6G series workshop
February 12, 2025

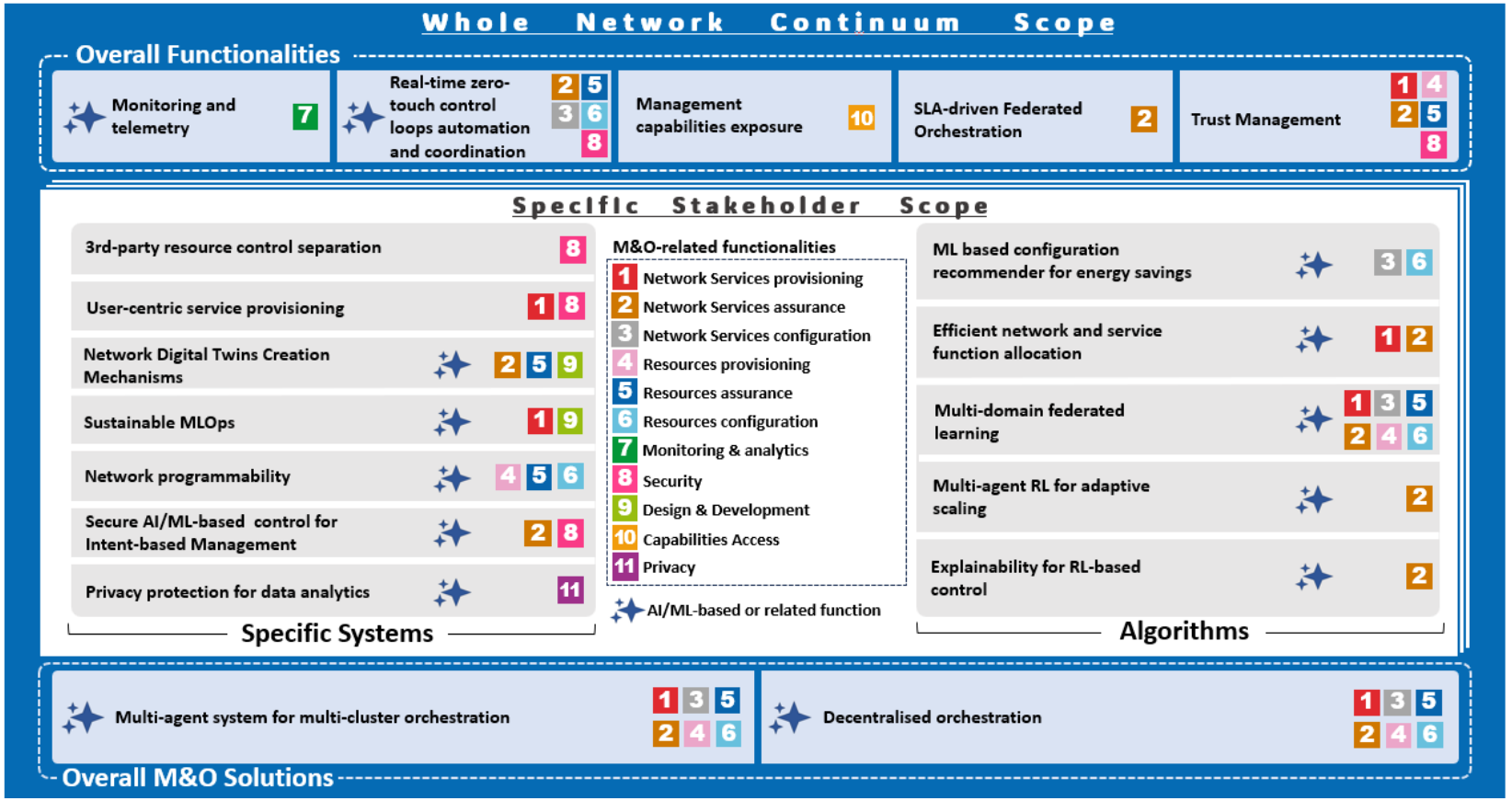
Hexa-X-II: Foundations on 6G Smart Network Management and Orchestration Enablers

Ricard Vilalta (CTTC)
Hexa-X-II
hexa-x-ii.eu





Hexa-X-II WP6
6G Smart Network Management framework



Deliverable D6.5
Final Design on 6G Smart Network Management Framework

Co-funded by the European Union
6GSNS
Hexa-X-II project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095759.

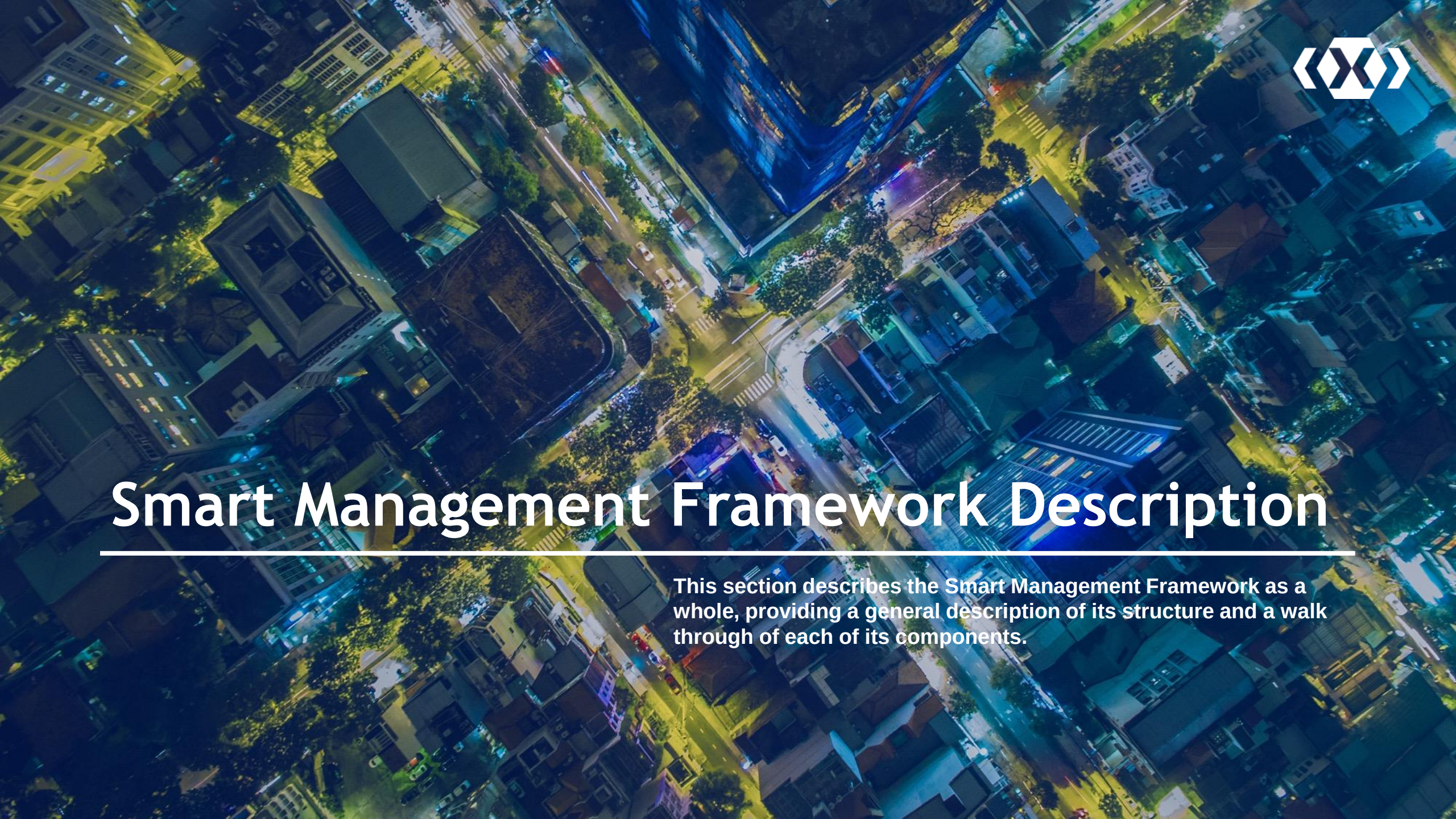
Date of delivery:	28/02/2025	Version:	1.0
Project reference:	101095759	Call:	HORIZON-JU-SNS-2022
Start date of project:	01/01/2023	Duration:	30 months

Smart Management Framework Description

Framework components implementation and Evaluation

Implementations based on the Framework

Conclusions

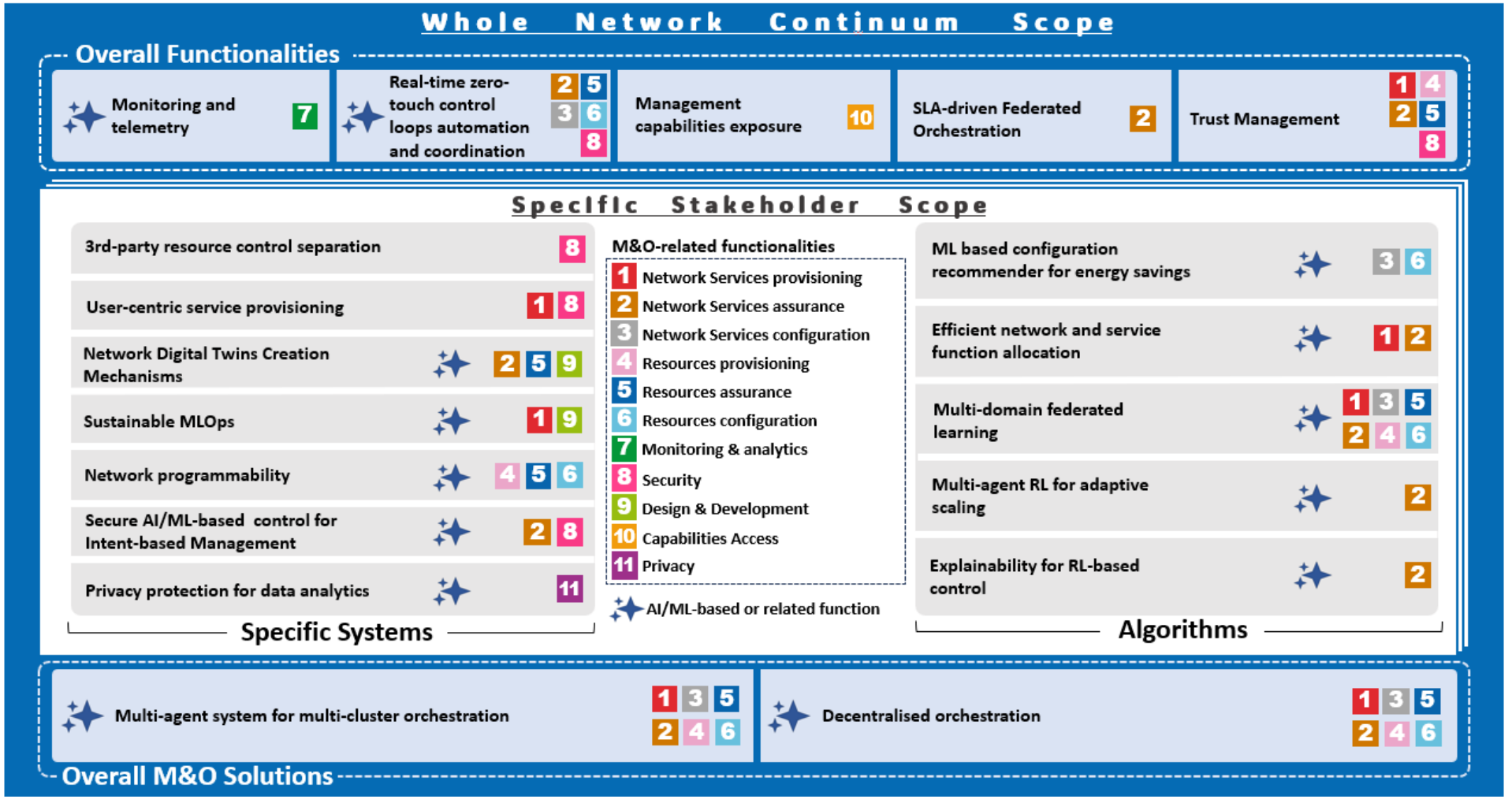


Smart Management Framework Description

This section describes the Smart Management Framework as a whole, providing a general description of its structure and a walk through of each of its components.

Hexa-X-II Smart Management Framework - Overall view (1/2)

The figure below provides an overview of the smart management framework, with its main technical enablers grouped into different categories:



The framework is designed as a supporting structure on which the M&O systems towards 6G can be built, offering a system of rules, ideas, and innovations that can be used to plan and decide on such systems.

Hexa-X-II Smart Management Framework - Overall view (2/2)

Technical enablers are grouped into two overall scopes:

- Those targeting the whole network continuum scope (outer light blue frame), i.e., considering the network domains beyond the individual stakeholder's boundaries.
- Those in the particular scope of specific stakeholders (inner white rectangle).

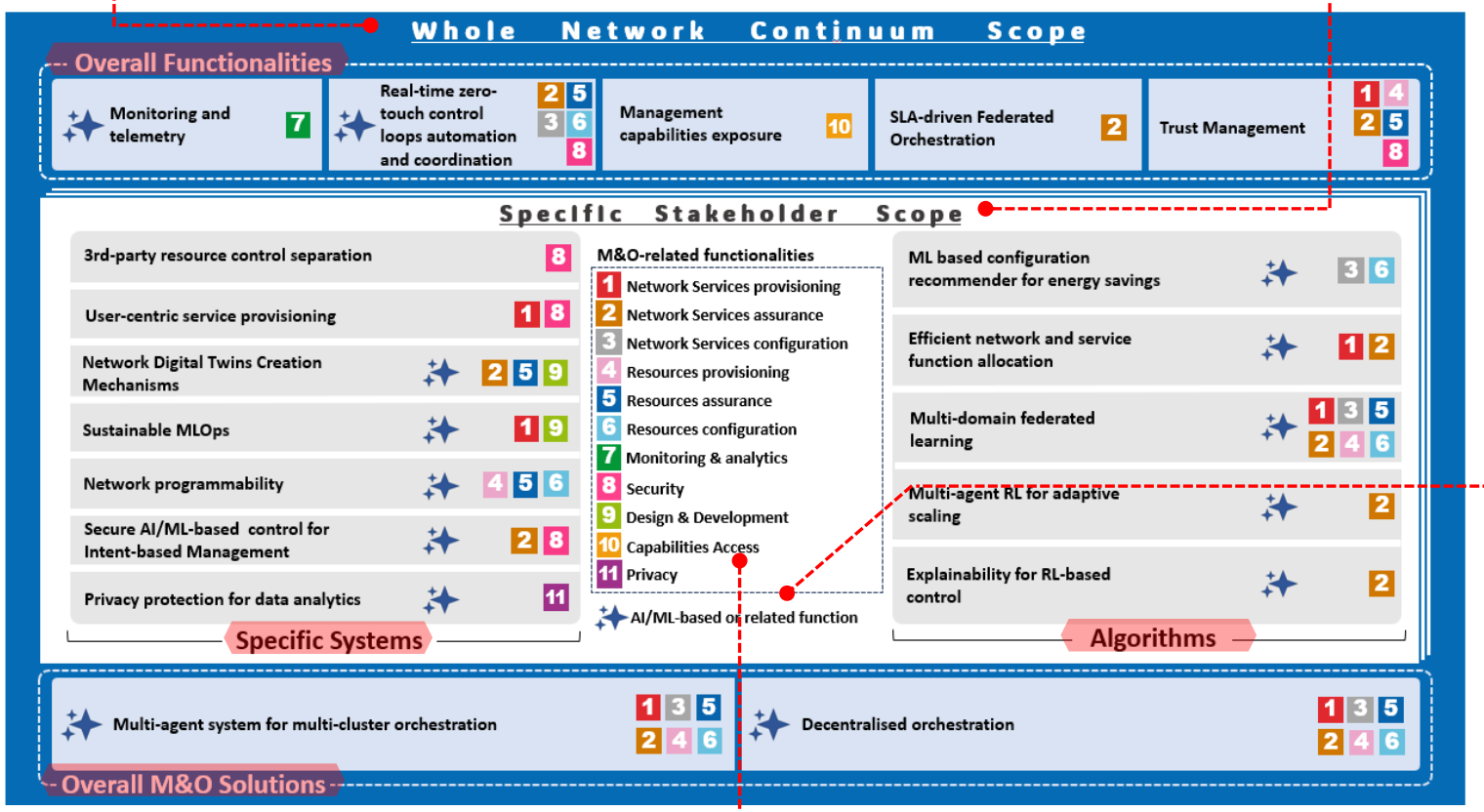
Enablers are also grouped into four main categories highlighted in red in the figure:

a) Overall M&O Solutions (bottom) with enablers integrating an extensive set of M&O mechanisms across the whole network continuum.

b) Overall Functionalities (Top Rectangle): Specific functionalities also targeting the whole network continuum.

c) Specific Systems (Left Grey Blocks): Systems for specific stakeholders.

d) Algorithms (Right Grey Blocks): Selection of algorithms, also to be deployed within the stakeholder's scope.

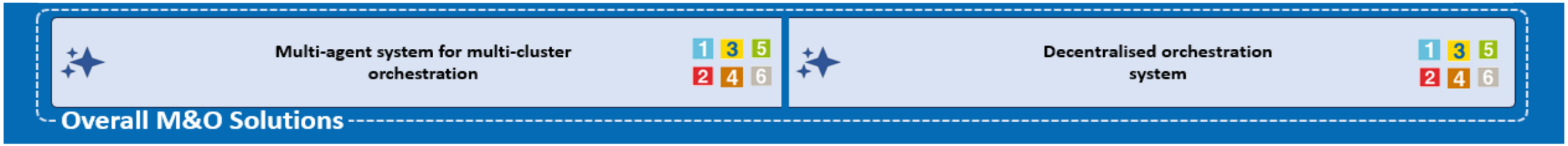


Beyond these common management functions, the Framework also includes cutting-edge technologies, e.g., the extensive usage of AI/ML (represented by the sparkle icon ✨), zero-touch automation through closed control loops, or digital twins creation mechanisms, among others.

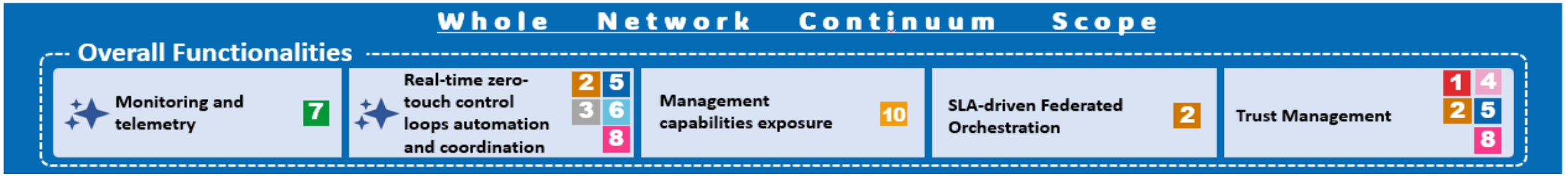
The Framework includes those functionalities commonly found in M&O systems (e.g., service/resource provisioning, assurance, monitoring…), represented by the coloured numbered list in the middle of the figure. These numbers are assigned to specific components based on their functionality.

Hexa-X-II M&O Framework
Overall M&O Solutions

- The Overall M&O solutions are enablers integrating a rich set of M&O mechanisms, targeting to manage and orchestrate network services and resources across the whole network continuum. The “overall” term here refers the extensive set of functionalities integrated in these solutions.
- Two approaches are offered in the framework, namely Hierarchical and Decentralised.
  - The Hierarchical approach is based on a multi-agent system for multi-cluster orchestration and includes a centralised E2E orchestrator and distributed agents to manage resources and services across platforms and domains, including also the extreme-edge domain, and integrating AI/ML techniques for the proactive allocation of service components and to perform predictive M&O actions.
  - The Decentralised approach targets to manage network and services in a fully distributed manner, focusing on providing service continuity, scalability, and optimised resource usage considering the highly heterogeneous and the volatile resources in the extreme-edge domain. It includes zero-touch infrastructure discovery mechanisms and AI/ML for predicting changes in the infrastructure.
- Main challenges addressed:
  - The envisaged highly distributed and multi-stakeholder ecosystem towards 6G.
  - The integration of the extreme-edge domain, with its volatile resources, cloud-native scale, and varied kind of devices.
- Key concept: Utilising the combined computing and storage capacity of the extreme-edge domain to
  - Distribute workloads efficiently,
  - Reduce data communication needs,
  - Lower latency, potentially surpassing current 5G capabilities,
  - Enable new business models for stakeholders.



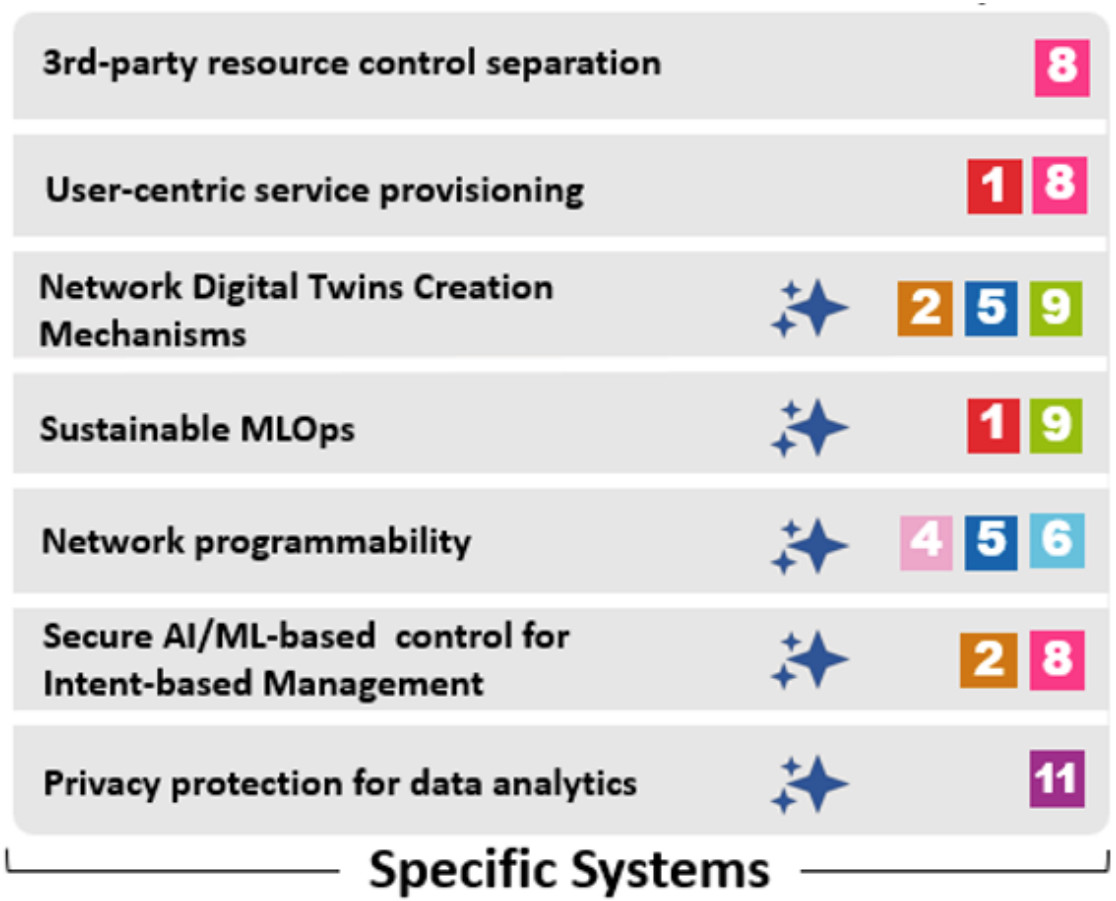
Hexa-X-II M&O Framework
Overall Functionalities



This section outlines the five key functionalities in the framework that, although not so general as the Overall M&O Solutions described before, can complement and enrich those overall solutions, also in the scope of the entire network continuum. They are the following:

- **Monitoring and telemetry**, enables the integration of diverse monitoring protocols and user-defined metrics across various network domains and support AI/ML models by feeding heterogeneous, multi-domain data for improved decision-making and proactive network management.
- **The real-time zero-touch control loops automation and coordination mechanisms**, intended to automate network management through adaptable and configurable control loops, integrating AI/ML for predictive actions, and allowing autonomous responses to real-time network changes or proactive optimisation actions.
- **The management capabilities exposure** that facilitates cross-domain connectivity, allowing stakeholders to integrate their M&O systems.
- **The SLA-driven federated orchestration mechanism**, supporting dynamic SLA definitions in multi-stakeholder environment using blockchain for autonomous SLA management, reducing 3rd party involvement.
- **The trust management mechanisms**, which can be used to integrate trust evaluation as part of the M&O systems, targeting to ensure secure and efficient resource allocation, particularly in multi-stakeholder environments.

Hexa-X-II M&O Framework Specific Systems



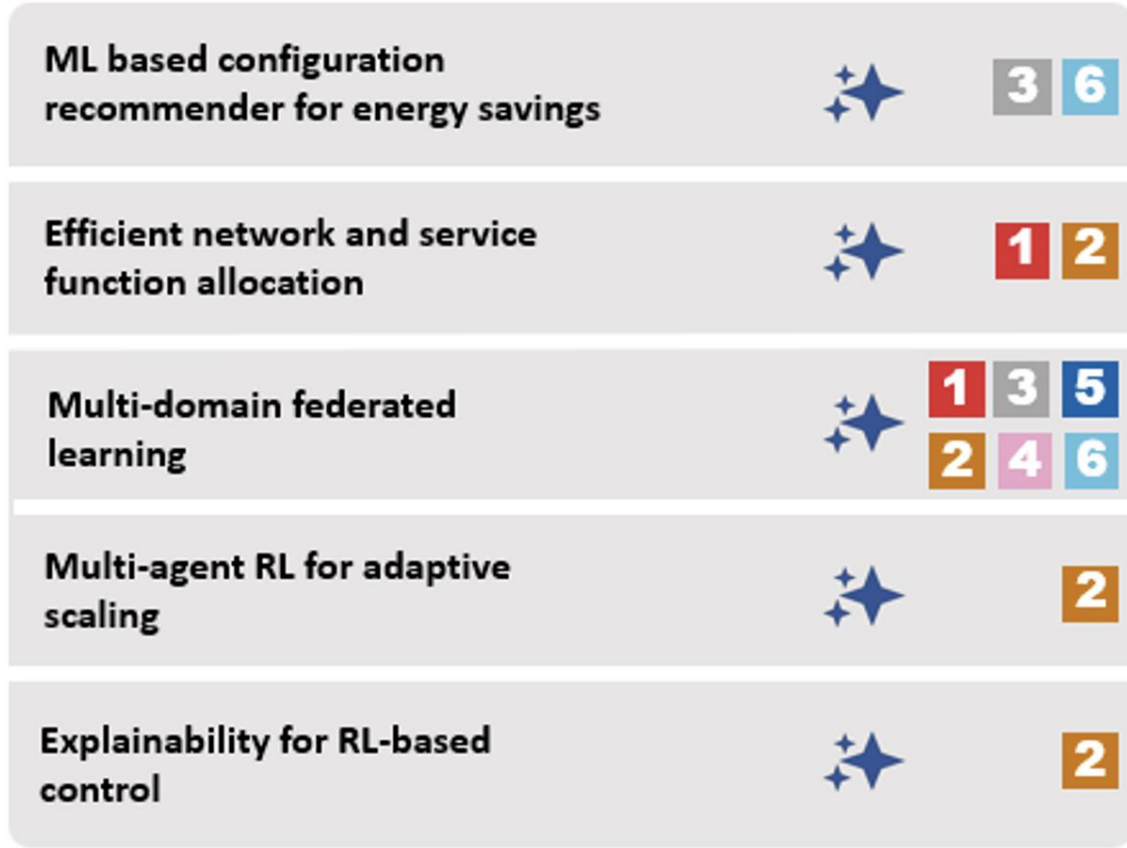
This block groups the key systems operating at the stakeholder level in the management framework. The following technical enablers are included here:

- **The 3rd party resource control separation system**, which makes possible to establish separate M&O spaces per tenant in multi-tenant environments for secure and precise control over services, applications, and resources.
- **The User-centric service provisioning system**, which enables more dynamic and flexible SLA definitions.
- **The Network Digital Twins creation mechanisms**, to create virtual models of network environments for safe pre-production testing and real-time insights through connection with live systems.
- **A sustainable ML Operations (MLOps) asset**, to create automated AI/ML-based service workflows, enabling also the monitoring of the energy consumption in the different stages of those workflows.
- **Network programmability enabler**, which integrates the Software Defined Networks (SDN) technology for the future 6G networks with a cloud-native model and offering new interfaces for emerging devices.
- **Secure AI/ML-based Control** to support intent-based management systems (addressed in the context of WP2) to enhance their security.
- **A privacy-preserving data analytics enabler**, to ensures sensitive data protection during AI/ML processes, and enabling privacy-preserving analytics.

Hexa-X-II M&O Framework Algorithms

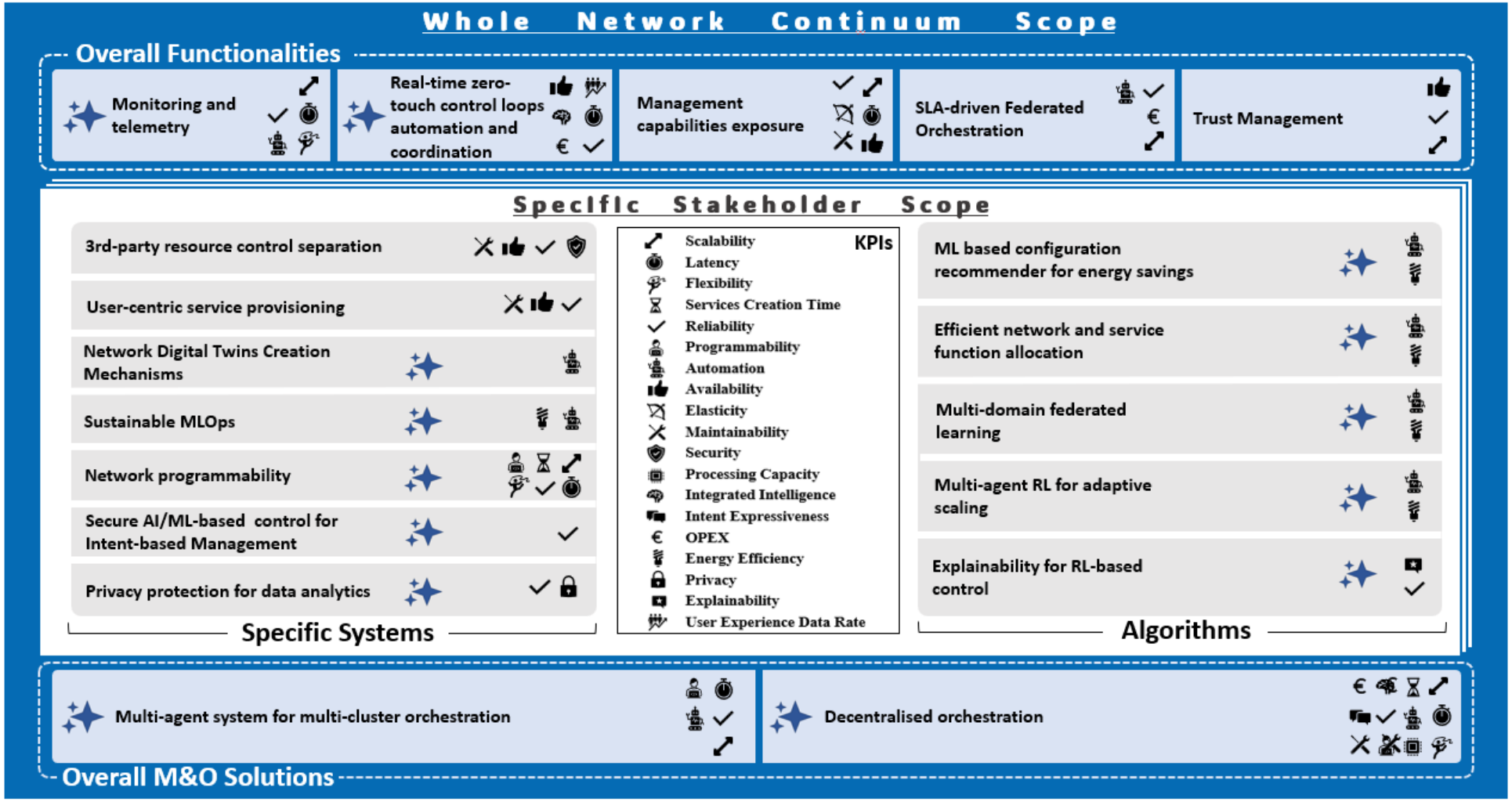
This section of the Framework includes a set of selected algorithms for future 6G systems. It emphasises the importance of incorporating certain algorithms into the management framework with a primary focus on AI/ML algorithms. The selected algorithms are the following:

- **ML-based Configuration Recommender**, to optimises energy efficiency in 6G base stations by reducing power consumption.
- **Algorithms for Efficient Network and Service Function Allocation**, focusing on energy-efficient network function allocation. Suitable for resource-limited edge devices.
- **Multi-domain federated Learning Algorithm**, which optimises compute resource allocation for federated learning with minimal impact on energy consumption and other network services.
- **Multi-Agent RL Algorithm**, which enables adaptive resource scaling to meet service-level objectives, such as latency and energy efficiency, in dynamic network conditions.
- **Explainability Algorithms for RL Control**: Provides human-understandable explanations for decisions made by RL-based control algorithms, enhancing transparency and trust.

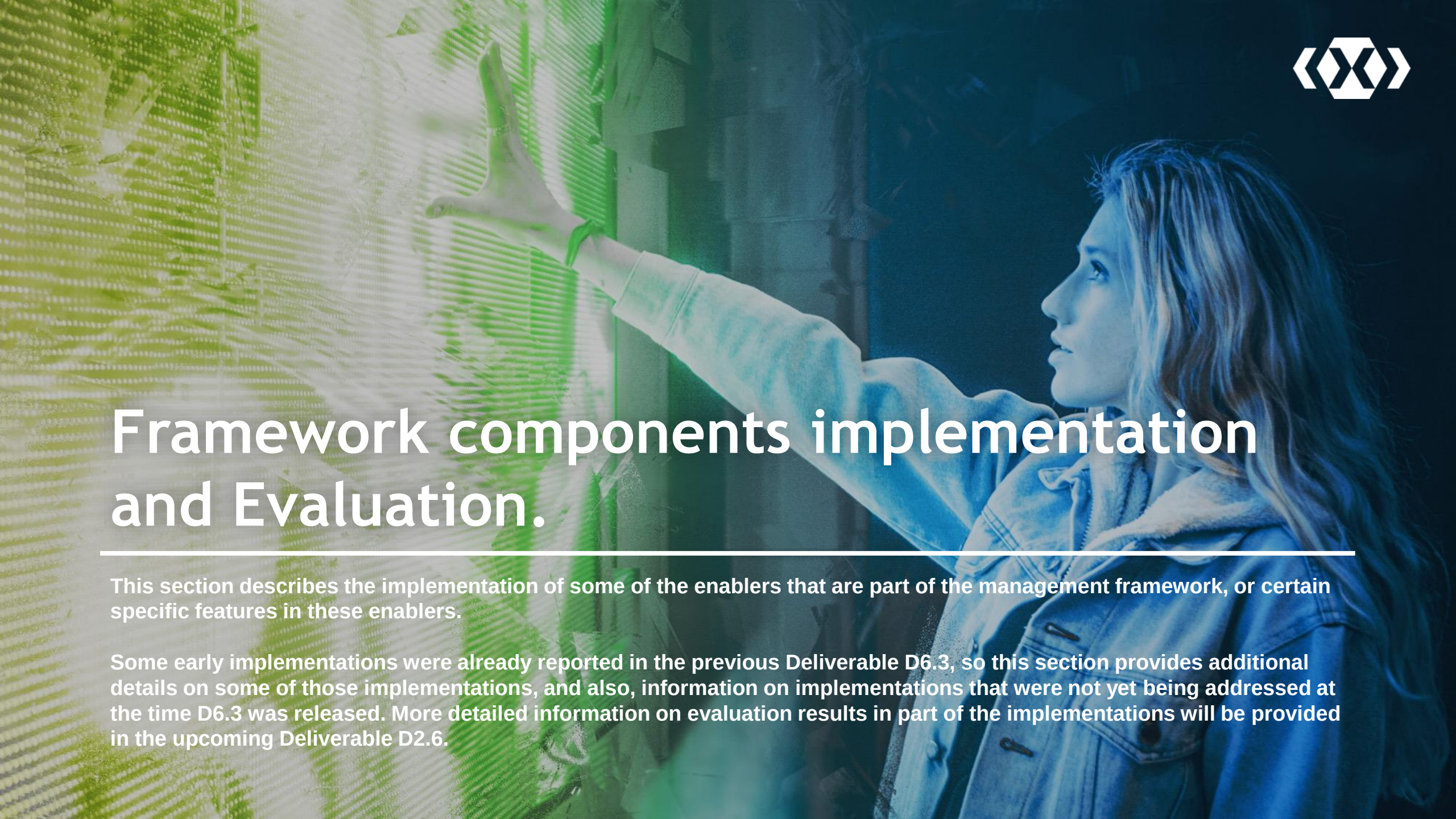


Related KPIs

The following figure shows the mapping between the impacted KPIs identified in the previous Deliverable D6.3 (listed in the middle of the figure), and the different assets of the management framework:



Values of these KPIs can be found in the following slides regarding the practical implementations carried out during the reporting period of Deliverable D6.5, or will be included in the next D2.6 regarding the results in the final PoCs of the project being addressed in the context of WP2.

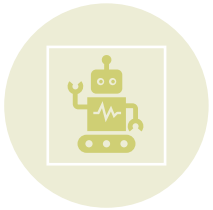


Framework components implementation and Evaluation.

This section describes the implementation of some of the enablers that are part of the management framework, or certain specific features in these enablers.

Some early implementations were already reported in the previous Deliverable D6.3, so this section provides additional details on some of those implementations, and also, information on implementations that were not yet being addressed at the time D6.3 was released. More detailed information on evaluation results in part of the implementations will be provided in the upcoming Deliverable D2.6.

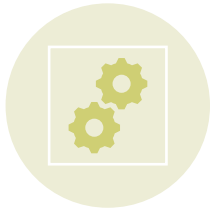
Framework components implementation and Evaluation



AI-ENABLED RT ZERO-TOUCH CONTROL LOOP ANALYSIS FUNCTION

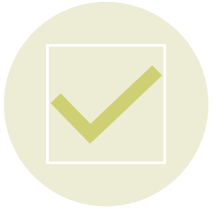
PENALTY-BASED MANAGEMENT OF CONCURRENT SERVICE CLS

CONFLICT DETECTION FOR THE REACTIVE ACTIVITIES REQUESTED BY CLOSED LOOPS



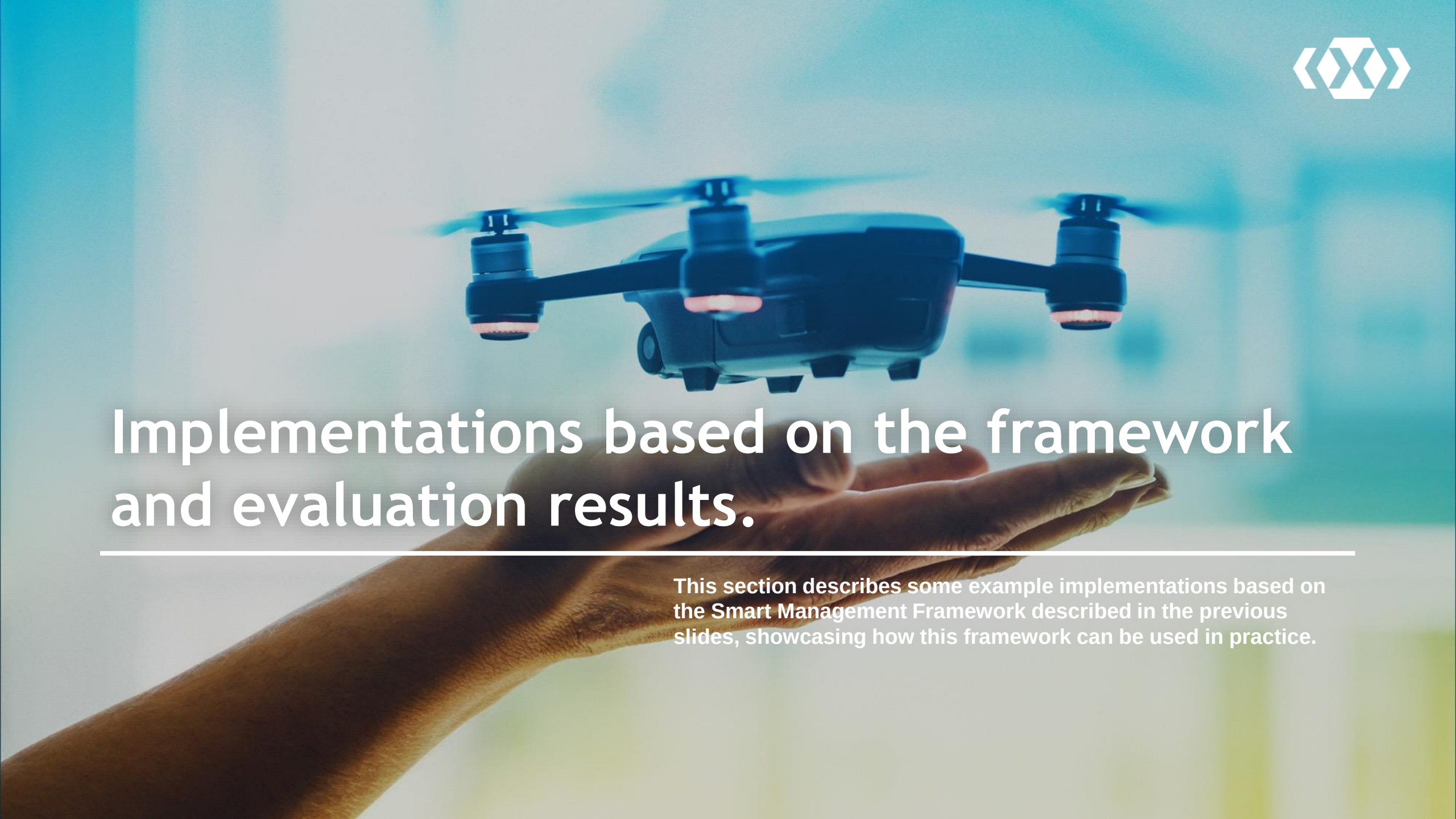
HUMAN-ASSISTED TRAINING OF COGNITIVE CLOSED LOOPS FUNCTIONS FOR NETWORK AUTOMATION

SUSTAINABLE MLOPS



ETSI TERAFLOWSDN

MONITORING AND TELEMETRY

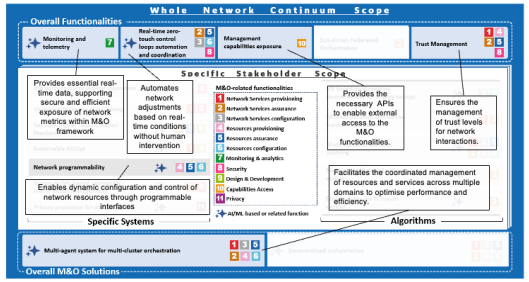


Implementations based on the framework and evaluation results.

This section describes some example implementations based on the Smart Management Framework described in the previous slides, showcasing how this framework can be used in practice.

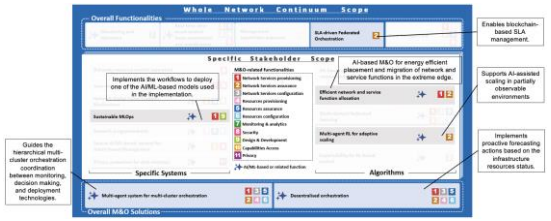
Overview

The following implementations have been performed, combining different enablers of the management framework (highlighted in red in the figures):



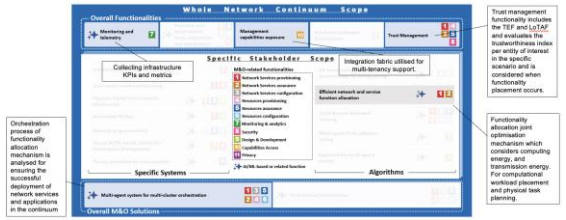
1. Usage of the management capabilities exposure system.

Showcases the usage of the Management Capabilities Exposure enabler considering different use cases: the integration of a vertical industry, and failure detection and recovery scenarios.



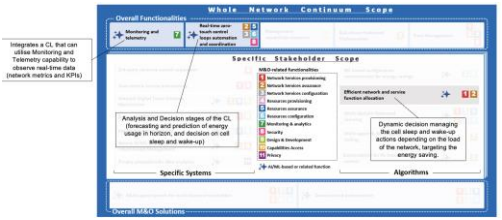
2. Orchestration on the network continuum.

Showcases different M&O scenarios on the network continuum, including proactive migration of service components, MLOps, services federation, and trust management.



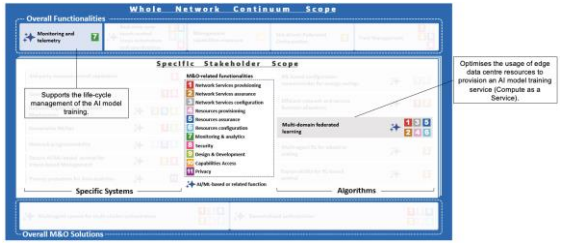
3. Functionality allocation in a cobot-powered warehouse inventory system.

Orchestration of a network service providing an automated inventory management solution for accurate and efficient warehousing operations using collaborative robots.



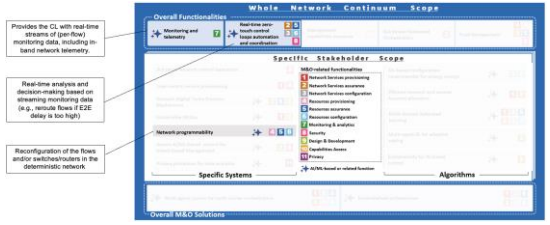
4. ML based configuration recommendation for energy saving.

Fully automated CL-based solution for correcting flow misconfigurations in a scalable way in deterministic networks. The system takes autonomous decision for cells sleep and wake-up.



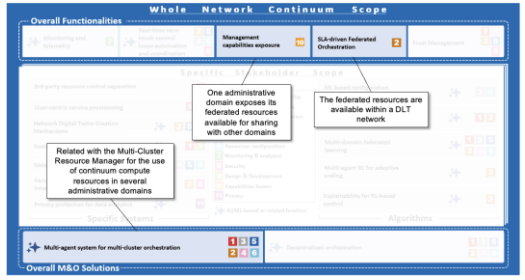
5. Resource assignment for federated learning.

Showcases how telco operators could leverage on rich data sources of connected devices and on the deployment of edge compute resources to provision AI model training as a service, in line with the CaaS paradigm.



6. Flow Reconfiguration based on Dynamic Monitoring and Closed Loops in Deterministic Networks.

Provides an automated CL-based solution for correcting flow misconfigurations in a scalable way in deterministic networks by exploring trade-offs between different forms of telemetry.



7. Edge convergence over federated resources for the computing continuum.

Explores the capabilities of the CAMARA EdgeCloud APIs in the management of the compute resources in the network continuum, and the possibility to extend them to be used with federated resources of external administrative domains.

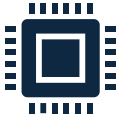
Conclusions

Conclusions

Objective:

Contributes to the design of the Hexa-X-II E2E 6G System Blueprint.

Development and evaluation of the 6G Smart Network Management Framework based on enablers specified in D6.3.



Framework Components

Overall Management & Orchestration (M&O) Solutions

General Functionalities

Specific Systems and Algorithms

Design & Evaluation

Detailed Component Design: Includes mechanism specifications, implementation details, and enabling technologies.

Evaluation & KPIs:Individual component results

Workflow scenarios showcasing collaboration among multiple components

KPIs defined to measure performance and effectiveness

Key Innovations

Decentralized Intelligence & Automation

Privacy & Security embedded in M&O mechanisms

AI/ML Integration:

- Multi-agent approaches
- Cognitive control loops
- Decentralized and federated orchestration schemes

Challenges: Model training, accuracy demands, resource orchestration across network continuum

Conclusion

The 6G Smart Network Management Framework introduces novel approaches essential for future 6G networks.

Emphasizes flexibility, AI-driven orchestration, and robust end-to-end services.

Ongoing PoC work and further research will refine and validate these mechanisms.

Insights and recommendations for the future (1/3)

These and the following slides provide an overview of the next steps considered for the development of the concepts and technical enablers in future iterations.

- Trends and future work for the overall M&O solutions
  - Multi-agent M&O techniques:
    - Consider the combination of multi-agent techniques with reliable and explainable AI frameworks to improve adoption of mechanisms.
    - Consider the emergence of agentic AI frameworks where multiple agents can collaborate and undertake different tasks (e.g., recommenders, RL-driven actions).
    - Study the opportunity to combine these approaches with modern observability stacks (e.g., based on open telemetry specifications) to assist decision making by agents.
    - Consider to provide support regarding the integration of networks with far edge/edge/cloud technologies for time critical operations (e.g., real time data processing of high data volumes).
    - Examine trust, security and privacy aspects by the agents.
  - Decentralised M&O techniques:
    - Further development of components to tackle scalability aspects.
    - Study and integration of alternative AI/ML models for the ISPM component.
    - Examination of synergies with other M&O approaches.

Insights and recommendations for the future (2/3)

- Trends and future work regarding the overall functionalities in the framework
  - Monitoring and telemetry:
    - It is considered that the innovations in TeraFlowSDN, MEC integration, and automation frameworks can pave the way for a more flexible, intelligent, and future-proof networks, aligning with emerging 6G requirements.
    - Plan for the refinement of the supported AI/ML mechanisms for automation, as well as the promotion of the implementations toward standardisation.
  - Zero-touch RT network automation:
    - New descriptors would be provided for unified CL modelling, mechanisms and workflows for governance and coordination.
    - New mechanisms to support real-time CL functions and governance, combined with monitoring and telemetry functionalities, and multi-cluster resource orchestration mechanisms.
  - Management Capabilities Exposure:
    - In the context of Hexa-X-II an Integration Fabric has been developed as inspired by ETSI ZSM, acting as a new integration/exposition based on event-driven approach. This approach could be generalised in the future, elevating it as an active component to decentralise the way to coordinate network functions and components.

Insights and recommendations for the future (3/3)

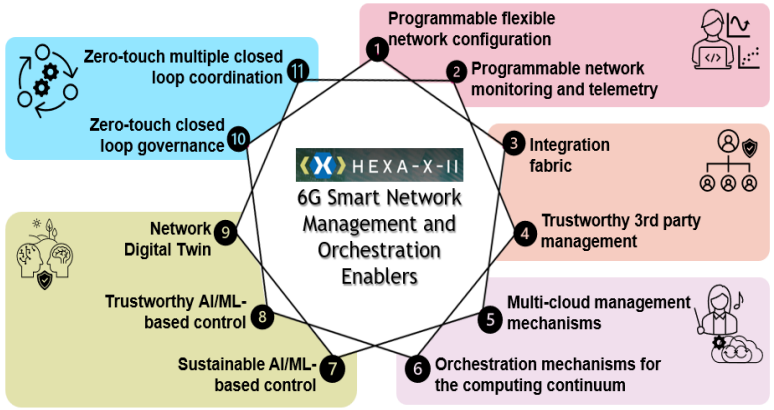
(cont. from the previous “overall functionalities“ bullet)

- SLA-driven federated orchestration
  - improvements are planned on prediction-based triggers of Smart Contracts for tighter latency bounds
- Trust management:
  - a trust assessment function and an associated ontology have been designed for the network continuum, along with the definition of internal interfaces and data models between TEF and LoTAF
  - it is envisaged that the common trust management model will be able to share information across multiple domains, trust will be delivered as a transparent notary service (TNS) to promote external audits, trust level agreement will be declared to formalise end-user’ requirements, while intent-based trust management will be supported

- Trends and future work for specific systems and algorithms:
  - The Network Digital Twins (NDT) concept has been introduced in Hexa-X-II to improve automation and support optimal decision making. This work could be considered as a starting point for future implementations.
  - The Sustainable MLOps approaches could be further extended to support different AI/ML paradigms and ML workloads.
  - Network programmability solutions are expected to expand significantly, supporting advanced orchestration across the network continuum in the future. These solutions are considered essential, particularly when integrated with Open APIs that enable convergence with edge/cloud orchestration (e.g., CAMARA APIs).
  - Third-party resource control separation and user-centric service provisioning mechanisms explored in Hexa-X-II are envisaged to be promoted within the 3GPP SA5 activities. These solutions extend Role-based Access Control (RBAC) mechanisms with dynamic, model-driven permissions tailored to tenants, by using dynamic URSPs (User Equipment Route Selection Policies) for personalised service activation, as well as the integration with closed-loop automation ensuring SLA compliance.

Want to learn more about Hexa-X-II WP6?

Deliverables D6.1 & D6.2



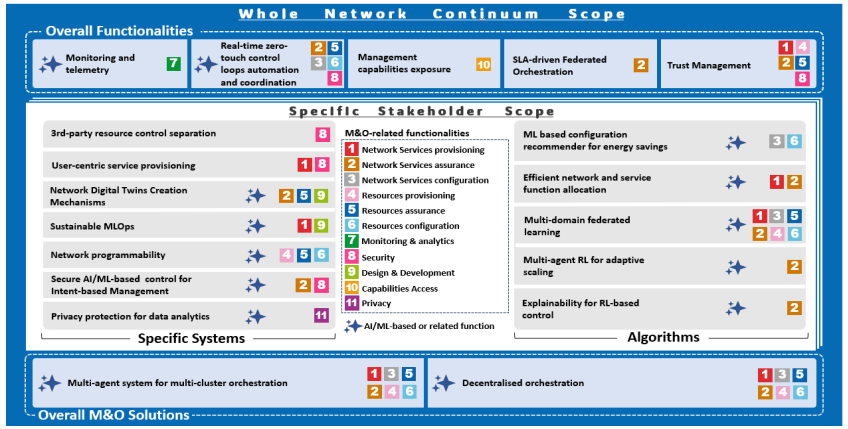
*Identification of the initial set of the 6G smart network management **technical enablers**. 11 enablers were early identified, grouped into 5 categories.*

Deliverable D6.3

Enabler #1: Network programmability framework.
Enabler #2: Monitoring and telemetry framework.
Enabler #3: Management capabilities exposure framework.
Enabler #4: Security framework.
Sub-enabler 4.1: Third-party resource control separation enabler.
Sub-enabler 4.2: User-centric service provisioning system.
Sub-enabler 4.3: Trust management system.
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.
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.
Enabler #7: Network digital twins creation mechanisms.
Enabler #8: Real-time zero-touch control loops automation and coordination system.

*Enablers streamlined renaming them and introducing the sub-enablers concept. Initial concept of the **Smart Management Framework** based on that set of enablers.*

Deliverables D6.4 & D6.5



*Final definition of the WP6 **Smart Management Framework**. Early report in the D6.4 presentation and full description in Deliverable D6.5.*

HEXA-X-II.EU //

Co-funded by the European Union

6GSNS

Hexa-X-II project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095759.