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

Hexa-X-II

D6.2 Summary Slides: Foundations on 6G Smart Network Management Enablers

hexa-x-ii.eu

Executive summary

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

Introduction on the **main drivers** behind the development of 6G technology; Identification of **environmental, social, and economic factors** influencing the adoption and deployment of 6G technology as well as related potential benefits and challenges

Overview of **Hexa-X KPIs** which will be used to measure the success and efficacy of the Smart Network Management strategies as well as elaboration on the overarching **objectives and goals for Management and Orchestration (M&O**) in the Hexa-X-II project

The main part of the deliverable consists of the **<u>description of the design foundation for 11 identified M&O enabler</u>**<u>s</u>.

For each enabler, the deliverable presents: i) the main motivation or which problem each enabler aims to solve, ii) its objectives, iii) a more detailed description, iv) the main State of The Art (SoTA) items in which each enabler relies on and Beyond SoTA Analysis, v) identified components and interfaces, and vi) its relationship with other enablers. .

The M&O enablers are planned to be validated in **Proof of Concept (PoC)** being integrated to build a concrete use cases: PoC#A.1: Sustainability and trustworthy-oriented orchestration in 6G) and PoC#B.1 : AI-assisted end-to-end lifecycle management of a 6G latency-sensitive service across the compute continuum.

Table of Content

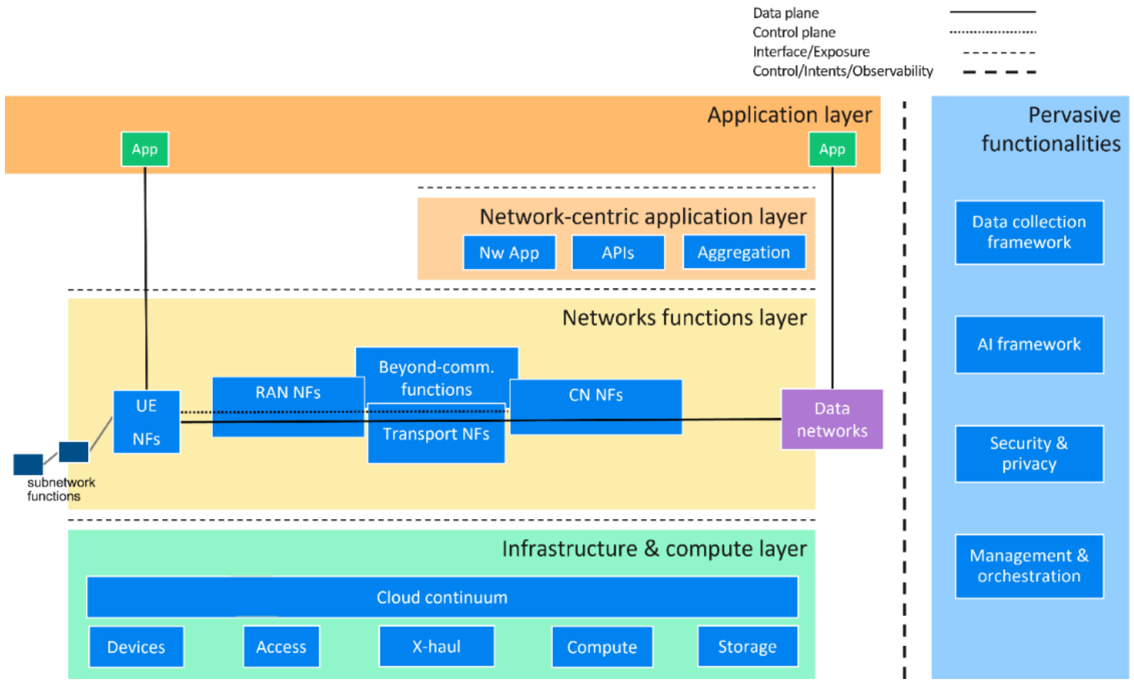
Introduction

Objective of the document and Hexa-X-II project context

The overall objective of D6.2 is to provide the **initial design foundations for the envisioned enablers** that will be implemented as part of the **smart network management** sub-system that is targeted in Hexa-X-II project.

The identification of the enablers and their initial design foundations has been performed based on:

- 6G drivers and KPIs/KVIs analysis elaborated by Hexa-X-II project in [HEX223-D1.1].
- Analysis of the functional objectives regarding Management and Orchestration (M&O) established in Hexa-X-II Description of Action (DoA).
- Background information elements that have been identified in the State of the Art (SoTA) exploration, including Hexa-X Management and Orchestration principles.
- Initial end-to-end Hexa-X-II system blueprint provided in [HEX223-D2.1].



Hexa-X-II Initial 6G E2E system blueprint [HEX223-D2.1]

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.

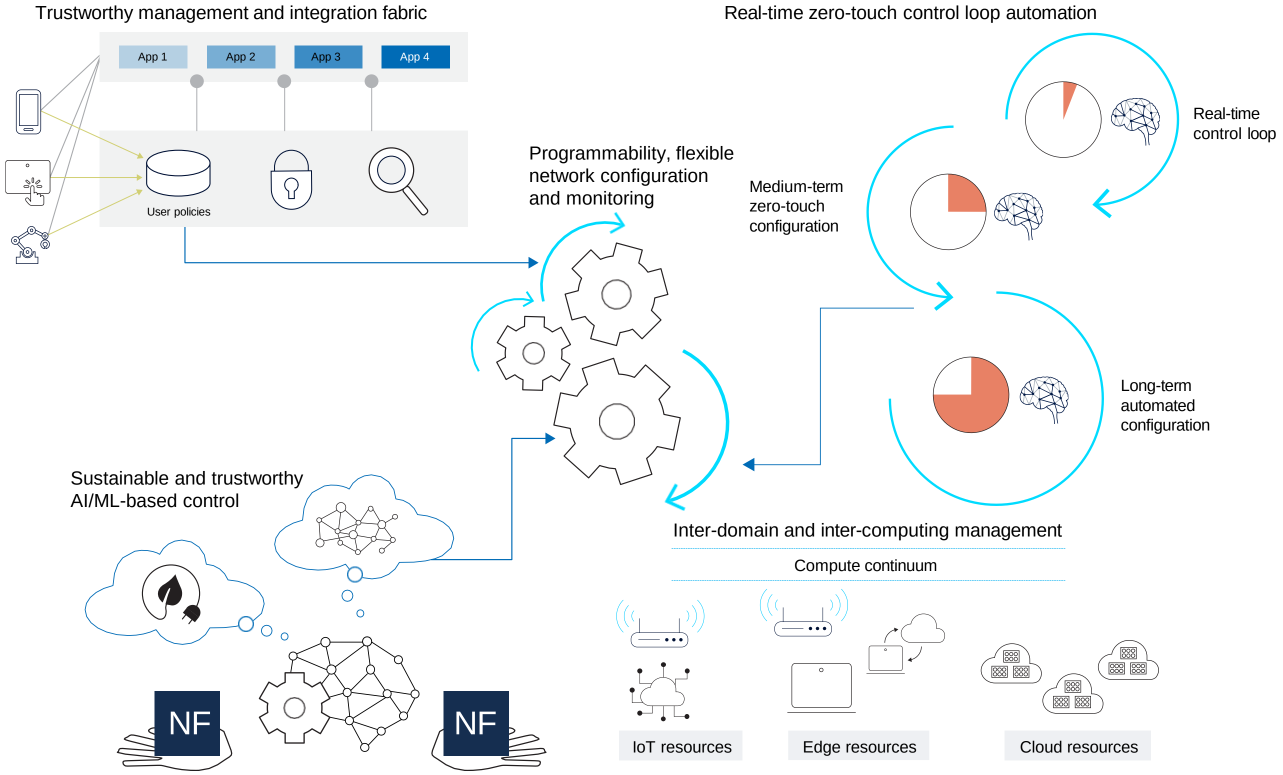
Management & Orchestration Drivers and Objectives Analysis

Environmental, Social and Economic 6G Drivers and KVIs for M&O

- **Driver #1: Environmental Sustainability**
  - Goal: Reduce network impact on the environment through decarbonization, circularity, and reduced raw material use.
  - Strategies: Reuse 5G and legacy equipment, build modular and durable equipment, target net-zero carbon emissions, digital inclusion, circular economy, and biodiversity.
  - Key Performance Indicators (KPIs) carbon footprint reduction, raw material use reduction, e-waste reduction, circularity monitoring, and equipment lifespan.
  - Applicability to M&O Enablers: Use of renewable energy sources and energy efficiency design principles
- **Driver #2: Social Sustainability**
  - Trustworthiness is crucial for M&O framework success, encompassing security, privacy, and reliability, measured by KPIs like security breaches, privacy violations, and system downtime.
  - Applicability to M&O Enablers: like user-centered design and data governance frameworks align with these objectives, optimizing the M&O framework for trustworthiness and digital inclusion
- **Driver #3: Economic Sustainability**
  - Designing and operating the 6G network economically, providing value to users through a value-based design approach.
  - KPI: customer satisfaction, revenue growth, and cost efficiency to measure success in value-based design.
  - Applicability to M&O Enablers: Open innovation and co-creation, contribution to OPEX reduction by means of network automation.

Hexa-X-II Smart Network Management Objectives

- Obj.1: Design and develop a **programmable cloud-native micro-service-based Management and Orchestration (M&O) framework** for the future 6G networks, which is represented in the centre of the figure as all the rest of objectives/enablers will be relying on it.
- Obj.2: Design and develop mechanisms that collectively define a 6G enabled **trustworthy** environment, with a **user-centric integration fabric** that ensures **multi-tenancy** support and SLA verifiability.
- Obj.3: Develop **synergetic orchestration** mechanisms for managing the deployment of 6G services over heterogeneous resources **across the IoT-to-edge-to-cloud continuum.**



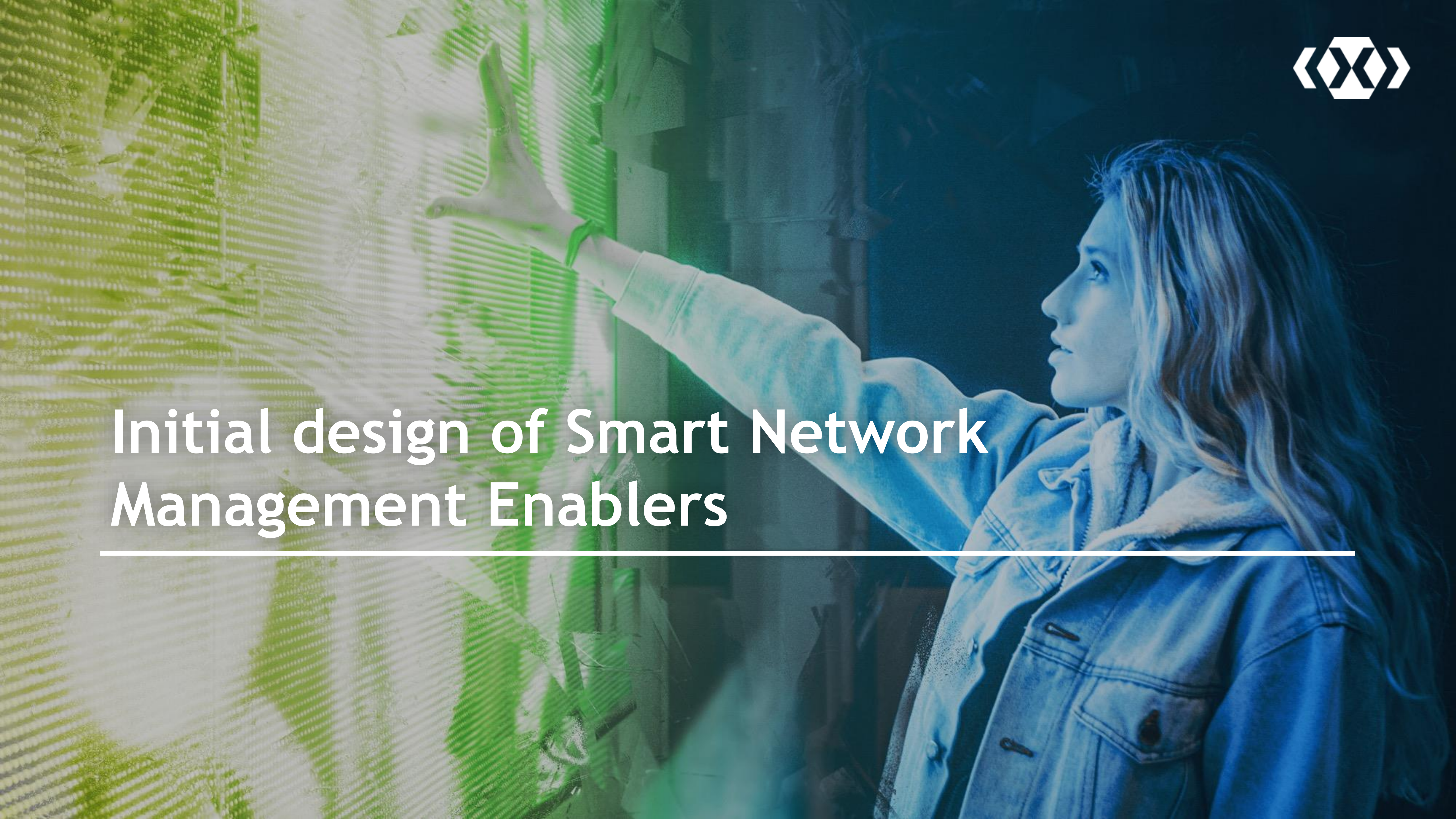
Hexa-X-II Smart Network Management Objectives

- Obj.4: Design and implement **robust and trustworthy AI/ML-based network control** solutions with optimal **energy efficiency and sustainability** targets.
- Obj.5: Design and develop **zero-touch M&O mechanisms for closed loop automation** and continuous service assurance, guaranteeing compliance with relevant 6G KPIs while reducing OPEX.

Enablers identification

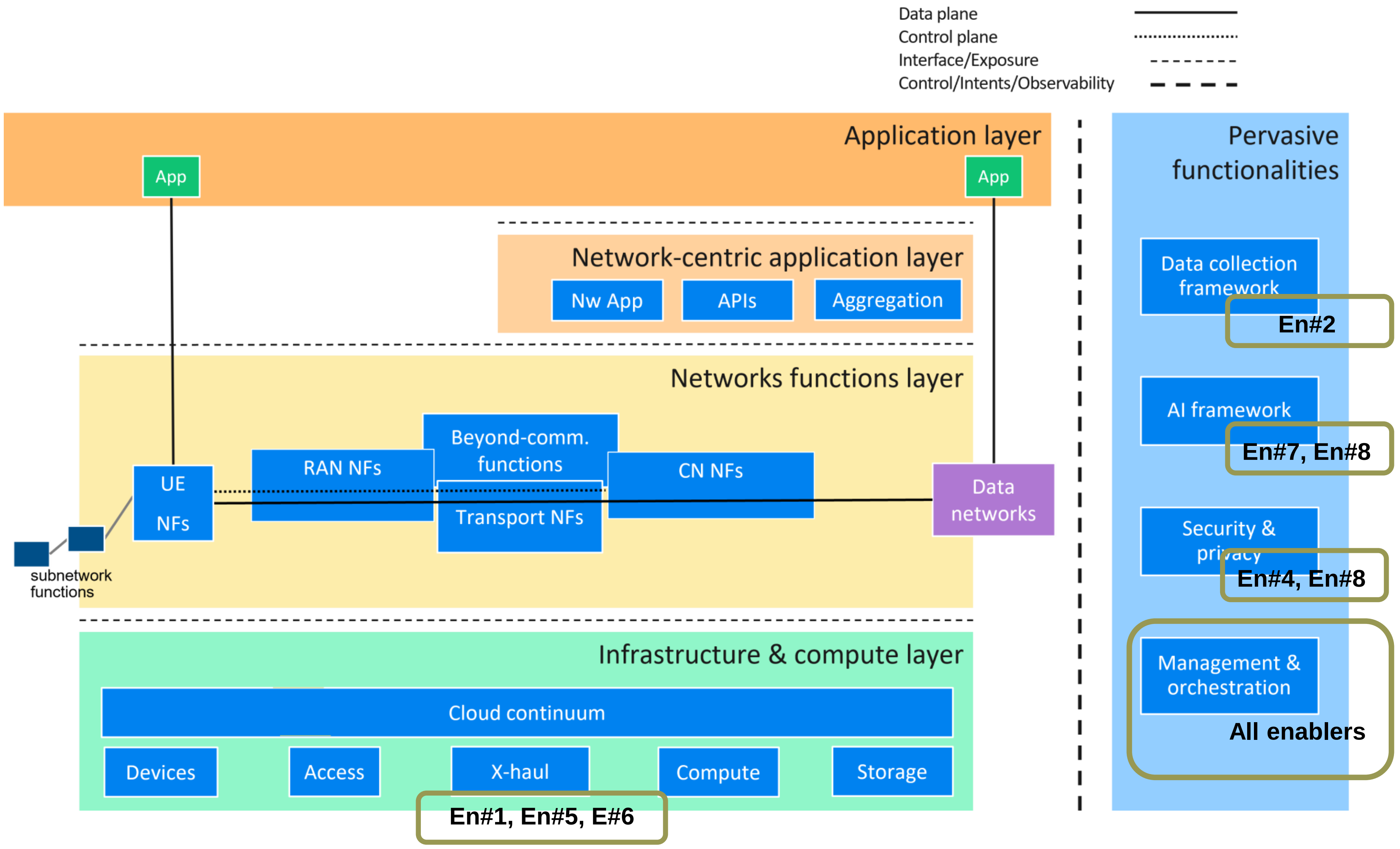
For each of the objectives the following enablers have been identified, which constitute a total list of 11 enablers:

- **Programmability, flexible network configuration and monitoring** → Obj.1
  - Enabler #1: Programmable flexible network configuration
  - Enabler # 2: Programmable network monitoring and telemetry
- **Trustworthy management and integration fabric** → Obj.2
  - Enabler # 3: Integration fabric
  - Enabler # 4: Trustworthy 3rd party management
- **Inter-domain and inter-computing management** → Obj.3
  - Enabler # 5: Multi-cloud management mechanisms
  - Enabler # 6: Orchestration mechanisms for the computing continuum
- **Sustainable and trustworthy AI/ML-based control** → Obj.4
  - Enabler # 7: Sustainable AI/ML-based control
  - Enabler # 8: Trustworthy AI/ML-based control
  - Enabler # 9: Network Digital Twins
- **Real-time Zero-touch control loop automation** → Obj.5
  - Enabler # 10: Zero-touch closed loop governance
  - Enabler # 11: Zero-touch multiple closed loop coordination



Initial design of Smart Network Management Enablers

Hexa-X-II initial system blueprint and its relationship with M&O enablers



Hexa-X-II initial system blueprint and its relationship with M&O enablers

Enabler #1: Programmable flexible network configuration

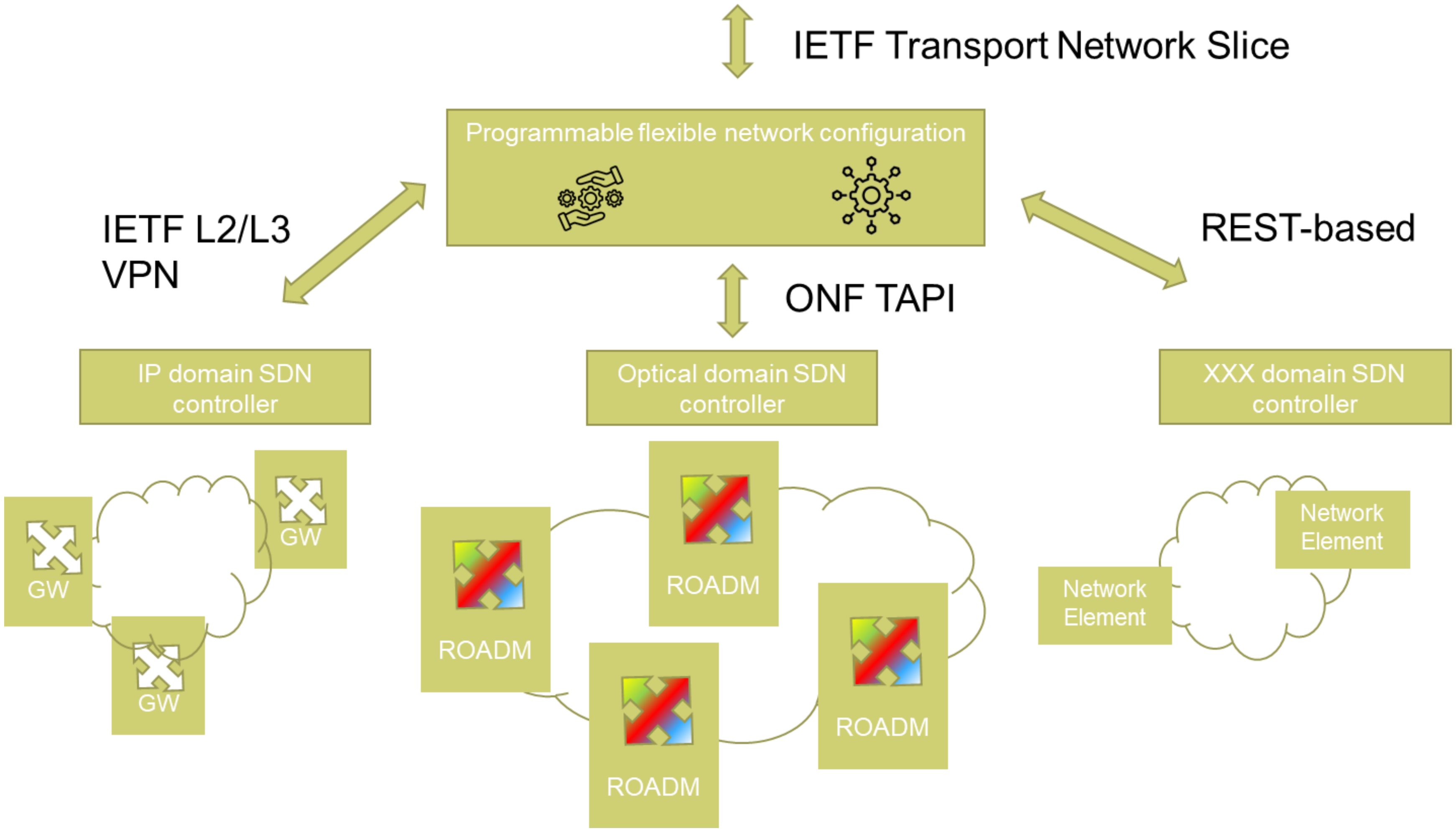
- **Motivation**
  - Traditional transport networks are mostly static and inflexible.
  - Network upgrades and integration of multiple network domains take long time.
  - Requirements and traffic patterns change often.
  - Security issues often require quick reactions.
  - Both programmability and flexible configuration are needed through standard interfaces.
- **Enabler’s objectives**
  - Control and Management of programmable (i.e., software-defined) network elements.
  - Enable forwarding control of data plane network elements and flexibility through programmability and configuration.
- **Enabler’s high-level description**
  - Cloud-native Software Defined Networking (SDN) controller for programmable network configuration.
  - APIs enable standard ways to interact with the network.
  - Cloud-based (SDN) controller for network automation.

Enabler #1: Programmable flexible network configuration

- **Related State of the Art**
  - Telecom Infra Project (TIP) Open Optical & Packet Transport (OOPT) Mandatory Use Case Requirements for SDN for Transport (MUST) [TIP21]
    - Defines hierarchical architecture and interfaces based on multiple Standardization Bodies: ONF Transport API [TAP22], IETF models (L2VPN [RFC9291], L3VPN [RFC9182]).
  - Open-Source cloud-native ETSI TeraFlowSDN controller (TFS)
    - Open-Source Cloud-native SDN controller driven by ETSI community [VMC+21].
- **Beyond the State of the Art**
  - Design general interfaces to ease new device type control through Device plugins and Service plugins.
  - Align SDN architecture with ETSI MEC 015 (T6.3 related), to offer BandWidth Management (BWM) Services to MEC applications [mec-015].
  - Analyze and extend ETSI Zero-touch Service Management (ZSM) architecture for SDN networks control and management (T6.5 related).
  - Analyze in a whitepaper missing gaps with operator requirements: Missing Interfaces, Evaluate maturity, Propose prioritization, Support ETSI TFS release 3.0 and 4.0.

Enabler #1: Programmable flexible network configuration

- Hierarchical approach for Programmable Flexible Network configuration
- Multiple technological network domains
  - IP
  - Optical
  - Microwave
- Support for multiple NorthBound/SouthBound Interfaces.



SDN-based high-level architecture supporting the programmable flexible network configuration enabler

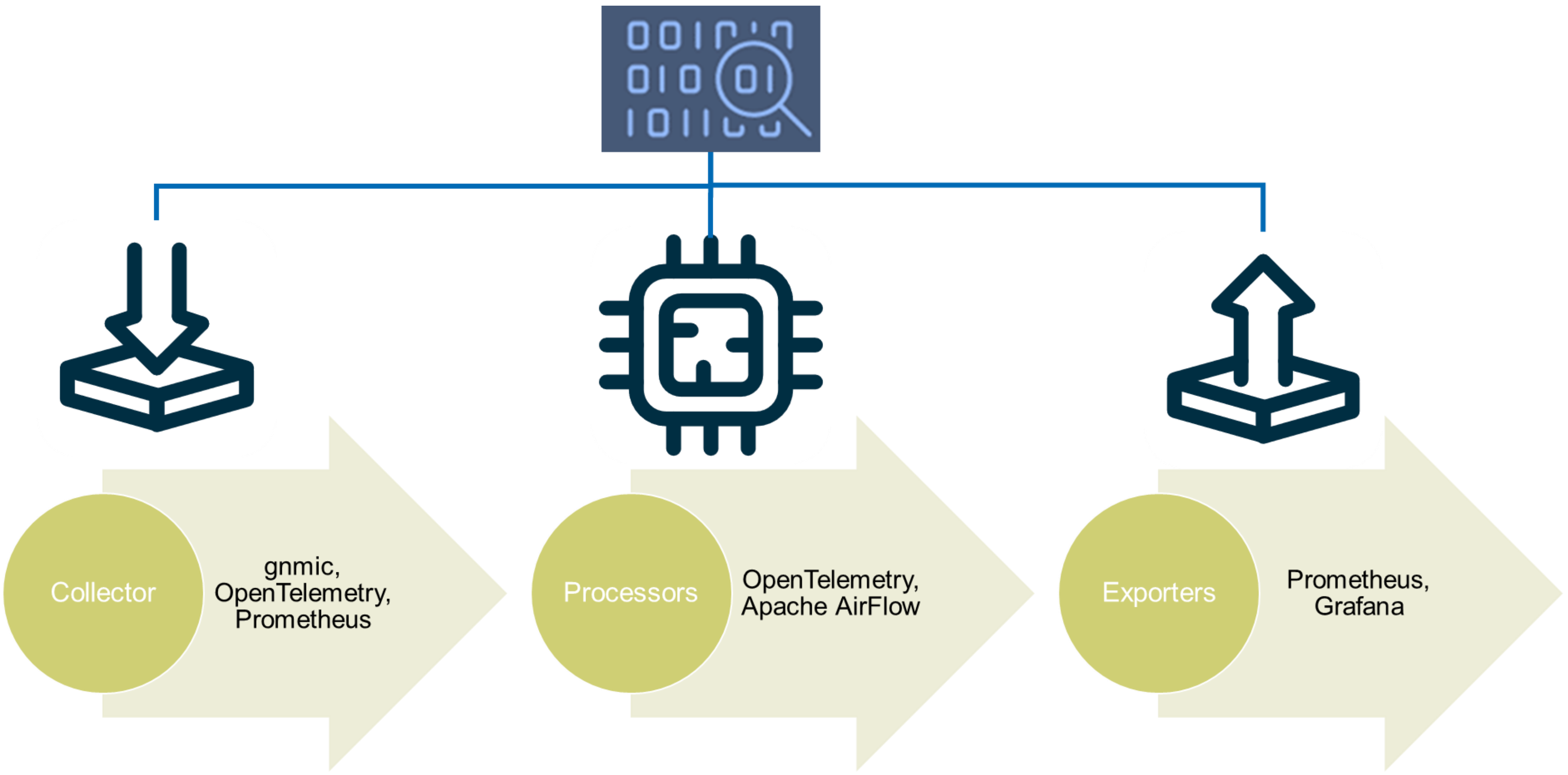
Enabler #2: Programmable network monitoring and telemetry

- **Motivation**
  - Monitoring virtual networks on hybrid and multi-cloud environments with highly distributed architectures is a challenging task.
  - Limited visibility, blind spots and security vulnerabilities.
  - Legacy monitoring has too much focus on visualization with defined and narrow metrics making it difficult to identify problems that require different view.
  - Programmability and automation can provide possible real-time data and end-to-end behavior visibility
  - Data can be leveraged for Network AI.
- **Enabler's objectives**
  - Collect and allow analysis of network performance data possibly in real-time across multiple network domains.
- **Enabler's high-level description**
  - Real-time data allows faster response to security and performance issues.
  - This also enables programable optimization across the whole network.
  - Includes support for multiple monitoring protocols, such as NETCONF, REST, YANG, gRPC, gNMI, SNMP.

Enabler #2: Programmable network monitoring and telemetry

- **Related State of the Art**
  - Many different monitoring solutions from different scopes:
    - Networks
    - Services
    - Applications
    - E2E measurements
  - Proprietary Mobile Network Operator monitoring solutions
  - Notable Open-Source projects:
    - Prometheus [PRO23]: open-source monitoring system with a dimensional data model, flexible query language, efficient time series database and modern alerting approach.
    - OpenTelemetry [OPT23]: an Observability framework and toolkit designed to create and manage telemetry data such as traces, metrics, and logs.
    - gNMI [GNM23]: protocol for data streaming from the network device and provides the functionality to configure and retrieve operational and configuration states while providing a powerful method for switch management.
- **Beyond the State of the Art**
  - Architectural perspective
    - Based on a scalable framework (such as proposed in SotA).
    - Contribute towards analysis of monitoring of extreme-edge devices
    - Data fusion of different signals – derived metrics
    - Analysis mechanisms (e.g., ML-based) for correlating signals and identifying events that call for remediation actions
  - API, components
    - OpenTelemetry specification adaptation and integration
  - Map architectural perspective to different solutions.
    - Energy monitoring: Scaphandre [SCA23] will be used as part the current enabler to be applied to improve energy observability metrics throughout the whole continuum for both network and computing resources.
    - TeraFlowSDN (TFS) monitoring: Persisting KPI and alarm setting
    - TFS scalable framework
    - Distributed tracing
    - Enhancement of monitoring platform developed by NXW for integration in closed loops

Enabler #2: Programmable network monitoring and telemetry

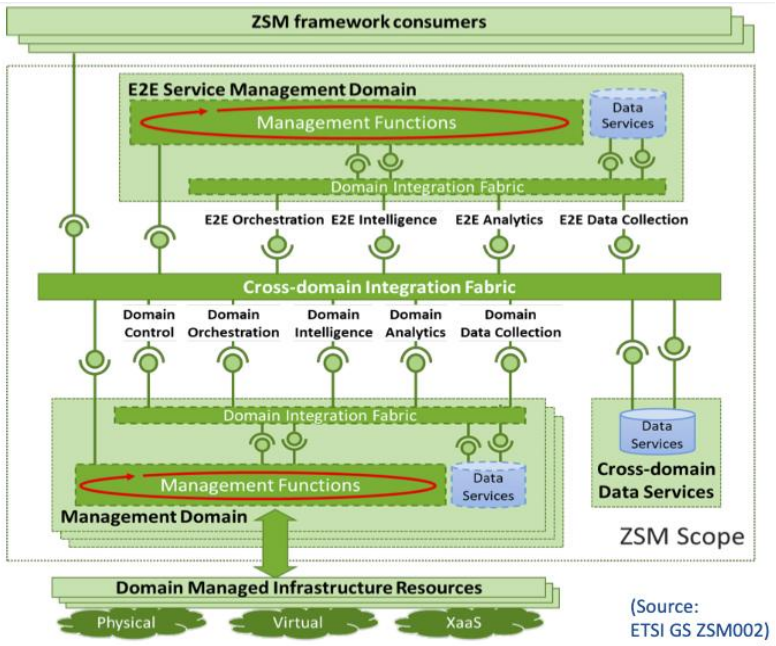


High-level illustration of the Programmable network monitoring and telemetry technology approach

Enabler #3: Integration fabric

- **Motivation**
  - Hexa-X-II derived solutions provide a lot of capabilities of different nature. These capabilities can be classified according to different criteria (see right-side table).
  - These capabilities provide modular features that can be customized and aggregated to deliver digital services. Only the management capabilities fall in the scope of this enabler.
  - Aggregation and customization needs to be done using programmable compositional patterns with cloud-native practices
- **Enabler's objectives**
  - Definition of service bus to allow liquid and frictionless interoperation between Hexa-X-II derived solutions capabilities of interest.
- **Enabler's high-level description**
  - Re-factoring the connectivity of today's capabilities, enabling cross-domain connectivity of loosely coupled and fine-grained services
  - Adopting Service-Based Management Architecture for managing the interconnection of Hexa-X-II M&O systems, enabling more programmability and adopting a cloud-native paradigm.
  - Service bus aligned with ETSI ZSM concept of cross-domain integration fabric.

Semantics	Infrastructure domains	Operational domain
• Network capabilities • Cloud capabilities • RFS mgmt capabilities • CFS mgmt capabilities • Zero-touch capabilities	• Telco capabilities • On-prem capabilities • Public cloud (hyperscaler) capabilities	• Operator managed capabilities • 3rd party managed capabilities



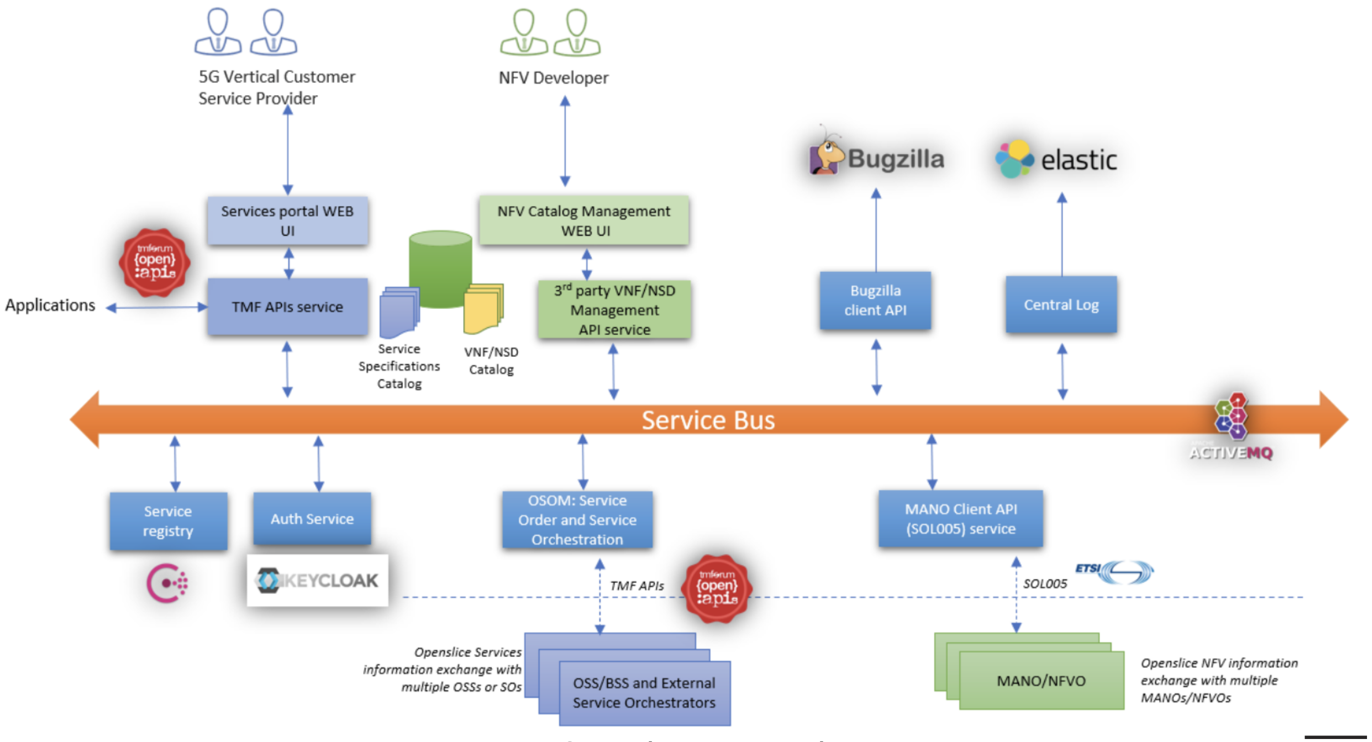
ZSM framework reference architecture [zsm-002]

Enabler #3: Integration fabric

- **Related State of the Art**
  - Standards: ZSM integration fabric [zsm-002]. ZSM goal is to enable zero-touch automated network and service management in a multi- vendor environment.
  - Open-source solutions: service mesh and message broker (see right-side table)
  - Open-source communities: Openslice (see right-side figure) a framework for managing network slices in 5G and beyond, enabling operators to allocate resources and deliver diverse services over a shared infrastructure [OPE23].
  - PoC "Security SLA assurance in 5G network slices (INSPIRE-5GPLUS)" showcasing a security closed-loop across multiple domains and sites interconnected using a security framework based on [zsm-poc6].
- **Beyond the State of the Art**
  - Consider scenarios wherein management domains belong to different administrative domains (multi-stakeholder)
  - Consider scenarios wherein one or more management domain operate on the extreme-edge (resource volatility).
  - Enhancements over service bus built-in features, for it to be used in the above scenarios. These features include connectivity, reliability, security and observability.

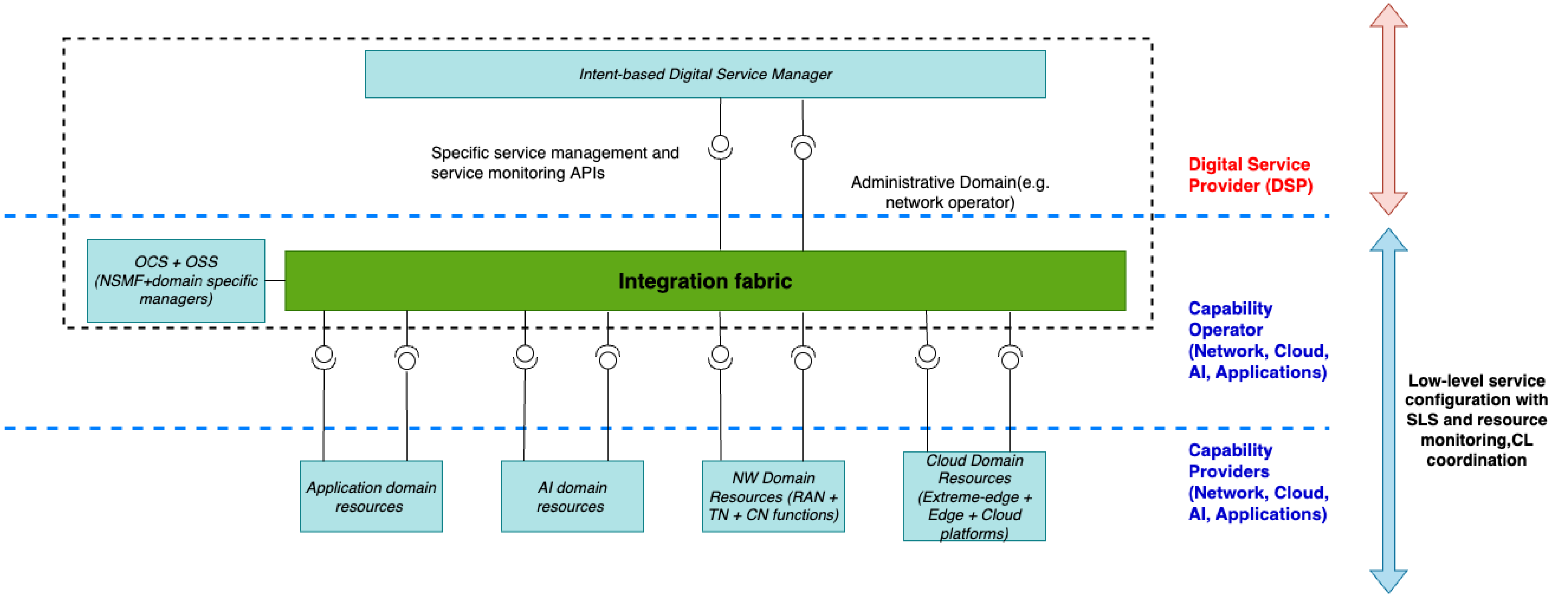
Service mesh	Message broker
Istio, HashiCorp Consul, LINKERD, envoy	RabbitMQ, NATS, PULSAR

CNCF open-source possible solutions for integration fabric implementation



Openslice service bus

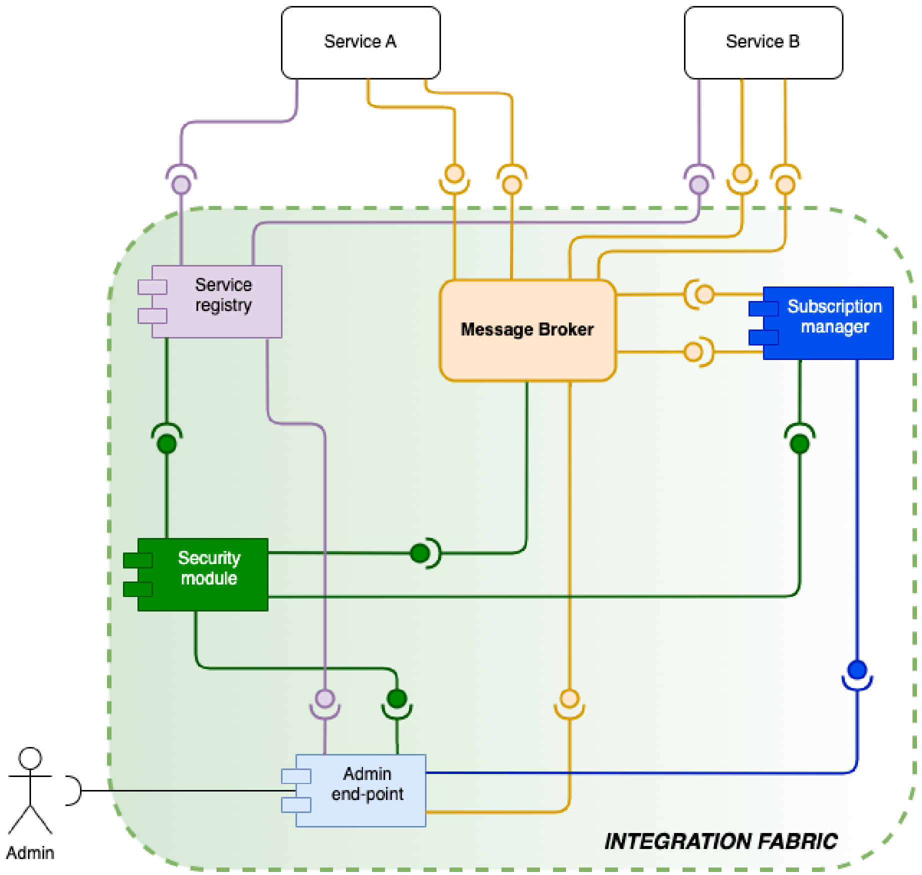
Enabler #3: Integration fabric



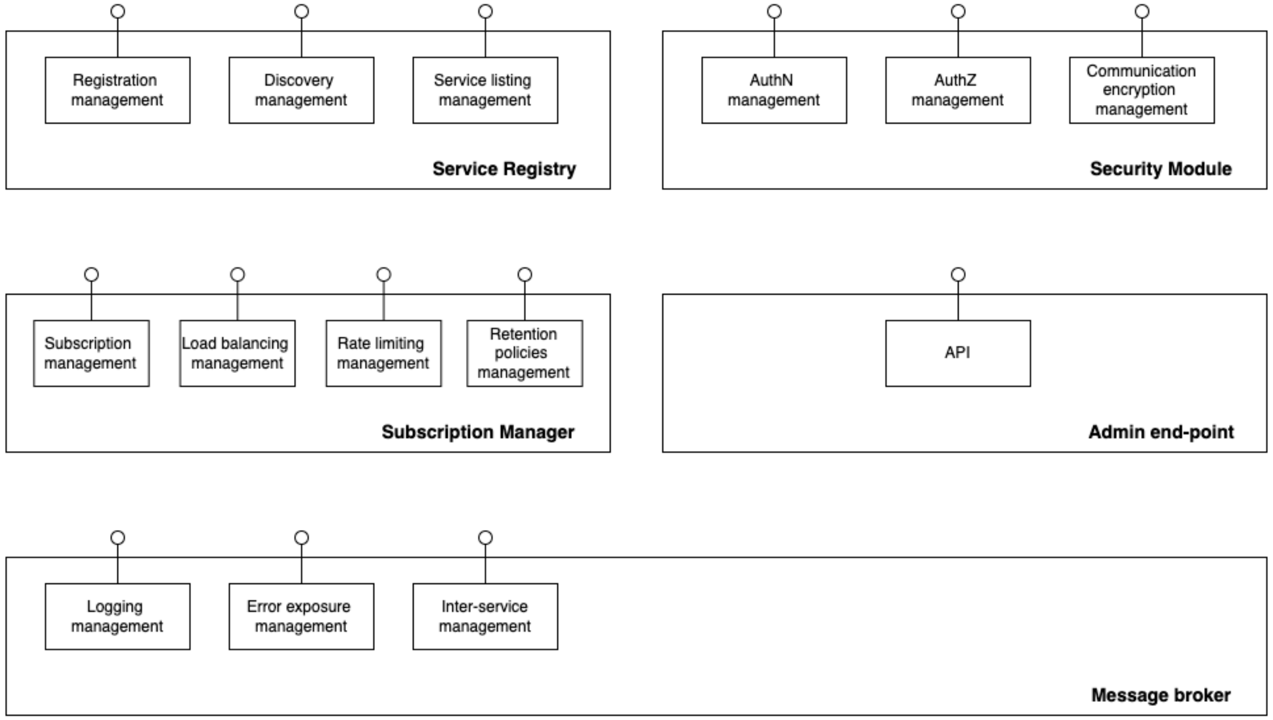
High-level view of the Hexa-X-II integration fabric architecture

Enabler #3: Integration fabric

- Architectural approaches with Message broker
  - Starting from ETSI ZSM concept of cross-domain integration fabric it is presented a possible architecture exploiting the event-driven architecture based on message broker potential.
  - The architecture with message broker make possible to create an event driven architecture to establish a communication channel between services under its scope. This make them able to trigger actions and exchange information



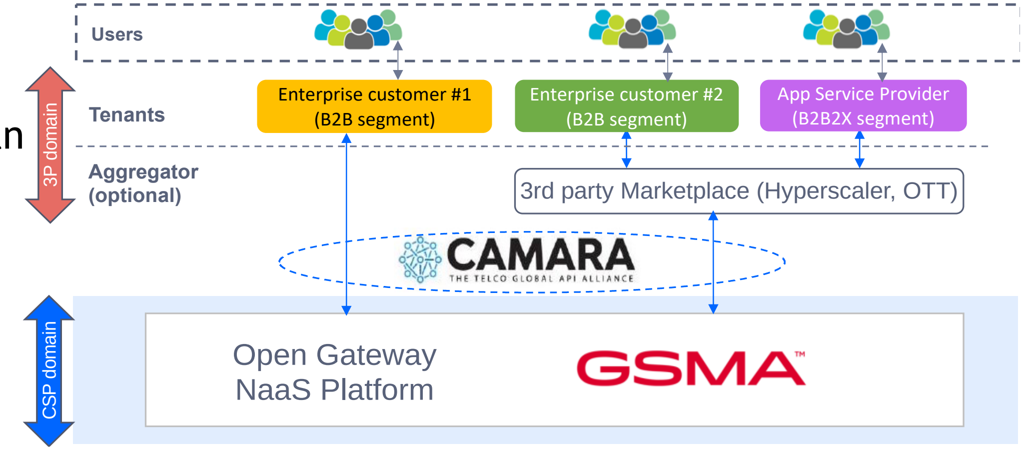
Integration fabric with message broker architecture



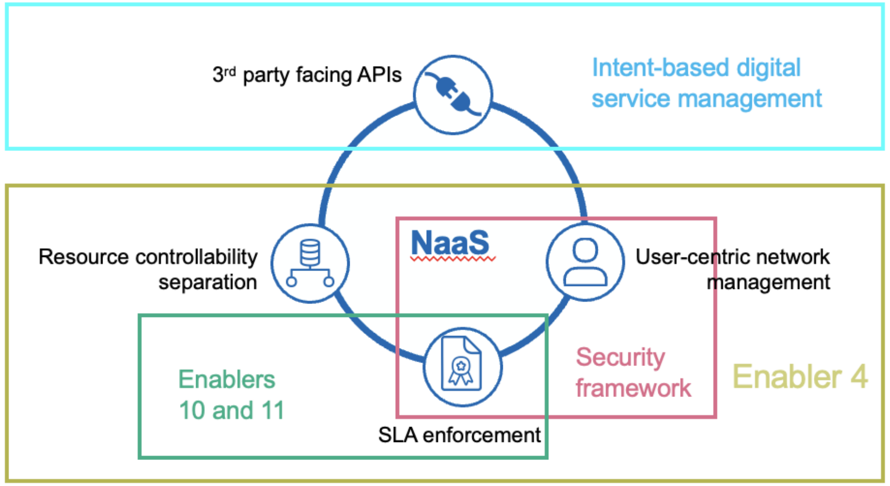
Integration fabric with message broker interfaces

Enabler #4: Trustworthy 3rd party management

- **Motivation**
  - Hexa-X-II aims to become a programmable service platform that can be easily accessed by 3rd parties (tenants), including app developers, aggregators and enterprise customers
  - This requires controllable and auditable exposure of capabilities to individual 3rd parties, tailored to their “tenant” profile: market segment, trust level, subscribers, and SLAs.
- **Enabler’s objectives**
  - Definition of operator internal solutions to ensure isolation (performance, management, and security) in multi-tenant environments.
- **Enabler’s high-level description (Separated in three tracks)**
  - Resource controllability separation track: provision of segregated yet customized management spaces to different 3rd parties
  - User-centric network management track: 3rd party subscribers with personalized service experience, while being compliant with regulation in force.
  - SLA enforcement track: covers SLA translation, assurance and verifiability from 3rd parties. SLA includes:
    - Key Performance Indicators (KPIs)
    - Key Value Indicators (KVIs)
    - Trust Level Agreement (TLA) components



Trustworthy 3rd party management: industry ecosystem



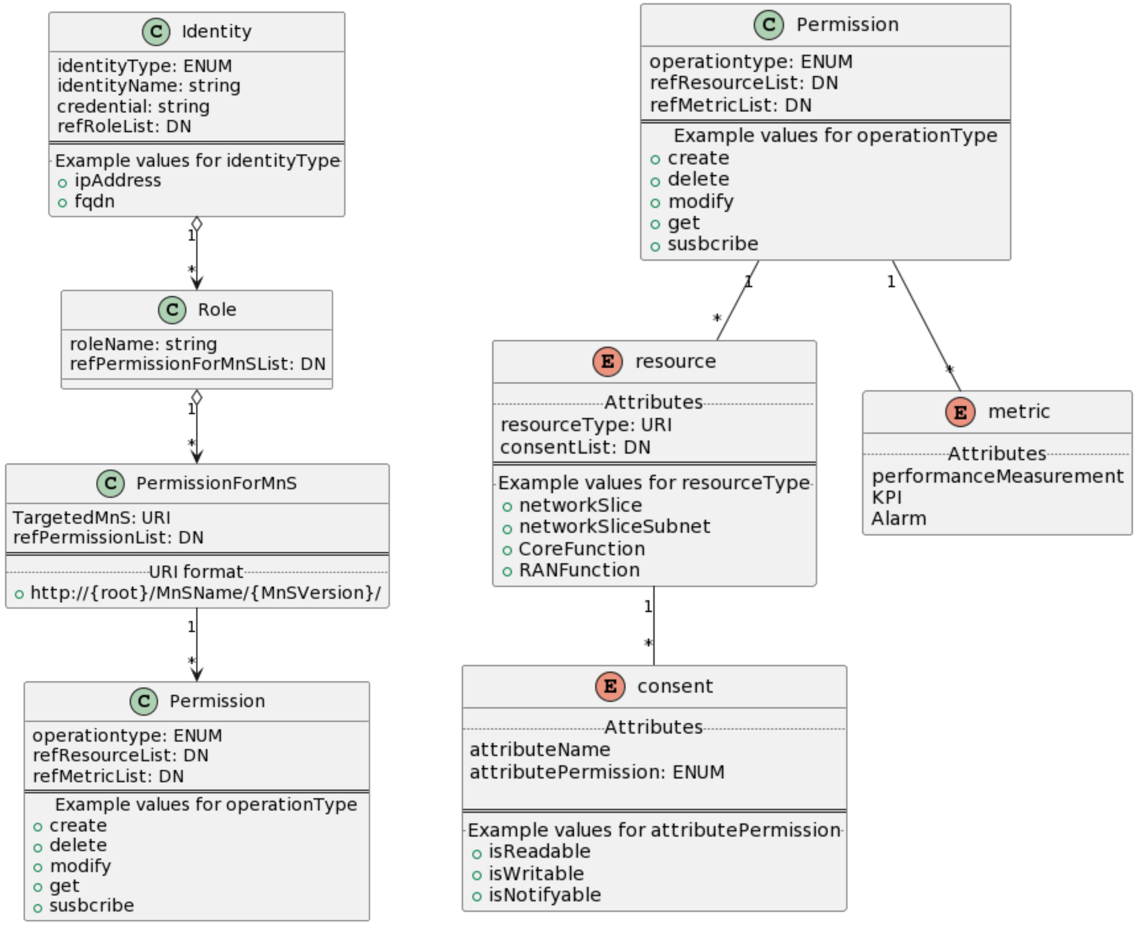
Trustworthy 3rd party management: tracks

Enabler #4: Trustworthy 3rd party management

- **Related State of the Art**
  - Resource controllability separation track
    - 3GPP SA5: TR 28.817 (study on access control [28.817]), TS 28.541 (3GPP Network Resource Model [28.541]), TR 28.804 (study on tenancy concept in 5G networks and slicing mgmt [28.804]), TR 28.824 (study on network slice mgmt capability exposure [28.824]).
    - ETSI ZSM: GR 010 (security management).
  - User-centric network management track
    - Different user types: Business to Customer (B2C), Business to Business (B2B) and Business to Business to Anything (B2B2X).
    - User Equipment Route Selection Policy (URSP) topic: 3GPP SA2 (URSP structure), GSMA TSGNS (Device internals for URSP matching logic), GSMA ENSWI (traffic categories for B2C slicing)
    - Regulatory landscape regarding Open Internet (Net Neutrality) and user consent (GDPR).
  - SLA enforcement track
    - Policy-based static rules defined in H2020 projects (e.g., 5G-VINNI, 5GEVE, 5Growth).
- **Beyond the State of the Art**
  - Resource controllability separation track: Specify role-based access control (RBAC) solution, that allows native multi-tenancy support in Service-Based Management Architecture (SBMA).
  - User-centric network management track: URSP enhancements to deliver regulation-compliant user experience in B2B2X scenarios, in federation and wholesale environments.
  - SLA enforcement track: consider elastic (range value based) and dynamic (modified on-the-fly) SLAs.

Enabler #4: Resource controllability separation track

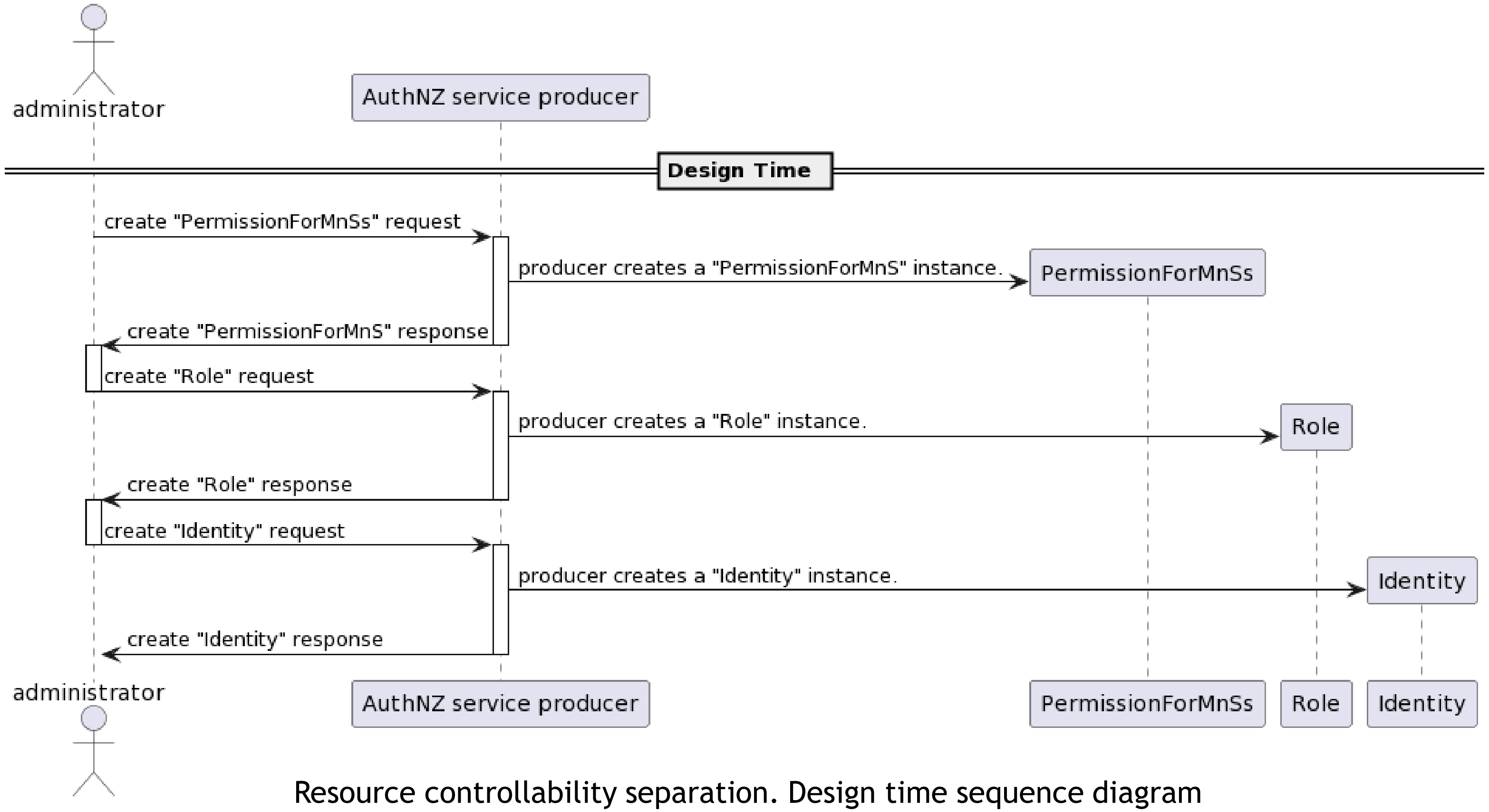
- This track aims to provision of segregated yet customized management spaces to different 3rd parties.
- Design of an information model (see right-side figure) enforcing ‘identity to role’ assignment in SBMA environment
- Role: represents a set of permissions.
    - Enables the storage of information as to what resources and actions an authorized consumer can work upon.
    - A network operator defines a pre-defined set of roles at design time.
- Identity: represents the identity of a tenant in the M&O system
    - Assigned by the network operator to a set of defined roles upon tenant registration.



This is an early solution design. Further refinements are expected before development phase

Enabler #4: Resource controllability separation (4.A)

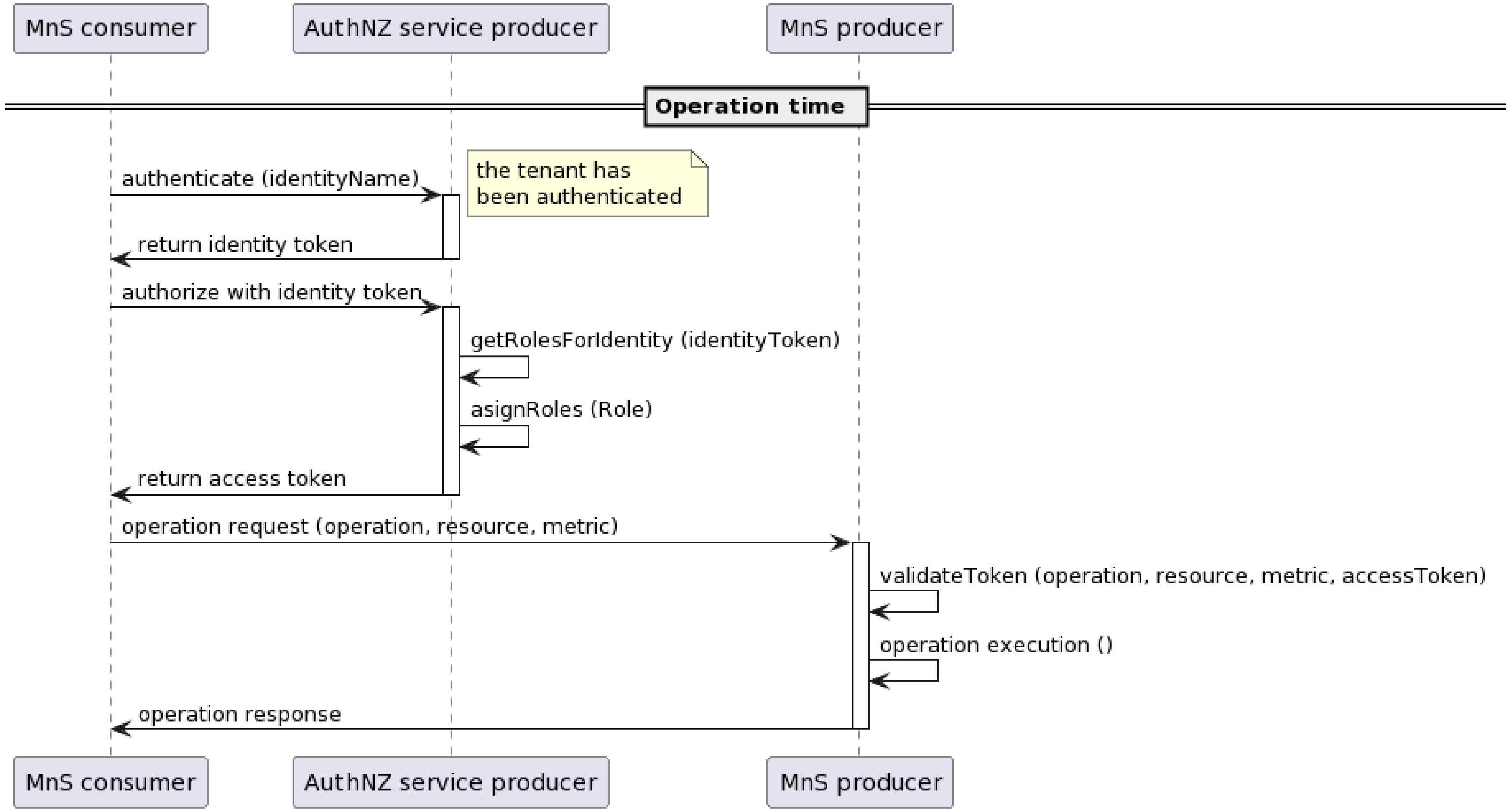
- Design time: two stages
  - Before tenant is registered in the system: the admin defines the permissions and roles
  - Upon tenant registration: the admin creates the identity for that tenant, and proceed with “identity role assignment” (the identity is provisioned with one or more roles).



Resource controllability separation. Design time sequence diagram

Enabler #4: Resource controllability separation (4.A)

- Operation time:
  - a tenant wants to gain access and consume Hexa-X-II capabilities
  - Authentication + authorization.
  - RBAC to authorize access to requested capabilities (operation, resource, metric).



Resource controllability separation. Operation time sequence diagram

Enabler #4: User-centric network management (4.B) and SLA enforcement (4.C)

- User-centric network management
  - Mission:
    - provide 3rd party with personalized service experience, while being compliant with regulation in force.
    - Focus on 3rd party == application service provider. 3rd party subscriber == operator end-user.
  - Mechanisms:
    - The M&O system receives information on individual 3rd party subscribers, including user ID (e.g., MSISDN, IPv4+port, IPv6) and subscribed services.
    - The M&O system injects this information on the end user profile (data base in core network), and configure QoS settings (policy control in core network).
    - The core network will generate proper URSP rules to the end users, offering them tailored service experience.
- SLA enforcement track
  - Mission:
    - Translate SLA components (<KPI list>, <KVI list>, <TLA list>) into control and monitoring operations.
    - Assurance and (external) verification of SLA, supervising SLA components are continuously met during service lifetime.
  - Mechanisms: use of zero-touch closed loop governance (enabler 10) and coordination (enabler 11)
    - Departing from policy/rule-based approach, which is legacy from the standpoint of Hexa-X-II
    - Customizing closed loop stages (i.e., monitoring, analysis, decision and execution) to allow elastic and on-the-fly SLAs.

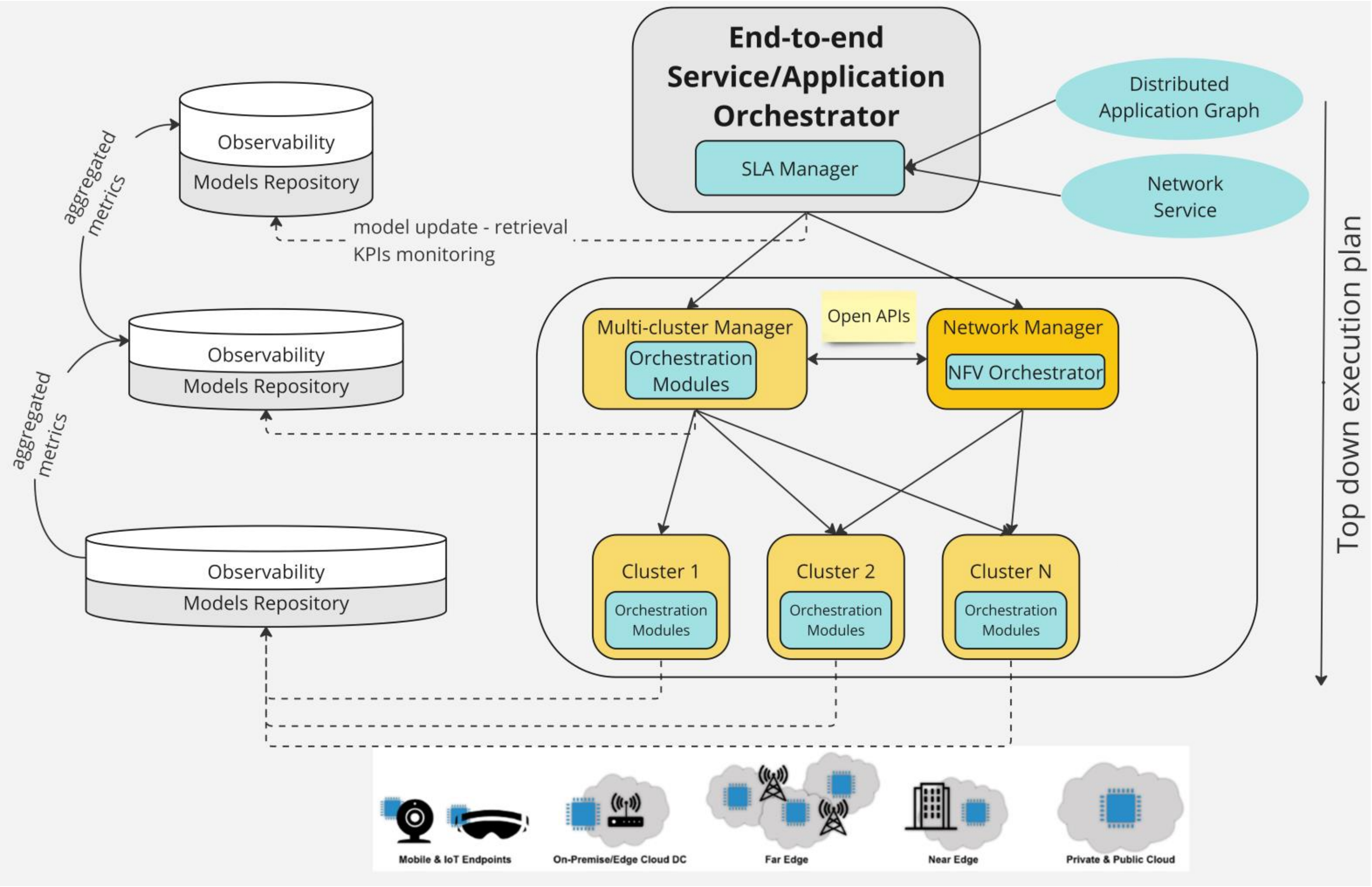
Enabler #5: Multi-cloud management mechanisms

- **Motivation**
  - Some real-world applications and network services have special needs for deployment in multi-cloud infrastructure
  - Specific challenges arise when deploying applications/services across multi-cloud/multi-cluster environments
  - Collaboration across providers is needed (e.g., network providers, edge/cloud computing providers), as well as resource abstraction and brokering
  - The same issues for resource management are present for monitoring resources
- **Enabler’s objectives**
  - Provide performance guarantees in multi-cluster deployments, while respecting the defined constraints (e.g., collocation of part of application components) and requirements (e.g., very low latency at the edge part, security in specific links)
- **Enabler’s high-level description**
  - Provide a centralized interface for management and monitoring of resources
  - Adopt hierarchical decision-making solutions
  - Investigate two approaches, one with interaction between a network manager and a Cloud Management Platform (CMP) and another with pure container orchestration solution (K8s)
  - Incorporate AI/ML for optimal resource allocation, load-balancing, predicting and preventing disruptions
  - Distributed Ledger Technology (DLT) for multi-domain federation
  - Take advantage of multi-cluster management tools (e.g., Karmada, Liqo, Kata Containers)

Enabler #5: Multi-cloud management mechanisms

- **Related State of the Art**
  - Application lifecycle management across the computing continuum
    - Proactive adaptation, temporal evolution
  - Efficient resource allocation
    - Service placement, Task scheduling
  - Multi-cluster management tools
    - e.g., Liqo, Karmada, Open Cluster Management
  - Multi-domain federation
  - 6G and Edge computing convergence standards
- **Beyond the State of the Art**
  - Interoperability of heterogeneous resources
  - Resources abstraction and brokering in the computing continuum
  - (Intent-driven) Planning components (resources management) in multi-cluster infrastructure
  - Automation through AI/ML techniques
  - Inter-cluster communication/networking management

Enabler #5: Multi-cloud management mechanisms



Multi-cloud Orchestration Mechanisms for Distributed Applications and Network Services

- The figure aims to depict a high-level approach that can be followed for the support of multi-cluster management functionalities.
- The design of the architectural approach will be provided in the upcoming period.
- Observability and ML techniques can be exploited to assist orchestration mechanisms.

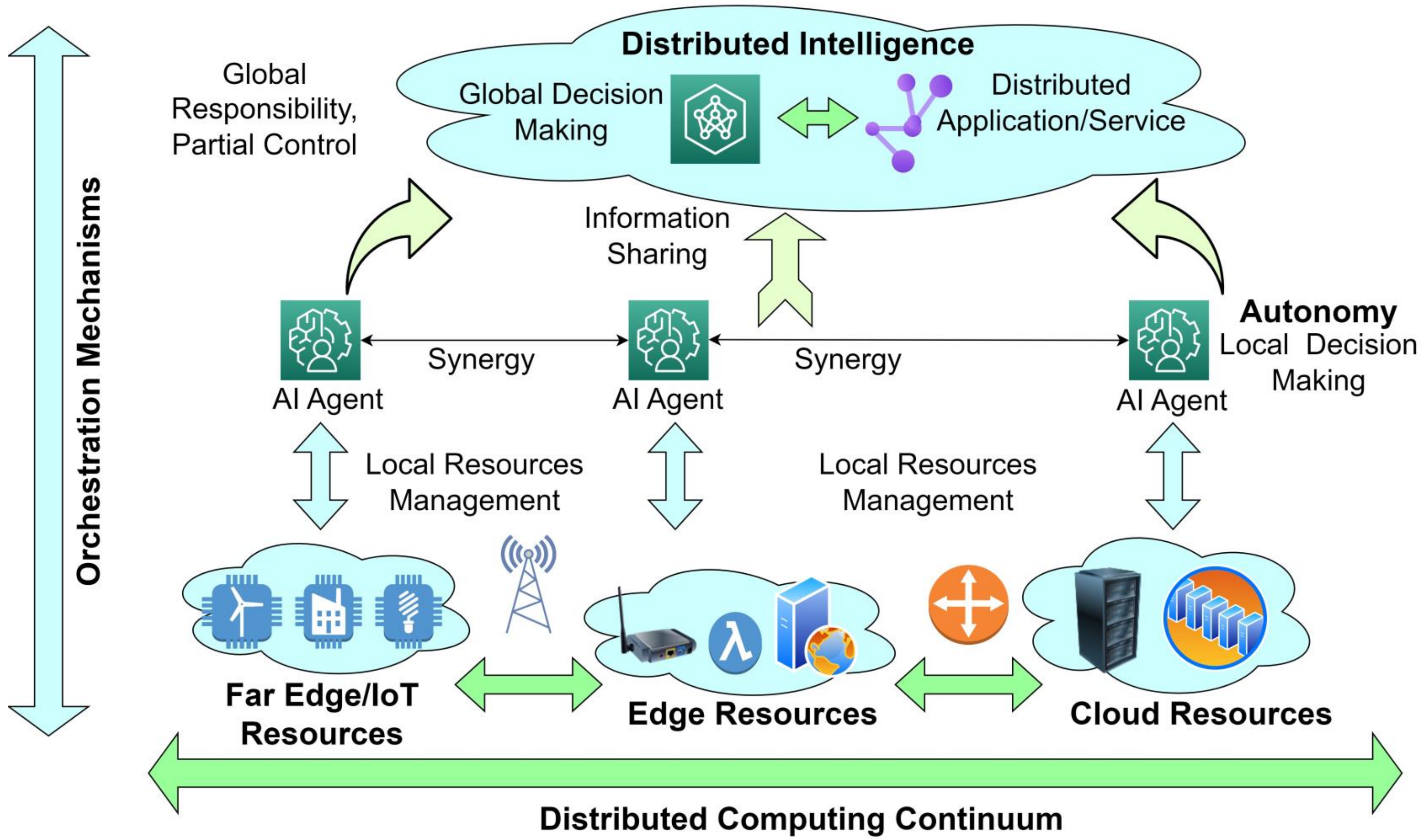
Enabler #6: Orchestration mechanisms for the computing continuum

- **Motivation**
  - The rise of IoT and Edge Computing extended the orchestration possibilities not only to the Cloud domain, but also the Edge and the Extreme Edge/IoT domain
  - Centralized control of distributed applications/network services is not always efficient or even possible
  - Impacted processes include service placement, scaling and migration, as well as task dispatching and load balancing
- **Enabler’s objectives**
  - Enhance convergence, interoperability and openness of orchestration solutions for the computing continuum, by promoting the synergy between different providers or orchestration entities
- **Enabler’s high-level description**
  - Consider different types of synergies: among multiple cloud/network providers/MNO, among the cloud application and network provider/MNO, and among multiple management agents in a single provider
  - Investigate multi-agent systems (MAS) and extract information from their relations to form optimal orchestration strategies
    - Analyze application/service graphs and extract features
    - Exploit application/service characteristics and real-time performance
    - Enhance orchestration in synergy with network SLAs
  - Take advantage of ML mechanisms and data fusion of observability/telemetry signals provided by Enabler 2 to assist orchestration

Enabler #6: Orchestration mechanisms for the computing continuum

- **Related State of the Art**
  - Initial work for the challenges and the design of orchestration mechanisms for the computing continuum [RCV22]
  - Request dispatching at the edge – task offloading [HSW+21]
  - Service autoscaling, migration
  - Service mesh management
- **Beyond the State of the Art**
  - Hierarchical decision-making mechanisms with distribution of control points across the computing continuum
    - Degree of centralization: Global orchestration vs local autonomy at the compute continuum
  - Development of AI-driven multi-agent systems/Collaborative AI mechanisms for assisting orchestration actions
  - Interplay between network provider/MNO and Over the Top (OTT) players (edge/cloud providers)
  - Observability feature extraction for evaluating orchestration actions at (near) real-time
    - Causal relations

Enabler #6: Orchestration mechanisms for the computing continuum

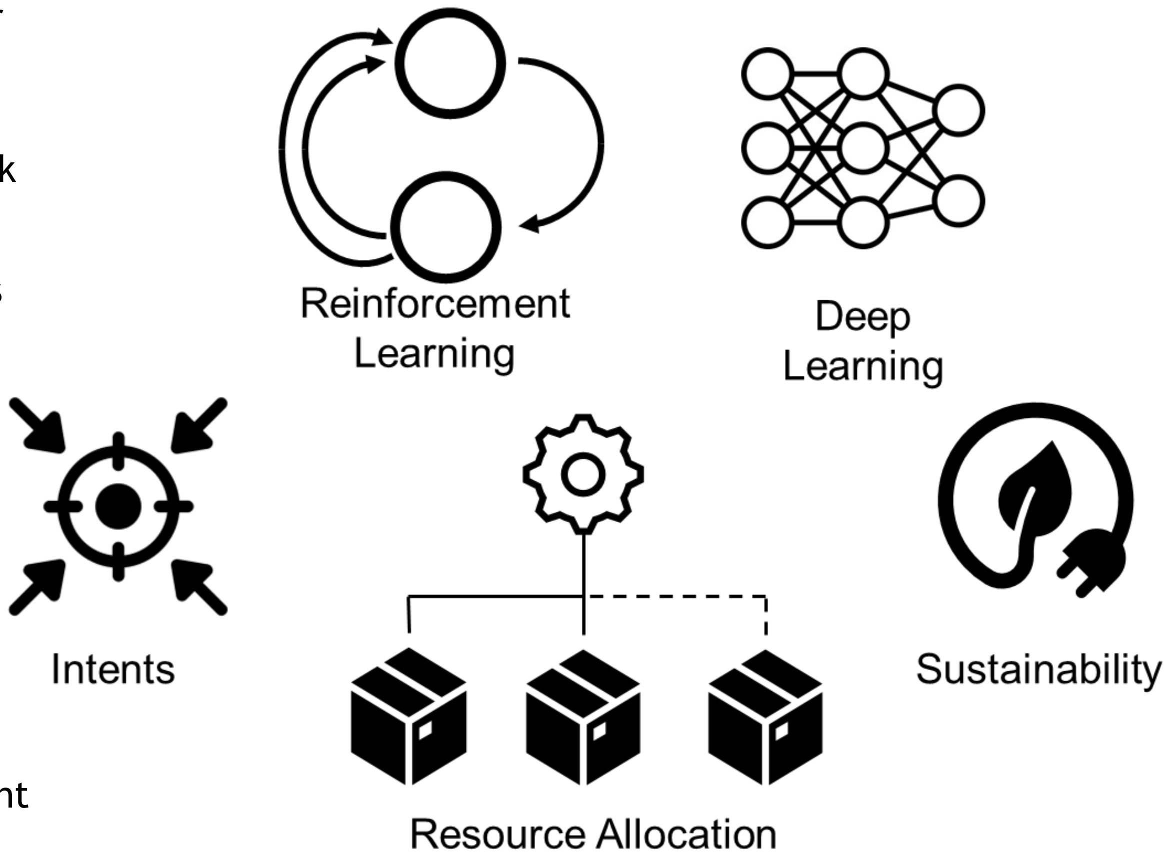


Collaborative Orchestration Mechanisms (based on multi-agent systems) for the Computing Continuum

- The figure aims to depict a high-level approach that can be followed for the development of synergetic orchestration mechanisms.
- The design of the architectural approach will be provided in the upcoming period.
- The developments can take advantage of multi-agent systems.

Enabler #7: Sustainable AI/ML-based control

- **Motivation**
  - Operators of 5G networks are actively seeking to reduce their operational expenses
  - When these expenses relate to energy savings, they often use an energy-saving state of network functions
  - Network distribution towards the edge and number of network functions increases complexity
  - Actions can also conflict with each other
  - Avoid additional energy consumption from the use of AI/ML as it requires lots of computing.
  - Explore tradeoffs between energy consumption and performance
- **Enabler's objectives**
  - Improve the process(es) of network management from automated operations towards autonomy and include energy efficiency as another objective next to performance
- **Enabler's high-level description**
  - Use intent-based management including energy saving goals and translate SLA requirements with AI/ML algorithms
  - Develop AI/ML algorithms for optimal resource allocation (target performance, minimal energy) adaptive to environment and network state
  - Consider sustainable MLOps to prevent ML training wasting more energy than saved in the network
  - Federating AI/ML mechanisms for network management considering their energy footprint

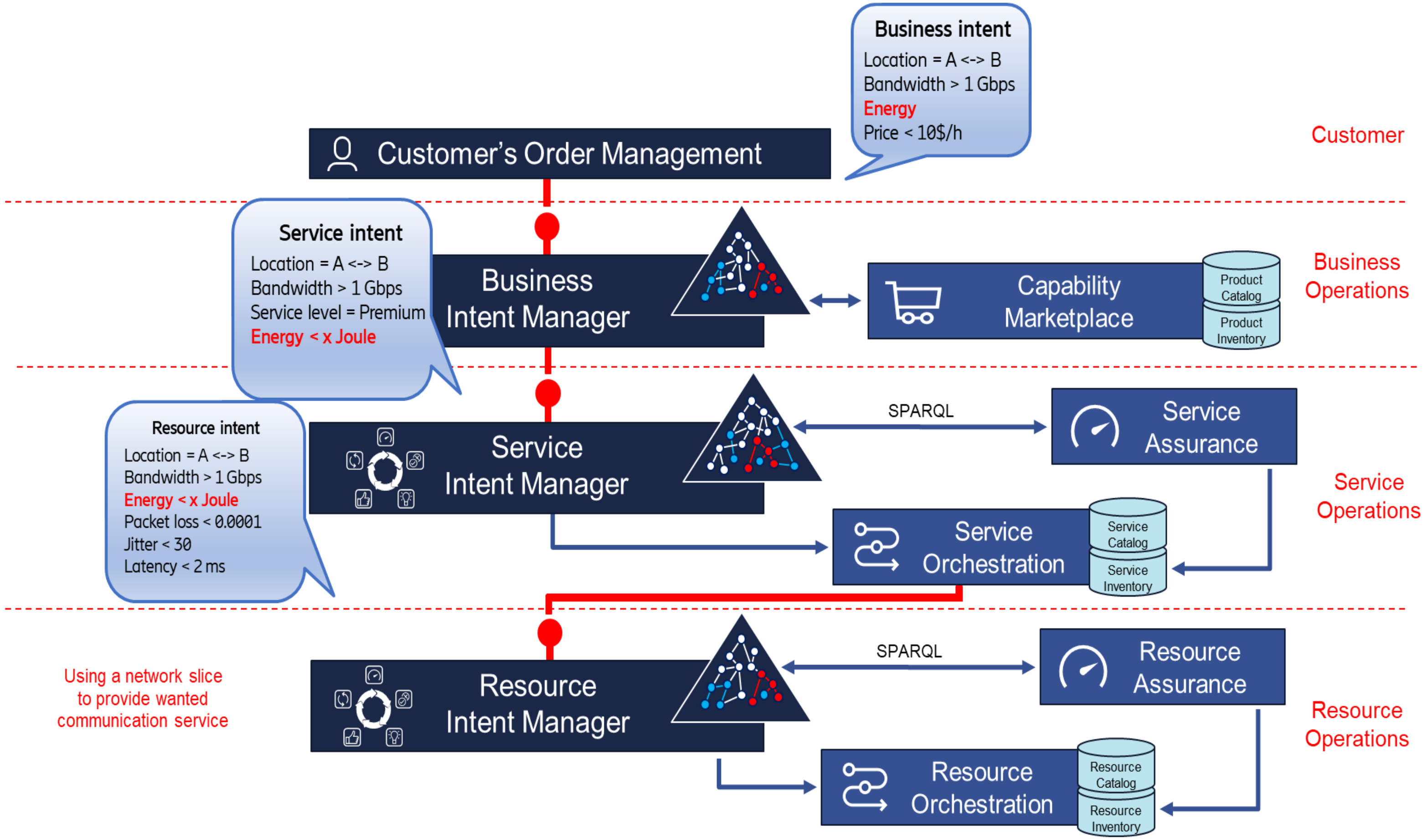


Enabler 7 methods and technologies

Enabler #7: Sustainable AI/ML-based control

- **Related State of the Art**
  - Intent-based network management [PMS+18].
  - Reinforcement Learning and Multi-Agent RL for resource allocation.
  - Dynamic VNF placement, chaining and re-configuration.
  - ML can bring energy efficiency improvement but also further energy consumption (NVIDIA trained MegatronLM (smaller model than GPT-3) over 9 days approximately consuming ~27kWh, almost 3 times the average consumption of US homes per year).
- **Beyond the State of the Art**
  - How to include energy and sustainability related information in intent formulation.
  - Network control for proactive, dynamic and energy-efficient resource allocation and re-allocation for a continuous optimization of the performance objectives
  - Optimization to use green energy for the ML model training phase (possibly the most energy consuming) so it is assured that the AI/ML energy consumption level is under the energy level they are estimated to be saving.
  - Consider application context (performance, location, resource sharing with NFs) and requirements.

Enabler #7: Sustainable Intent-based Management



An example of layered levels with intents containing energy related information

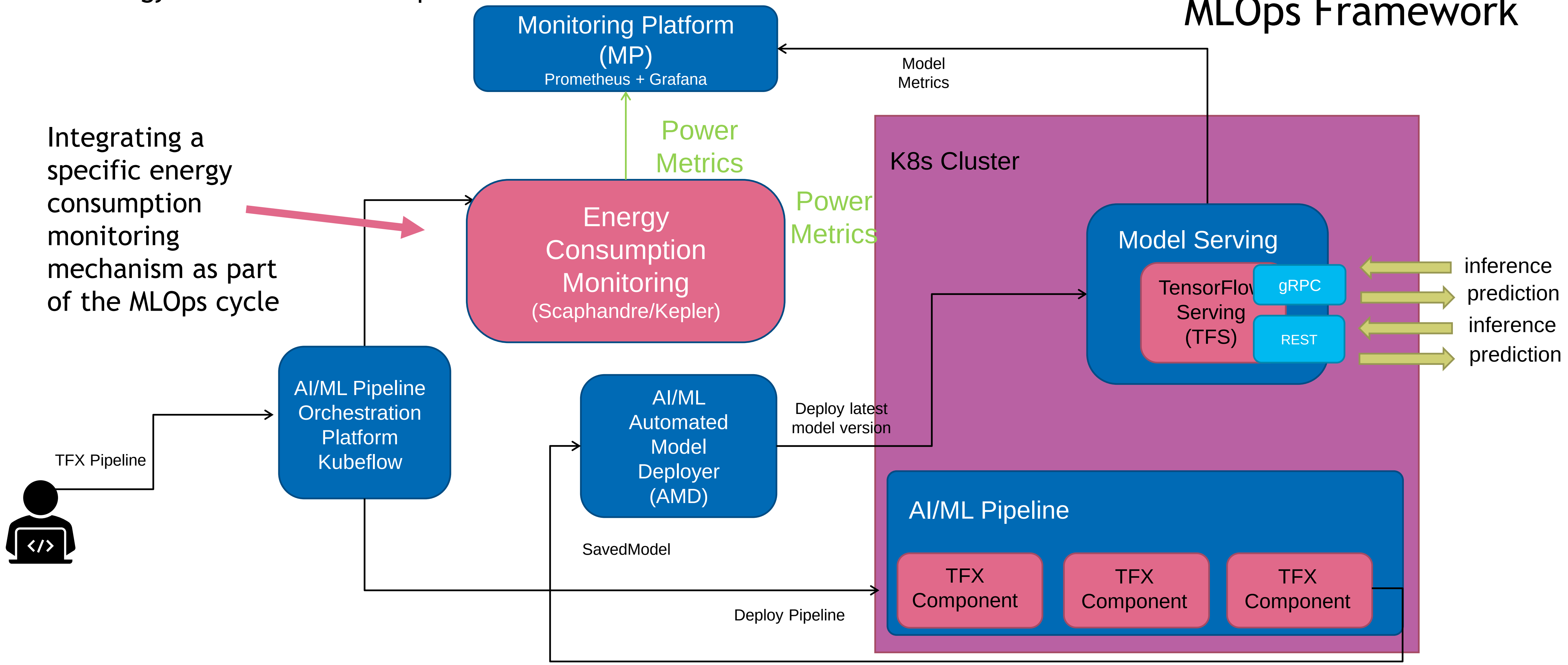
- The figure aims to depict a high-level view on how different expectations that include energy saving and QoS provisioning can take place at the different level of service management.
- Intents can provide autonomy to network management and make it aligned with the ultimate aim of implementing intelligence.

Enabler #7: Sustainable MLOps

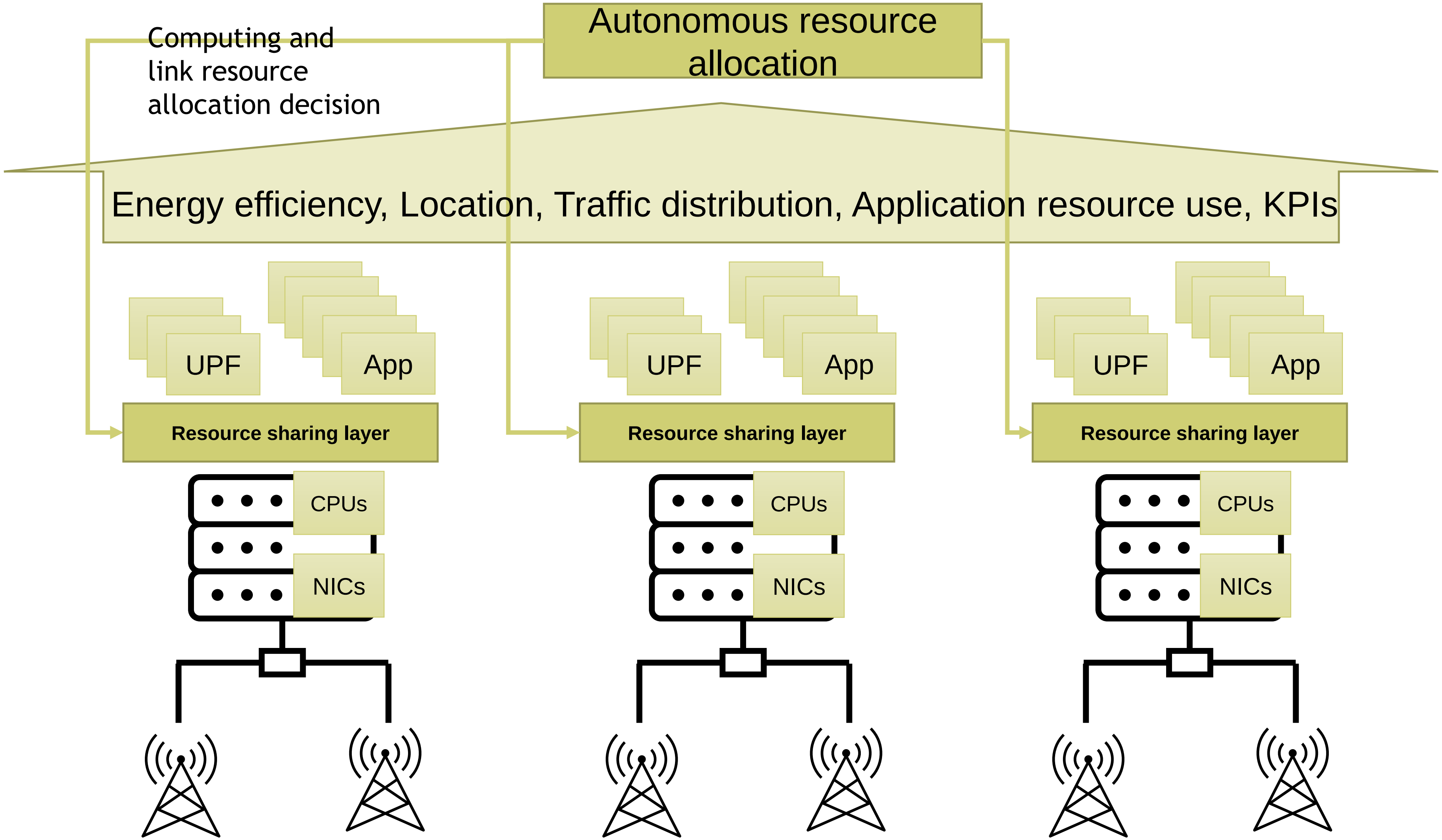
- The ML model training phase is the most energy consuming phase of the AI/ML technology
  - the training phase in the MLOps cycle will be moved across time and/or space so it is performed using green energy sources as much as possible

MLOps Framework

Integrating a specific energy consumption monitoring mechanism as part of the MLOps cycle



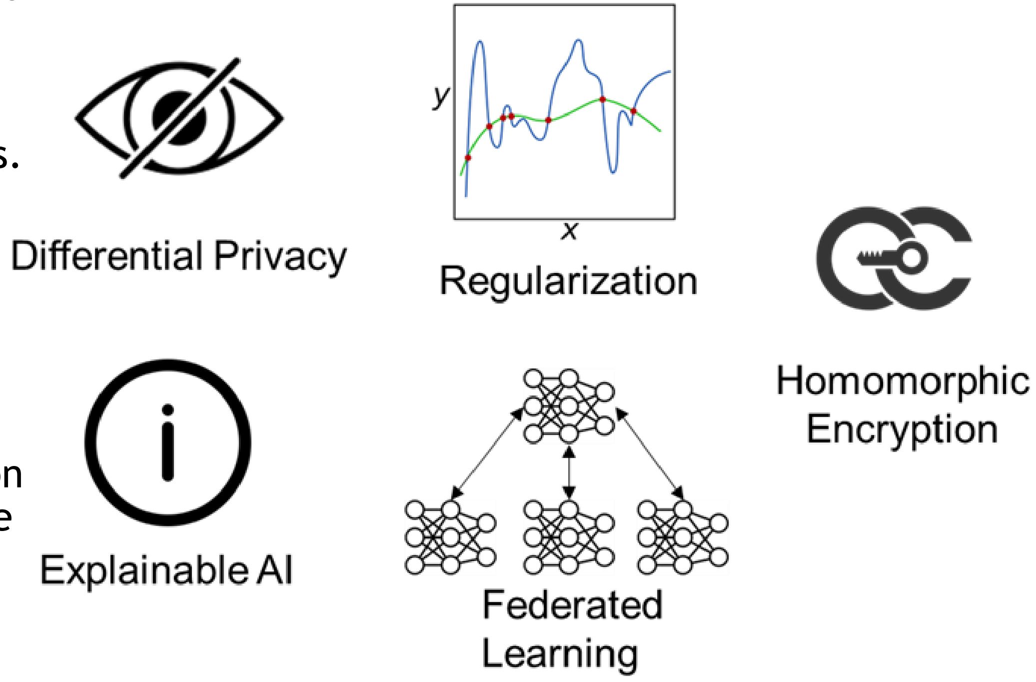
Enabler #7: Optimal adaptive multi- resource allocation



Optimal resource allocation (target performance, minimal energy) adaptive to environment and network state

Enabler #8: Trustworthy AI/ML-based control

- **Motivation**
  - Attacks against the AI/ML models deployed in network management systems can affect the entire network and/or business operation.
  - AI/ML systems used in network management and orchestration need to ensure robustness, privacy, and transparency.
- **Enabler's objectives**
  - Provides more robust models by protecting against adversarial attacks.
  - Minimize the collection and storage of personal data.
  - Provides clear explanations and justifications of the AI's reasoning or decision-making process.
- **Enabler's high-level description**
  - Analyze the vulnerability of AI/ML-driven systems against adversarial attacks and applicability of model regularization, defensive distillation and adversarial training in the mitigation of adversarial attacks on the management plane
  - Use differential privacy, homomorphic encryption, secure multi-party computation or federated learning to minimize leakage of personal and sensitive data.
  - Take current solutions from the field of Explainable AI (XAI) and apply them in a AI-driven network management procedure to generate a human-understandable, interpretable, and transparent answer for a behavior.

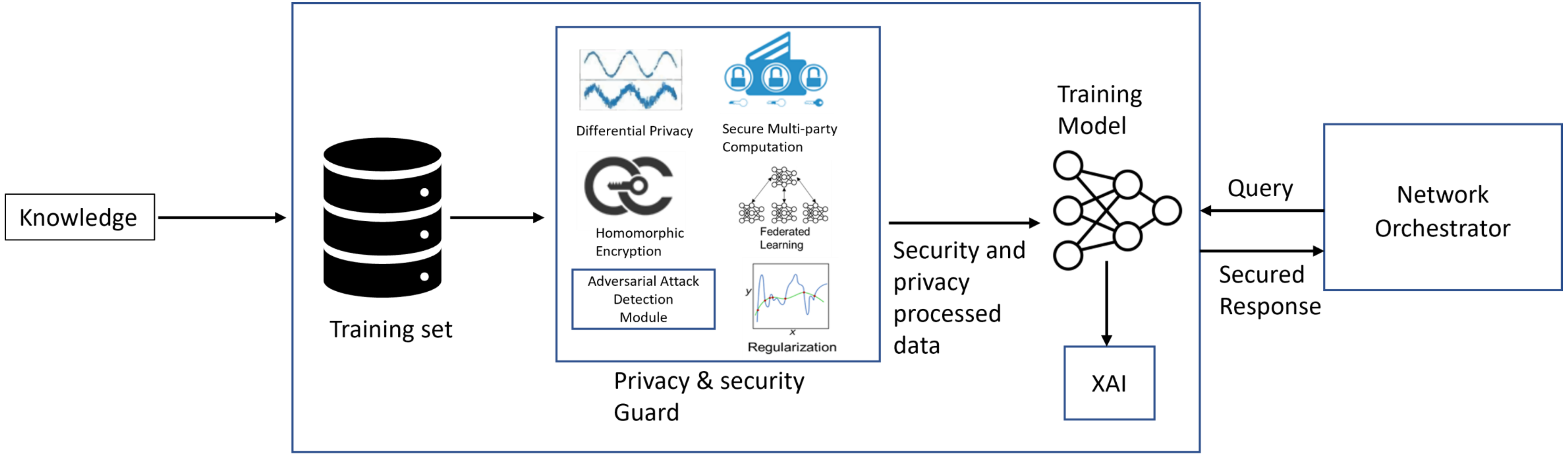


Enabler 8 methods and technologies

Enabler #8: Trustworthy AI/ML-based control

- **State of the Art**
  - Security vulnerabilities of AI-driven Zero-Touch Network and Service Management in 5G, and mitigations by adversarial training [BEN20].
  - Distributed architectures. Collaboration and data sharing between different Management Domains (MD) to improve accuracy and speed up of orchestration decisions.
  - Privacy and trust issues in collaborative learning.
  - Challenges of managing and orchestrating the massive number of slices in 6G networks using AI-driven zero-touch management and orchestration and the importance of explainable AI (XAI) tools to ensure trustworthiness and transparency among the interacting actors in the slicing ecosystem [BRI20, ROY22].
- **Beyond the State of the Art**
  - The probable shortcomings of AI systems must be evaluated in conceivable AI-driven management tasks and use cases.
  - Develop AI systems that are resilient to adversarial attacks and malicious manipulations to ensure the security.
  - Preserve privacy and protect sensitive data in AI system using enhancing such as federated learning and secure computation methods such as homomorphic encryption which allow data analysis without disclosing sensitive data.
  - Develop interpretable machine learning models that clarify the reasoning and decision-making process of AI systems in management plane.
  - Thus, we should concentrate our efforts on providing the required level of robustness, privacy, and explainability to AI systems.

Enabler #8: Trustworthy AI/ML-based control

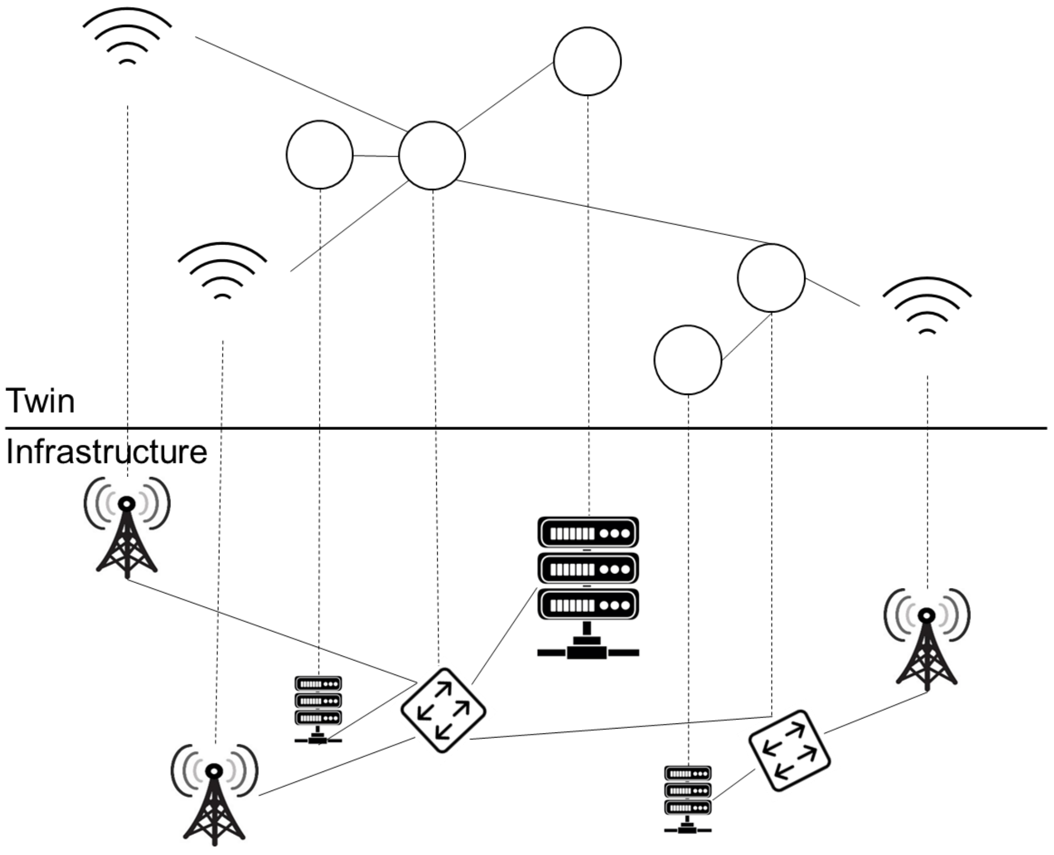


Trustworthy AI/ML function

- An example of interaction between a Network Orchestrator and a Trustworthy AI/ML function in the management plane
  - Tighter integration with the functionality being part of the orchestration is also viable

Enabler #9: Network Digital Twins

- **Motivation**
  - VNFs and CNFs are expected to share physical resources on top of a flat cloud computing infrastructure
  - Intelligent orchestration layer decides deployments with algorithms that require solution space exploration
  - This exploration is not feasible in production environments due to possible performance degradations
  - Network management needs a true model of the managed infrastructure so algorithms implementing autonomy can perform solution space exploration
- **Enabler's objectives**
  - Use Digital Twinning technologies to generate network/infrastructure models with the objective of integrating those models in closed management loops as copies of their real counterparts
- **Enabler's high-level description**
  - Definition of Network Digital twin, considering IETF draft or other standard body views
  - Definition of control and monitoring flows for the generation and update of the twin
  - Use of Graph Neural Networks (GNN) to create network models used as Digital Twins



Enabler 9 Depiction

Enabler #9: Network Digital Twins

- **State of the Art**
  - VNF and infrastructure performance monitoring, profiling and prediction [Enabler 2].
  - Architecture and monitoring control loops for Digital Twins [ALM22].
  - GNN for network performance evaluation [FER22].
- **Beyond the State of the Art**
  - Selection of relevant features for accurate Digital Twin generation.
  - Personalized Digital Twins per use case with generalization/granularity trade-off depending on needs.
  - Digital Twins of networks including multiple resource types and technologies (i.e. virtualization, radio resources…).
  - Use of GNN to generate Digital Twins of network infrastructures.
  - Continuous network monitoring and Digital Twin update loop.

Enabler #9: Network Digital Twin pipeline components

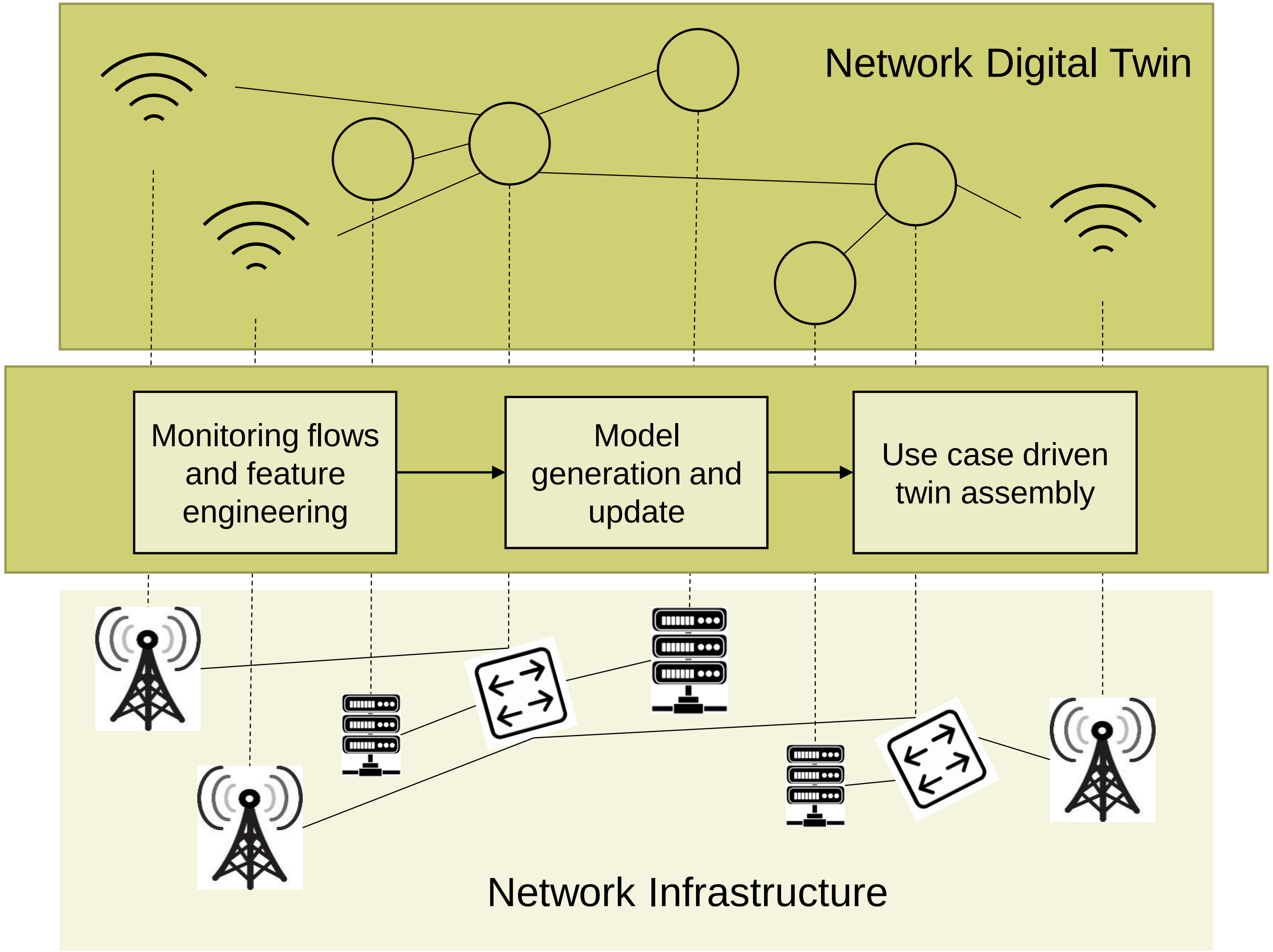
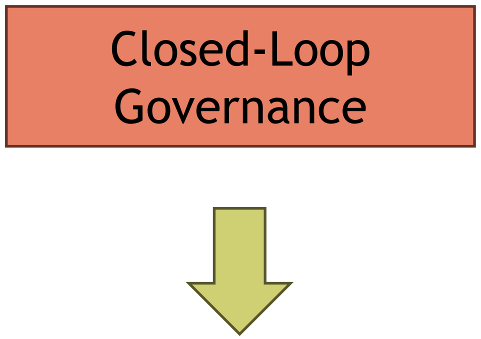


Illustration of possible steps in a pipeline for twin model (top) generation and assembly from data from the real infrastructure (bottom)

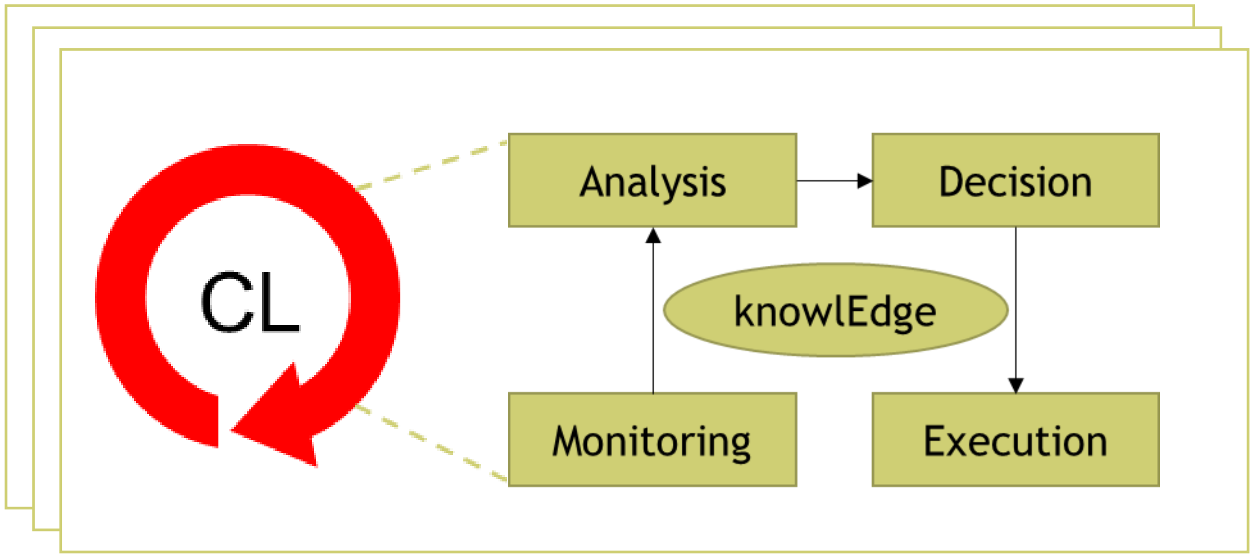
Enabler #10: Zero-touch closed loop governance

- **Motivation**
  - 6G networks will increase in complexity due to the inclusion of many technologies, multiple domains, variable topologies and levels of virtualization
  - High variety of devices, services, requirements and levels of isolation will need to be managed together on a shared infrastructure
  - Automation is already present in current networks but will not be enough for the next levels of complexity [CBS+22]
- **Enabler's objectives**
  - Limiting or even removing operating staff from network management loops is imperative to speed up operations, increase network performance on the basis of dynamic conditions and reduce operational costs
  - Governance for programming and monitoring the provisioning of Closed-Loop (CL) functions to automate CL's delivery and adaptation at various level of abstraction (e.g., per-technology, per-domain, per-tenant, etc.)
- **Enabler's high-level description**
  - Automation in provisioning, configuration, and operation of Multi-dimensional CLs for mobile network automation with different time granularities (real-time, short-medium-long term), domain scopes (radio resources, core functions, transport networks, edge/cloud) and architecture layers (physical infrastructure, network and service layers).
  - AI/ML models for prediction within CL
  - ML sandbox domains with Network Digital Twins models developed in Enabler 9 for space exploration in CLs



Automated Orchestration of single, multi-dimensional CLs:

- CL Instantiation & Life-cycle management in edge-cloud continuum
- CL Functions configuration
- CL Functions monitoring & Operation

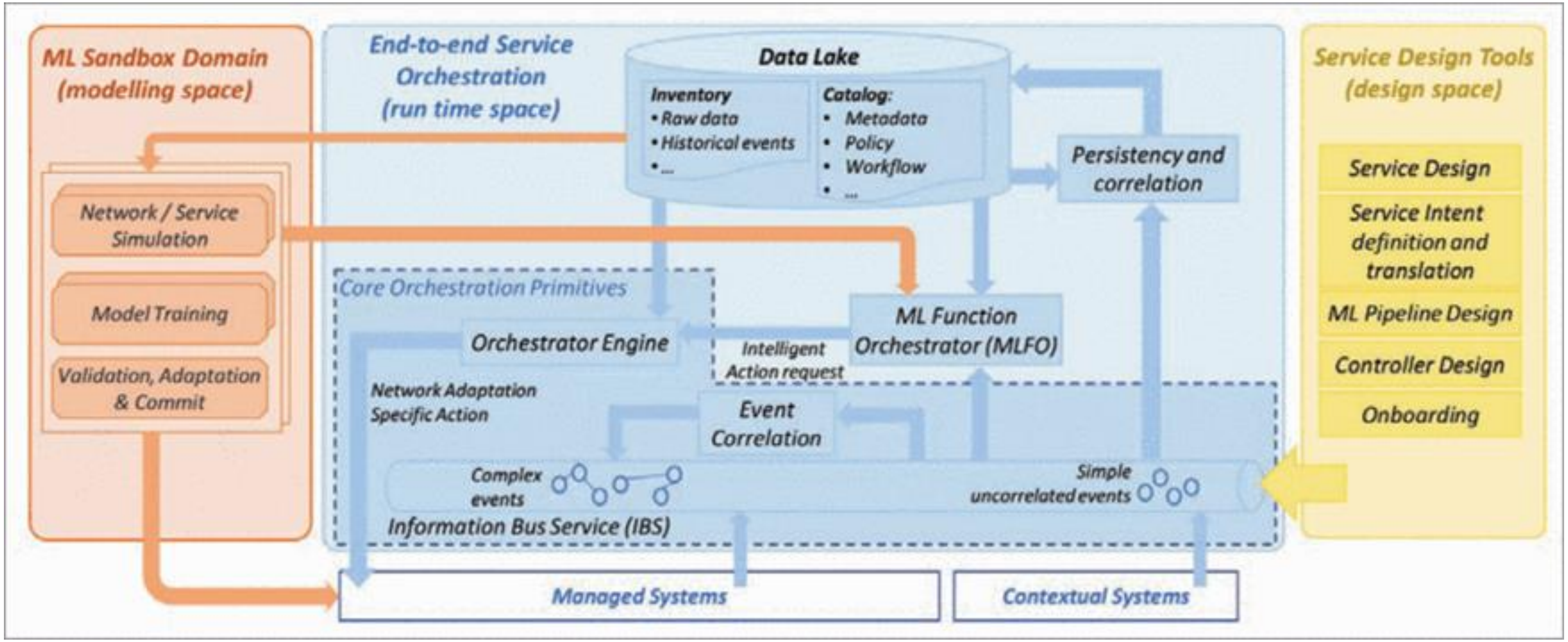


Closed Loop Governance

Enabler #10: Zero-touch closed loop governance

- **State of the Art**
  - ETSI Zero-touch network and Service Management (ZSM)
    - ETSI GS ZSM 009-1: Closed-Loop Automation – Enablers [zsm-009-1]
    - ETSI GS ZSM 009-2: Closed-Loop Automation – Solutions for automation of E2E service and network management use cases [zsm-009-2]
  - 3GPP - Management Services for Communication Service Assurance
    - TS 28.535: Requirements [28.535]
    - TS 28.536: Stage 2 and Stage 3 [28.536]
  - ETSI GR ENI 008, 010, 017 [eni-008][eni-010][eni-017]
    - Control Loop Architectures
      - OODA (Observe, Orient, Decide, Act)
      - MAPE-K (Model-Analyse-Plan-Execute-Knowledge)
      - FOCALE (Foundation - Observe - Compare - Act - Learn – rEason)
      - GANA (Generic Autonomic Networking Architecture)
      - COMPA (Control, Orchestration, Management, Policy, and Analytics)
      - Cognitive Control Loops (FOCALE v3)
    - Applicability of AI mechanisms for network automation
  - Monitoring Platforms integrating OSS like Prometheus, Grafana, Telegraf, InfluxDB, Kafka
  - AI/ML tools and platforms based on OSS like KubeFlow and TensorFlow

Enabler #10: Zero-touch closed loop governance



State of the Art ML sandbox domain used for model validation [LMOC21]

- CL Governance needs to orchestrate, configure, and operate all the ML-related functions that compose the Analysis stage as part of the global CL life-cycle management.
  - For example, in this case ML models are continuously evaluated at runtime, possibly with the usage of Network Digital Twins, and retrained on updated dataset whenever needed

Enabler #10: Zero-touch closed loop governance

- **Beyond the State of the Art**
  - CL function splitting in SBA 6G Management System and interaction with 6G Management services
  - Programmability through standard interfaces
  - AI/ML application towards cognitive CL
  - Knowledge sharing across the different stages of CL
  - CL orchestration as part of network (including transport) and service management
  - CL function placements and scaling
  - CL governance service interface modelling and translation logic towards CL function Management

Enabler #10: Zero-touch closed loop governance

- **High-level enabler system view**

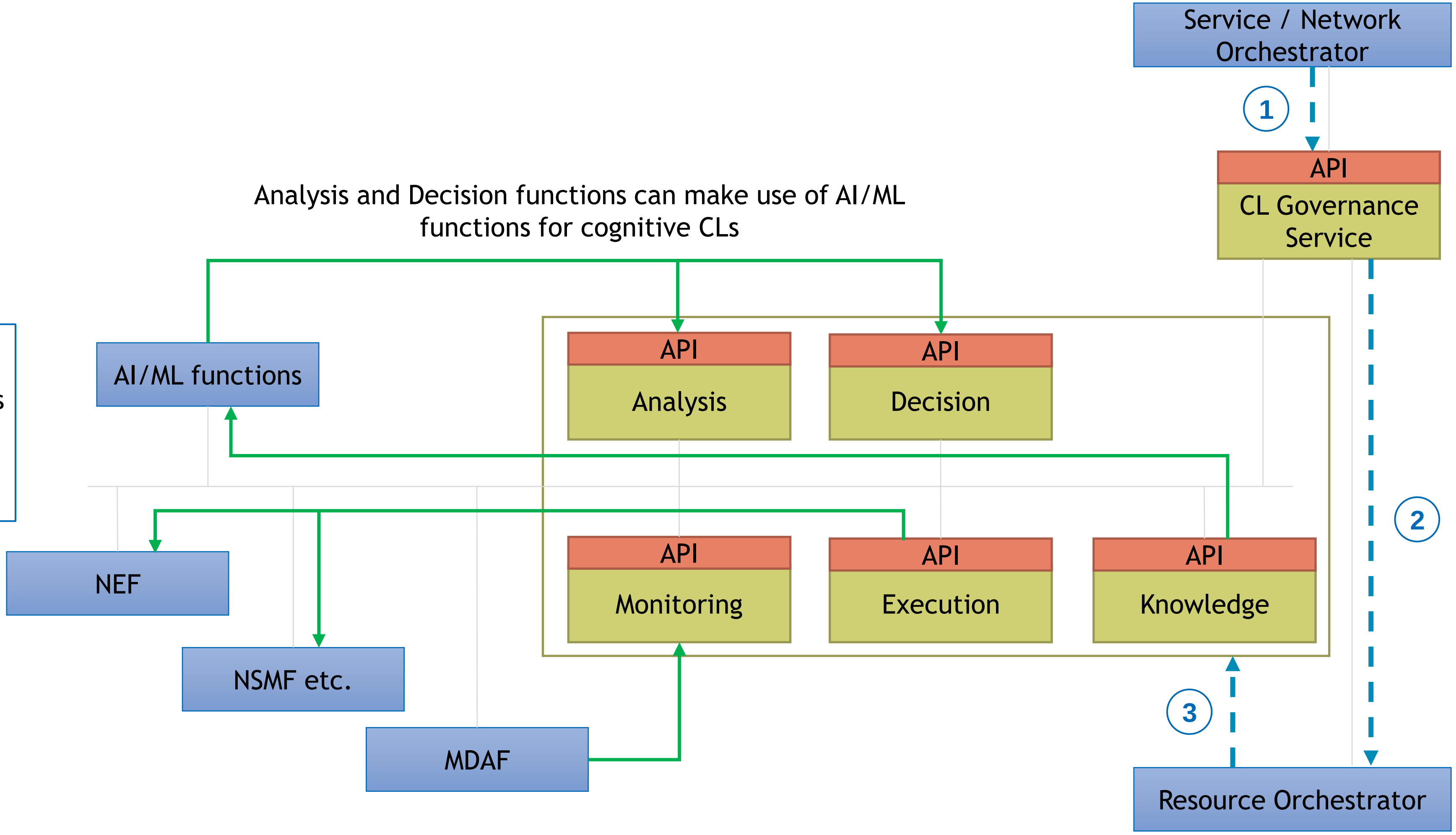
6G System Functions

Closed-Loop Functions

Function Interactions

Provisioning Operations

1. Provisioning and execution of CL services
2. Provisioning of CL functions
3. Dynamically deployed as SBA virtual functions of the 6G Mgt system



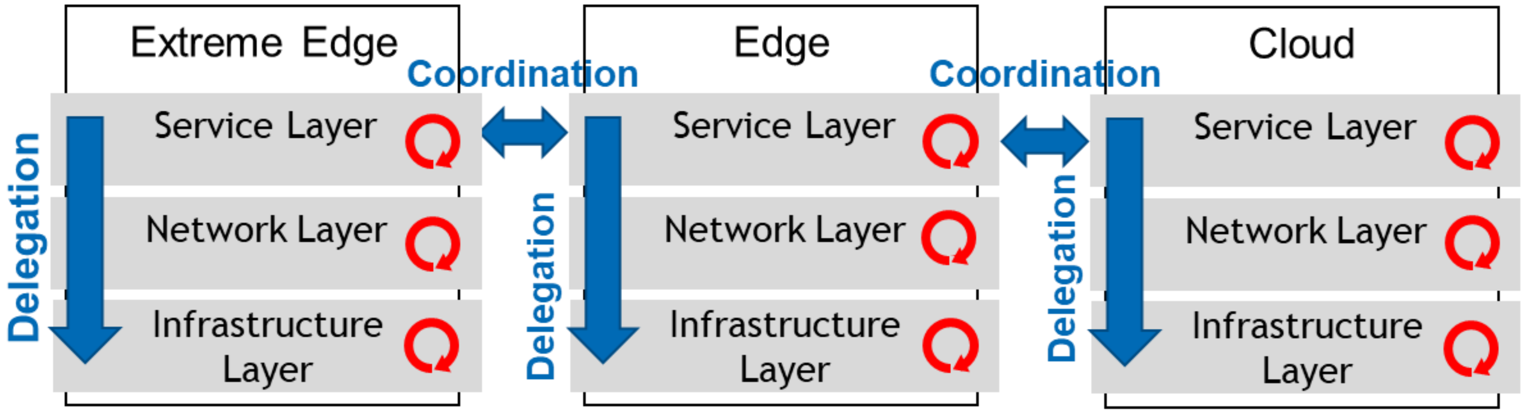
CL components and governance service

Enabler #11: Zero-touch multiple closed loop coordination

- **Motivation**
  - Adoption of multiple CLs may bring undesired effects due to contrasting decisions
  - Different objectives, operating on restricted scopes with limited visibility of entities
  - Coordination by sharing information and feedback, conflict avoidance and having network objectives is necessary
- **Enabler's objectives**
  - Multiple-closed loop coordination in an automatic manner
  - Maximize the control effect while mitigating conflicts and avoiding race conditions due to concurrent and contrasting decisions and eventually leading to network instability
- **Enabler's high-level description**
  - Peer-to-peer versus hierarchical models of multiple CLs
  - Different cooperation models for different stages – monitoring, analysis, decision and execution
  - Short vs long term decision coordination
  - Domain or layer separation of CLs – service/network/infrastructure layers, cloud/edge/extreme edge, access/transport/core network, per tenant/per slice
  - Workflows and interfaces among CL coordinating functions to jointly operate the functions implementing CL stages across interdependent CL instances

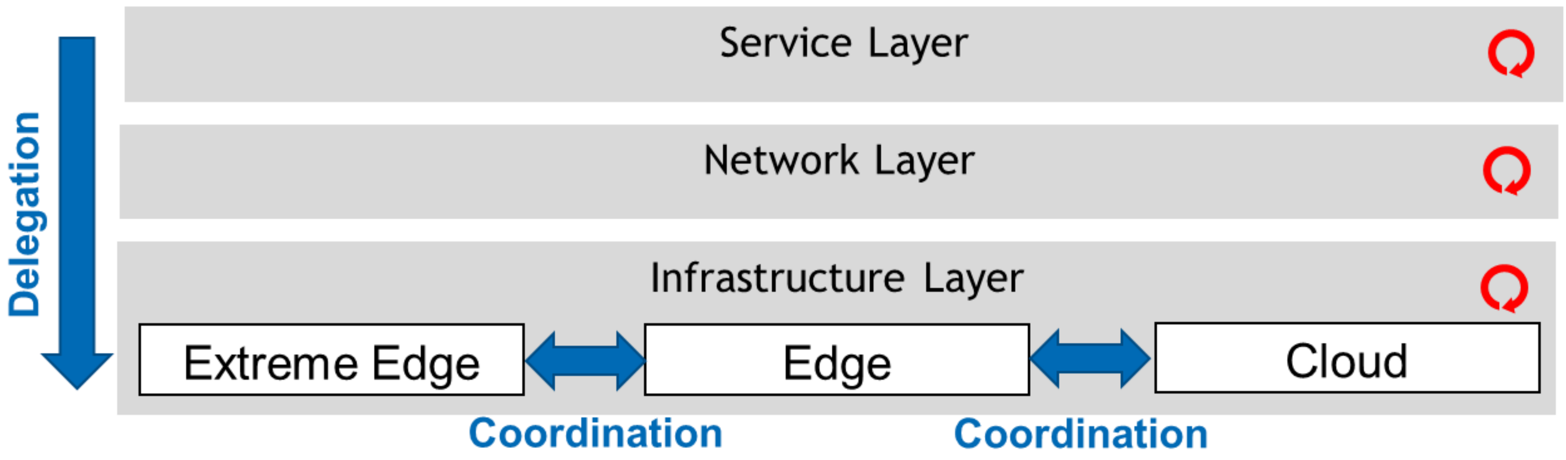
Enabler #11: Zero-touch multiple closed loop coordination

- **Possible coordination points to be explored**



Peer-to-peer coordination among CLs at extreme edge domains with hierarchical delegation of per-layer CL

- Abstraction. Coordination at Service layer:
  - Federation/Multi-operator
- complexity



Multi-domain CLs combined with peer-to-peer coordination of per-domain CLs at the infrastructure layer

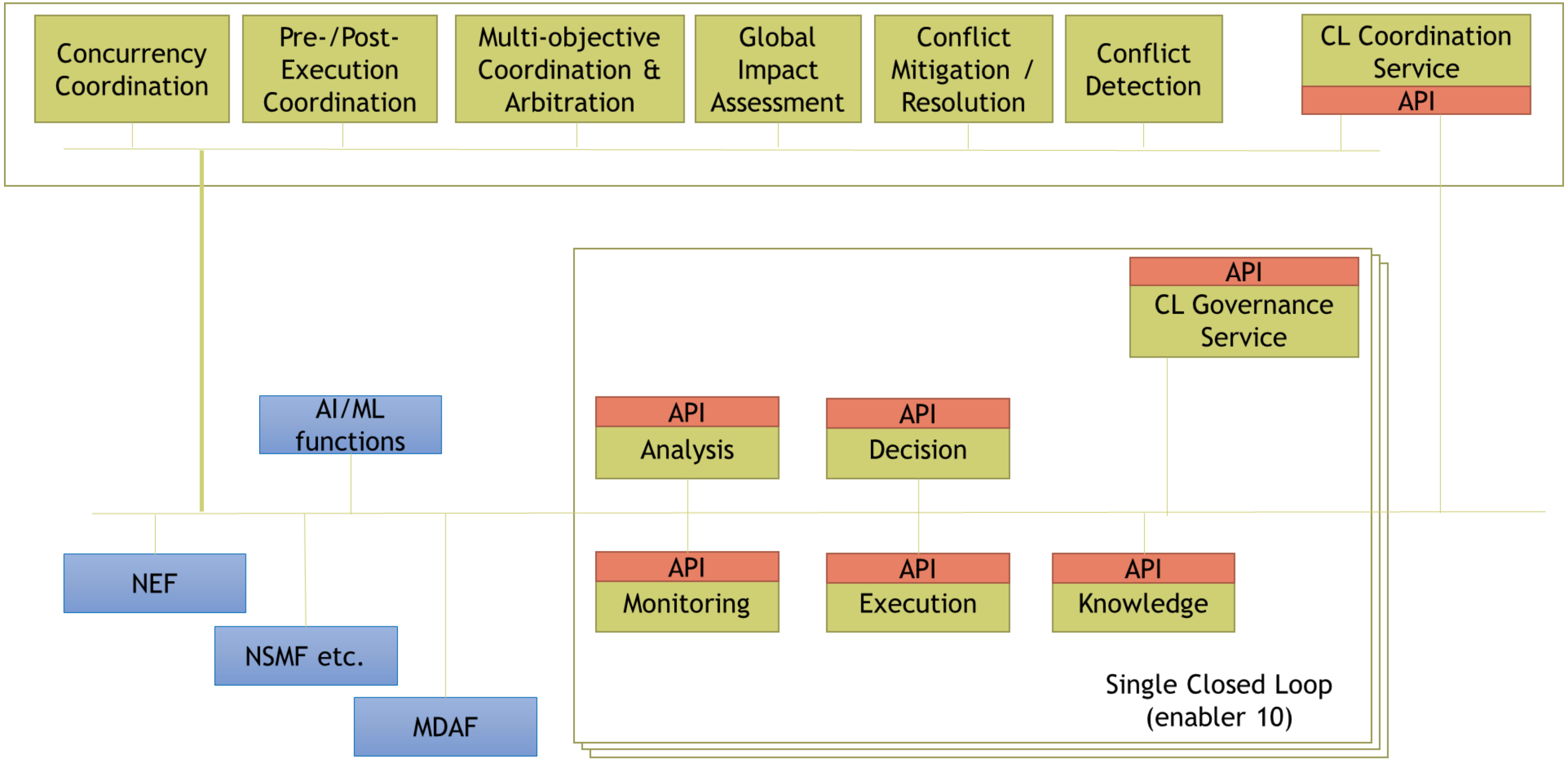
- Complexity
- Coordination at Network layer: single operator scope?

Enabler #11: Zero-touch multiple closed loop coordination

- **State of the Art**
  - ETSI Zero-touch network and Service Management (ZSM)
    - ETSI GS ZSM 009-1: Closed-Loop Automation – Enablers [zsm-009-1]
    - ETSI GS ZSM 009-2: Closed-Loop Automation – Solutions for automation of E2E service and network management use cases [zsm-009-2]
  - 3GPP - Management Services for Communication Service Assurance
    - TS 28.535: Requirements
    - TS 28.536: Stage 2 and Stage 3
- **Beyond State of the Art**
  - Analyze how CL Coordination services can be declined in different CLs collaboration models (e.g., delegation vs. escalation) and CLs scopes (multi-layer, multi-tenant, inter-domain, …)
  - Define workflows and interfaces for relevant coordination functions
  - Implementation of concrete examples of CL coordination and conflict detection and mitigation
  - Investigate which API should be exposed across multiple CL
  - Investigate a possible applicability of CAPIF
  - Sharing of Knowledge across multiple CL

Enabler #11: Zero-touch multiple closed loop coordination

- **High-level enabler system view**



Multiple CL coordination architecture

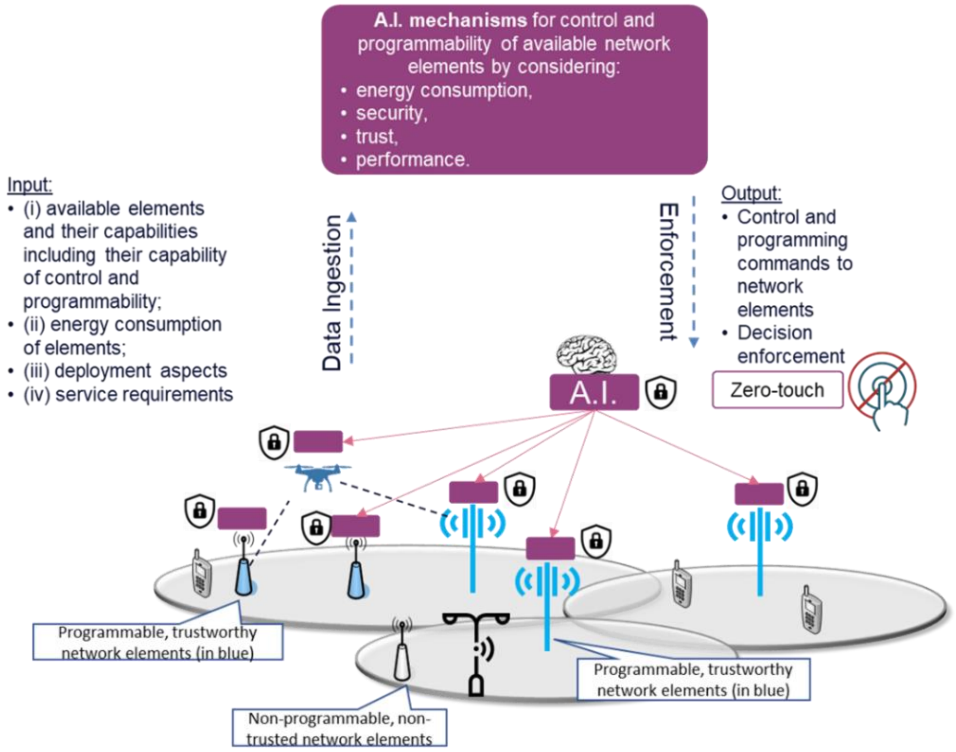
Planned Proof of Concepts

Component-PoC#A.1. Sustainability and trustworthy-oriented orchestration in 6G

- Objective/Scope
  - AI mechanisms for controlling and programming 6G network elements with focus on reducing energy consumption.
  - Optimization of resource allocation for energy efficiency while considering performance and security requirements.
  - Network programmability and a zero-touch approach for automated network reconfiguration and energy-aware self-optimization at runtime.
  - Harden AI models to protect against security and privacy attacks targeting AI functionality.
- Functionalities
  - Inputs include identification of network elements, trust levels, capabilities, energy considerations, deployment intricacies, service requirements, and secure data collection.
  - Privacy-enhanced AI mechanisms manage control and programmability, balancing energy, security, trust, and performance.
  - Dynamic deployment and configuration of monitoring probes for AI-based traffic profiling and network monitoring.
- Output
  - Control and programming commands for network elements, enabling critical decisions.
  - Focus on trustworthy zero-touch operations for service quality, energy efficiency, and reliability.
- Benefits

  Achieve zero-touch control and programming of 6G network elements with trustworthiness and security, safeguarding AI against potential attacks.

  Enhance reliability, energy efficiency, and performance, contributing to sustainability goals.



High level view of the PoC#A.1

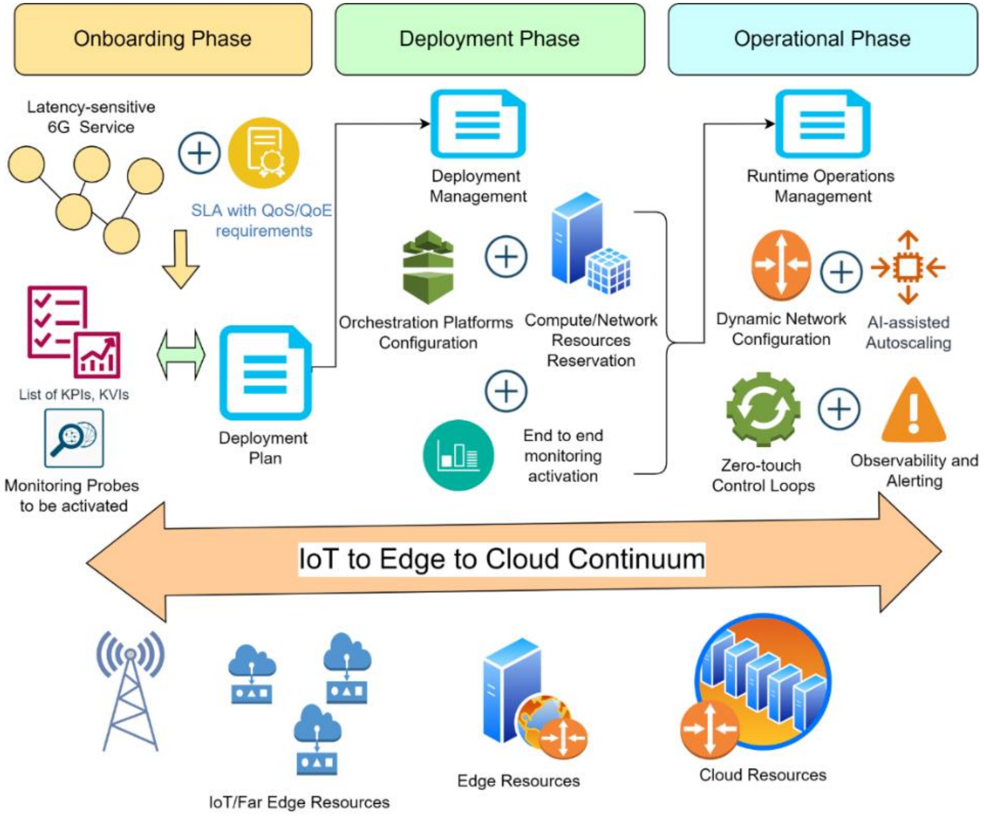
Component-PoC#A.1. Sustainability and trustworthy-oriented orchestration in 6G

Enablers contributions to Component PoC#A.1:

- Enabler 1 → specific network element control and management will be considered together with cloud-native SDN controller.
- Enabler 2 → monitoring framework will be provided and integrated with other enablers.
- Enabler 3 → communication bus that eases the multi-domain solutions integration ensuring secured data exchange.
- Enabler 4 → Trust manager component for evaluating the trust level of each network/compute node (e.g., servers, robotic nodes) available in the system with the use of AI/ML.
- Enabler 6 → deployment and runtime management mechanisms for the developed service/application chain, considering resources in the edge and cloud part of the continuum.
- Enabler 7 → Optimisation mechanisms for functionality placement (including various computational workloads, services etc.) to the available compute nodes (e.g., servers, robotic nodes) towards energy efficiency and trustworthiness.
- Enabler 8 → exploration of how AI/ML-based control can be protected against adversarial attacks and privacy attacks to provide a more robust model and to prevent sensitive data to be disclosed.
- Enabler 10 → provisioning of CL functions for automated migration of application components among cobots, based on battery level.

Component-PoC#B.1. AI-assisted end-to-end lifecycle management of a 6G latency-sensitive service across the compute continuum

- Objective
  Validate key processes for managing the end-to-end lifecycle of latency-sensitive 6G services.
  Encompasses onboarding, deployment, and operational phases over programmable infrastructure across the compute continuum, including devices and cloud computing resources.
  Emphasizes automated service onboarding, synergetic orchestration, and the integration of AI technologies.
- Key Features for Validation
  - Quick and reactive management of bursty workloads, automated scaling policies, and agile end-to-end network configuration.
  - Data fusion and prompt telemetry data analysis for bottleneck identification, anomaly detection, and corrective actions.
- Functionalities
  - Onboarding phase: Define deployment types, privacy, and QoS/QoE requirements. Translate SLA prerequisites, licensing strategy, and management fabric setup.
  - Inter-computing deployment: Seamlessly integrate computing elements, specify orchestration mechanisms, activate monitoring systems, and configure network equipment.
  - AI-assisted operational phase: Continuous monitoring, AI-driven scaling, compute optimization, edge computing performance enhancement, dynamic network reconfigurations, and zero-touch control loops.
- Benefits
  - Comprehensive validation of end-to-end 6G service lifecycle management.
  - Automated service onboarding, synergetic orchestration, and AI infusion.
  - Enhanced efficiency, agility, and intelligence for latency-sensitive 6G services.
  - Foundation for advanced low-latency communication and service provision.



High level view of the PoC#B.1

Component-PoC#B.1. AI-assisted end-to-end lifecycle management of a 6G latency-sensitive service across the compute continuum

Enablers contributions to Component PoC#B.1:

- Enabler 1 -→ specific network element control and management will be considered together with cloud-native SDN controller.
- Enabler 2 → Monitoring framework will be provided to acquire, process and export multiple data sources. Provision of QoS and telemetry data to the activated orchestration mechanisms.
- Enabler 3 → ease the onboarding and operational phases, ensuring a multi-domain communication bus, that enables liquid and frictionless interoperation between services.
- Enabler 4 → Trust manager component for evaluating the trust level of each network/compute node (e.g., servers, robotic nodes) available in the system with the use of AI/ML.
- Enabler 5 → Management of the deployment of the service over multi-cluster infrastructure. Activation of scaling policies per part of the infrastructure, management of live migration mechanisms and management of interconnection of the clusters.
- Enabler 6 → Enforcement of intelligent orchestration mechanisms, considering intent-driven approaches for deployment of distributed application/service components, as well as technologies that are based on multi-agent systems and reinforcement learning techniques.
- Enabler 10 → Provisioning of multiple CLs exploiting AI techniques at the analysis stage and with CL functions deployed in the continuum.
- Enabler 11 → Coordination of multiple CLs operating in different domains (e.g., for resource orchestration over edge and cloud domains), with conflict resolution mechanisms.

Conclusions

Conclusions

D6.2 has reported about the foundations design work in Hexa-X-II project concerning Smart Network Management enablers.

Key Elements Covered:

- Overview of 6G technology development drivers, including environmental, social, and economic factors related to M&O.
- Elaboration of overarching objectives and goals for smart network management in Hexa-X-II.
- Identification of M&O Enablers and description on: i) Motivation and problem-solving objective, ii) Description overview, iii) Key references in the State of The Art (SoTA) and how the enabler advances beyond SoTA, iv) Identification of possible components and interfaces, v) Relationship with other enablers.

	PoC# A.1	PoC# B.1
Enabler 1: Programmable flexible network configuration	X	X
Enabler 2: Programmable network monitoring and telemetry	X	X
Enabler 3: Integration fabric	X	X
Enabler 4: Trustworthy 3rd party management	X	X
Enabler 5: Multi-cloud management mechanisms		X
Enabler 6: Orchestration mechanisms for the computing continuum	X	X
Enabler 7: Sustainable AI/ML-based control	X	
Enabler 8: Trustworthy AI/ML-based control	X	
Enabler 9: Network Digital Twins		
Enabler 10: Zero-touch closed loop governance	X	X
Enabler 11: Zero-touch multiple closed loop coordination		X

- Planned Proof of Concepts (PoCs) Selected enablers will be integrated into the following PoCs.
- PoC#A.1: Sustainability and trustworthy-oriented orchestration in 6G.
- PoC#B.1: AI-assisted end-to-end lifecycle management of a 6G latency-sensitive service across the compute continuum.

Related Future work:

- Further requirements will be incorporated in the following design iteration, once use cases work analysis released in performed (Dec’23).
- The overall Hexa-X-II system blueprint regarding M&O functionalities will be considered for the update of the current enablers in following iterations in the project in a top-down approach.
- The current enablers will be considered also in a bottom-up approach to design the 6G platform blueprint for the whole Hexa-X-II project.
- Next deliverable on Smart Network Management Enablers will be delivered by June 2024 providing an extended Design of 6G Smart Network Management Framework. This report will contribute to the 2nd iteration design of the overall Hexa-X-II system blueprint.

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