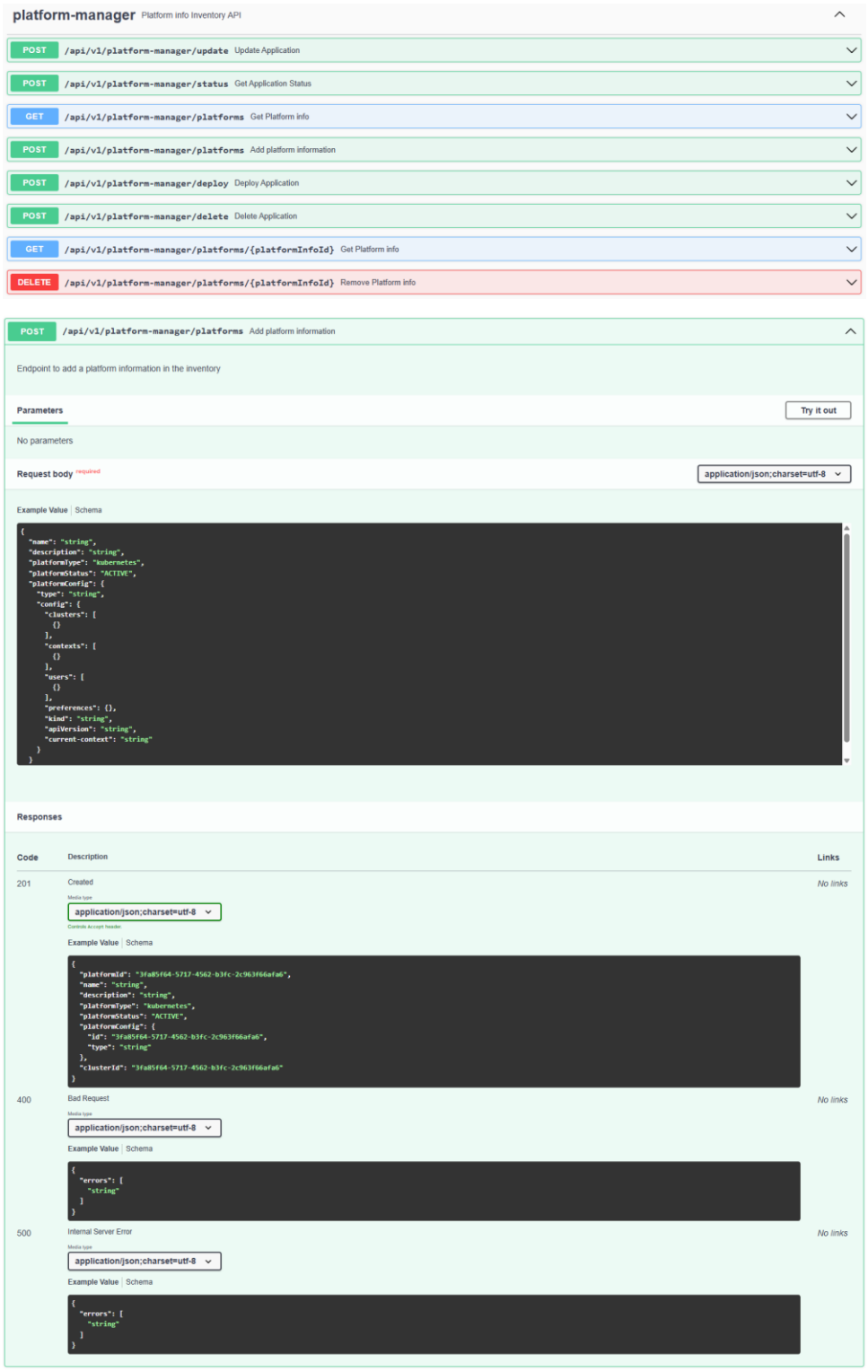


Figure 3-23: Platform Manager endpoints and API specification for adding platform info.

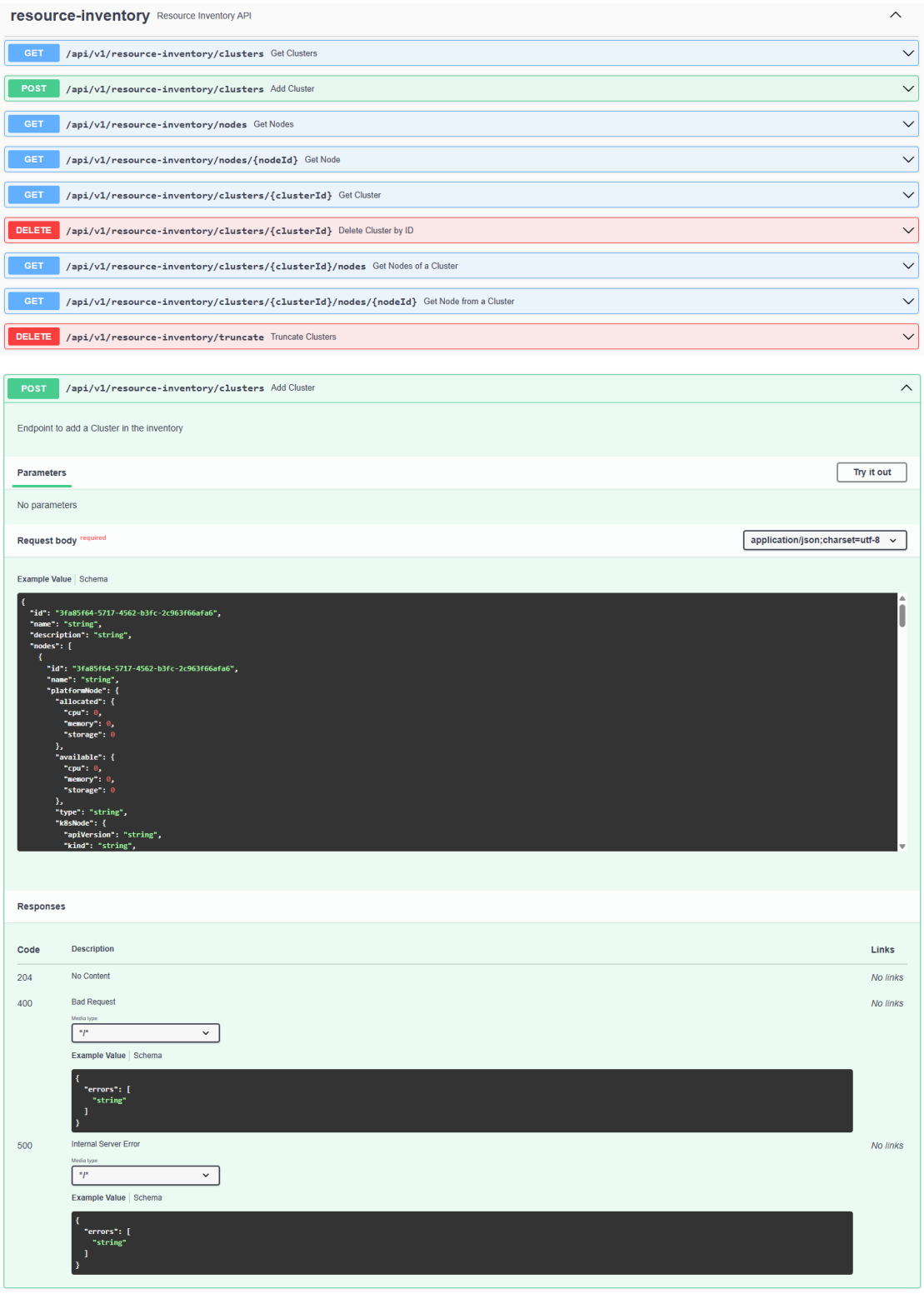
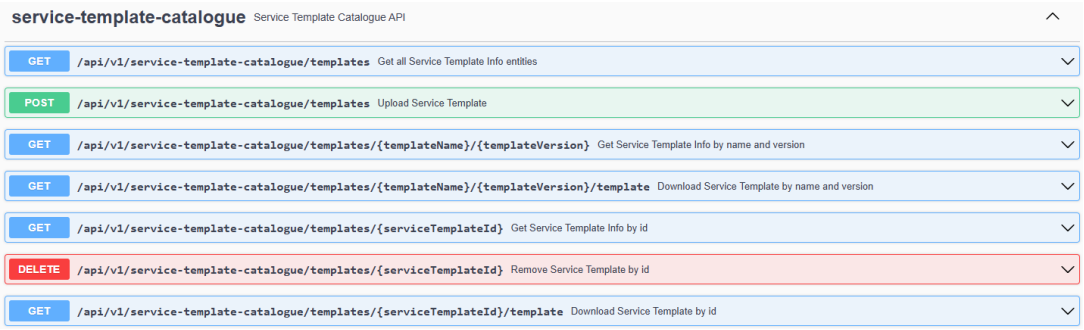


Figure 3-24: Resource Inventory endpoints and API specification for adding new cluster.

PoC services were managed through two more modules of the Resource Orchestrator (Rec-Exec): the Service Template Catalogue, in charge of onboarding, querying info, downloading and removing their templates from the repository (Figure 3-25), and the Service Deployer, responsible for their deployment on the active Kubernetes cluster (Figure 3-26). A service template can be uploaded providing name, version and type together with a zip file (Figure 3-25); it can be then deployed providing the service name, the cluster ID and the list of atomic components (Figure 3-26).



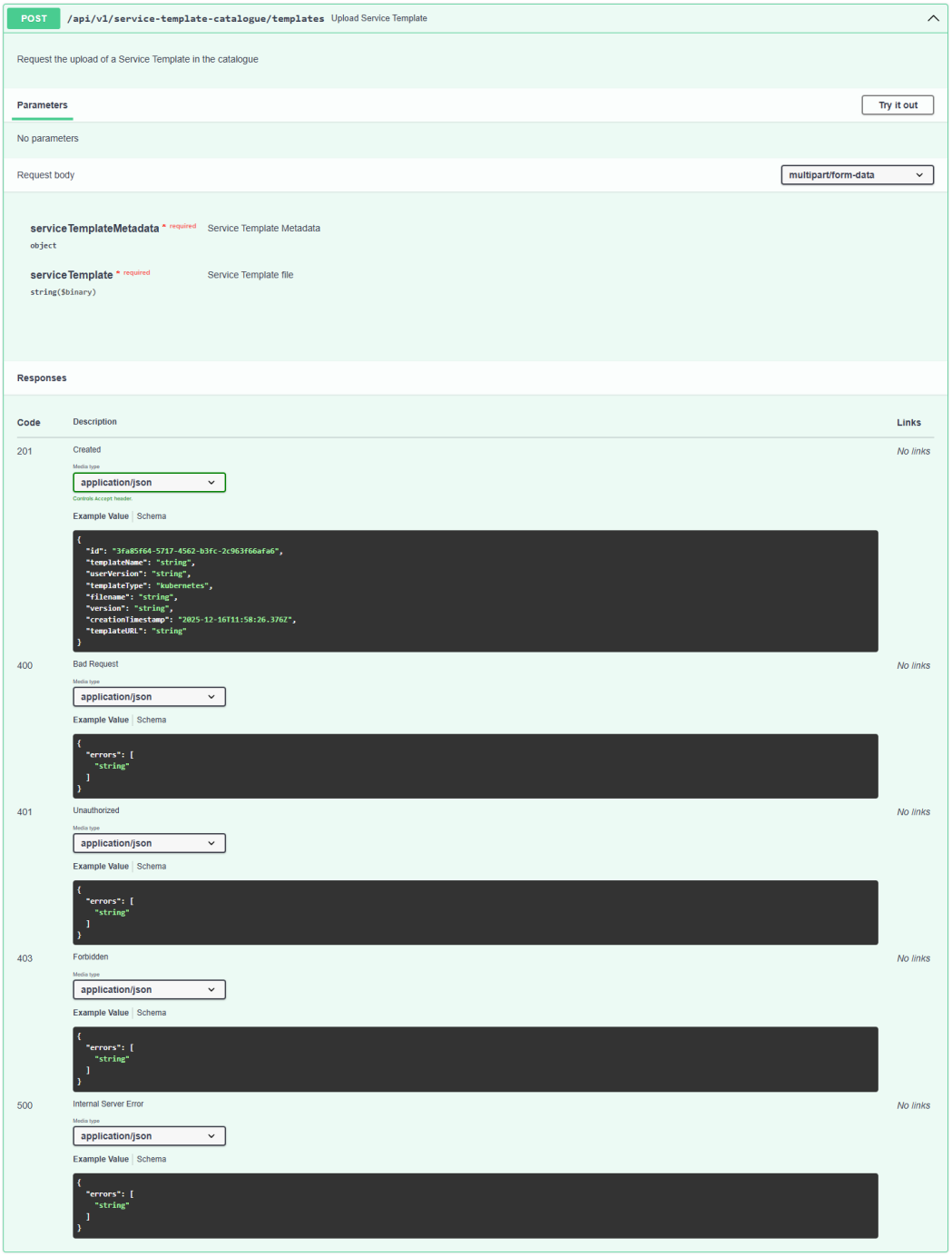


Figure 3-25: Service Template Catalogue endpoints and API specification for adding new service template.

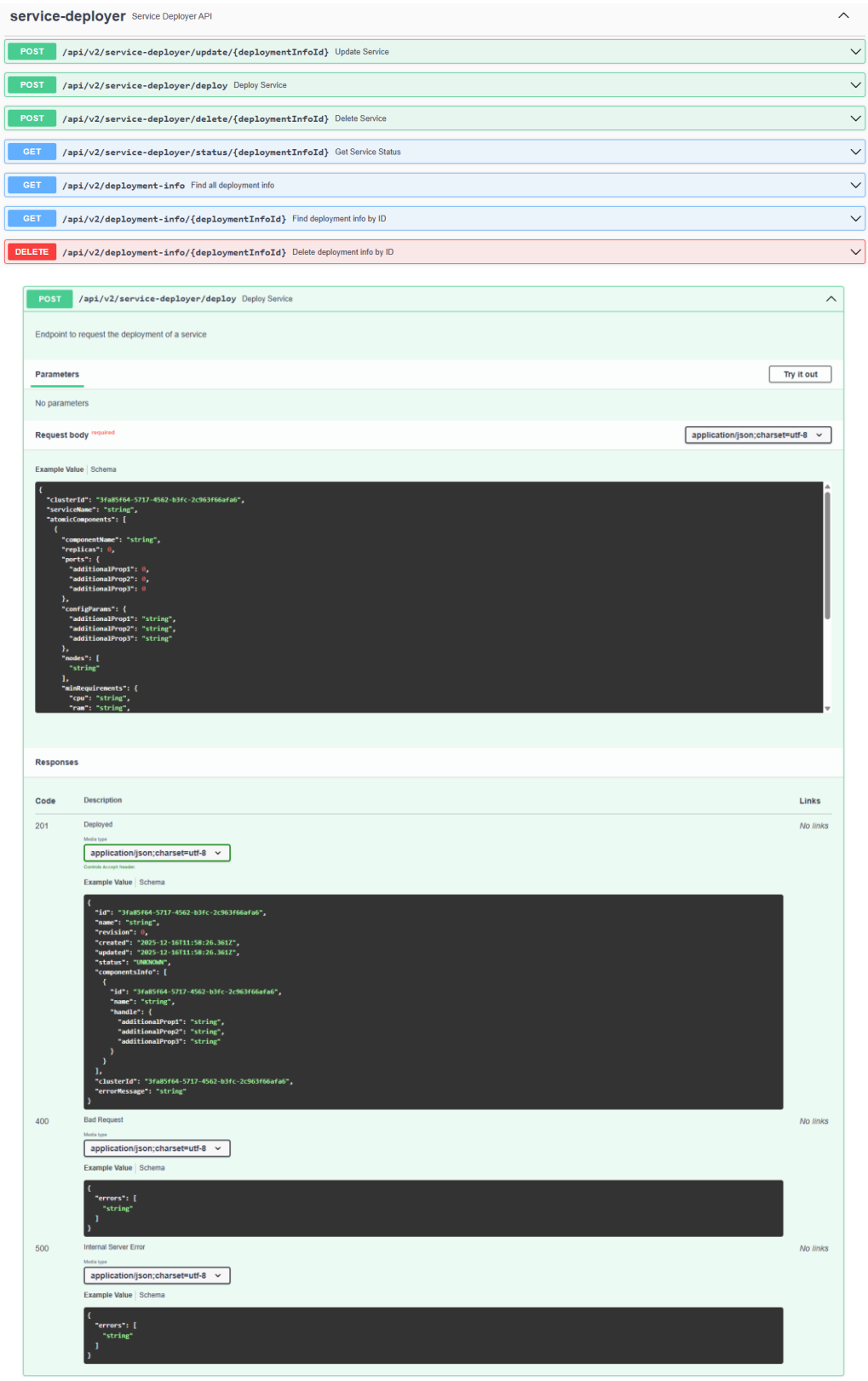


Figure 3-26: Service Deployer endpoints and API specification for deploying a service.

4 Conclusions

This deliverable presents an updated report of the integration activities and testbed deployment, building as an iteration over the previous deliverable D5.1. In particular, it emphasizes newly achieved outcomes in interface enhancements, expanded integration of ADROIT6G components, and the targeted resolution of gaps previously identified in D5.1 and during *Testing Cycle 1*.

The project continues to advance across its defined PoCs: (i) holographic teaching, (ii) terrestrial 6G IIoT featuring extreme mMTC, (iii) railway automation supported by NTNs, and (iv) collaborative construction robots. Progress in this phase has involved updating the testbed environments to accommodate revised architectural and component requirements, while extending APIs and inter-component interfaces in line with the lessons learned from earlier test cycles.

The previous identified gaps and subsequent mitigation measures have strengthened the alignment of testbed capabilities with the ADROIT6G architecture and the needs of the targeted PoCs. Each PoC implementation has been iteratively refined, incorporating feedback and key integration insights, thereby improving the overall technical readiness of the solution stack. The integration decisions for ADROIT6G components and algorithms have been re-evaluated and updated as necessary, with new and existing components now being integrated through enhanced dry-run procedures on the upgraded testbeds.

The iterative validation process remains organized into two main testing cycles:

1. *Testing Cycle 1* has concentrated on component-level and initial integration validation, addressing isolated technical and interoperability gaps while providing a preliminary assessment of KPIs.
2. *Testing Cycle 2* is focusing on comprehensive system-level and end-to-end validations, leveraging the integrated ADROIT6G components and upgraded testbed environments to measure improvements against state-of-the-art baselines and further assess KPI/KVI advancements.

With the conclusion of this deliverable, the project enters the next phase of validation and experimentation, equipped with refined integrations and closed gaps. These advancements set the stage for thorough evaluation and final KPI/KVI measurement, as will be detailed in the upcoming WP5 deliverables D5.4 and D5.6.

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References

[1] ADROIT6G Consortium, "D5.1 Report on integration and testbeds deployment in lab settings - Initial", 2024.
[2] TorchServe, [Online]. Available: https://docs.pytorch.org/serve/