



ADROIT6G: Distributed Artificial Intelligence-driven open and programmable architecture for 6G networks

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Hexa-X-II Workshop on 6G Architecture and Standards
17/10/2024



'ADROIT6G 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 Grand Agreement No 101095363'



Co-funded by the European Union



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Overall Concept

ADROIT6G proposes disruptive innovations that will make fundamental changes to the way networks are designed, implemented, operated, and maintained.

Adopting a fully **distributed AI-driven dynamic** paradigm with **functional elements** automatically **deployed on-demand** as **virtual functions** in **cloud-native environments**, across the **far-edge, edge and cloud domains**, operated by **different stakeholders**.



- ▶ Project Name: ADROIT6G
- ▶ Stream: B0101 SNS-JU Call-1
- ▶ Project website: www.adroit6g.eu
- ▶ Project Coordinator: Prof. Ch. Verikoukis (ISI/ATH)
- ▶ Technical Managers: Prof. V. Vasilou (CYENS) and Dr. J.Vardakas (IQU)
- ▶ Total budget: 5,967,436 euros
- ▶ Duration: 36 Months, Begin: 1/1/2023



O1: Propose a novel 6G system architecture that integrates a distributed AI framework for combined communication, computation and control and empowers the convergence of networks and IT systems to enable new future digital services.

O2: Create an AI-driven Management & Orchestration and control framework for 6G Networks.

O3: Architect a distributed and secure CrowdSourcing.

O4: Develop energy-aware models for multimodal Representation Learning.

O5: Evolve the cellular infrastructure to allow the true integration of deep-edge devices in communication and computation functions.

O6: Enable Non-Terrestrial Networks connectivity for highly reliable Industrial IoT Services.

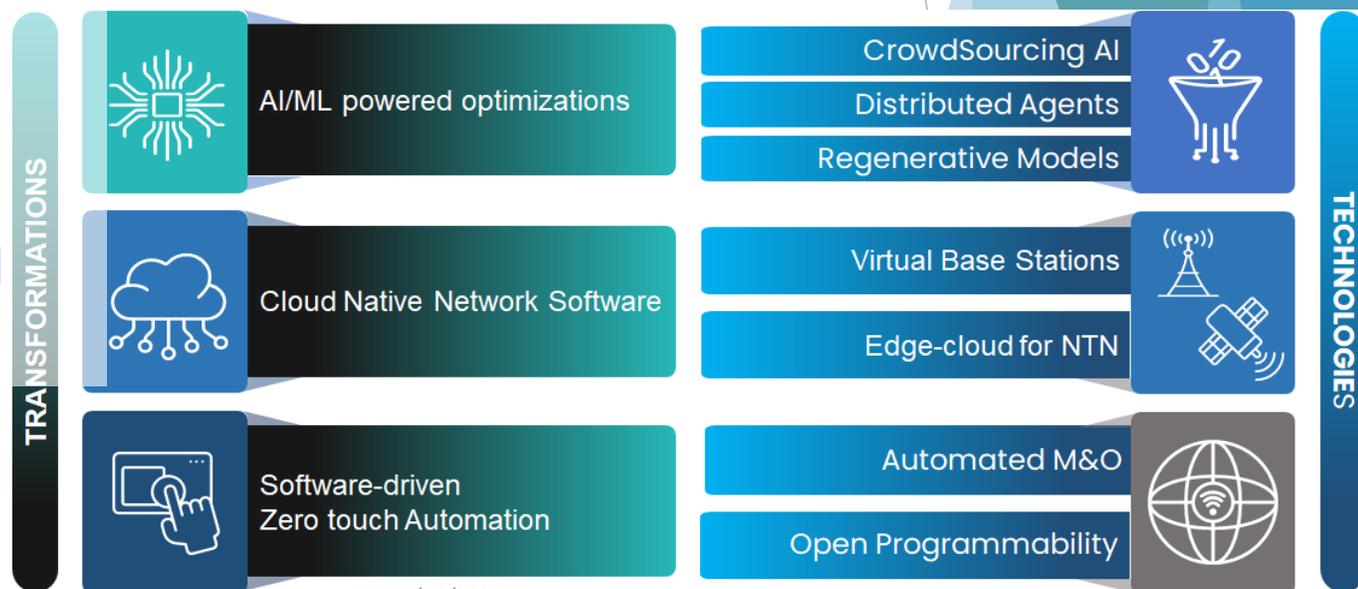
O7: Extend and demonstrate the use of decentralized AI for Device-to-Device communications.

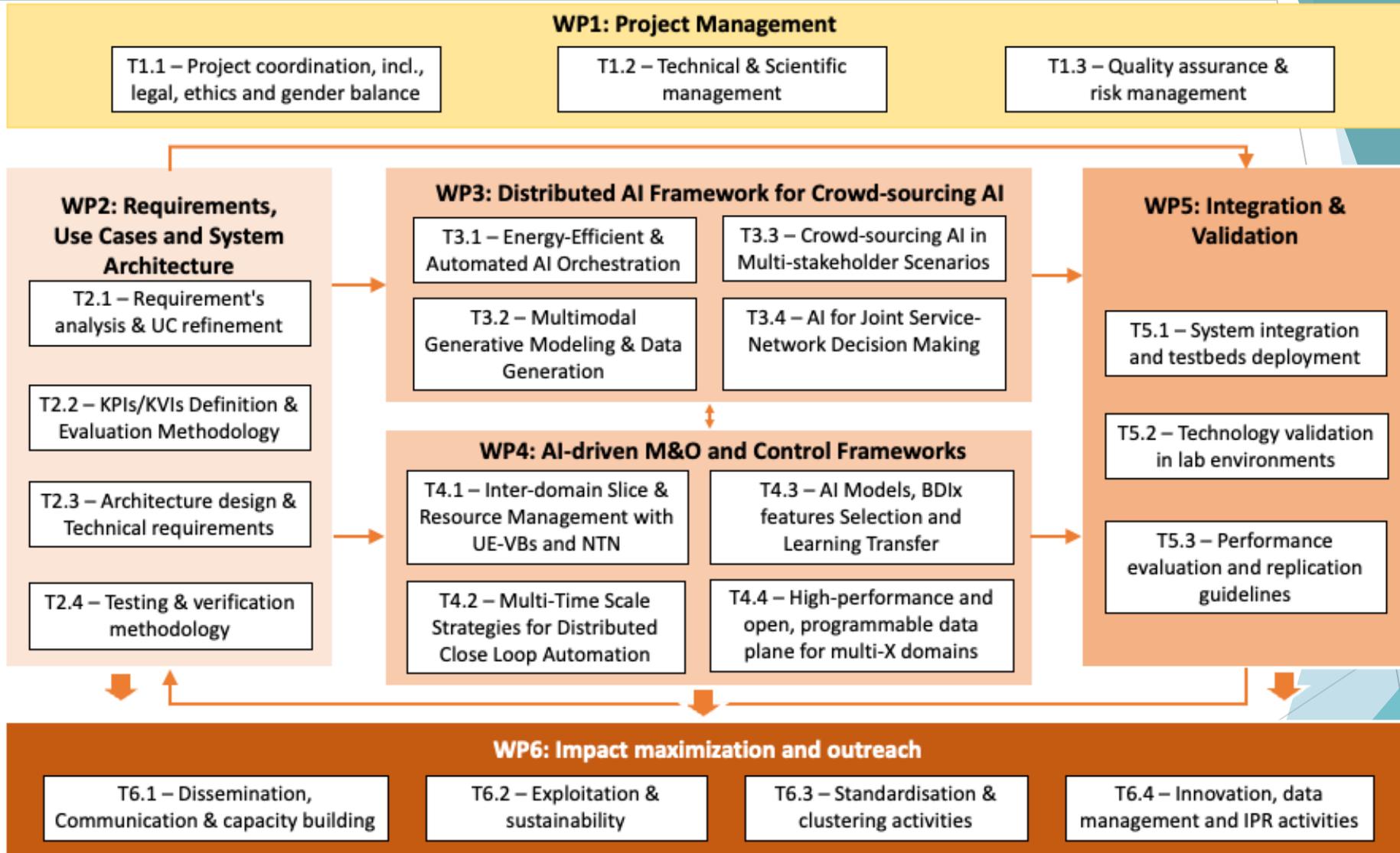
O8: Support data plane acceleration.

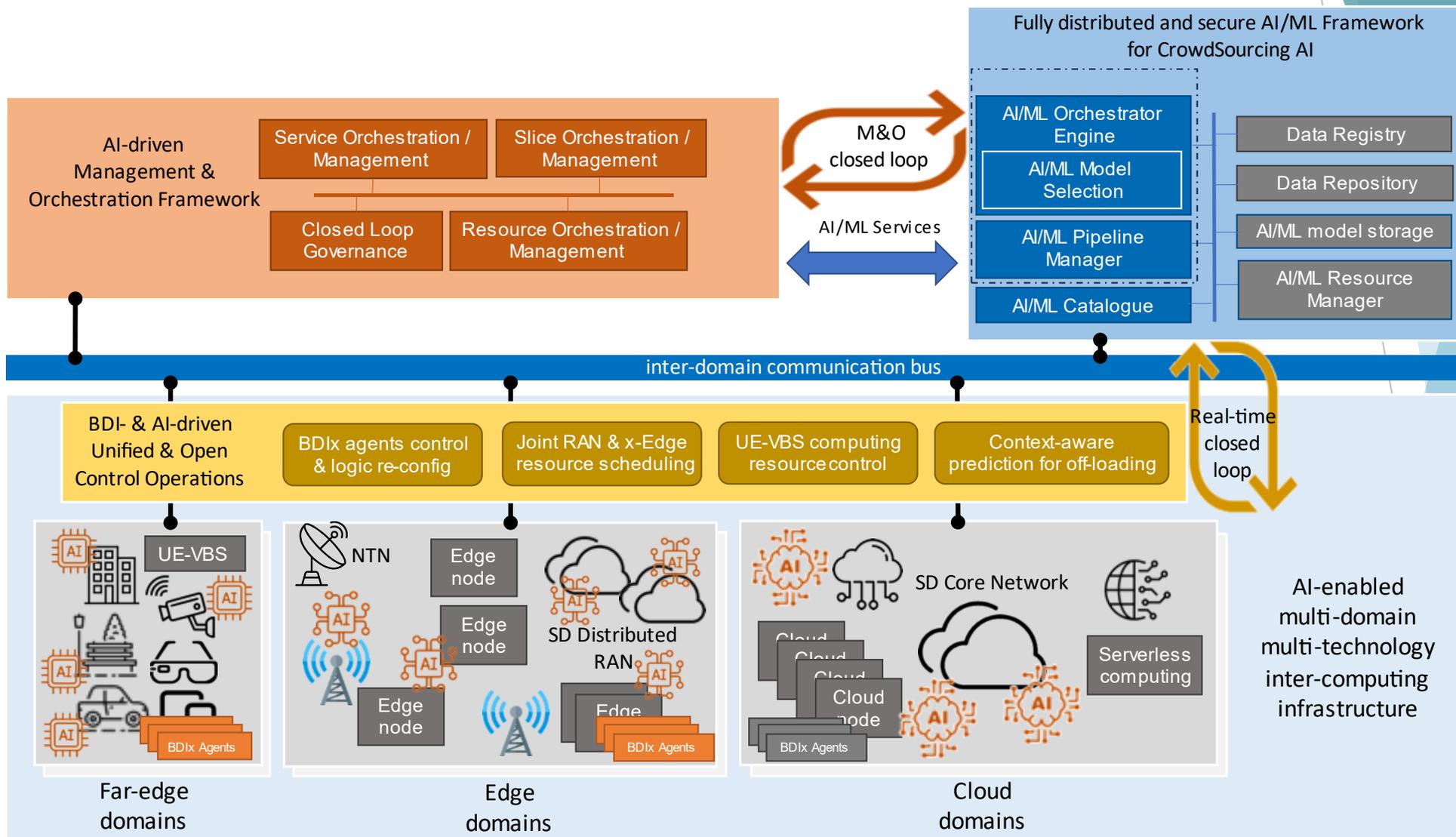
O9: Integrate and demonstrate the potential and user value of ADROIT6G through relevant experimentation, testing, and validation of its innovations in PoCs in lab settings.

ADROIT6G Key Transformations for 6G Evolution:

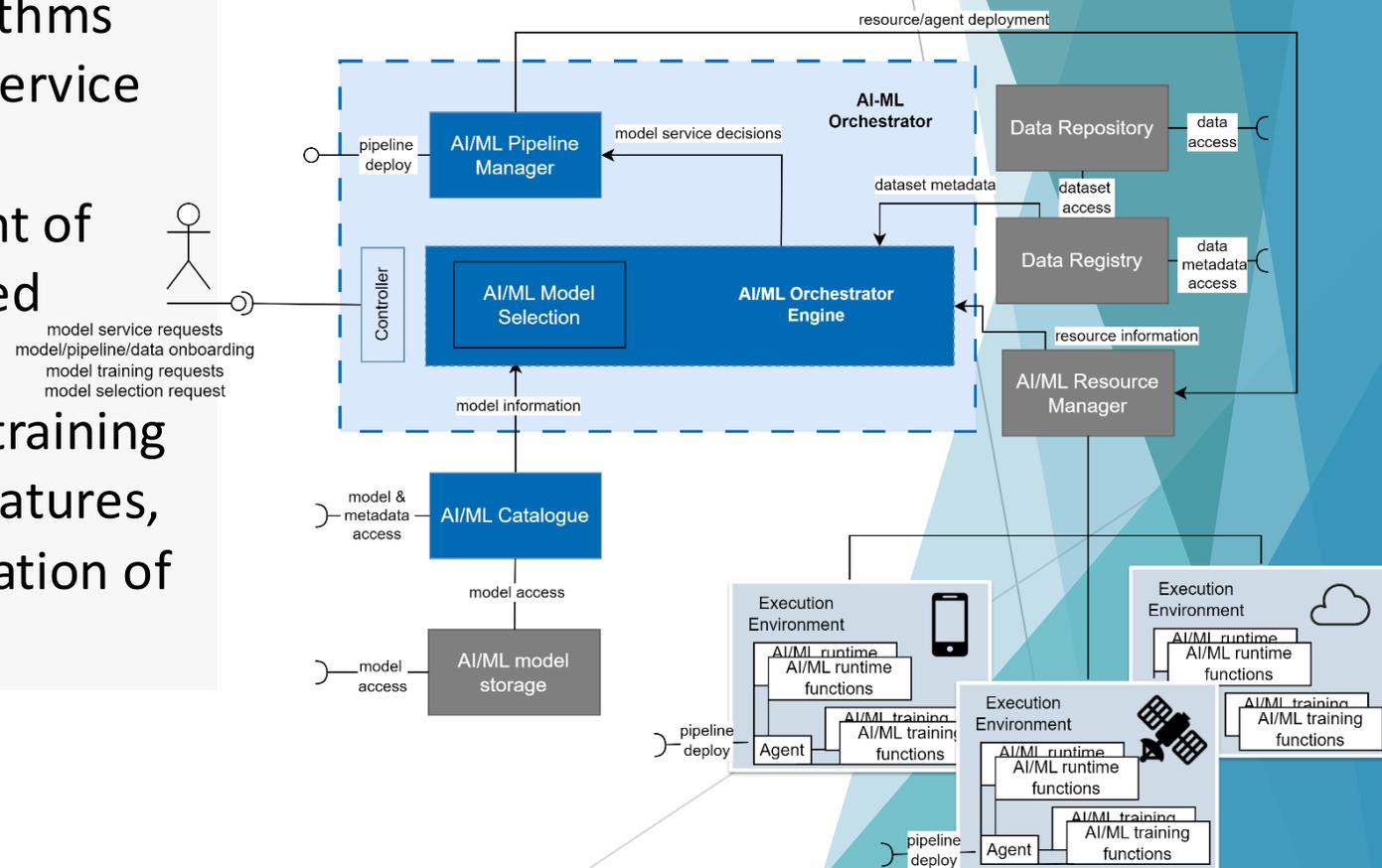
- **AI/ML-powered Optimisations:**
 - Harnessing Distributed Artificial Intelligence.
 - Aim for high performance and full automation.
- **Cloud-native Network Software:**
 - Implementation across various edge-cloud platforms.
 - Integral security in the network user plan.
- **Software-driven Operations:**
 - Zero-touch operations.
 - Full automation for network and delivered services.





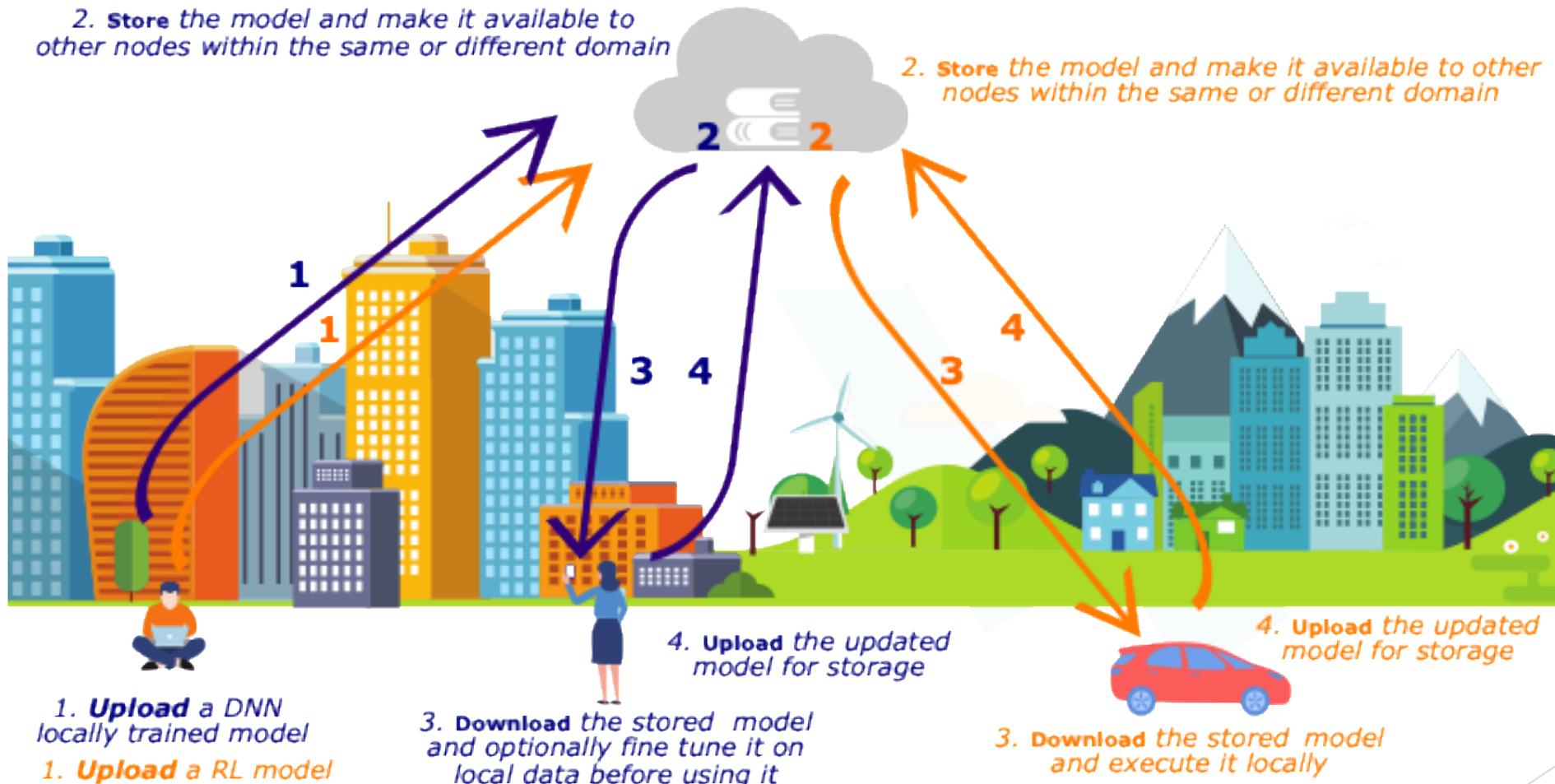


- **AI/ML Orchestrator Engine:** determines the orchestration approach for each requested AI/ML task.
- **AI/ML Model Selection:** contains the algorithms and methods of model selection based on service and resource requirements.
- **Pipeline Manager:** manages the deployment of training and runtime AI/ML functions defined through pipelines.
- **AI/ML Catalogue:** contains information on training runs, data used, training results, model signatures, model specific execution environments, location of saved model versions.



2. Store the model and make it available to other nodes within the same or different domain

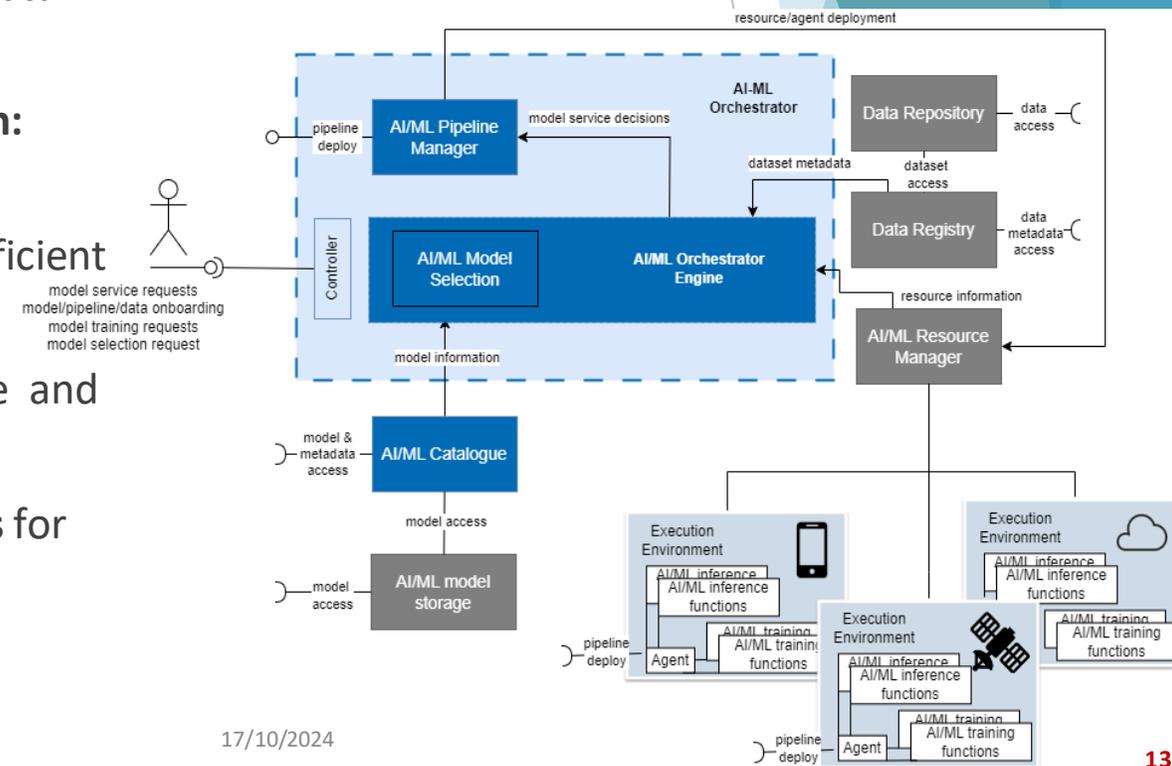
2. Store the model and make it available to other nodes within the same or different domain



► **CrowdSourcing AI: Sharing and reuse of knowledge (already trained models) within the system**

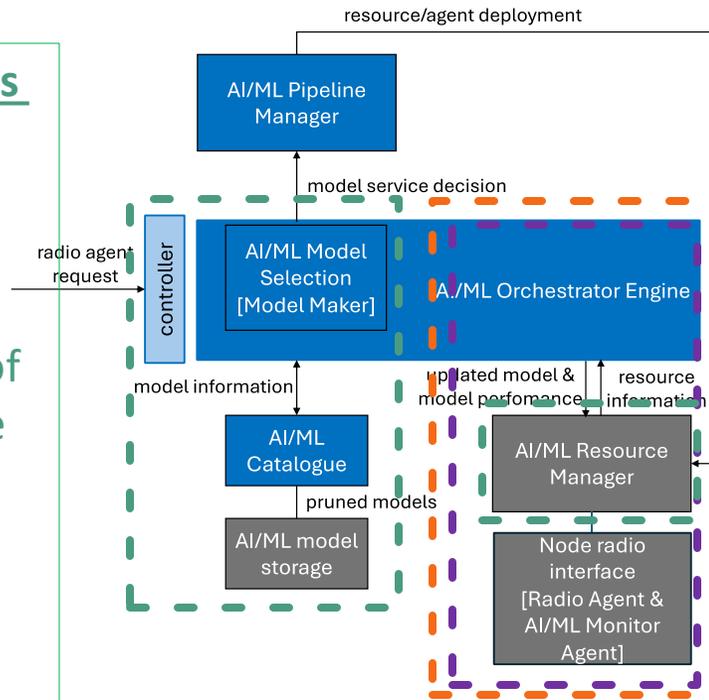
► **Note: FL implements distributed training, but not model sharing or knowledge reuse**

- ▶ CrowdSourcing AI: Algorithms and Reference Architecture for knowledge sharing and reuse
- ▶ Major Innovations towards an efficient and effective ML pipeline:
 - **Deployment and migration** of VNFs (implementing ML models) across system nodes and domains
 - **Input Data:** New models for the generation of multi-modal data: (i) in the presence of data loss and (ii) for bandwidth savings
 - **ML model selection, creation, configuration, and adaptation:** Meta-learning and transfer learning-based techniques
 - **Training:** Dependable and fair distributed training, energy-efficient & scalable model training
 - **Inference:** cooperative energy-efficient **inference** at the edge and task offloading
 - **Resource usage:** Design of efficient **mobile nodes topologies** for the implementation of distributed learning; Robust RL-based algorithms for joint communication/computation resource management



Optimal D2D topologies

Deep GNN-based optimisation service to enhance the use of CrowdSourcing AI. Collective intelligence of the network to improve spectral efficiency and power consumption by optimising network structures under base stations.

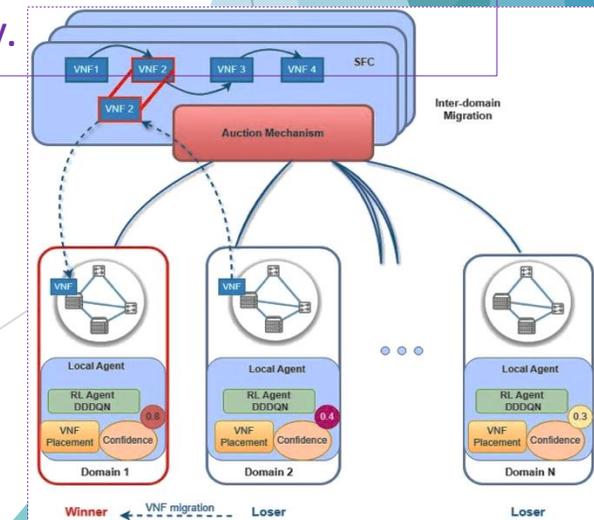


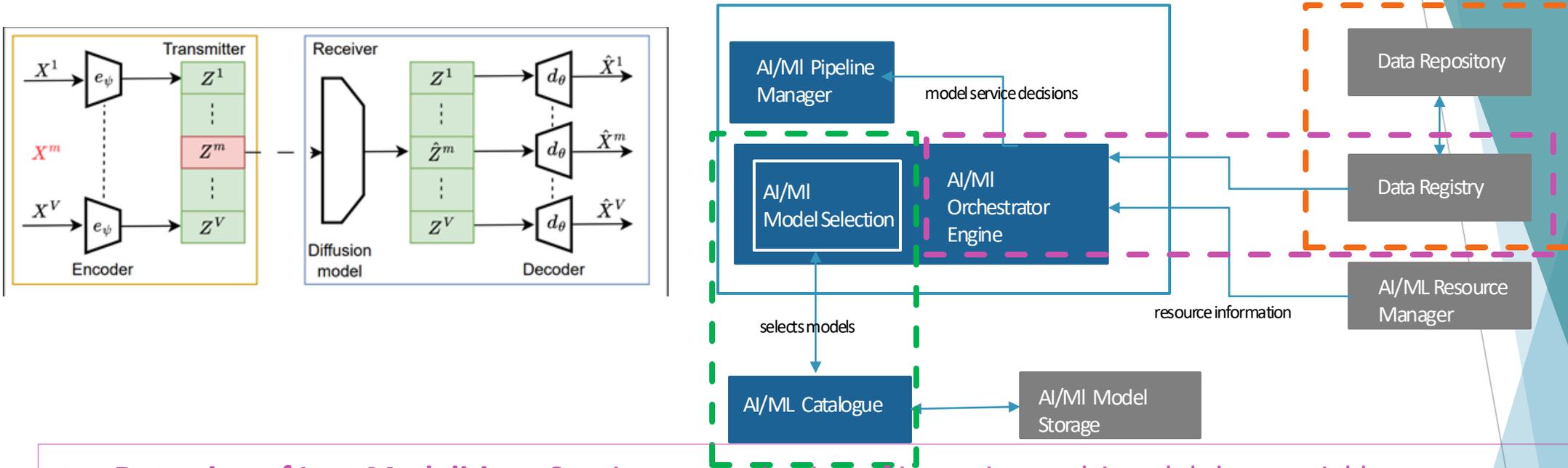
Migration of ML models is implemented as VNFs, whenever such models are implemented as stateful micro services.

Inter-domain Migration

Local RL Agent Dueling Double DQN (DDDQN) is used to design the Predictors for VNF Migration.

Inter-domain VNF placement strategy: distributed RL agents in different domains generate an action based on their DDDQN assessment and bid with their confidence to host the VNF in their domain. An Auction Mechanism aggregates the confidence metrics from all agents, **selecting the action with the highest collective confidence**, ensuring that the final decision reflects a consensus among agents, considering diverse perspectives and leading to a more robust VNF placement strategy.

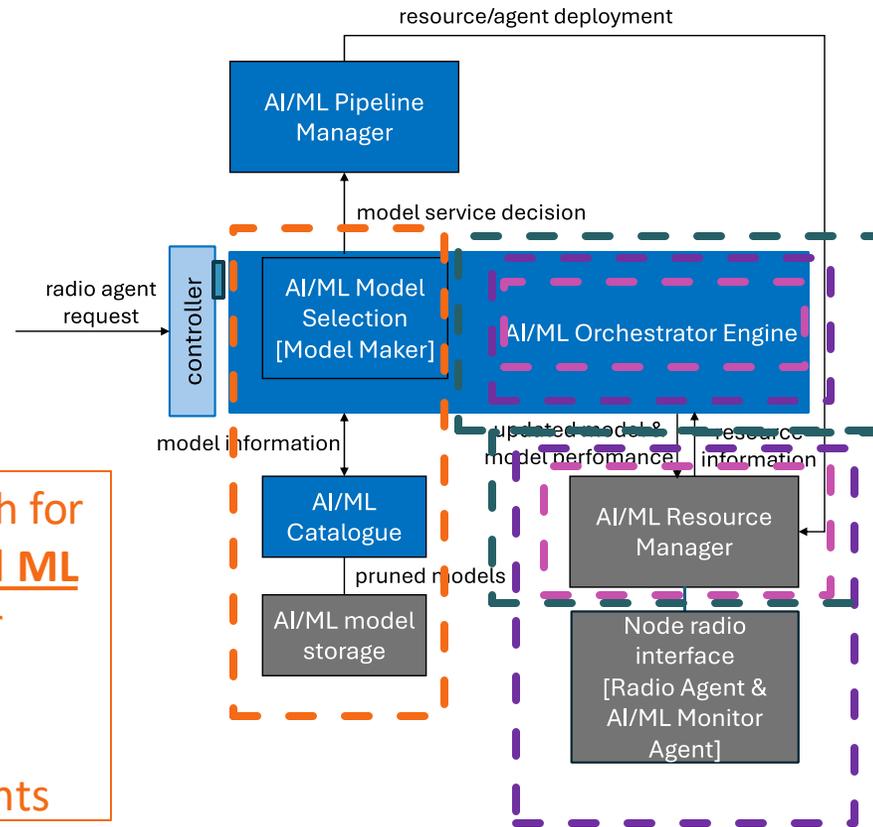
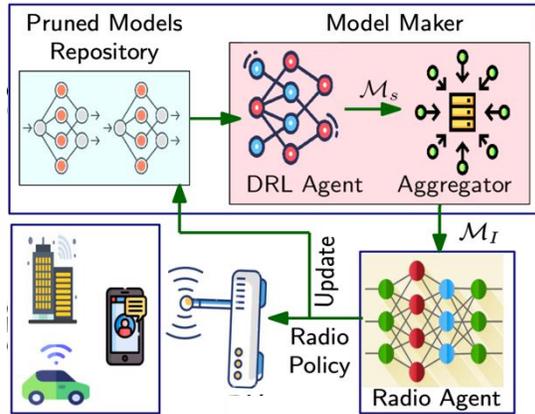




► **Detection of Lost Modalities:** Continuous monitoring of incoming multimodal data, quickly identifying instances where certain modalities are missing or compromised.

► **Cross-generation with Generative Models:** Upon loss detection, the system activates its generative models. These models generate synthetic data that closely mimics the original characteristics of the lost modalities.

► **Integration of Synthetic Data:** The generated synthetic data is integrated, replacing the missing or corrupted modalities. This allows AI/ML models or any end-user application to proceed with their analyses as if no data loss had occurred.



Dependable and fair distributed training strategies to (i) minimize learning time (proxy for cost), or/and (ii) reduce resource consumption while meeting requirements on loss

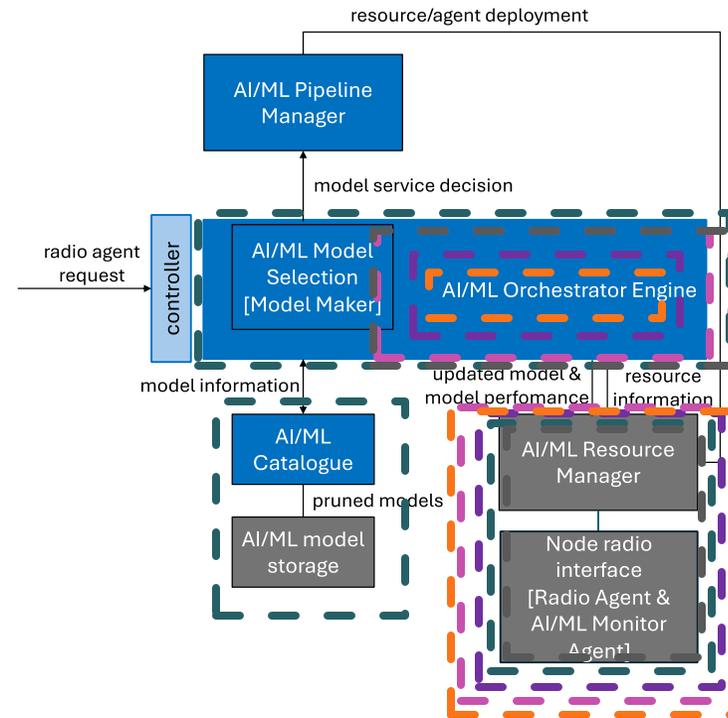
Meta-learning, distributed approach for ML model selection, Crowdsourced ML model creation, and adaptation for
 1) matching nodes' computing capabilities and
 2) meet time & accuracy requirements

2-step Transfer learning: clusters of similar (in traffic distribution or geo proximity) gNBs coordinated by an edge server for hyperparameter optimisation during training (FL)

Edge server-end devices cooperate for energy-efficient inference: determining best cooperation strategy, accounting for data privacy and energy availability, as well as the possibility to compress the ML model to reduce energy impact

Traffic and **energy-efficient BDIx** agent configurations: generation of an XML policy file that will train an ANFIS model for plan library Desires conversion to Intentions using priority values. DAIS (Distributed Artificial Intelligent Solution) for the forming of D2D communication network under Base Station.

Stochastic **quantization** for **energy-efficient** decentralized learning: to reduce the size of transmitted models using **quantization** leading to **energy savings** while maintaining **fast convergence** and **preserving privacy**.

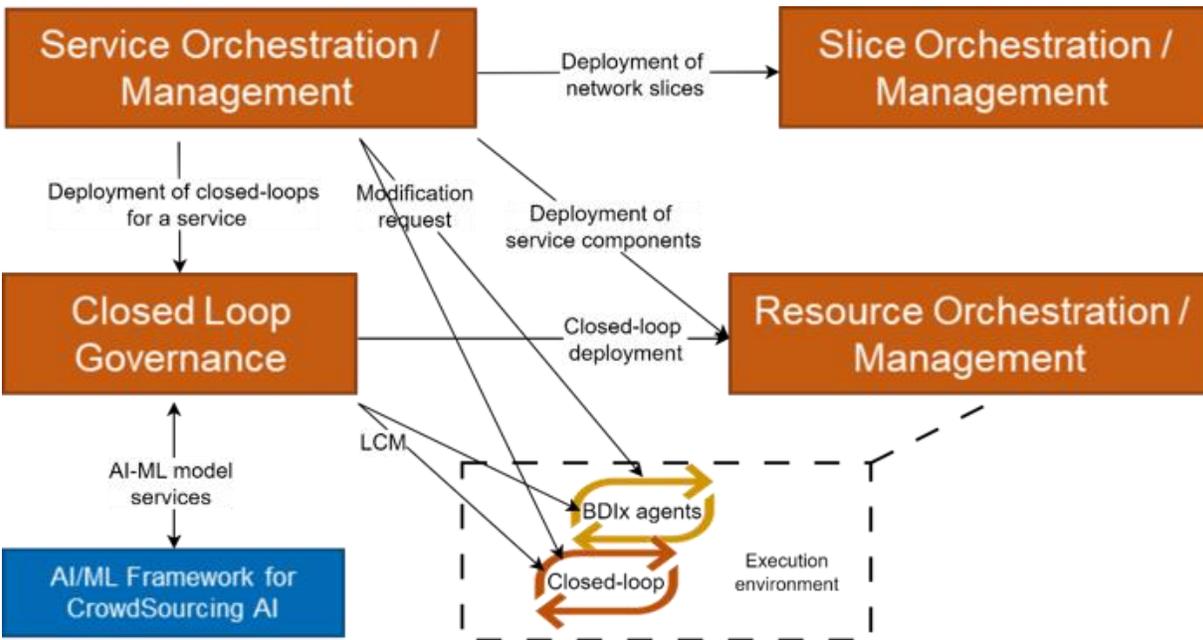


A **scalable and energy-efficient FL algorithm**: a lightweight Hessian estimation and adaptive step sizes to **improve convergence speed** and **reduce communication overhead** in distributed networks.

Scheduling and Offloading Techniques Across Multiple Domains: a Lyapunov-based reinforcement binary **offloading strategy** to perform computation tasks with non-partitionable datasets. The proposed solution could be duly optimised for either **data rate** or **energy-efficient solution**

Development of robust algorithms for Joint Resource Management: a **multi-objective Reinforcement Learning (MORL)** agent is employed to jointly allocate communication and computational resources with low computational complexity, optimizing multiple contradictory objectives simultaneously. The MORL agent improves consistency and reduces the number of required agents, neural networks, and training processes.

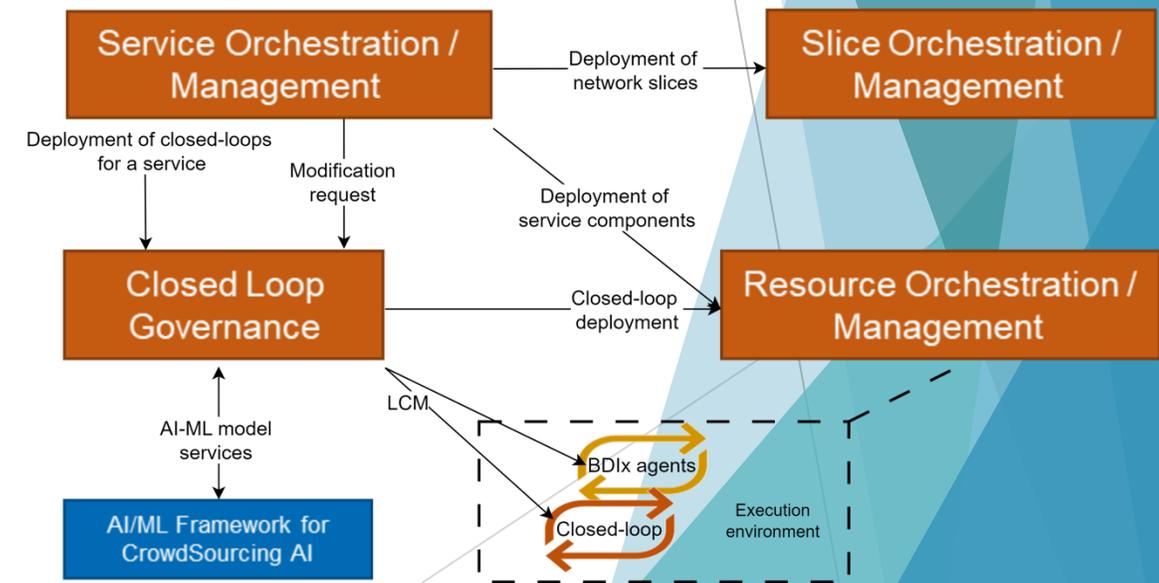
- **Closed-loop governance:** innovative modules for the interaction with the Crowdsourcing AI or model automation. Extends the concepts in ETSI GS ZSM 009-2 for deploying and overseeing a diverse range of closed-loops. It also handles function splitting, resource allocation, migration, and scaling actions of closed-loop functions.

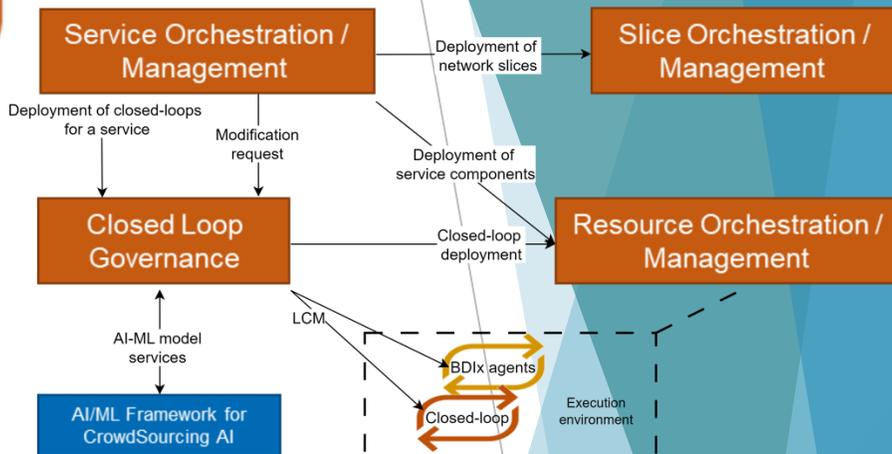
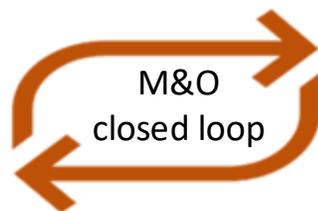
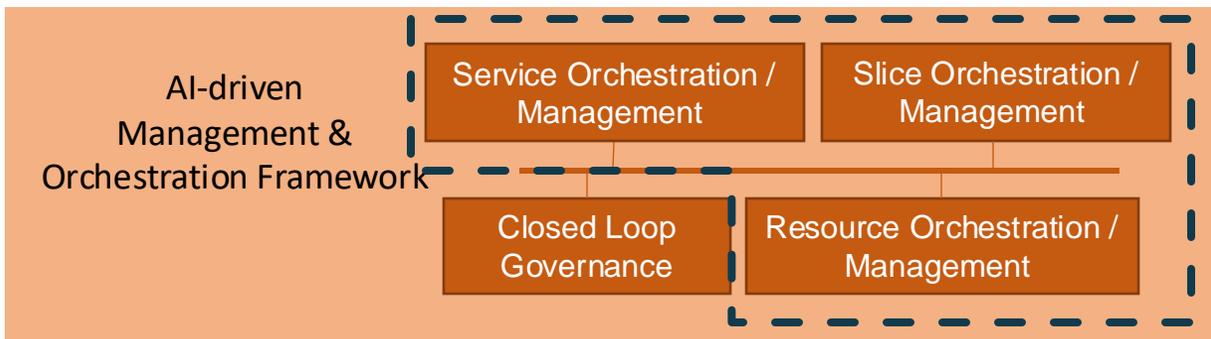


- **Slice & Resource Orchestration and Management:** Learning rate FL policy that manages and orchestrates heterogenous network slice-related computing resources deployed in the ADROIT6G physical infrastructure.

- **Service Orchestration and Management:** lifecycle management of vertical services, including orchestration of components communication services and network slices (3GPP TR 28.801).

- ▶ AI-driven Management and Orchestration & AI-driven control operations development
 - ▶ **Fruition of the User Equipment as Virtual Base Station (UE-VBS) concept,**
 - ▶ Support for creating **E2E services involving AI-enabled zero-touch mechanisms**, utilizing NTN compute resources, and utilizing UE-VBS in distributed environments,
 - ▶ **Algorithms and mechanisms to optimize resource utilization and service quality** in both the management and orchestration and real-time control levels,
 - ▶ **Distributed Beliefs – Desires - Intention extended (BDIx) framework development** for use in UE-VBS
- ▶ Programmability and reconfigurability of the network
 - ▶ **Programming Protocol-Independent Packet Processors** development for traffic isolation,
 - ▶ **Satellite Communication and Computing framework emulation for global, distributed, and dynamic NTN networks**





Service Orchestration/Management

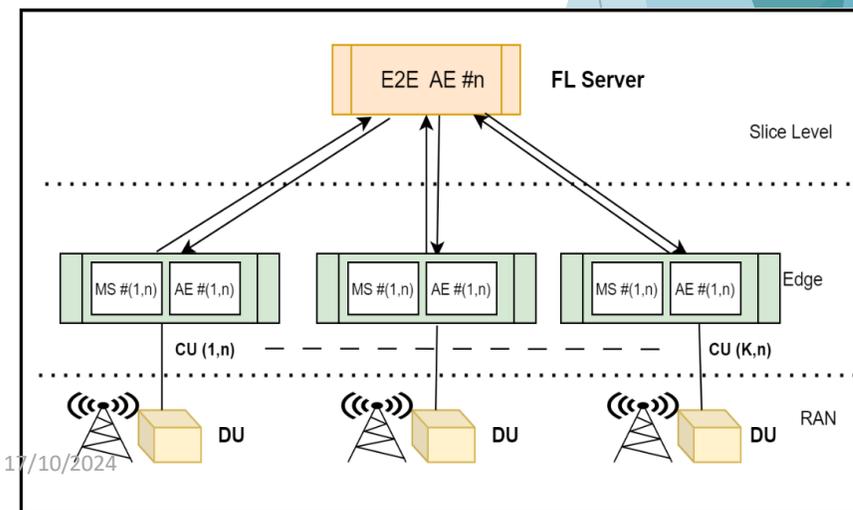
Support deploying multi-domain E2E services including:

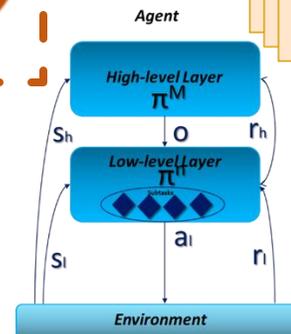
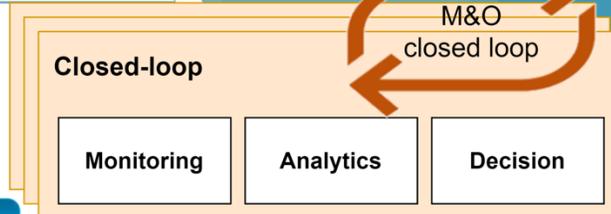
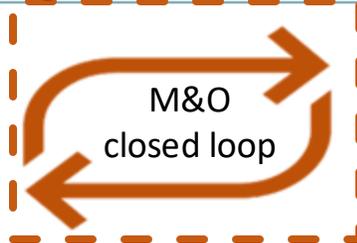
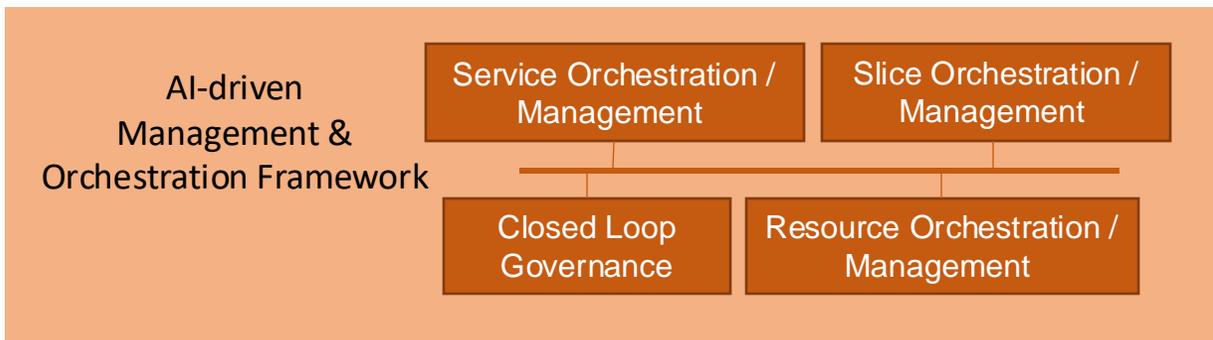
- NTN communication and satellite compute resources
- UE-VBS and BDIx networking, storage and computing resources
- Closed-loop functions for zero-touch management



SLA-driven FL solution for 6G zero touch network slice management

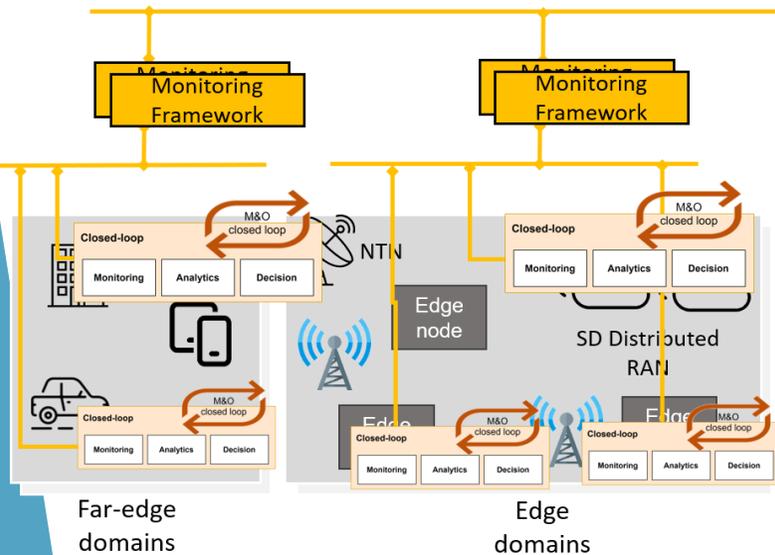
- Managing and orchestrating heterogenous network slice-related computing resources deployed in the RAN-Edge domain
- Addresses monitoring scattered data across the network while reducing the computational costs and enabling fast local analysis and decision
- Implemented a cloud-native FL environment





Monitoring functions for distributed data collection

- Collaborative and distributed instances for metric acquisition
- Programmable data distribution and sharing among instances according to the data requirements

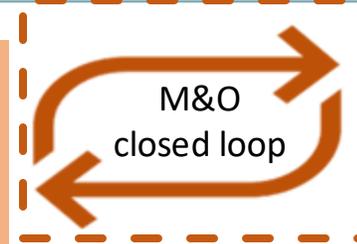
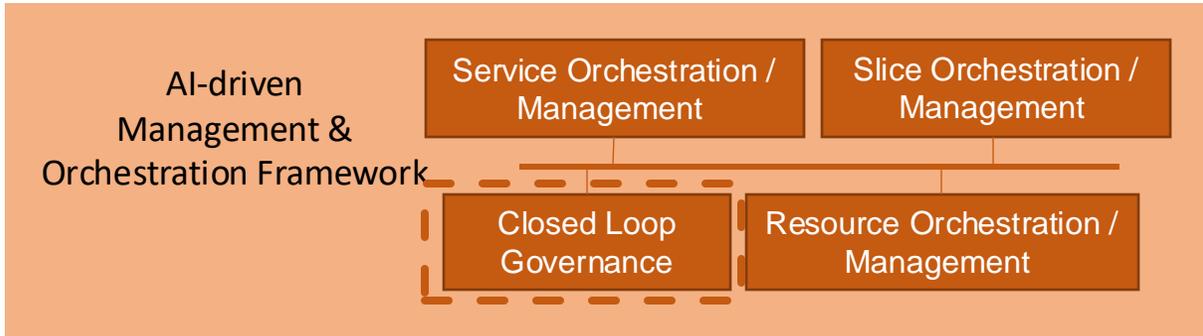


Decision Engine framework

- Integrates Hierarchical Reinforcement Learning (HRL) and Incorporates a multi-task Soft Actor-Critic (SAC) for high-level strategic decisions and advanced Deep Q-Network architectures for precise low-level actions

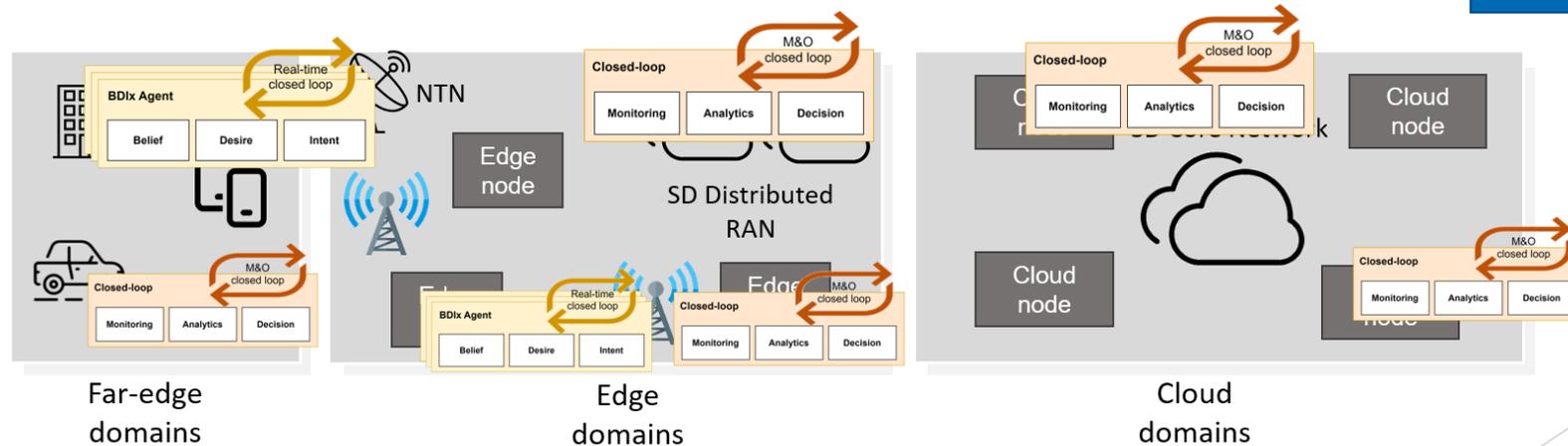
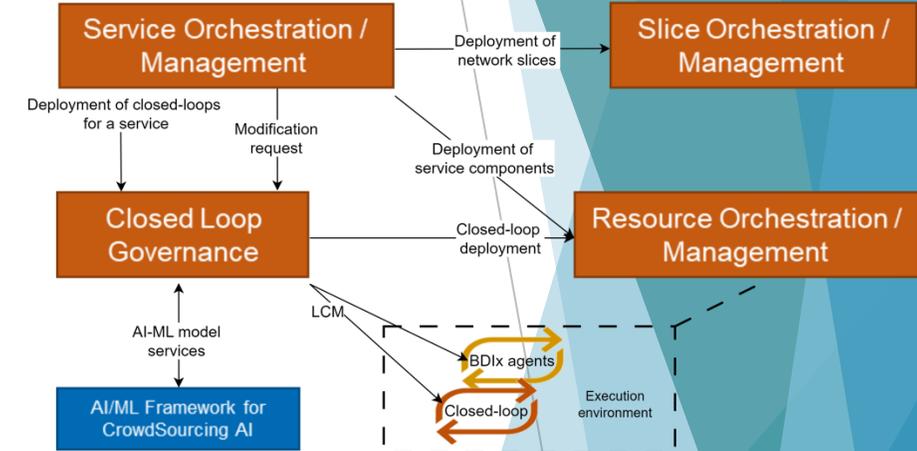
Algorithms for predictive monitoring and SLA offering

- Predictive monitoring of data on the cloud for the behavior and performance of the applications
- Neural network-based regressions to predict possible SLA violations for minimizing convergence time and the actual SLA violation rates.

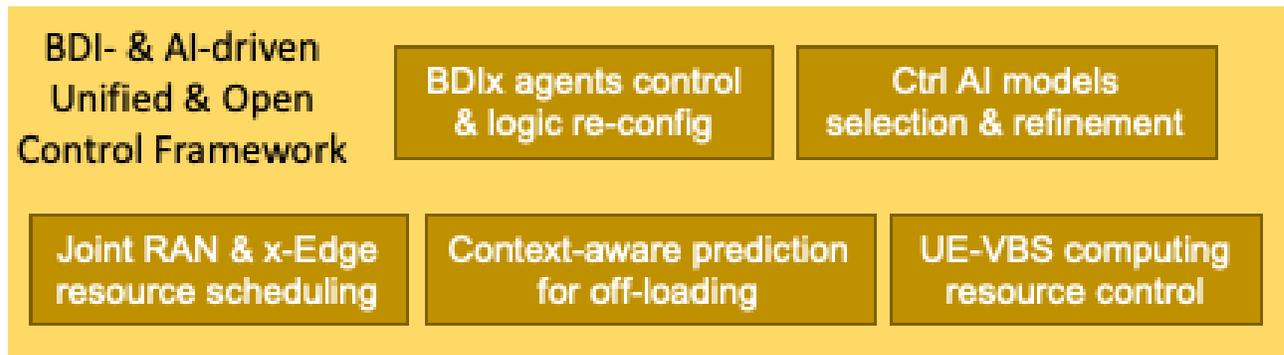


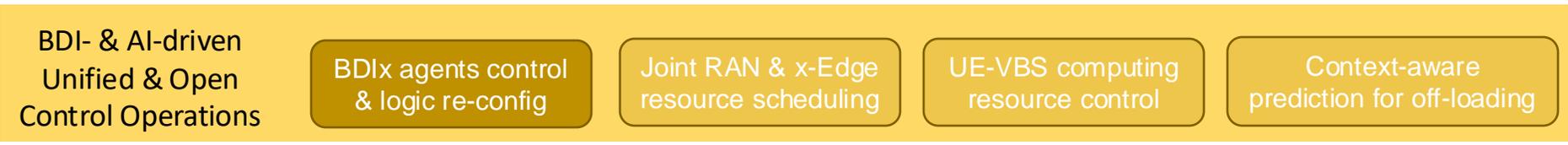
Closed-loop Governance

- Interaction with the ADROIT6G CrowdSourcing AI framework for full model automation for AI-based closed-loop functions
- Closed-loop Governance extends the concepts in ETSI GS ZSM 009-2 for deploying and overseeing BDix closed-loops in zero-touch automation



- Manages real-time and near-real time loops for network automation.
- Allocates resources dynamically based on current conditions and predictions.
- Handles resource congestion, scheduling, computation off-loading, and VM/content allocation.
- Oversees the BDIx agents, their re-configuration, and UE as Virtual Base Station (UE-VBS) resources.

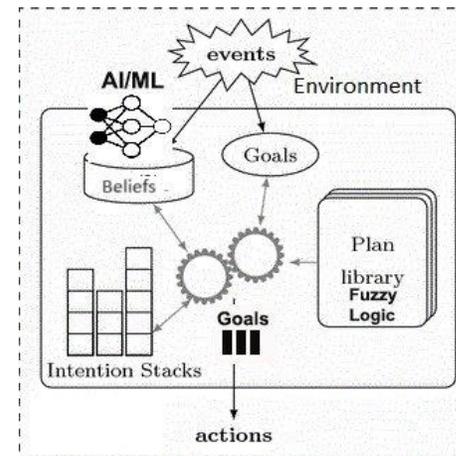
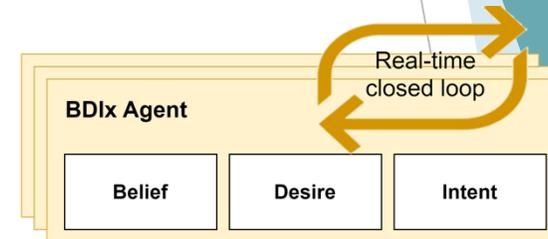




BDIx agents

Located on Mobile Devices alongside the UE-VBS computing resource control

- Control the UE device in terms of networking and collaborates with UE-VBS in terms of resource handling.
- Create a decentralized and intelligent RAN infrastructure
- Optimize transmission by selecting the Transmission Mode (D2D-Relay, D2D-Multihop Relay, D2D-Client) in D2D communication
- Built in the DAI framework - operate autonomously or in collaboration, sharing knowledge, data, and goals to achieve complex tasks
- AI-driven Plan Library - Adaptive Neuro-Fuzzy Inference System for priority of desires (optimization algorithm)



BDI- & AI-driven Unified & Open Control Operations

BDIx agents control & logic re-config

Joint RAN & x-Edge resource scheduling

UE-VBS computing resource control

Context-aware prediction for off-loading

Real-time closed loop

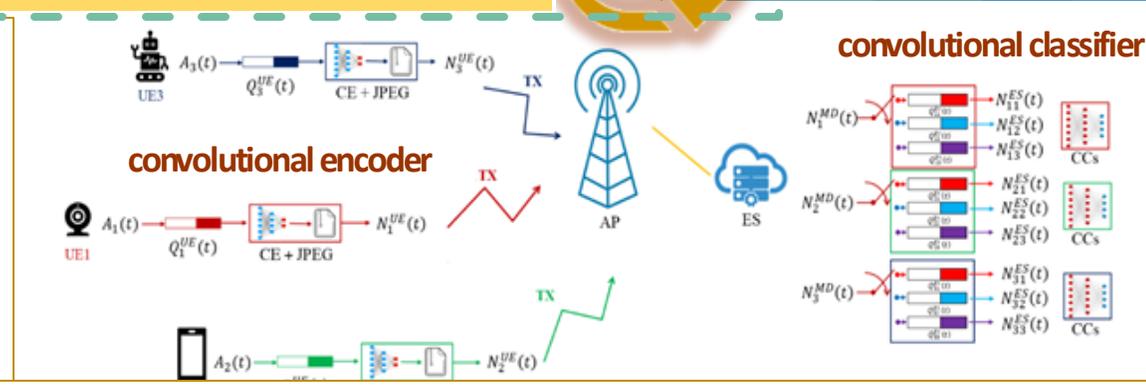


Federated Learning and Deep Feedback Neural Networks in the DAI Framework for Autonomous Radio Resource Management in D2D Communications

- Determine optimal overlay frequency band selection and feedback of a newly joining D2D device based on current network state and device information

Energy-Efficient Edge Resource Management in Multi-User Goal Oriented Communication

- Optimization in a split of the deep neural network to be used inference task between transmitter and receiver
- Selection of best **CE-CC** pair based on energy consumption, latency delay, classification accuracy

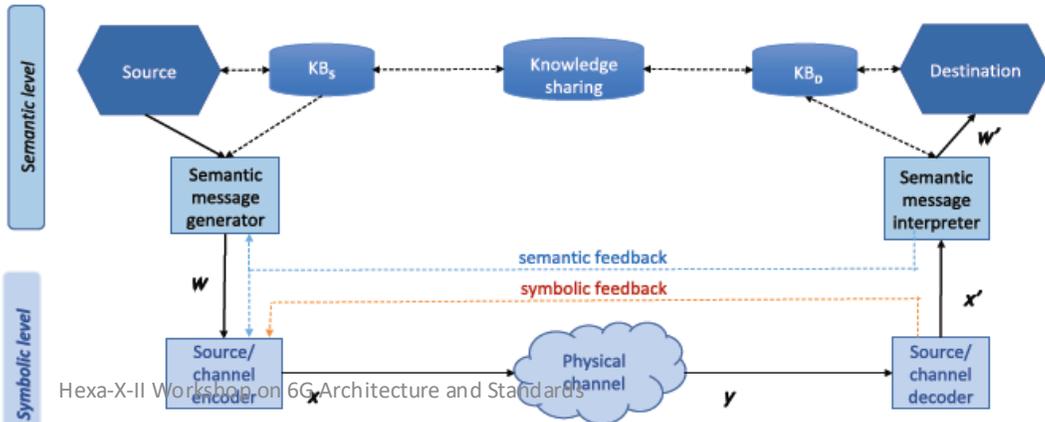


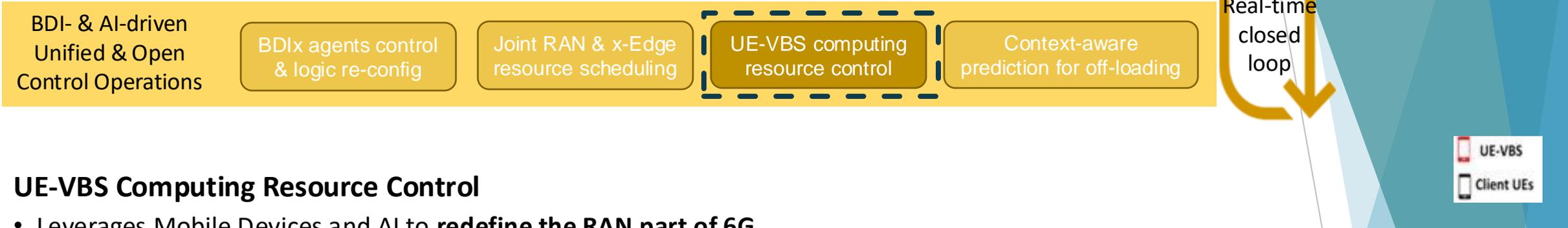
Semantic Communications Based on Adaptive Generative Models and Information Bottleneck

- Focuses on what is being transmitted instead of how – the receiver can recreate a message semantically equivalent to the transmitted one exploiting generative models
- Introduces degrees of freedom to encoding/decoding rules to improve efficiency

Information-theoretic analysis of multi-modal sources and adaptive off-loading

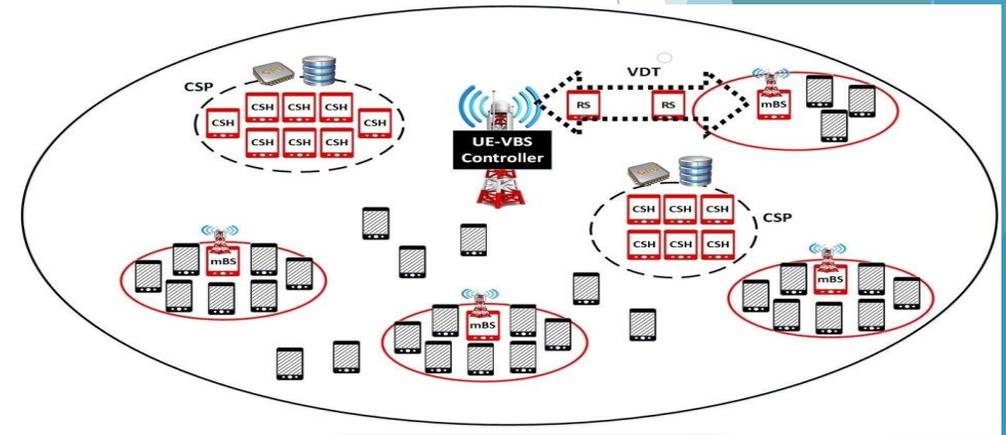
- In support of models capable of learning joint representations from multi-input data sources especially in environments where multi-modal sensor data collection may be unreliable
- Applied to intelligently modulate the amount of data transmitted by an intelligent decomposition into redundant and non-redundant information sources

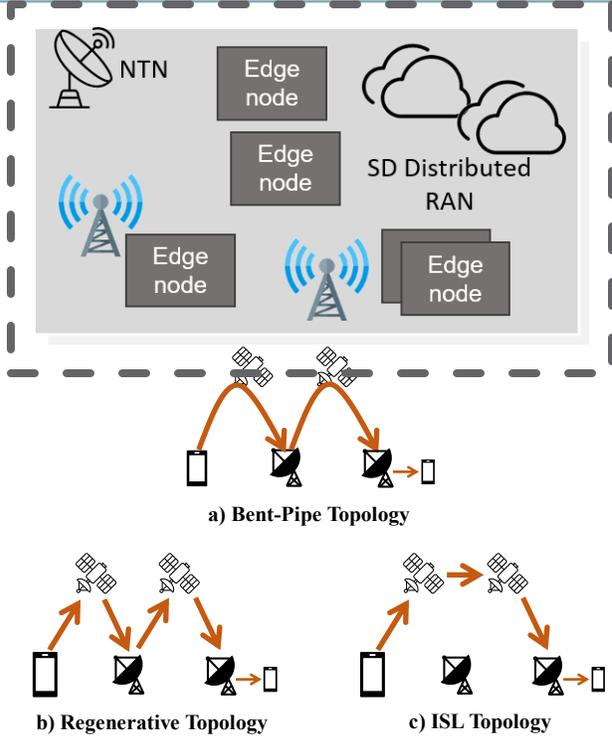




UE-VBS Computing Resource Control

- Leverages Mobile Devices and AI to **redefine the RAN part of 6G** networks: Represents a major advancement in the evolution of decentralized AI-based cellular networking
- **Augments the network's cellular infrastructure and establishes a unified storage and computational** framework within the mobile network, enabling the execution of demanding tasks at the far edge
- As more Mobile Devices join the network, its networking, storage, and computational capabilities increase, forming in this manner an intelligent “open-resource” cellular infrastructure





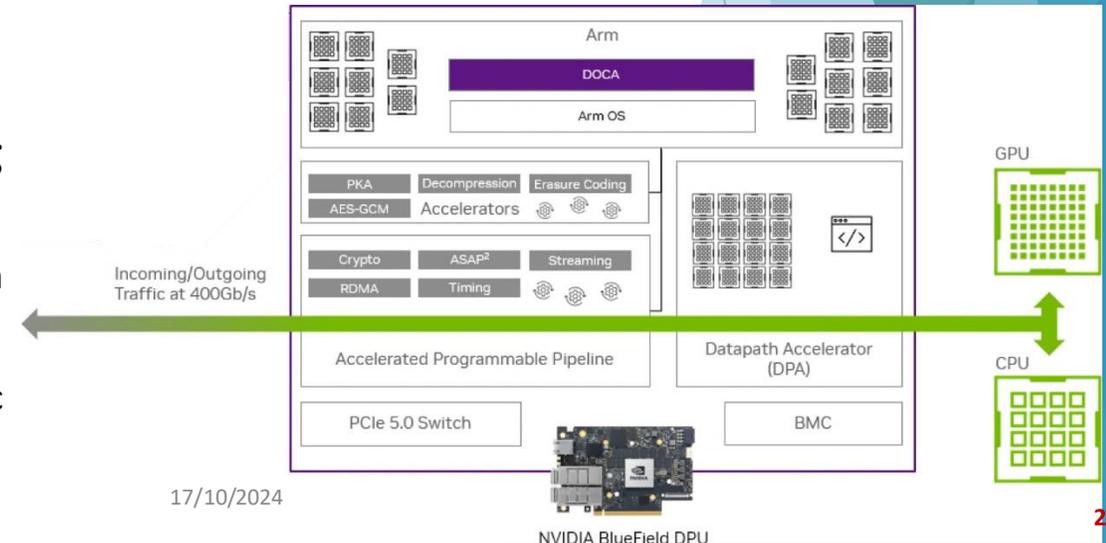
Satellite communication and computing framework emulation

Realistic network emulation for global, distributed, and dynamic NTN networks to be instantiated, e.g. satellites, ground stations, and devices, including link handover

- Different orbits (i.e., LEO, MEO, and GEO) & different satellite topologies (i.e., bent-pipe topology, regenerative topology, and ISL-based)
- Computing and storage resources as part of the satellite payloads
- Provides a Digital Twin of the Satellite strata
- Exposes APIs that allows applications/devices to have more control of its user plane, either by actively trigger its reconfiguration or by getting network-related monitoring

Unified Programmable Data Plane and Traffic Isolation by using Programming Protocol-Independent Packet Processors (P4)

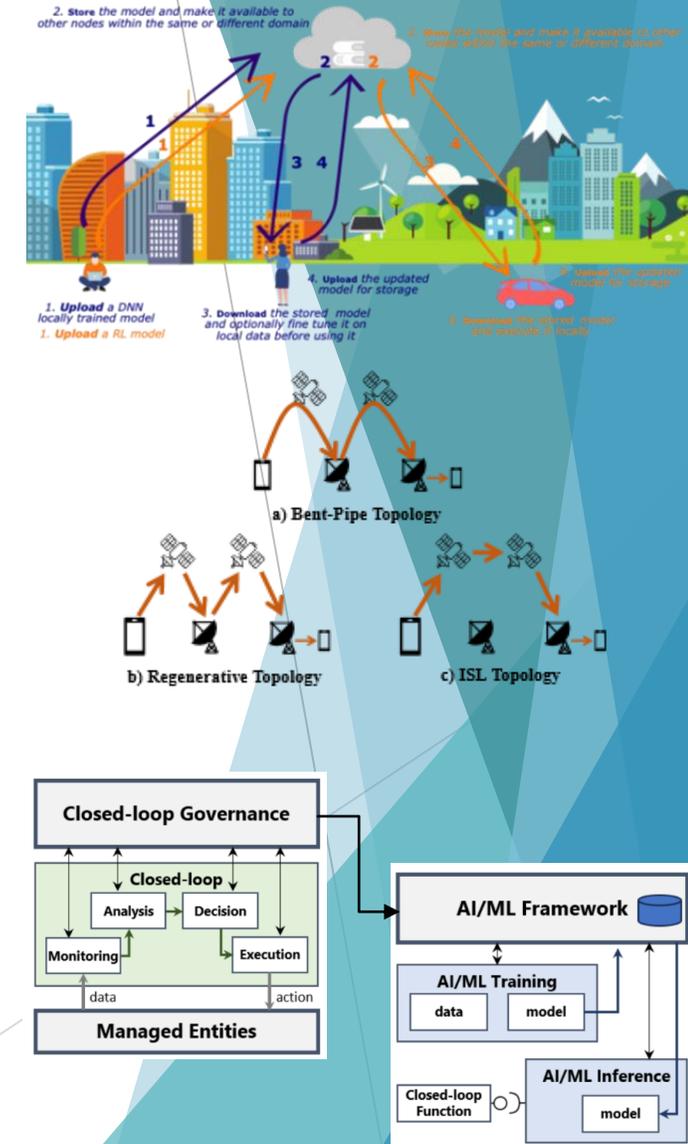
- Creates an end-to-end (from the switch to the DPU), universally controlled data plane to achieve and support the data plane acceleration
- Traffic isolation: having pipelines that can adapt to the different types of traffic dynamically and isolate the traffic (different traffic on different pipelines)



HEXA-X-II



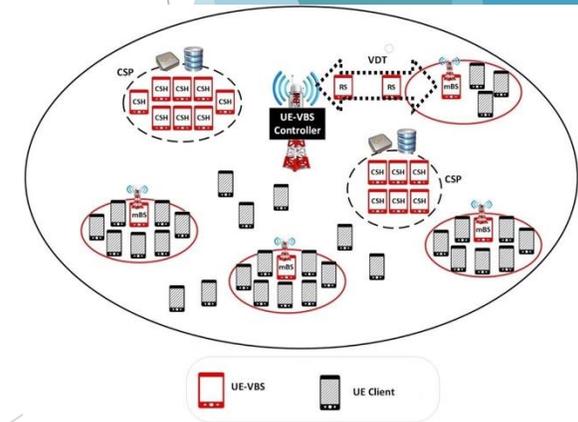
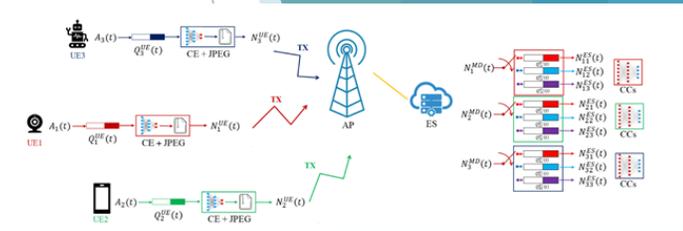
MLOps/AIaaS	Crowdsourcing AI/ML platform
<ul style="list-style-type: none"> Streamline of the entire life cycle of ML models during development, automating deployment through pipelines Providing accessible AI capabilities through a variety of APIs, eliminating the need for application developers to build and manage their AI infrastructure Sharing and reuse of knowledge (already trained models) within the system 	
<ul style="list-style-type: none"> Possible Collaboration: In defining common APIs, AI/ML service models, data models, to expose AI/ML capabilities 	
Network of networks - NTN	Satellite communication and computing framework emulation / Service Manager
<ul style="list-style-type: none"> Incorporation of NTN into multi-domain E2E services to create a seamless and ubiquitous communication system Possible Collaboration: In defining common APIs to expose service capabilities both at the service level and NTN M&O 	
Real-time zero-touch control loop automation and coordination system	Distributed closed-loop automation for AI-driven Management and Orchestration
<ul style="list-style-type: none"> Continuous monitoring of the network metrics and services' performance so the M&O system can automatically identify, detect or predict potential issues, failures, bottlenecks, or inefficient configurations, to trigger and coordinate dynamic reactions Interaction with the Crowdsourcing AI/ML Platform allows for integration of AI/ML models into AI-enabled closed-loop functions 	
<ul style="list-style-type: none"> Possible Collaboration: In defining a common approach (deployment models, workflows, interfaces) for the incorporation of AI-services and AI-functions in support of the AI-enabled closed-loops 	





Compute offloading	Offloading Techniques Across Multiple Domains
<ul style="list-style-type: none"> Techniques and algorithms to determine optimal computation offloading from one device to another with more suitable capabilities Techniques and algorithms for the optimization in a split of the deep neural network to be used for the inference task between transmitter(UEs) and receiver(Edge/Cloud) 	
<ul style="list-style-type: none"> Possible Collaboration: In the validation of solutions in broad use cases 	

Network of networks - Subnetworks architecture / Collaborative edge computing	User Equipment as Virtual Base Station (UE-VBS)
<ul style="list-style-type: none"> Leverages Mobile Devices to redefine the RAN part of 6G networks: evolution to a decentralized AI-based cellular networking Augments the network's cellular infrastructure and establishes a unified storage and computational framework within the mobile network, enabling the execution of demanding tasks at the far edge 	
<ul style="list-style-type: none"> Possible Collaboration: In defining common APIs to expose service capabilities 	



Using the collaboration on the definition of common APIs, data and service models for the Crowdsourcing AI/ML platform ADROIT6G can leverage the strong presence of Hexa-X-II in the standardization bodies

- Support/help in the identification and selection of relevant bodies for contributions
 - E.g. ETSI ISGs, 3GPP
- Support/help proposing/pushing contributions



Immersive XR - Holographic Teaching Extreme eMBB

A teacher provides the lecture at home/office, while the students attending physically the class, can watch the teacher's holographic entity delivering the lesson



Collaborative robots (cobots) in construction Extreme URLLC & Extreme mMTC

Robots and drones that need to coordinate actions with each other in a construction site. Coordination will be conducted in three dimensions, to avoid collision and enable collaboration of robots in the air (drones).



Terrestrial 6G IIoT Extreme mMTC

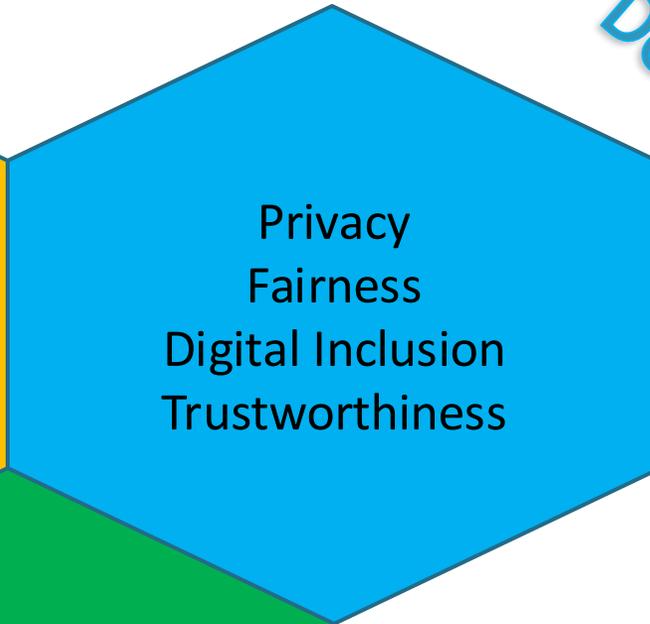
In a production line of an **automotive manufacturing process** sensors and actuators (i.e., IIoT devices) communicate with each other, and taking actions in **sub-millisecond time intervals**, within a confined area, executing different robotic functionalities.



NTN for low-bitrate IIoT Extreme mMTC

Trackside IIoT devices and **on-train terminals**, that send data to a remote cloud. Edge Cloud components on the devices, in satellites and in the remote data centre pre-process and route data and perform control depending on the application logic and in case of issues in the communication path.

Innovation



Democracy



Ecosystem

▶ Contributions to the ETSI ENI WG

- ▶ Crowdsourcing AI solution to minimize AI/ML carbon footprint and enable efficient AI/ML training and inference in distributed systems.

▶ Contributions to the ETSI ZSM and ETSI MEC WG

- ▶ Distributed closed loop automation in AI-driven Management & Orchestration frameworks for multi-stakeholder ecosystems.

▶ Contributions of the UE-VBS Computing Continuum concept to 3GPP SA1 group

- ▶ Consider standardization of BDI Agents for Self-Organizing UE-VBS.

▶ Contribution to the 3GPP SA2 group

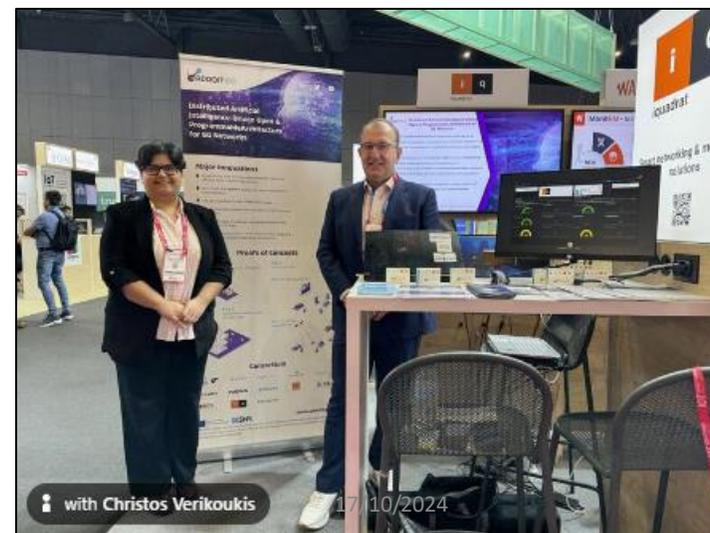
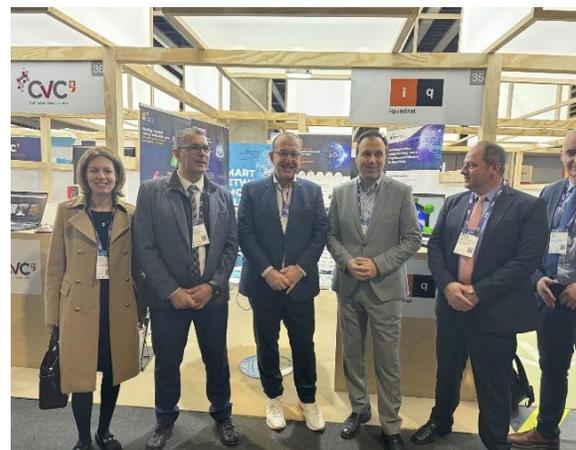
- ▶ Consider contribution of the NTN / 6G integration solution from Terrestrial 6G IIoT PoC.

Dissemination

- 10 peer reviewed journal publication
- 10 conference papers
- 1 organised Special Session/Workshop
- 1 open-source code repository
- 11 participations in Exhibitions
- 1 organised Summer School

Communication

- Project website
- 3 released e-Newsletters
- 5 Press-releases
- 2 Project flyers
- 1 Promotional videoclip
- 1 Demo video
- 2 interviews
- 5 Public talks
- 2 Rollup Banners





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Thank You!!!



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