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Hexa-X-II D2.3 Deliverable

# D2.3 summary slides: Interim overall 6G system design

Hexa-X-II

[hexa-x-ii.eu](http://hexa-x-ii.eu)

2024-06-30



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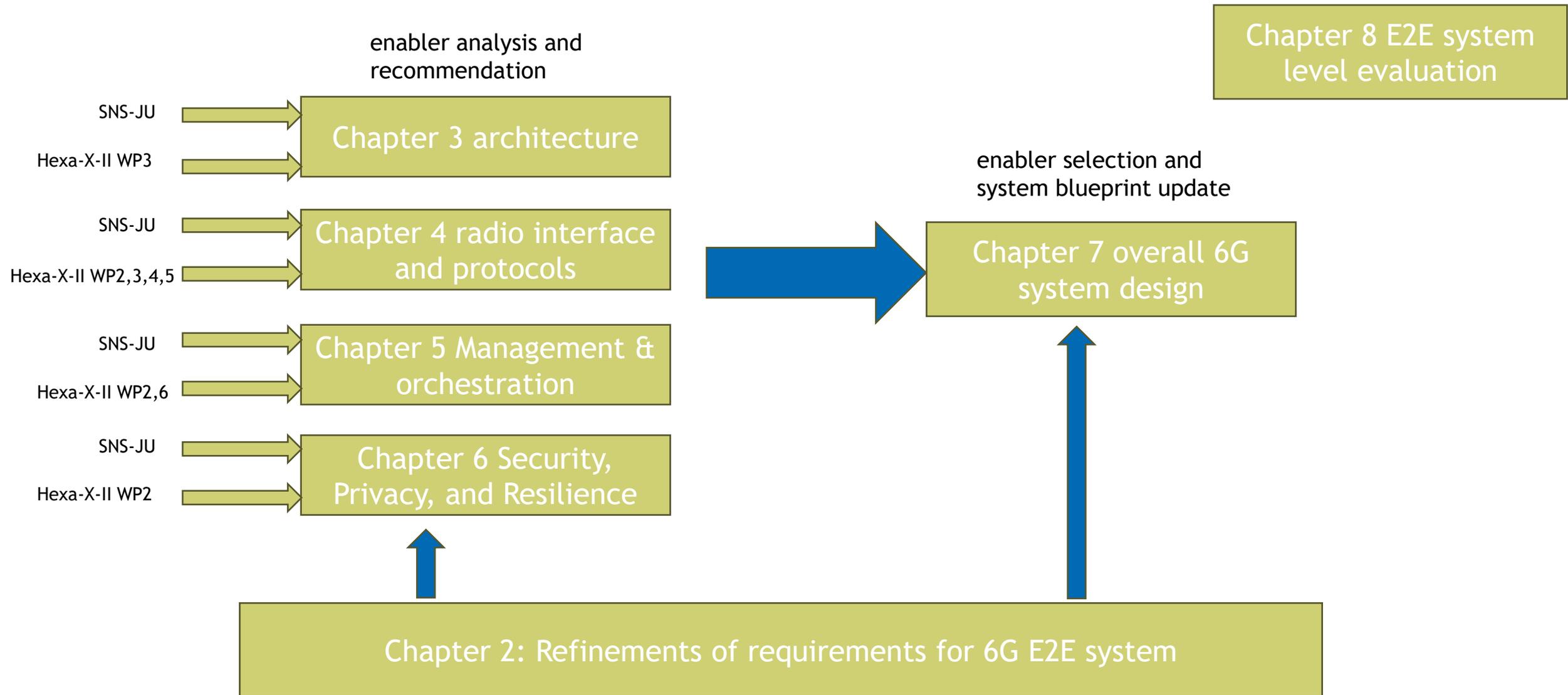
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# Deliverable structure





# Chapter 2

## Refinements of requirements for 6G E2E system

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# 6G system requirements refinement (from [HEX223-D22])

## Functional requirements refinements from requirements in D2.2

- **Use case related**
  - Data synchronization
  - Immersive mapping as a service
  - Affordability
  - Improved human-machine interaction
  - Interoperability
- **Operational**
  - Object recognition and tracking
  - AI/ML training and inferencing complexity and model generalization capability
  - Scalability
  - Transport
  - Security
  - Environmental, social, economic KV requirements

## Technical requirements grouping per use cases

- **Seamless Immersive Reality**
  - bitrates <250 Mbps both uplink and downlink
  - guaranteed E2E latency <10 ms
  - accurate positioning of the devices
- **Cooperating mobile robots**
  - bitrates <10 Mbps
  - E2E latencies <0.8 ms)
  - high service reliability (5-7 nines) and similar positioning accuracy
- **Network assisted mobility**
  - bitrates <10 Mbps
  - guaranteed E2E latencies <20 ms
  - guaranteed coverage >99.9%
  - service availability 99.99% within the service space, working at high speeds and supporting seamless handovers
- **Real-time digital twin**
  - bitrates >100 Mbps
  - guaranteed E2E latency ~1 ms
  - very high service reliability (7 nines) and coverage (4 nines)
  - high local connection densities (<10 /m<sup>2</sup> indoor)
- **Ubiquitous Network**
  - service area to >99% of Earth's surface
  - Bitrate <25 Mbps
  - E2E latency 10-100 ms
- **Transmission jitter/packet delay variations**
  - ranges from 100 μs to 100 ms for prospective use cases from other SNS JU projects
- **Human-centric services**
  - sets extreme requirements on the security, privacy, and reliability (up to 99.999%), while requiring modest latencies (100s ms)



# Chapter 3

## Architecture enablers

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# Architecture enablers (1)

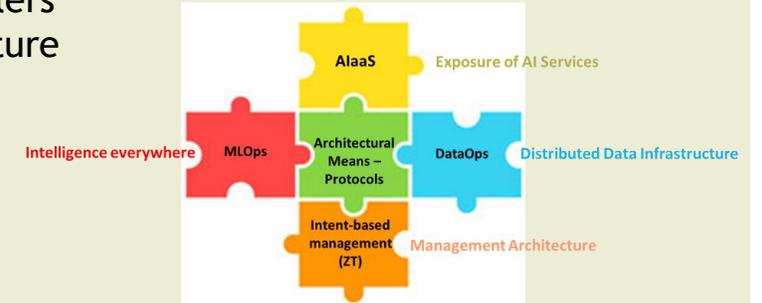


## Architecture enabler types

### Data-driven architecture

Data-driven architecture is a system design approach where decisions and actions are based on data analysis.

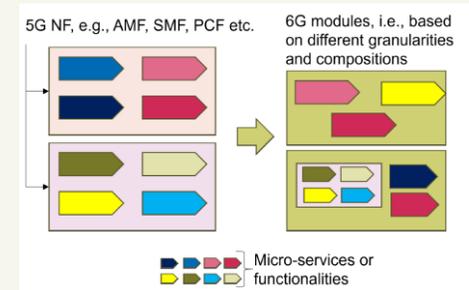
The framework of the enablers of the data-driven architecture



### Network modularization

Data-driven architecture is a system design approach where decisions and actions are based on data analysis.

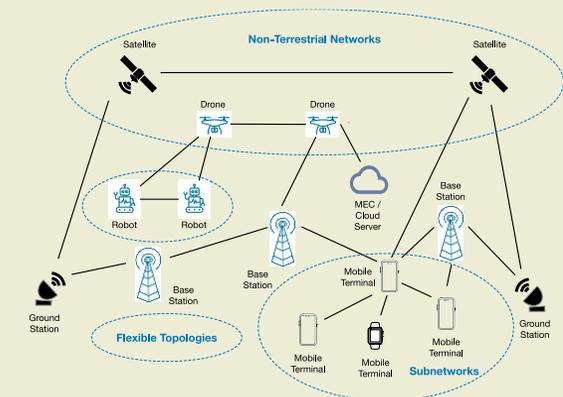
Network modularisation principle



### New access and flexible topologies

The network of networks enabler deals with how to develop and integrate flexible topologies (such as terrestrial subnetworks and Non-Terrestrial Networks).

Network of networks



# Architecture enablers (2)

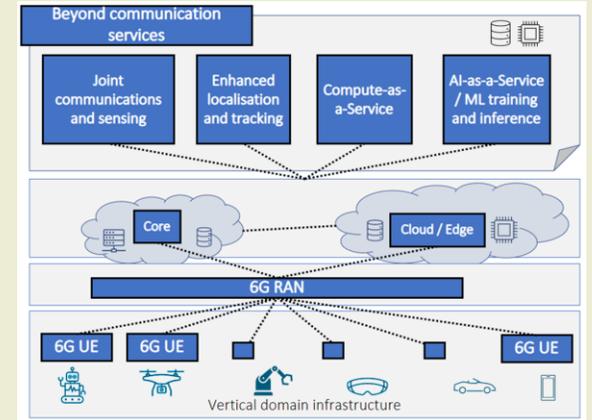


## Architecture enabler types

### Network Beyond Communications

The enablers for the beyond communication network aim to support new 6G services such as sensing and compute, and how to expose the resulting data to be used both in-network and externally.

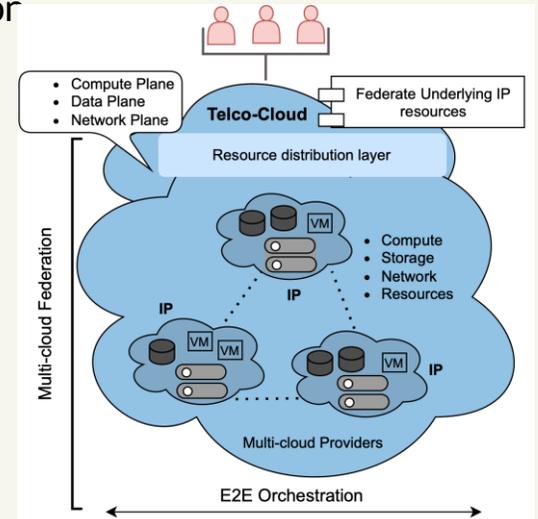
### Network beyond communication



### Virtualisation and Cloud transformation (IoT-Edge-Cloud continuum)

The Virtualisation and Cloud transformation area aims to develop a cloud platform for 6G requirements.

### Multi-domain/multi-cloud federation and orchestration



# Architecture recommended enablers (1)



Architecture enablers are recommended mainly based on their importance to the 6G system and some other considerations such as maturity, high level functionality, dependency on other enablers, importance towards migration, fulfilment of design principles, etc.

Data-driven architecture	Network modularization	New access and flexible topologies	Network Beyond Communications	Virtualisation and Cloud transformation (IoT-Edge-Cloud continuum)
MLOps	6G Network modularisation	Network of networks	Exposure and data management	Integration and orchestration of extreme edge resources in the computing continuum
ALOps	E2E service design in modular 6G	Multi-connectivity	JCAS Protocols, signalling and procedures	Multi-domain/Multi-cloud federation
DataOps	Network migration enabler		Compute protocols, signalling and procedures	
			Application-/Device-specific BCS optimisation	

# Architecture recommended enablers (2)



Data-driven architecture	Description
<b>MLOps</b>	This is the core enabler that focus on streamlining the entire life cycle of ML models during development, automating deployment through CI/CD pipelines.
<b>ALOps</b>	This is the core enabler that focus on providing accessible AI capabilities through a variety of APIs, thereby eliminating the need for application developers to build and manage their AI infrastructure.
<b>DataOps</b>	This is the core enabler that focuses on ensuring data quality by cleaning and validating data for precise AI model training.

Network modularization	Description
<b>6G Network modularisation</b>	This is the core enabler that focus on the 6G NF creation, i.e., how a NF should design, what are the tradeoffs of different design granularities, the streamlining of the interfaces for different 6G use cases etc.
<b>E2E service design in modular 6G</b>	This enabler details how the new NF composition can affect the E2E design and the service attributes. Furthermore, it focuses on the concepts such as 6G network slicing (and multi-tenancy) and orchestration, i.e., that are needed for the cost-effective coexistence of multiple use cases and operators.
<b>Network migration enabler</b>	This enabler is related to how 5G migration towards 6G will be handled.

New access and flexible topologies	Description
<b>Network of networks</b>	This enabler aims to develop so-called subnetworks and integrate these sub-networks into a full network of networks. This helps improve coverage and mobility performance.
<b>Multi-connectivity</b>	This enabler aims to improve reliability and user throughput as well as reduced complexity. This would reduce the standardization, implementation, and testing costs without any reduction in performance.

# Architecture recommended enablers (3)



Network Beyond Communications	Description
Exposure and data management	This enabler focuses on secure and efficient data exposure, essential for managing the vast information generated by diverse devices, including RAN infrastructure and IoT devices.
JCAS Protocols, signalling and procedures	This enabler addresses the architectural implications and requirements for integrating sensing capabilities into the network, facilitating novel BCS applications such as JCAS.
Compute protocols, signalling and procedures	To support CaaS and offloading, it will naturally be necessary to evaluate and develop the required protocols, signalling and procedures.
Application-/Device-specific BCS optimisation	This enabler focuses on tailoring network operations to the specific needs of applications and devices, enhancing the efficiency and effectiveness of BCS data consumption. This enabler encompasses mechanisms for optimizing the placement and resource allocation of application functions, considering computational and communication resources and security/privacy constraints.

Virtualisation and Cloud transformation (IoT-Edge-Cloud continuum)	Description
Integration and orchestration of extreme edge resources in the computing continuum	To support extreme edge exploitation as part of the infrastructure, it is necessary to evaluate and develop the required interfaces and orchestration mechanisms that can deal with this heterogeneous, dynamic, and volatile extreme edge environment.
Multi-domain/Multi-cloud federation	This enabler is about the capability to aggregate cloud services provided by multiple domains and providers into a single and coherent cloud. To this end, the cloud continuum should provide intent-based interfaces for cloud services and the 6G Core network should provide intent-based interfaces for network services.

# SNS JU project enablers



<b>Non-terrestrial networks</b> Project : 6G-NTN	<b>In-X subnetworks</b> Project : 6G-SHINE	<b>Deterministic communication</b> Projects : DETERMINISTIC6G & PREDICT-6G Projects	<b>X-haul solutions</b> Project : FLEX-SCALE
6G NTN work to some extent is included in the <b>network of network</b> enabler.	The main enabler from 6G-SHINE complements the work in <b>network of networks</b> .	<b>Time sensitive networks enabler (DETERMINISTIC6G)</b> <ul style="list-style-type: none"><li>• Packet delay correction</li><li>• Improved ultra-reliable, low latency communication (URLLC)</li><li>• Data-driven latency characterization</li><li>• RAN resource management</li></ul>	FLEX-SCALE enablers are especially on <b>midhaul and backhaul</b> . It includes flexible and programmable transceivers, to be used for software defined networking control in aggregation, metro and core routers.
		<b>Wireless-friendly, adaptive end-to-end scheduling algorithms enabler</b> <ul style="list-style-type: none"><li>• DETERMINISTIC6G considers novel algorithms to calculate wireless-friendly E2E schedules</li><li>• PREDICT-6G focuses on improving the data plane architecture</li></ul>	



# Chapter 4

## radio interface and protocol enablers

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# Flexible radio protocol - Design options for control & user planes

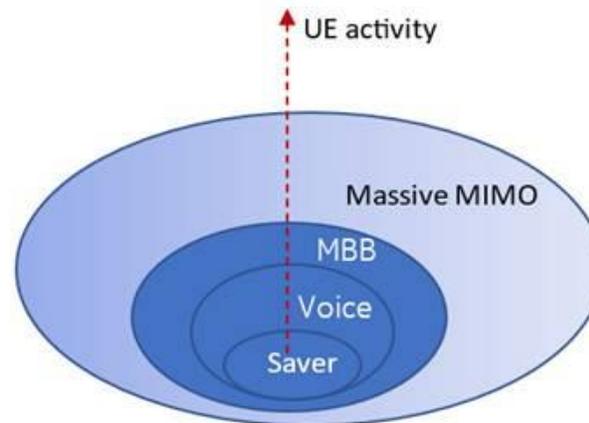


## Flatter RRC design

- Avoiding hierarchy levels by, e.g., a single standalone architecture, a single spectrum aggregation, no higher layer protocol split (F1), no notion of serving cells and BWPs
- No enforcing nor prohibiting procedures by ASN.1
- Faster switch among several RRC configuration variants
- In-line definition of delta-signalling of releasing by default to reduce signalling, e.g., during handover

## Modular RRC design

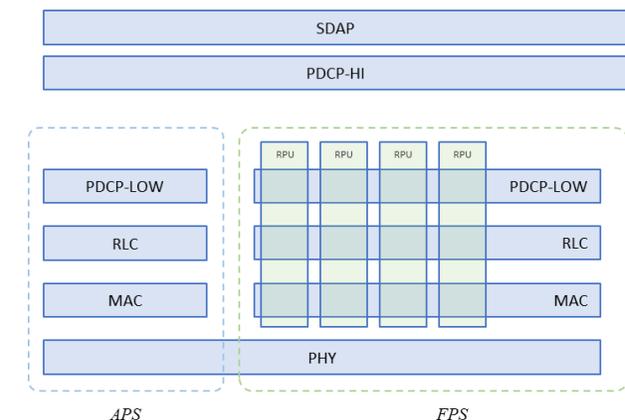
- Modular RRC could be built with RRC “profiles” to achieve a simpler RRC design and UE configuration.
- RRC profiles would be RRC configurations that UE and network store.
- RRC profiles can be tailored to suit UE operation of different form factors (such as low-cost, smartphone, ...) and performance profiles (such as low latency, power-saving, voice ...).



Power Saving vs. UE activity: Separate RRC profiles for each use case.

## User plane design

- U-plane design based on two-stack approach can enable simpler device implementations not mixing all mechanisms and optimizations.
- Simple devices may only implement a stack designed for low bitrate services with maximum coverage (APS).
- More complex and capable device would implement APS and a high bitrate designed stack (Fast Protocol Stack (FPS)).
- FPS would focus on processing-friendly and implementation-friendly design employing the concept of radio processing units.



Two stacks for the user plane in 6G with RPU concept to facilitate parallel processing

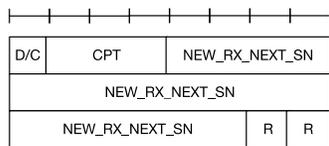
# Flexible radio protocol - Data recovery



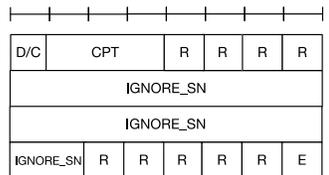
## Cross-layer interaction for data recovery

- Enhance RLC AM protocol by allowing window movement, by skipping ReTX of some already TX'ed RLC PDUs and informing RLC RX entity.
- Three possible realizations are introduced:
  - Use of new RLC Control PDU type(s).
  - Repurpose RLC ReTX for new data.
  - Repurpose RLC ReTX for PDCP Out-Of-Window SN.

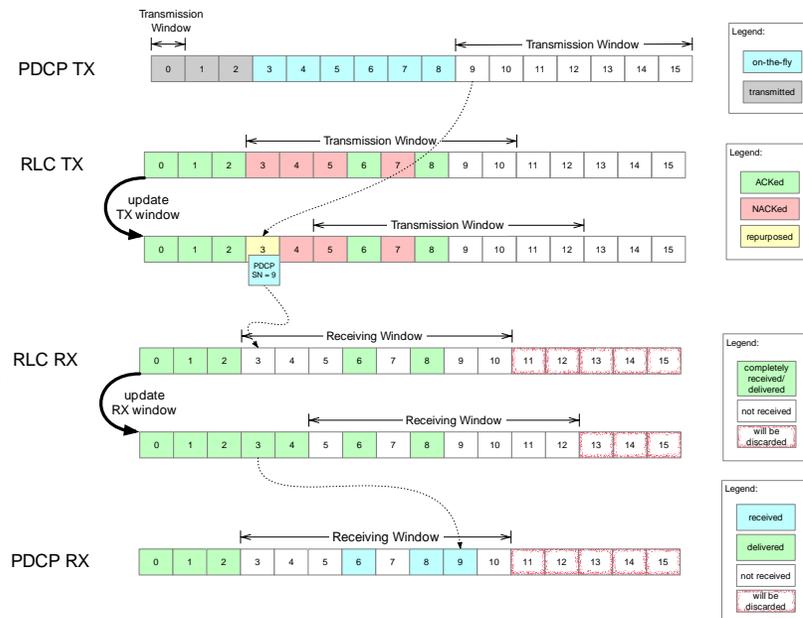
Control PDU indicating new RX\_NEXT with 18bit SN



Control PDU indicating SN(s) to be ignored with 18bit SN



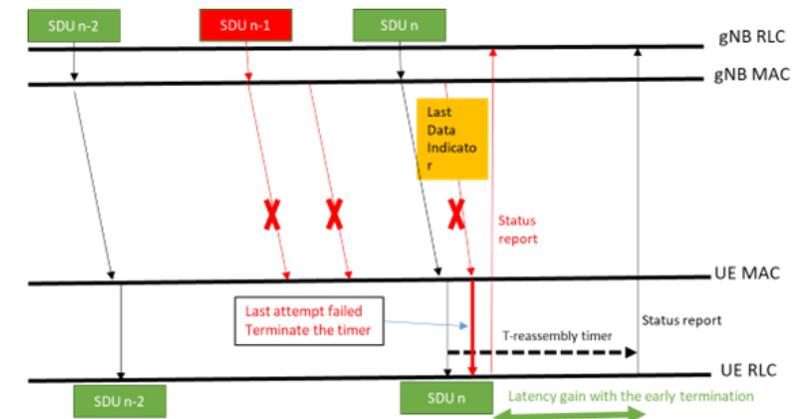
New RLC Control PDU Types



Repurpose RLC ReTX for new data

## RLC and MAC interactions for enhanced RLC retransmission process

- In 5G, RLC does not know when the maximum number of retransmissions at the MAC layer has been reached.
- RLC retransmission delay can be reduced by cross-layer interaction and information from the MAC layer.
- An example of RLC and MAC interaction can be the gNB informing the UE MAC of its configured maximum number of HARQ retransmissions, or communicates to UE that last retransmission has been attempted.
- For more complex scenarios with multiple RLC AM processes, different operations can be introduced within RLC operation.



Flow diagram of an example for RLC and MAC cross-layer interaction and the latency gain

# Flexible radio protocol - Security

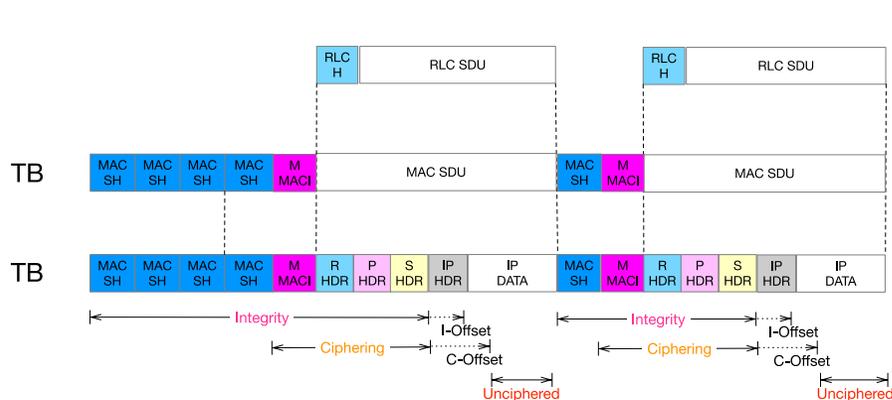


## Ciphering and Integrity Protection

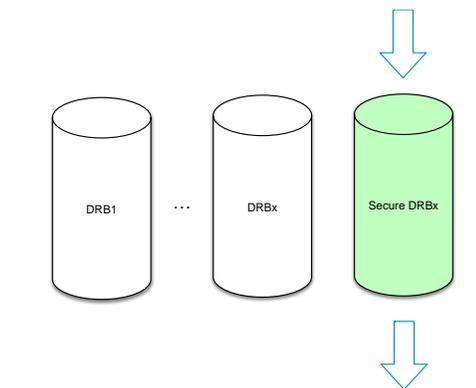
- Move Ciphering and Integrity functionality from PDCP to MAC
  - Integrity protect all L2 headers (i.e., SDAP, PDCP, RLC, MAC SHs including MAC CEs).
  - Cipher the MAC SDU part containing SDAP, PDCP and RLC headers.
  - Additionally ciphering/integrity offsets (i.e., I-Offset and C-Offset) define how much of Higher Layer Data is protected (e.g., IP Headers, Ethernet Header, complete payload as in NR, etc.).
- Define an additional “Secure DRB”
  - Uses I-Offset and C-Offset to protect the complete data like NR legacy.
  - DRB with limited throughput and Latency, to limit HW requirements.

## Protected zones in MAC layer

- 6G MAC layer can introduce “protected zone” to achieve additional MAC layer protection.
- A “protected zone” can be added per transport block (MAC PDU) that is encrypted and integrity protected by the MAC layer before the transport block is passed to the physical layer.
- This new MAC layer security solution may be applied in different variants with respect to what information is protected by the MAC layer.
- For example, many transport blocks may not contain a protected zone at all.
- In another example, all traffic except MAC subPDUs carrying user plane PDUs is in protected zones, thus maximizing the amount of control traffic that is protected and executing the crypto operations for all this traffic on a single protocol layer, the MAC layer.



Proposed AS security



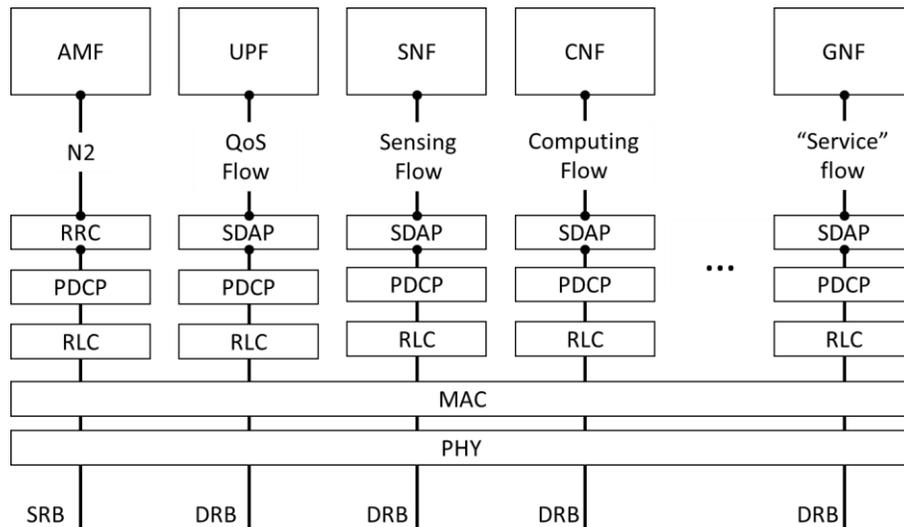
AS security with secure DRB extension

# Flexible radio protocol - Support of beyond communication



## SDAP protocol for beyond communication services

Optimized handling of data generated by beyond-communication services, such as integrated sensing, compute as a service (CaaS), or AlaaS, to allow directly forward the large amount of data from the base station to the appropriate network function (NF) instead of UPF.

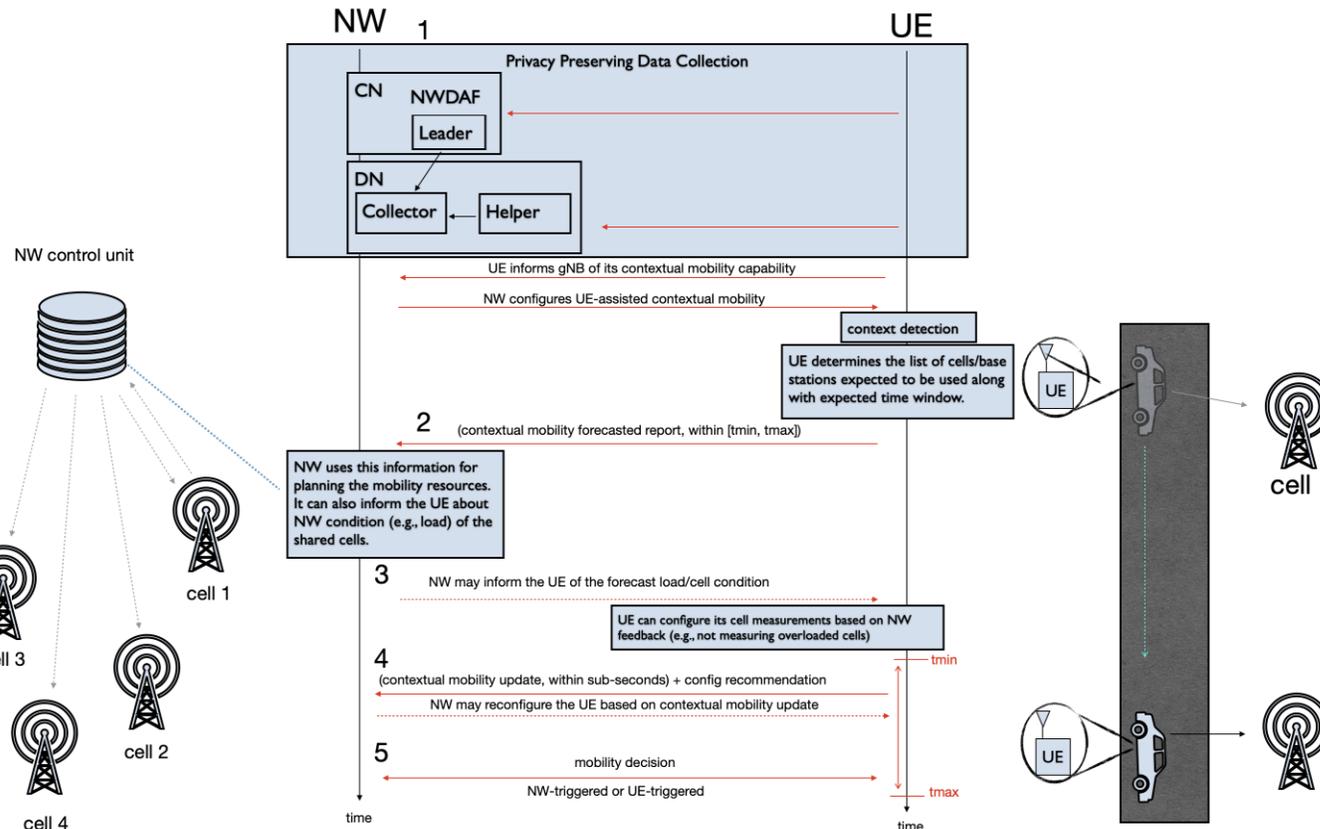


# Mobility procedures (1)



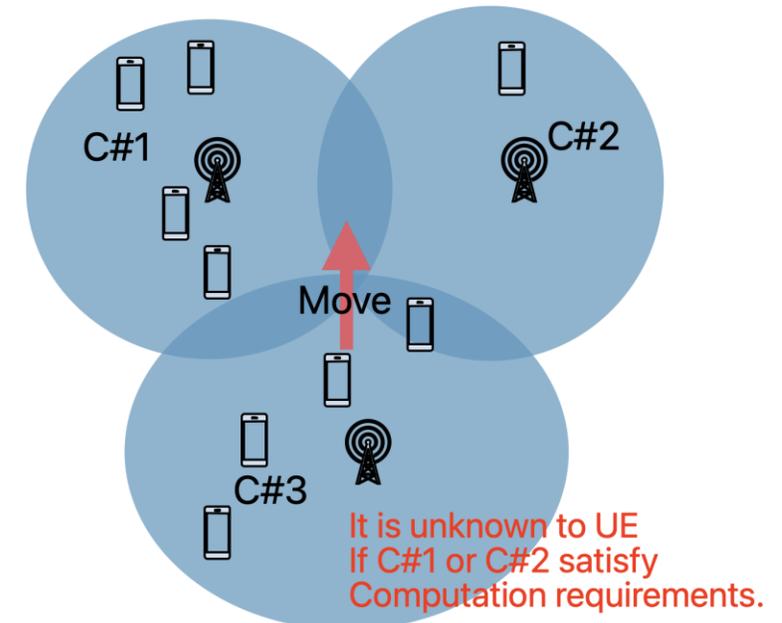
## Data Driven Mobility

- Data driven mobility mechanism may leverage the capabilities of UEs and result in a more informed decision, by considering not only the signal measurements but also the information collected by the other sensors and UE traffic pattern prediction.



## Computation Aware Mobility

- The emergence of new use cases as stated in [HEX223-D12] requires reliable compute capabilities offered by the network such that UEs may offload some of the computations to the edge.
- The mobility procedures in 5G e.g. baseline/conditional handover rely on signal measurements, however this may not be sufficient for computation offloading use cases if the target cell does not satisfy computation requirements of the UE.
- Computation aware mobility procedures allow the UEs to evaluate its own computation requirements as well as the computation capabilities of the base station(s) before initiating mobility procedures (e.g., baseline handover or conditional handover) to the target base station.



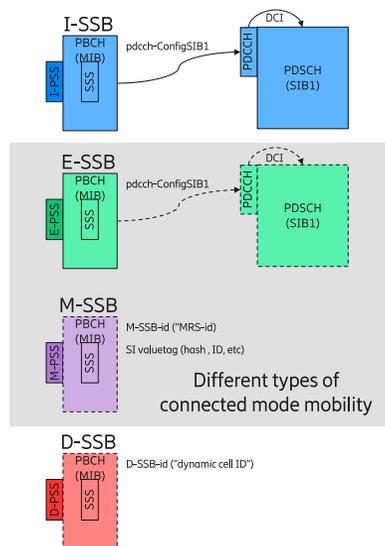
# Mobility procedures (2)



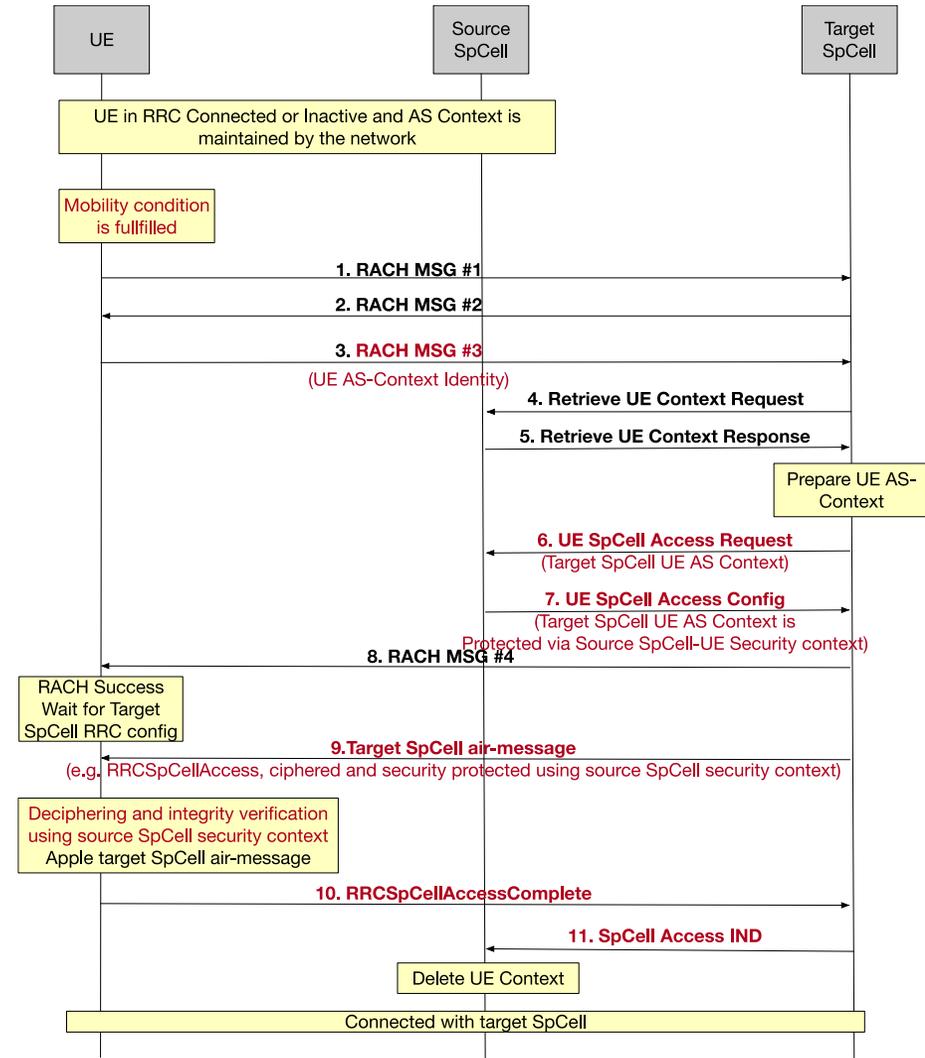
## Separation of IDLE/CONNECTED mode signalling

Multiple separate SSBs compared to a single root SSB in 5G. This allows the network to turn off nodes that are not used, and a need to study mobility procedure for it.

- Idle mode-SSB: in IDLE mode and provides system information
- Mobility SSB: for mobility measurement and contains an identify for beam or Tx-Rx point
- Dynamic/dedicated SSB: for serving cell measurement



## Enhanced SpCell Change with UE Initiation

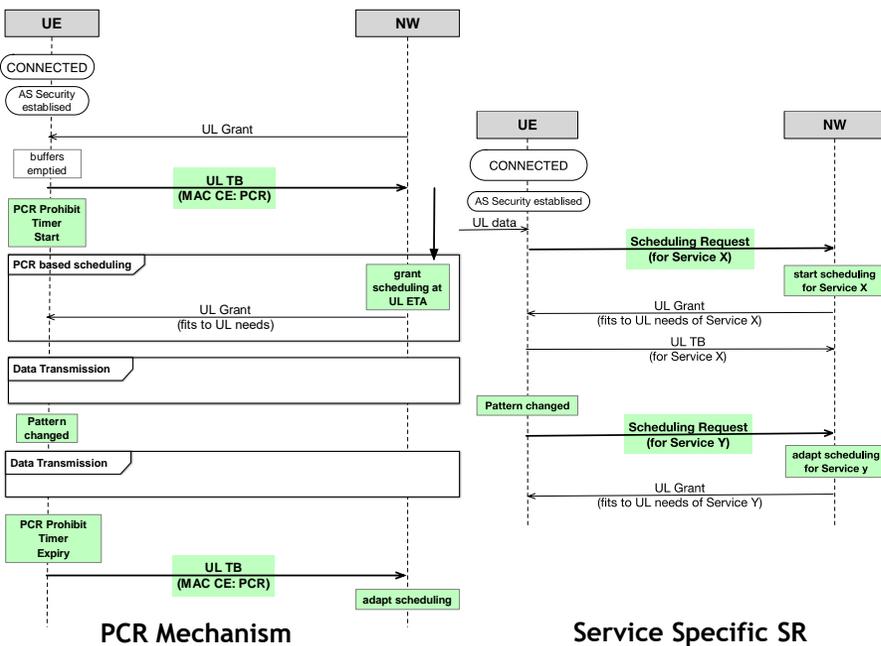


# Support for architecture and higher layer - Application-NW interaction for service differentiation



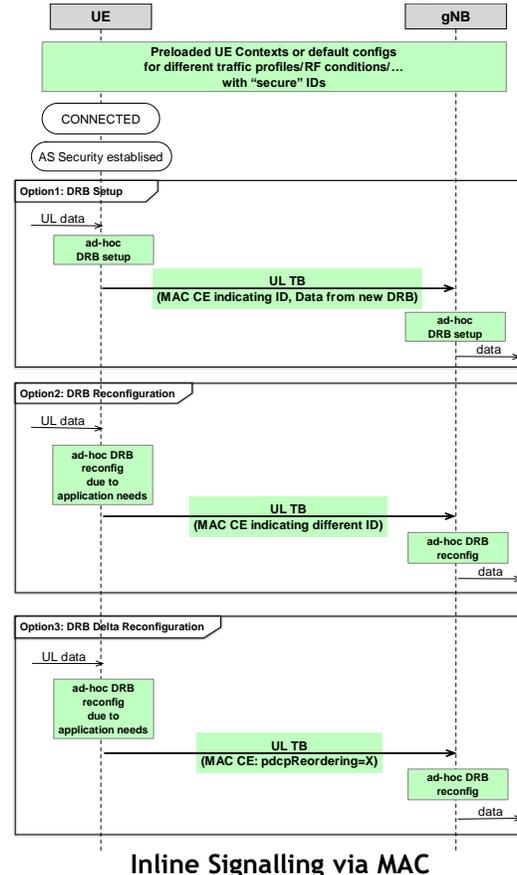
## Low Latency Scheduling

- UE indicates what traffic pattern to expect via Periodic Cadence Report (PCR).
  - PCR prohibit timer to avoid abuse of frequent PCRs changing the grant scheduling back and forth.
- Introduce multiple SR configurations for different applications, services, QoS Flows or Traffic profiles.
  - Different SRs may be different in time domain, frequency domain, cyclic shift of the PUCCH sequence.



## Ad-Hoc RB and Inline Signalling

- Dynamic setup, reconfiguration, and release of RBs based on App/Services requirements via inline MAC CE signalling.
- Reduced signaling overhead, more App awareness & UE intelligence.



## Dynamic adaptation of QoS resources for interactive services

- Hard QoS metrics guarantees for service provisioning in the cellular network is not optimal for high bandwidth adaptive applications.
- Adaptive resource type can be introduced in 6G for applications that tolerate adaptation of their QoS requirements in a controlled and responsive manner within RAN congestion timescales, and with the criterion for adaptation being to optimize the achievable rate while fulfilling a maximum PDB.

	Non-GBR	GBR	DC-GBR	Adaptive
<b>Bit rate</b>	No bit rate guarantees	Bit rate guarantees	Bit rate guarantees. Burst peak rate guarantees	“Soft” bit rate and (optionally) burst peak rate guarantees
<b>Latency</b>	Should not exceed PDB by >2% of packets at uncongested cell	Soft upper bound, shall not exceed PDB by >2% of packets	Strict upper bound, shall not exceed PDB by allowed PER	Soft upper bound, shall not exceed target PDB by more than target PER percentage of packets (*)
<b>PER</b>	Packets exceeding PDB do not count to PER		Packets exceeding PDB count to PER	

Comparison of the current and new resource types in terms of QoS metrics behaviour

# Support for architecture and higher layer - Integration of Architectural enablers



## Network Connectivity Evolution Enablers

- Consists of network of networks, multi-connectivity, protocols, signaling and procedures for beyond communications functionalities and network migration.
- Network of networks contributes to creating a seamless and ubiquitous communication system with the use of terrestrial subnetworks and NTN.
- Multi-connectivity is associated with the radio protocols via the evolution of Carrier Aggregation (CA) and Dual Connectivity (DC) and the aggregation of different access network in the RAN.
- The protocols, signaling and procedures for beyond communications functionalities, is concerned with both compute offloading and JCAS
  - For compute offloading, new functional nodes (i.e., offloading node (ON), computing node (CompN) and compute offload controlling node (CCN)) that could be flexibly deployed anywhere in the wireless network are introduced along with proposed messaging exchange for node discovery and compute tasks offloading.
  - For JCAS, new Sensing Management Function (SeMF) is introduced determining the sensing resources depending on the sensing requirements, radio conditions, and sensing constraints. Additional information exchange between the RAN nodes and SeMF is needed to assist with sensing resources and sensing service management.
- Multi-Radio Spectrum Sharing (MRSS) should be transparent to legacy devices and rely on native 6G device capabilities, which can be achieved if MRSS reuses 5G signals to minimize coexistence overhead.

## AI Enablers

- MLOps, AlaaS, and DataOps are complementing each other to achieve an AI-native system.
- MLOps addresses the ML development lifecycle, including data preparation, model training, deployment, and monitoring.
- Integration of MLOps requires radio protocols to adopt new signaling and information exchange between various network entities and the UE.
- Integration of privacy-preserving data collection and learning introduces new architectural elements such as data aggregators (i.e., leaders and helpers) and collectors, which are based on privacy-preserving cryptographic protocols.
  - Leader may be realized as a network data analytics function (NWDAF) service responsible for the coordination of data aggregation of encrypted UE data and share it with Collector.
  - Collector may reside in the data network to preserve UE ownership of the data.
  - Helper may be in data network, assists the Leader with the computation
  - Privacy is preserved under the assumption that the Leader and the Helper do not collide (i.e., do not contain the same data shares).

# Support for radio and future device enablers - Integration of radio enablers



## Joint Communication and Sensing

- Seamless integration of sensing functionality and communication service
- Key considerations include:
  - Deployment
  - Waveforms
  - Resource allocation
  - Security

## Energy Efficient Radio Design

- Prioritization of energy and cost efficiency through a flexible radio design
- Operation modes comprise fixed hardware configuration alongside adjustable software settings:
  - Software updates can be conducted with procedures established in 5G, while hardware changes may require modifications in standards

## Intelligent Radio Air Interface Design

- Application of AI and ML techniques for design and optimization of wireless air interfaces
- AI/ML-driven design is applied at transmitter, receiver, and transmitter and receiver jointly
- Main aspects
  - Modulation and coding
  - Channel state information acquisition and compression
  - MIMO transmissions
  - Compensation for hardware impairments

## Inclusive Radio Interface

- Handover enhancements for seamless integration of NTN and TN with approaches for
  - Reduction of NTN handover signalling overhead using quality of service aware omission of handover common information and random time-based conditional handover
  - Change of physical cell indicator without handover

## Spectrum Access Solutions

- Spectrum sharing schemes
  - New assumptions on radiation patterns and user equipment deployments
  - Simulation and stochastic methods for TN-NTN spectrum coexistence
  - Framework for joint investigation of 5G-NR and 6G
- Low-latency spectrum access with focus on initial and shared access

# Support for radio and future device enablers - Integration of device enablers



- Based on the work presented in D5.2, 6G device classes can be divided into two categories:
  - Novel 6G device classes: In this category, the devices are expected to be novel compared to 5G device types. The device classes identified are: Reliable High Data Rate with Bounded Latency (RHDRBL), High reliability and low latency (HRL), Energy Neutral (EN).
    - RHDRBL and HRL device classes may introduce additional considerations in Radio Resource Management logic at the base station and the packet scheduler.
    - EN device class will require RRC extensions to enable an efficient energy management at the UE side and the RAN node side.
  - Enhancements from 5G devices: In this category, the devices targeting the relevant 5G use cases (i.e., massive Machine Type Communication, enhanced Mobile Broadband, and Ultra Reliable Low Latency Communication) will continue enhancing their design objectives in 6G.
    - The support of this category may introduce stricter QoS requirements and QoS control, evolving the current 5G mechanisms available in the radio interface for 6G.

# Radio interface/protocol specifics from SNS-JU projects



## DETERMINISTIC6G

- From radio protocol perspective, DETERMINISTIC6G discusses many of the advances in the state of the art in resource allocation that aim to ensure reliable and predictable communication services. For example, solutions for streamlining the repetition and retransmission processes, latency prediction architectures, etc.
  - DETERMINISTIC6G addresses dependable time-critical applications that require strict guarantees in Packet Delay (PD) and Packet Delay Variation (PDV) beyond optimizing average throughput and latency current applications need.

## 6G-NTN

- There are many design drivers and TN-NTN integration aspects under investigation that will involve innovations from radio protocols, such as AI driven radio resource control, energy efficient service delivery in multi access technology network (i.e., NTN/TN), interference mitigation through AI driven RRM, access protocols enhancements to optimize mobility, split options between TN-NTN, etc.
  - The 6G-NTN ambition is to ensure the full-fledge integration of the NTN component into the 6G system.

# Radio interface and protocol enablers recommendation



## Radio protocol enablers:

- Control plane: flatter and modular radio resource control
- User plane: a dual configuration, data recovery and reordering, ciphering and integrity protection on lower layers, SDAP for beyond communication
- Mobility: data driven mobility, computation aware mobility, support of separation of IDLE/CONNECTED mode signalling

## Radio protocol support for higher layer enablers:

- Application-Network interaction for service differentiation and QoS/QoE management
- AI
- Network of networks
- Multi-connectivity
- Beyond communication enablers (compute offloading, JCAS)

## Radio protocol interface/protocol support for lower layer enablers on radio and device:

- Multi-RAT Spectrum Sharing (MRSS)
- Energy efficient radio
- Inclusive radio interface
- Intelligent radio air interface
- Flexible spectrum access
- Novel device classes (e.g., energy neutral)



# Chapter 5

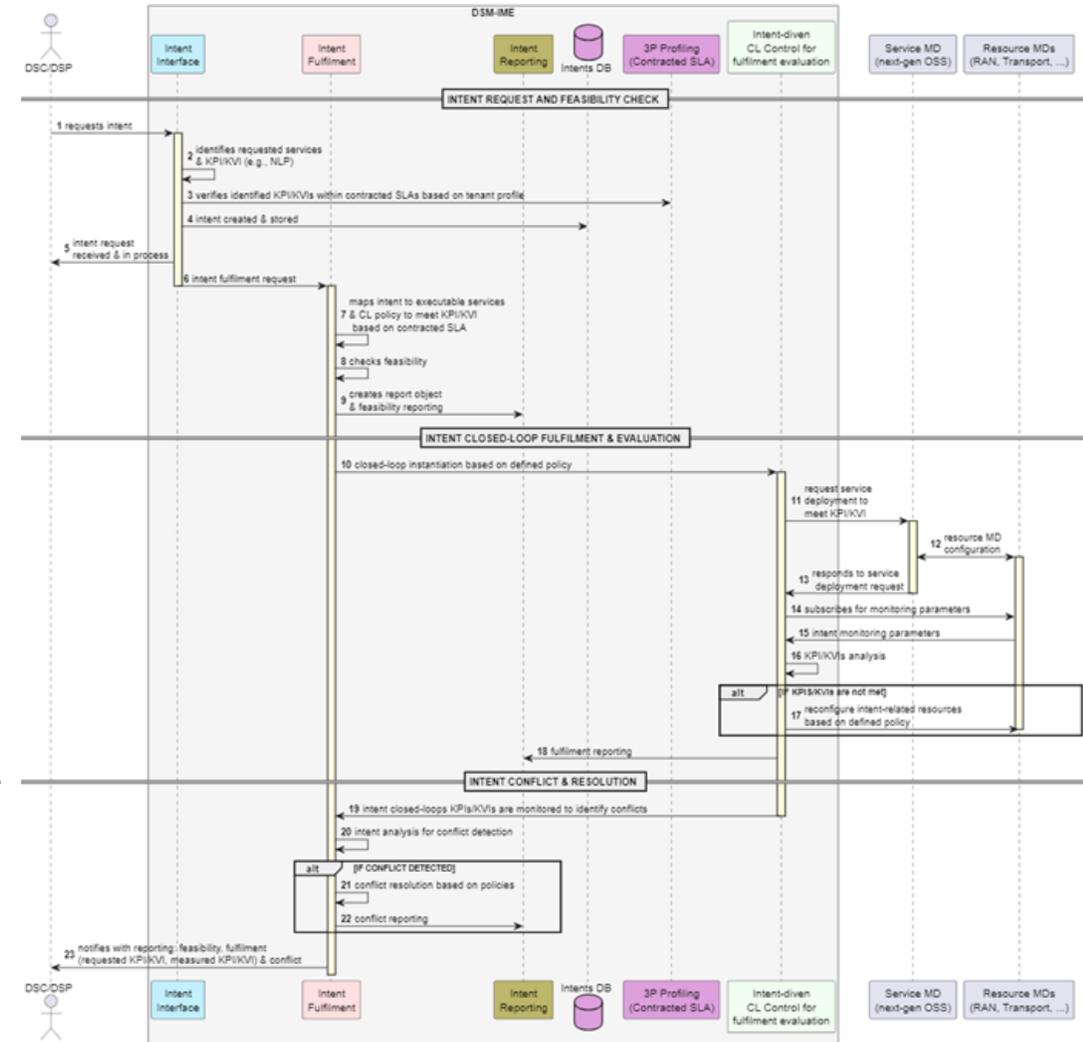
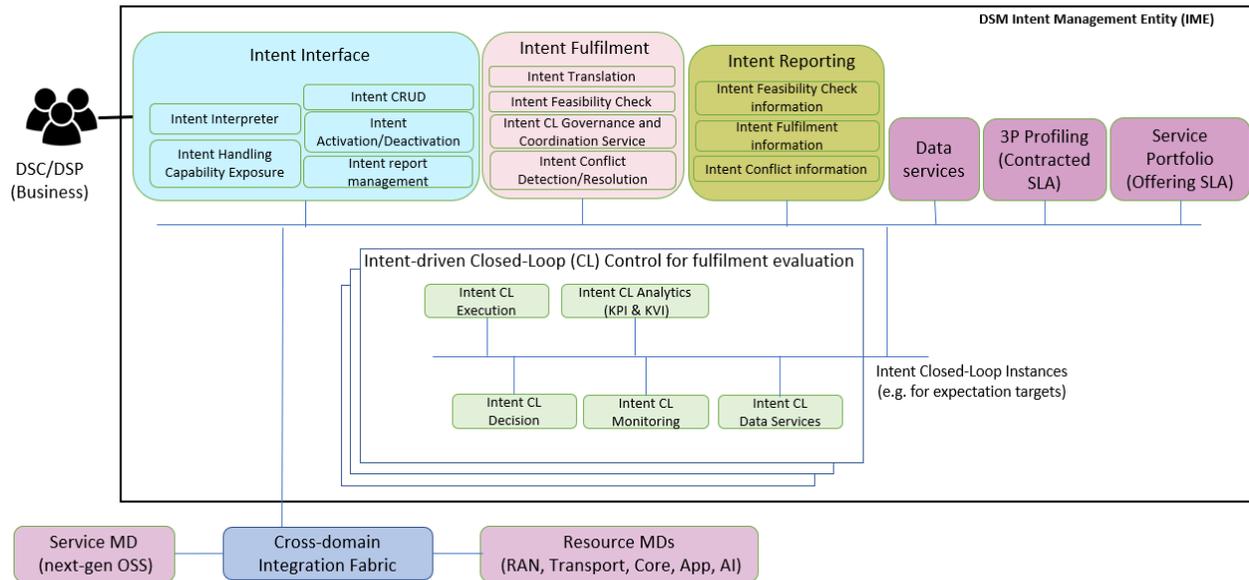
## Management and orchestration enablers

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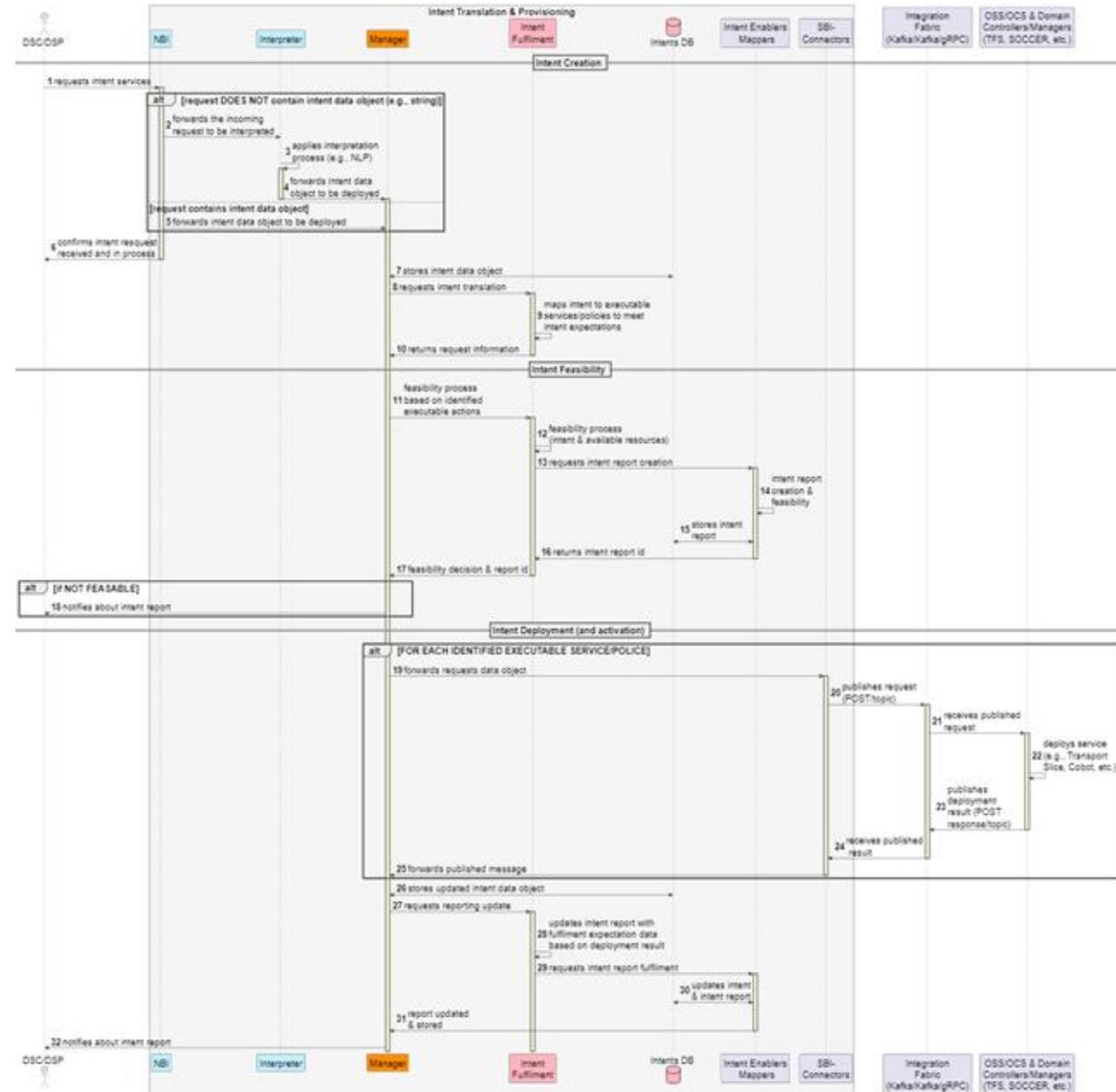
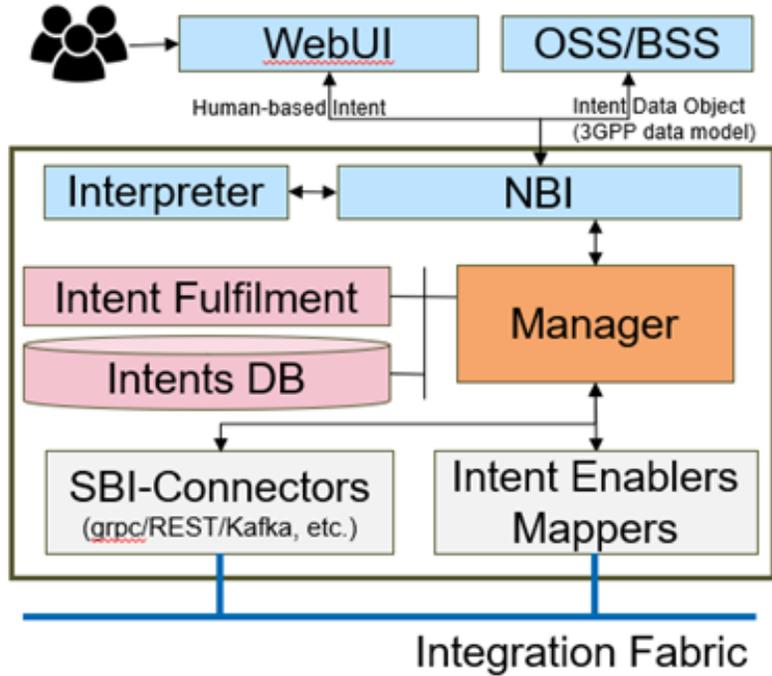
# Intent-based digital service manager functional architecture



## • Evolutions since its previous version:

- Renaming modules and functionalities to improve clarity.
  - "Intent/interface Handler" to "Intent Interface"
  - "Intent Report Configuration" functionality to "Intent Report Management"
  - "Intent Fulfilment Internals" to Intent Fulfilment"
- Functionalities re-organization to decrease complexity-
  - "Intent Management" functionalities moved into the "Intent Interface" module
  - Added the "intent Translation" functionality
  - CL related functionalities joined into "Intent CL Governance and Coordination Service"

# Enabler 1: Intent Translation & Provisioning



Operation	Path	Method
Create intent	/itp/1.0/intent/intent={id}	POST
Delete intent		DELETE
Query intent		GET
Activate intent	/itp/1.0/intent/activate/intent={id}	PUT
Deactivate intent	/itp/1.0/intent/deactivate/intent={id}	PUT



# Enabler 2: Data fusion mechanisms based on telemetry data

## Architecture

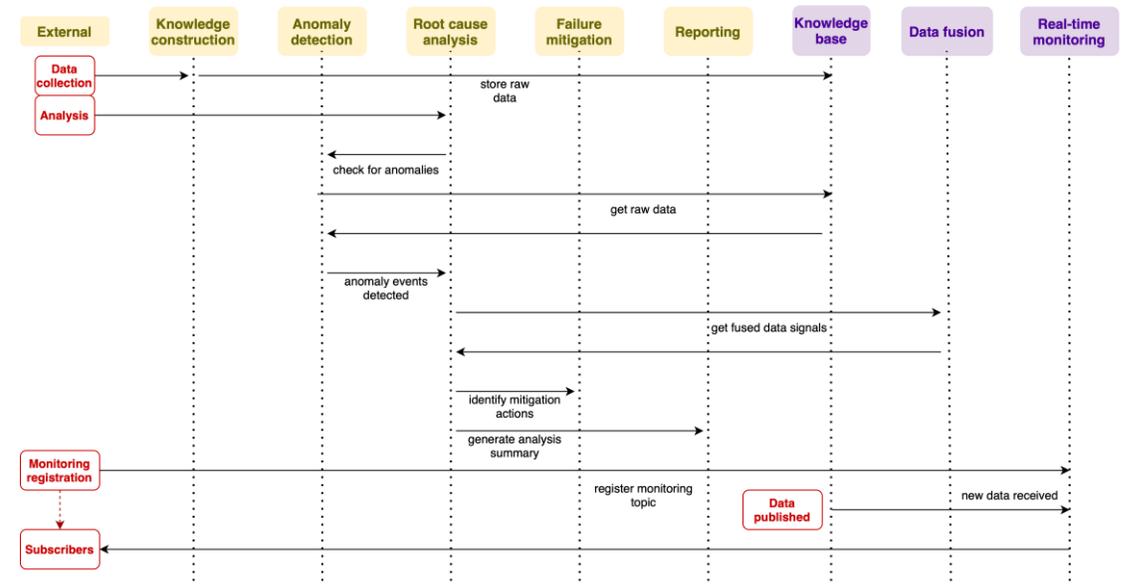
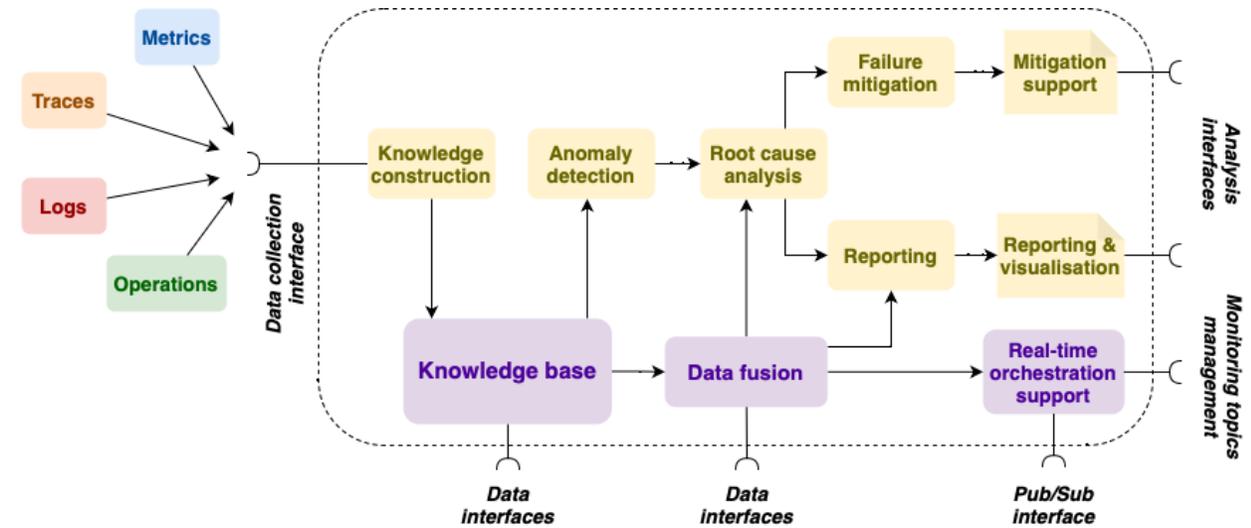
- Knowledge construction
- Analysis
  - Anomaly detection
  - Root cause analysis
- Mitigation
  - Failure mitigation
  - Reporting

## Interfaces

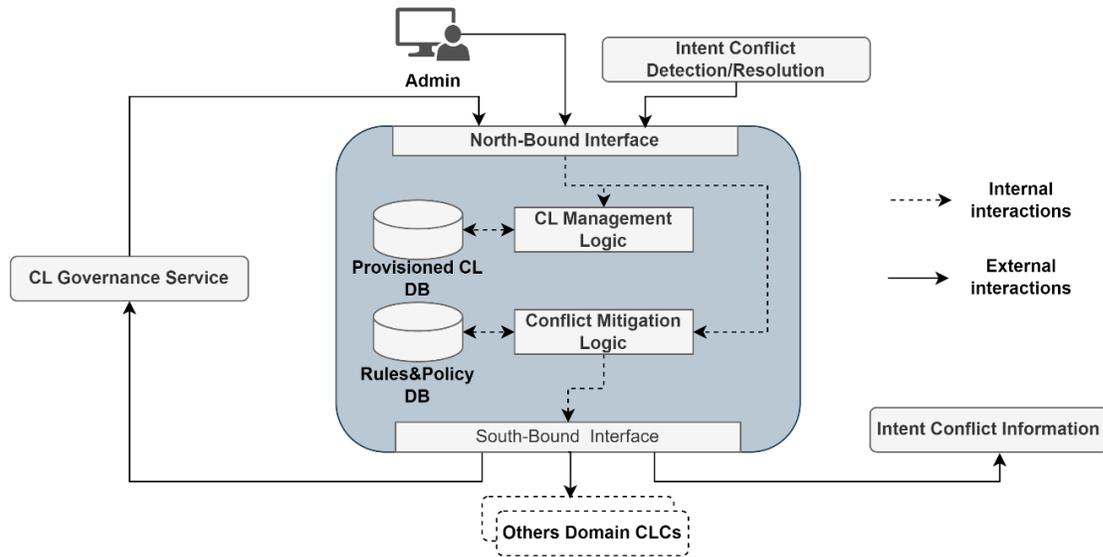
- Data collection
- Data access (Data interfaces)
- Real-time orchestration support (Pub/Sub interface)
- Analysis report

## Workflow

- Data collection
- Analysis (failure identification, mitigation)
- Monitoring



# Enabler 3: Intent Closed Loop Coordination



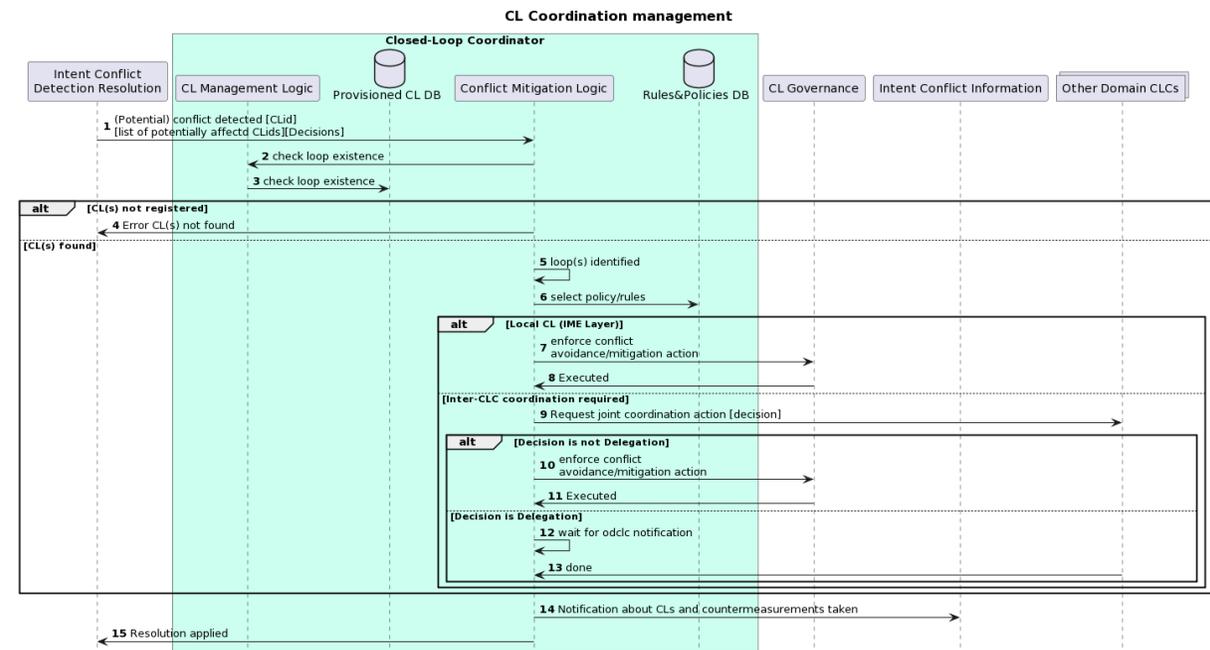
## • NBI: CLC access interface:

- Interaction with Intent Conflict Detection/Resolution module
- CL registration/removal from CL Governance
- Administrative interface for Rules & Policies management

## • SBI: consumer of the external modules' interfaces :

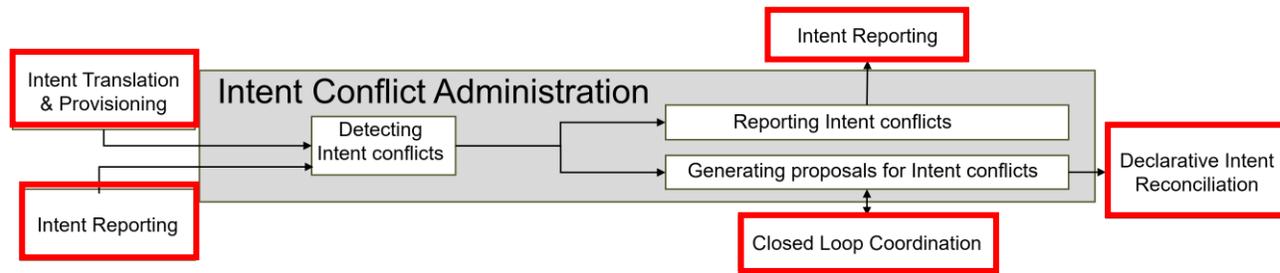
- CL Governance interaction (conflict avoidance/mitigation Start/Stop CL, update configurations, collect information about running CLs)
- Intent conflict report for conflict notifications
- Other CLCs to avoid multi-domains/layers conflicts and enable CL collaborations

- **CL Management logic.** Allows the registration of the CLs at their creation from the CL Governance.
  - **Provisioned CL DB** maintains CL information (configurations, goals, targeted resources, etc. )
- **CL conflict mitigation logic.** Exploits the **Rules and Policies DB** to know how to act in the case of CL conflicts.
  - enforce command and retrieve information from the CL Governance, generate notification for the Intent Conflict Report.
  - incorporate a mechanism for interacting with its own counterparts in other domains.

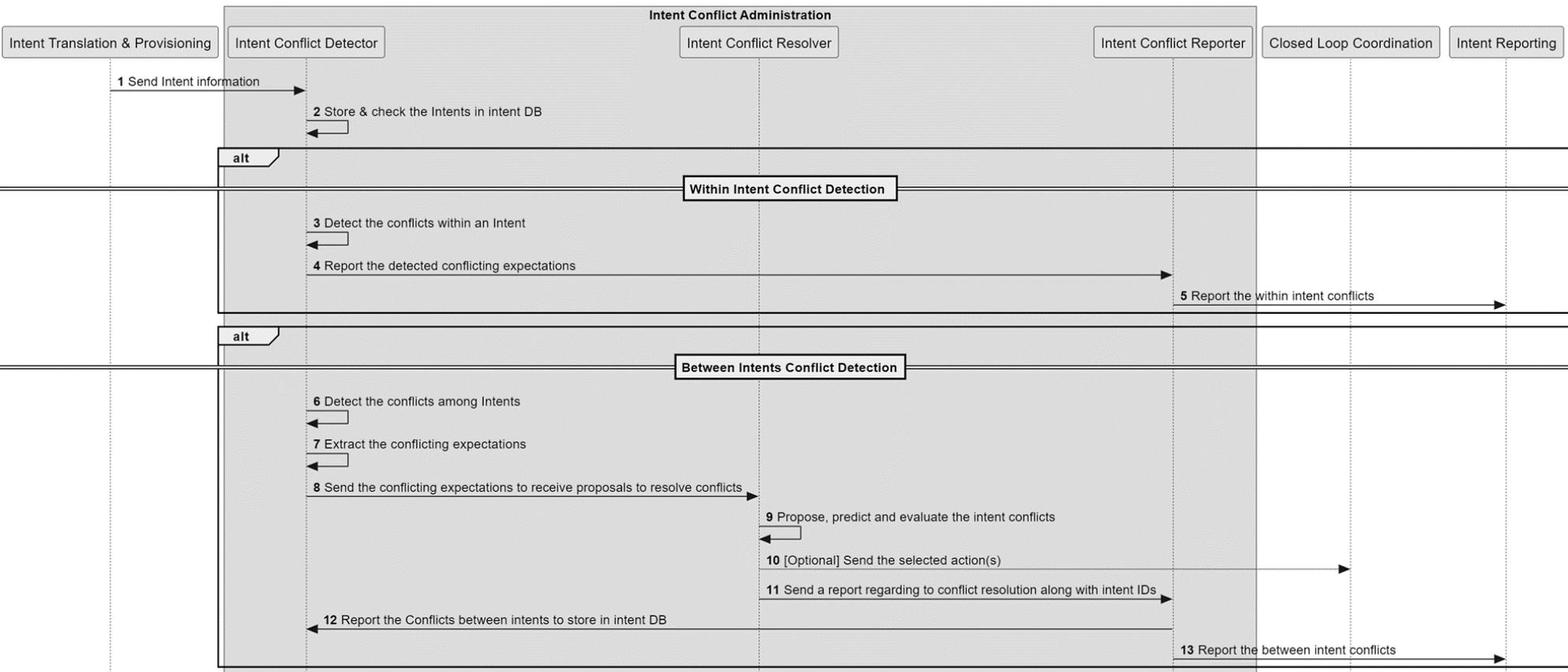




# Enabler 4: Intent Conflict Administration



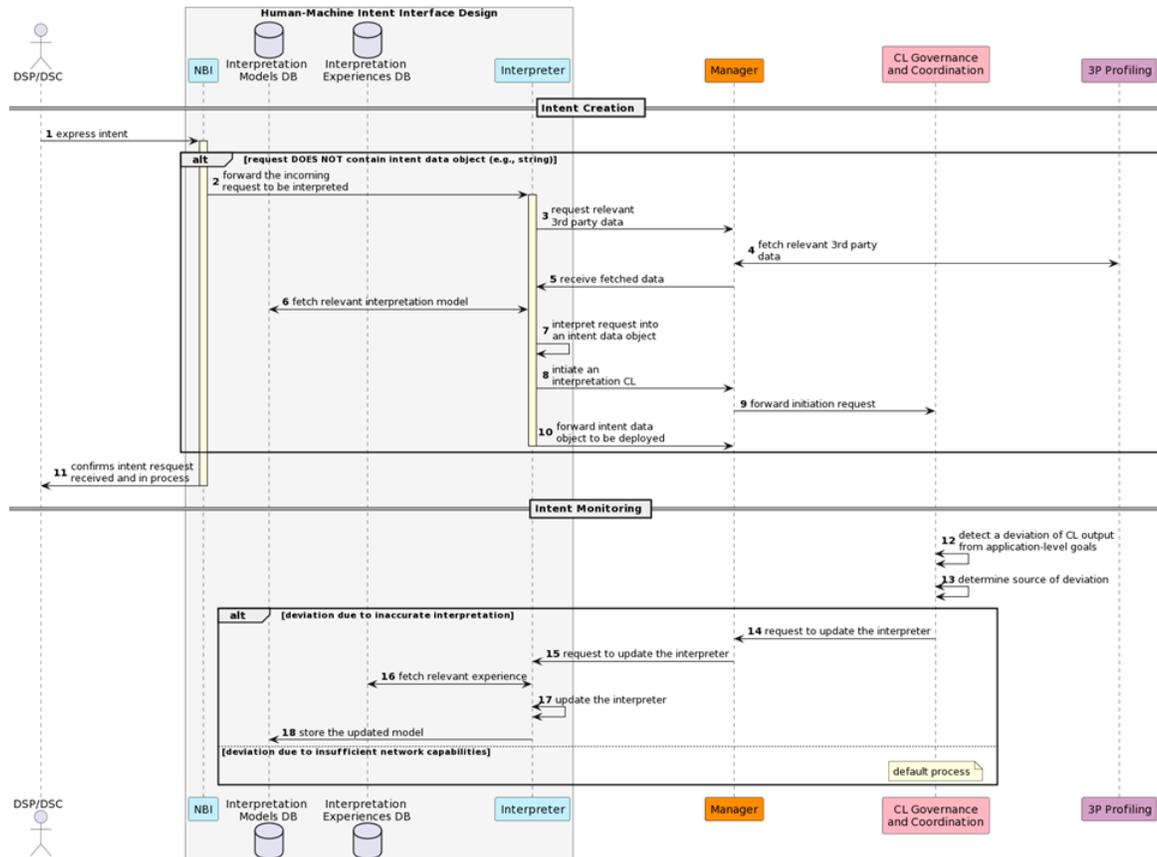
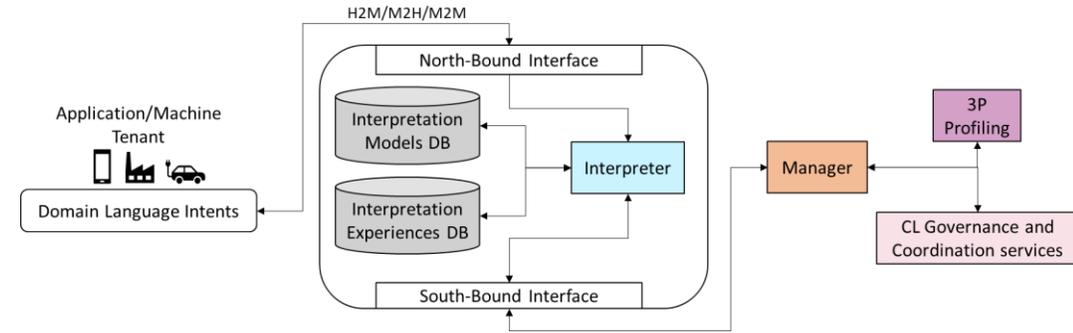
- **Detecting intent conflicts** detects intent conflicts in two scenarios: when validating the intent and continuously monitoring the intents once deployed.
- **Generating proposals for intent conflicts** proposes actions and predicts their effects to mitigate the conflict.
- **Reporting intent conflicts** generates a detailed description of the intent conflicts.



# Enabler 5: Human-machine intent interface design



The main objective of this enabler is to allow users/applications from different domains/verticals to express the intents in their own domain language without any telecom/network knowledge (No restriction to use the network domain language or any standardized data objects).



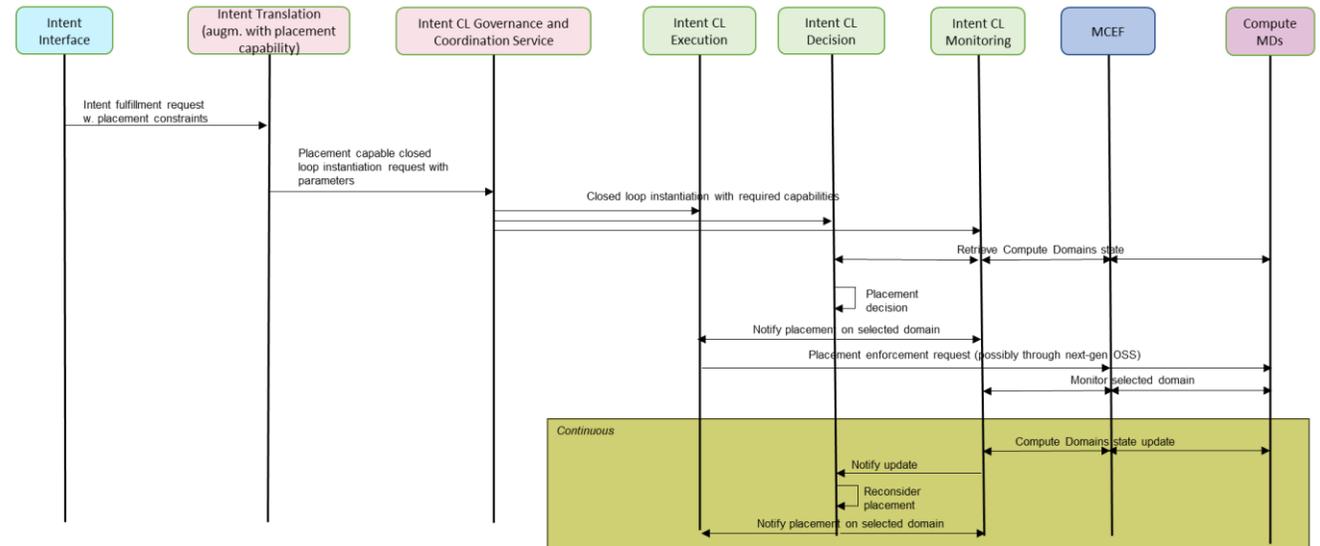
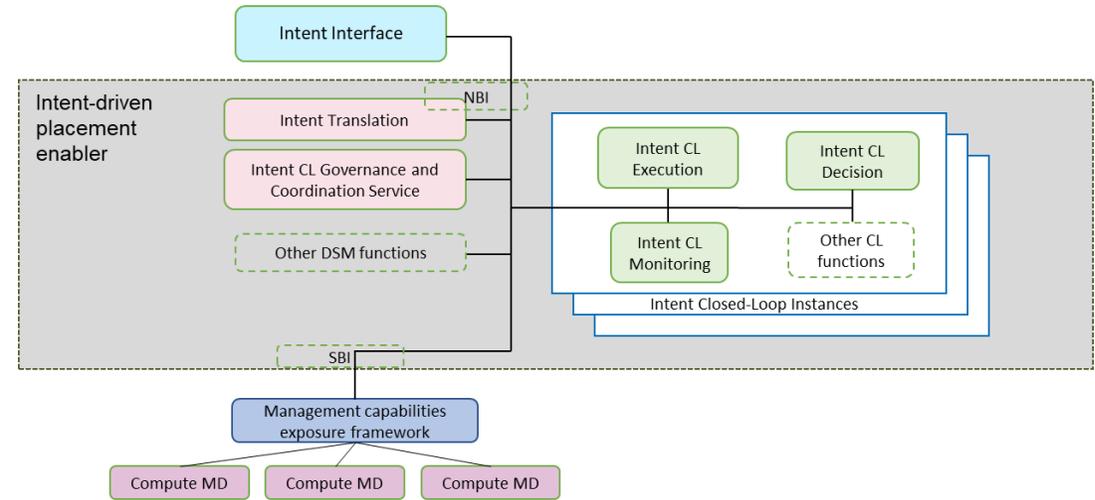
The NBI enables the users to express their intents to the network and receives feedback. It could be: Human to Machine (H2M)/Machine to Human (M2H) or Machine to Machine (M2M).

The SBI allows the interpreter to interact with other modules in the IME through the Manager. Those modules are: 3P Profiling, and Closed Loop Governance and Coordination Services.

# Enabler 6: Intent-driven placement



- Goal: Extend Intent Fulfilment mechanisms to support intent-driven compute placement in the cloud continuum.
  - deriving the execution domain (agent) to contact and request orchestration through the MCEF integration fabric
  - taking into account the current state through compute domain telemetry
  - spawning and maintaining a (set of) closed-loop(s) in charge of reacting to changes notified through the compute domain telemetry or other sources of context information to adjust placement to maintain according to the intent expression



# Enabler 7: Declarative Intent Reconciliation

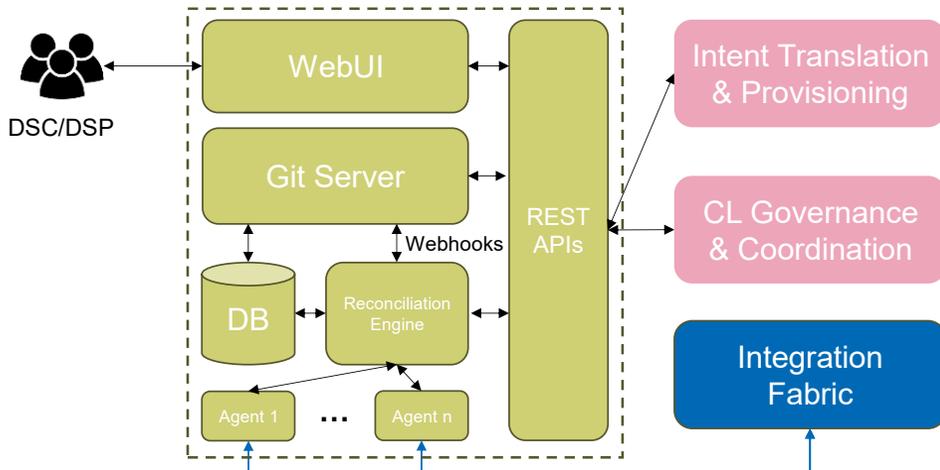


- Internal Architecture:

- Git Server
- Reconciliation Engine
- Agent

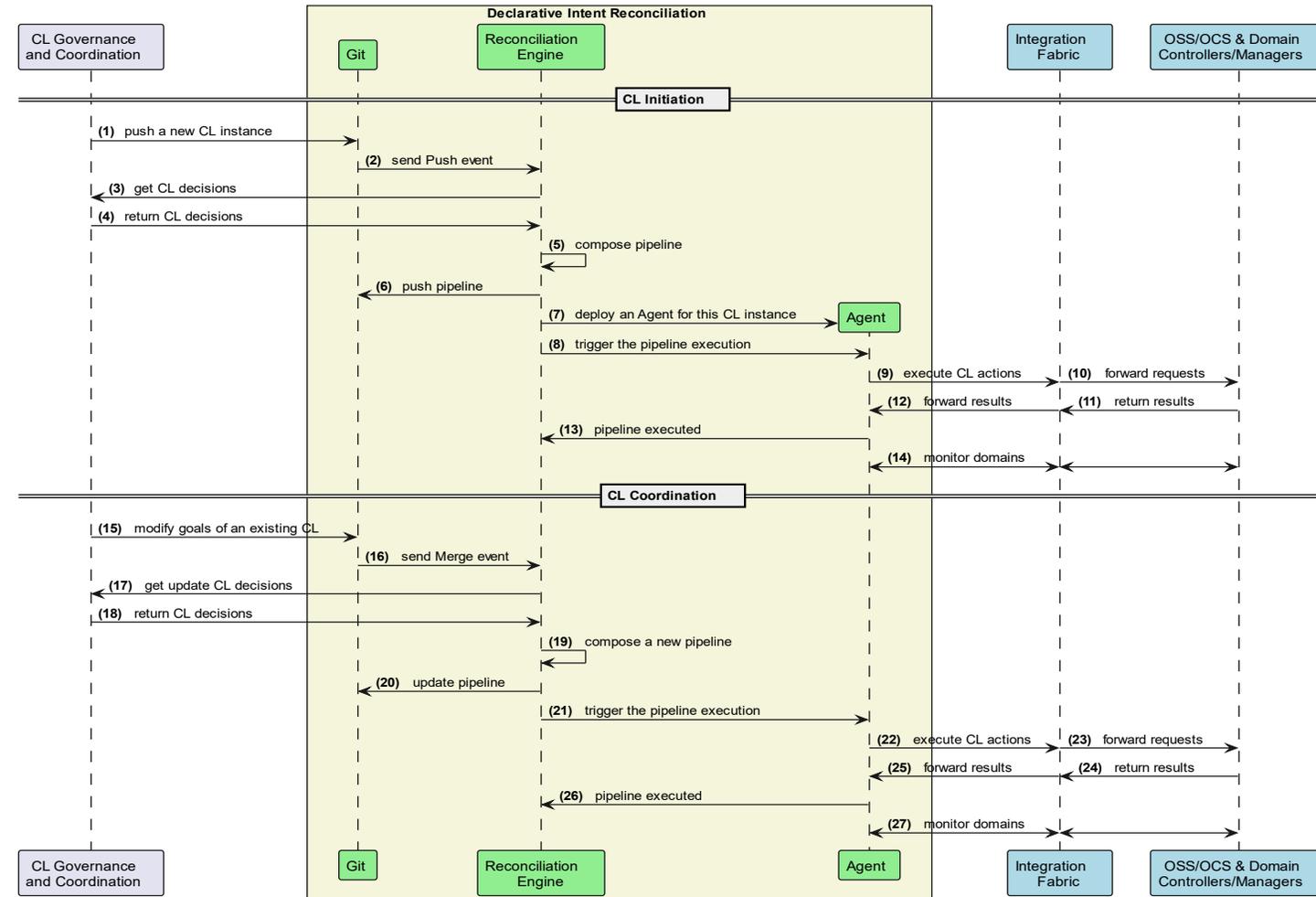
- External Interfaces to manipulate CL information (goals and actions) and execution pipelines

- WebUI
- REST APIs



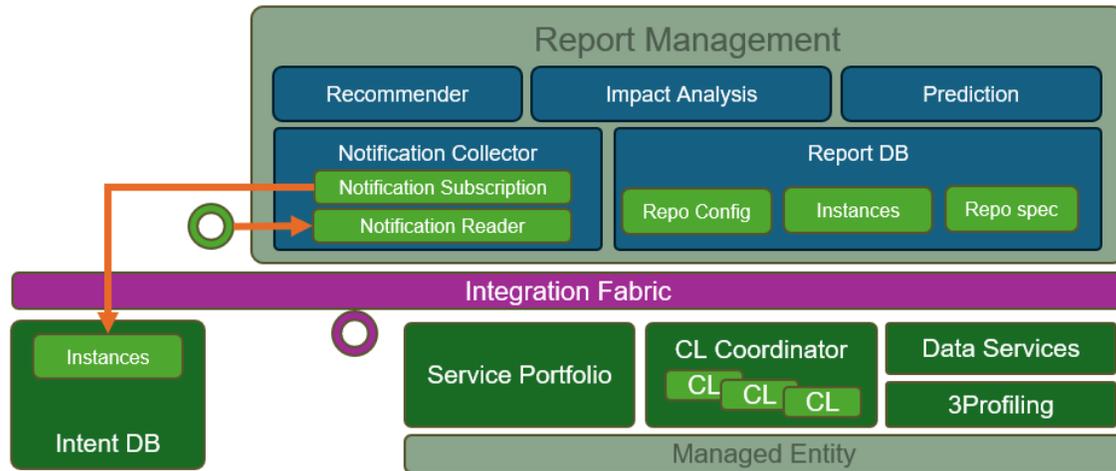
- Workflow:

- CL Initiation: a new Agent is created upon each CL initiation.
- CL Coordination: CL conflict resolution triggers pipeline updates.

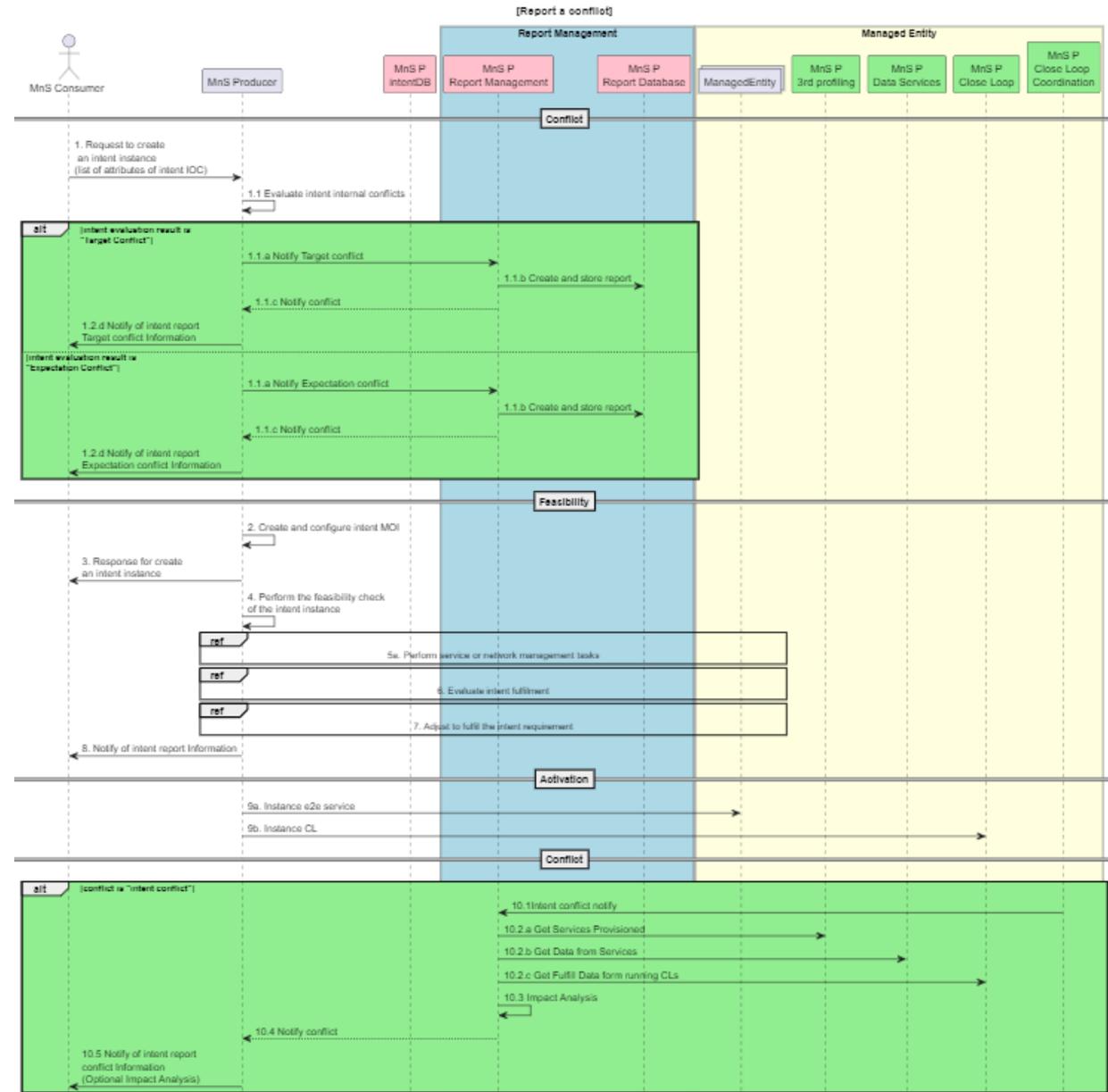




# Enabler 8: Intent Reporting

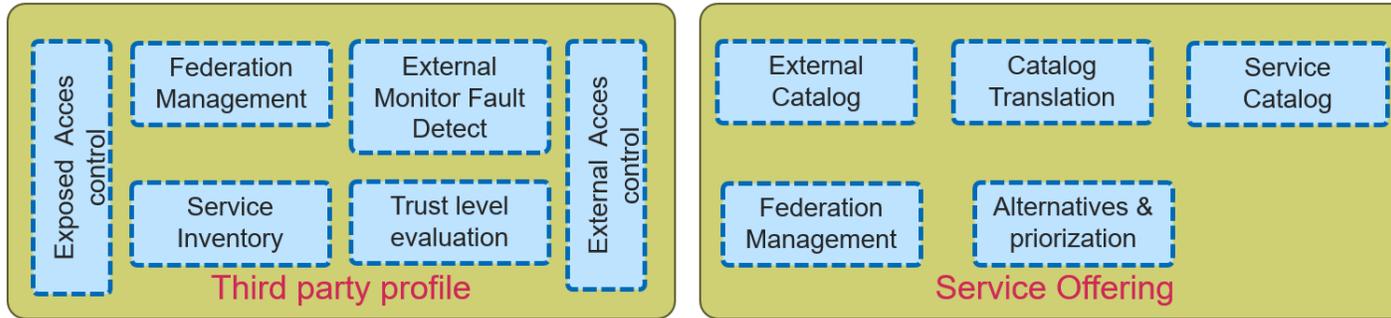


- Exposes the information associated with the intent-based management actions reflecting the status of the intent in three scenarios: feasibility, conflict management and fulfillment.
- External interfaces: notification channels, expose report information and access to external data for report management. Intent database, service portfolio, conflict coordinator.
- Optional components: Impact analysis, recommendation and KPI forecasting.



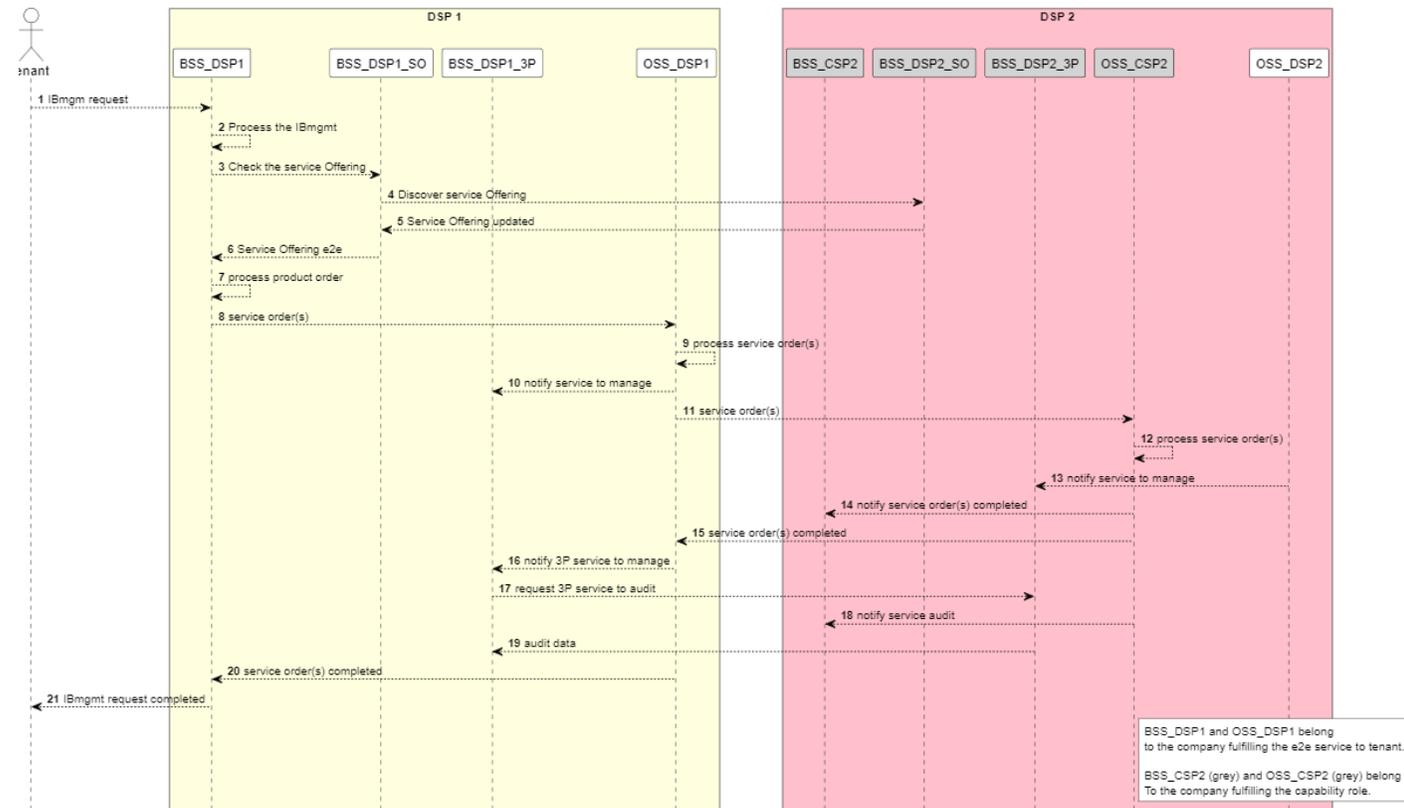


# Enabler 9: 3rd party services



- 3rd party profile for tenants that are going to access to the Hexa-X-11 system.
- service offerings linked to tenants according to well-defined SLAs.

- Third-party profile includes the information related with the user, the permissions, the trust level in federation scenarios, services contracted and SLAs.
- Service offering includes service characterization with its flavors (SLAs, coverage), relationships with other services.
- Federation interconnection management support.
- External interfaces: expose internal service catalog and access to external service catalogs, federation management, service discovery, performance and fault monitoring.





# Network services M&O related enablers

1. Network Programmability Framework
2. Monitoring and Telemetry Framework
3. Management Capabilities Exposure Framework
4. Security Framework
5. Synergetic Orchestration Mechanisms for the Computing Continuum
6. AI/ML algorithms
7. Network Digital Twins Creation Mechanisms
8. Real-time Zero-touch Control Loops Automation and Coordination System

## **Cloud transformation enablers:**

1. Integration and Orchestration of Extreme Edge Resources in the Cloud Continuum
2. Multi-cloud/Multi-domain Federation

# Additional M&O enablers from other SNS-JU projects



- 1. 6G Automation and Optimization:** Enabler from the DETERMINISTIC6G project, which focuses on:
  - Multi-vendor automation and management (LCM, FCAPS, orchestration, optimization) driven by intents and operator deployed Apps, supporting analytics and service exposure.
  - Automation for service assurance e.g., based on intent-based management.
- 2. Intent -based Orchestration and LC Management:** Enabler from the DESIRE6G project, which focuses on:
  - Programmability of KPIs on extreme networks.
  - Management of intents.



# Enabler recommendation

1. Network Programmability Framework
2. Monitoring and Telemetry Framework
3. Management Capabilities Exposure Framework
4. Security Framework - Trust Management System
5. Synergetic Orchestration Mechanisms for the Computing Continuum
6. AI/ML algorithms (both two sub-enablers are selected)
7. Network Digital Twins Creation Mechanisms
8. Real-time Zero-touch Control Loops Automation and Coordination System
9. Integration and Orchestration of Extreme Edge Resources in the Cloud Continuum
10. Multi-cloud/Multi-domain Federation



# Chapter 6 security, privacy and resilience (controls and enablers)

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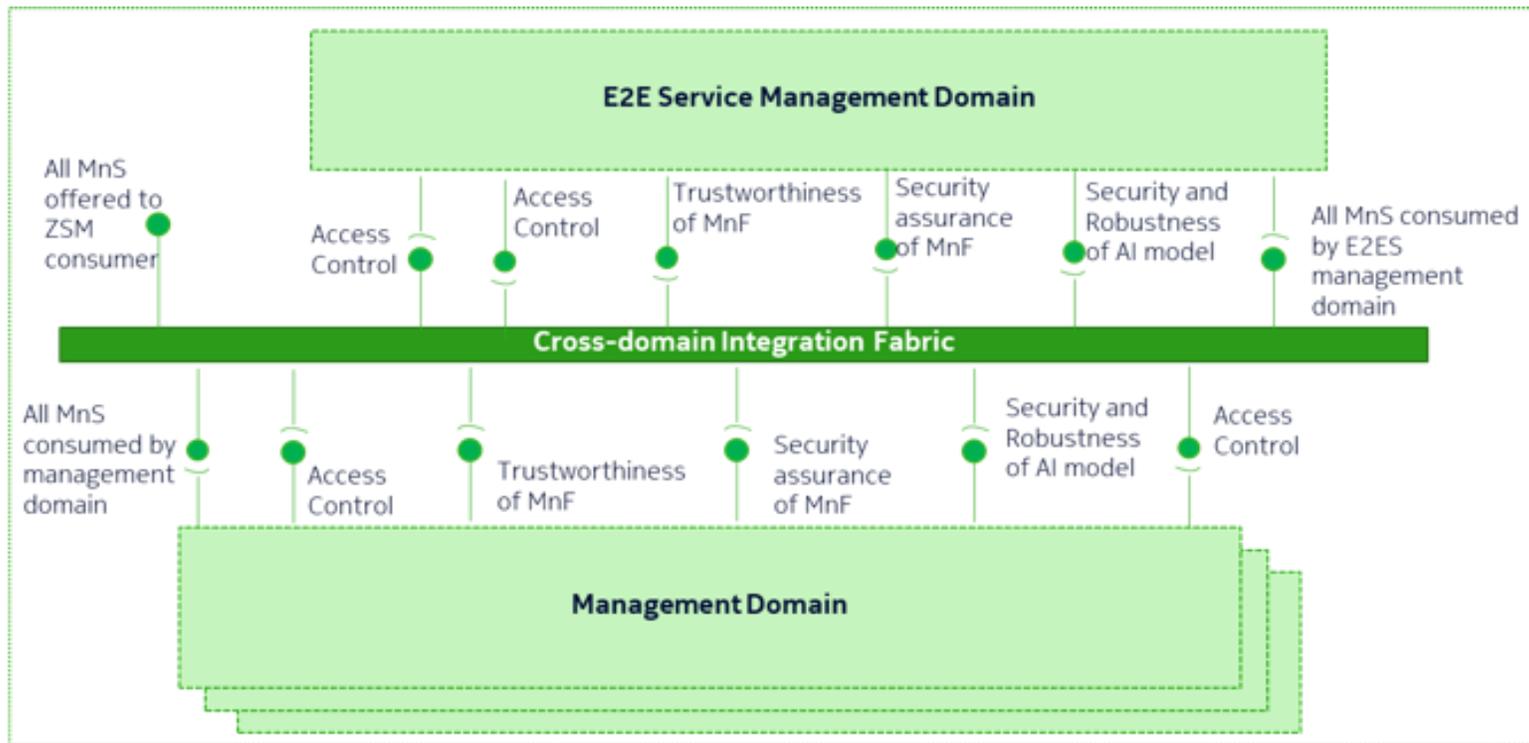
# An E2E View: Controls and Enablers

- Focus the Security, Privacy and Resilience (SPR) work on the identification and description of *SPR controls*
  - Not necessarily new, differential functionalities, but addressing specific threats
    - Mechanisms to detect them and to mitigate their impact
  - To be applied in infrastructure and service design and planning, and to be used by *enablers*
    - With a SPR or any other objective
- Structured along the *threat families* they address, as described in D2.2
  - Architectural trends
  - Pervasive, trustworthy AI
  - Trust infrastructures
  - Physical layer security
- Advice on design patterns and use of the SPR controls
  - Coordination with the relevant WPs and their SPR concerns
  - Identification of relevant SPR enablers in other SNS JU projects
- Interface to security controls
  - Structured around specific SPR enablers



# Interfaces for SPR Controls

- Use a general loosely coupled model, compatible with the OAM integration fabric
  - Controls are accessed through APIs, either local or remote
- Based on a few basic principles
  - General loosely-coupled model, compatible with the WP6 *integration fabric*
  - API-oriented (not necessarily REST in all cases, like crypto)

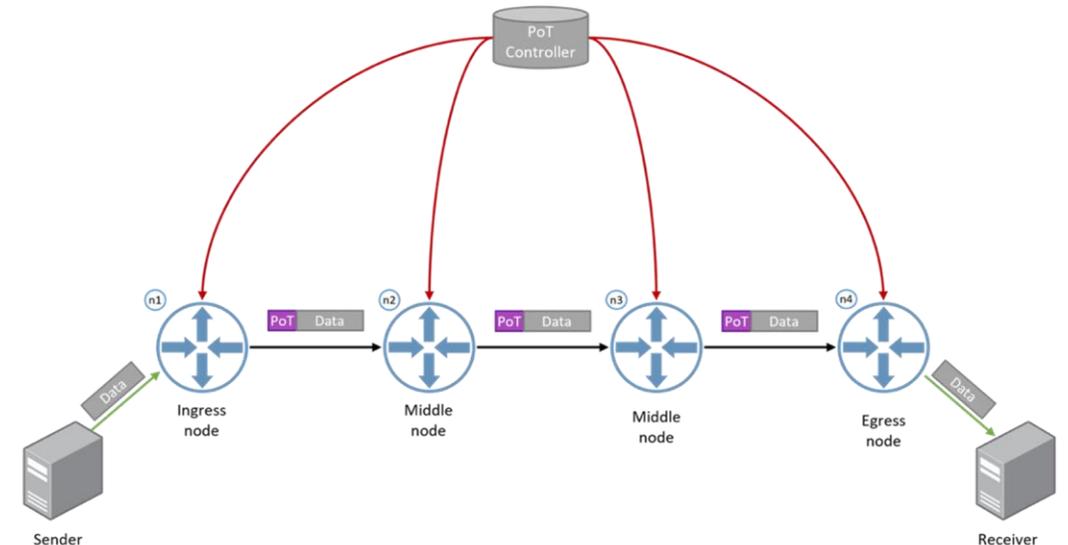
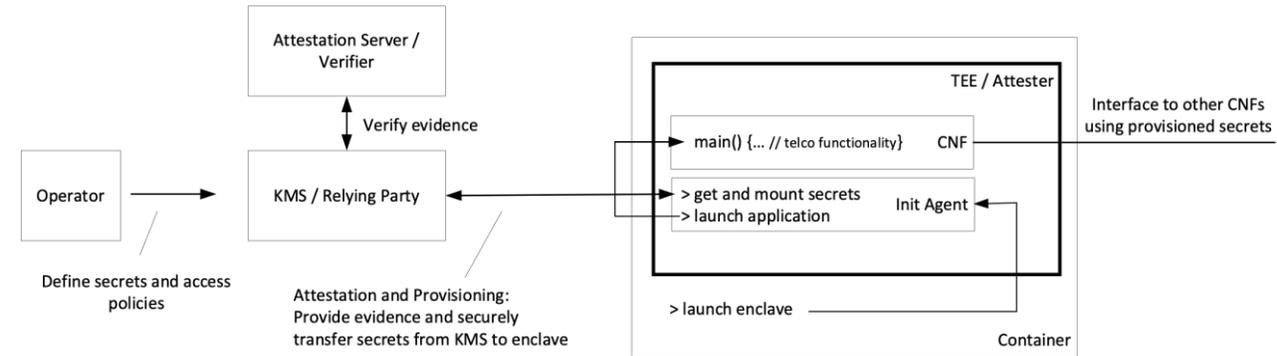


- Use ETSI ZSM014 as foundation for these interfaces
  - A set of security interfaces well aligned the above principles
  - Use it as base, validate and extend it as required



# SPR Controls - Attestation Capabilities

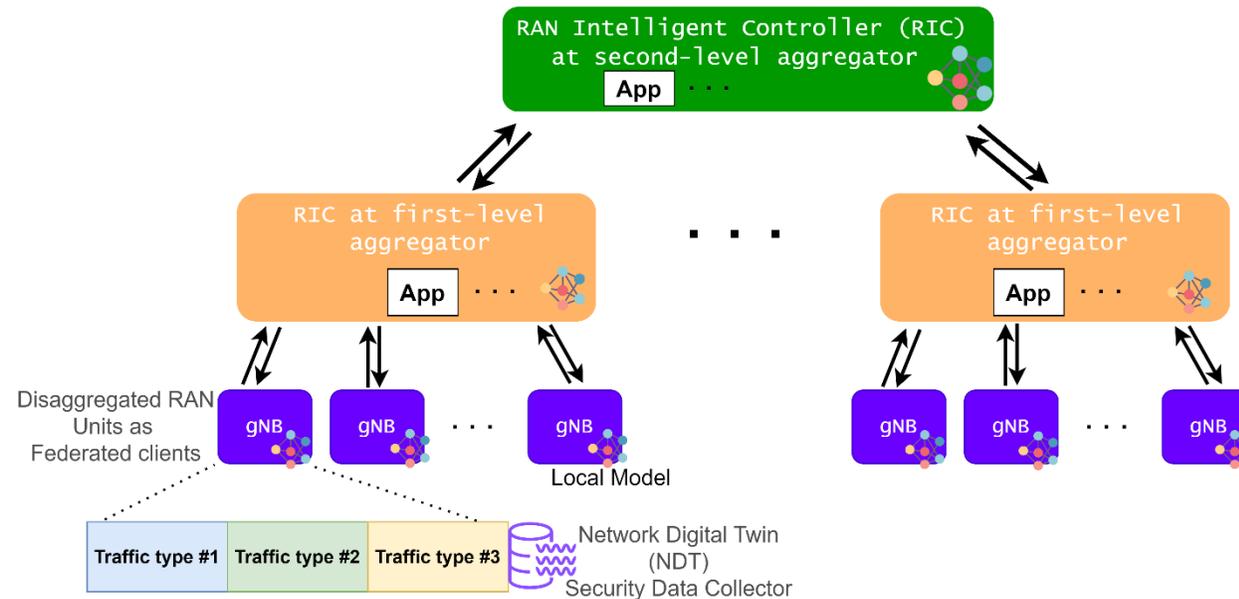
- Confidential Computing
  - Integrity of compute infrastructure, images and workloads
  - Trusted execution environment (TEE)
  - Remote attestation (RA)
  - Analysis and quantification of the performance overhead
  - Analysis of the need for a layer abstracting different approaches to TEEs
  - Standardization of RA and combined attestation
- Topology Attestation
  - Ensure path enforcement in under-/over-lay topologies
  - Sharing a small segment of metadata added to (some) packets
  - NBI of the PoT controller
  - Integration in a more general SDN environment
  - Common interface for both attestation controls





# SPR Controls - AI Features

- Anomaly detection in disaggregated environments
  - Address disaggregated architecture threats by means of Federated Learning
  - Increase safe integration with the use of synthetic data, NDT generated

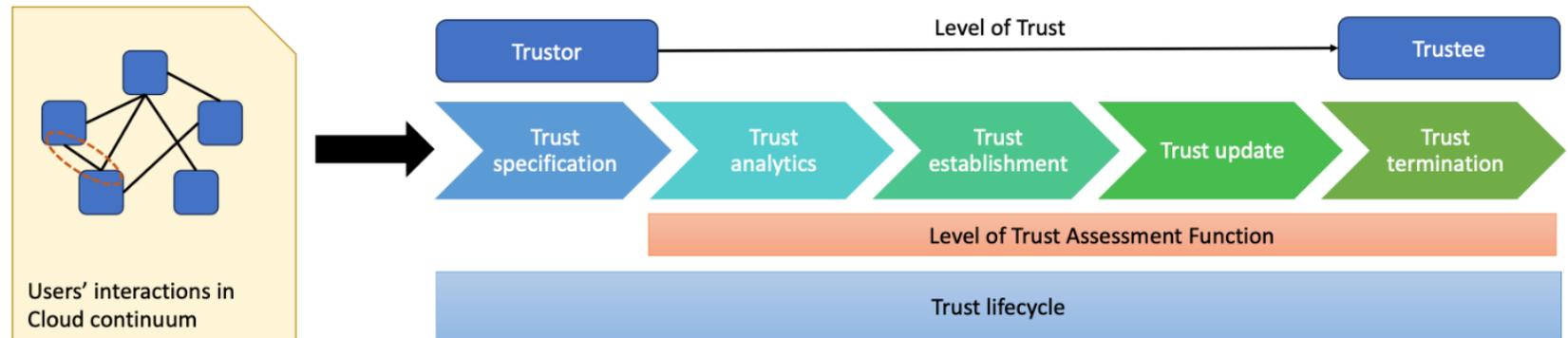


- Secure and privacy-enhanced machine learning
  - Provide interpretable explanations in attack detection and mitigation
  - Address the security-privacy balance in federated learning

# SPR Controls - Trust Fabric



- Crypto transition
  - Support quantum-safe and cloud-aware crypto mechanisms to satisfy:
    - Agility, maintaining evolution paths as algorithms and technologies evolve
    - Pliability, able to adapt to network management best practices
  - Controls based on ongoing projects in the Quantum Flagship and Horizon Europe
- Evolved LoTAF
  - Extend the original concept formulated in Hexa-X
  - Objective attributes, including NDT-based evaluation
  - Reputation systems
  - Subjective assessment
  - Trust lifecycle model









# Recommendations on SPR and Further Work

- Address the identified enablers, according to their current TRL
  - TRL 5-6, consolidated enablers
    - Confidential network deployment
    - Disitributed ledgers
  - TRL 3-4, experimental enablers
    - Trustworthy AI
    - Quantum-resistant crypto transition
    - Level of Trust assessment
  - TRL 1-2, concpetual, PLS-focused enablers
    - Context awareness
    - Anomaly detection
    - Deception mechanisms
    - JCAS threat mitigation
  - Report experiment results on the associated SPR controls
- Address SPR considerations in other WPs
  - Map them on the identified enablers and SPR controls
- Address the integration of selected enablers from other SNS JU projects
  - Lifecycle management
  - Security orchestration



# Chapter 7

## Overall 6G system design

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# Methodology for 6G technology enabler selection to update the 6G system blueprint

Enabler selection methodology : Knowledge Graph Method

Features for Recommended Enablers

Implementation: Noisy Knowledge Graph

Implementation: Pruning Parameters and Pruned Graph

Updated list of selected enablers after the pragmatic considerations

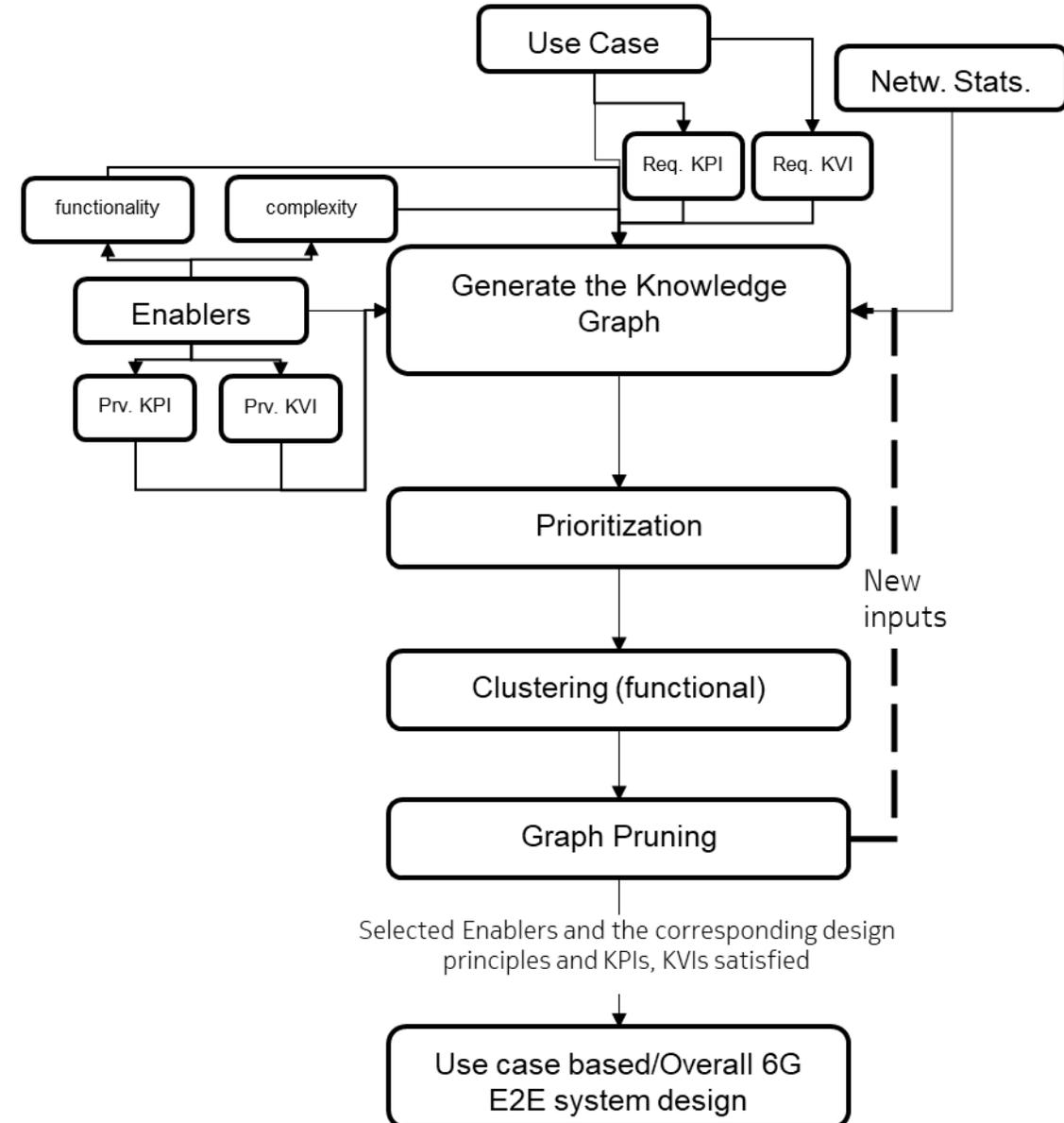
System blueprint refinement

Mapping selected enablers in the 6G E2E system blueprint

# 6G Technology enabler selection methodology : Knowledge graph method



- Step 1: Develop a Noisy Knowledge graph by utilizing the meta-data collected.
- Step 2: Prioritize the enablers and their dependencies that are essential for the 6G E2E system design.
- Step 3: Certain inputs might provide the same level of functionality, or they may achieve similar objectives. Hence, those inputs are clustered on the basis of functionality.
- Step 4: Graph pruning, i.e., selection of enablers, utilizing the defined objective and the constraints.
- Step 5: If a new enabler becomes available or the existing features of the enabler changes, the method can be reiterated to obtain a new or updated selection of enablers.



# Features for recommended enablers



Parameter Name	Explanation
Recommendation based on prioritization	Enablers are considered as High, Medium, or Low on prioritization scale towards inclusion into the 6G E2E system blueprint depending on their current state of development and experimentation.
High-level functionality	The main functional behaviour offered by the enabler. Needed functionalities are identified from the system requirements in section 2.1.
Enabler TRL level	The technical readiness level (TRL) of the enabler, with TRL-1 being just a concept and TRL-9 being deployable in product.
Standards requirement	Enablers could be requiring standardization effort, or they may not be needing any standardization.
Importance towards Migration	Certain enablers may be present in 5G and it will be important to maintain/evolve them to ensure a smooth migration to 6G. Interoperability with 5G is one important requirement for the 6G system in section 2.1.
Hardware requirements	The Enabler may or may not require new hardware components when implemented.
Dependency on other Enablers	An enabler might have a dependency on other enablers which are being explored across the Hexa-X-II project or other SNS-JU projects.
Existence of standard Interfaces	The enablers, which have dependency on each other, may or may not have readily available standardized interfaces.
Use case applicability	The use cases (established in the Hexa-X-II deliverable D1.2 [HEX23-D12]) to which the enabler is applicable.
Fulfilment of design principles	The design principles that a given enabler fulfils.

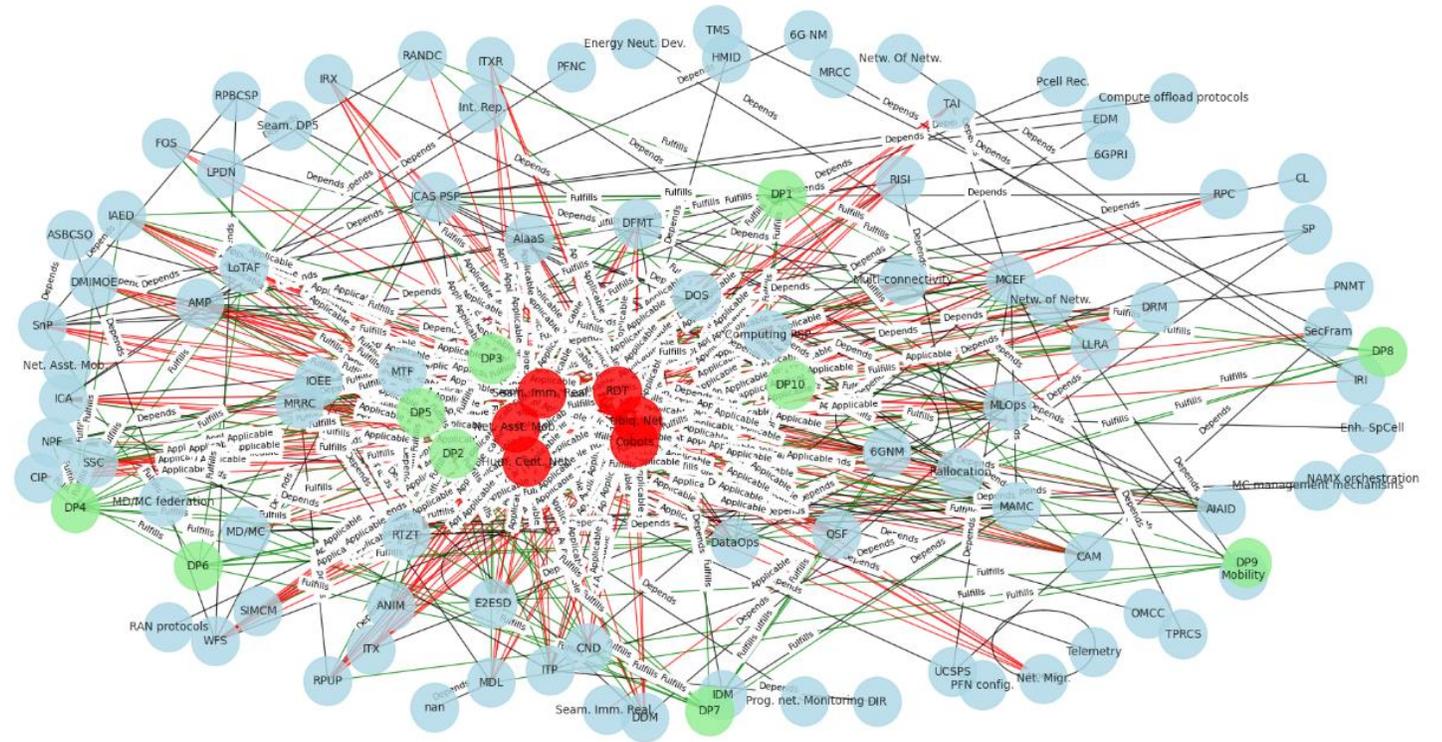
Enabler name	Recommendation based on prioritization	High-level functionality	Maturity (TRL level)	Standards requirements	Relevance to migration	Additional hardware requirements	Dependency on other enablers	Requires new interfaces	Applicable use cases *	Design principles addressed
Data recovery mechanisms	High	Optimizations of retransmission schemes	TRL 2	Yes	No	No	No	No	1,2,3,4,5,6	5
Ciphering & Integrity Protection	High	Enhance the ciphering and integrity protection	TRL 2	Yes	No	Not sure, to be determined	No	No	1,2,3,4,5,6	4,6
Intelligent transmitter and receiver	High	Signal processing functions	TRL 6	Yes	No	No	MLOps	No	1,2,3,4,5,6	N/A
Intelligent receiver	High	Receiver related algorithms	TRL 6	No	No	No	MLOps	No	1,2,3,4,5,6	N/A
6G network modularisation	High	Network functions layer, might also have limited impact on Pervasive functionalities	TRL 1	Yes	Yes	No	No	No	1,2,3,4,5,6	3,4,5,6,7,8,9
MLOps	High	Pervasive functionalities - AI Framework	TRL 2	Yes	No	No	DataOps, AIAaS, arch. means & protocols	No	1,2,3,4,5,6	2,3,6,10

link to meta-data collection <https://doi.org/10.5281/zenodo.12570057>

# Implementation: Noisy knowledge graph



Full Noisy Knowledge Graph with red bubbles representing use cases, green bubbles representing design principles and the blue bubbles representing the recommended enablers and their dependencies.



# Implementation: Pruning parameters and pruned graph

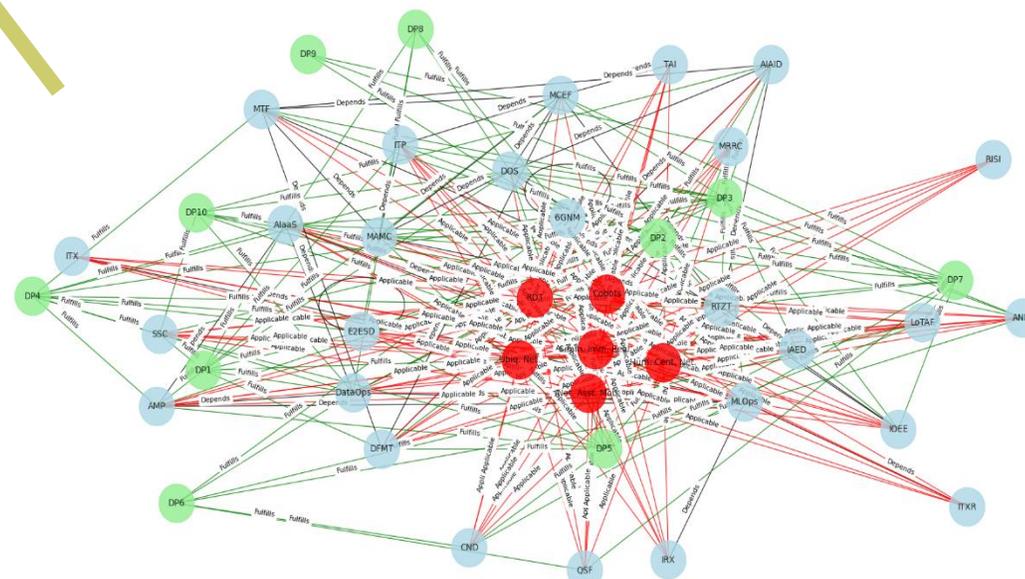


## Selected enablers by utilizing KG method

Category	Enabler Name
Service Exposure	Management capabilities exposure framework
Beyond communication services	AIaaS
6G network functions modularization & E2E design	6G Network modularisation
	E2E service design in modular 6G
Flexible radio integration & protocols	Modular RRC
Interaction with Application layer	Application-NW interaction for service differentiation and QoS/QoE management
Intelligent radio interface	Intelligent transmitter
	Intelligent receiver
	Intelligent transmitter and receiver
	Spectrum sharing, coexistence
	RIS system integration
New devices	Identification of 34 new 6G device classes (RHDRBL, HRL, <del>EMTC</del> , EN)
Intent-based management	Intent Translation & Provisioning
Multi-platform orchestration	Multi-agent systems for multi-cluster orchestration
	Decentralised Orchestration system
Cloud continuum integration	Integration and orchestration of extreme edge resources in the computing continuum
Closed loop control	Real-time Zero-touch control loops automation and coordination system
	AI/ML-based control algorithms for sustainability.
Security & privacy controls (pervasive functionalities)	Confidential Network Deployment
	Quantum-Safe Cryptography
	LoTAF
	Trustworthy AI
AI framework	MLOps
Data framework	Architectural means and protocols
	Monitoring and Telemetry Framework
	Data fusion mechanisms based on telemetry data DataOps

We perform the pruning of the noisy KG, wherein we set the parameters.

Parameter	Value
Priority	1
Maturity	>3
Edge connectivity	>10



# Updated list of selected enablers after the pragmatic considerations

Given their importance from a technical and operational perspective for the 6G E2E system, it is proposed to add the following enablers as part of the pragmatic considerations:

## Chapter 3 on architecture enablers

- Network migration
- Network of networks
- Multi-connectivity
- Compute protocols, signalling and procedures
- Multi-domain/multi-cloud federation

## Chapter 4: radio interface and protocol enablers

- Flat RRC design
- Radio processing units for user plane
- Ciphering and integrity protection
- Data recovery mechanisms
- SDAP (radio) protocols for beyond communication services
- Separation of IDLE mode and CONNECTED mode signalling
- Data driven mobility
- Computation aware mobility
- JCAS protocols, signalling and procedures
- JCAS waveforms and frame structures
- JCAS resource allocation

## Chapter 5: management and orchestration enablers

- Federated orchestration system
- Network Digital Twin

## Chapter 6: security, privacy and resilience

- JCAS security and privacy

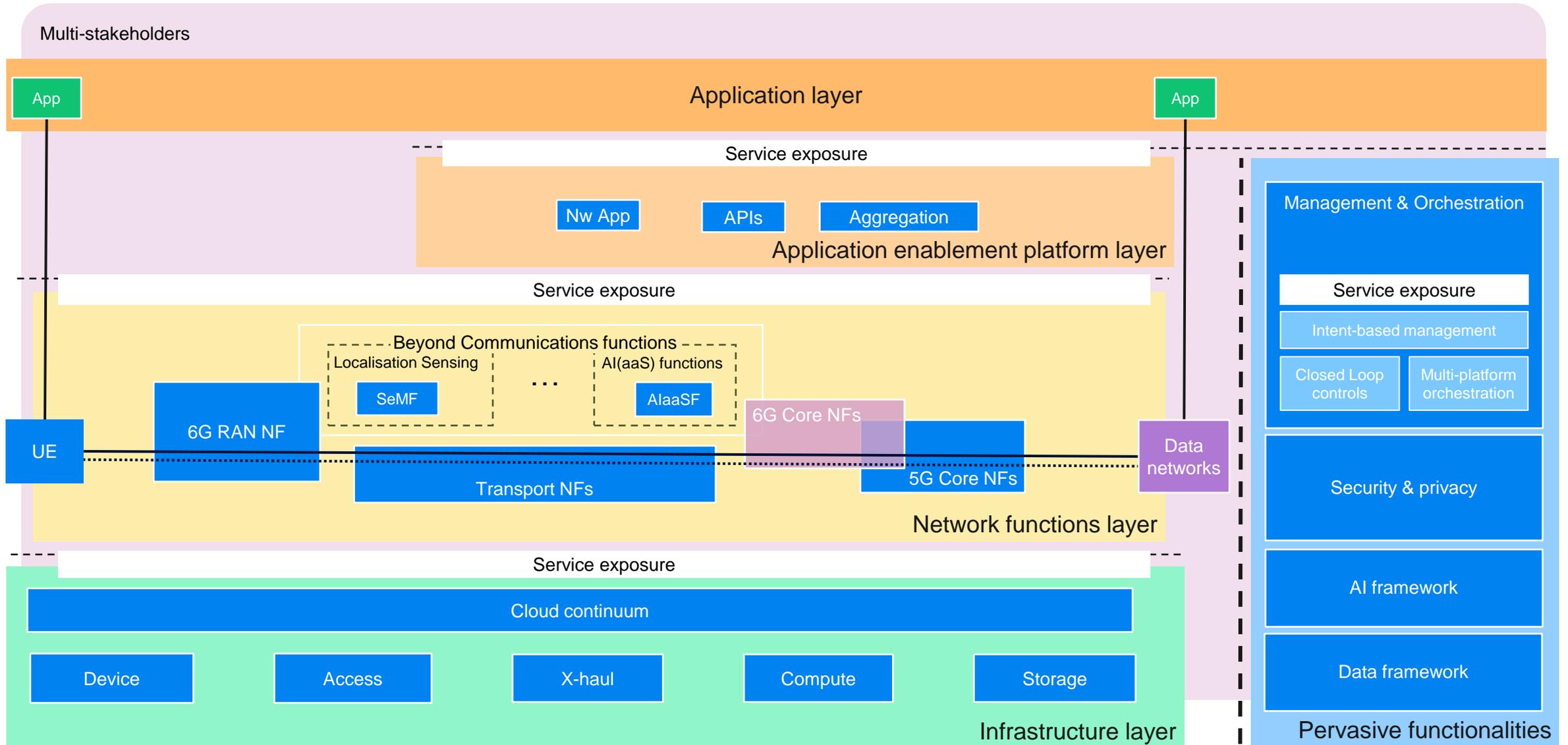
Category	Enabler Name
Intelligent radio interface	Intelligent transmitter
	Intelligent receiver
	Intelligent transmitter and receiver
	Spectrum sharing, coexistence
JCAS PHY	JCAS waveforms and frame structures
	JCAS resource allocation
New devices	Identification of 3 new 6G device classes (RHDRBL, HRLL, EN)
Flexible radio interface and protocol	Modular RRC
	Flat RRC design
	Separation of IDLE mode and CONNECTED mode signalling
	Ciphering & integrity protection
	Data recovery mechanisms
	SDAP protocol for beyond communication services
	Radio processing units for user plane
Mobility procedure	Data driven mobility
	Computation aware mobility
Interaction with Application layer	Application-NW interaction for service differentiation and QoS/QoE management
Smooth path from 5G	Network migration

Category	Enabler Name
Network functions	6G Network modularisation
	E2E service design in modular 6G
New access and flexible topologies	Multi-connectivity
	Network of networks
Cloud continuum integration	Multi-domain/multi-cloud federation
	Integration and orchestration of extreme edge resources in the computing continuum
Beyond communication services	AlaaS
	JCAS protocols, signalling and procedures
AI framework	Compute protocols, signalling and procedures
	MLOps
Data framework	Architectural means and protocols
	Monitoring and telemetry framework
	Data fusion mechanisms based on telemetry data
Service Exposure	DataOps
	Management capabilities exposure framework
Intent-based management	Intent translation & provisioning
Synergetic orchestration	Multi-agent systems multi-cluster orchestration
	Decentralised orchestration system
	Federated orchestration system
Closed loop control	Real-time zero-touch control
	loops automation and coordination system
Network digital twin	AI/ML-based control algorithms for sustainability.
	Network digital twin creation mechanisms
Security & privacy controls (pervasive functionalities)	Confidential network deployment
	Quantum-safe cryptography
	LoTAF
	JCAS security and privacy
	Trustworthy AI

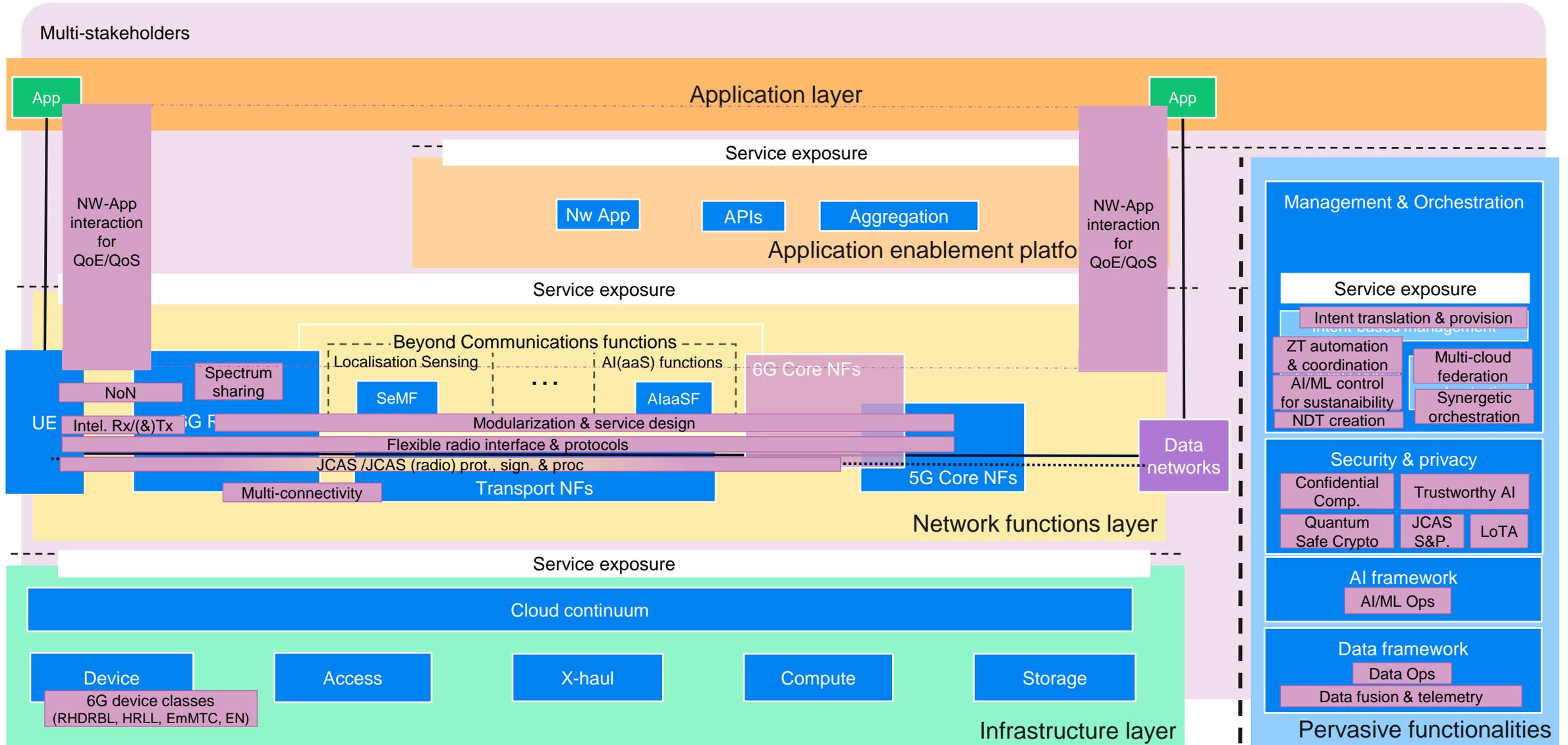
# System blueprint refinement



Data plane  
Control plane  
API/Interface/Intents  
Control/Observability



# Mapping selected enablers in the 6G E2E system blueprint





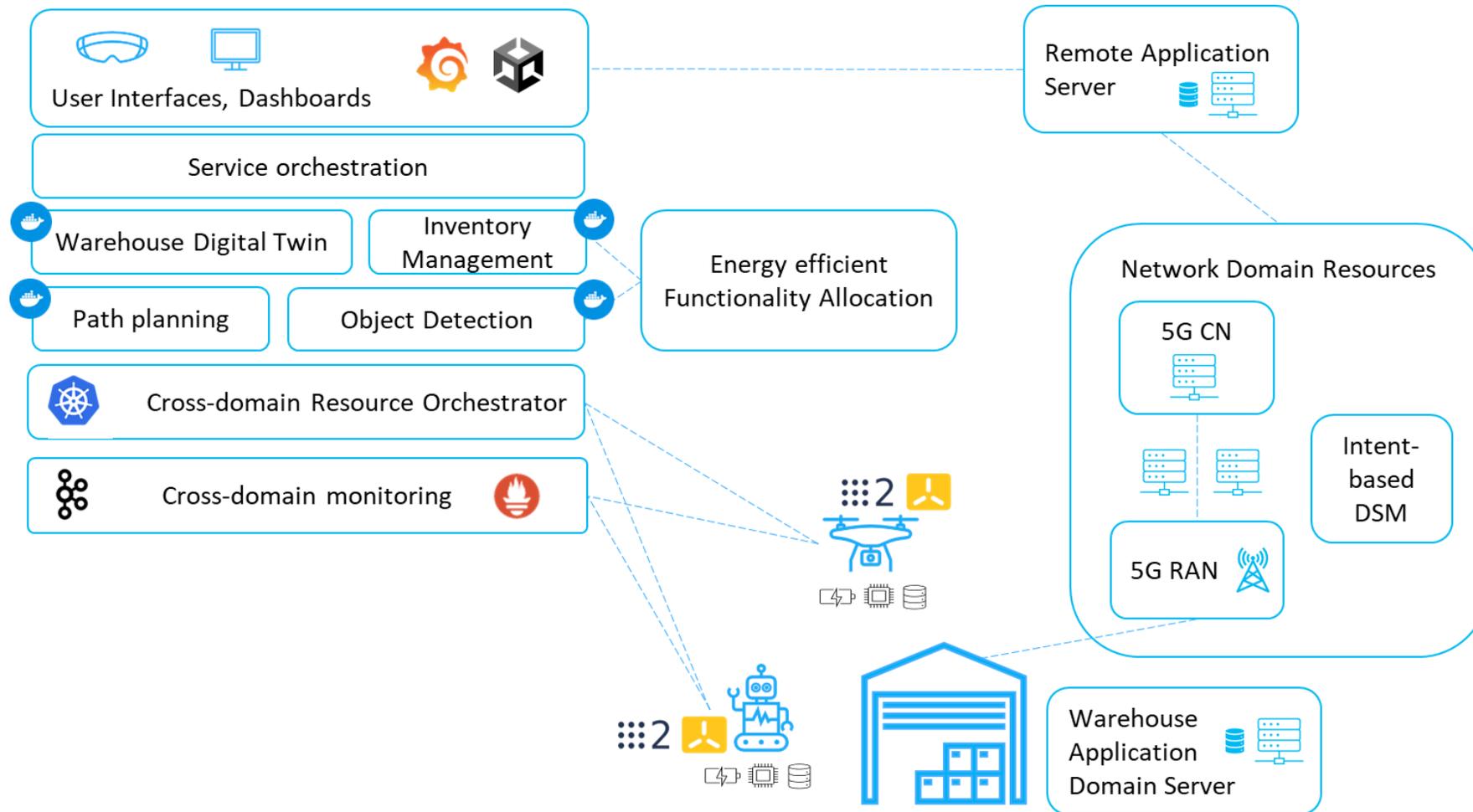
# Chapter 8

## E2E system level evaluation

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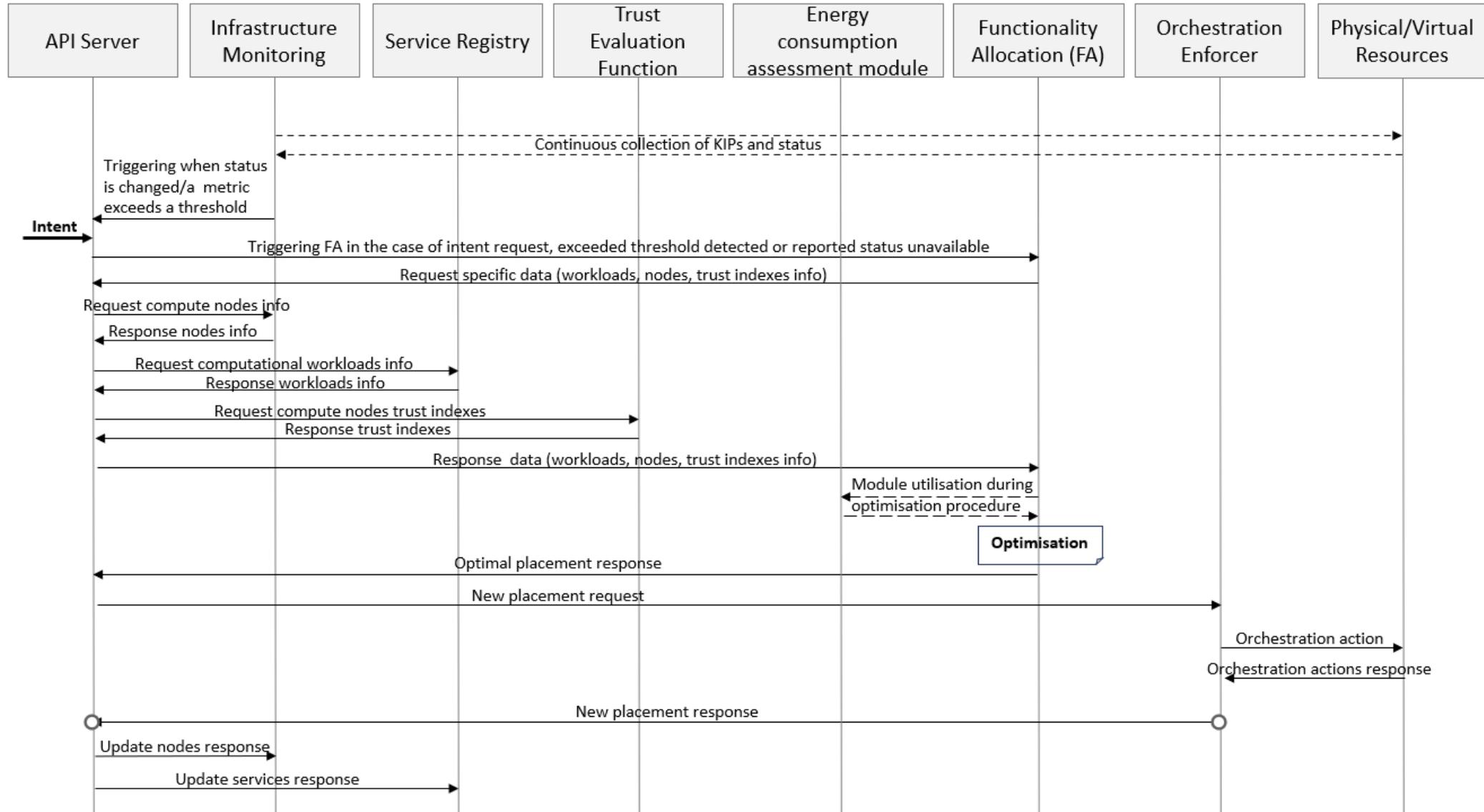


# System-PoC A



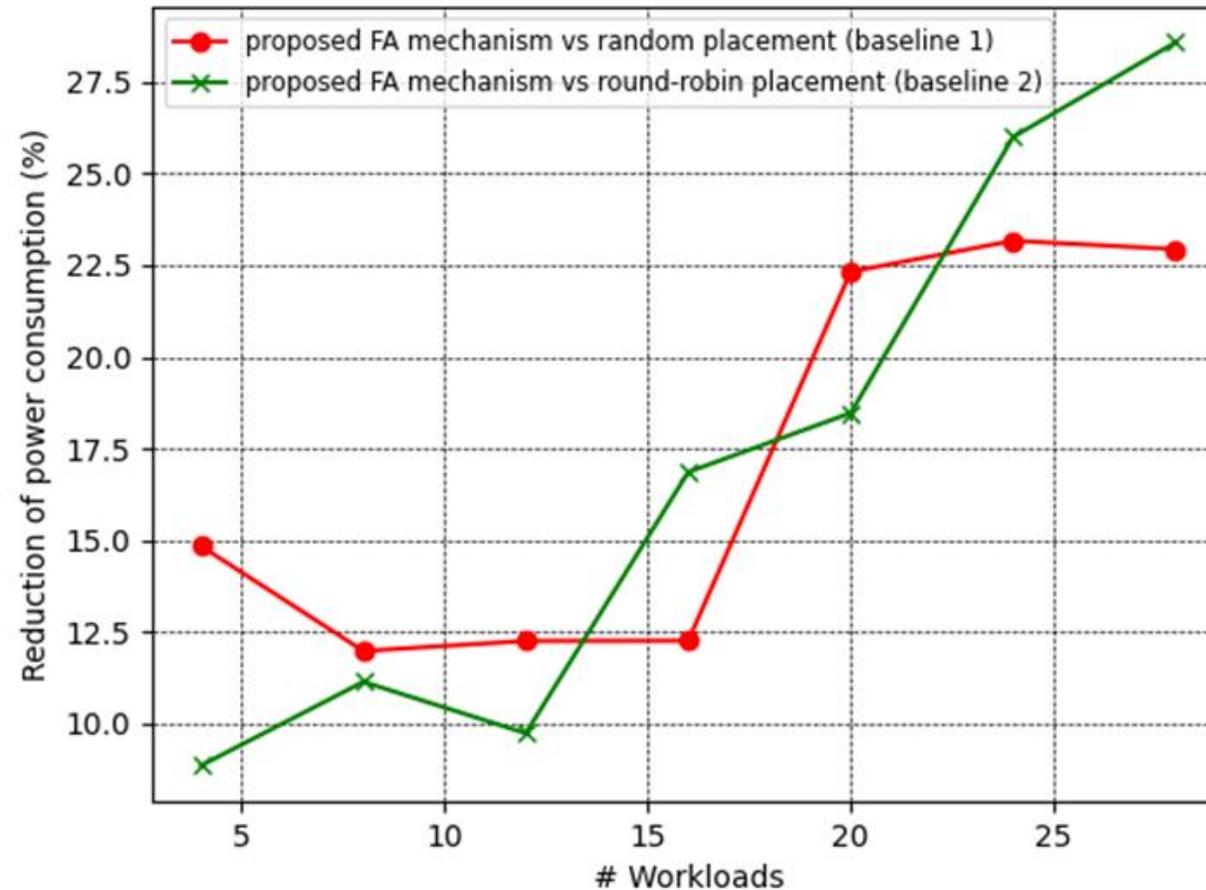
Overview of the platforms and tools configuration for the warehouse inventory management designed solution [HEX223-D22]

# System-PoC A



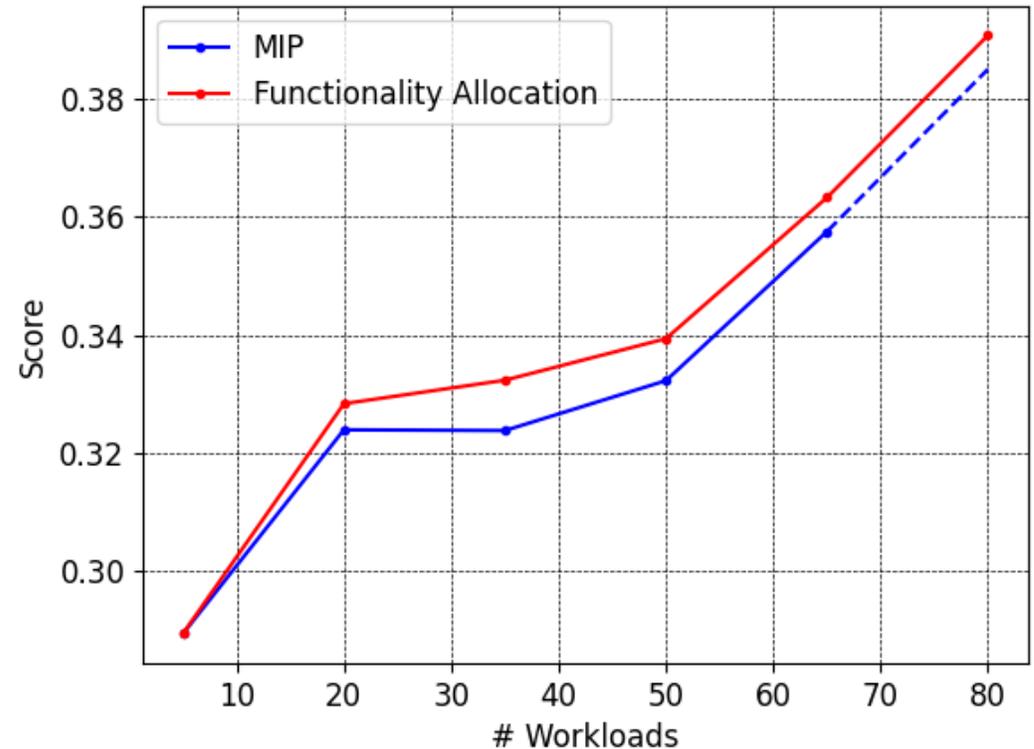
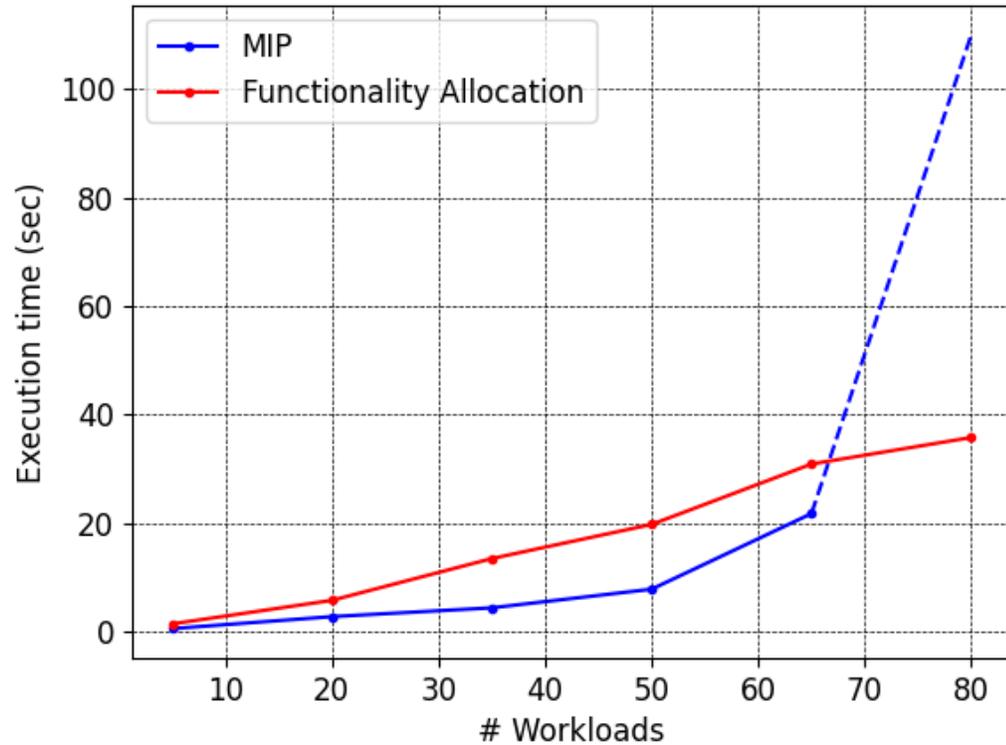
Message sequence diagram of System-PoC A [HEX224-D6.3]

# System-PoC A



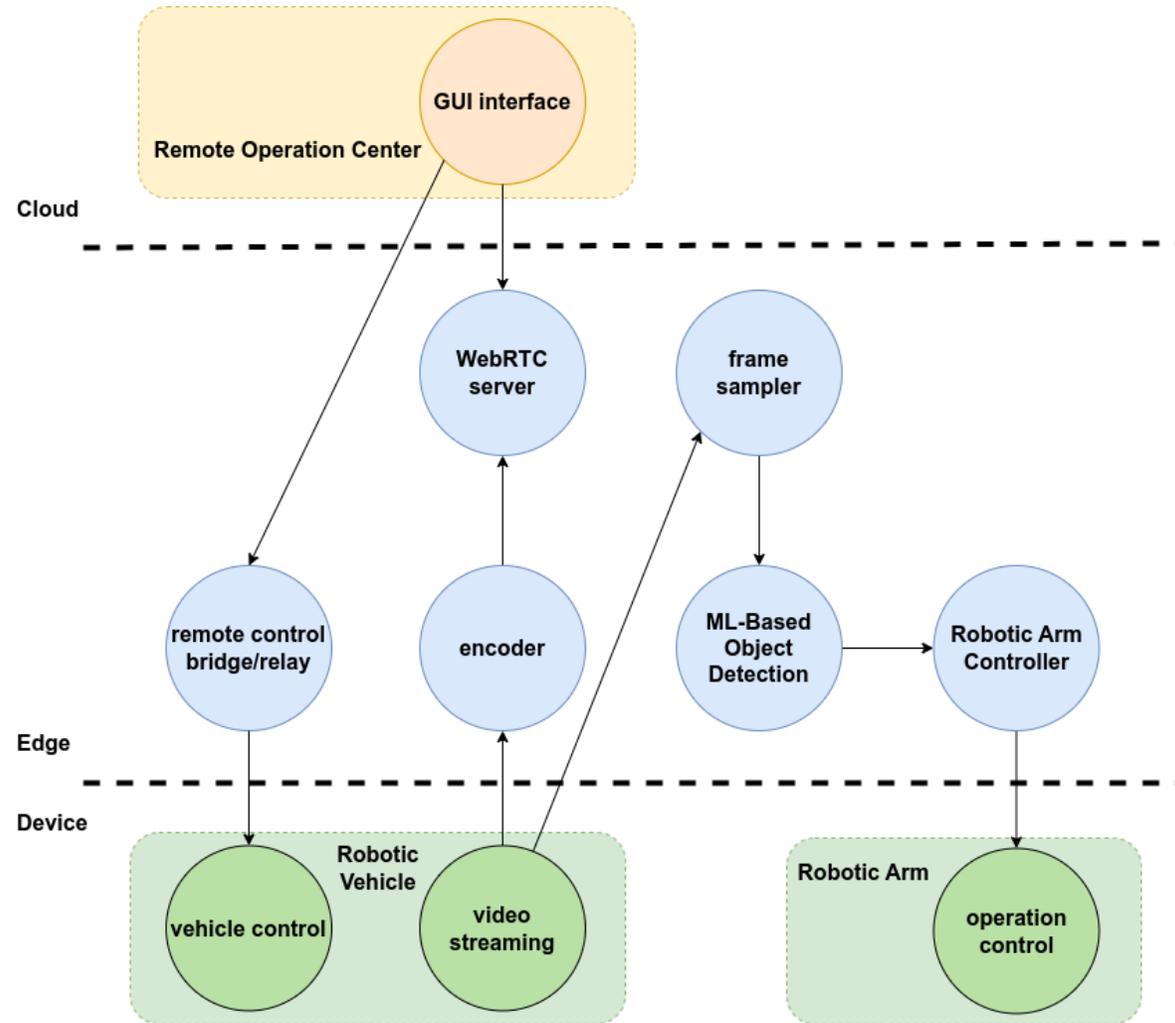
Reduction of power consumption with increasing number of compute workloads of the proposed FA mechanism compared to two baseline algorithms [HEX223-D22]

# System-PoC A



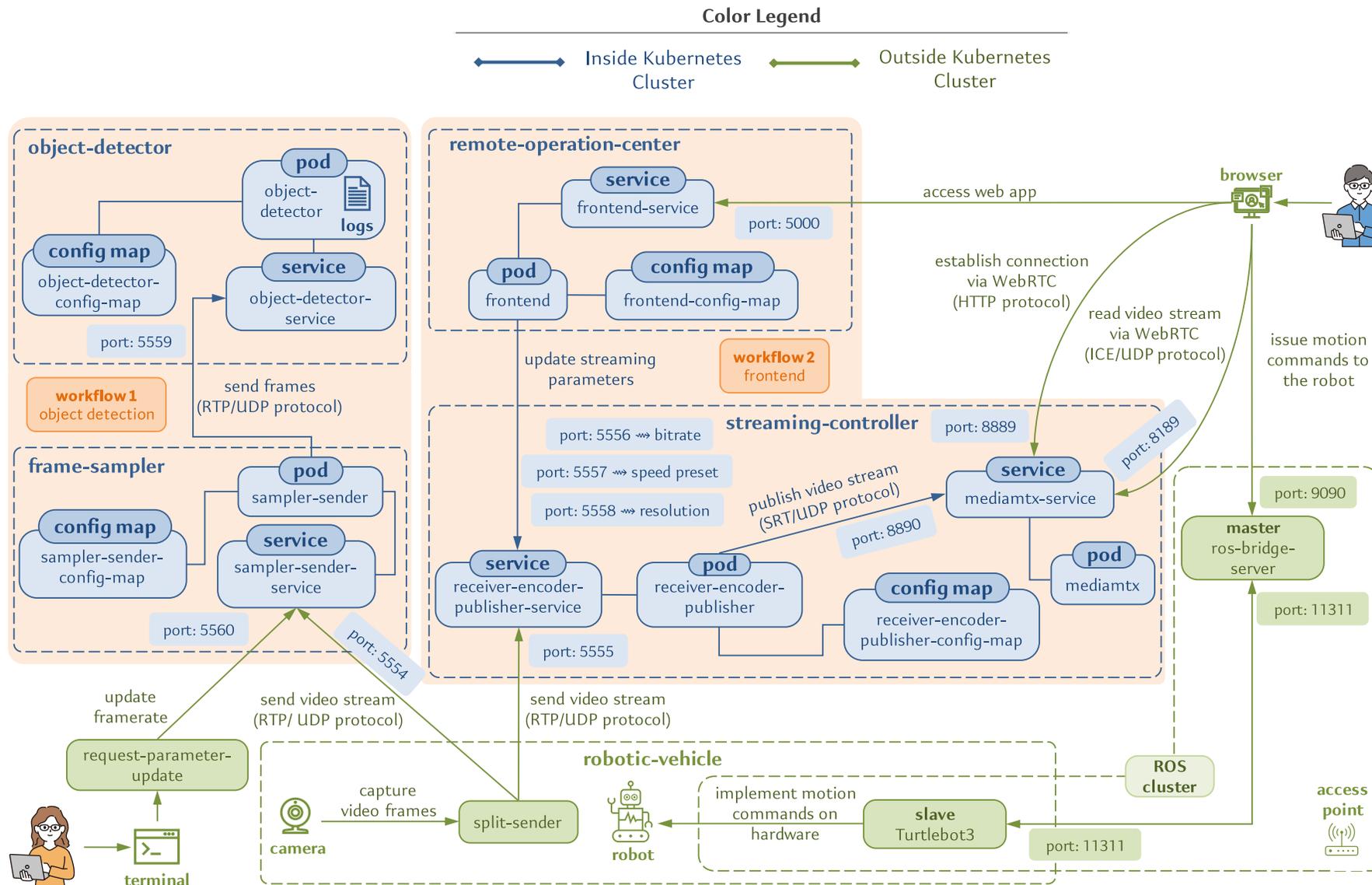
Comparison of the execution time (left) and the scores (right) achieved with increasing number of workloads having a fixed number of compute nodes (43) for the functionality allocation algorithm and PuLP GLPK MIP solver [HEX224-D63]

# Component-PoC#B.1 - AI-assisted E2E lifecycle management of a 6G latency-sensitive service across the compute continuum



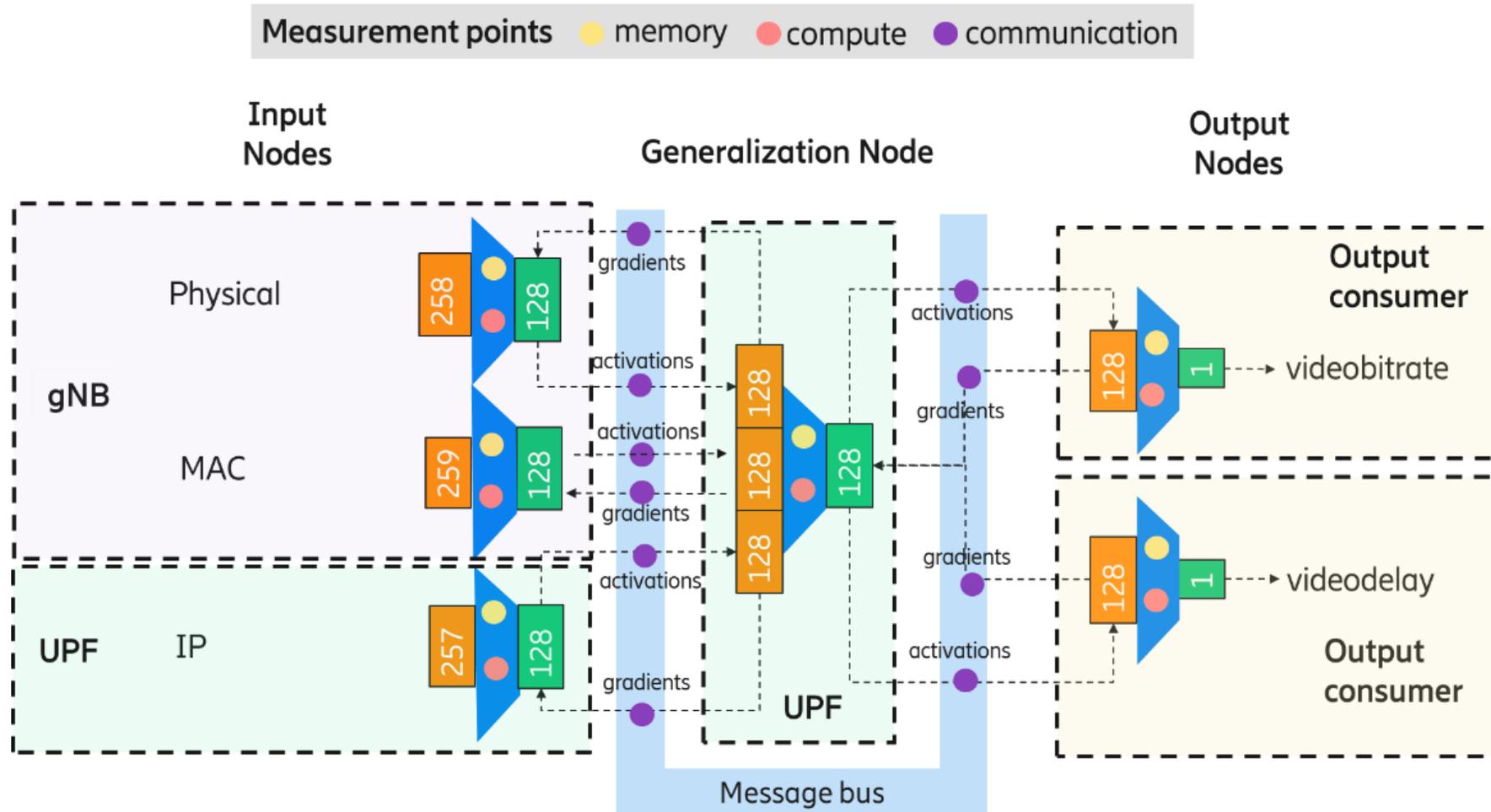
A high-level overview of the architecture and the design of the developed latency-sensitive application in Component-PoC#B.1

# Component-PoC#B.1 - AI-assisted E2E lifecycle management of a 6G latency-sensitive service across the compute continuum



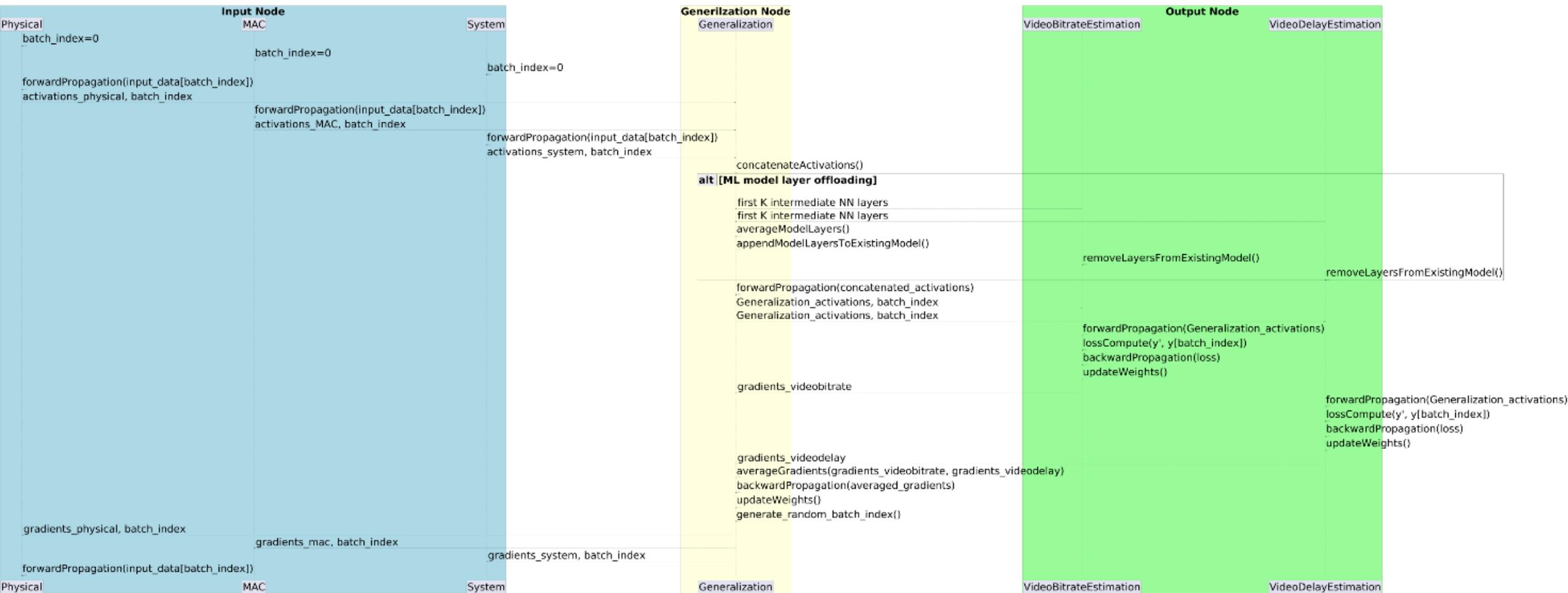
A detailed view of the Component-PoC#B.1 application's deployment

# Component-PoC#B.2 - Training and inference of collaborative distributed machine learning model on a dynamically changing heterogeneous 6G architecture environment



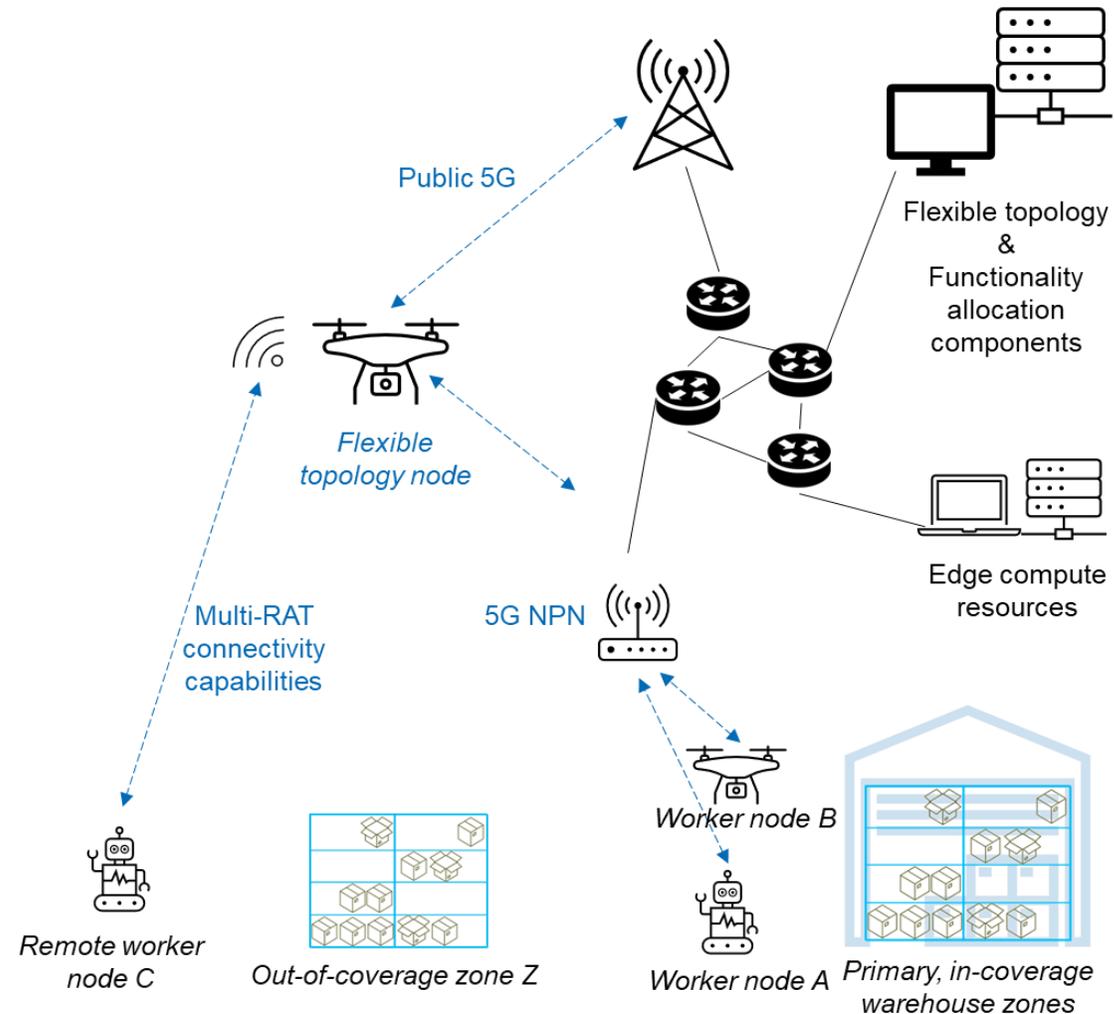
Split Neural Network setting that enables training an ML model collaboratively between network functions. [HEX224-D33 - Section 8.1]

# Component-PoC#B.2 - Training and inference of collaborative distributed machine learning model on a dynamically changing heterogeneous 6G architecture environment



The sequence diagram of model generalization to multiple use cases and model layer offloading is illustrated in split learning setting.

# Component-PoC#B.3 - Trustworthy flexible topologies in 6G, leveraging on “beyond communication” aspects



Flexible topology architecture for showcasing Component-PoC#B.3 inventory management scenario, realized through a trio of Worker Nodes, consisting of two AMRs and a single autonomous UAV, all operational within a spatially defined area [HEX224-D33]



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**6G**SNS

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