Partners: ATO, ASA, CTT, IMEC, NXW, TID, OPT, TNO, ICC, UC3, WIN, EBY

Hexa-X-II

D6.3 Summary Slides: Initial Design of 6G Smart Network Management Framework

hexa-x-ii.eu

Executive summary

Second public deliverable released by the “Smart Network Management” Work Package in Hexa-X-II project

Contribution to the 2^{nd} iteration of the Hexa-X-II end-to-end system blueprint, with a consolidated design of **Management and Orchestration (M&O) technical enablers**.

Updated categorization and structure of M&O enablers, with analysis of their **role and complementary contributions to Hexa-X-II Smart Network Management system**.

Mapping of M&O enablers to Hexa-X-II design principles and 6G stakeholders, innovations towards 6G networks and impact on **KPIs/KVIs**.

The core of the deliverable describes **8 M&O enablers**, some of them organized in sub-enablers, providing:

(i) **technical foundations** for programmable network configuration and monitoring, capability exposure, synergetic orchestration across multi-domain continuum, and zero-touch network automation,

(ii) transversally supported by **advanced techniques** for security and trustworthiness, AI/ML algorithms, and network digital twins.

M&O enablers are presented in terms of (i) technical approach and enabler design, (ii) ongoing implementation, (iii) early validation results, and (iv) impact to KPIs/KVIs. Several M&O enablers are integrated in Hexa-X-II **Proof of Concepts (PoC).**

Analysis of alignment with end-to-end system blueprint as **key contribution towards Hexa-X-II system design**.

Table of Content

Introduction

Objective of the document

The overall objective of D6.3 is to provide the **design, initial implementation, and early validation results of M&O enablers** that are being implemented as part of the **smart network management** sub-system in Hexa-X-II project.

- Evolution and restructuring of M&O enablers defined in D6.2 [HEX223-D6.2]
  - Consolidated design
  - Initial implementation and early validation, contributing to Hexa-X-II PoCs
  - Impact on KPIs/KVIs
  - Alignment with Hexa-X-II E2E system blueprint
- Intermediate milestone towards definition of M&O system for future 6G networks
  - Aligned with the inter-WP and multi-cycle methodology defined in Hexa-X-II to build the E2E system blueprint
  - Contribution to 2nd iteration bringing lessons learnt from early implementation, validation and initial PoC integration

The output of this document will be considered into the next design iteration of the Hexa-X-II end-to-end system design in a bottom-up approach.

Smart Network Management

Methodology

D6.3 as a key contribution to the 2nd iteration between WP6 and WP2 for the design of the Hexa-X-II 6G E2E System Blueprint

Global framework for Smart Network Management:

- Contributions to Hexa-X-II architecture design principles
- Mapping with 6G stakeholders
- Innovations towards Hexa-X-II M&O framework

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Design, implementation and early validation of M&O enablers

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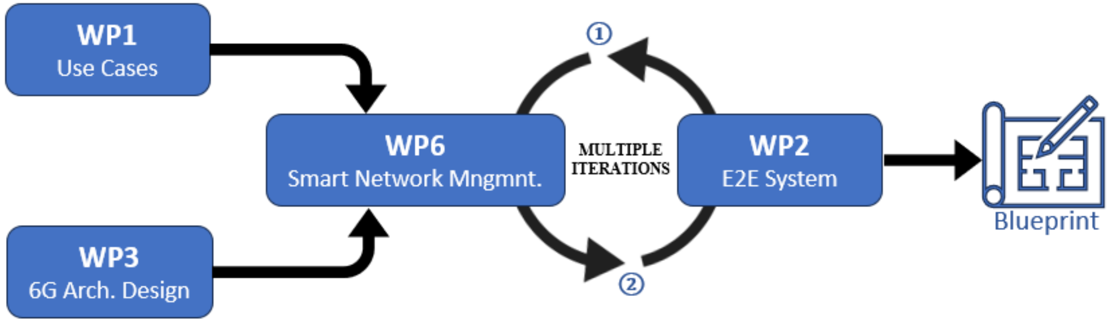
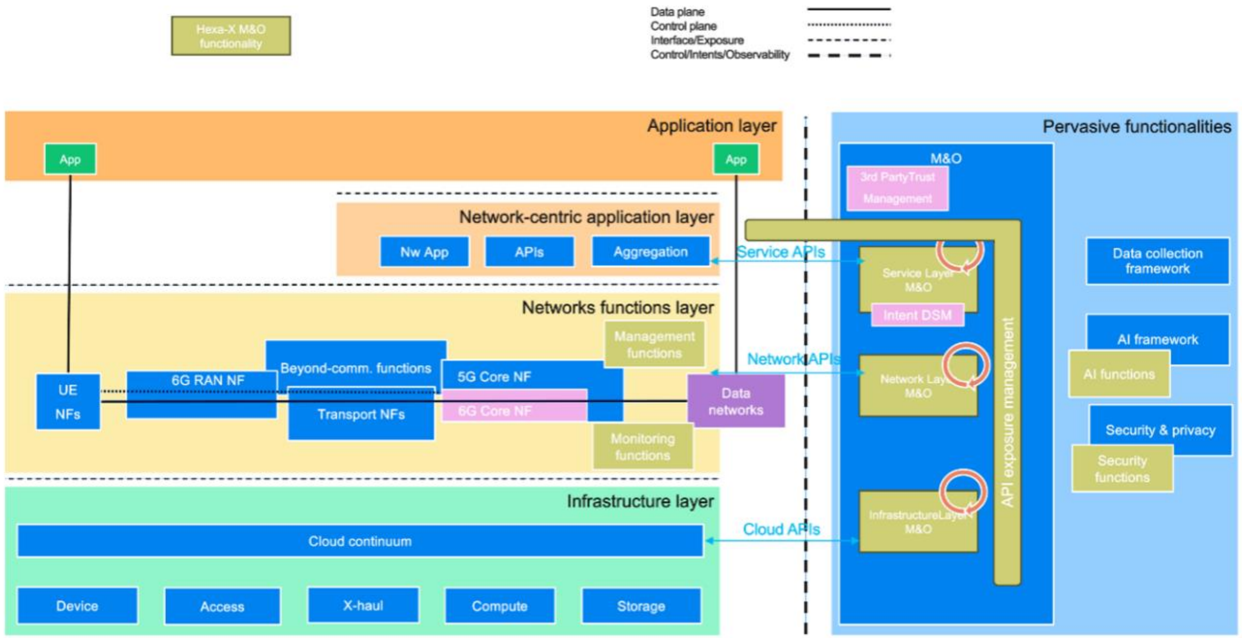
Alignment of M&O enablers with E2E system blueprint

- Mapping over existing components
- Gap analysis for features, components and interfaces
- Feedback on alternative architectural choices



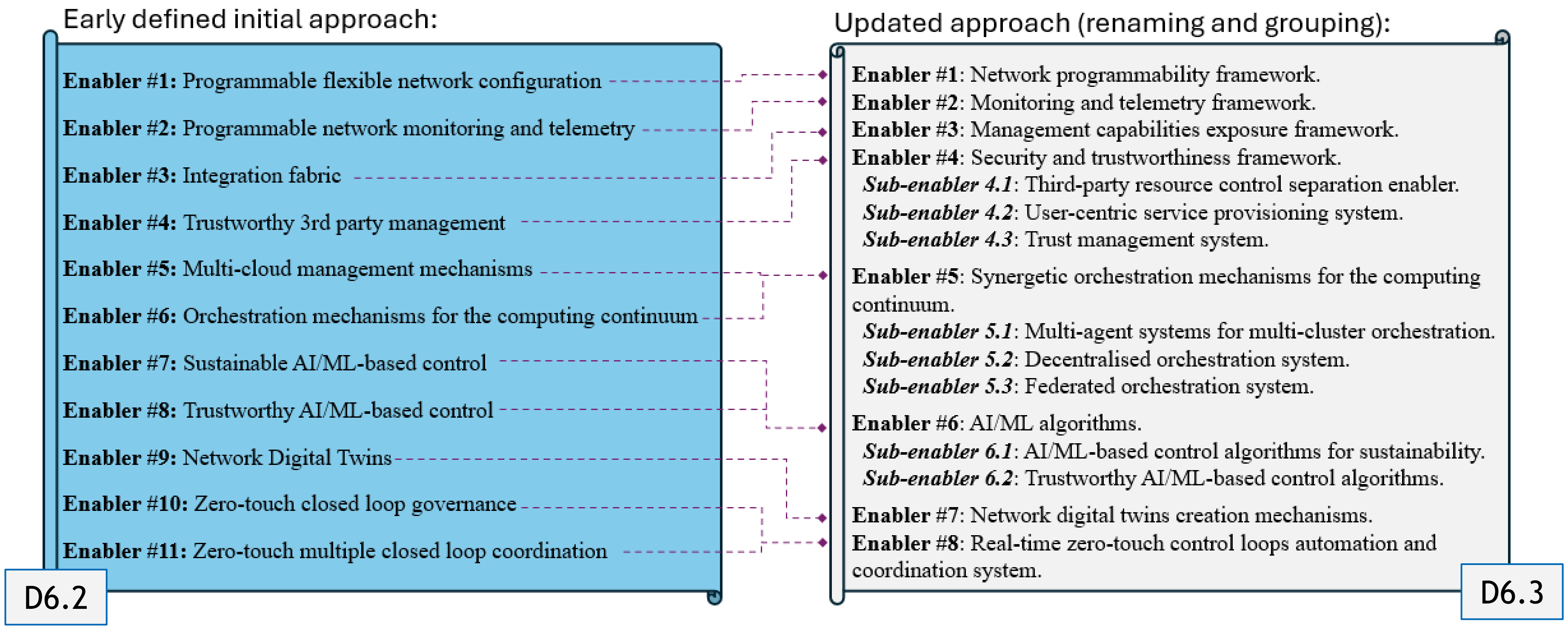
WP6 interactions with other Hexa-X-II WPs



Hexa-X-II E2E system blueprint provided by WP2

M&O Technical Enablers

- Restructuring and evolution of M&O technical enablers from Deliverable D6.2
  - System-oriented approach, identifying artifacts, mechanisms and systems to provide M&O functionalities
  - Consolidation and aggregation of enablers, introducing sub-enabler concept to differentiate among complementary technical aspects



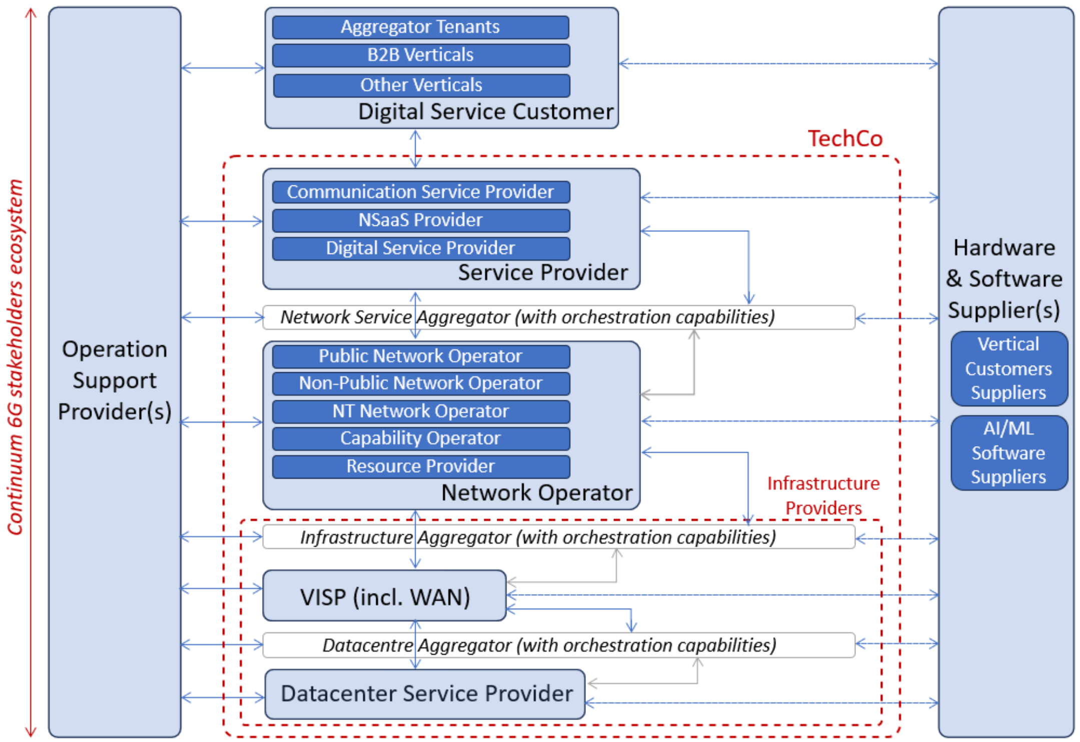
M&O enablers re-definition

Mapping with Hexa-X-II architecture design principles

WP6 Enablers ↓ / Design principles →	Principle 1	Principle 2	Principle 3	Principle 4	Principle 5	Principle 6	Principle 7	Principle 8	Principle 9	Principle 10
1: Network programmability framework		◆	◆	◆	◆		◆			
2: Monitoring and telemetry framework		◆	◆							◆
3: Management capabilities exposure framework	◆		◆				◆			
4: Security and trustworthiness framework										
4.1: Third-party resource control separation enabler					◆	◆		◆		
4.2: User-centric service provisioning system			◆			◆				
4.3: Trust management system						◆				
5: Synergetic orchestration mechanisms for the computing continuum										
5.1: Multi-agent systems for multi-cluster orchestration	◆	◆	◆				◆			◆
5.2: Decentralised orchestration system	◆	◆	◆	◆	◆		◆	◆		◆
5.3: Federated orchestration system	◆	◆	◆							
6: AI/ML algorithms										
6.1: AI/ML-based control algorithms for sustainability		◆	◆							◆
6.2: Trustworthy AI/ML-based control algorithms					◆	◆				
7: Network digital twins creation mechanisms	◆	◆								
8: Real-time zero-touch control loops automation and coordination system		◆		◆						

Mapping with 6G stakeholders

- Roles already considered for 5G systems
  - Service Providers, Network Operators, Virtual Infrastructure Service Providers, Data Centre Service Providers
- New 6G specific roles (aligned with D2.2):
  - Capability Operator (COP)
  - Resource Provider
  - TechCos
  - Service Customers
    - Aggregator Tenants (e.g., Hyperscalers, Marketplaces, Telco Consortium)
    - B2B Verticals, including vertical industries following B2B model and Application Service Providers following B2B2C model



Roles towards 6G

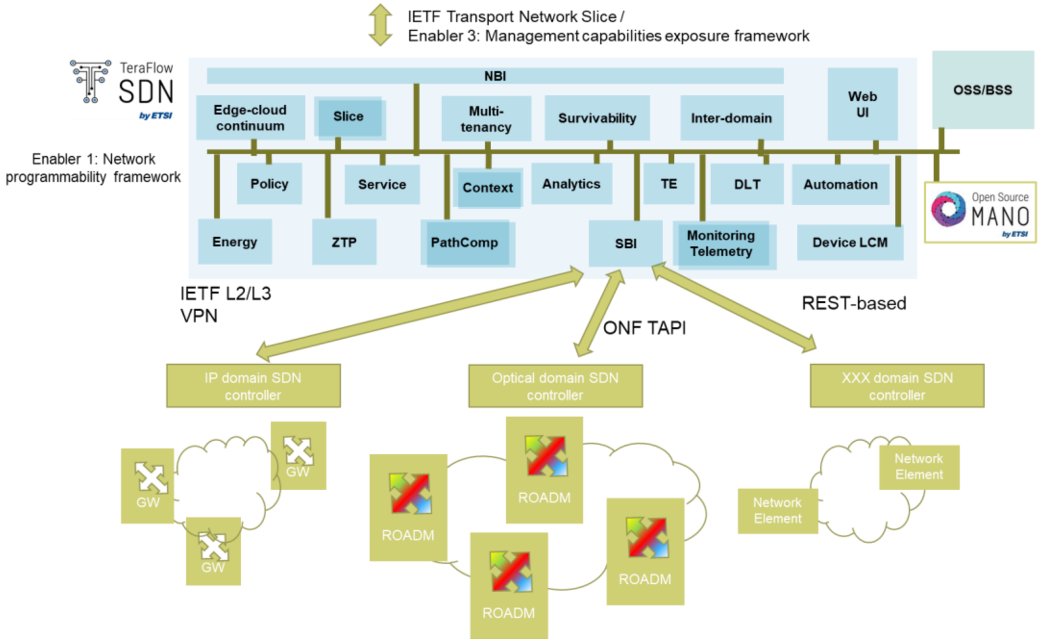
Innovations towards Hexa-X-II M&O framework

- **Enabler 1:** SDN-based transport network control alignment with cloud-native approach and cloud continuum concept, with interfaces for new devices supporting disaggregation of network elements in whiteboxes and network operating systems.
- **Enabler 2:** Monitoring and telemetry framework for future 6G networks, with scalable, multi-source, data- and event-driven approaches and capable of supporting tracking of energy usage.
- **Enabler 3:** Dynamic and automated registration and discovery of network elements and services, in cloud-native and multi-stakeholder environments.
- **Enabler 4:** Granular access control for efficient support of multi-tenancy, personalized and user-centric service definition with automated management of SLAs enriched with trustworthiness KVIs, estimation and management of trustworthiness.
- **Enabler 5:** Various approaches for synergetic orchestration in computing continuum extended to extreme-edge devices, e.g., with multi-agent and *system of systems* orchestration based on hierarchical decision-making principles, decentralized orchestration for scalable support of heterogeneous extreme-edge nodes, and inter-domain federation leveraging blockchains and smart contracts.
- **Enabler 6:** Extension of AI/ML frameworks in support of:
  - Sustainability, with AI/ML algorithms for energy-efficient network configuration, optimization or federation, and energy-efficient MLOps pipelines to reduce energy consumption in ML models training.
  - Trustworthiness, with techniques for explainable, privacy-preserving and secure AI, with robustness to adversarial or privacy attacks.
- **Enabler 7:** Creation of Network Digital Twins for accurate and real-time network representation, in support of datasets generation.
- **Enabler 8:** Automated provisioning, management and coordination of closed-loops for zero-touch network automation, integrated in service and network lifecycle, assisted by AI/ML techniques and capable to interact and collaborate for joint optimization, arbitration and negotiation, as well as detection and mitigation of conflicts.

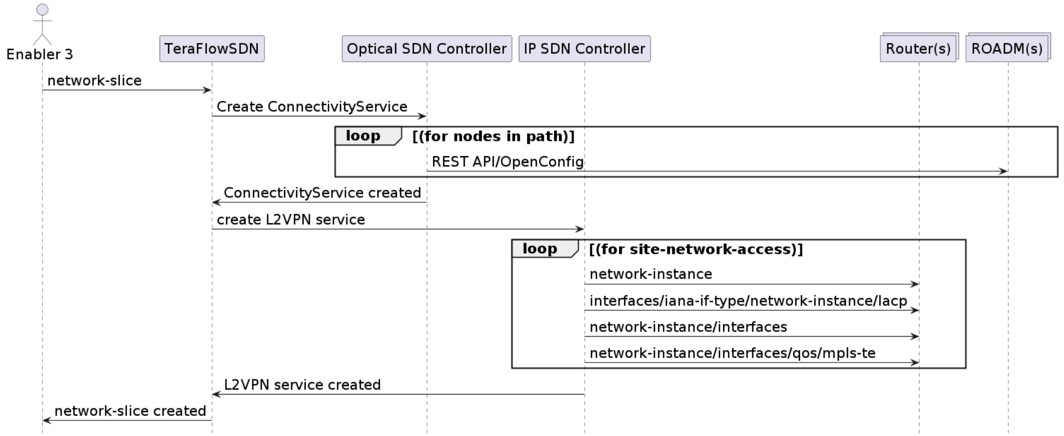
Enablers for Management and Orchestration

Enabler #1: Network programmability framework

- Software-defined networking (SDN) provides a programmable and flexible approach to network configuration by separating the network control plane from the data plane, allowing network administrators to centrally manage and orchestrate network policies and configurations.
- Application programming interfaces (APIs) provide a standard way for applications and services to interact with the network infrastructure, enabling programmable automation and orchestration of network functions and policies.
- Cloud-based network management platforms provide a scalable and flexible approach to network management and orchestration, enabling network administrators to manage and monitor network configurations and policies from a central location, regardless of the physical location of network devices.
- Interfaces: Service-oriented and Device-oriented.
- Enabler is aligned with Telecom Infra Project.
- ETSI TeraFlowSDN to serve as reference implementation for Telecom Infra Project
- Hierarchical approach for Programmable Flexible Network configuration
- Multiple technological network domains
  - IP
  - Optical
  - Microwave
  - TSN/DetNet
- Support for multiple NorthBound/SouthBound Interfaces.
  - Based on YANG data models.



Network Programmability Framework: design

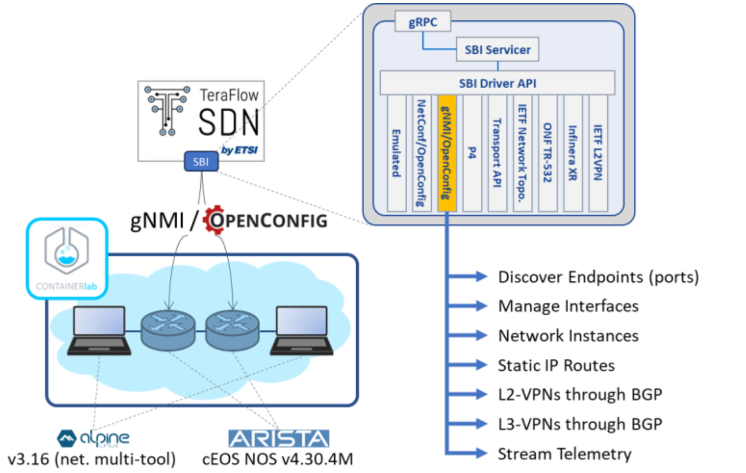


Network Programmability Framework: E2E workflow for provisioning of IETF slice

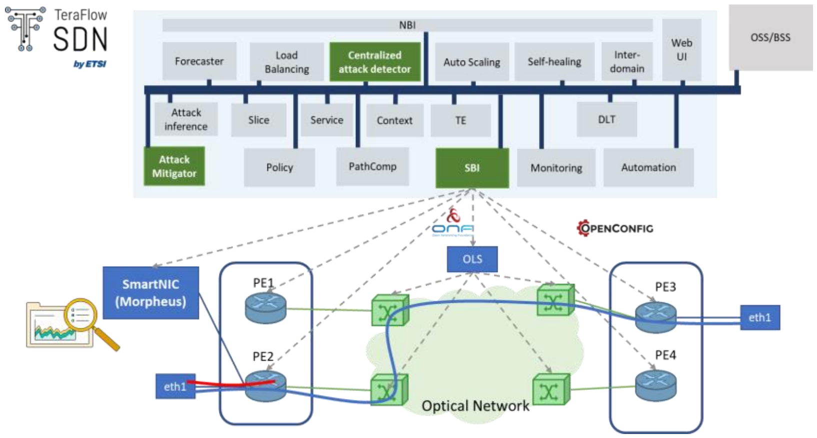
Enabler #1: Network programmability framework

Preliminary implementation and early validation results

- **TeraFlowSDN using data-plane in-a-box**, for quick demonstrations of TFS and its integration as a transport SDN controller with an emulated transport network
- **SmartNIC Transceiver support using OpenConfig extensions.** SDN-enabled anomaly detection mechanism, extending TFS with support for SmartNICs and creation of Anomalous Behaviour Profiling.
- **Time Sensitive Networking and Deterministic Networking SDN controller.** Development of technology specific dedicated SDN controller.
- **Automated transport network re-configuration.** Closed loop execution actions for transport network re-configuration, aligned with ETSI TeraFlowSDN ZSM Monitoring-Analytics-Automation Loop.
- **MEC Bandwidth Management service integration with SDN controller.**
- **Integration of TM Forum APIs with ETSI TFS NBI.** Align the concepts defined by TM Forum through “Autonomous Networks Technical Architecture” [TMF- IG1230] with “ETSI GR ZSM 011 – Zero-touch network and Service Management” [zsm-011] and correlated with IETF Slice Interface.



TeraFlowSDN SBI driver gNMI/OpenConfig + Dataplane-in-a-box based on ContainerLab



TeraFlowSDN SBI driver gNMI/OpenConfig + Dataplane-in-a-box based on ContainerLab

Enabler #1: Network programmability framework

Impacted KPIs

- **Scalability,** exploiting cloud-native architectures for provisioning of intense volume of connectivity services.
    - Distributed orchestration network elements to handle increased amount of network services and workloads of different shapes and sizes.
- **Latency,** relying on configuration of network elements on the whole network continuum.
    - Optimal allocation of services, through network programmability in the cloud continuum can lead to a large reduction in latency.
- **Flexibility,** through scalable and cloud-native network control and management in support of multiple network hierarchies and technologies.
- **Services Creation Time.**
- **Reliability**.
    - Enabler designed to specifically target the necessary redundance by design, so multiple instances can be easily managed.
- **Programmability**.
    - Highly programmable by itself, relying on the cloud-native principles as a whole (e.g., all the network elements, such as routers, communicate using exposed interfaces, which enable programmability, and could be provided relying on highly automated DevOps practices).

Enabler #2: Monitoring and telemetry framework

Programmable network monitoring and telemetry involves the use of software-defined networking (SDN) and other automation technologies to collect and analyze data about network traffic and performance in real time.

Gain greater visibility into their networks, identify potential issues more quickly, and respond to problems in a more efficient and effective manner.

Some of the key technologies and protocols used in programmable network monitoring and telemetry include: NETCONF, YANG, gRPC, gNMI and SNMP.

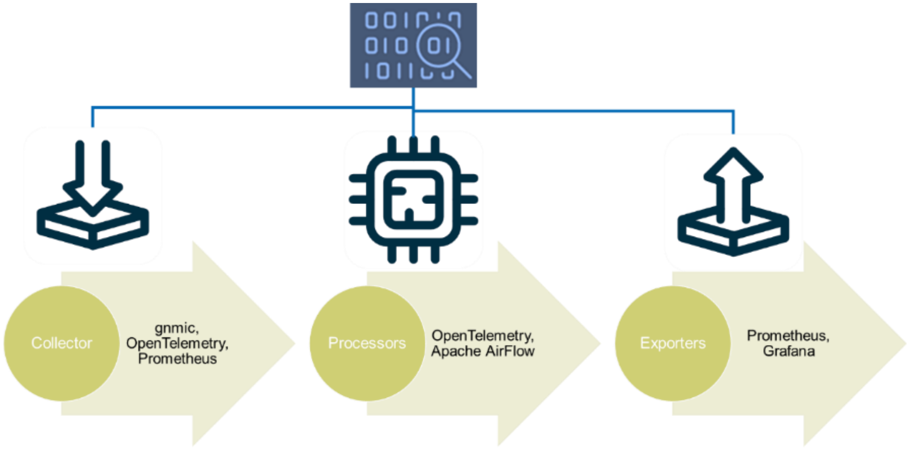
Programmable network monitoring and telemetry can be used in a wide range of environments, including data centers, cloud infrastructure, and enterprise networks.

Provide solution that is able to scale: Metric acquisition, Metric derivation, Metric publication.

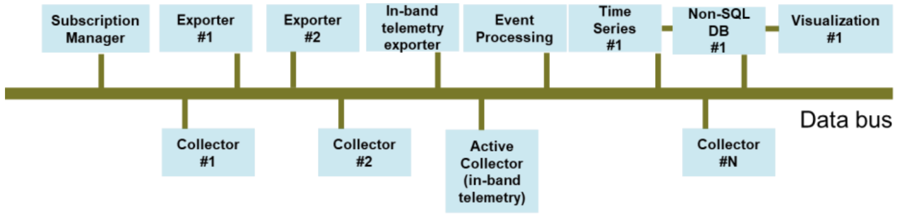
Relationship with Enablers: Enabler 3.

Enabler #2: Monitoring and telemetry framework

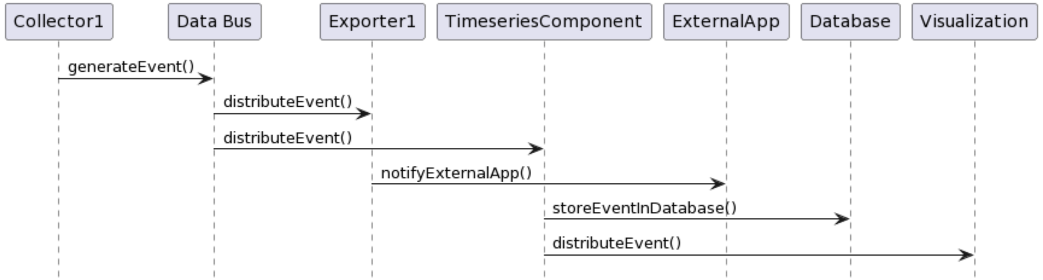
- Network Monitoring and Telemetry framework leverages Software-Defined Networking (SDN) and automation technologies to enhance network data collection and analysis.
- Key Components:
  - Monitoring: Continuous oversight of network performance and status.
  - Telemetry: Automated real-time data collection from diverse network sources.
- Technological Advancements:
  - Network Data Analytics Function (NWDAF): A 5G core functionality extending into 6G networks, facilitating extensive data collection from heterogeneous sources.
  - Beyond data collection, it addresses event reception, forwarding, fusion, and processing within a scalable cloud-based architecture.
- Framework Highlights:
  - Multi-layered Data Collection: Integrates data from virtual and physical network components, enhancing operational insights.
  - Multi-vendor Strategy: Promotes scalability and flexibility across the network ecosystem.
- Benefits:
  - Real-time Data Analysis: Provides a robust foundation for network management decisions.
  - Performance Optimization: Identifies underutilized resources for improved network configurations and cost-efficiency.
  - Energy Efficiency: Measures energy consumption to develop algorithms balancing operational demands with sustainability.
- System Architecture:
  - Scalable and Secure: Incorporates robust security, privacy measures, and scalability to manage cloud-scale operations effectively.
  - Sequential Processing: Efficiently handles metrics and alerts through a series of independent yet interconnected steps—acquisition, normalization, visualization, evaluation, and publication.
- Tools and Processes:
  - Collector Stage: Utilizes tools like gnmic, OpenTelemetry, and Prometheus for raw data gathering.
  - Processor Stage: Allows data parsing and aggregation.
  - Exporter Stage: Uses OpenTelemetry to distribute processed data.
  - Visualization: Prometheus and Grafana transform data into actionable insights for real-time issue detection and decision-making.



Monitoring and telemetry framework: design



Monitoring and telemetry framework: internal architecture



Monitoring and telemetry framework: sequence diagram

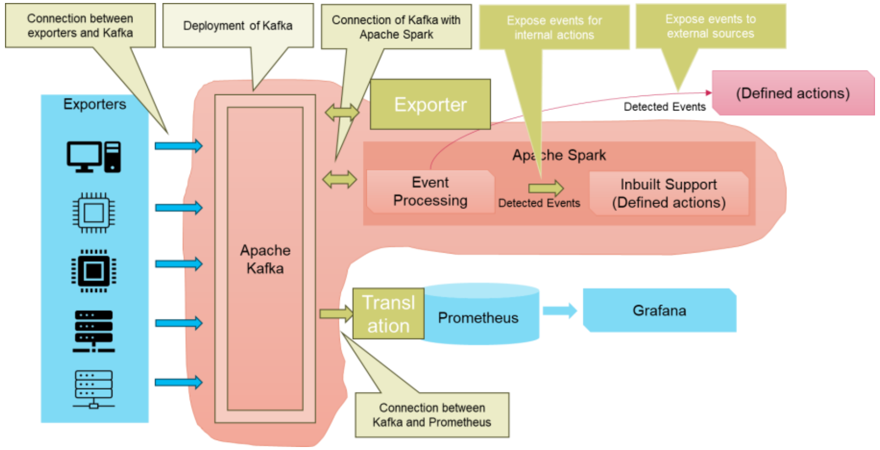
Enabler #2: Monitoring and telemetry framework

Preliminary implementation and early validation results

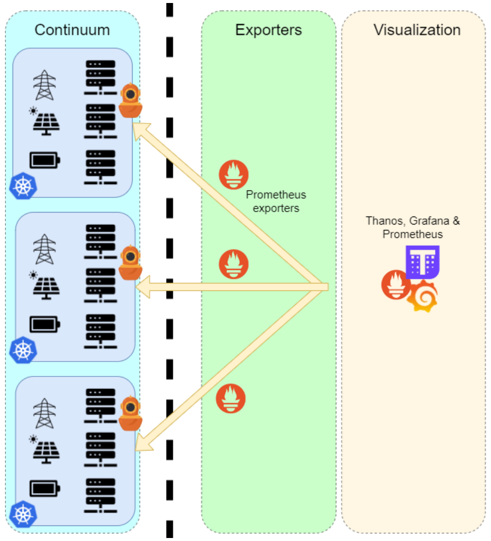
- **TeraFlowSDN event-driven monitoring.** ETSI TeraFlowSDN event-driven monitoring module gathers extensive data from devices across various environments, including cloud and edge. This data triggers decisions to optimize infrastructure conditions and respond to anomalies, such as unusual energy consumption patterns. To manage and distribute this data effectively, the module utilizes Apache Kafka, an open-source platform ideal for high-throughput data streaming and real-time processing, enabling dynamic policy implementation for optimal platform function.
- **Energy monitoring.** Energy monitoring platform using Kubernetes, Scaphandre, Prometheus, and Grafana for data collection and visualization across compute layers.
- **Monitoring platform for integration in closed loop.** Monitoring Platform as a zero-touch closed-loop (CL) monitoring function in PoC B, managing data from cobots to optimize battery usage and ensure network connectivity. This system involves hierarchical closed loops that handle task migration and network path recovery, using data from various sources to maintain service efficiency and reliability.

Conceptual solutions

- **Passive/in-band and active telemetry for TSN/DetNet networks.** Monitoring in TSN and DetNet networks is critical to uphold network promises. The monitoring algorithm evaluates trade-offs among passive, active, and in-band telemetry methods to minimize overhead and maintain data flow latency. Coordination across multiple segments ensures effective end-to-end flow monitoring.
- **Data fusion for signal correlation and remediation actions.** Signal data fusion uses active and passive telemetry from various sources to mitigate and prevent system and network failures. OpenTelemetry provides methodologies for real-time data access in distributed systems, using OTLP Collector in centralized or distributed setups. Data, including metrics, traces, and logs, is collected, processed to identify anomalies, and analyzed for system orchestration.



TeraFlowSDN event-driven monitoring



Energy Monitoring Platform implementation high-level diagram

Enabler #2: Monitoring and telemetry framework

Impacted KPIs

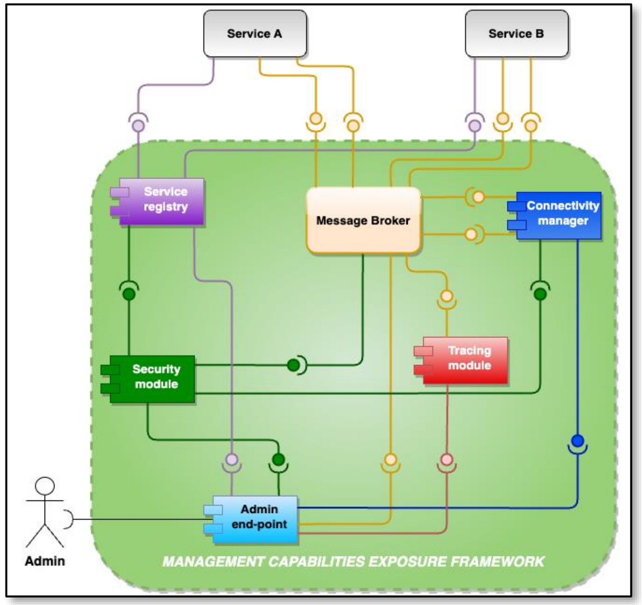
- **Scalability:** this enabler ensures that network monitoring and telemetry can scale to meet increasing demands without degradation in performance. The system's architecture, designed to handle cloud-scale operations, effectively manages large volumes of data and network activities, preventing bottlenecks that can impede scalability.
- **Latency:** the real-time data gathering capabilities of this system minimize latency in network monitoring and decision-making processes. By leveraging protocols like NETCONF, gRPC, and gNMI, the system can quickly collect, process, and react to data from various network components, ensuring timely responses to dynamic network conditions.
- **Flexibility:** the suite of automation technologies and the use of diverse protocols (NETCONF, REST, YANG, gRPC, gNMI, SNMP) enable this enabler to be highly adaptable to different network configurations and requirements. This flexibility allows network administrators to tailor the monitoring and management solutions to specific needs, enhancing the overall efficiency of network operations.
- **Reliability:** the enablers data acquisition mechanism underpins dependable network performance monitoring and fault detection, thereby increasing the overall reliability of network operations.
- **Automation:** automation is a core component of this enabler, with protocols designed to facilitate the automation of network management tasks and the orchestration of network functions and policies. This allows for more efficient use of resources and reduces the need for manual intervention, thereby enhancing operational efficiencies and reducing the potential for human error.

Impacted KVI:

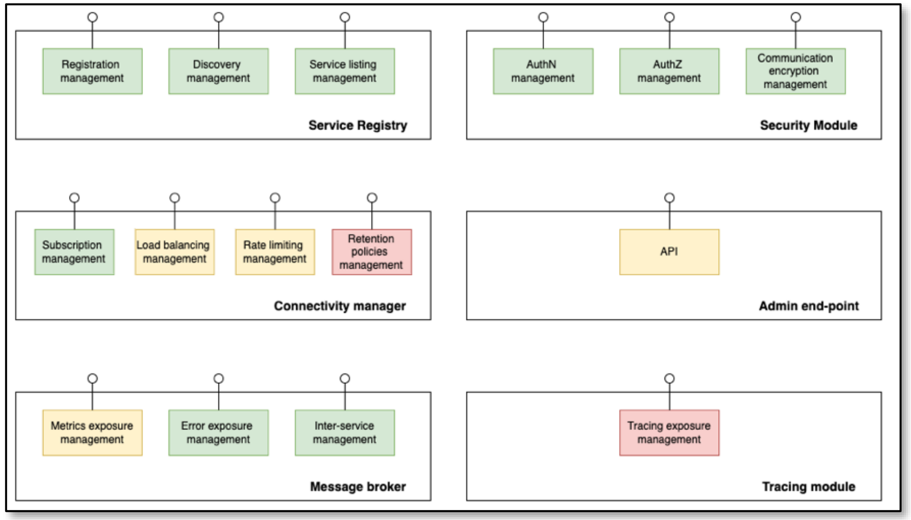
- **Sustainability:** focus on monitoring energy consumption across network elements, including computational resources. This capability is pivotal for developing algorithms aimed at optimizing energy use, thus supporting sustainable network operations. By enabling more energy-efficient network configurations and operations, this enabler helps reduce the overall environmental impact of network infrastructures.

Enabler #3: Management capabilities exposure framework

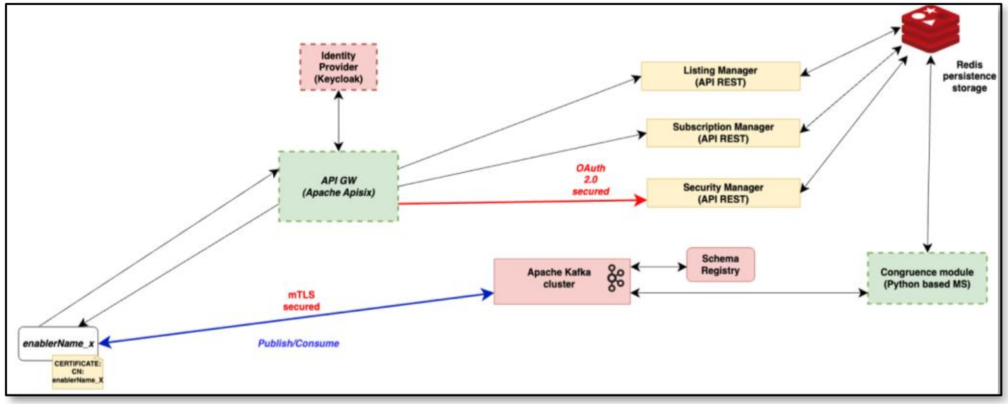
- This enabler proposes an implementation of the Integration Fabric inspired by ETSI ZSM.
- Dynamic service registration and discovery, following a plug-and-play concept.
  - Automates the process of registering and discovering management functions.
  - Reduces the need for manual interventions.
- Implemented in cloud-native environments, in scenarios involving several stakeholders.
- Hexa-X-II comprises a prototype implementation and demonstrates the use of previously proven concepts of Hexa-X project, extending them for multi-site settings



Management Capabilities Exposure Framework: design



Management Capabilities Exposure Framework: interfaces

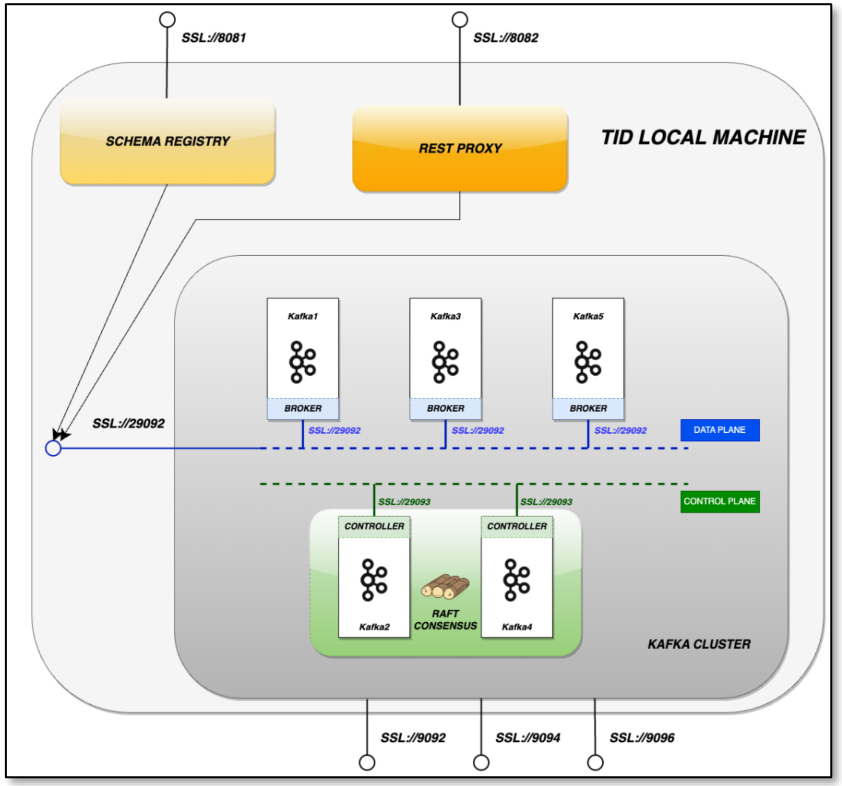


Management Capabilities Exposure Framework: main components and interaction

Enabler #3: Management capabilities exposure framework

Preliminary implementation and early validation results

- Initial prototype being developed and tested at one of the partners' local testbed (Telefonica)
- Integration planned in PoC B.1, to serve as central communication bus and exposition of interface in the E2E architecture.
- Plans to present the prototype to ETSI ZSM community as a reference implementation of the ETSI ZSM Integration Fabric.
- **Kafka-based implementation**
  - Two Apache Kafka controller nodes, for the Control Plane; in charge to coordinate the communication, like partition leader election, the replicas distribution and topic partition assignation to the different broker nodes.
  - Three Apache Kafka broker nodes, as actual message brokers at the Data Plane, handling message exchange and topic subscriptions.
  - A Schema Registry, maintaining updated and storing the schemas used during the communication with the topic.
  - A REST Proxy, to publish to/consume from the Kafka cluster using REST operations, for integration with parties unable to deploy a Kafka client.
- Public OpenAPIs:
  - Registration APIs: https://kafka.hexa.tid.es/registrationAPI/docs
  - Listing APIs: https://kafka.hexa.tid.es/listingAPI/docs
  - Security APIs: https://kafka.hexa.tid.es/securityAPI/docs



Apache Kafka cluster structure

Enabler #3: Management capabilities exposure framework

Impacted KPIs

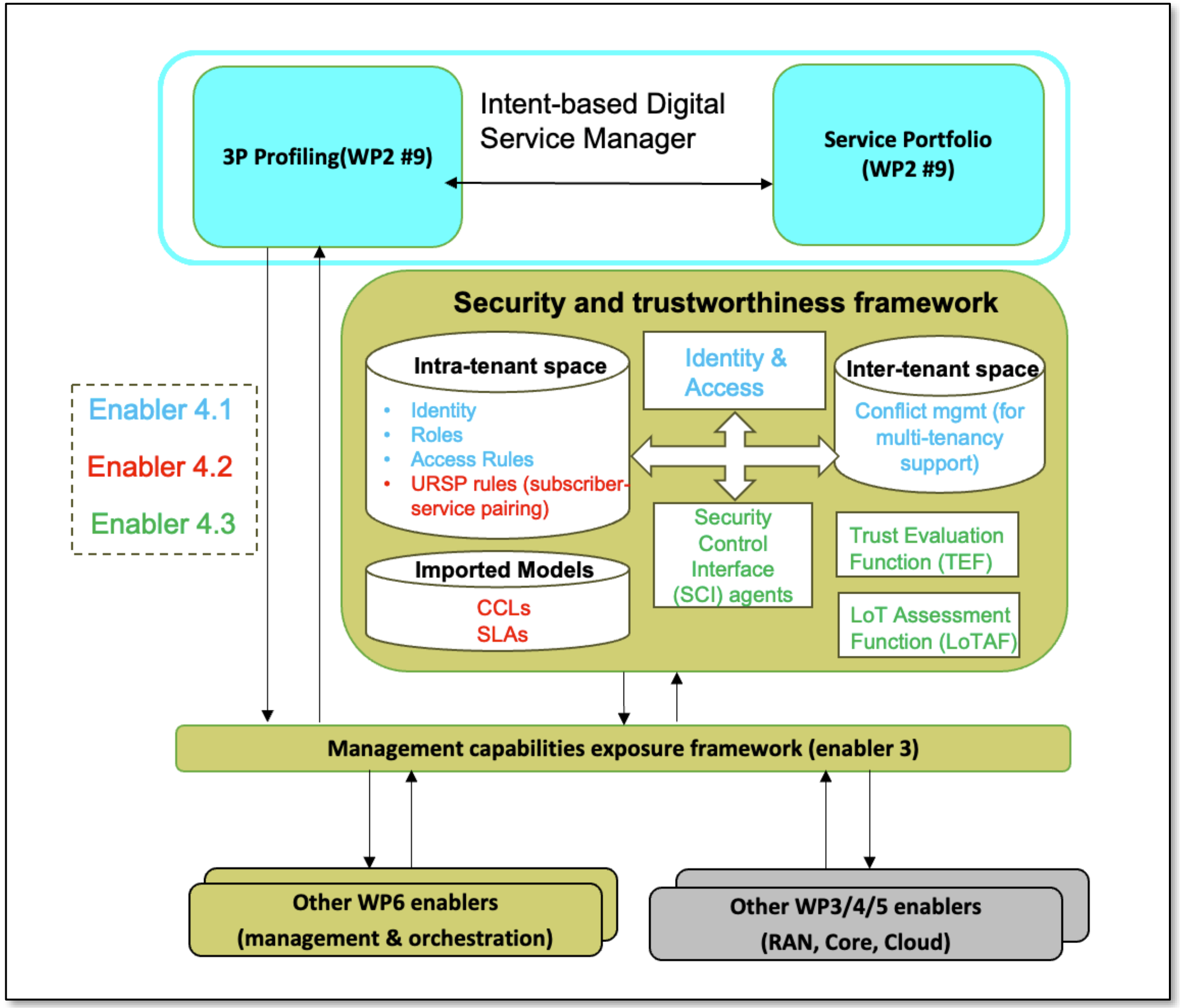
- **Scalability:** this enabler is made to communicate with any third party that embeds a Kafka or REST client. This increases scalability by enabling the quick creation of unique, fixed or volatile communication channels inside or between domains.
- **Latency:** the purpose of this enabler is to make it easier to link and communicate with enablers in a multi-domain scenario. It is well known that latency can be affected by relocating resources between domains. Communication latency can be reduced by offering a better communication channel that improves the exposure of capabilities inside the network continuum.
- **Availability:** the event-driven architecture allows for increased network programmability and automation, hence improving availability. Recovering from runtime failures in a short amount of time is made feasible by the ability to set up communication channels using basic REST API calls. By doing this, the overall downtime caused by communication problems amongst the network continuum's enablers can be decreased.
- **Reliability:** one of the goals of this enabler is to provide dedicated global channels of communication for failures and status updates pertaining to currently onboarded entities. Having a real-time health view of communications between resource onboarded can help prevent service degradation and reduce the overall number of failures.
- **Elasticity:** this enabler provides an elastic communication medium by automatically providing and de-provisioning resources in response to changes in workload. In practical terms, this involves adjusting the communication channel according to the workload need.
- **Maintainability:** the system is intended to be easily maintained, particularly in terms of the on-boarding/off-boarding of resources that use this enabler. This can be done in a fully automated manner and facilitated by an easy-to-use REST API.

Impacted KVIs

- Trustworthiness: This component enhances the reliability of data by ensuring consistency and accuracy through real-time updates and unified management, thereby enhancing security with centralized controls. Furthermore, it facilitates compliance with comprehensive audit trails (data access, modifications, and transactions). Additionally, it promotes transparency with end-to-end visibility, and supports better decision-making through integrated data, which provides a comprehensive view by combining data from various sources, enabling more informed and accurate decisions. This facilitates the creation of a trustworthy environment by providing reliable and secure information exchange across all systems.
- Inclusiveness: This enabler enhances inclusiveness by enabling seamless communication, transparent data accessibility and collaborative workflows across diverse systems and stakeholders. It ensures compatibility with multiple platforms, flexibility for individual needs, scalability and compliance with accessibility standards. This fosters a culture of inclusivity in decision-making and collaboration.
- Sustainability: This component serves to facilitate interconnections within the E2E system. Its utilisation can result in a reduction in integration costs, as it employs REST interfaces and the event-driven paradigm. Additionally, it has the potential to minimise energy consumption, thereby optimising the operations and configuration of the parties involved in communications.

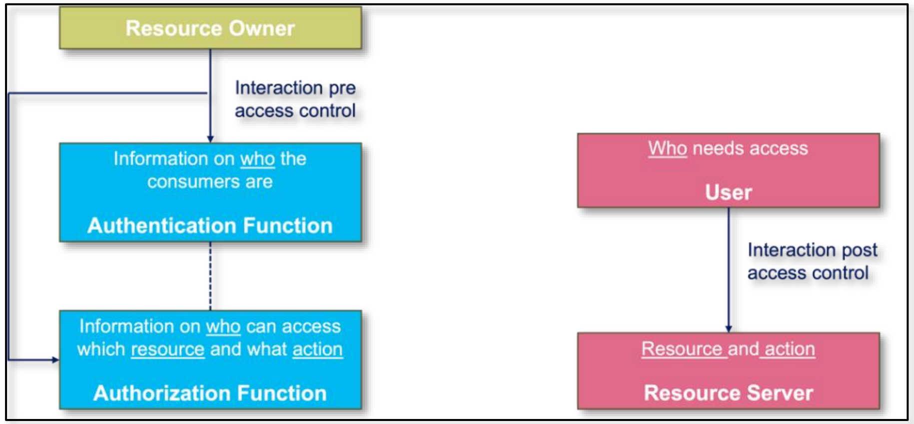
Enabler #4: Security and trustworthiness framework

- **Sub-enabler 4.1:** 3rd party resource control separation enabler
- **Sub-enabler 4.2:** User-centric service provisioning system
- **Sub-enabler 4.3:** Trust management system

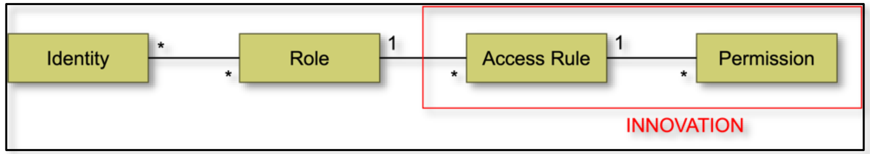


Sub-enabler #4.1
Third-party resource control separation enabler

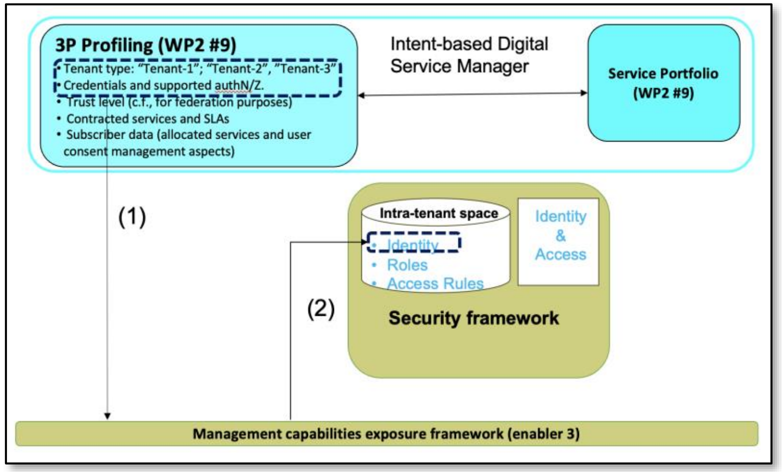
- Enabler defining the scope and impact of the **“tenancy” concept in a M&O system.**
- Mechanisms to provide tenants with segregated yet customized management spaces.
- Management spaces defining what tenants are authorized to do with regards to:
  - the operation of their allocated services;
  - the control of their applications, including their interaction with the offered resources, allowing for a frictionless network-application integration.
- Going beyond the SotA of Role-Based Access Solutions (RBAC) supported by LDAP with two new entities: access rule and permission
- Covering the gap towards 6G by defining a **granular access control solution targeting authentication, authorization and auditability.**
- Tenants can be provisioned with tailored management spaces, avoiding conflicting each other on resource sharing environments.



Access control governance framework



Conceptual model for extended RBAC



Third party on-boarding: system view

Sub-enabler #4.1
Third-party resource control separation enabler

Impacted KPIs

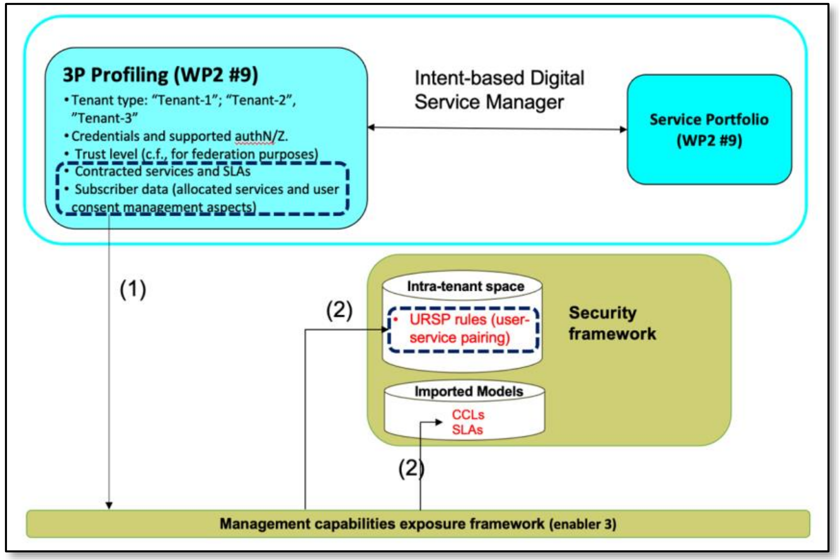
- **Availability:** by separating resource control for third-party entities, the system can prevent one tenant from monopolizing resources or causing disruptions that affect the availability of services for other tenants. This ensures that each tenant has fair access to resources and reduces the likelihood of downtime due to resource contention or malicious activities.
- **Reliability:** resource control separation helps maintain the reliability of the system by isolating the impact of failures or errors within individual tenant environments. If a particular tenant's application or activities lead to a failure, it can be contained within their allocated resources without affecting the reliability of other tenants' services. This isolation minimizes the propagation of failures and enhances the overall reliability of the system.
- **Security:** separating resource control for third-party entities enhances security by enforcing strict access controls and permissions. It allows administrators to define and enforce policies governing the interactions between tenants and system resources, mitigating the risk of unauthorized access, data breaches, or malicious activities. Additionally, by isolating each tenant's environment, the impact of security breaches or vulnerabilities can be contained, limiting their scope and protecting the integrity and confidentiality of other tenants' data and services.
- **Maintainability:** resource control separation simplifies system maintenance and management by providing clear boundaries between tenants' environments. This allows to apply updates, patches, and configurations more efficiently, without affecting the operations of other tenants. It also facilitates troubleshooting and debugging processes by isolating issues to specific tenant environments, making it easier to identify and resolve problems without disrupting overall system maintainability.

Impacted KVIs

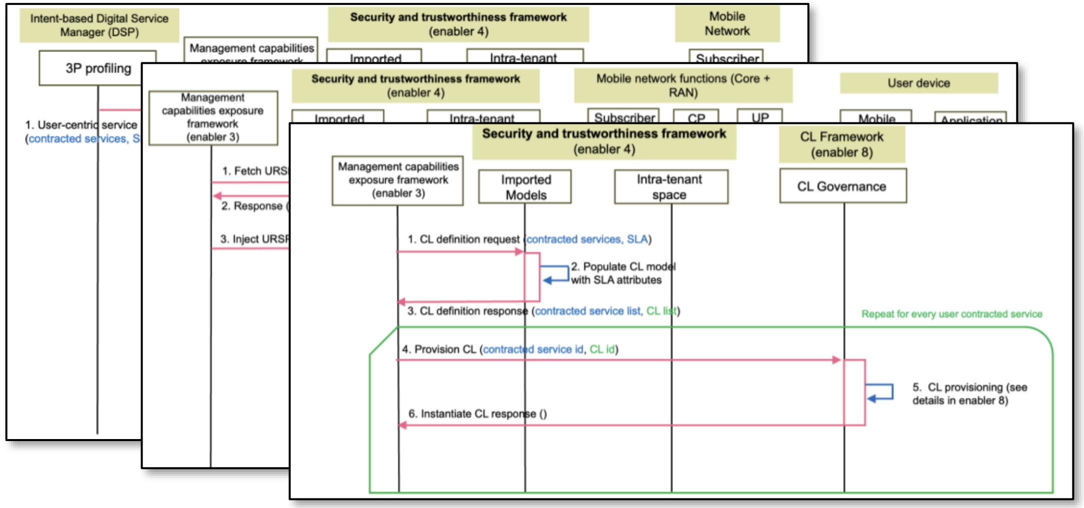
- **Trustworthiness:** third-party resource control separation significantly impacts the trustworthiness of 6G networks by reinforcing confidentiality, integrity, availability, data privacy, operation resilience and security. It serves as a foundational element in building trust among stakeholders providing a resilient, secure, and trustworthy digital ecosystem.

Sub-enabler #4.2
User-centric service provisioning system

- Provisioning of tenant subscribers with optimal and personalized experience, according to their preferences, SLAs of subscribed services, and network context.
- **User-centric service delivery track:**
    - URSP assisted solutions applicability to 6G specific devices.
    - Assessment of UE Route Selection Policy (URSP) assisted solutions with user consent management and user data protection.
- **SLA enforcement track:**
    - Enriching SLAs with trustworthiness KVIs.
    - Exploring how closed loop automation solutions can be reused and adapted to fulfil SLA assurance activities, and the advantages they exhibit against today's policy-based solutions (i.e. making SLA elastic and dynamic).
- System components:
    - **Intra-tenant space:** specifies the management space provisioned to each registered tenant. This management space is the result of mapping information from the 3rd party profiling component into properties that the M&O layer can interpret and act upon.
    - **Imported models:** a repository that stores the SLA models (defined in Intent-based Digital Service Manager) and Closed Control Loops. These models help to provide zero-touch solutions for service assurance, using closed loop automation to supervise the compliance of tenant services to the signed SLAs.



User-centric service provisioning – internal architecture



Workflows for service fulfillment, activation and assurance

Sub-enabler #4.2
User-centric service provisioning system

Impacted KPIs

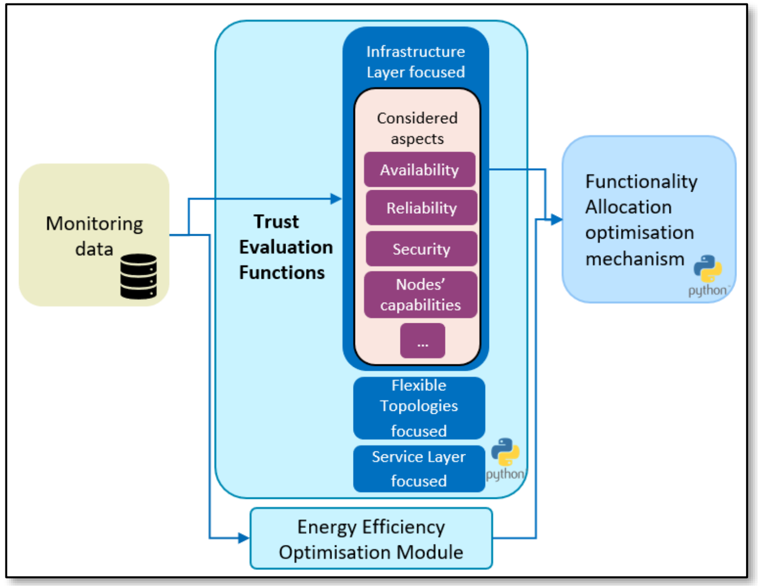
- **Availability**: it measures the proportion of time a service is fully operational and accessible to users. High availability ensures that the network services are always accessible, minimizing downtime and ensuring that subscribers can rely on continuous service performance.
- **Reliability**: it assesses the ability of the network to perform its required functions under stated conditions for a specified period of time. Reliability includes the network's capacity to handle errors, recover from failures, and maintain service continuity in the face of challenges such as hardware malfunctions or high traffic.
- **Maintainability**: this involves the ease with which a system can be maintained in order to correct defects or their causes, improve performance or other attributes, or adapt to a changed environment. In network services, maintainability can refer to the ease of updating the system, fixing issues, and scaling services to meet changing demands.
- **Guaranteed device throughput:** this KPI measures the minimum data transfer rate that must be maintained for each device connected to the network, ensuring efficient and consistent performance.
- **Maximum number of PDU sessions:** it represents the upper limit of simultaneous packet data unit sessions that can be handled by the network, ensuring that the network can support a high volume of data traffic without degradation in service quality.
- **Maximum number of registered subscribers:** this is the maximum number of subscribers that can be registered and supported by the network at any given time, indicating the network's capacity.
- **Maximum latency:** this KPI specifies the maximum allowable delay in data transmission, ensuring timely communication which is critical for applications requiring real-time interaction, such as VoIP or gaming.
- **Error rates:** measures the frequency of errors during data transmission, which can affect the quality and reliability of network services.

Impacted KVIs

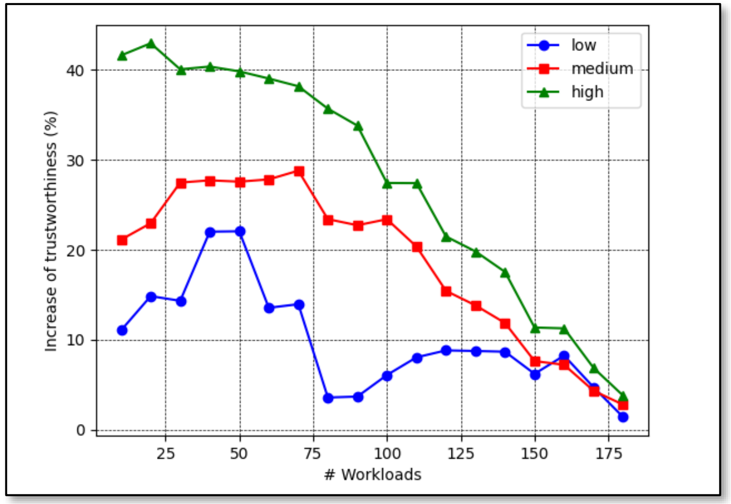
- **Trustworthiness:** User-centric service provisioning significantly enhances the trustworthiness of future 6G networks by focusing on the specific needs and expectations of users regarding security, privacy, and reliability.

Sub-enabler #4.3
Trust management system

- Trustworthiness estimation procedure of compute nodes and infrastructure components through trust evaluation function.
- Cloud orchestration engines use the output of the trust evaluation functions, among other factors, to allocate workloads into compute nodes, targeting maximum trustworthiness and efficiency.
- In progress on extending the scope to also estimate the trustworthiness level of communication paths that hold sensitive data workloads as they transit the network.
- Preliminary implementation integrated in **PoC#A** and **PoC#B**
- Impacted KPIs
  - **Reliability and availability**, as trust evaluation functions for accessing trust indexes
  - **Scalability**, contributing to optimization of resource management and functionality allocation
- Impacted KVI: **trustworthiness**



High-level architecture of trust evaluation functions



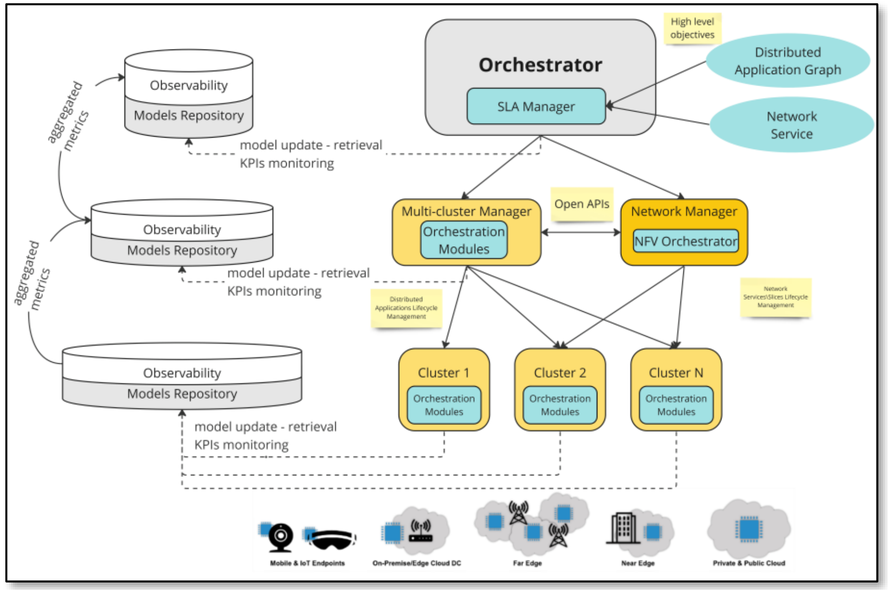
Trustworthiness measurements of the metaheuristic functionality allocation mechanism

Enabler #5: Synergetic orchestration mechanisms for the computing continuum

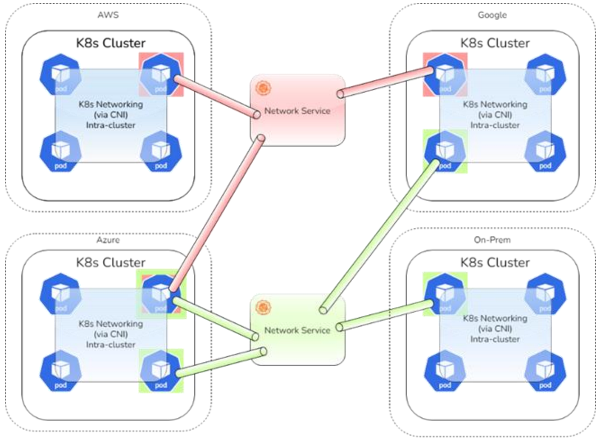
- Sub-enabler 5.1: Multi-agent systems for multi-cluster orchestration
- Sub-enabler 5.2: Decentralised orchestration system
- Sub-enabler 5.3: Federated orchestration system

Sub-Enabler #5.1:
Multi-agent systems for multi-cluster orchestration

- **Synergetic Orchestrator:** manages the deployment of distributed service or application graphs over resources in the computing continuum.
    - Synergies among multiple agents, with each agent responsible for decision making in a local or global administrative area
- **Multi-cluster Manager:** responsible for the management of compute resources across the continuum, in extreme edge, edge, cloud clusters.
- **Network Manager:** responsible for management of network resources across the computing continuum.
    - **Network service mesh** mechanisms can be applied for managing connectivity across the network service/application components deployed in different clusters.

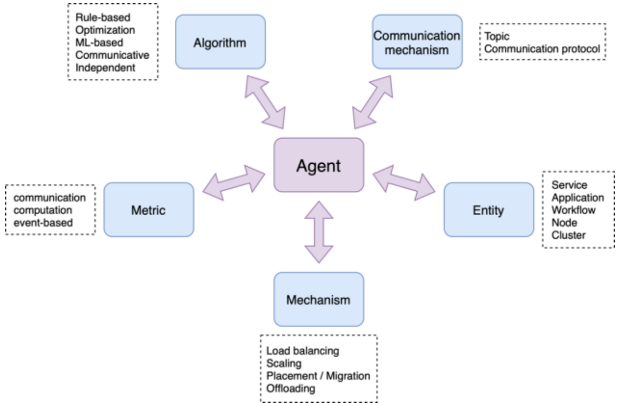


High-level view of multi-cluster orchestration components for the computing continuum

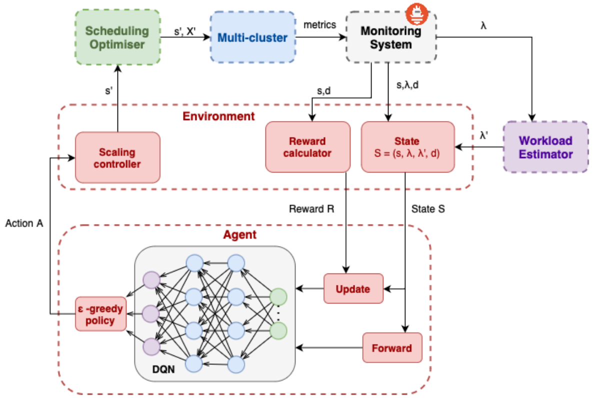


Network Service Mesh solution over Kubernetes clusters

Source: https://networkservicemesh.io/docs/concepts/enterprise_users/



Multi-agent interactions

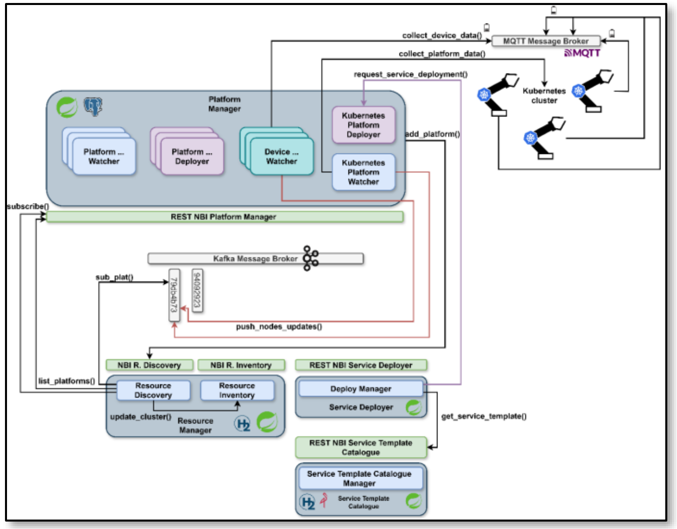


RL-driven autoscaling mechanisms for multi-cluster deployments

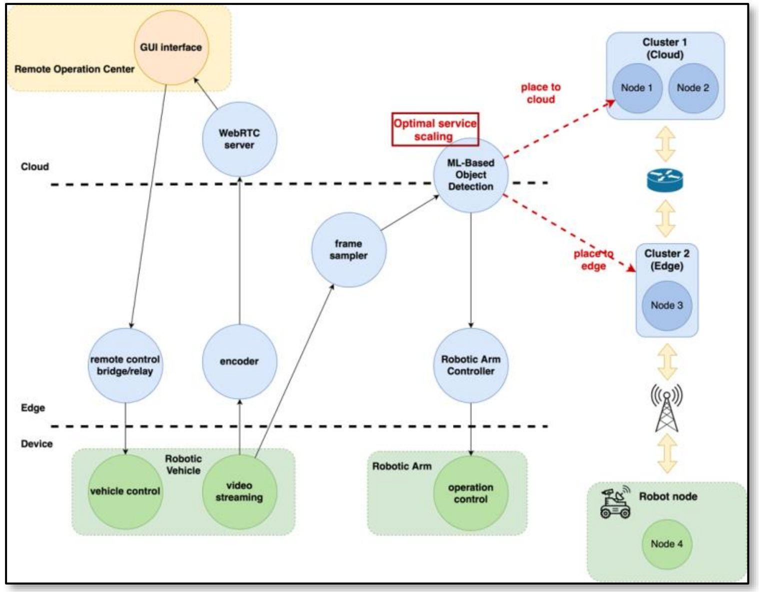
Sub-Enabler #5.1:
Multi-agent systems for multi-cluster orchestration

Preliminary implementation and early validation results

- **REC-EXEC** multi-technology resource orchestration platform, as example of multi-cluster resource manager specialized for extreme-edge resources. Integrated in PoC#B.
- **RL-driven autoscaling,** implemented in a multi-cluster setup with two clusters in a lab deployment emulating edge-cloud environments. Experiments based on a low-high workload scenario and integrated in PoC#B.
- **Functionality allocation mechanisms**, with a computational workload placement functionality allocation algorithm based on the genetic algorithm paradigm.



REC-EXEC implementation



RL-driven autoscaling implementation

Sub-Enabler #5.1: Multi-agent systems for multi-cluster orchestration

Impacted KPIs

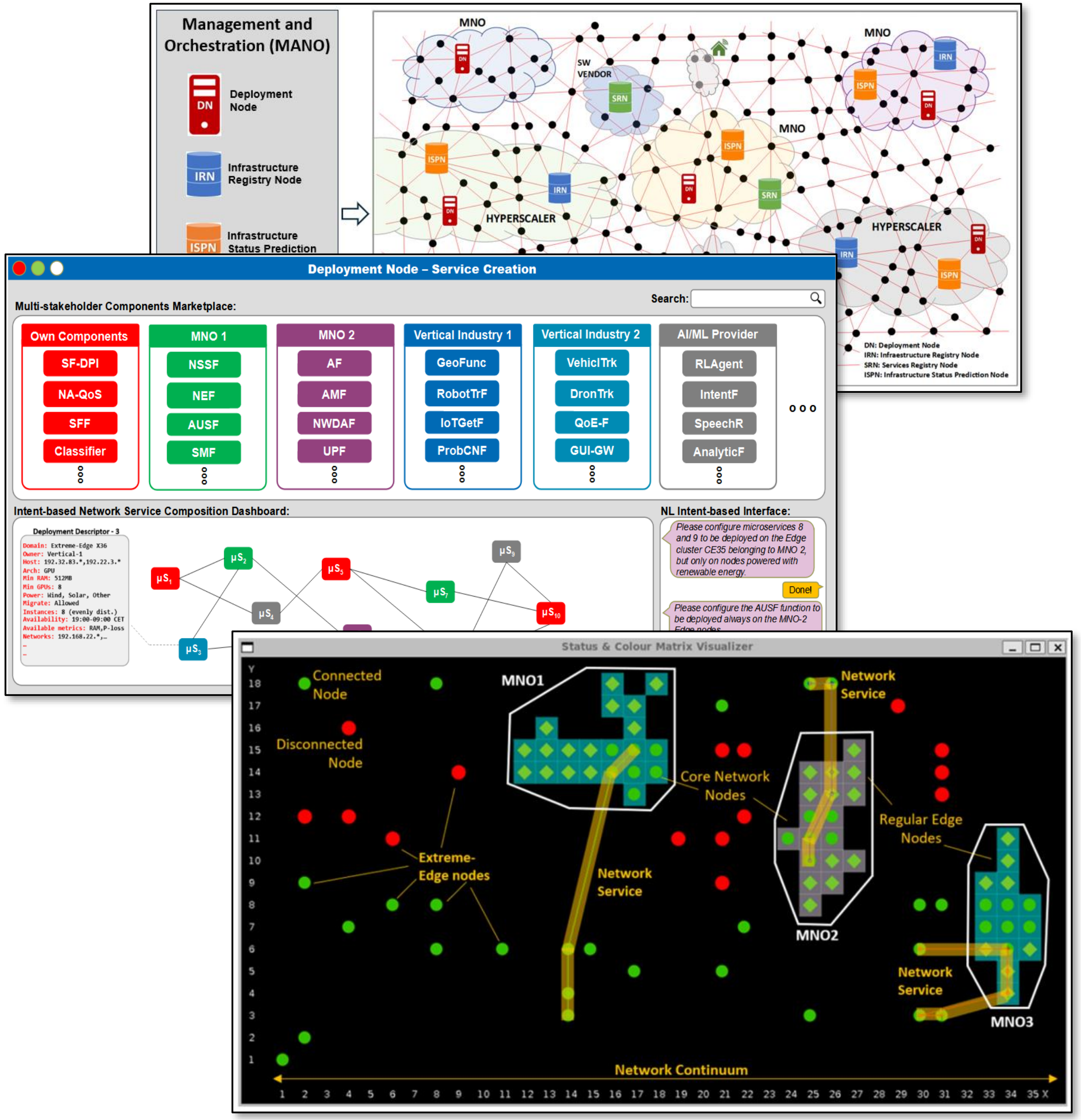
- **Latency**: the provided mechanisms for optimal placement and runtime management of network/application service graphs can lead to improvements in the end-to-end latency for the provision of a service/application.
- **Reliability**: the continuous monitoring/observability of the performance metrics for the various deployments can lead to proactive and reactive decision making for the management of events and failures in the service provision and the infrastructure management,
- **Scalability**: the provided mechanisms for autoscaling of the compute resources across the continuum lead to increased efficiency of the scaling decisions, considering performance, energy and cost metrics.
- **Programmability**: the provided mechanisms manage programmable compute and network resources across the computing continuum, while the provided orchestration interfaces are fully programmable and configurable.
- **Automation**: automation and decentralized intelligence characteristics are injected within the various orchestration mechanisms, leading to reduction of the administration overhead by network/system administrators and optimal services provision.

Impacted KVIs

- **Sustainability,** through support of optimal placement and lifecycle management of distributed network services and applications from an energy efficiency perspective.

Sub-Enabler #5.2: Decentralized orchestration system

- Highly distributed approach targeting the management and orchestration on the envisaged 6G network continuum.
- Integrates into the management and orchestration processes the extreme-edge domain, which can be massive in scale, and where infrastructure resources can be highly heterogeneous, volatile, mobile, and belonging to a multiplicity of stakeholders.
- Multi-domain by design: service chaining through multiple domains can be done relying on the service components exposed interfaces, based on the microservices federation approach.
- Composition and deployment of services based on high-level declaration of intents.
- Incorporates highly automated service provisioning and device discovery mechanisms.
- Clear separation of resources and responsibilities for the services provisioning (done with a minimal set of highly distributed network elements) and assurance (which can be tailored and deployed as part of the network services themselves).
- Relying on AI/ML techniques to deal with the complexity of the extreme-edge domain, e.g., to predict the random behaviour of the extreme-edge devices and implement proactive orchestration mechanisms.
- Facilitates the different stakeholders (e.g., MNOs, vertical industries, software vendors or infrastructure providers) to integrate their specific technological solutions in the network continuum.
- PoC being implemented in the context of the System PoC B.



Sub-Enabler #5.2: Decentralized orchestration system

Impacted KPIs

- **Scalability,** as a distributed system, able to handle an increased amount of network services and workloads of different shapes and sizes, and without requiring complex centralized systems that could become bottlenecks or single points of failure.
- **Latency.** The proposed approach relies on deploying service components on the whole network continuum, beyond the MNO own domain, and relying on network resources from multiple datacentres and in different geographic regions, so making it possible to move the necessary service components in close proximity to where they are actually requested by end users. This can lead to a large reduction in latency for certain time-sensitive applications, beyond what can be done in 5G with regular edge nodes.
- **Flexibility**, with integration of vertical parties that, instead of having to adapt to an external MNO-centric orchestrator, could just integrate their own service components exposing their interfaces in a cloud native way.
- **Processing Capacity**, considerably expanded by integrating resources at the extreme-edge domain.
- **Automation.** Devices discovery processes and registry of infrastructure resources highly automated. Migration of service components through volatile extreme-edge nodes. Deployment of network services and resource placement fully automated.
- **Services Creation Time**.
- **Integrated intelligence,** with AI/ML algorithms to enable proactive M&O actions and for services assurance processes.
- **Reliability,** targeting high-volatility of resources in extreme-edge domains, which could unexpectedly vary their capabilities, move or even fully disconnect.
- **Programmability,** relying on the cloud-native principles as a whole.
- **Maintainability,** through the automation of on-boarding/off-boarding of infrastructure resources.
- **Intent expressiveness,** with network services that can be defined following intent-based approaches.
- **OPEX would be reduced for MNOs,** through delegation on a wide set of external distributed resources and M&O mechanisms.

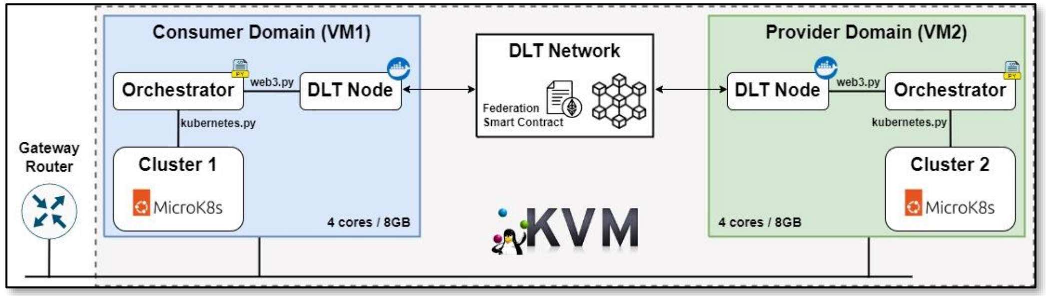
Impacted KVIs

- **Sustainability,** through efficient management of extreme-edge nodes.

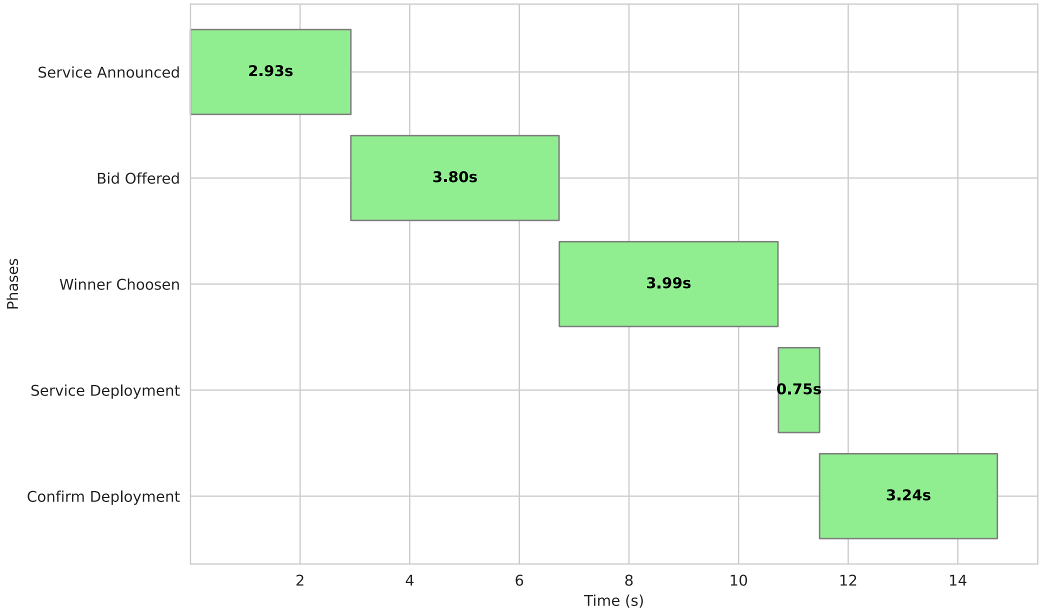
Sub-Enabler #5.3: Federated Orchestration System

Preliminary implementation and validation results

- Federated system with KVM as Virtual Infrastructure Manager, MicroKubernetes as orchestrator and **Ethereum** as DLT network for smart contracts usage and federation process management
- Aligned with **PoC B**



DLT-based service federation: initial implementation



Average duration of service federation steps

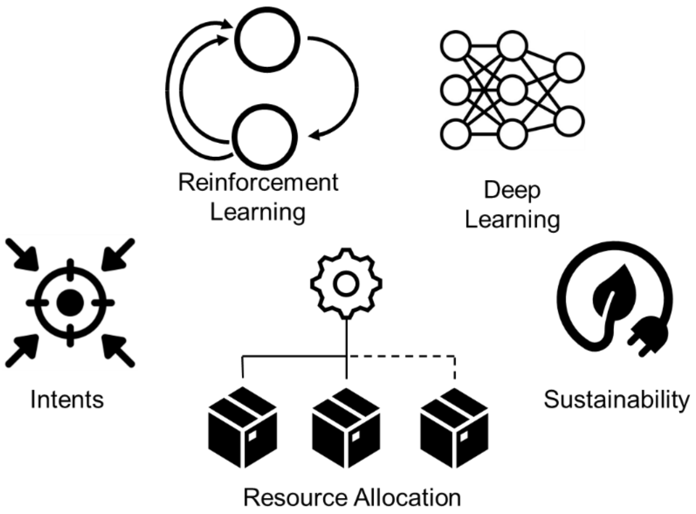
Sub-Enabler #5.3:
Federated Orchestration System

Impacted KPIs

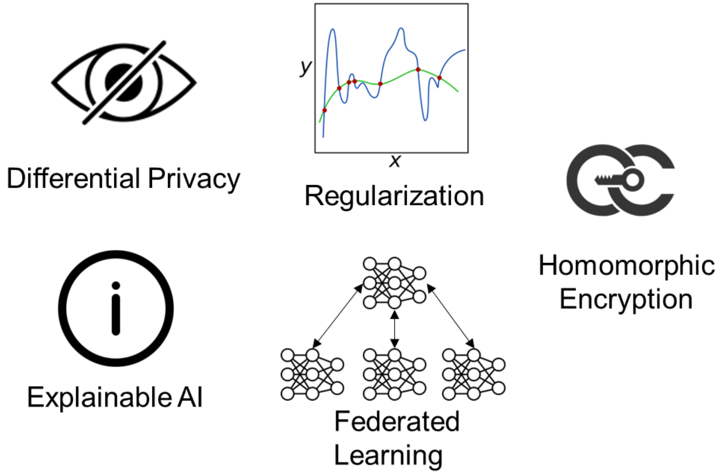
- **Reliability:** The autonomous provisioning of a service in third-party domains ensures service continuity in the event of unforeseen roaming scenarios which in legacy systems would necessitate services to be dropped.
- **OPEX reduction:** Given that this system provides a trustworthy mechanism through which service level agreements can be reached, executed and policed without a costly intermediary legal framework, the operational costs of network operators is greatly reduced.
- **Scalability:** This mechanism is highly scalable given that all that is required for operators to participate in this scheme is a representative node in the blockchain, they need not establish prior agreements with every possible third-party provider as in traditional systems.
- **Automation:** This scheme fully automates the legacy BSS based SLA establishment process and integrates it into the OSS processes related to service provisioning.

Enabler #6: AI/ML Algorithms

- Sub-enabler 6.1: AI/ML-based control algorithms for sustainability
- Sub-enabler 6.2: Trustworthy AI/ML-based control algorithms



Sub-enabler 6.1: AI/ML-based control algorithms for sustainability



Sub-enabler 6.2: Trustworthy AI/ML-based control algorithms

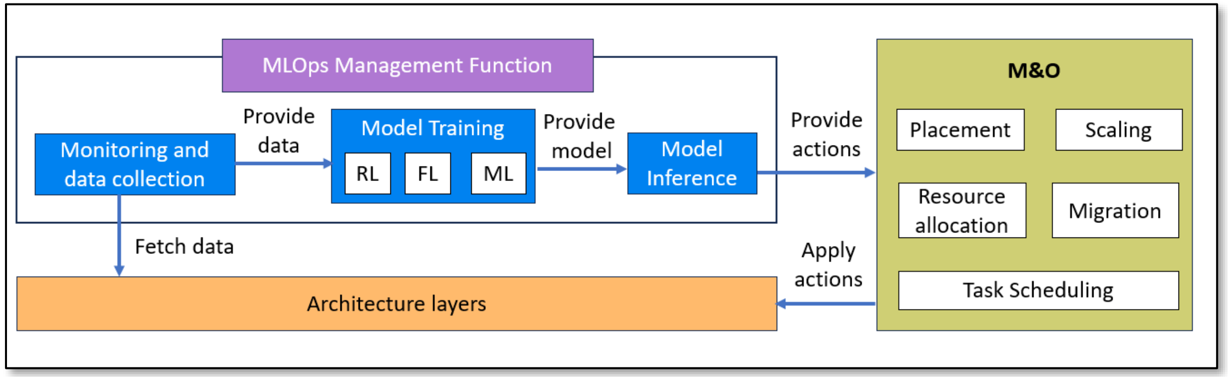
Sub-Enabler #6.1:
AI/ML-based control algorithms for sustainability

Objectives

- AI/ML based network and service control for sustainability and energy efficiency.
- Lifecycle management actions: placement, resource allocation, migration, scaling.
- Sustainable MLOps.

System components

- **Monitoring and data collection** function, interfacing with different layers and components and collecting data on the state of the network infrastructure and services.
  - Collected metrics relate to service KPIs (e.g., latency and throughput) and energy consumption values.
  - Collected data provided as input to the AI/ML model to make decisions, as well as for evaluating the results of the applied decisions.
- **Model training,** responsible for training of AI/ML models to perform automated M&O actions (e.g., service deployment, migration, scaling) while optimizing energy efficiency or other performance metrics.
  - Model training may be centralized on a single instance, or distributed over multiple instances or domains such as in Federated Learning.
- **Model inference,** responsible for performing inference of the trained models, and providing control actions to be performed by the M&O system.
- **MLOps Management Function,** responsible for orchestrating the lifecycle of the AI/ML model
  - May trigger model training, data collection, and deployment on the inference instances
  - Monitoring and minimization of the energy consumption of the steps in the MLOps control loop of the models.

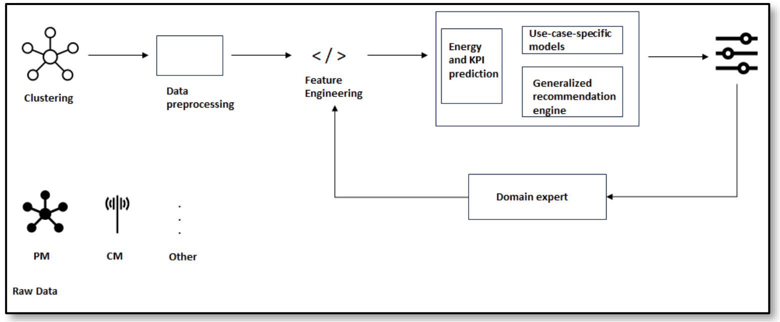


High-level architecture for AI/ML-based M&O

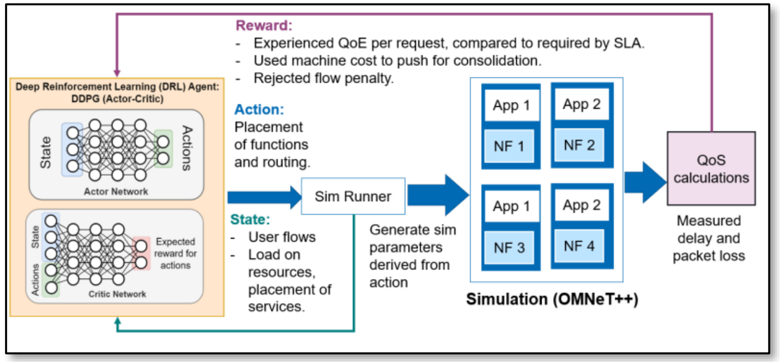
Sub-Enabler #6.1:
AI/ML-based control algorithms for sustainability

Preliminary implementation and early validation results for each algorithm

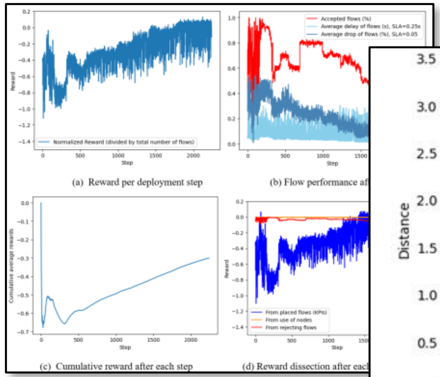
1. ML-based configuration recommendation for energy saving
2. Resource efficient network function deployment
3. Energy efficient resource allocation
4. Sustainable MLOps
5. Multi-domain Federated Learning
6. Multi-agent Reinforcement Learning for adaptive scaling



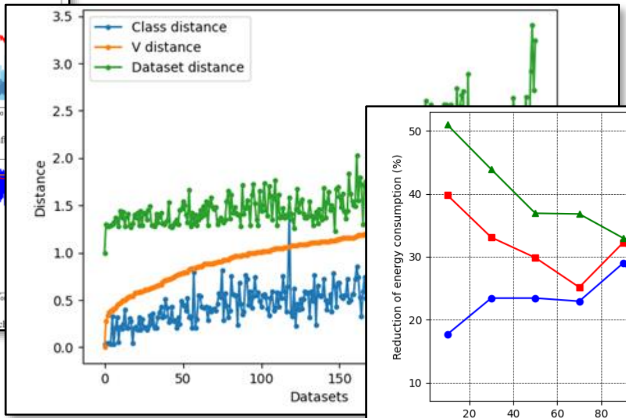
Implementation design for algorithm 1



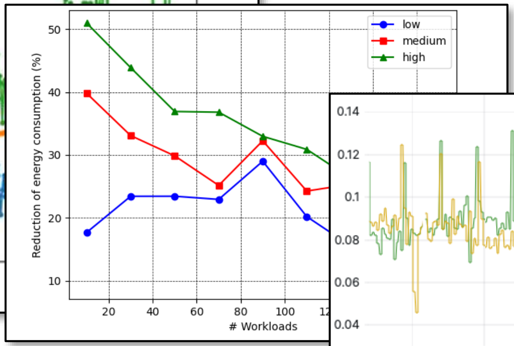
Implementation design for algorithm 2



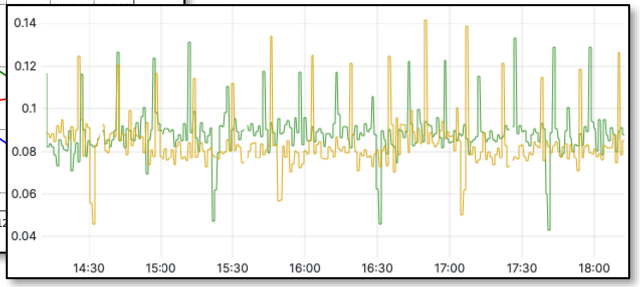
Results of experiments with algorithm 1



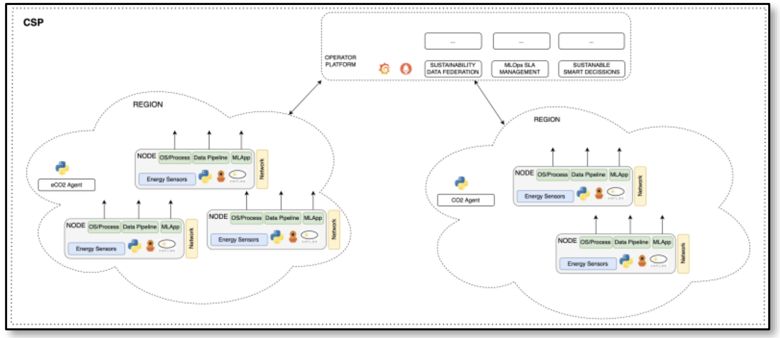
Results of experiments with algorithm 5



Results of experiments with algorithm 3



Results of experiments with algorithm 5



Implementation design for algorithm 4

Sub-Enabler #6.1:
AI/ML-based control algorithms for sustainability

Impacted KPIs

- **Energy efficiency:** AI-based resource efficient network function deployment minimizes resource use through consolidation by reducing the number of used nodes, which translates into energy saving, while optimizing end-to-end latency and packet loss metrics. Energy efficient resource allocation and physical tasks scheduling also leads to improvements in the total energy consumption of the system by collecting sensing, localization, traffic and mobility pattern data as input for the AI/ML algorithm. AI-based solutions can also be used to automate and optimize post-deployment orchestration operations such as service migration or scaling to minimize energy usage. On the other hand, the energy consumption of the MLOps workflow for the different phases of model training and maintenance can be assessed and optimized by retrieving metrics of different granularities from the workflow. When using Federated Learning in a multi-domain edge architecture context, each step to convergence bears a data communication load and energy cost as the FL members exchange data. Thus, optimizing the local clustering of edge nodes reduces data communication and energy cost.
- **Service KPIs:** Service KPIs such as the end-to-end latency and throughput are optimized through the AI-based M&O control procedures for resource allocation, task scheduling and post-deployment lifecycle management.
- **Automation:** This enabler contributes to automating the M&O control system and reducing OPEX through full zero-touch M&O decision mechanisms using AI-based solutions which provide more efficient decisions compared to manual or default decision mechanisms. Additionally, the developed configuration recommendation system allows for increased automation of the network and service M&O by translating high-level requirements into configurations that best match the performance and energy related requirements.

Impacted KVIs

- **Sustainability:** the energy and resource efficiency targets in the different AI-based solutions lead to reduced energy consumption by the system for computing, data transmission, MLOps workflows, as well as the energy consumed for using hardware edge nodes.

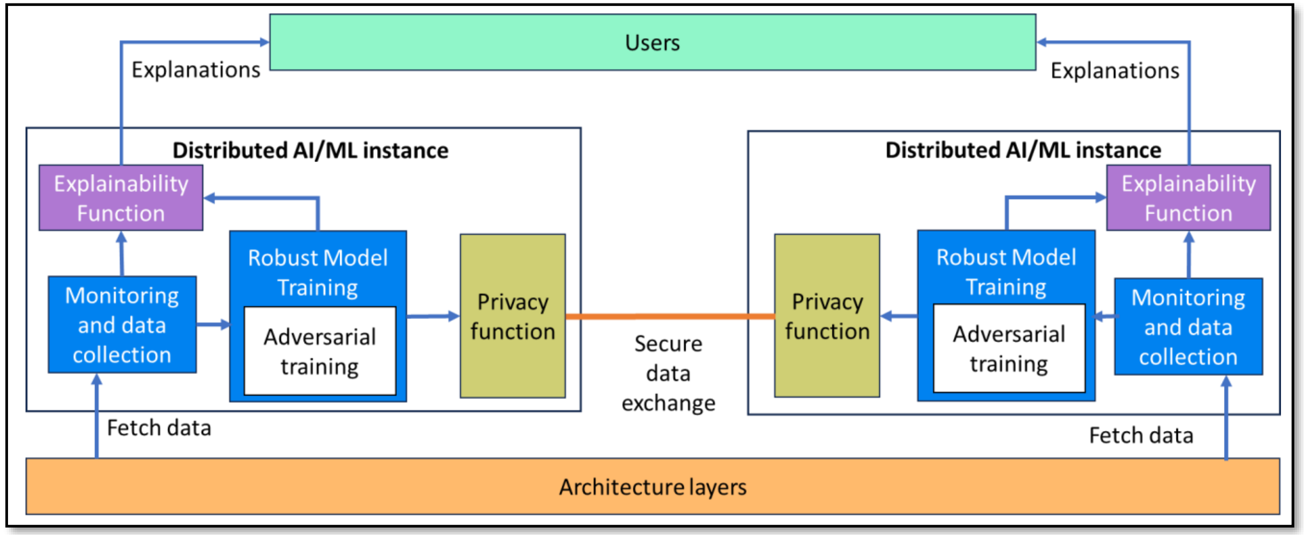
Sub-Enabler #6.2:
Trustworthy AI/ML-based control algorithms

Objectives

- Improve trustworthiness of the AI/ML control system via the implementation of defense mechanisms against privacy and adversarial attacks.
- Explainability on the provided output.

System components

- **Robust model training,** responsible for performing AI/ML model training by including adversarial attack samples in the training dataset to create AI/ML models that are more resistant against adversarial attacks.
- **Privacy functions.** In distributed training (e.g., Federated Learning), the model updates are exchanged among the components, making data vulnerable to privacy attacks. The privacy functions are deployed with each distributed instance, and used to exchange data in a secure and privacy-preserving manner.
- **Explainability function,** applying XRL techniques to provide human-interpretable explanations of the AI/ML-based decisions in the M&O framework.



High-level architecture for trustworthy AI/ML-based control

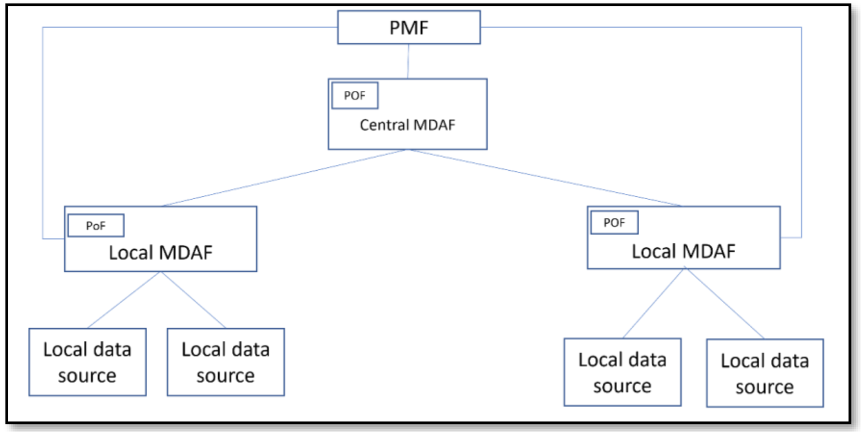
Sub-Enabler #6.2: Trustworthy AI/ML-based control algorithms

Preliminary implementation and early validation results

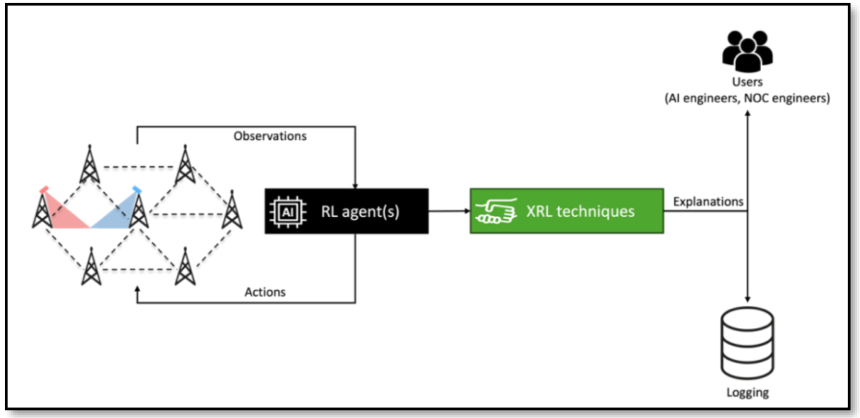
- Secure AI/ML-based control for Intent-based Management System

Conceptual solutions

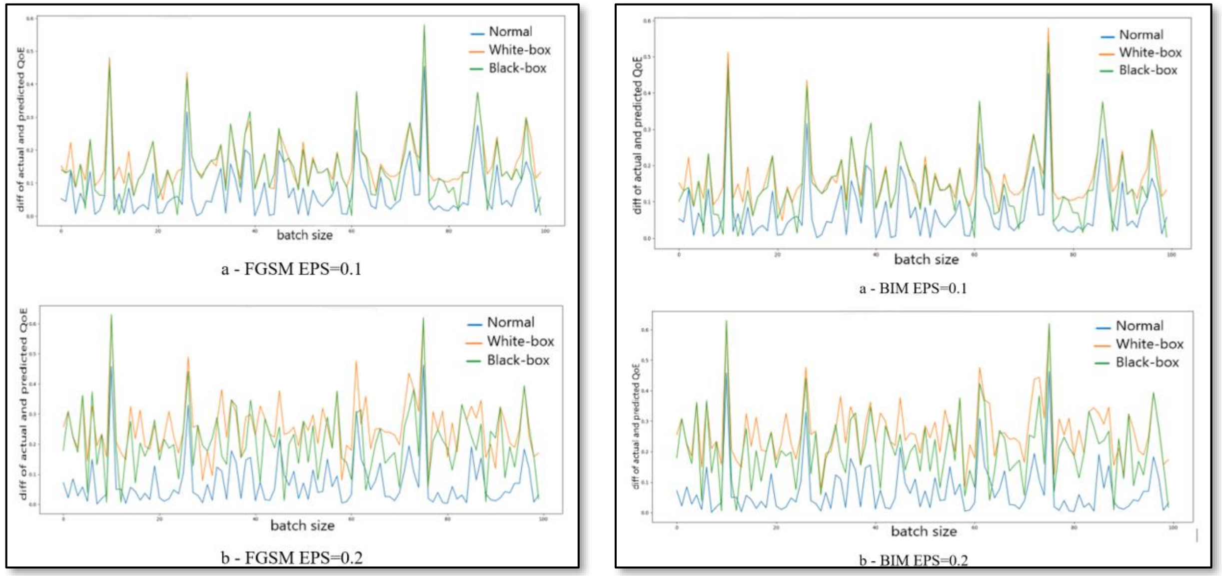
- Privacy protection framework for data analytics in M&O
- Explainability for RL-based Control in M&O



Overview of privacy protection framework



XRL integration with RL-based control



Adversarial Attack using FGM and BIM methods

Sub-Enabler #6.2:
Trustworthy AI/ML-based control algorithms

Impacted KPIs

- **Reliability,** allowing to develop mechanisms to protect AI/ML models from adversarial attacks that may affect decisions made by the system and reduce its overall performance.
- **Privacy,** allowing to protect the system against privacy attacks designed to access and leak sensitive data collected and stored in the system.
- **Explainability**: model explainability can improve the interpretability and transparency of the model and its decisions, and increase the trustworthiness of the AI/ML decisions by providing human readable explanations for each provided output.

Impacted KVIs

- **Trustworthiness,** protecting the AI/ML decision system against performance degradations and data leaks, and providing human readable explanations for the reasoning of AI/ML-based decisions.

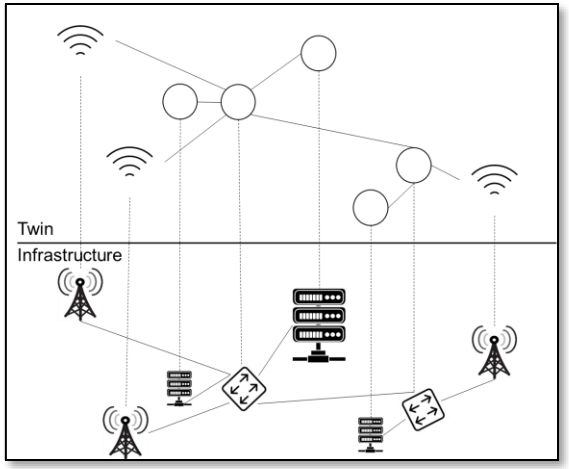
Enabler #7: Network Digital Twins creation mechanisms

Objectives

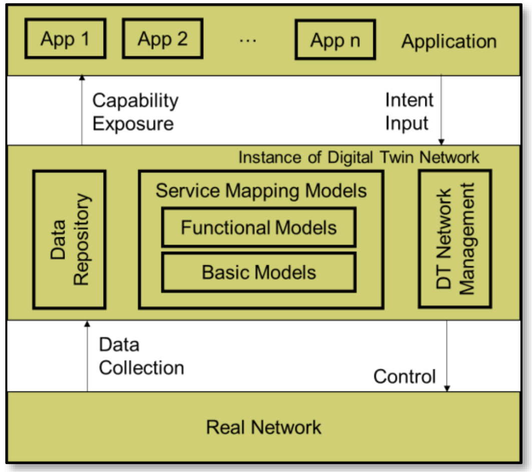
- Network Digital Twin creation mechanism to provide a digital replica of the infrastructure.
- Provide accurate feedback on control actions before applying them on the real network.

System components

- **Real Network**, may include various components (e.g., a mobile access network, a transport network, a mobile core, or a backbone) and may span singular or multiple network administrative domains. It could also include both physical entities and virtual elements that cooperatively deliver network services.
- **Data Collection**, leveraging Enabler 2 to obtain data from monitoring tools present in the real network.
- **Data Repository**, responsible for gathering and preserving diverse network data to construct different models.
  - Gathers and refreshes real-time operational data from various network elements
  - Offers data services such as rapid retrieval, concurrent conflict resolution, and batch services, through unified interfaces to the Service Mapping Models subsystem.
- **Service Mapping Models**, providing model instances of network applications to facilitate the programmability of services in line with Enabler 1.
  - Basic models: provide real time representation of actual network elements, topology and link states.
  - Functional models: deal with network analysis, fault diagnosis and prediction. Functional models can also be leveraged for lifecycle tasks such as network planning, optimization and maintenance.
- **Digital Twin Network Management**: responsible for life-cycle management of digital twins. It tracks their performance, resource consumption as well as the models that constitute the twins.
  - Models can be updated or replaced to enhance the accuracy of the digital twin.



Network Digital Twin representation



IETF Reference Architecture for Network Digital Twins

Enabler #7: Network Digital Twins creation mechanisms

Impacted KPIs

- **Service KPIs,** enabling the training of advanced algorithms for network and service management in a more efficient manner, improving their performance and decision quality, and KPIs such as energy efficiency, latency, or bit rate.
- **Automation:** The use of advanced models that are true copies of the infrastructure hosting NFs complements the work on closed management loops. It allows for autonomous prediction of the impact certain management actions will have, thus removing complex policy decision trees made by network operational teams.

Impacted KVIs

- **Trustworthiness,** providing a more accurate representation of the network state and thus improving the performance and accuracy of the decision mechanisms.
- **Sustainability**, through NDT-driven AI/ML models for optimizing energy consumption.

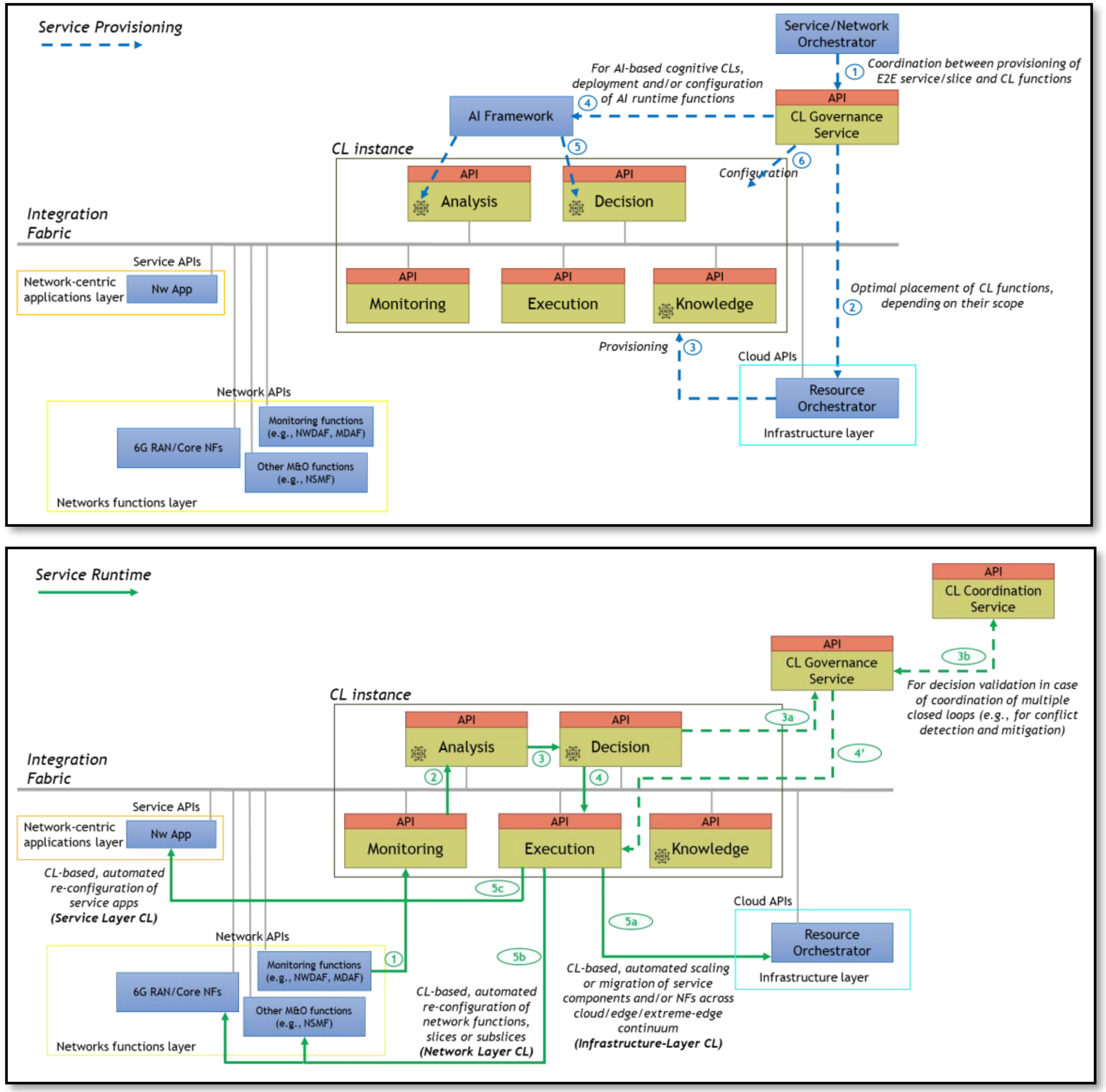
Enabler #8:
Real-time zero-touch control loop automation and coordination system

Closed-Loop Governance

- Closed-loop (CL) **stages,** applicable technologies and interfaces
  - Monitor, Analyze, Decide, Execute, Knowledge
- Splitting of **(virtualized) CL functions** and their interactions
  - Applicable technologies, open source tools, standard interfaces and information models
- **Placement and scope** of CL functions
- Cooperation with and **interfaces to other M&O components**
  - Monitoring, AI framework, SDN controllers, Orchestrators
- Lifecycle management, configuration, and orchestration of CL functions, implemented via **CL Governance**
- CL management interfaces for **interaction with external entities** (including external closed loops)

Closed-Loops Coordination

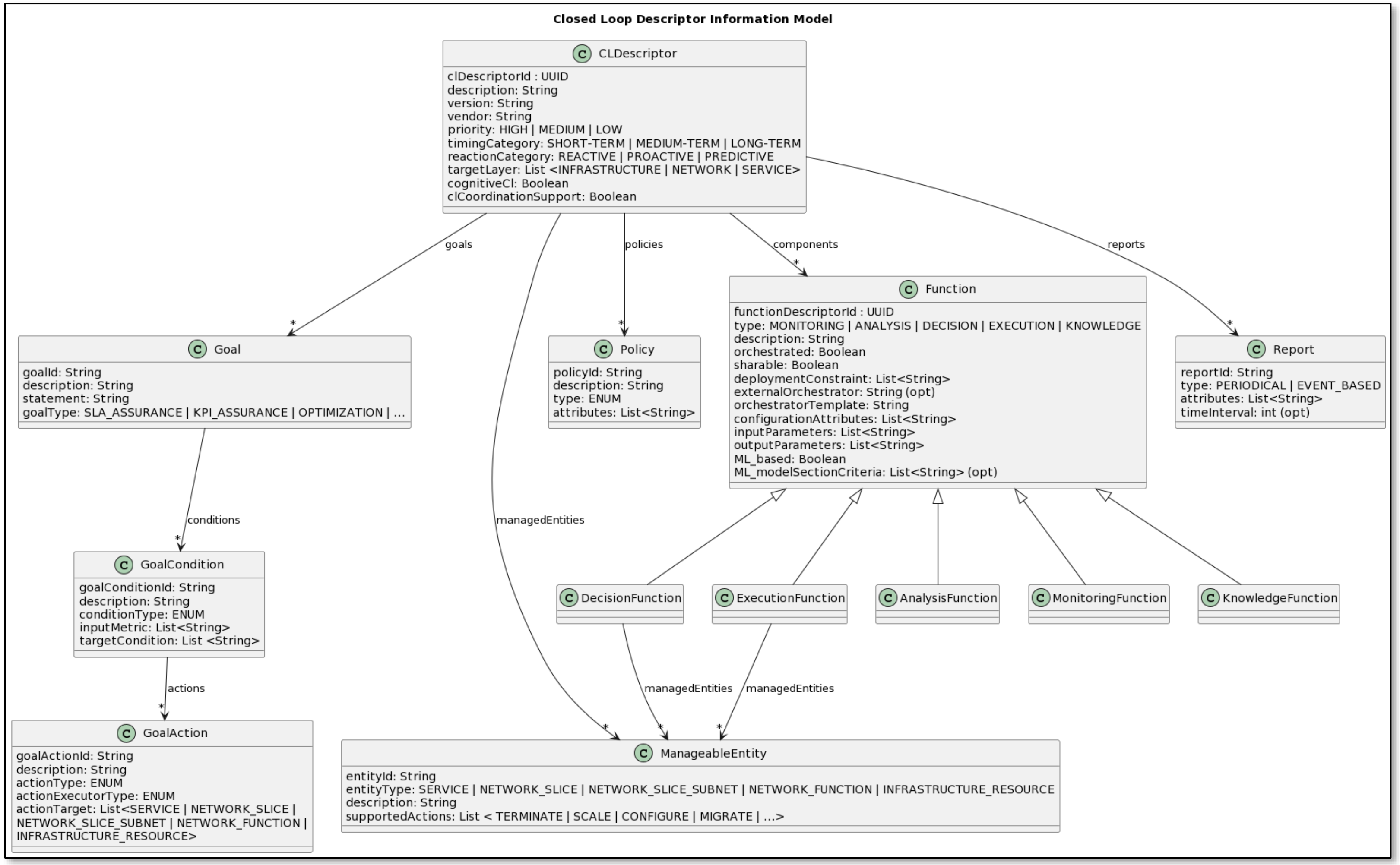
- Models for **interaction and cooperation** among multiple CLs
  - **Peer vs. hierarchical vs. nested** CLs
- **Coordination of concurrent CLs** with multi-dimensional scopes
  - Cross-layer: @service vs. @network vs. @infrastructure layer
    - <u>*@computing resource vs @network level → Selected for PoC*</u>
- Collaboration models:
  - **CL delegation and escalation**
  - CL coordination for **Conflict management**



System components and interactions with other M&O elements

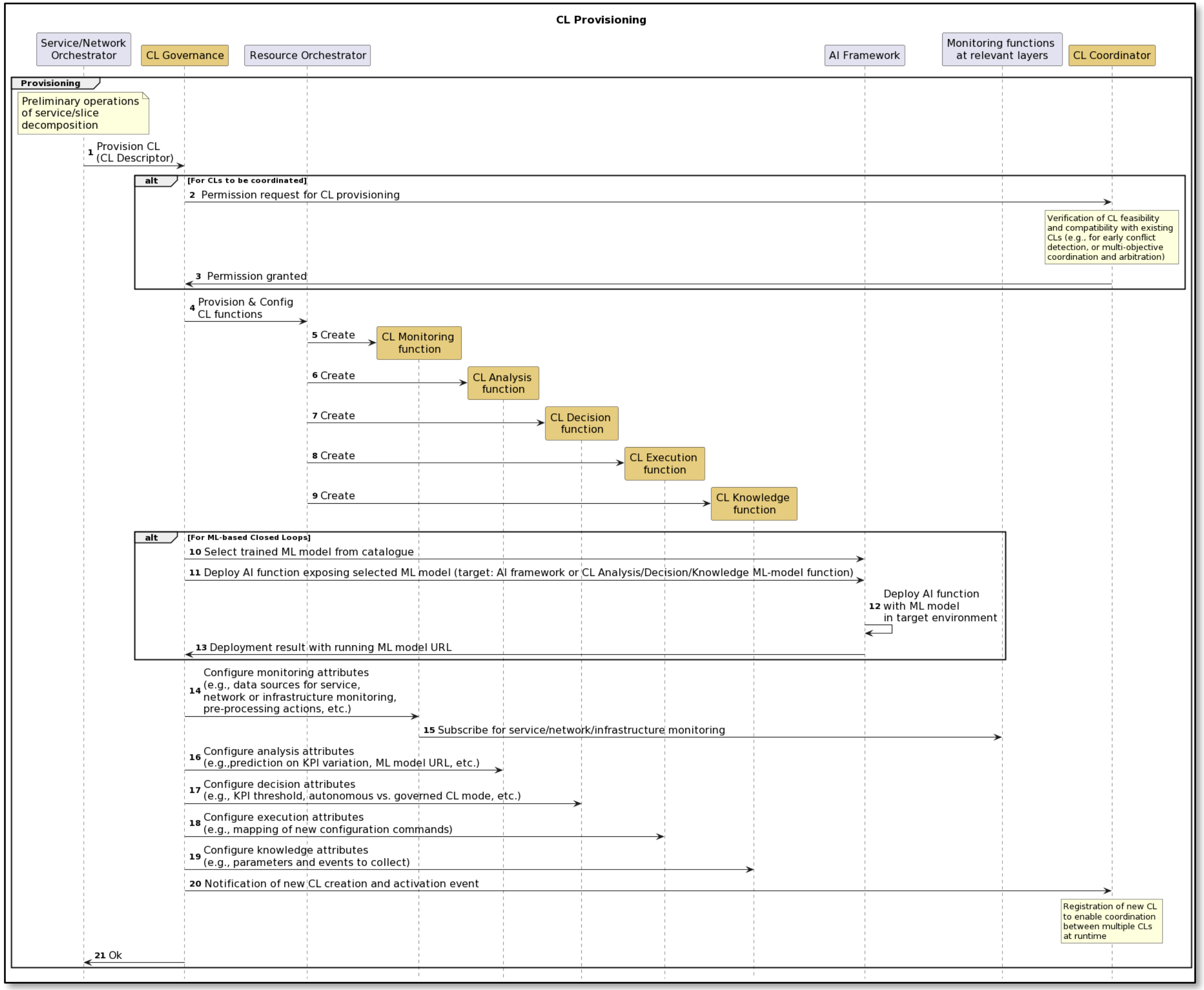
Enabler #8:
Real-time zero-touch control loop automation and coordination system

Information model for CL descriptors, as input for automated CL provisioning in CL Governance.



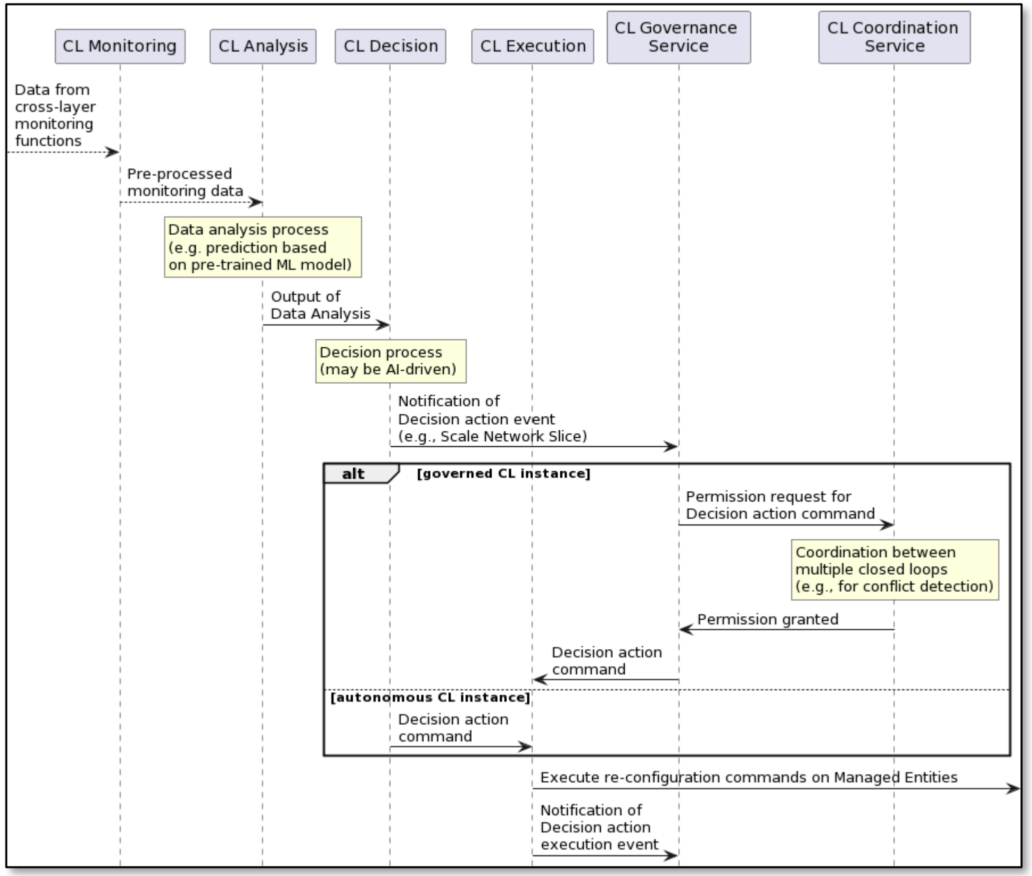
CL descriptor information model

Enabler #8:
Real-time zero-touch control loop automation and coordination system



Workflows for

CL provisioning and runtime.

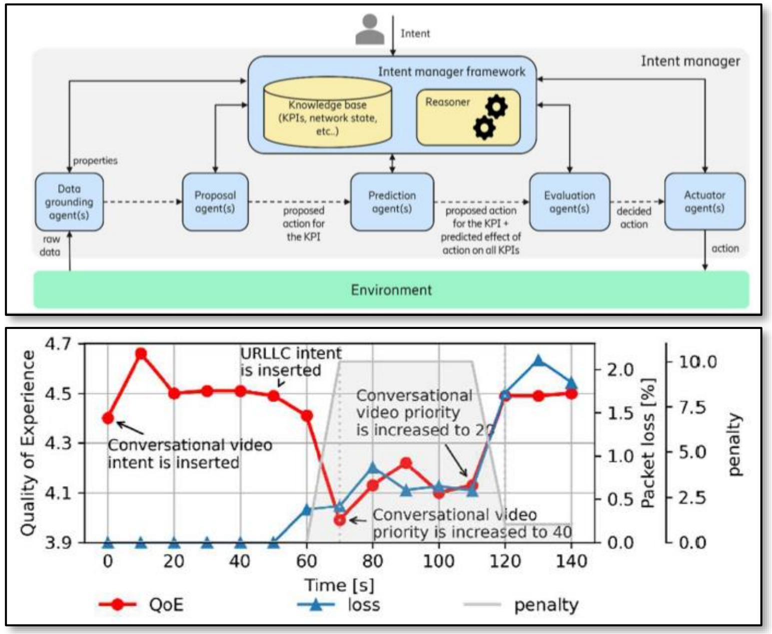


Enabler #8: Real-time zero-touch control loop automation and coordination system

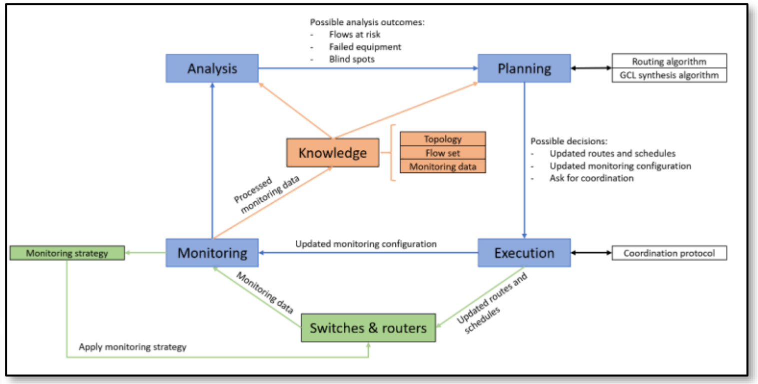
Preliminary implementation and early validation results
- Closed-loop governance and coordination function
- Specialized CLs: automation of transport network slices
- Penalty-based management of concurrent service CLs

Conceptual solutions
- Specialized CLs: TSN/DetNet control
- Specialized CLs: Dependencies in AI/ML models and NDTs

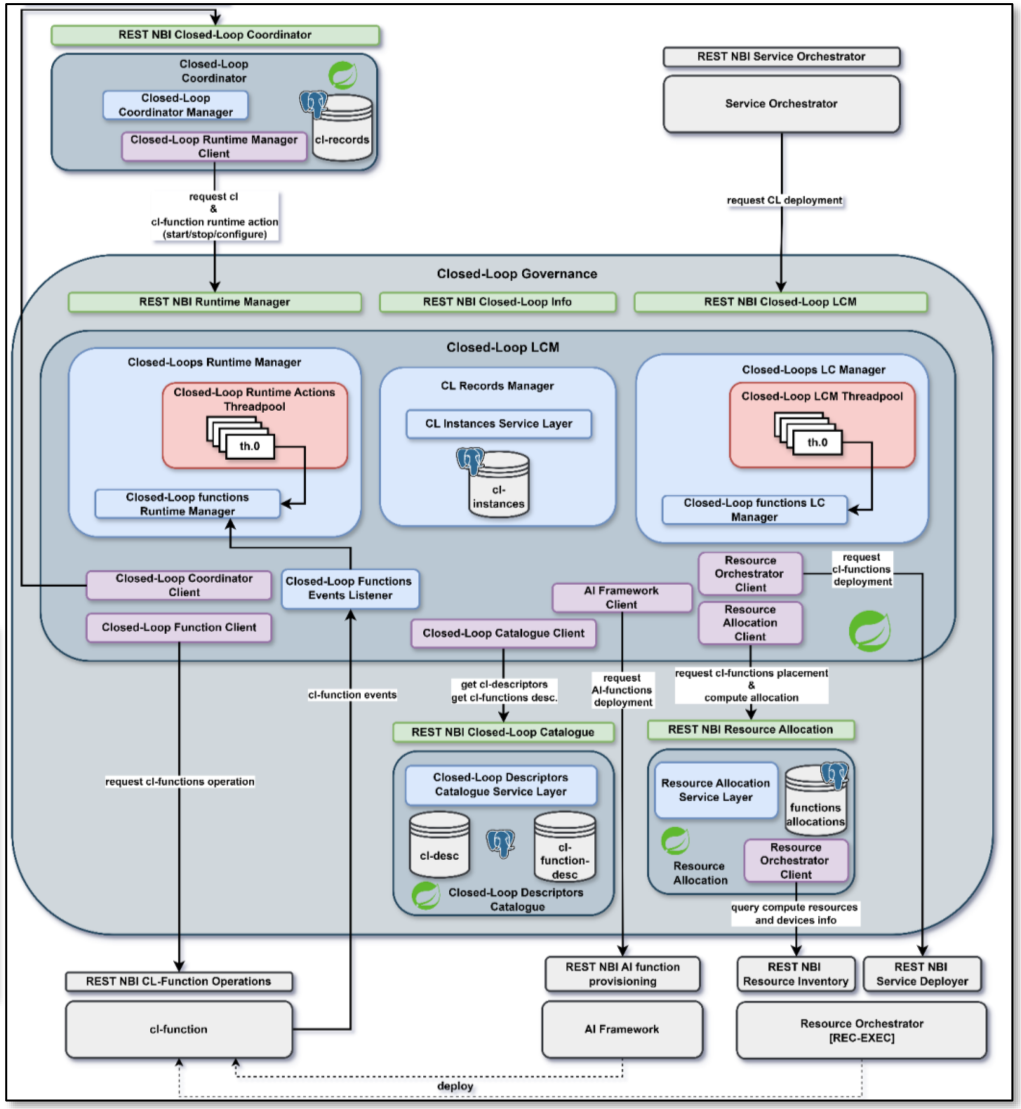
Relation with other enablers
- Specialized CLs for decentralized orchestration system
- Specialized CLs: Service autoscaling in the continuum



Intent Manager system with penalty-based management of concurrent CLs



Specialized CL for TSN/DetNet control: conceptual solution



Software design of CL Governance and Coordination functions

Enabler #8:
Real-time zero-touch control loop automation and coordination system

Impacted KPIs

- **User Experience Data Rate,** with CLs that automatically migrate service components on edge nodes closer to the users and adjust the allocation of network and computing resources according to network load and performance, allowing to guarantee the data rate perceived by the end user.
- **End-to-end latency,** with CLs that move application components according to users' mobility patterns or adjust resource allocation in the continuum, driven by predictions on users' position, processing and traffic load. This reduces the end-to-end latency perceived by the user.
- **Reliability,** through the increased level of network automation, with CLs that can operate not only in reactive modes (e.g., to solve network failures after their detection), but also in proactive and predictive mode re-optimizing the resource allocation to prevent congestions.
- **Service-level reliability,** implemented through the same mechanisms of reliability, but with CLs operating at the service level, using strategies based on preventive scaling or replication of service components. CLs coordination enables concurrent work of CLs operating at network and service layers, guaranteeing their consistency and avoiding conflicting decisions.
- **Availability,** with CLs specialized to guarantee the continuity of the end-to-end service and mobile connectivity, with the required level of QoS.
- **AI/ML-related capability,** through cognitive closed loops, where analysis and decision functions are implemented through AI/ML agents possibly deployed in a distributed environment. The CL Governance function, through its interaction with the AI framework, supports the provisioning and configuration of AI functions to be used in the context of closed loops.
- **OPEX reduction for MNOs,** through automation of M&O operations limiting human intervention and guaranteeing an optimized usage of the available resources, with self-configuration, self-adaptation, and self-optimization capabilities in the network logic.

Impacted KVIs

- **Trustworthiness**
  - Improved service and network reliability.
  - Usage of trustworthy AI in cognitive CLs for network automation.
- **Sustainability**
  - Energy efficiency, with energy constraints or energy-related criteria for CL placement and re-optimization algorithms.

Alignment of M&O enablers with the E2E system blueprint

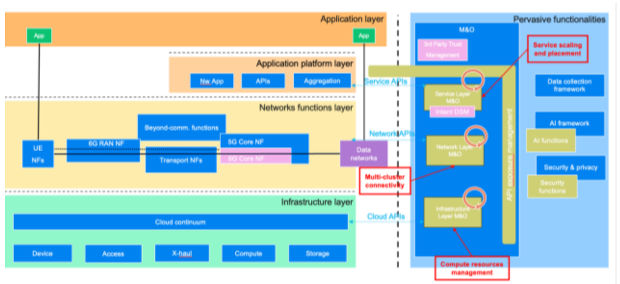
Alignment of M&O enablers with the E2E system blueprint

WP6 Enablers	Aligned	Update Required
1: Network programmability framework	◆	
2: Monitoring and telemetry framework	◆	
3: Management capabilities exposure framework		◆
4: Security and trustworthiness framework		
4.1: Third-party resource control separation enabler		◆
4.2: User-centric service provisioning system		◆
4.3: Trust management system		◆
5: Synergetic orchestration mechanisms for the computing continuum		
5.1: Multi-agent systems for multi-cluster orchestration	◆	
5.2: Decentralised orchestration system		◆
5.3: Federated orchestration system		◆
6: AI/ML algorithms		
6.1: AI/ML-based control algorithms for sustainability	◆	
6.2: Trustworthy AI/ML-based control algorithms	◆	
7: Network digital twins creation mechanisms		◆
8: Real-time zero-touch control loops automation and coordination system		◆

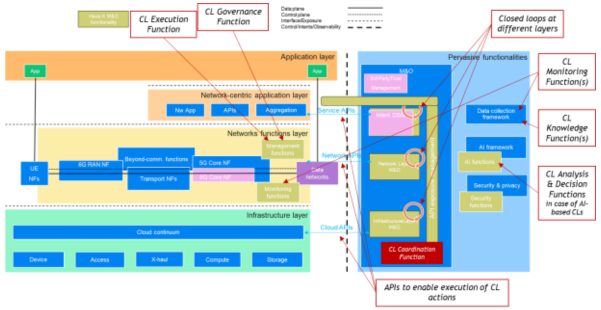
Analysis performed for each enabler, identifying:

- Mapping with existing components in the blueprint
- Updates required in existing components
- New components and/or interfaces in support of M&O enablers

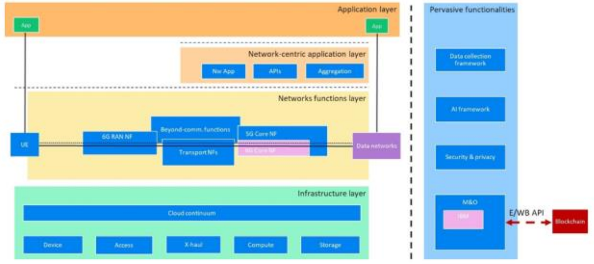
Example of full alignment



Example of partial alignment and required update with new component



Example of required update with new interface & component



Contributions to dissemination activities

Contributions to dissemination activities

Paper	Partners	Enablers
R. Pires, et al., “Closed-Loop Automation in 6G for Minimum Downtime Task Continuity in Surveillance Cobots”, EuCNC and 6G Summit, June 2024	VTT, NXW	#2, #5.1, #8
P. Alemany, et al., “Multi-Stakeholder Intent-based Service Management Automation for 6G Networks”, EuCNC and 6G Summit, June 2024	CTT, TID, NFR, VTT, NFI, EAB, EBY, ICC, NXW, OPT	#1, #3, #4.2, #8
J. Miserez, et al., An east-westbound control architecture for multi-segment deterministic networking, 2024 IFIP Networking Conference (IFIP Networking). IEEE, June 2024	IMEC	#1
R. Vilalta, et al., “Applying Digital Twins to Optical Networks with Cloud-native SDN Controllers”, IEEE ComMag, 2023	CTT, TID	#1, #2
R. Vilalta, et al., Providing Anomalous Behaviour Profiling by extending SmartNIC Transceiver support in Packet-Optical Networks	CTT, TID, ATO	#1
R. Vilalta, et al., Demonstration of Intent-Based Networking for End-to-End Packet Optical Cloud-native SDN Orchestration, ECOC 2023.	CTT	#1
C. Manso, et al., Introducing End-to-End Location Awareness in Packet-Optical Networks	CTT	#1
M. Karaca, et al, “Utilizing Causal Learning for Cognitive Management of 6G Networks”, IEEE International Conference on Machine Learning for Communication Networks (ICMLCN), Sweden, May 2024	EBY	#8
S. Kerboeuf, et al., "Design Methodology for 6G End-to-End System: Hexa-X-II Perspective," in IEEE Open Journal of the Communications Society, 2024	All	All

Contributions to papers

Demonstration	Partners	Enablers
Decentralised orchestration in PoC#B.	ATO, ASA	Sub-enabler 5.2
Closed-loop for automated service migration among cobots in PoC#B.	NXW, VTT, CTT	Enablers 2 Sub-Enabler 5.1 Enabler 8
M&O enablers with cobots on warehouse inventory management PoC#A/B	WIN	Sub-enablers 4.3, 5.1, 6.1
TeraFlowSDN controller and data plane in-a-box	CTT	Enabler 1
Service autoscaling	ICCS	Sub-Enable 5.1
ETSI MEC PoC 14: Network resource allocation for Application specific requests using MEC BandWidth Management service and TeraFlowSDN	CTT, TID	Enabler 1

Contributions to demonstrations

Conclusions

Conclusions

- D6.3 as fundamental contribution towards the design of the Hexa-X-II E2E 6G System Blueprint, in its 2nd iteration
- Key contributions:
  - Unified definition of technological enablers for 6G smart network management framework, with a common technical approach:
    - Enablers' system components and workflows
    - Proposals for internal execution logic, algorithms and applicable technologies, with preliminary implementations or conceptual solutions
    - Analysis of proposed M&O enablers with respect to an intermediate version of the blueprint:
      - Some misalignments to be solved in next iteration
      - Suggestions for blueprint evolution, not only in terms of new components, procedures and interfaces, but also for what regards the representation of global concepts, e.g., for resource continuum or multi-domain aspects.
  - Analysis of impact on KPIs and KVIs for future 6G networks
    - Driver for prioritization of M&O enablers for their progressive integration in Hexa-X-II end-to-end system blueprint in WP2
    - Feed to KPIs and KVIs specification in WP1, from M&O perspective, with clear focus on sustainability and trustworthiness
- Preliminary implementation and initial validation results for most of M&O enablers
  - Feeding PoCs and demonstrations in conferences and public events
  - Providing realistic examples of how M&O components can be integrated with other elements of the end-to-end system blueprint (developed in other WPs)
  - Use-case oriented approach, to provide feedback to WP1 for refinements of Hexa-X-II use cases

HEXA-X-II

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6GSNS

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