Partners: Nokia, Ericsson, Atos, Intel, Nextworks, Orange, TU Dresden, TIM, UC3M, Univ. Pisa, Wings

HEXA-X D5.3 Deliverable

D5.3 summary slides

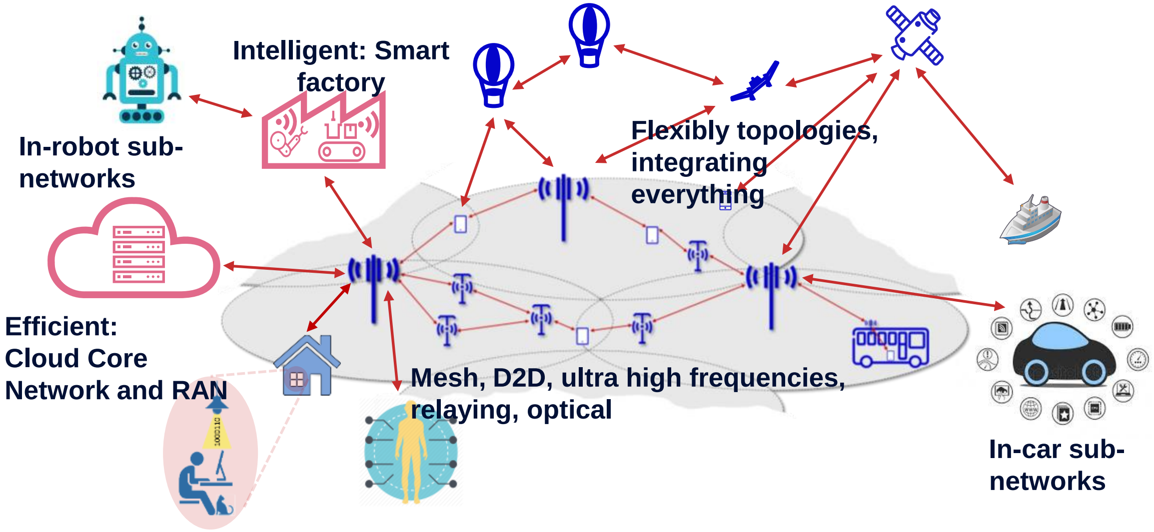
Hexa-X

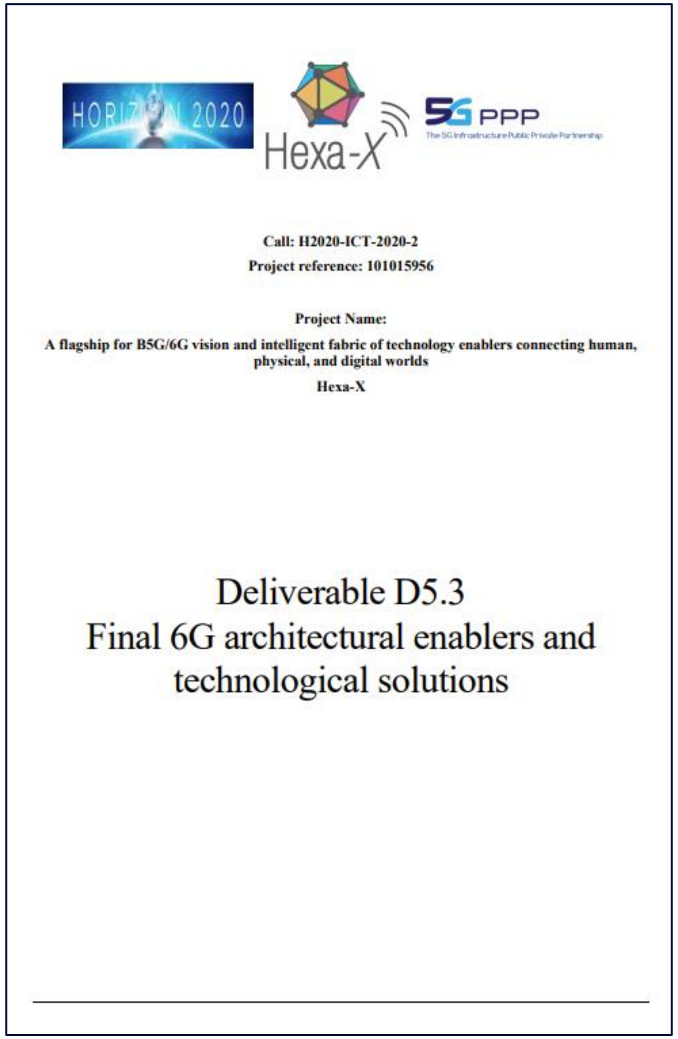
hexa-x.eu

2023-04-30

Introduction

- Main objectives are to develop:
  - Intelligent network: Technical enablers for AI integration and network programmability
  - Flexible network: Architectural components that support a new flexible network design
  - Efficient network: Streamlined and redesigned architecture for a cloud-native RAN and CN
- This document is the third and last deliverable of WP5, building on D5.1 and D5.2
- This slides in this slide-set has the section number in the title so it is easy to go to the corresponding D5.3 word document if more information is needed




HORIZON 2020

Hexa-X

5G PPP

Call: H2020-ICT-2020-2

Project reference: 101015956

Project Name:

A flagship for B5G/6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds

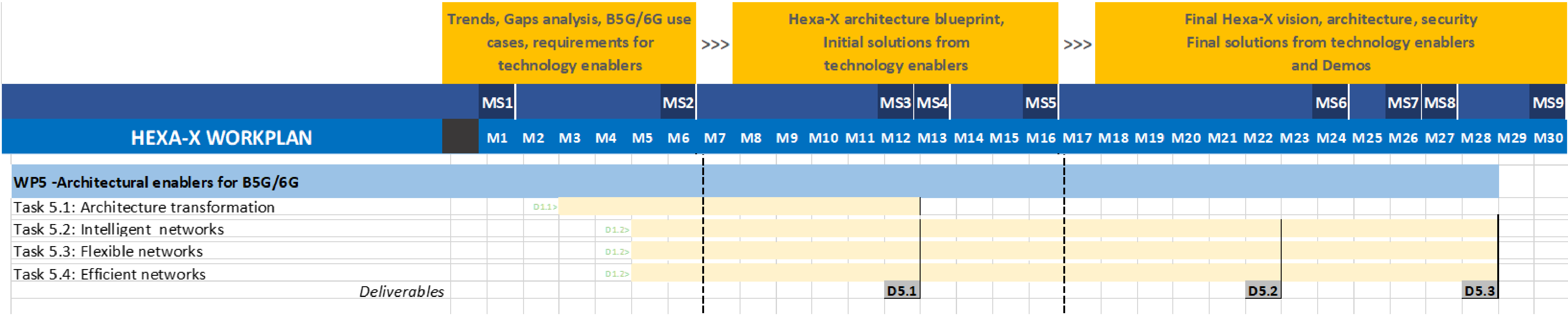
Hexa-X

Deliverable D5.3

Final 6G architectural enablers and technological solutions

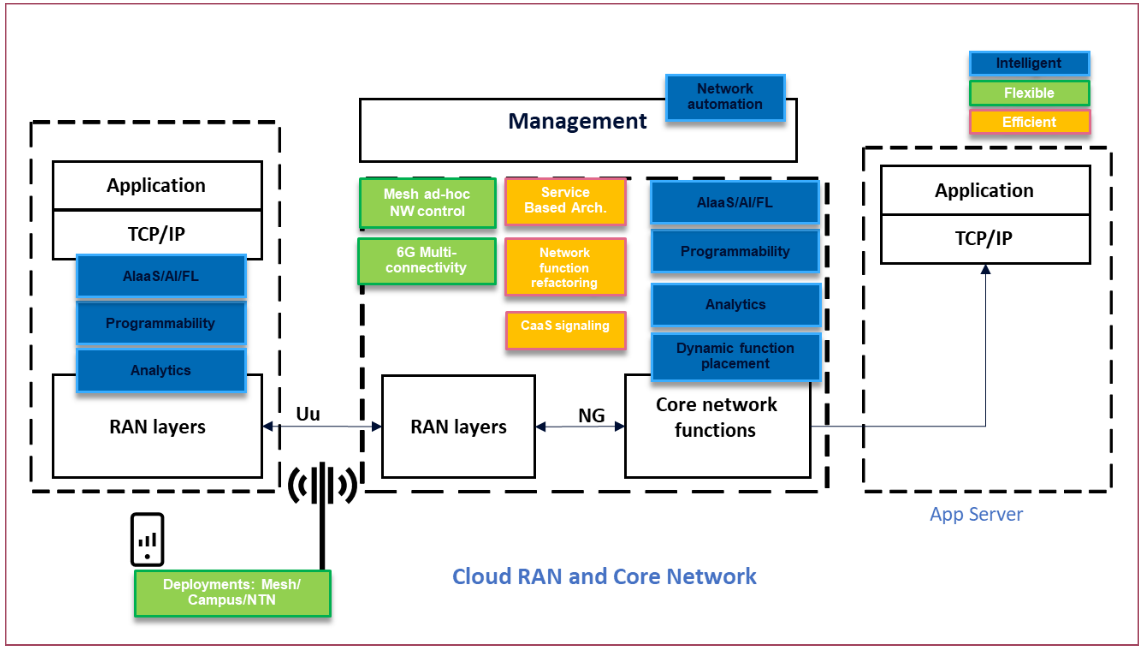
Deliverables and the timeline

- *MS02: Trends and drivers for architecture design **M06***
- *D5.1: Initial 6G architectural components and enablers, M12*
- *D5.2: Analysis of 6G architectural enablers' applicability and initial technological solutions, **M22***
- ***D5.3: Final 6G architectural enablers and technological solutions, M28***



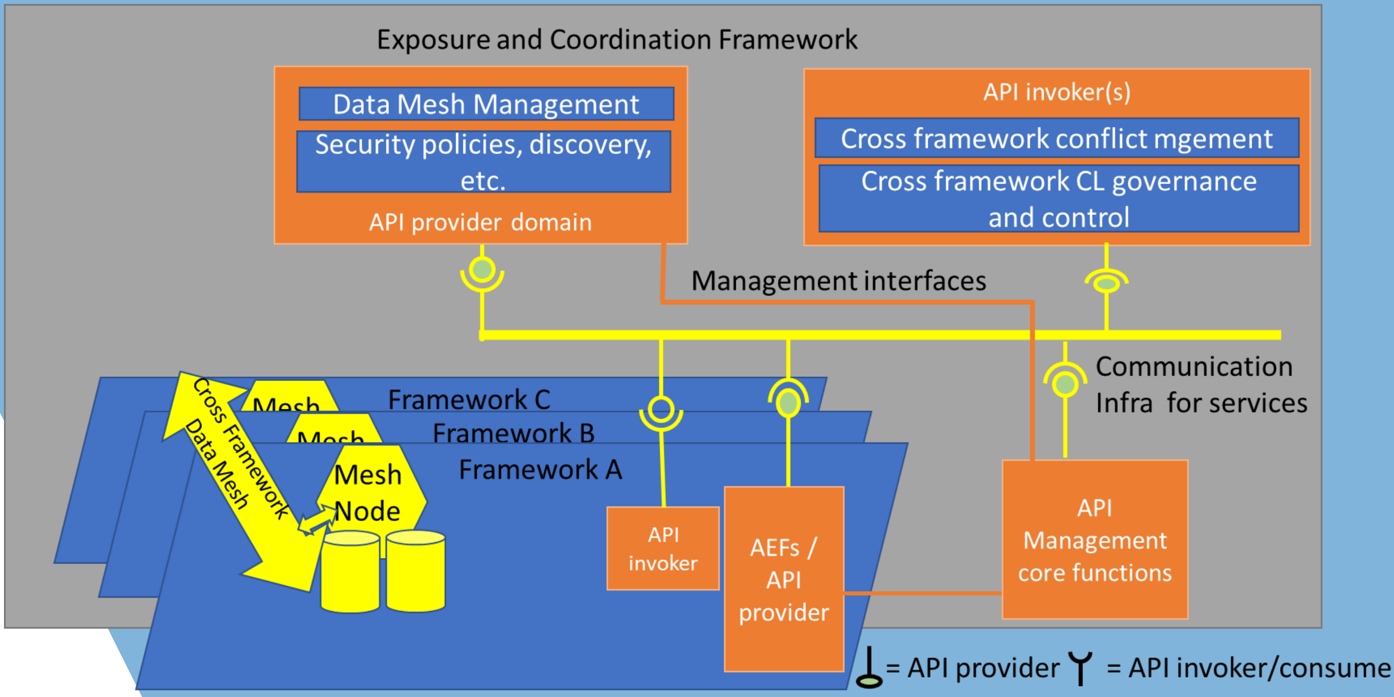
2 - WP5 overview of the architecture

- The intelligent network (blue boxes in Figure) deals with enablers for developing a fully integrated AI and programmable network.
- The flexible network enablers (green boxes in Figure) consist of a mix of enablers for radio resource management and for supporting new deployment such as mesh networks and NTN.
- The efficient network enablers (orange boxes in Figure) are a collection of new ways to streamline the RAN and CN architecture, minimize the signalling needs and make the architecture more flexible.



2.1 Exposure and Coordination Framework

- **Background**
  - Several frameworks have been introduced for the Hexa-X architecture. Each framework has its own specific purpose, resources, data and services that it can expose for the benefit of other frameworks.
- **Motivation**
  - How to expose different services and data between the frameworks?
  - Different frameworks can be integrated into a unified deployment where they can use and share services and resources from other frameworks.
- **Solution**
  - Depending on the level of integration a flat SBA style tightly integrated approach between the functions of different frameworks can be applied, or the integration API management framework defined in WP6 [D6.2] can be used for loose integration where each framework is considered as separate management domain.



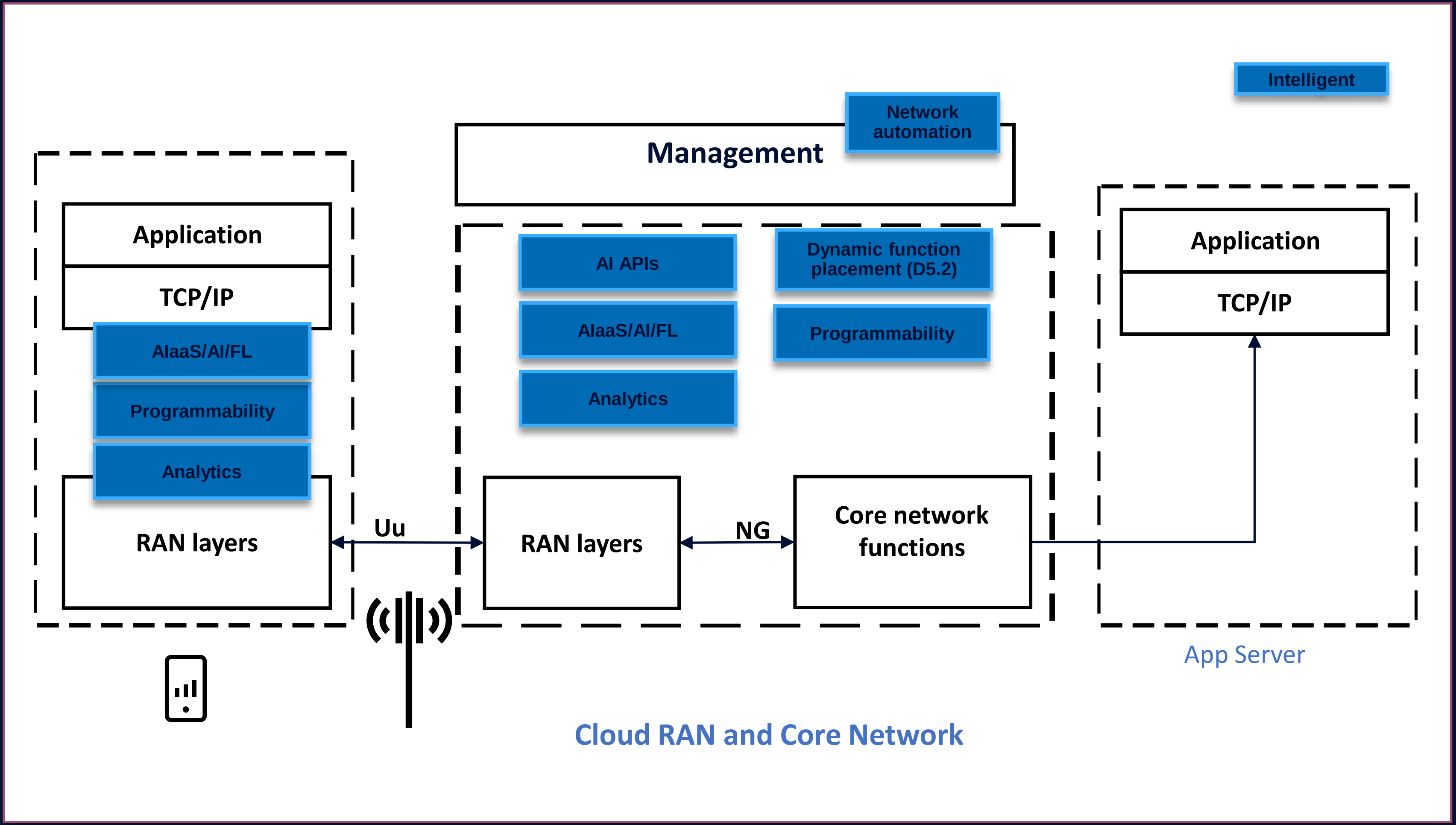
Loose integration of frameworks

- **Conclusions**
  - The Exposure and Coordination Framework should contain cross framework governance and control (i.e., related policies, conflict management, API discovery)
  - CAPIF for API management and Data Mesh for streaming data used in loose integration. SBA at the function level in tight integration.

Intelligent network enablers

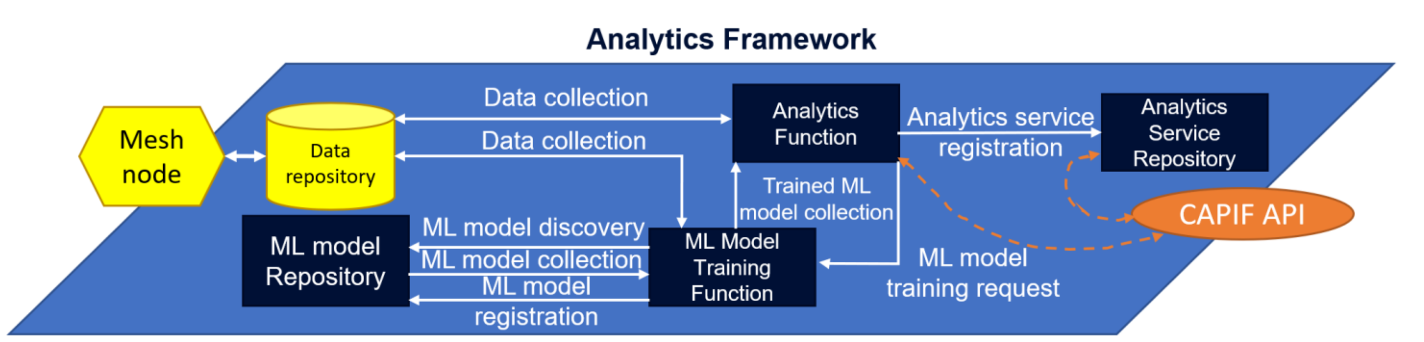
3 Intelligent network introduction

- Intelligent network is based on common enablers for AI as a Service (AIaaS), Federated Learning as-a-service (FLaaS), that leverage data acquisition, data exposure and a common cross-domain analytics framework.
- The network automation and orchestration are integral parts of Intelligent network using AI and analytics to run the network in a fully automated manner.
- Intelligent network enablers operate across the cloud continuum from the central cloud to the edge and to far edge including the UE.



3.1.1 Analytics framework

- **Background**
  - Currently no consistent analytics framework exists cross-planes and cross-domains.
  - Each plane/ domain (RAN, Core, and Management) independently taking care of data collection and production of analytics.
- **Motivation**
  - Provide the integration of AIaaS and support distributed AI agents for the analytic framework.
  - Identify opportunities to taking advantages of trained models stored in repositories and input data set by another domain/plane.
- **Solution**
  - Develop an End-to-End analytic framework in order to be able to exchange knowledge and analytics cross-planes and cross-domains.

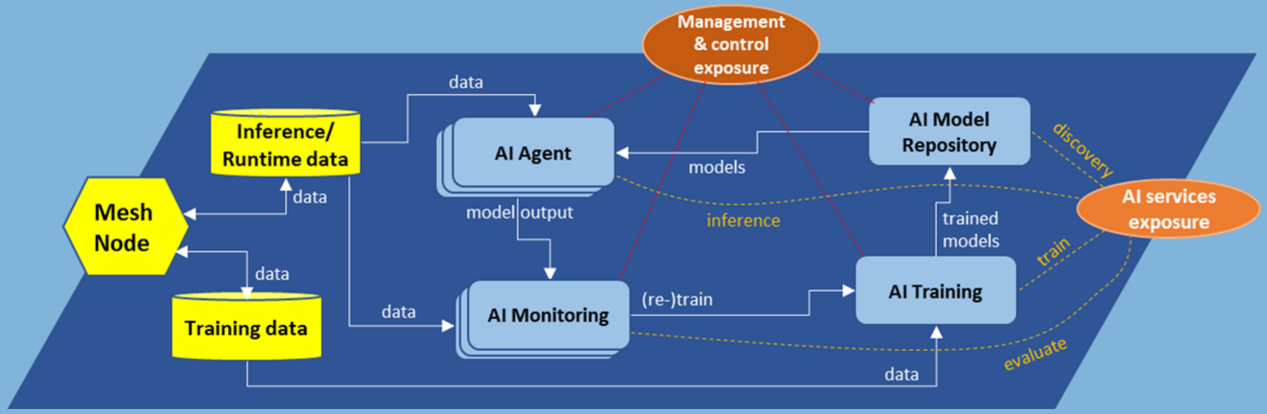


Analytics framework entities	Required services	Provided services
ML model training function	ML model discovery	ML model training service
	ML model collection	
	ML model registration	
	Data (set) collection	
Analytics Function	Analytics service registration	Perform Analytics, inference and Prediction
	Data collection	
	ML model training	
	Trained ML model collection	
	ML model discovery	
Analytics service repository		Analytics discovery
		Analytics update
ML model repository		ML model discovery
		ML model update

- **Conclusions**
  - The proposed solution provides an end-to-end framework for unified analytics production across-domains/planes by taking advantages of trained ML models and data sets. This can result in improvement of the communication between RAN management and the core network which are currently limited to requests/responses through the OAM as well as improvement of sharing knowledge in terms of analytics.

3.1.2 AIaaS framework

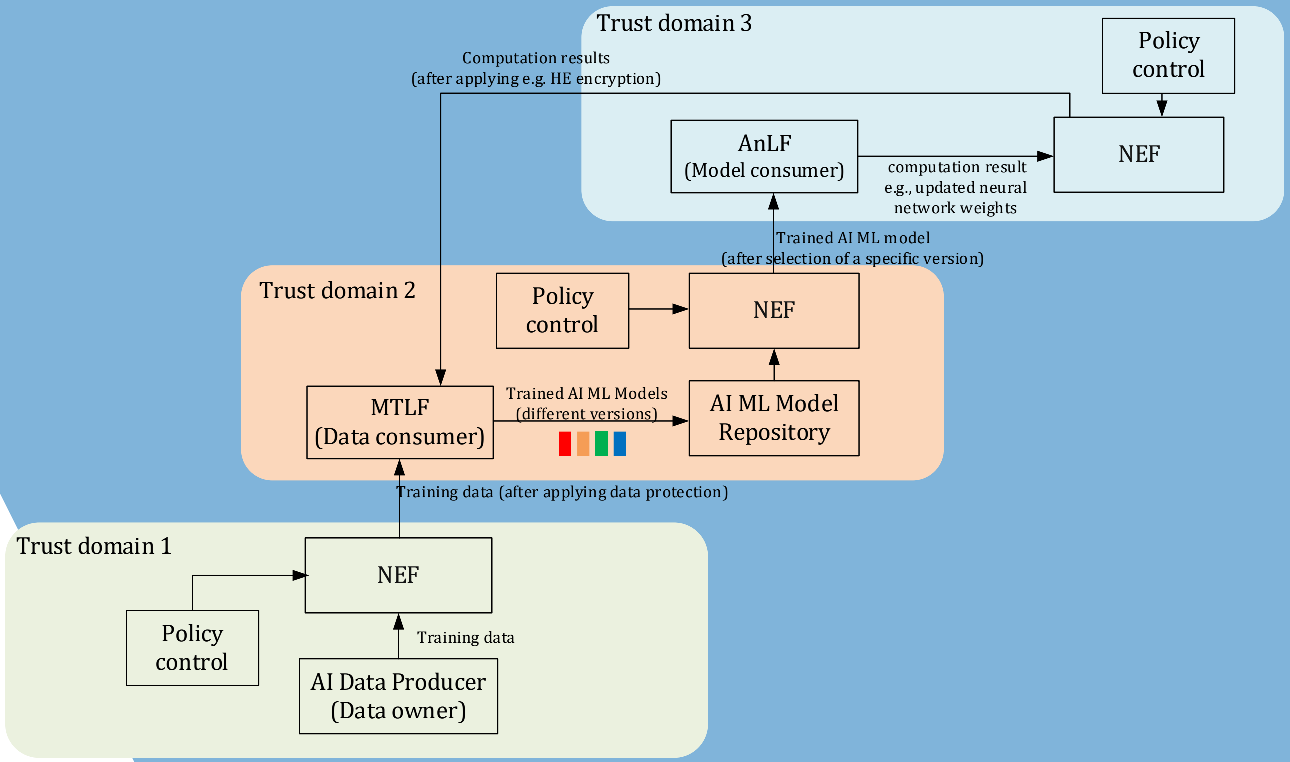
- **Background and motivation**
  - Common services and functions for consumption of in-network AI capabilities are needed to enable 6G intelligent networks.
- **Solution**
  - Interconnected AI functions in support of tailored closed loops
    - network and service/application automation,
    - cloud-native in-network AI virtualized functions.
  - Three main AI related operational workflows supported
    - training, inference, monitoring,
    - agnostic from AI functions deployment model.
- **Conclusions**
  - Enable a unified exposure (through 3GPP CAPIF-like) approach to facilitate AI services consumption
    - discovery, train, evaluate, infer.



AIaaS framework functions	Required services	Provided services
AI model repository		AI/ML model discovery
		AI/ML model storage
		AI/ML model update
AI training	AI/ML model storage	AI/ML model training
	AI/ML model update	
	Training Data ingestion	
AI agent	AI/ML model discovery	AI/ML model inference
	Inference Data ingestion	AI/ML model onboard
AI monitoring	AI/ML model inference	AI/ML model performance evaluation
	Inference Data ingestion	AI/ML model re-training decision logic (policy based)

3.1.2.2 Managing cross-network domain trust for in-network learning

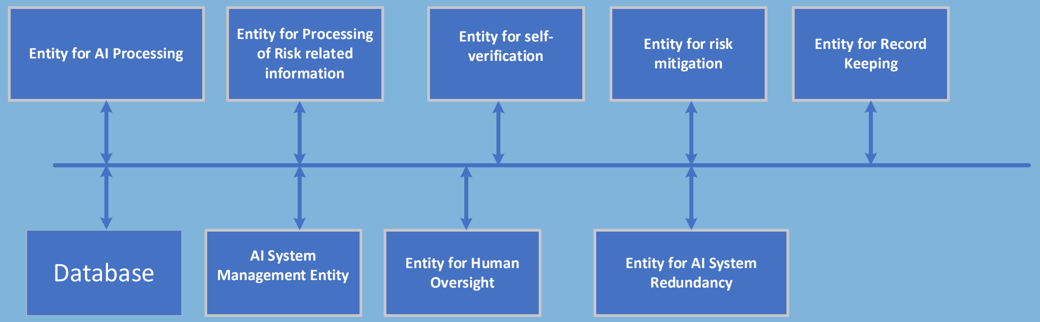
- **Background**
  - In Hexa-X delivery D5.2 (see [HEX-D52]) a platform was introduced supporting the management of cross-network domain trust for in-network learning
- **Motivation**
  - Evolve the cross-domain and multi-trust level network environment towards envisioned deployments.
  - Investigate how to support secure AI across domains.
  - Investigate the exposure of AI framework services using CAPIF.
- **Solution**
  - A framework for managing multiple cross-domains is proposed supporting secure exchange of AI related information:
    - Training data protection, e.g., using differential privacy (local DP), anonymization, pseudonymization, encryption (e.g., homomorphic encryption (HE))
    - AI ML Model protection, e.g., by generating different AI ML model versions using, e.g., DP-SGD.
    - Computation result (e.g., updated neural network weights when participating in FL) protection, e.g., by applying HE.
  - The framework supports the integration with CAPIF.
- **Conclusions**
  - The **"AI communication and computing overhead"** architecture KPI can be positively impacted, as the scope of operation of a given AI agent can be extended to different privacy domains. The benefit consists in bypassing the need to replicate a model within each trust domain, provided that the privacy requirements are addressed within each domain.



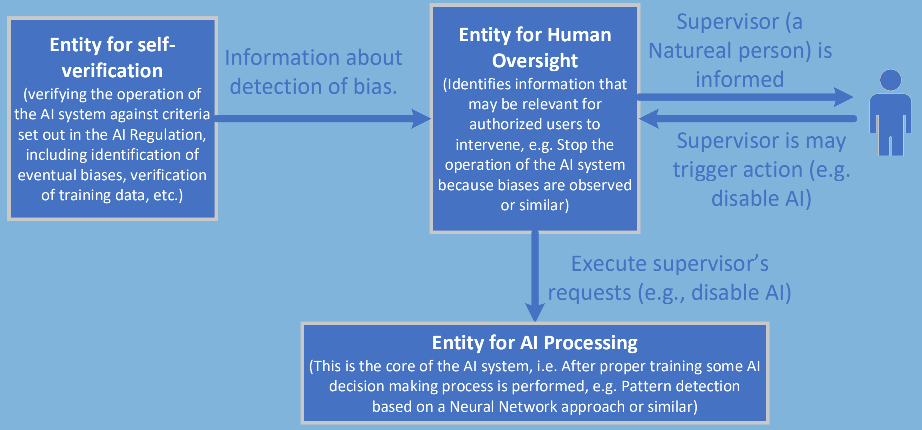
Interactions between AI frameworks of different trust domains

3.1.2.3 In-network AI system architecture addressing requirements of the EU AI regulation

- **Background**
  - The EC is supporting the development of a European Artificial Intelligence Act (AI Act *) by the European Parliament and Council.
  - In Hexa-X Deliverable D5.2, Annex A.2 [HEX-D52], a proposed system architecture was derived in accordance with the requirements of the draft AI Act.
- **Motivation**
  - Further build on the D5.2 architecture proposal and derive interactions between the inherent entities with the objective to meet requirements laid out in the draft AI Act.
- **Solution**
  - New functional architecture is proposed, in which the entities introduced in D5.2 are being interconnected through a bus as shown in the upper right side.
  - Interactions between the various entities of the AI Architecture depending on a specific use case are identified (see lower right side).
- **Conclusions**
  - The proposed functional architecture and interactions reflect the main EU AI Regulation requirements and further accommodate for user interaction and the connection of the AI system to a database that may be used for the provision of suitable reference training data, logging of user actions, logging of AI system behavior, etc.



Functional Architecture interconnecting entities of AI System Architecture through a Bus



Interactions of entities of AI Architecture – Avoidance of undesired biases

(*) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL LAYING DOWN HARMONISED RULES ON ARTIFICIAL INTELLIGENCE (ARTIFICIAL INTELLIGENCE ACT) AND AMENDING CERTAIN UNION LEGISLATIVE ACTS, Brussels, 21.4.2021

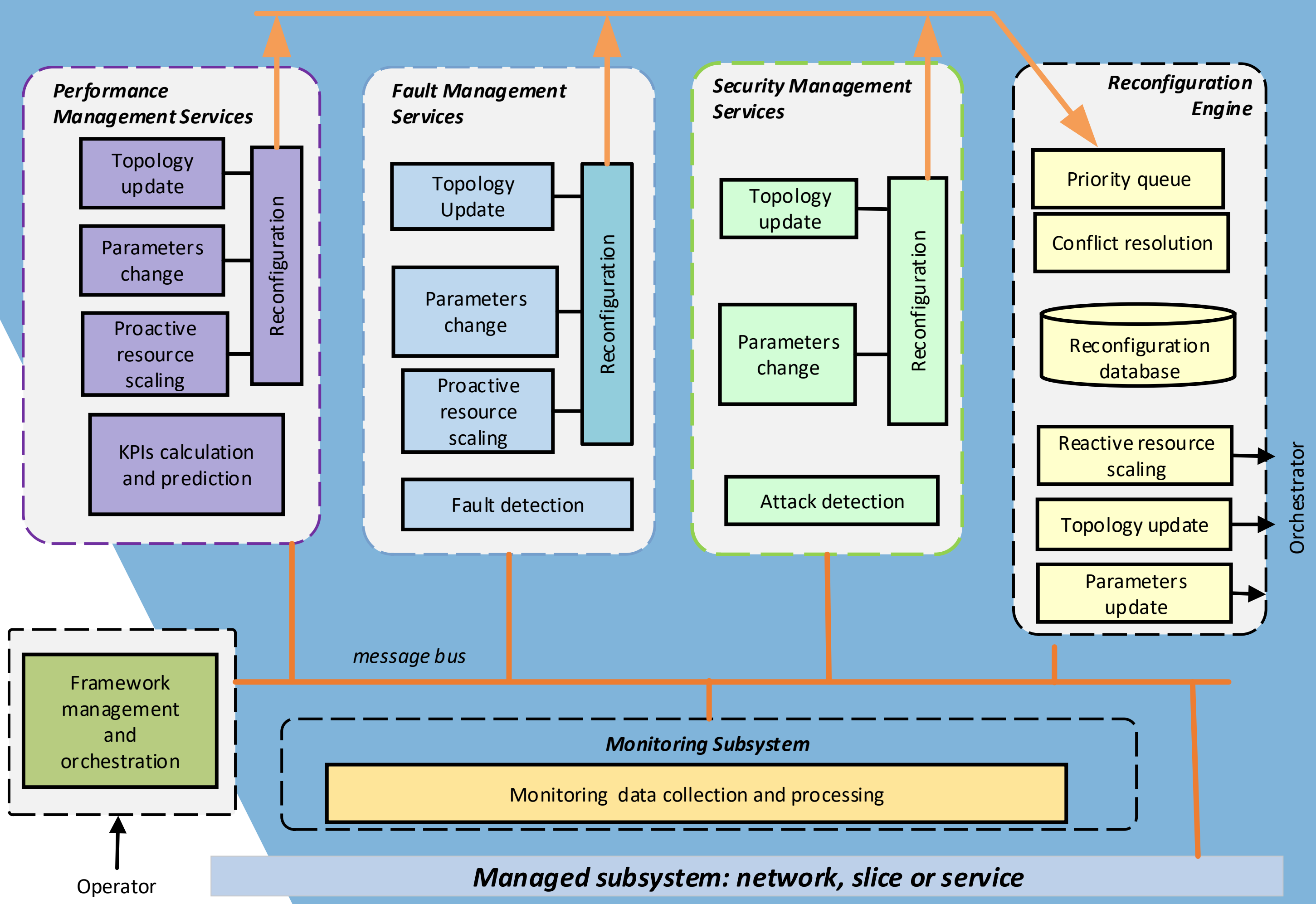
3.1.3 Programmable management

Background and Motivation

- ETSI Zero Touch Network and Service Management (ZSM) requirements concern, among others, the mechanisms for detection and conflict resolution between different closed loops inside a domain and in other domains. In almost all Control Loop-based (CL-based) approaches, each management function has a specific goal that is realised independently of other goals. Coordination of multiple management functions has been proven to be difficult, and only partial solutions based on priorities or time separation between different management functions are used in practice.

Solution

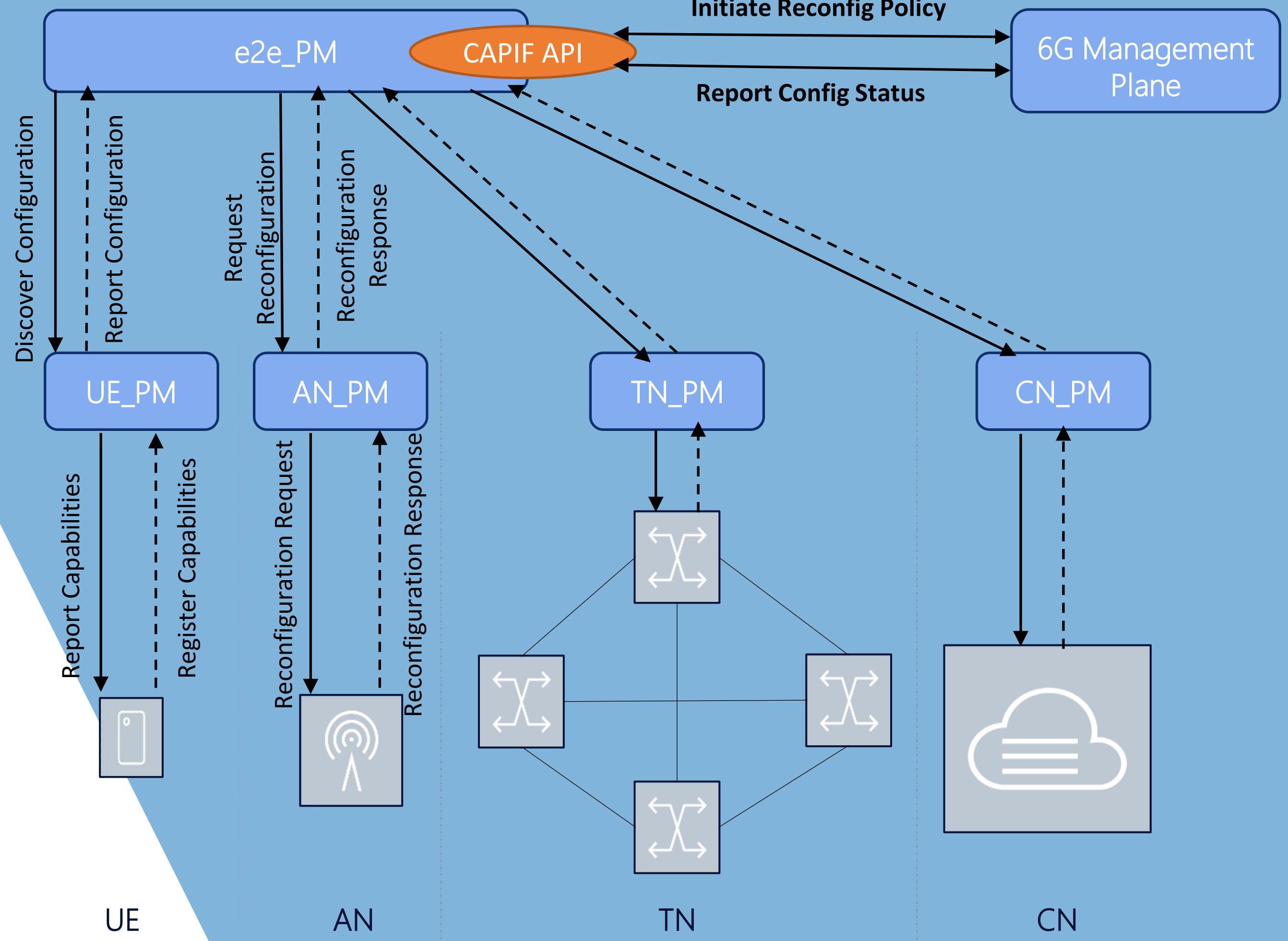
- The presented concept (see figure) assumes that functionality of the Management Platform of a Management Domain can be decomposed into a set of Management Services (MS). MS set can include programmable Fault, Performance and Security Management Services.
- The concept has two components that are common for all MSs, namely the Monitoring Subsystem and the Reconfiguration Engine. Both components are involved in the reduction of the mutual impact of MSs, on the monitoring, and reconfiguration side, respectively.



3.1.4 Programmability Framework

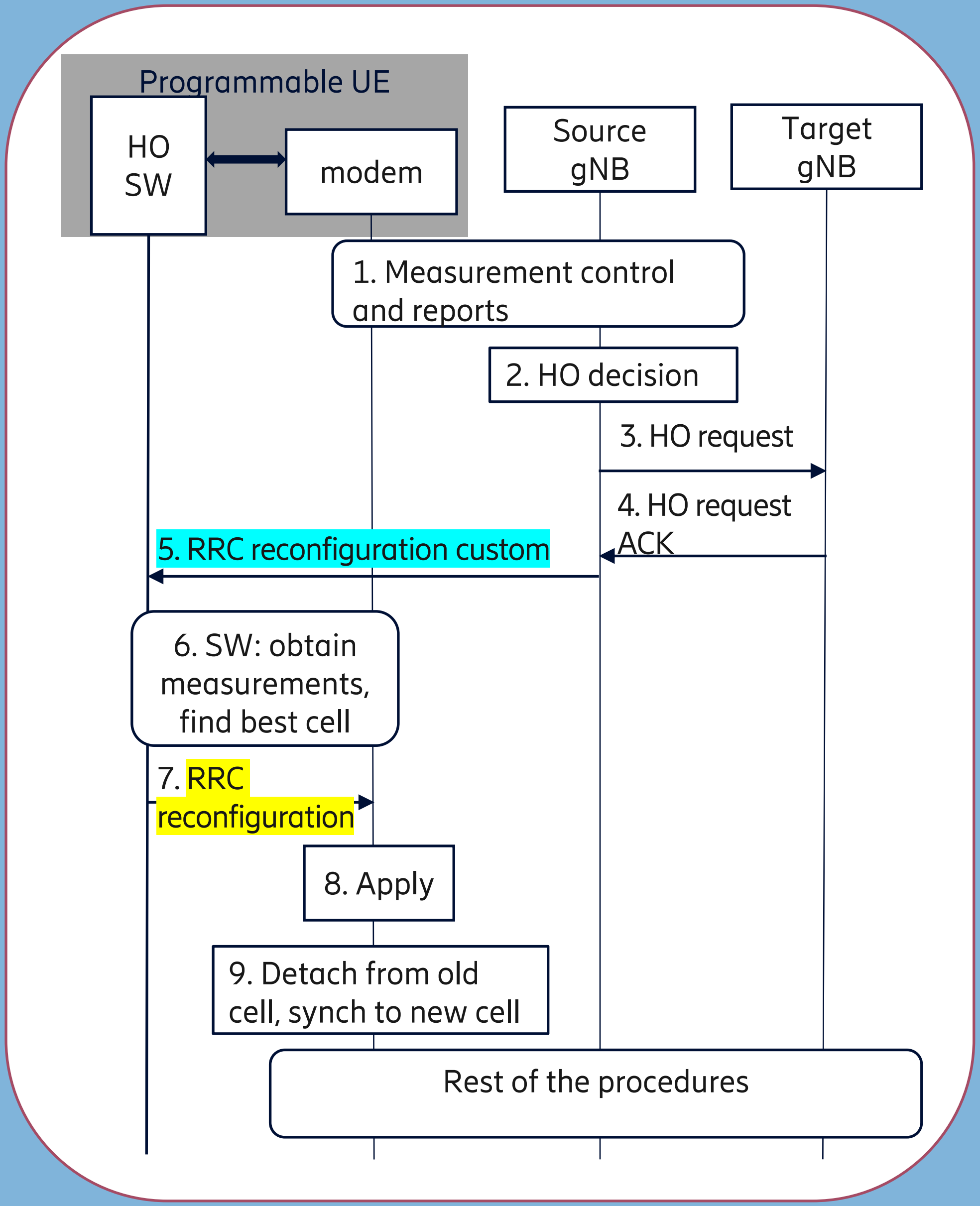
- **Background and Motivation**
  - Supporting programmability in the network's infrastructure enables the flexible reconfiguration of the behavior of this infrastructure over time.
  - The 6G infrastructure is made up of a heterogeneous pool of processing solutions that span different domains (UE, AN, TN, and CN).
  - It is important to properly manage these different infrastructure elements and expose this reconfigurability feature to the management plane.
- **Solution**
  - Local programmability managers (UE_PM, AN_PM, TN_PM, etc.) are defined for different domains to:
    - Discover programming capabilities of underlying infrastructure.
    - Abstaract the implementation details of different devices.
    - Establish channels to reconfigure the behavior of devices.
  - Central e2e_PM is defined to interact with local managers on one side and the 6G management plane functions on the other side to enable reporting configurations status and initiating new reconfiguration policies.
- **Conclusions**
  - The proposed programmability framework specifies some relevant mechanisms and services needed between different manager elements (local_PM and e2e_PM) and the 6G management plane to enable customizing the behavior of the system's fabric to meet the demands of different use case requirements.

PM: Programmability Manager
UE: User Equipment
AN: Access Network
TN: Transport Network
CN: Core Network



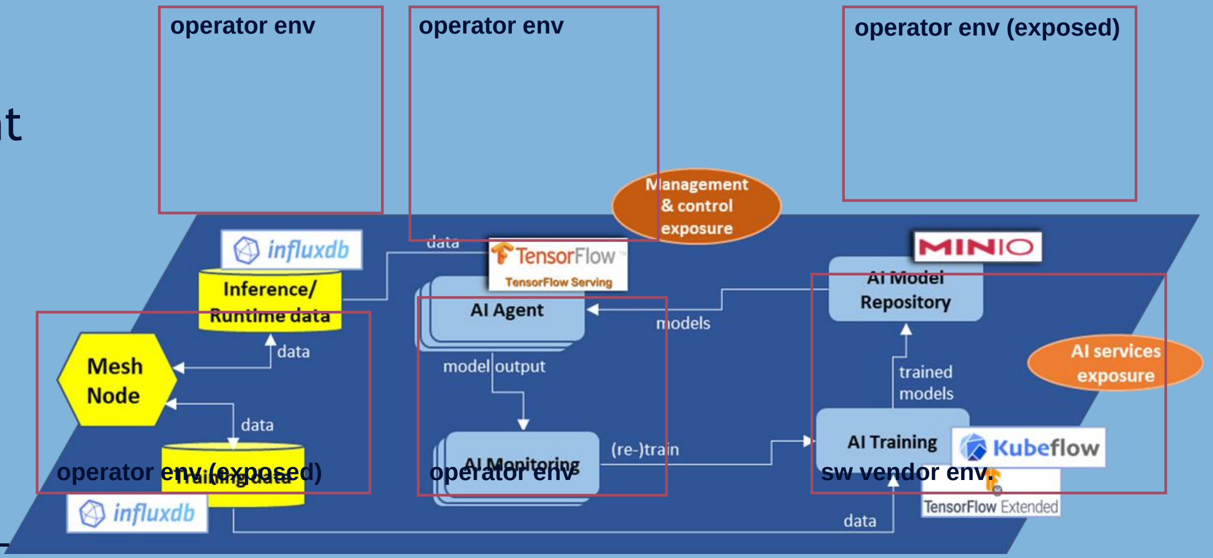
3.2.6 UE programmability

- **Background**
  - The air interface evolves through 3GPP standardization. While this process is vital for the success, it has some drawbacks. New features and functionalities take a long time to be introduced
- **Motivation**
  - Extend the D5.2 by adding concrete example architecture and use case for the application of UE programmability
- **Solution**
  - Adding programmable entity to UEs including suitable interface to the UE modem. The installed software (SW) from network on UE side can control the modem.
  - This enables on the fly introduction of new features via the custom RRC reconfiguration (5), which the new software can interpret (6) and apply a RRC configuration to the modem (7)
- **Conclusions**
  - The UE programmability concept has a potential to unleash fast paced innovation of air interface. Initially, pragmatic aspects may limit the scope to only higher layers. Still, the network overall will enjoy a better time to market for higher layer features. Next step is to develop a full solution by addressing functional requirements explained in D5.2



3.2.1 AIaaS Framework AI functions for MLOps

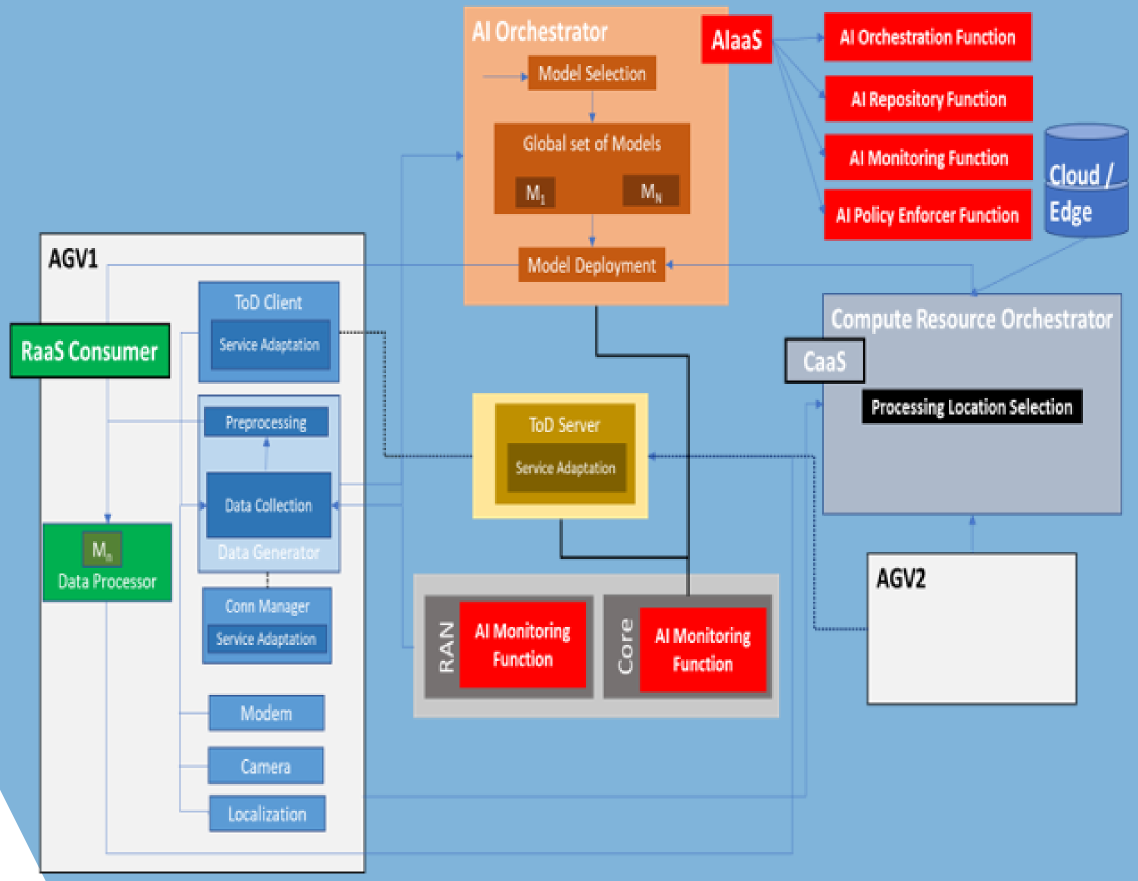
- **Background and motivation**
  - Validate the AIaaS framework concepts & operational workflows in a concrete use case.
  - Identify candidate opensource tools to implement (part of) the AI functions.
- **Solution**
  - Cloud-native AI functions to showcase the combined use of DevOps and AI/ML
    - across software vendor (dev) and mobile operator (production) environments,
    - introduce automation, pipelining, monitoring in the AI/ML models lifecycle (from development to deployment into production).



- **Conclusions**
  - Opensource tools selected and adopted for the implementation of some of the AI functions
    - AI training: Kubeflow, TensorFlow Extended
    - AI repository: MinIO
    - AI agent: TensorFlow Serving
    - Inference/Runtime & Training data store: InfluxDB

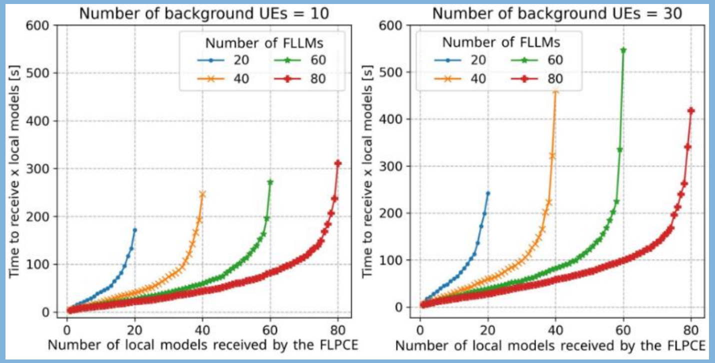
3.2.2 Distributed AI services

- **Background and Motivation**
  - AIaaS and CaaS should be in the expected 6G architecture to provide AI service allocation, instantiation, and operation and proposed an Architecture [Hexa-X D5.2].
  - There is a need to develop methods for efficient monitoring, anomaly detection, and for assisted troubleshooting of distributed intelligence by utilizing AIaaS and CaaS frameworks.
- **Solution**
  - Develop methods and verify them based on an architecture implemented for predictive QoS in the teleoperated driving use case.
- **Conclusion**
  - An Architecture for realizing Predictive QoS
    - Suitable for implementing methods for efficient monitoring, anomaly detection, and assisted troubleshooting of distributed intelligence.
    - Verification of the methods on the specified use case with the help of the architecture composed of AIaaS and CaaS.

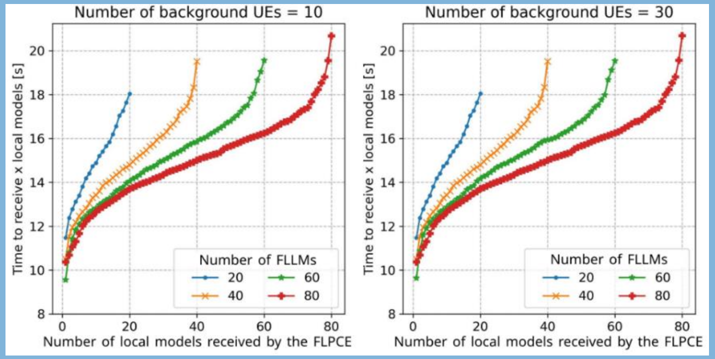


3.2.3 Evaluation of the FLaaS framework

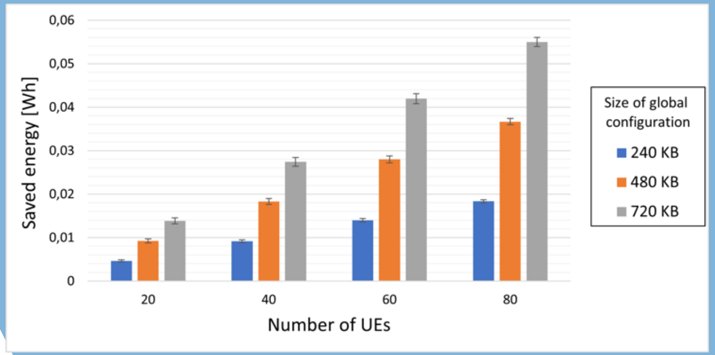
- **Background**
  - In [HEX-D52], a framework for enabling Federated Learning as a Service (FLaaS) was described
  - In FLaaS, an entity called FL Local Manager (FLM) performs local model training on behalf of the UE participating in the FL process
- **Motivation**
  - The framework supports flexible deployment options, including hosting the FLM at either the UE or the edge of the network (e.g., as MEC apps)
  - Different deployments have different impact on the performance of the FLaaS framework
- **Evaluation**
  - In D5.3, two different deployments has been evaluated:
    - FLMs at the UE side
    - FLMs at the MEC side
  - Evaluation in terms of
    - Time required to complete the overall training time of the global AI model
    - Energy consumption
  - Scenarios with
    - Increasing number of UEs participating in the FL process
    - Increasing load in the RAN
- **Conclusions**
  - Enabling local model training at the edge of the network is beneficial in terms of overall training times of the global AI model, due to more computing power available and preventing sending big AI models over the RAN
  - As a consequence, gNBs can save more energy, contributing to reducing the TCO of the network



Time to receive local models, when FLMs are deployed at the UEs



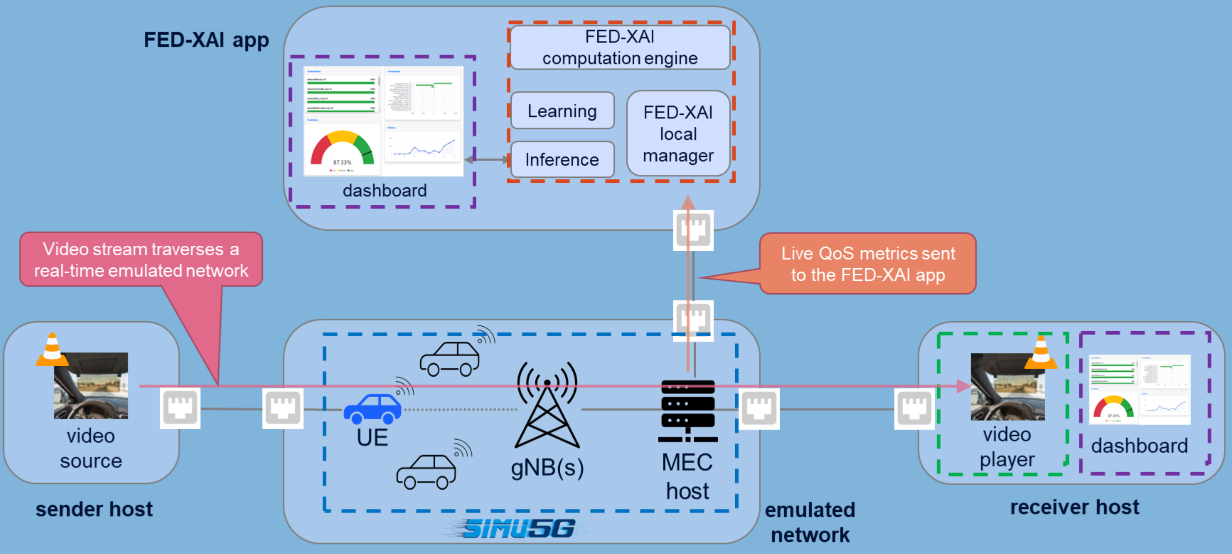
Time to receive local models, when FLMs are deployed at the MEC



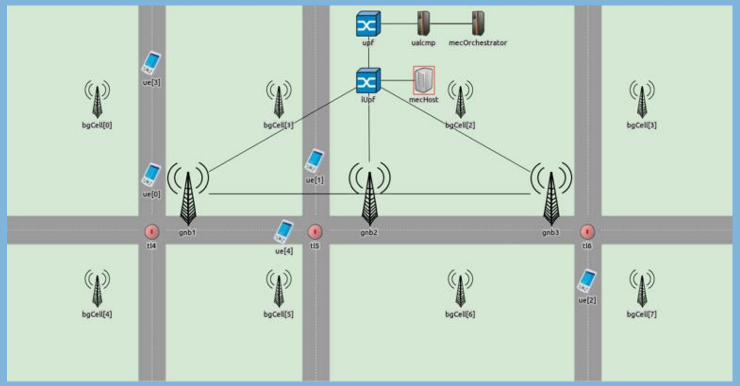
Energy saved by a gNB when FLMs run at the MEC

3.2.3.1 FED-XAI PoC

- **Problem**
  - Showcase the benefits of Federated Learning of eXplainable AI models (FED-XAI)
  - Tele-operated Driving (ToD) use case
  - Predict when the quality of the received video stream will degrade
  - Explainability provides insight on the possible countermeasures to both the user and the network
- **Implementation**
  - Real-time video streaming using commercial video server/player
  - *Offline* training of a global FED-XAI model and online forecasting of the video quality implemented using Intel OpenFL (following the FLaaS framework)
  - Real-time dashboard showing forecasts and corresponding root causes
  - Network emulated using Simu5G, used to:
  - Generate a training dataset via a large simulation campaign
  - Send live QoS metrics to OpenFL for online training
  - Network scenario configured according to to data from TIM's live RAN



Implementation of the real-time FED-XAI testbed



Emulated network scenario

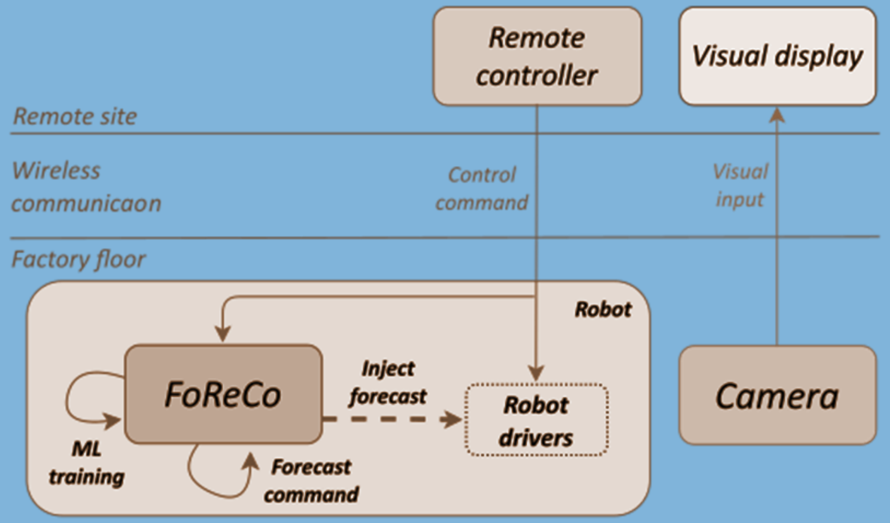
3.2.4 FoReCo (Forecast based recovery method)

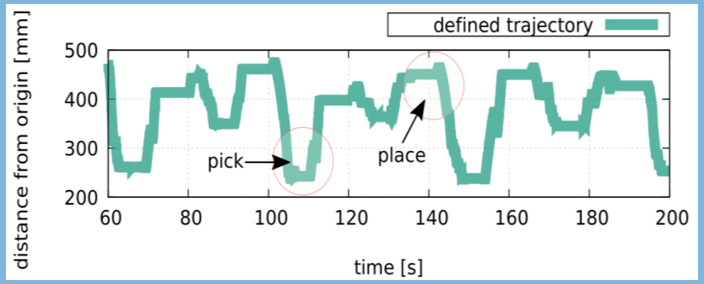
- **Background and Motivation**
  - IEEE 802.11 has good performance and low latency, achieving reliability, transparency, and stability for real-time remote control required in many applications remains a critical challenge due to the highly unpredictable, unreliable, and interference-prone wireless channel.
  - Real-time remote control and coordination of robot manipulators in industrial applications
  - To increase the reliability of the network at application level
- **Solution**
  - FoReCo is a predictive control loop that infers delayed or lost commands and feeds them to the robot control loop
  - Uses ML algorithms to infer delayed and lost commands

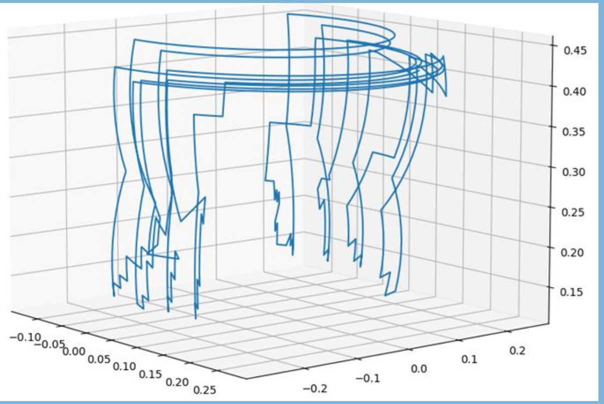
$$\min_{\vec{w}} \frac{1}{\alpha H} \sum_{i}^{\alpha H} d\left(c_i, f\left(\{c_j\}_{i-R}^{i-1}, \vec{w}\right)\right)$$

  - Top figure shows FoReCo building blocks and remote-control system
  - The system shows the details of the interactions between the remote site (where the controller is located) and the factory floor over a communication channel
  - To obtain weights ($\vec{w}$) FoReCo creates Robot trajectory dataset (bottom figures) with pick and actions of an experience and inexperienced operators

- **Conclusions**
  - Performance has been assessed under simulated environment with wireless interference
  - Provides high precision by reducing the trajectory error

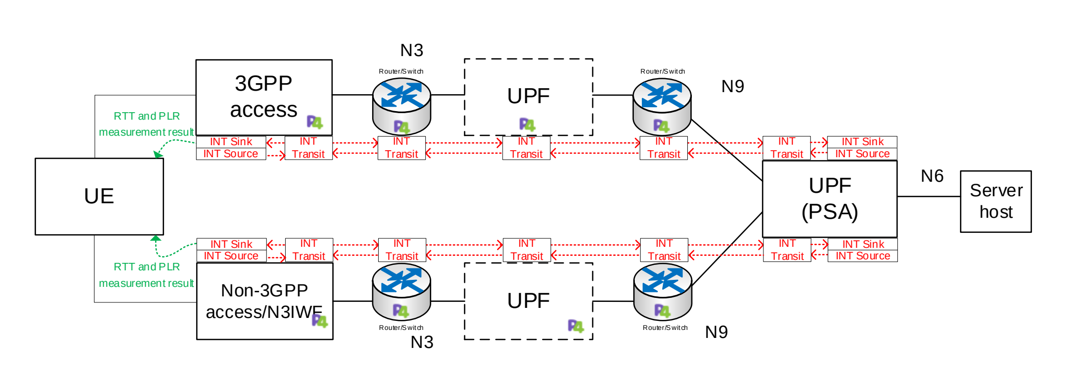






3.2.5 Network programmability for traffic steering and adaptive packet processing

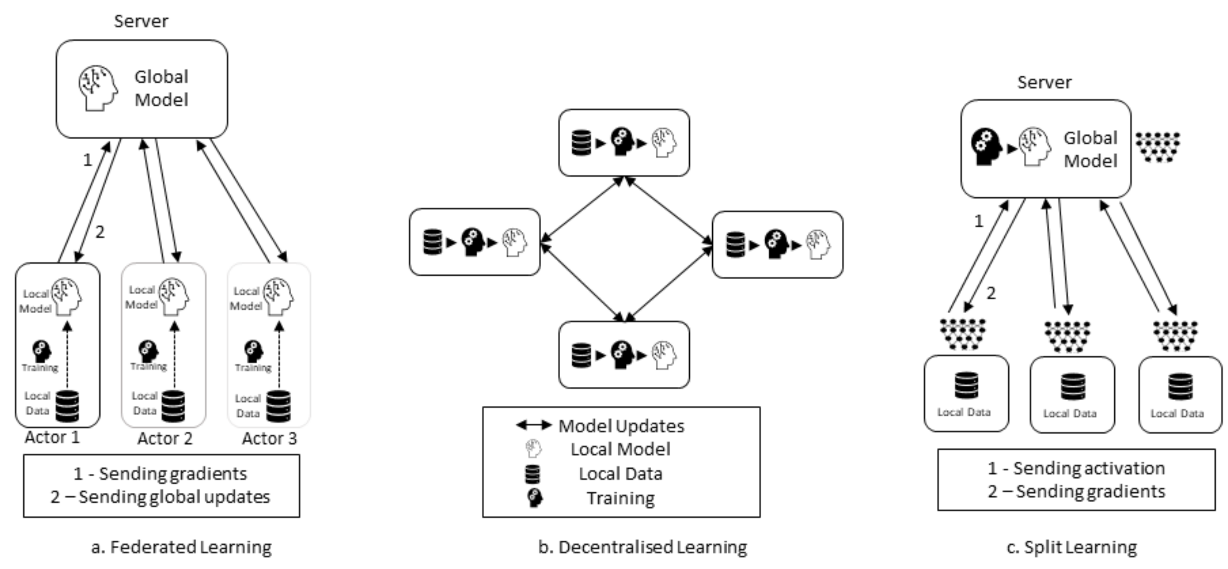
- **Background**
  - Programmable data planes are expected to enable rapid development of new network functionality. In Hexa-X delivery D5.2 (see [HEX-D52]) we have discussed how networks will become programmable by introducing NIC, routers, and switches supporting network programming (e.g., based on the P4 programming language).
- **Motivation**
  - Improve existing 5GS ATSSS performance measurements and packet processing functionality by leveraging the P4 programming language.
  - Evolve legacy QoS differentiation methods in the transport network.
- **Solution**
  - An advanced ATSSS solution has been proposed (see right side) with overhead in the number of data to be exchanged over the access network.
  - Additionally, adaptive packet processing priority handling is proposed supporting dynamic adjustment to the varying network conditions.
- **Conclusions**
  - The proposed solutions will help to improve network performance and efficiency and positively affect the **"Convergence time"** architecture KPI.



Enhanced Transport network supporting ATSSS and Adaptive Packet processing priority handling

3.2.7 Integrated and distributed AI with supporting protocols

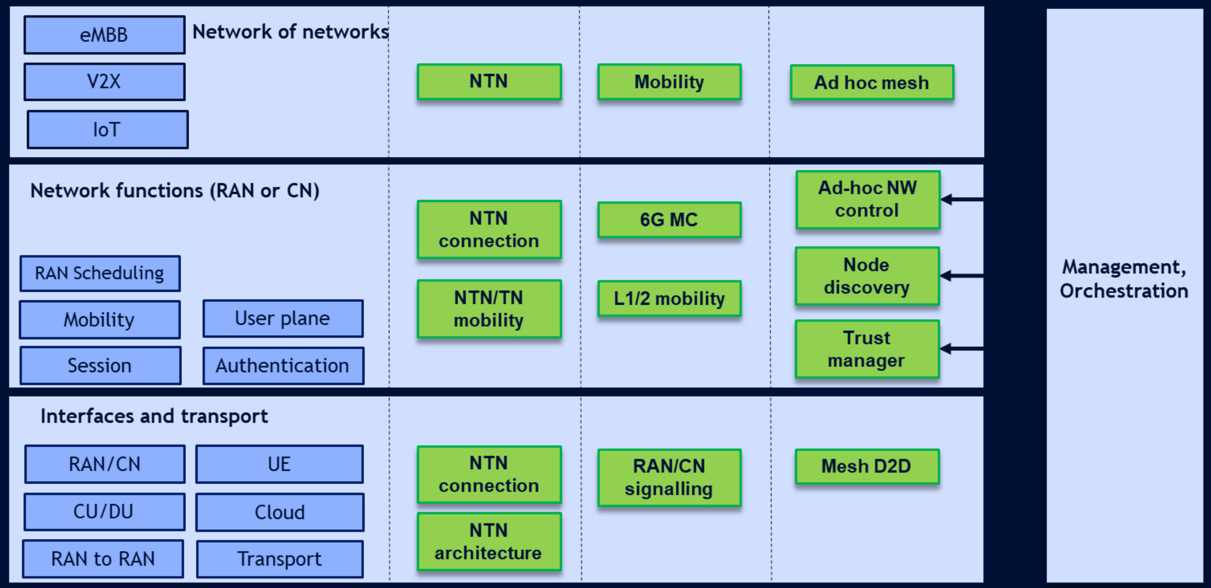
- **Background**
  - AI and ML are beginning to be key valuable tools in the context of mobile networks, as their complexity grows. As a consequence, data-based approaches have been raised as the next-generation shift for legacy model-based approaches.
  - The role of AI and ML in future 6G mobile networks will be to aid those tasks where legacy techniques are not able to cope with the new conditions and requirements related to those networks
- **Motivation**
  - Extend D5.2 definitions regarding these aspects and include the WP6 vision over AI/ML and its impact on the system's architecture.
- **Solution**
  - Present the main Centralized Learning AI/ML algorithms to understand their scope and limitations.
  - Introduce and explain Distributed AI/ML techniques, also known as Collaborative AI/ML techniques and demonstrate their advantages in multi-stakeholder and multi-domain scenarios.
- **Conclusions**
  - Distributed AI/ML techniques come with a wide range of advantages when facing the ecosystem of 6G networks, however it is important to consider that they also come with various challenges: (i) unbalanced data size, (ii) communication constrains, (iii) Privacy & Security.



Flexible network

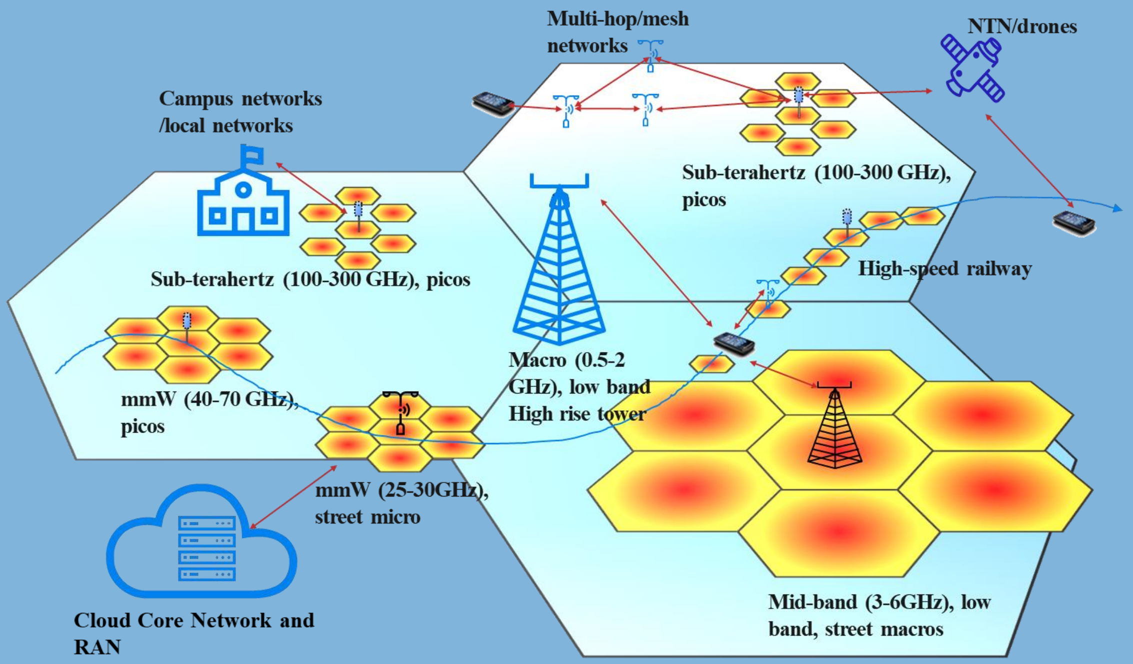
Flexible network introduction

- The Flexible network intend to enable extreme performance and global service coverage, while they can also achieve scalability to avoid overprovisioning when and where it is not needed
- The Flexible network area is divided in three domains:
  - **network of networks**
  - **network functions**
  - **interfaces/transport**
- Green boxes represent research topics in Hexa-X



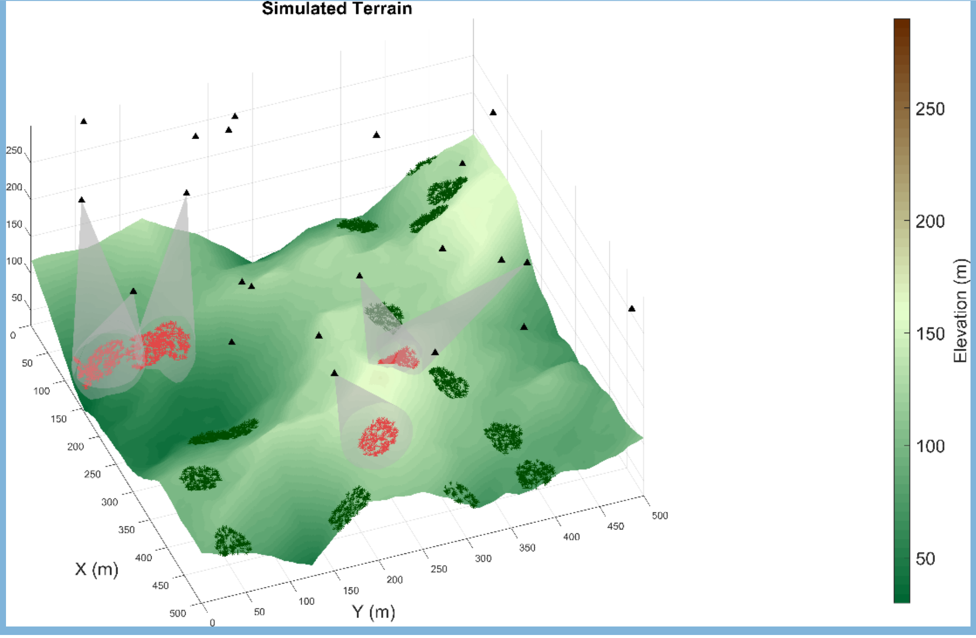
4.1 Network of network mobility

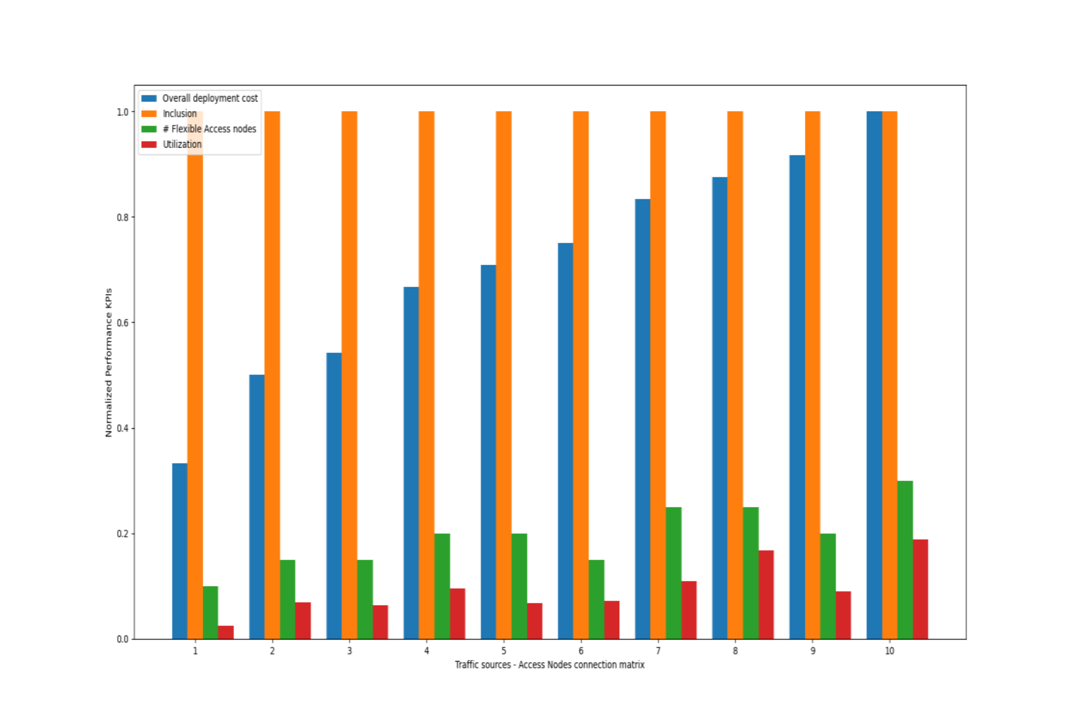
- **Motivation**
  - Hexa-X believes 6G will consist of many sub-networks, i.e., a network of networks.
  - Therefore, there is a need to efficiently integrate the different sub-networks. In addition, the mobility aspects must be enhanced to support 6G strict requirements on reliability and availability
- **Solution**
  - 6G should support L1/L2 mobility solutions to enable fast and reliable
  - New enhanced multi-connectivity solution for 6G, combing best features from Carrier aggregation and Dual connectivity
  - Develop dynamic spectrum sharing (a.k.a. Multi-rat spectrum sharing) for the 5G and 6G migration
- **Conclusion**
  - For a fully flexible network, 6G must be able to utilize the available spectrum efficiently and maintain a reliable connection. For this we propose a new 6G multi-connectivity solution for 6G, which combines the best features from CA and DC.



4.2 Flexible Topologies: Adhoc NW control

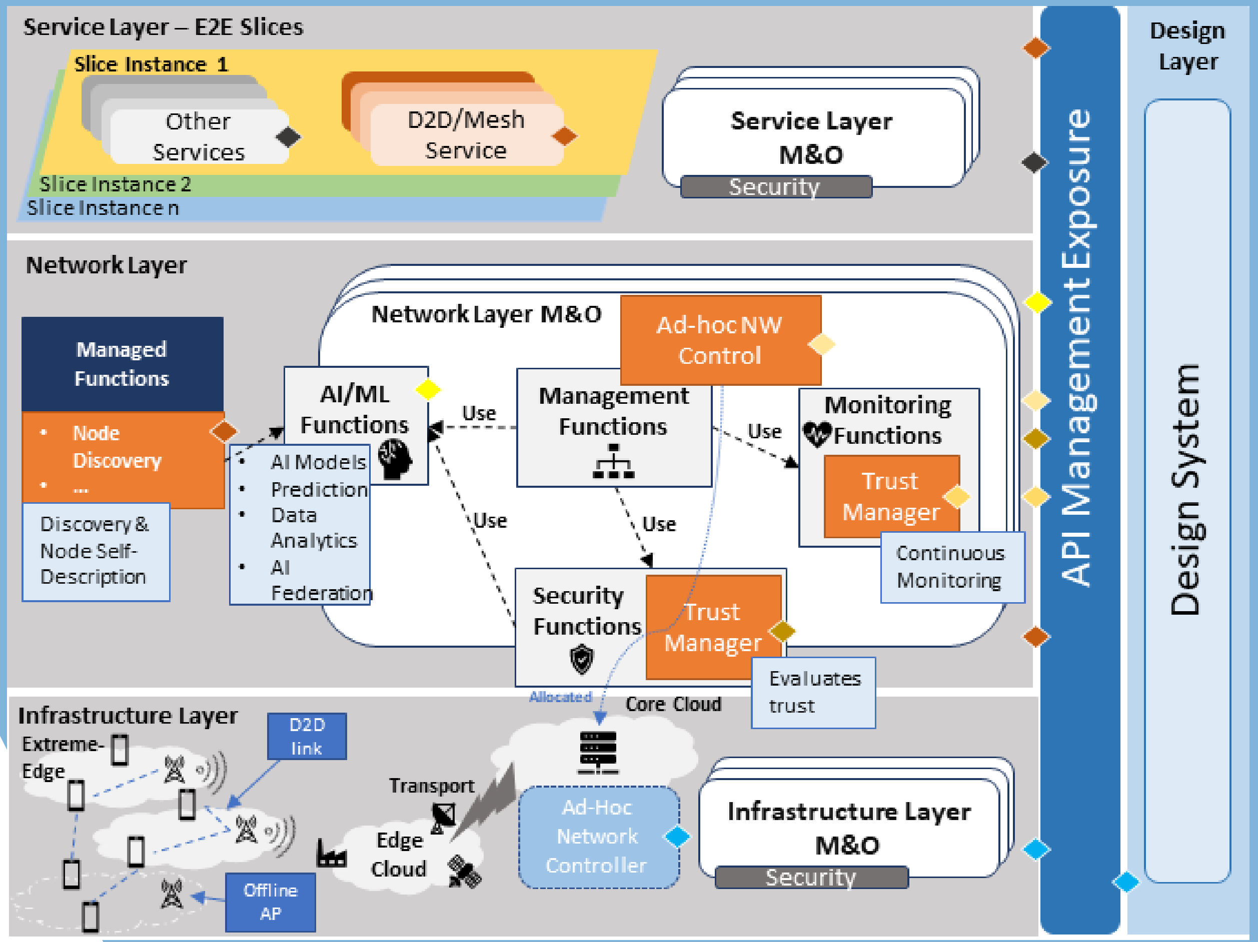
- ## Motivation
  - Remote areas in need of excess capacity, in which we need to collect data from some ground sectors or it can be some robots that operate in a critical situation and need connectivity.
  - Our aim is to serve these devices (sensors or robots) through a flexible topology consisting of a layer of access points. Consequently, we would like to have the access points being served by some sinks (e.g. terrestrial or NTN, etc.).
- ## Solution
  - B5G/6G flexible topologies – local structures (nodes with networking, incl. Ad-hoc, and computing resources, terminated at edge node) as coordinated extensions of infrastructure (temporary)
  - Selection of nodes and far-edge devices that will be admitted in the "ad-hoc" network formation; how much “trusted” is a node in order to be part of the D2D/mesh network
  - Maximization of the difference between trustworthiness minus the cost of the selected nodes and interconnections
    - Maximization of the overall system’s trust index
    - Selecting APs (AP locations) with “low cost”
    - Selecting interconnections that lead to minimum energy requirements
- ## Conclusion
  - In order to overcome challenges imposed by static infrastructure solutions, a flexible topology of access points, e.g. with the aid of unmanned aerial nodes, can be used. A proper selection of these nodes is achieved, in order to account not only for the maximization of the system’s trust but also for the minimization of the deployment cost.





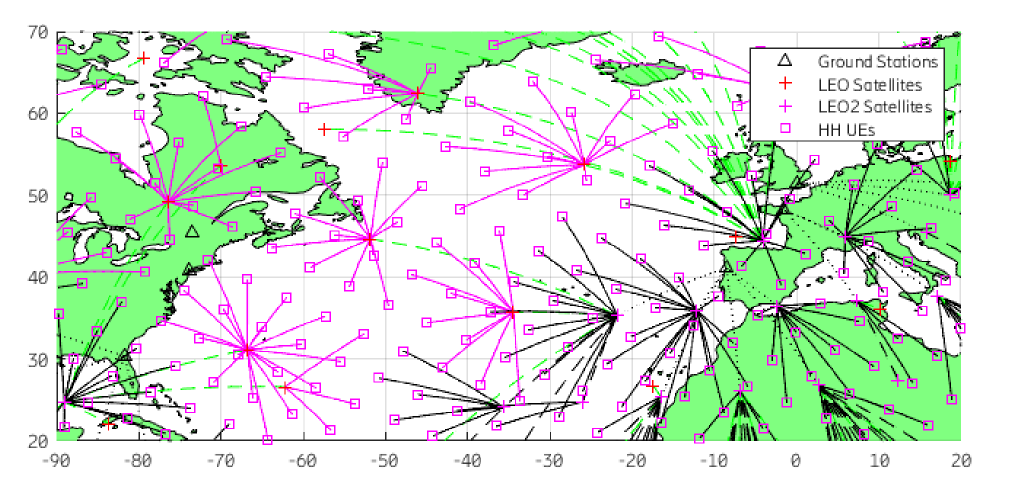
4.3.1 D2D Mesh Network Management and Orchestration

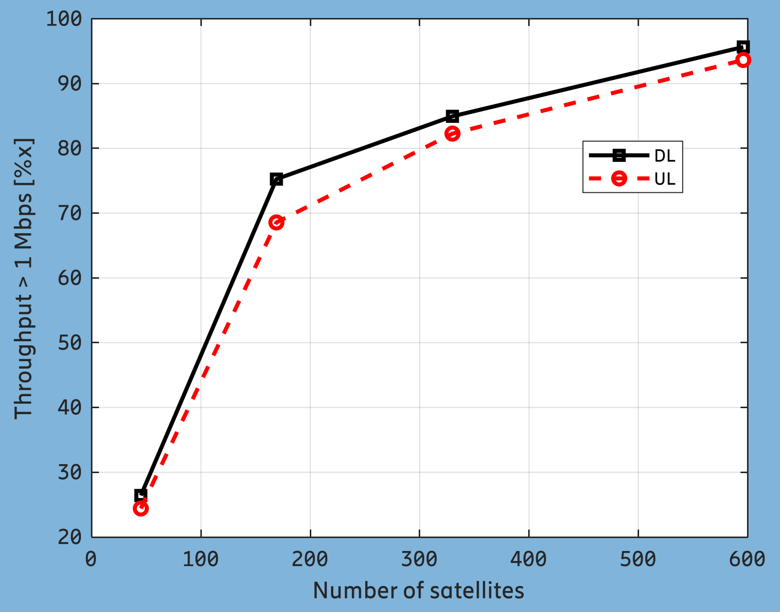
- **Background**
  - As described in D5.2, the Management and Orchestration (M&O) of future D2D ad hoc networks (e.g., WANETs or MANETs of any kind) requires to be able to cope with all the constraints associated to this kind of networks.
  - A mapping between the buildings blocks (BBs) of the D2D architecture presented in D5.2 and the WP6 M&O architecture modules was provided from a Network Layer perspective.
- **Motivation**
  - Fill the missing gaps left in D5.2 regarding a full integration of both architectures (D2D/M&O).
  - Integrate the remaining layers i.e., Service/App layer, Infrastructure Layer and Design Layer.
- **Solution**
  - Provide a new architecture design that fully maps both architectures giving a detailed vision at every layer.
  - The Service Layer reflects the capacity of the D2D architecture to face and deploy several types of services and to work with independent Slices.
  - The Infrastructure Layer reflects the whole compute continuum and depicts where D2D devices would be allocated.
  - The API Management Exposure cross-layer module enables network elements capability exposure in the various architectural levels both, inside and across, administrative domains.
  - The Design Layer exemplifies the implementation of cloud-native concepts in terms of bringing together development and operational teams.
- **Conclusions**
  - The upgraded mapping approach between the D2D architecture presented in Section 4.3 and the WP6 M&O architecture demonstrates that a full integration between them is completely feasible and gives a good baseline for potential implementations.



4.3.1 NTN and global coverage

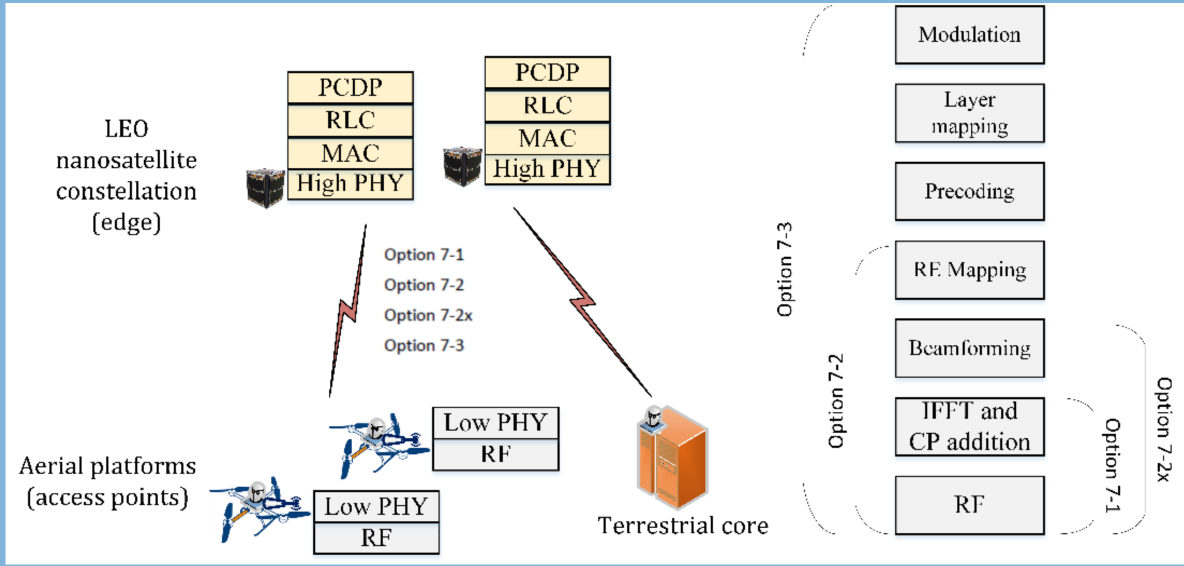
- **Background and Motivation**
  - The digital inclusion is one of the goals of 6G
  - 6G need solutions for global service coverage, connecting remote places, e.g., in rural areas, transport over oceans or vast land masses,
  - One of WP5's objectives is to find architectural solutions that support full global coverage
- **Solution**
  - Global service coverage is possible assuming an architecture that allows inter-satellite-link (ISL) hops.
  - To investigate the performance of such an architecture, a simulation of an NTN system covering Atlantic ocean has been performed.
  - The simulator computes the position in terms of latitude, longitude, altitude of each satellite in the constellation around the globe over time
  - The users are deployed (300 in total) in the region of interest and uniformly distributed over the area of interest and the gateways are deployed in the coast areas
  - The simulator calculates the position of each satellite with respect to each ground node in terms of elevation angle, distance, and azimuth
- **Conclusions**
  - Global service coverage is possible assuming an architecture that allows inter-satellite-link (ISL) hops.
  - To achieve 100% availability for a very low population, more than 600 satellites (with ISL) in LEO are needed.
  - For a very low population density, the 600 satellites can serve roughly 95% of the users with more than 1 Mbps. The simulation results shows that device throughput then depends on the number of satellites. With more available satellites per UE there is also an increase in available resources per UE.
  - Note that the results depend to a large extent on the simulation parameters used, such as the antenna gain, transmit power, bandwidths, etc

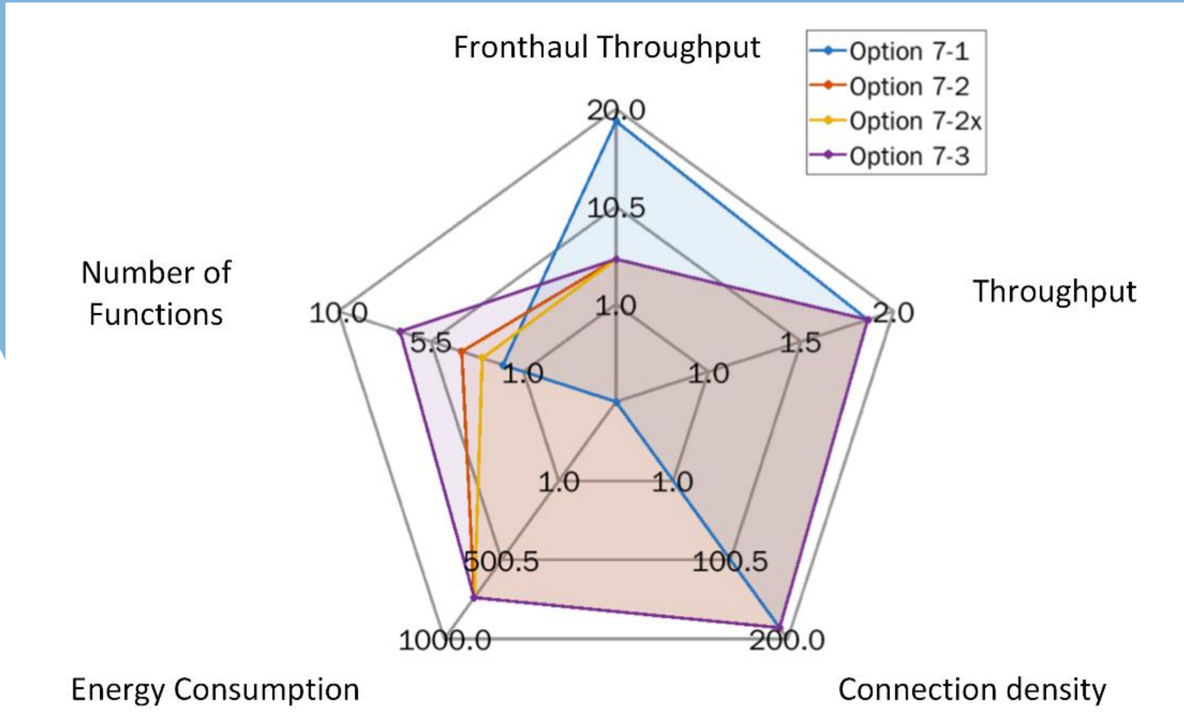




4.3.2 3D architecture

- **Background**
  - The 3D networks rise from the goal of 6G of providing network resources globally, to ensure network coverage and resources are available in remote and complex areas. This to enable the provisioning of 6G services everywhere.
- **Motivation**
  - In areas where no network is available, base stations can be deployed via unmanned aerial vehicles (UAVs) and satellites can host edge computing resources. However, the fronthaul link should ensure the required throughput to enable the communications of downlink and uplink.
- **Solution**
  - Functional split of the baseband unit (BBU) is applied. Various options are analyzed in order to see what satellite bandwidths can make the functional splits feasible.
- **Conclusion**
  - The choice of lower altitude CubeSats, despite the shorter orbit lifetime, looks better for what concerns the achievable QoS. Indeed, the pathloss is overall reduced and it is possible for the BBU to execute a higher number of turbo decoding iterations for higher percentages of the flight time.

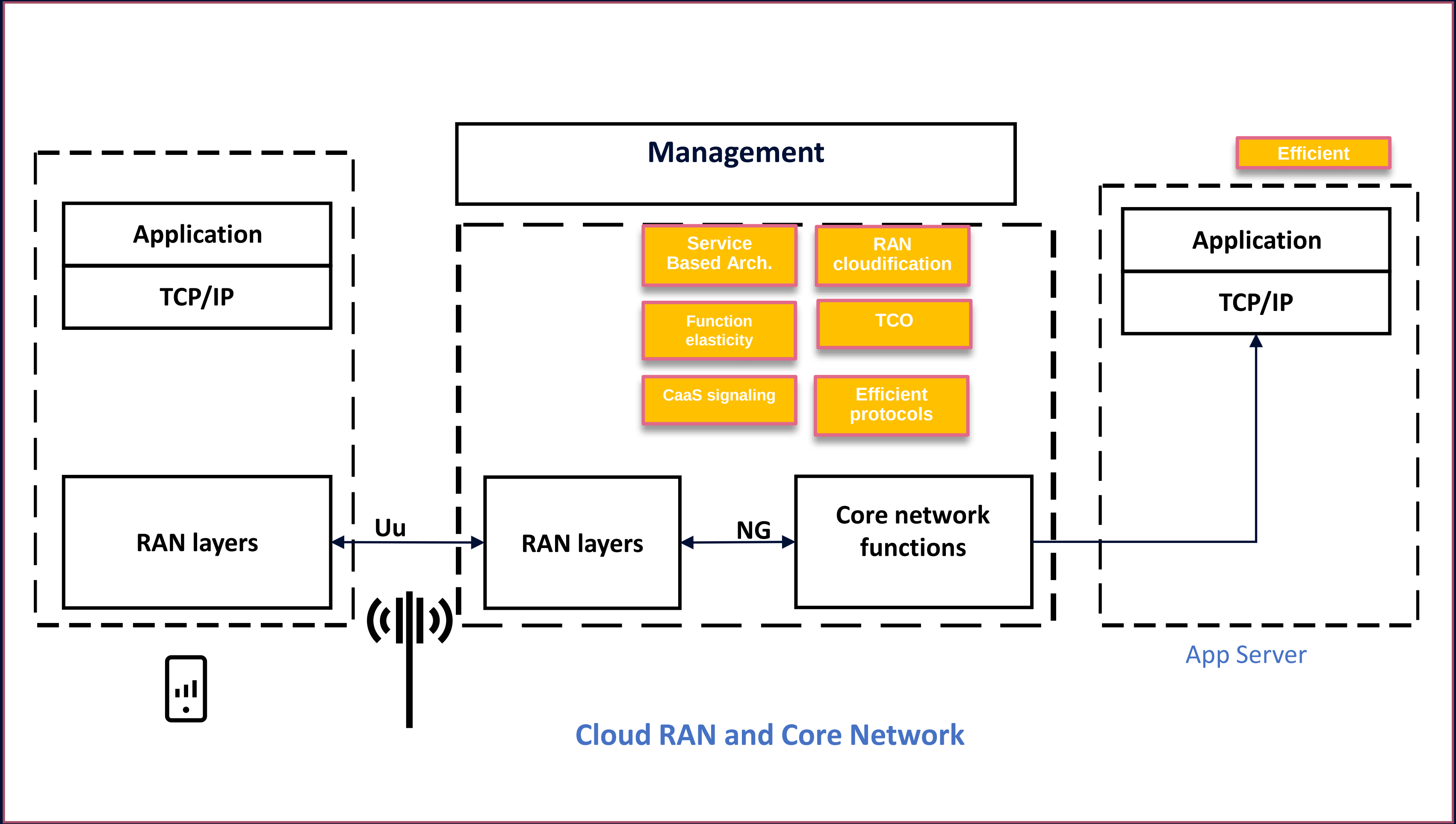




Efficient network

Efficient network introduction

- Efficient network enablers comprise new ways to streamline the RAN and CN architecture, minimize the signalling needs and make the architecture more flexible.
- Notable enablers include methods to extend the service-based architecture (SBA) to the RAN, new design of the network functions in order to make them more independent and self-sustained as well as possible to deploy in different cloud environments (network refactoring).



5.1 Service Based Architecture

- ## Background

  SBA comprising both RAN and CN, is assumed to be part of a future network. Changes to some existing nodes, e.g. the AMF, may be needed for efficient communication between nodes.

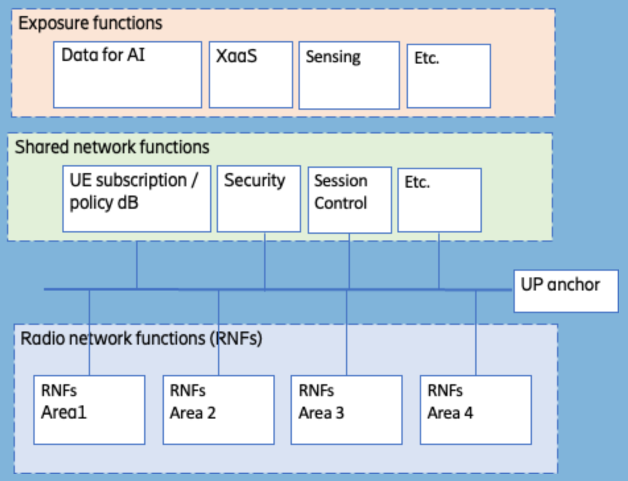
  The concept of independent network functions (NF) is promising, but design principles and consequences need to be investigated.

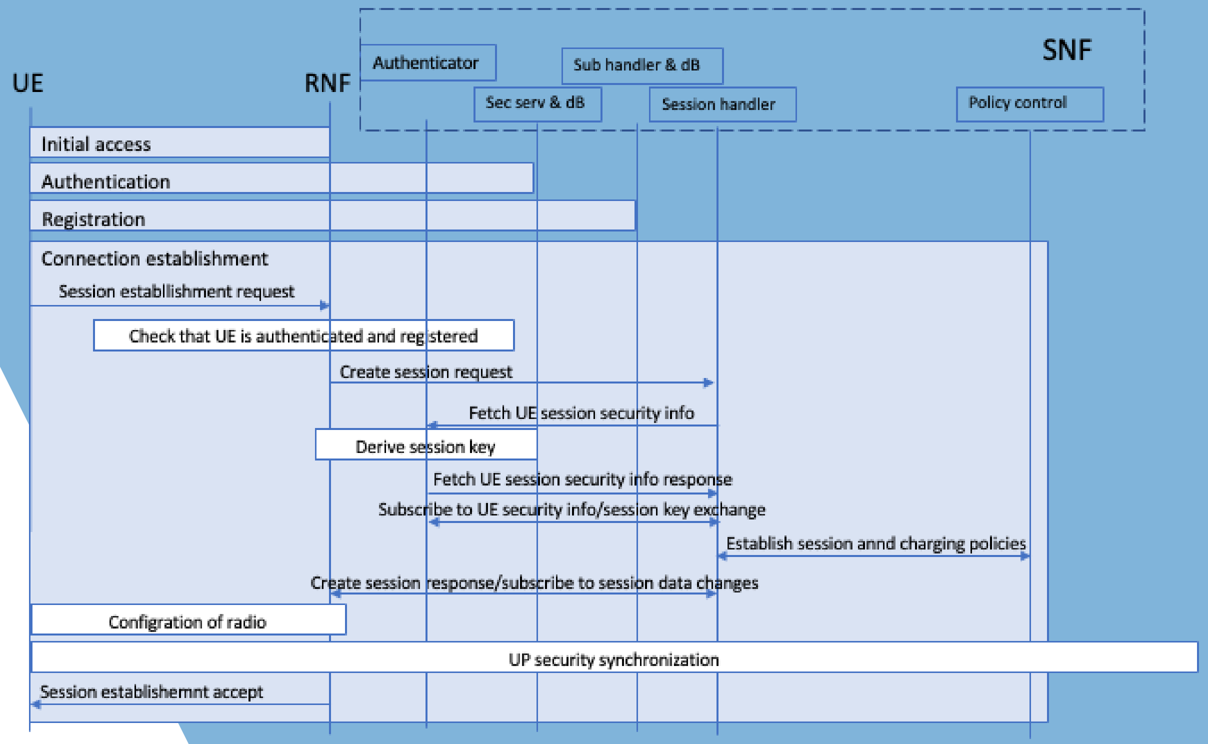
- ## Solution

  Design principles are established for how to realize SBA in order to fulfil objectives, such as, efficient signaling, function separation, independent functions.
  Design principles should apply to both procedures and NFs. A procedure may comprise several NFs.

- ## Conclusion

  With a systematic approach to NF design, it is possible to build independent procedures with efficient signaling.



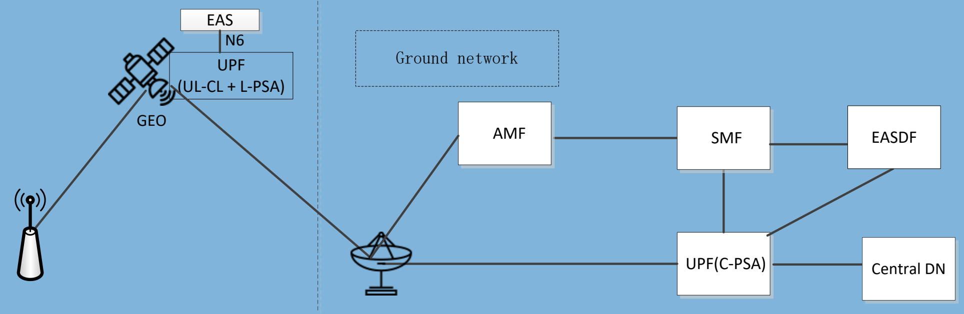


5.2 RAN cloudification: Edge Computing in satellite backhaul and fronthaul scenarios

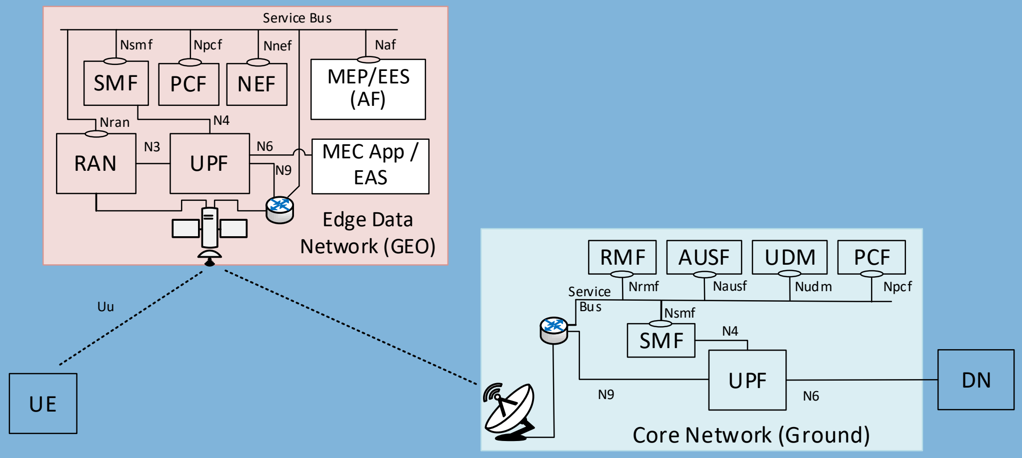
- **Background**
  - Current solutions for Edge Computing in satellite backhaul and fronthaul scenarios introduce significant latency to the control plane procedures (e.g. PDU Session establishment procedure) as the N2 and N4 interface are exposed over a satellite link (see upper right side).
- **Motivation**
  - Propose latency aware NF function placement for Edge Computing in satellite backhaul scenarios
  - Leverage the architectural building blocks proposed in Hexa-X delivery 5.2 for (i) dynamic function placement (DFP), (ii) the replacement of the N2 interface with a service-based interface (SBI), and (iii) distributed NAS enabling per NF service signalling.
- **Solution**
  - Satellite Edge Computing with latency-aware NF function placement (see lower right side) to reduce the control plane latency:
    - an SMF in the edge network terminates the N4 interface towards the UPF in the edge network to avoid the need to send PFCP messages over the satellite link.
    - The SMF in the core network terminates the N4 interface towards the UPF in the core network.
    - The AMF is no longer involved in forwarding messages between RAN and CN and its remaining functionality for registration and mobility management is moved into the new Registration and Mobility Management network function (RMF).

Conclusions

- Latency aware NF function placement can reduce the control plane latency introduced in satellite backhaul and fronthaul scenarios for Edge computing.



Satellite Edge Computing via UPF on-board



Satellite Edge Computing with latency-aware NF function placement

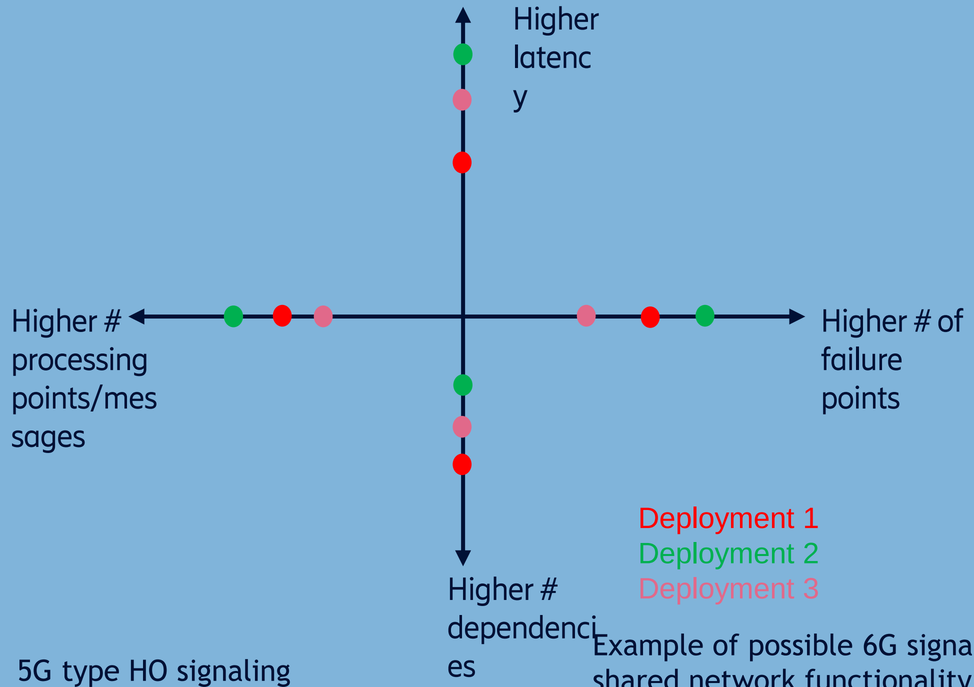
5.3 Efficient signaling

- **Background Motivation**
  - Investigate how a 6G architecture can be more efficient in terms of signaling, overhead and latency scalability, flexibility as well as resource and power consumption compared to previous generation.
- **Solution**
  - To achieve a more efficient signaling, we have defined three design principles:

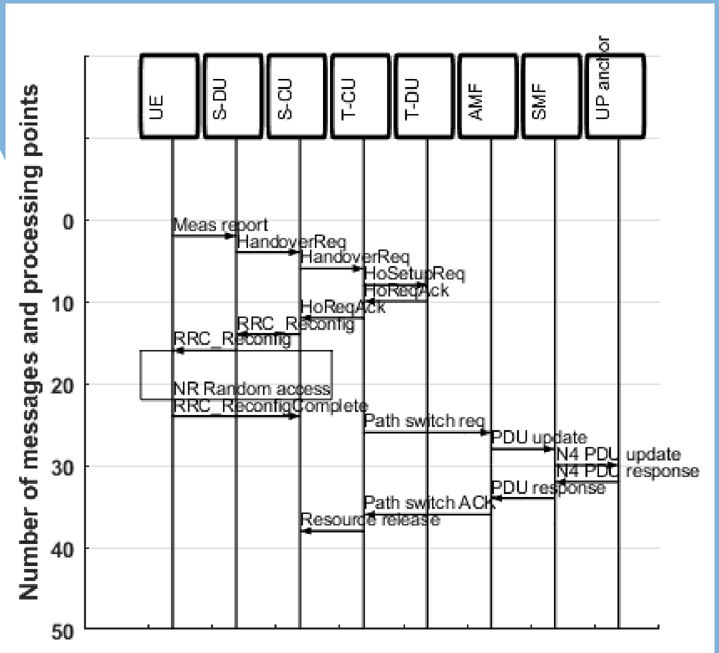
1. Exposed interfaces are service-based, where network interfaces should be designed for cloud use (i.e., cloud-native) with care taken to design proper service separation enabling service reuse, and ease of adding new services to the network.
2. Separation of concerns of network functions, which means that interaction among services, through their APIs, ensure minimal dependency with other network functions, so that network functions can be developed and replaced independently from each other.
3. Network simplification in comparison to previous generations, by utilising cloud-native RAN and CN functions with fewer (well-motivated) parameters to configure and fewer external interfaces.

  - In this study we demonstrate how different deployments affect one important variable, latency.

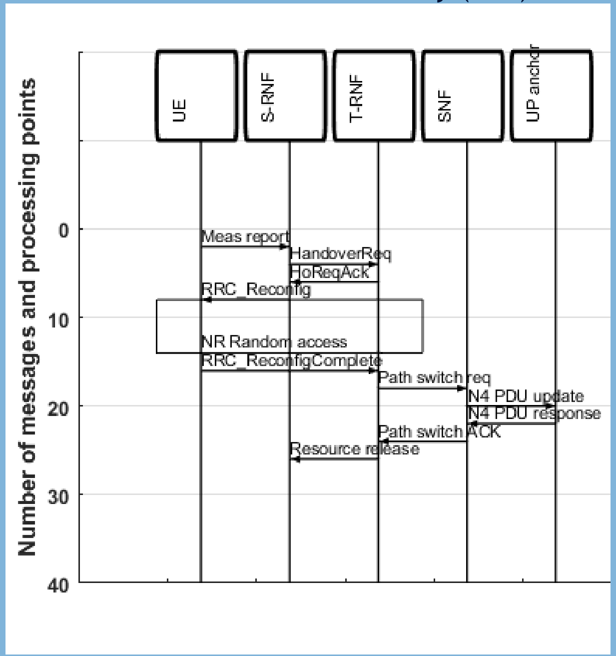
- **Conclusion**
  - A possible 6G SBA architecture with fewer interfaces and processing points is evaluated in terms of latency for a handover procedure. The results show that the latency of the control signalling of the handover procedure may be reduced.
  - It is not enough to reduce latency; there are other important measures, e.g. measures connected to resilience.



5G type HO signaling



Example of possible 6G signaling using shared network functionality (SNF)



5.4 TCO Aspects

- **Background**
  - In D5.1, initial considerations were presented on the mobile network TCO, including a breakdown of both CapEx and OpEx.
  - D5.2 outlined the methodology to achieve WP1's objective of reducing TCO by ≥ 30%. Moreover, the *baseline* architecture for comparison with 6G TCO (i.e., 5G NR SA), as well as mobile network cost items (which were grouped in 5 classes according to the GSMA work), were identified.
- **Motivation**
  - Joint WP5/WP1 activity with objective to achieve a TCO reduction ≥ 30%
- **Solution**
  - Hexa-X project identified some technical enabler families that can help reduce network costs. D5.3 describes the impact of each technical enabler on the cost items for two exemplary Hexa-X use cases, i.e., the "Fully merged cyber-physical worlds" and the "Interacting & cooperative mobile robots & flexible manufacturing".
- **Conclusion**
  - D5.3 presents a qualitative TCO analysis that demonstrates the existence of tech enablers that can positively impact the network costs
  - The qualitative TCO analysis carried out in D5.3 will be used in D1.4 to provide a quantitative estimation of the 6G TCO reduction for the "Fully merged cyber-physical worlds" use case when the identified technical enabler families will be deployed.

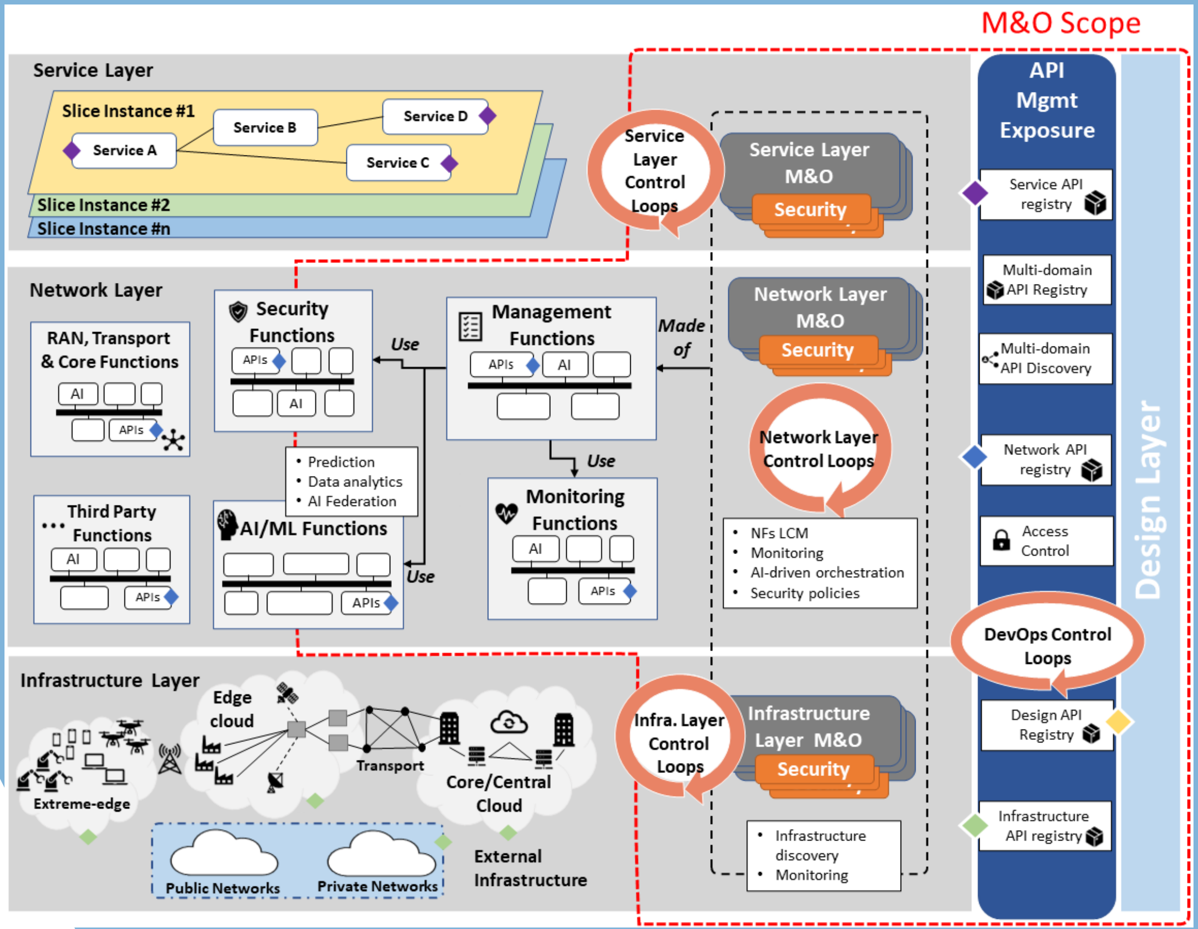
Weight	RAN infrastructure	Energy consumption	Backhaul	CN infrastructure	Other NW costs(1)
Intelligent networks enablers (UE and Network programmability, dynamic functions placement, analytics, AIaaS, AI-driven orchestration)	x	x		x	x
Flexible networks enablers (integration of sub-networks, campus, edge-to-Network-Cloud integration)	x	x	x	x	x
Efficient networks (Compute-as-a-Service, CaaS)					
6G RAN enablers (high-data rate links, localization and sensing)	x				
Service management enablers (continuum management and orchestration, AI-driven orchestration)		x			x

(1) This includes people, network management and maintenance costs

Hexa-X technical enablers impact to the TCO cost items for the "*Fully merged cyber-physical worlds*" use case.

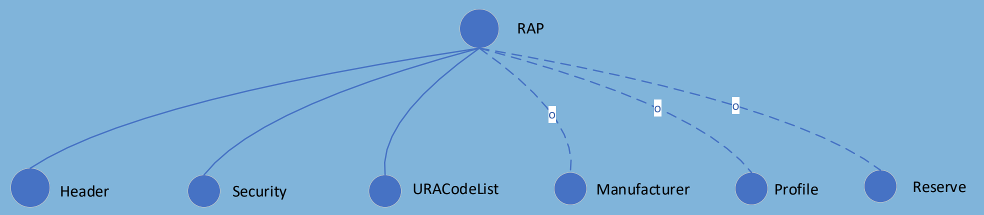
5.5 Developing interfaces for AI/ML driven orchestration

- **Background**
  - D5.2 provided some initial considerations on the potential interfaces that are required for AI/ML driven orchestration.
  - Mobile networks generations, before the 5G paradigm, were designed to work in a “per-domain” way and the interaction was limited to peer-to-peer reference points within the very same domain.
  - Continuous development towards more intelligent networks has driven many standards to generate Service Oriented Architectures.
- **Motivation**
  - To be able to add features such as dynamic function placement, high degrees of network automation, intent-based networking, services self-optimization and so on, a data-driven approach is required (AI-based), and new types of endpoints should be created that support multi-domain/multi-stakeholder scenarios.
- **Solution**
  - Demonstrate the concept of API Management Exposure as it is able to cope with the following features:
    - Flexible Cross-Domain data exchange
    - Capability Exposure
    - Capability Exposure Levels
    - Access Control
    - API Discovery & API Registration
- **Conclusion**
  - The need to overcome Reference-to-Reference “old” architectures has been demonstrated in order to be able to face the requirements that may rise with future 6G networks.
  - AI/ML driven orchestration requires such newer approaches.
  - The API Management Exposure concept, presented in D6.2 is a good candidate for this new communication paradigm.



5.6 CaaS framework

- ## Background
  - In D5.2, Section 5.7, a Software Reconfiguration Framework was introduced as defined by the European Telecommunications Standards Institute (ETSI) Technical Committee Reconfigurable Radio Systems (RRS), including a definition of a key Interface, i.e., the generalised Multiradio Interface (gMURI) [303681-1].
  - In October 2022, ETSI published a Technical Specification TS 103 850 which defines the format of a Radio Application Package (RAP) that is being used to provide a single or multiple Radio Application (s) and related information to a compute framework.
- ## Motivation
  - Extension of the upper RAP structure (on the upper right side) to be applicable for delegating/ offloading generic application related workloads (besides radio signal processing ones) to networked compute nodes based on different computing platforms.
- ## Solution
  - Define the content of the "Reserve" information element of the RAP data structure as outlined on the lower right side.
  - The “Reserve” element is proposed to be transformed into a structure with a number of attributes (alternatively, the proposed attributes can be also added to the tree structure above at the same level as the Reserve element, which in that case, can be maintained)
- ## Conclusions
  - The proposed Compute Federation architecture is generic and can be applied to be applicable for delegating/ offloading generic application related workloads (besides radio signal processing ones) to networked compute nodes based on different computing platforms. It is expected to positively affect the "TCO reduction" architecture KPI, due to the enablement of compute resource sharing without the need for an MNO to deploy an in-network computing infrastructure that would be maybe denser than needed to address client demands.



Top Level tree structure as defined by ETSI TS 103 850

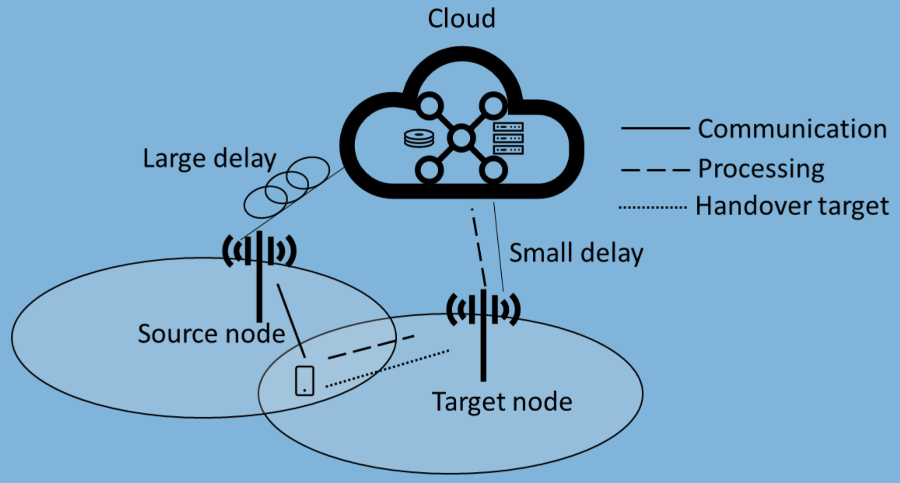
Requirements	Proposed new sub-elements
Data and data governance	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation) High-risk AI systems … shall be developed on the basis of training, validation and testing data sets that meet the quality criteria ...
Technical documentation	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): The technical documentation shall be drawn up in such a way to demonstrate that the high-risk AI system complies with the requirements …
Record keeping	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): High-risk AI systems shall be designed and developed with capabilities enabling the automatic recording of events (‘logs’) …
Transparency and information to users	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): High-risk AI systems shall … ensure that their operation is sufficiently transparent to enable users to interpret the system’s output and use it appropriately …
Human oversight	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): High-risk AI systems shall be designed and developed in such a way, including with appropriate human-machine interface tools, that they can be effectively overseen by natural persons during the period in which the AI system is in use …
Accuracy robustness and cybersecurity	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): High-risk AI systems shall … achieve, in the light of their intended purpose, an appropriate level of accuracy…
Risk management system	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): A risk management system shall be established, implemented, documented and maintained in relation to high-risk AI systems …
Quality management system	• Bit: “Requirement met”: 0 = requirement not met (likely no market access allowed in the European Single Market), 1 = requirement met • If applicable (if requirements are not met for all cases, but under specific conditions): Bit “Requirements met under specific conditions” = 1, following by a definition of the conditions, e.g. for a specific high risk application (as defined in the annex of [AIAct+21], for example biometric detection applications, critical infrastructure applications, etc,). • Further details on how to make sure that the regulation requirements are being met (possibly in text form or in machine readable representation): Providers of high-risk AI systems shall put a quality management system in place that ensures compliance with this Regulation …

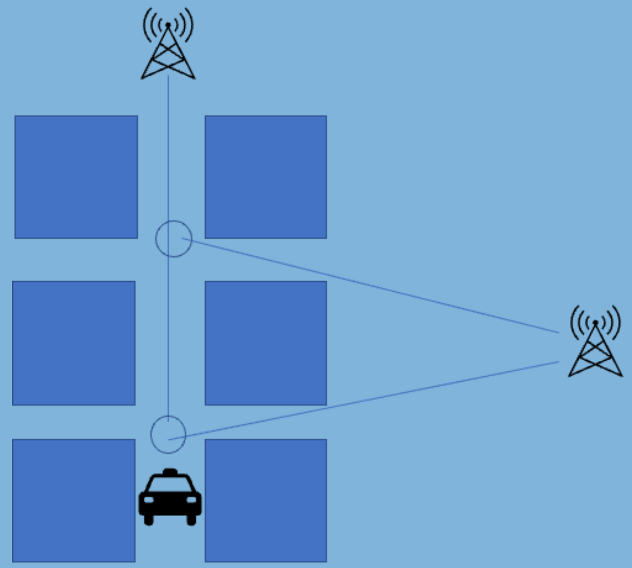
Sub-Elements ("children") of the proposed Regulation_Conformity attribute of the RAP "Reserve" attribute.

(*) ETSI EN 303 681-1 V1.1.2 (2020-06), Reconfigurable Radio Systems (RRS); Radio Equipment (RE) information models and protocols for generalized software reconfiguration architecture; Part 1: generalized Multiradio Interface (gMURI)

5.7 Handover improvements

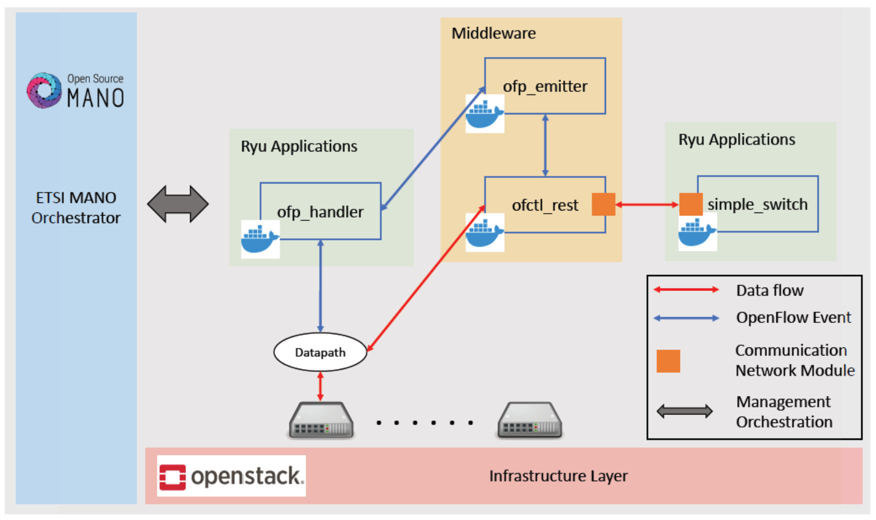
- Background
  - Mobility is one of the fundamental characteristics of a cellular system.
- Motivation
  - For most services handovers should be as fast as possible.
- Solution
  - The idea is to investigate how the handover latency can be reduced using cell-specific measurement offsets, the so-called q-offset. The q-offsets are added by the UE to the measurements of each cell before determining whether these fulfil the reporting criteria to prioritize handover to cells with lower latency.
  - Regarding sensing different attempts on using position as input to handover were examined. Using sensing, the direction and speed of a UE can be measured and perhaps even predicted.
- Conclusion
  - Applying the q-offsets can help reduce latency from handovers
  - Sensing can help improve (latency of) handovers. The potential is larger when satellites are involved compared to TN.

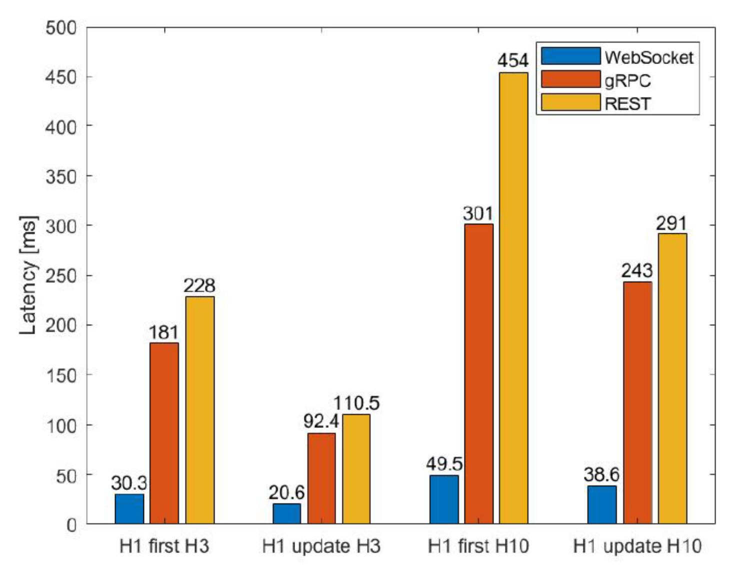




5.8 Microservice based SDN controller

- **Background**
  - An Agent is any possible network subfunction, protocol, tasks, sub-task etc. which can meet a given goal autonomously, employing intelligence. The first step of creating a multi-agent system is the split of the network functions into sub-functions.
- **Motivation**
  - Providing flexibility and automated resilience via distributed adaptive systems of agents. The SDN controller is a fundamental functionality of the control plane, which can be split in sub-functionalities. To make these agents, intelligence should be added subsequently.
- **Solution**
  - The SDN controller has been realized as a set of microservices that interwork to perform the complete functionalities of the original controller.
- **Conclusion**
  - In the design and implementation, the metrics of latency and scalability have been measured. This is fundamental step towards the creation of efficient networks based on micro-services and subsequently on multi-agent systems.





Hexa-x Quantified targets for the “Network evolution and expansion towards 6G”

Current status

4a) Simultaneous high rate and low E2E latency (>0.1 Tbps @ <1 ms)

Air interface considerations

Hexa-X

- Focus on focus is on DL user plane of an E2E packet flow assuming the connections is set up. Latency is measured for DL link data packet that leaves a server application and arrives at the application in the UE.
- Table 3-2 of HEX-D21 provides 100 Gbps data rate signal bandwidth analysis.

Modulation	bits / symbol (b/S), no coding	bits / symbol (b/S), 5/6 coding	RF BW no coding (GHz)	RF BW 5/6 coding (GHz)	BB BW no coding (GHz)	BB BW 5/6 coding (GHz)
BPSK	1	0.83	100.00	120.00	50.00	60.00
QPSK	2	1.67	50.00	60.00	25.00	30.00
16-QAM	4	3.33	25.00	30.00	12.50	15.00
64-QAM	6	5.00	16.67	20.00	8.33	10.00

- At least two to four parallel streams are needed either as point-to-point or distributed fashion (D-MIMO). For 480 kHz sub carrier spacing radio link latency of 90 - 100 µs is achievable HEX-D23. We allocate 100 µs for air interface.
- Thus, the limiting factor is not numerology or bandwidth, but UE and signal processing times in RAN.

Signal processing latency analysis for radio stack

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- We expect that the PHY layer processing time for 6G will 10 times shorter than current state of the are: 8 μs.

- Considering 5G carrier and a slot size of 2 OFDM symbol, 275 resource blocks with 12 subcarriers each OFDM symbol contains 275 * 12 sub-symbols. With 4 MIMO layers, the PHY can process 2 · 275·12·8·4=211200 bits within 8 μs processing time.

- Using same latency, as for PHY, for MAC, RLC, PDCP, SDAP and IP, the signal processing latency is 5·8 μs = 40 μs.

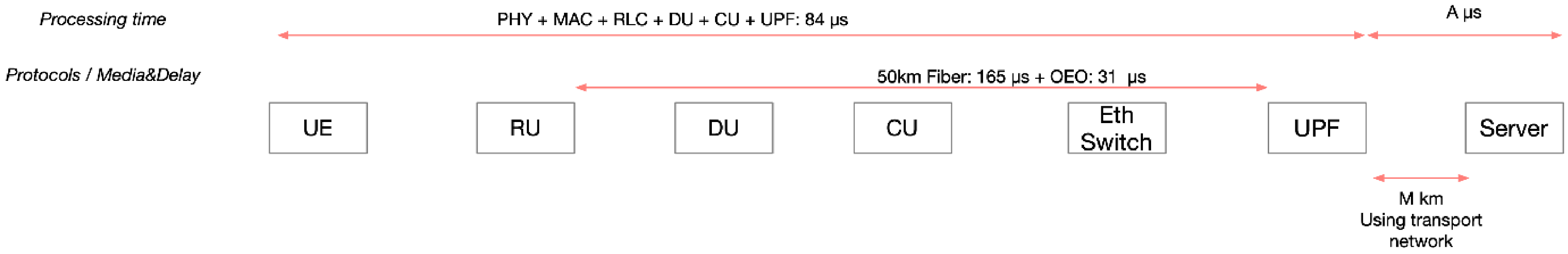
4a) Simultaneous high rate and low E2E latency (>0.1 Tbps @ <1 ms)

E2F latency for Single RAN with co-located CN and server

- E2E delay: UE radio stack delay + RAN stack delay + UPF delay = $40\ \mu s + 40\ \mu s + \alpha\ 40\ \mu s = 84\ \mu s$, α=0.1

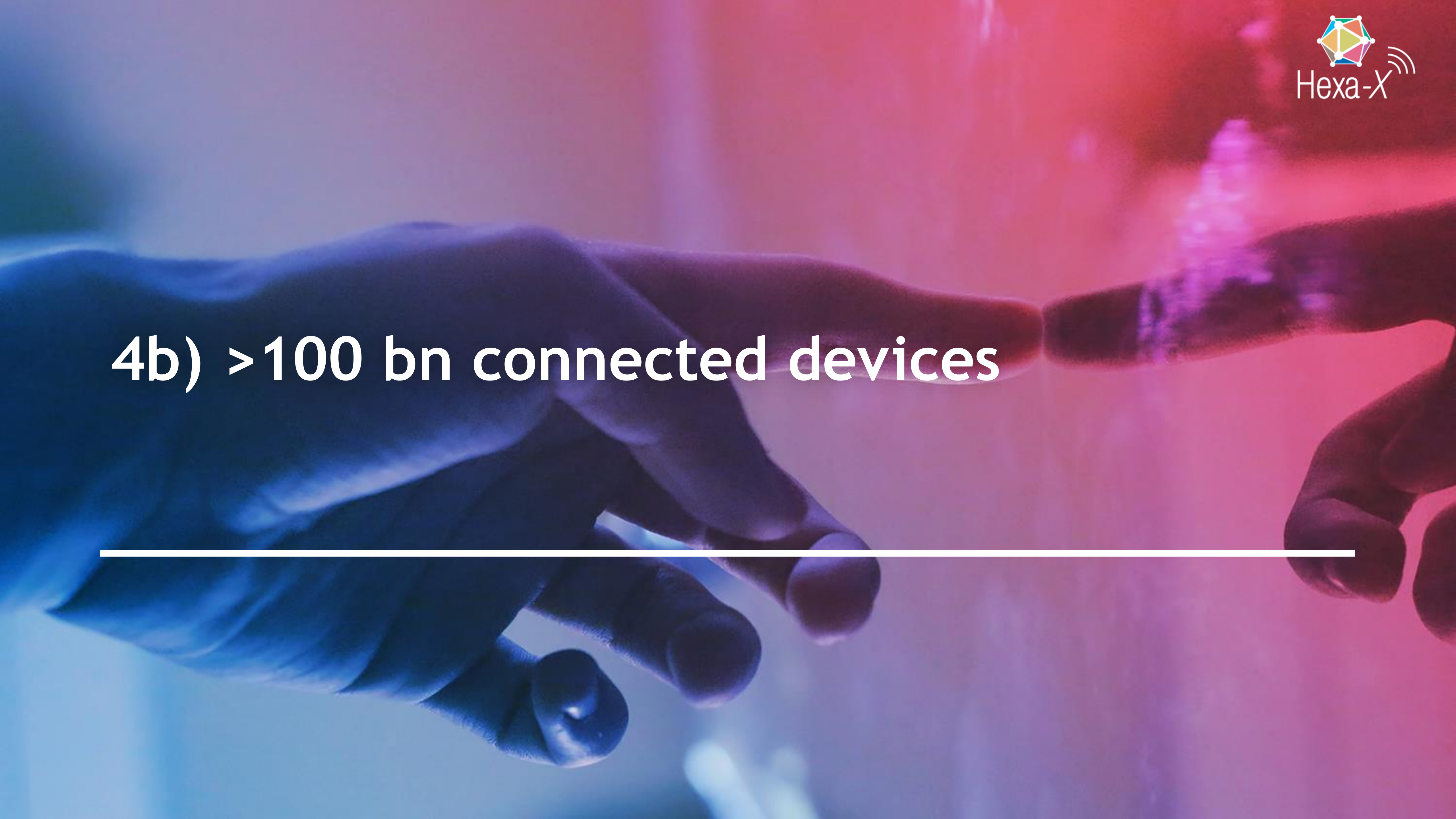
E2F latency for split RAN

- For split RAN case we need to take into account transport delays between RU, DU, CU, UPF and application server in addition to signal processing times.



- The application server is assumed to be 50 km from RU and the delay for optical fibre 3.3 µs/km.
- E2E delay: radio stack and UPF delays of 84 µs + fiber delay of 165 µs + OEO + ethernet 31µs) = 280 µs latency.

4b) >100 bn connected devices



Connection density

- This section describes how to reach the target of 100 billion devices.
- We have divided this into two methods.
  - The first method is to analyse the **connection density** results from 3GPP and ITU evaluations for NR which only concerns the radio (air interface) capacity.
  - The second method is to discuss how our **enablers** can contribute to the overall improvement of the E2E capacity for the required connection density.

Connection density

- Two main track here (so far)
  - 1) Use 3GPP connection density (RAN mostly)
  - 2) Hand-waving of our enablers (more E2E)

- The connection density is calculated as follows:
- $$C = \frac{N}{A} = \frac{N_{mux} \cdot W / mean(B_i)}{ISD^2 \cdot \sqrt{3}/6}$$
  - Where N = number of user supported per “cell”
  - A is the cell area
  - N_{mux} is the number of users on same resource, is typically set to 1
  - B_i is the long-term bandwidth requirements based on packet interarrival and simulated data rate and SINR
    - The term $W/mean(B_i)$ is giving the number of users that a TRxP can accommodate.
    - Packet interarrival rate is set to one 32 byte packet every 2 hours (mMTC traffic)

3GPP results

	Connection density [Millions per km²]	Bandwidth (W)	Cell radius	Frequency
NR Full Buffer 500m	36.008	180 kHz	500 m	700 MHz
NR Full Buffer 1732m	1.5034	180 kHz	1732 m	700 MHz
NB-IoT-RRCresume	1.225	180 kHz	500 m	700 MHz

- The possible connection density per square kilometre is shown for NR and Narrowband IoT

Apply a dense city to see if the 3GPP connection density can fulfil the 100 billion

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- Use dense cities to see if we can fulfil this target already with 5G
  - Scale 100 billions to world population (8 billions) (i.e. no of connections per person)
  - Multiply this with city population to get the needed connections in city centre
  - Compare with 3GPP connection density

City	Population [millions]	Area [km^2]	Target connection density [millions]	Maximum connections for NR_FB_1732m [millions]	Maximum NB-IoT-RRCresume [millions]
Paris	2.16	105.4	27.07	158.4	129.1
Athens	0.74	38.96	9.3	58.6	47.7

- Target connection for Paris: 2.16 million * (100/8) = 27 million connections
- 1.225 million connections per km2 => 105*1.22 = 129 possibly connections
- 5G can handle the target since 129 million >> 27 millions

Ways to improve number of connected devices

Connection density

- Increased SINR
- Increased bandwidth W
- Increased multiplexing
- Decreased ISD.

Enablers

- Improvement of the signalling efficiency (procedures)
- Virtualization and Service based type architecture allows more reuse of functions
- Independent NFs (separation of concerns)

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4c) (>99%) of global population reached with (>1 Mbps) data rates

4d) Full coverage (100%) of world area

4c) (>99%) of global population reached with (>1 Mbps) data rates
4d) Full coverage (100%) of world area

Assumptions

- The assumptions are the following:
  - Assume a certain cell area for the LEO satellite (and possibly GEO satellites too)
  - Assume a maximum of X satellites
  - Assume each satellite is equipped with beam forming and the gateway is a dish antenna with a certain antenna gain
  - Assume the satellites can relay the data (inter-satellite links)
  - Assume that it is enough tom simulate a limited area (e.g., Europe and Atlantic ocean)

4c) (>99%) of global population reached with (>1 Mbps) data rates
4d) Full coverage (100%) of world area

Methodology

1. Calculate the SINR per cell area for LEO satellites assuming no interference
2. Calculate the number of ISL hops and the ISL delay for each cell
3. Estimate the cell bitrate from the SINR
4. Assign a simple TCP model based on RTT (where the ISL delay is one part) to achieve a more realistic cell throughput
5. If TCP cell throughput > X Mbps over ALL areas in the world, then target 4d is fulfilled
6. For 4c) also add M users per cell to step 7 and X=1 Mbps.

4c) (>99%) of global population reached with (>1 Mbps) data rates
4d) Full coverage (100%) of world area

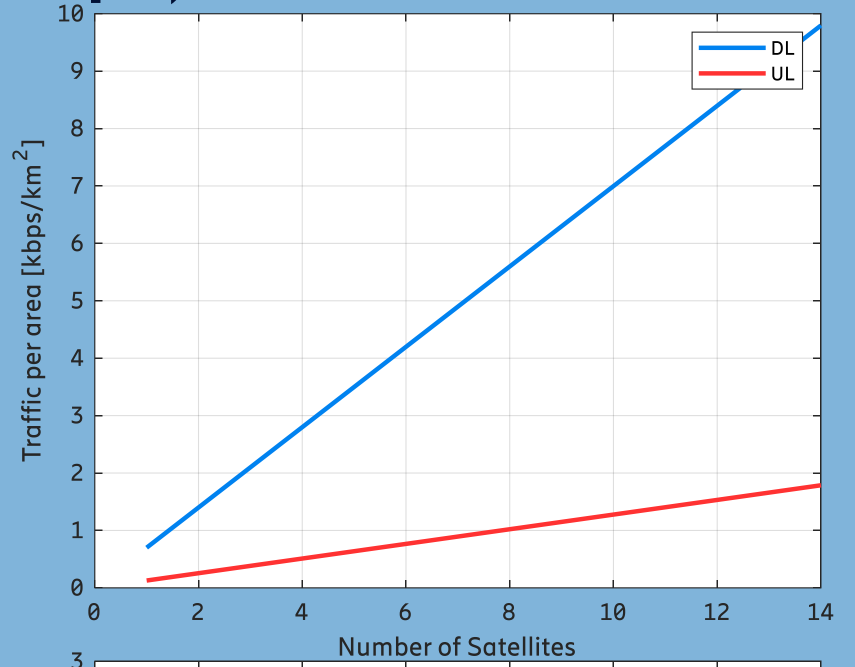
Parameters used for the evaluation

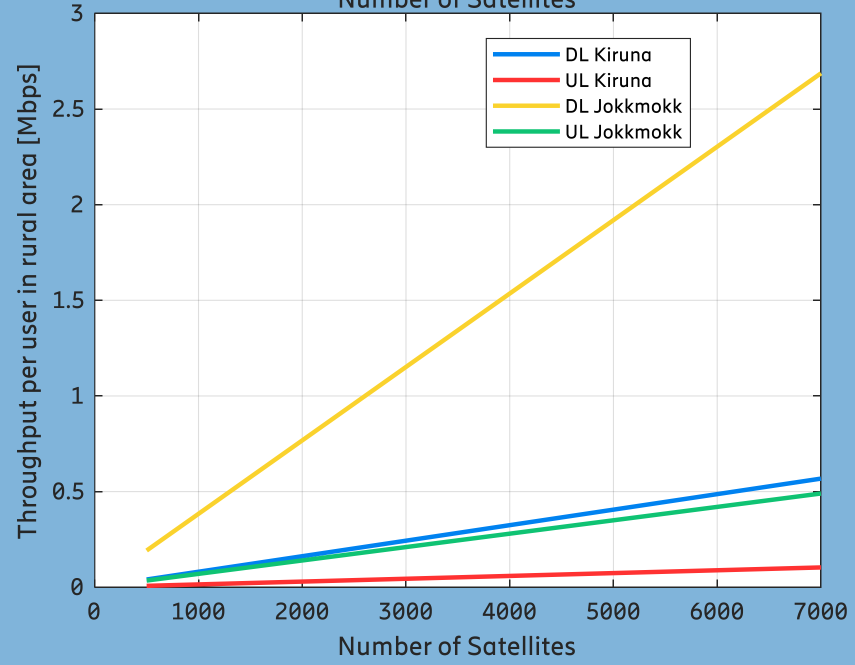
	Altitude [km]		Inclination [degrees]		No. of planes		No. of satellites per plane		
Phase	Orbit 1	Orbit 2	Orbit 1	Orbit 2	Orbit 1	Orbit 2	Orbit 1	Orbit 2	Total no. of satellites
0	1015	1325	98.98	50.88	3	6	5	5	45
1	1015	1325	98.98	50.88	6	20	13	11	298
1.5	1015	1325	98.98	50.88	12	20	13	22	596
2	1015	1325	98.98	50.88	27	40	13	33	1671

	UL Service link (UE to Sat.)	DL service link (Sat. to UE)	ISL	Feeder link
Carrier frequency	S-band (2 GHz)	S-band (2 GHz)	KA-band (20 GHz)	KA-band (20 GHz)
Bandwidth	4 MHz	10 MHz	400 MHz	400 MHz
Tx power	33 dBm	N/A	N/A	N/A
Number of beams	32	32	1	1
EIRP	N/A	40 dBW/MHz	40 dBW/MHz	40 dBW/MHz
Antenna gain	0 dB	30 dBi	30 dBi	30 dBi
Shadow fading	0 dB	0 dB	0 dB	0 dB
Misalignment loss	0 dB	0 dB	0 dB	0 dB
Link delay	5 ms	5 ms	5 ms per hop	5 ms
Min elevation angle	30°	30°	N/A	30°
Reuse factor	7	7	N/A	N/A

4c) (>99%) of global population with (>1 Mbps) data rates

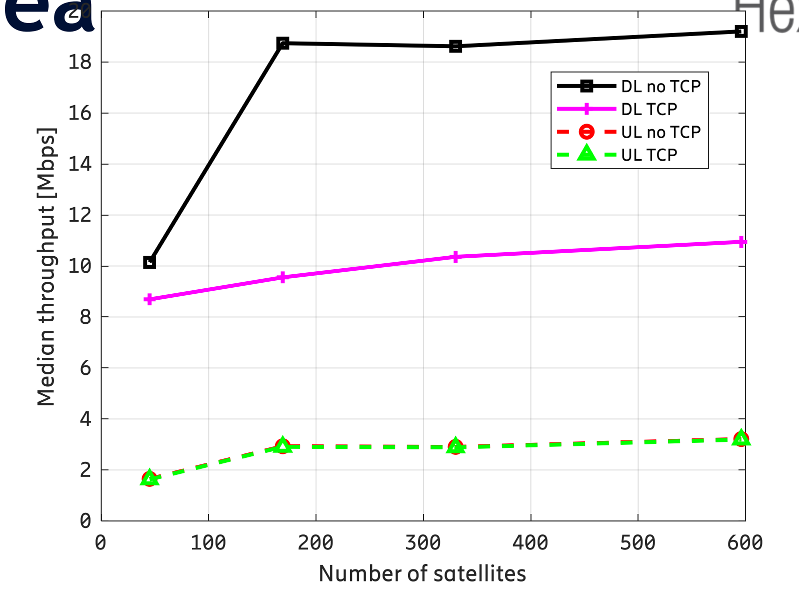
- **Background and Motivation**
  - WP5 has an objective to find architectural solutions that support full global coverage
  - Initial concept of an NTN architecture capable of efficient of inter-satellite-link (ISL) hops
- **Solution**
  - To find out if 99% (>99%) of global population with >1 Mbps data rate is feasible, we simulated a rural area and investigated the needed number of satellites to reach 1 Mbps per user (see lower figure).
  - We assume that high density populated areas are covered by the terrestrial network
  - Indoor coverage can be further improved by the Mesh network enabler presented here
- **Conclusions**
  - It is possible to reach (>99%) of global population with >1 Mbps data rate but only for areas with low population density and with relatively large number of satellites.

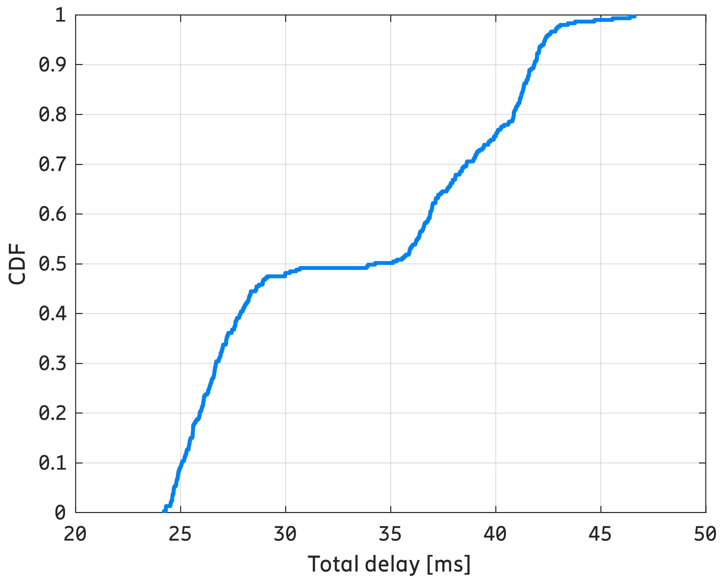




4d) Full coverage (100%) of world area

- **Background and Motivation**
  - WP5 has an objective to find architectural solutions that support full global coverage
  - Initial concept of an NTN architecture capable of efficient of inter-satellite-link (ISL) hops
- **Solution**
  - To find the full coverage, we simulated Atlantic ocean with 300 devices spread out over the area and investigated the needed number of satellites to reach 1 Mbps per device
  - To find the needed number of satellites to reach 100% connected devices, see slide 4.3.1
    - We need >600 satellites for this
  - The top figure shows the connected devices' throughput for different number of satellites (with and without TCP)
    - The DL throughput is clearly above 1 Mbps and due to the (RTT) delay it becomes limited by the TCP model
    - The UL throughput is around 3 Mbps, also above 1 Mbps
  - The lower figure shows the total one-way delay for the case with 600 Satellites
- **Conclusions**
  - It is possible to reach (>99%) of global population with >1 Mbps data rate but only for areas with low population density and with relatively large number of satellites.
  - Note that the results depend a lot on the simulation parameters used, such as the antenna gain, transmit power, bandwidths etc





Conclusions

Summary WP5 objectives

WPO5.1: Identified trends, use cases for gaps and principles for the architecture transformation

Objective fulfilled

WPO5.2: Developed an AIaaS architecture and programmability framework

Objective fulfilled

WPO5.3: Developed enablers for global service coverage and mesh networks, network of networks

Objective fulfilled

WPO5.4: Principles on how of enable efficient signaling for Cloud native RAN and Core network using Service based architecture

Objective fulfilled

WP5 objectives

Objective	Objective description	Progress
WPO5.1	Identify technology trends, use cases and requirements for architecture transformation.	Fully addressed in [HEX-D51].
WPO5.2	Develop technical enablers for Intelligent Networks capable of full AI integration and network programmability to boost connected intelligence. Distributed AI agents, running in both network functions and wireless devices, will be supported to provide increased network performance, while preserving the privacy of the users.	AIaaS framework with required services and functions are developed, together with the analytics framework needed (Section 3.1.2). A complete programmability framework is developed (see Section 3.1.4), both for the UE and the network side.
WPO5.3	Enable extreme performance and global service coverage within Flexible Networks. Vertical requirements will be addressed such as ultra-low latency via local ad hoc networks, cost-efficient global service coverage, and functionalities for securely managing local ad hoc networks in coordination with the infrastructure.	A concepts for ad hoc mesh network controller with management solution are developed and evaluated (see Section 4.2). The global service coverage are addressed with analysis of different TN architecture, including evaluations (see Section 4.3).
WPO5.4	The Efficient Networks will extend the existing Service Based Architecture for the Core Network to the Radio Access Network and wireless devices, streamlining and redesigning the functional architecture, merging or removing redundant functionalities and defining a clear functional split to reduce the Total Cost of Ownership related to network integration and implementation and improve network energy efficiency.	A concept for more self-sustained network functions assuming a cloud native CN and RAN extending current SBA concept (see Section 5.1). A method on how to perform a qualitative TCO analysis for some Hexa-X use cases are also developed (see Section 5.4).

Objective 4: Network evolution and expansion towards 6G Quantified targets

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4a) Access links supporting simultaneous high rate and low E2E latency (>0.1 Tbps @ <1 ms E2E)	4b) Supporting (>100 bn) connected devices in the network	4c) (>99%) of global population reached with (>1 Mbps) data rates at sustainable cost levels	4d) Full coverage (100%) of world area (see notes)
• It is possible to achieve a user plane latency lower than 1 ms for data rates higher than 0.1 Tbps • Assumptions: Cloud RAN/CN with LLS, server maximum 50 km away.	• 6G will probably be able to support >100 bn connections • Assuming low data rate (MTC) traffic • Signaling improvements and virtualization will also improve this	• It is possible to serve low population density areas with 1 Mbps/users assuming at least 14000 satellites in orbit, assuming a LEO constellation that allows efficient inter-satellite-link • See notes also	• For the “full (100%) global service coverage” target, the conclusion is that is feasible to support assuming a LEO constellation that allows efficient inter-satellite-link hops with at least 600 satellites and assuming very low user density.

Thank you!

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