



6G SNS



Architecture Enablers for 6G Subnetworks: The 6G-SHINE Vision

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Associate Profesor

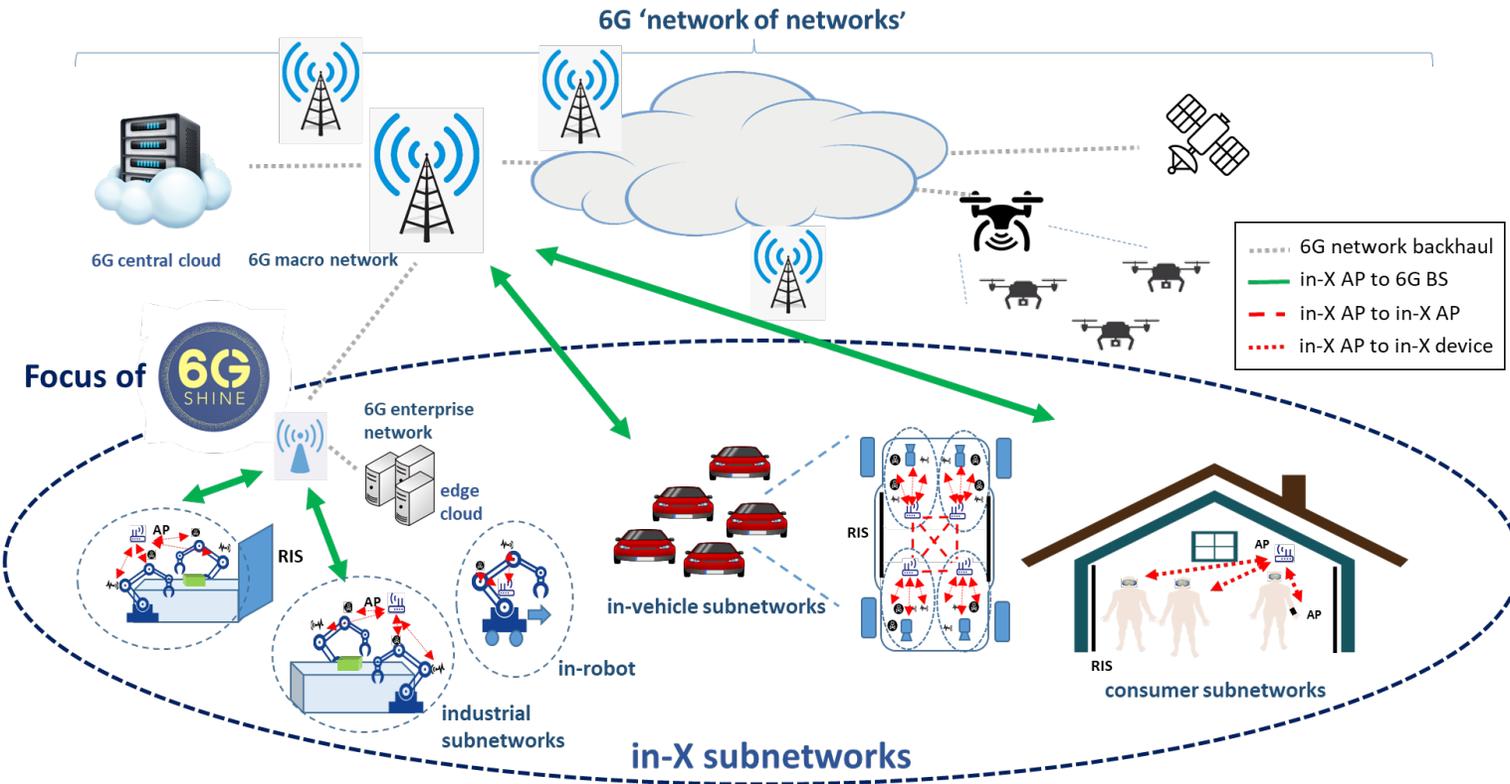
Universidad Miguel Hernández de Elche (UMH), Spain

with contribution of 6G-SHINE project partners



- **6G-SHINE vision**
- **Use cases**
- **Motivation & Architecture innovations for realizing subnetworks**
 - **Definition of subnetwork architecture**
 - **Subnetwork Management Node**
 - **Architecture enablers for RRM in subnetworks**
 - **Control & goal-oriented communications in subnetworks**
 - **Architecture enablers for dynamic computational offloading**
- **Standardization impact**
- **Conclusions**

6G-SHINE vision



Focus on **in-X subnetworks**, short range low power cells to be installed in entities like robots, vehicles, production modules, classrooms, etc.

Demanding performance requirements in terms of latency, reliability, or data rates

Potential **high density subnetwork crowds** (e.g., vehicles in a congested road)

Standalone operations, with potential **support of broader 6G network**

Architectural innovation needed to integrate short-range high-performance wireless subnetworks into broader communication infrastructure

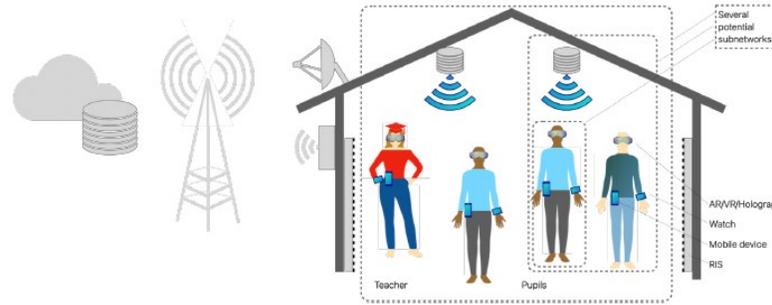
Considered in-X scenarios/use cases

- **Industrial:** Fast closed loop control (e.g, force control) in robots and production modules
- **In-vehicle:** motor control, breaking, advanced driver assistance systems (ADAS) sensors
- **Consumer:** XR applications for education, gaming, entertainment

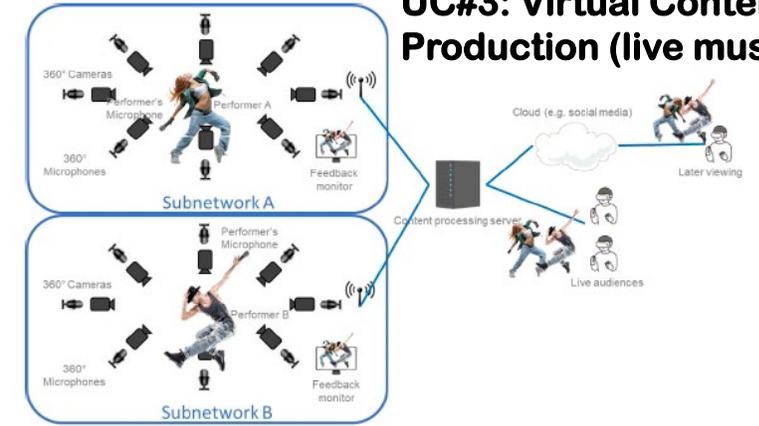
KPI

- Communication cycles: ~5-20 ms
- Packet sizes: ~B (sensor) – ~100 B (audio) – ~KB (visual)
- Delay: 5ms – 100ms
- Up to ~50 devices

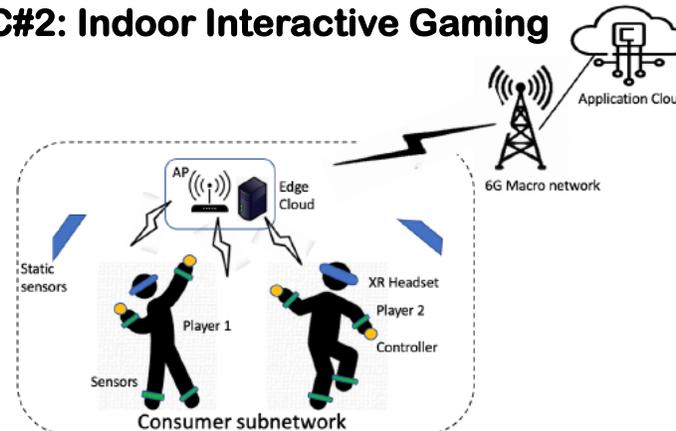
UC#1: Immersive Education



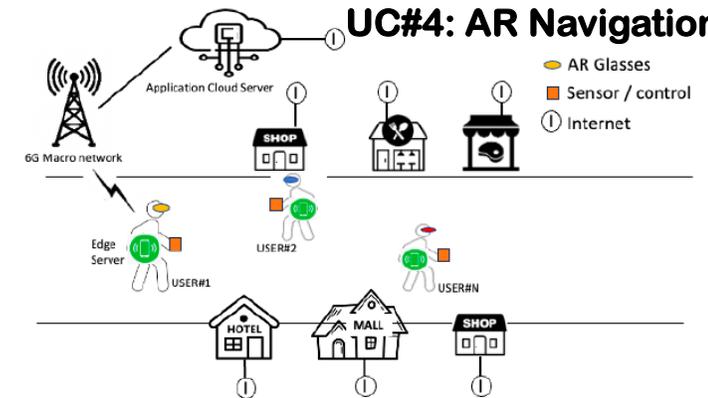
UC#3: Virtual Content Production (live music)



UC#2: Indoor Interactive Gaming



UC#4: AR Navigation



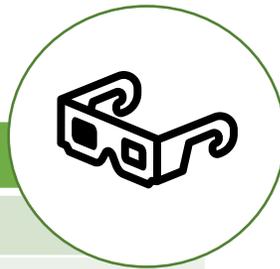
Consumer

Immersive education

Indoor interactive games

Virtual live production

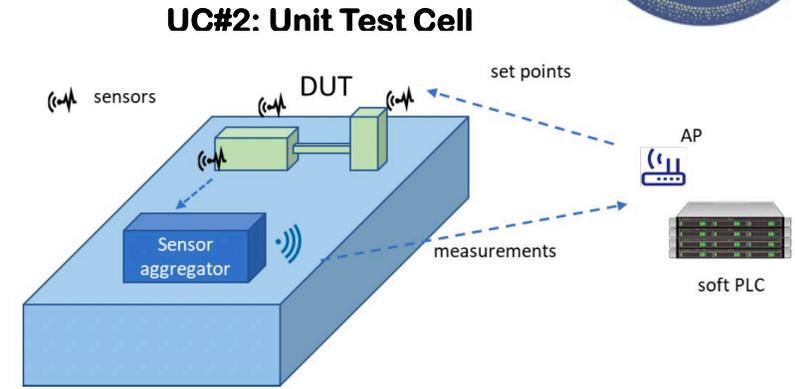
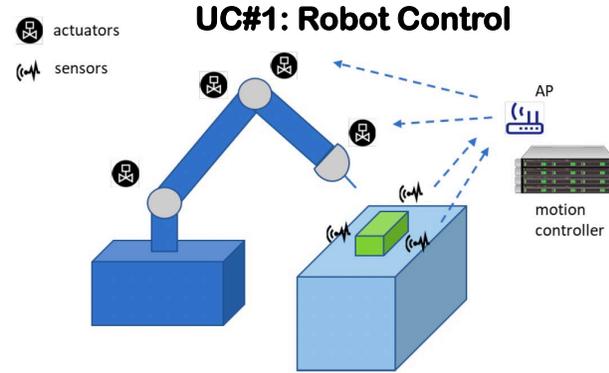
Augmented Reality (AR) navigation



Use cases - Industrial

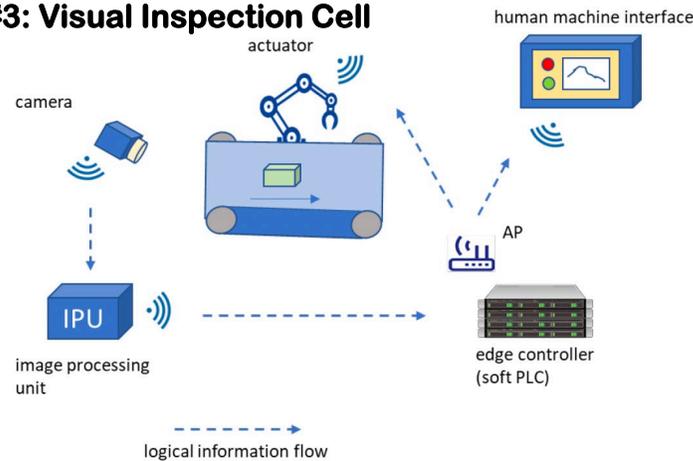
KPI

- Comm. cycles: from ~100 ms to ~100 us
- Packet sizes: 60-1300 bytes
- Prob. of consecutive errors <math><10^{-6}</math>
- Jitter <math><1\text{ us}</math>
- Up to ~50 devices (e.g., sensors)

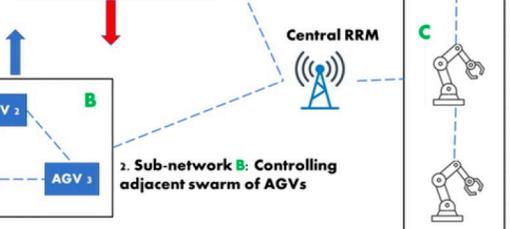
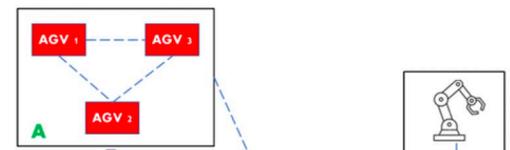


UC#5: Subnetwork segmentation and management

UC#3: Visual Inspection Cell

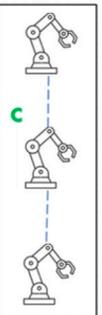


1. Sub-network A: Controlling swarm of AGVs



UC#4: Subnetwork Co-existence

3. Sub-network C: Controlling a production plant



Industrial

Robot control

Unit test cell

Visual inspection cell

Subnetwork coexistence in the factory floor

Subnetwork segmentation and management

Use cases – In-vehicle

KPI (derived from the supported automotive systems)

- latency: < 1ms
- data rate: from 2Mbps to 10 Gbps
- reliability: > 99.9%
- deterministic or bounded latency: yes
- control loop time: ~ ms



In-vehicle

Wireless zone Electronic Control Unit (ECU):

In-vehicle wireless subnetwork zone

Collaborative wireless zone ECU:

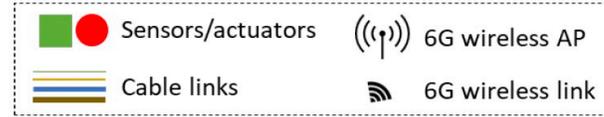
Functions across multiple in-vehicle zones

Inter-subnetwork coordination:

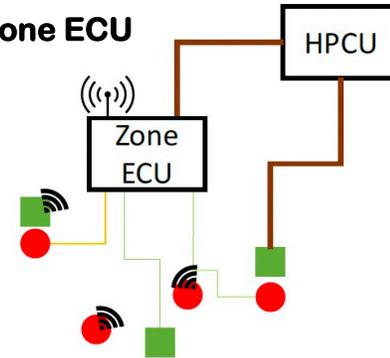
Collaboration between subnetworks in intra/inter-vehicle communications

Virtual ECU:

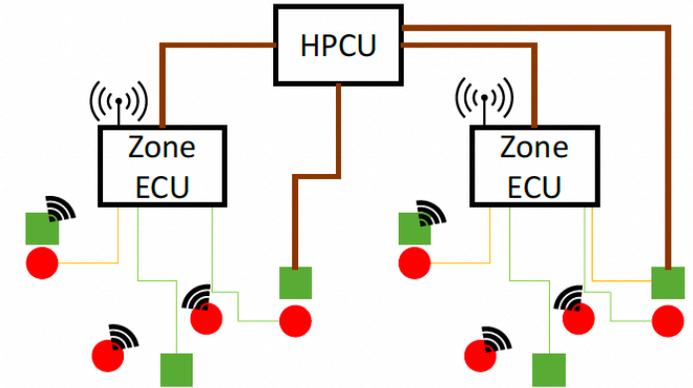
In-vehicle sensor data and functions processing at the 6G network edge



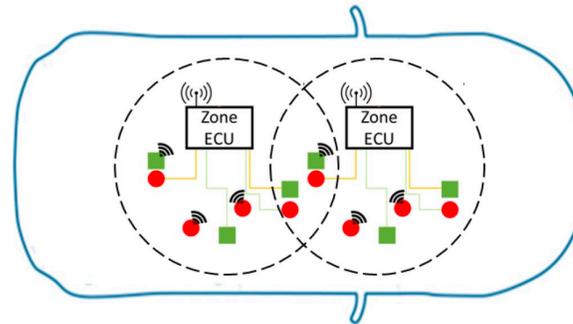
UC#1: Wireless Zone ECU



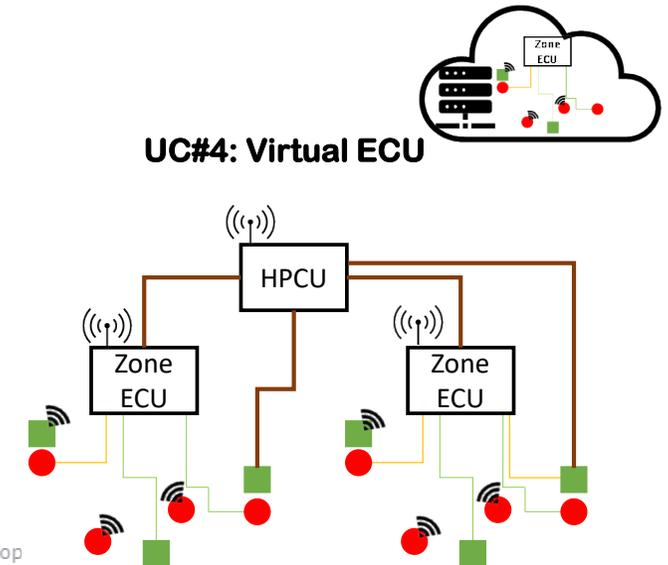
UC#2: Collaborative Wireless Zone ECU



UC#3: Intra/Inter-subnetwork Coordination



UC#4: Virtual ECU





- Lack of mechanisms and architectural enablers for the seamless integration of subnetworks with the 6G parent network
 - Capable of providing the dependable service levels demanded in subnetworks in a cost-effective manner
 - Considers the different degrees of capabilities of subnetwork elements
 - Current subnetwork-like 5G solutions (Personal IoT networks - PIN – or Ambient IoT networks) have different targets
- Support for (partially) independent operation of subnetworks
 - Full integration of subnetworks subsystems/operations can be cumbersome
 - Dynamic functional splitting and offloading necessary for the interworking & standalone operations of subnetworks with 6G parent network



- Definition of **flexible subnetwork architecture** applicable to different categories
 - Elements' roles & comm. modes & characteristics, subnetwork deployment options (e.g. nested)
- Interfaces for the **integration** of subnetworks **with the 6G** parent network
 - Advancing towards the 6G Network of Networks (NoN) paradigm
- **Interworking and functional split** of subnetwork with 6G parent network
 - Management of dynamic changes of roles & responsibilities based on changes in network topology
 - Survivability: support of temporary independent operation of subnetworks
- **Enablers for the efficient operation** through unified 6G networks
 - Authorization, RRM/interference management and computational offloading mechanisms

**... a subset is presented in what follows
(full details coming in our Deliverable D2.4)**

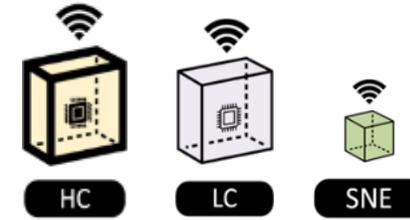
Definition of subnetwork architecture

Unicity of subnetworks concept + multiple identified scenarios => Flexible subnetwork architecture definition

Subnetwork elements: defined according to capabilities (computational, communication, power, energy ...)

- Element with High Capabilities (HC)
- Element with Low Capabilities (LC)
- Subnetwork Element (SNE)

Relative to each other
on a per-use case basis



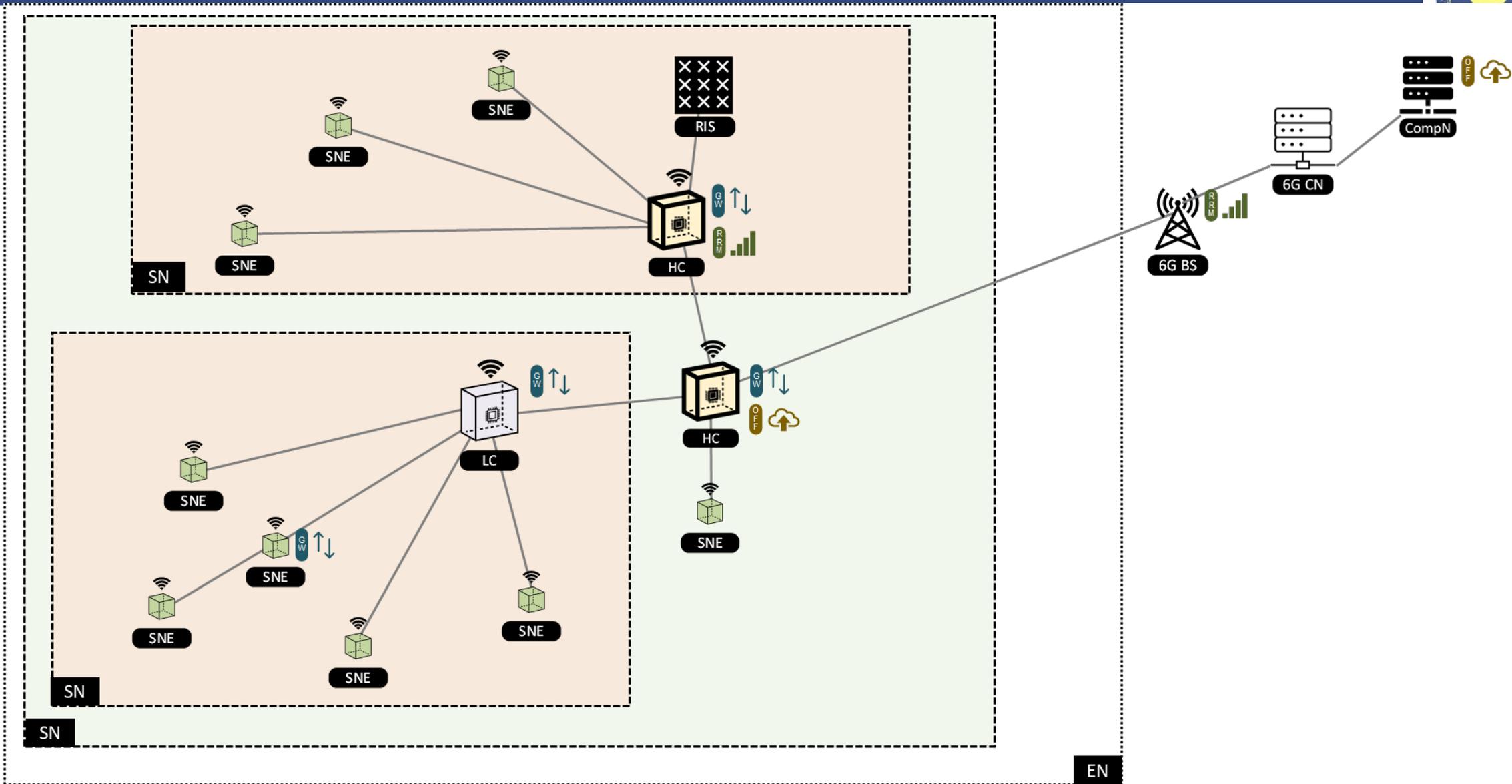
Elements roles: sets of functionalities/features that can be assigned to different elements present in the use case

- Gateway (GW): manage the data traffic routing within and/or across subnetworks 
- Compute Offloading (OFF): orchestrate application and/or network function offloading 
- Radio Resource Management (RRM): manage the radio resources of one or multiple other elements 
- Subnetwork Management (SNM): manages the operational activities of (e.g. authentication, handover procedures, master clock roles, and monitoring of network performance) 

Communication modes: communication relationships between the various types of elements

- Direct & indirect (relayed)

Reference subnetwork architecture

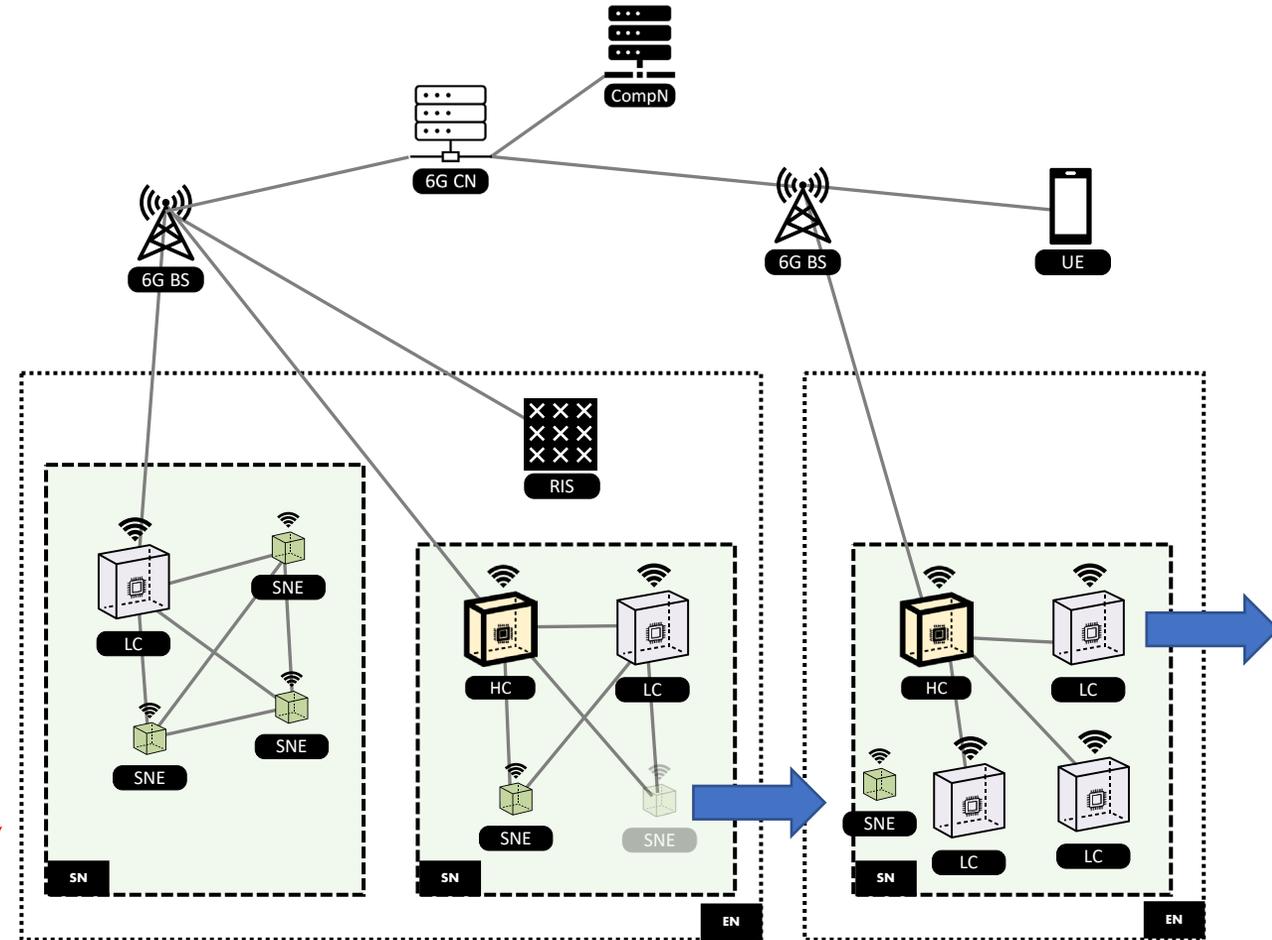


Advanced scenarios requiring architecture support



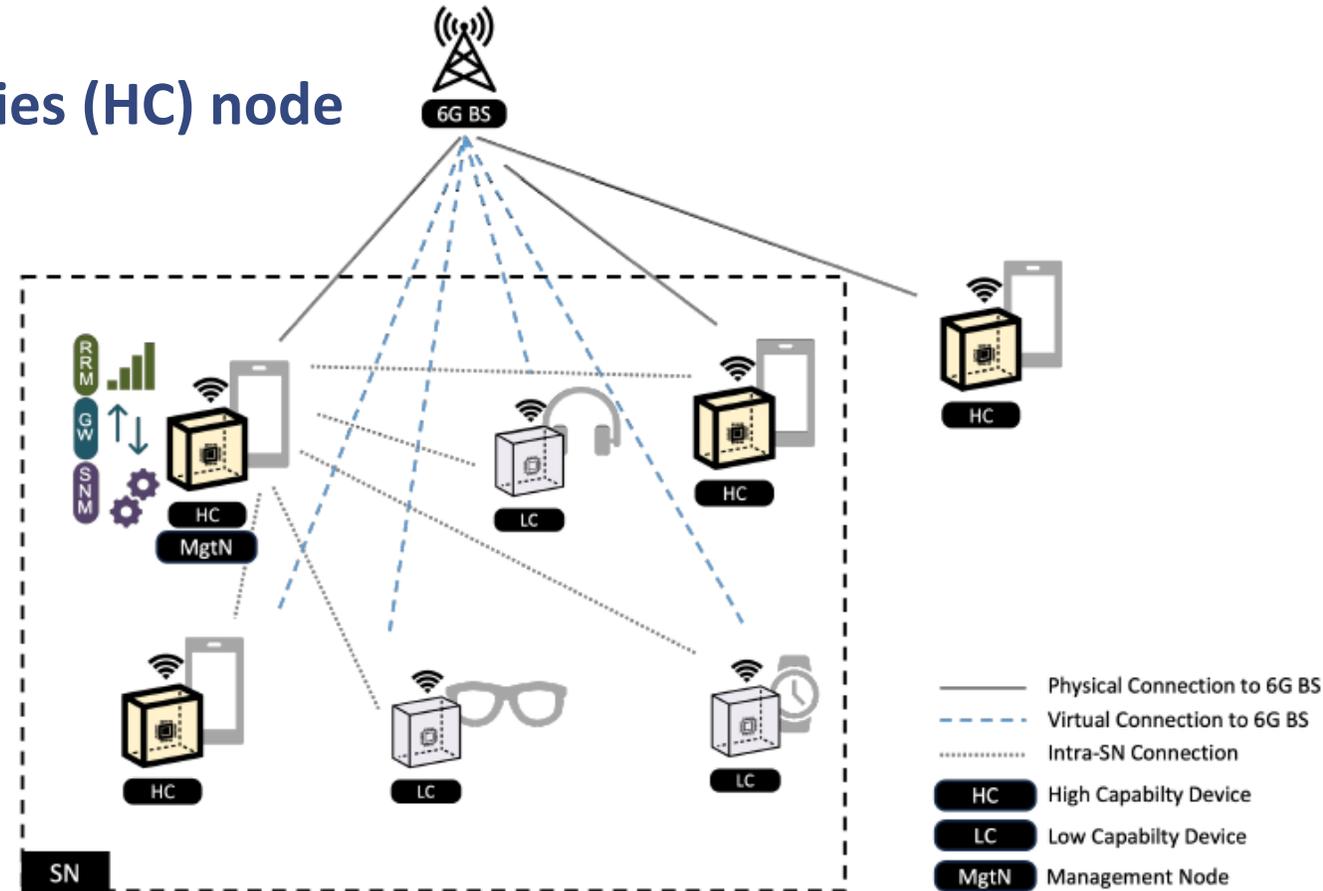
Identified scenarios of interest

ID	Scenario	Abbreviation	Description
S-01	Regular scenario	REG	The regular scenario without any special changes of the setup.
S-02	Join subnetworks	JOIN	Join of multiple subnetworks into one single one (generalization of inclusion of remote participant)
S-03	Ad-hoc subnetwork	ADHOC	Setting up an ad-hoc subnetwork (e.g. for AGV swarms at a production marketplace)
S-04	6G network outage	OUT	Outage of a parent network for static subnetworks (cannot be anticipated) Types: Data network access needed, Data network access not needed
S-05	6G network coverage hole	COV	Coverage hole of a parent network for mobile subnetworks (can be anticipated) Types: Data network access needed, Data network access not needed
S-06	Close subnetworks	VIC	Multiple subnetworks appear in each other vicinity
S-07	Join or leave a subnetwork	CHN	A device (SNE or AP) with an important role joins or leaves a subnetwork (both, when parent net available or unavailable)
S-08	Outage of an HC, LC	APO	An AP leaves the subnetwork or unexpectedly becomes unavailable through some other reason
S-09	Nomadic elements of a subnetwork	NOM	HCs, LCs, and SNEs can change group assignment between more than one subnetwork (also hierarchical in nested subnetworks)



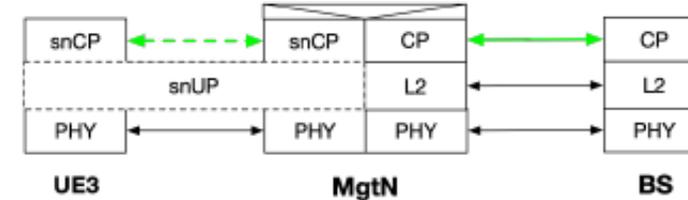
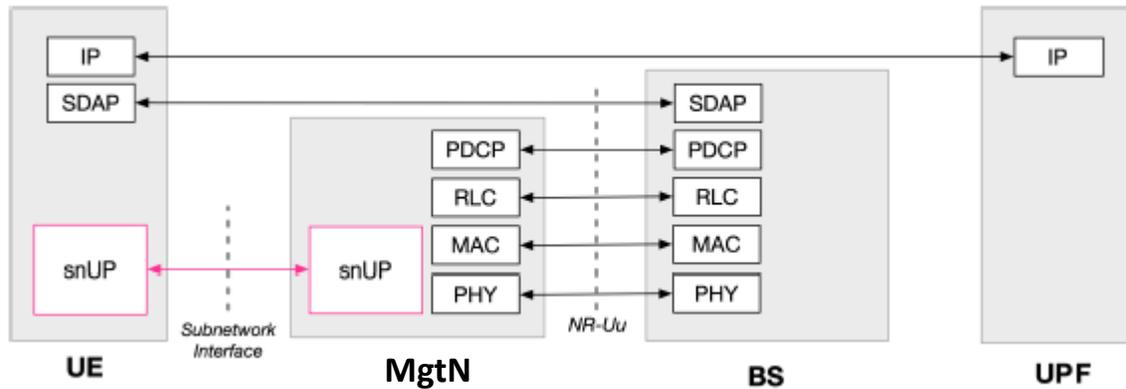
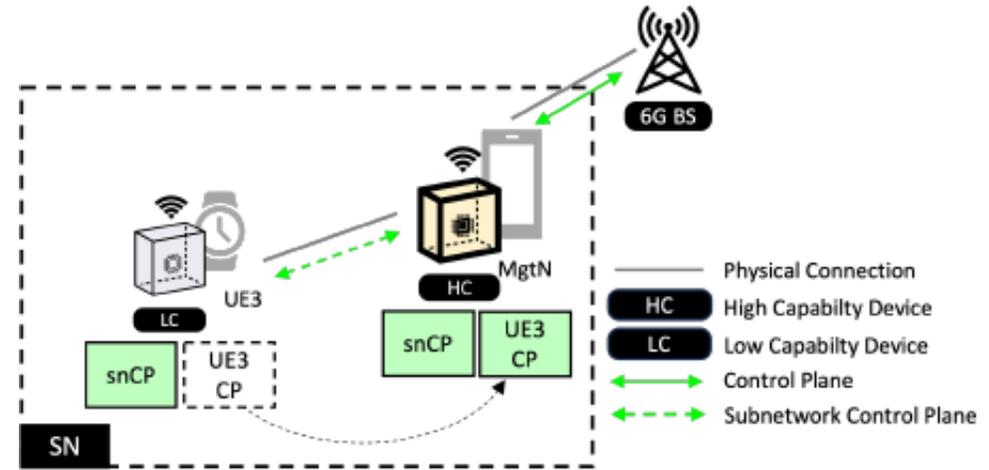
- **Management Node (MgtN): High Capabilities (HC) node with management role**

- Gateway connecting subnetwork nodes and the overlay 6G NW
- Functional splitting with 6G NW through the offloading of (some of) its functionalities
- Responsible for the local SN control and data routing
- Guarantees SN operation in the absence of an overlay NW
- Dynamic role, since a device might opt for switching to/from an LC or HC



MgtN: Lighter subnetwork communications architecture

- MgtN: Provides support to lighter...
 - ...subnetwork control plane (snCP) ...
 - Control plane functional splitting to HC-MgtN
 - **snCP** concentrates CP functionality of SN elements



... and user planes (snUP) ...

- 3GPP stack compliant until HC-MgtN ... and not to the SN elements

... to save power & reduce complexity for the SN operation



MgtN: Delegated subnetwork operations

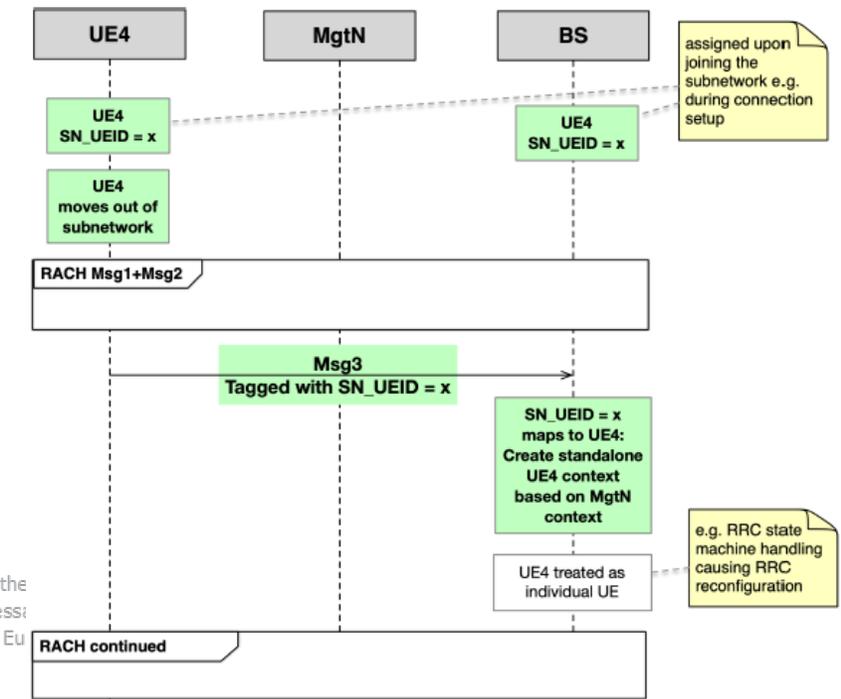
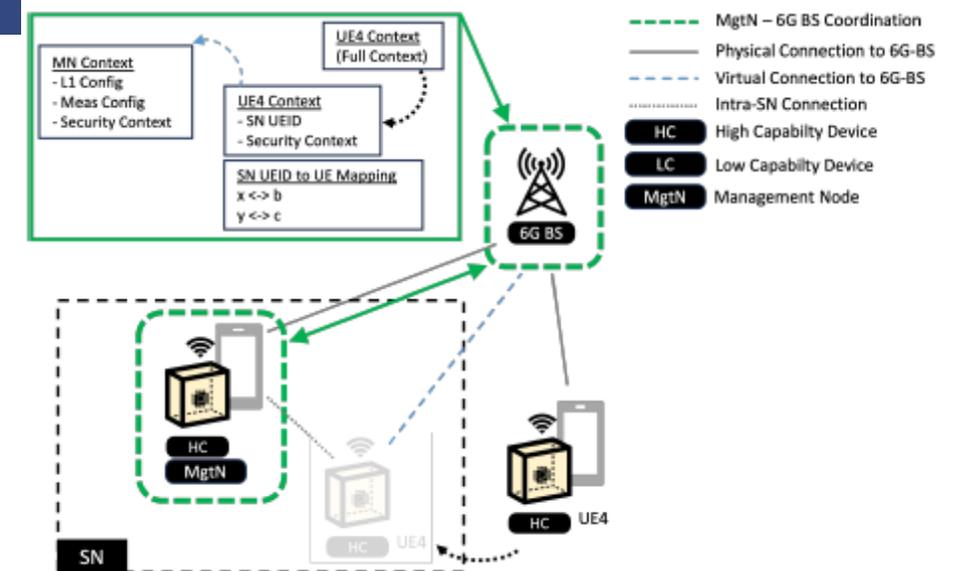
MgtN: takes main responsibilities in subnetwork

• Procedures for joining...

- Procedures for establishing SN elements as “members” of the SN - logical link between 6G and SNE via HC-MgtN
 - SNE (e.g. UE4)’s connection establishment request via HC-MgtN
 - SN_UEID gained and linked to the one of the HC-MgtN

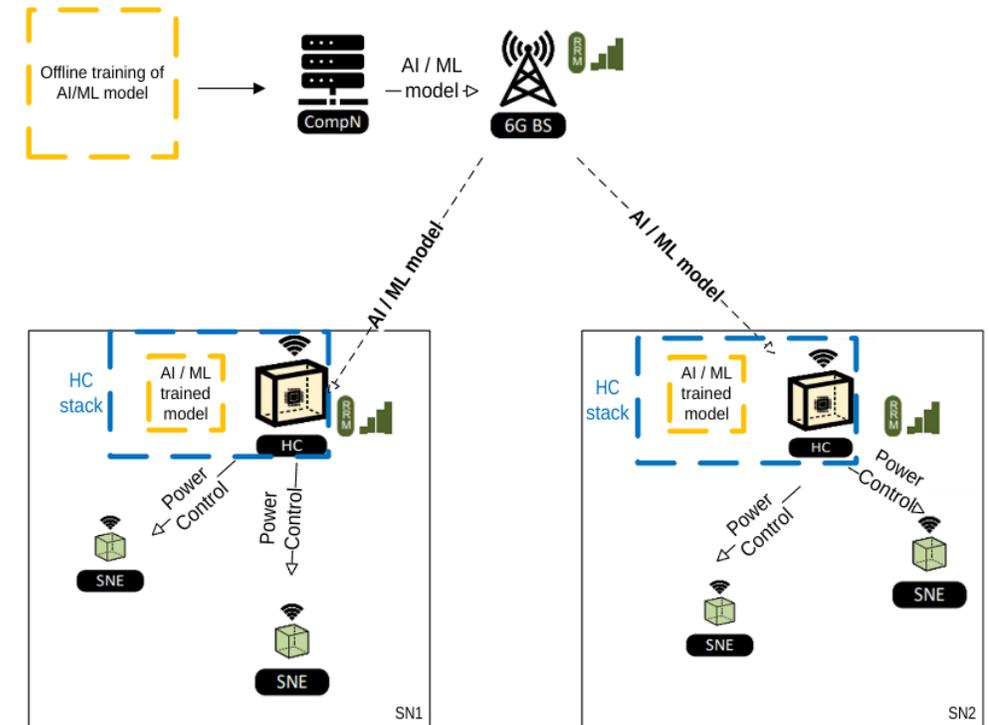
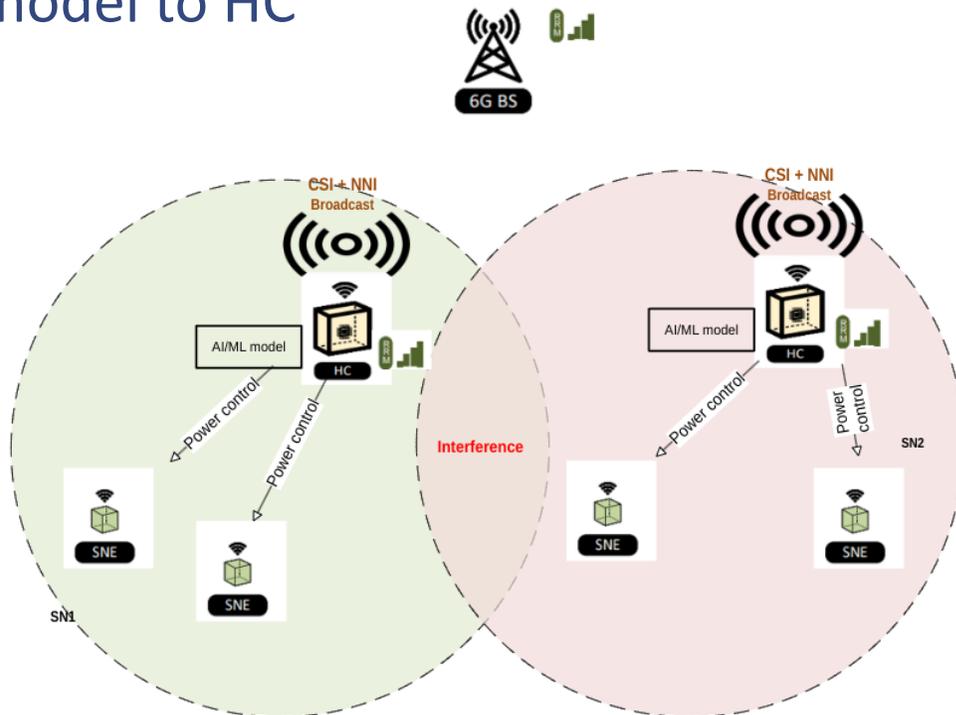
• ... & leaving the subnetwork

- SN_UEID gained through the joining procedure is utilized as identifier with the 6G network
 - UE context associated to the MgtN when leaving the SN



Architecture enablers for RRM in subnetworks

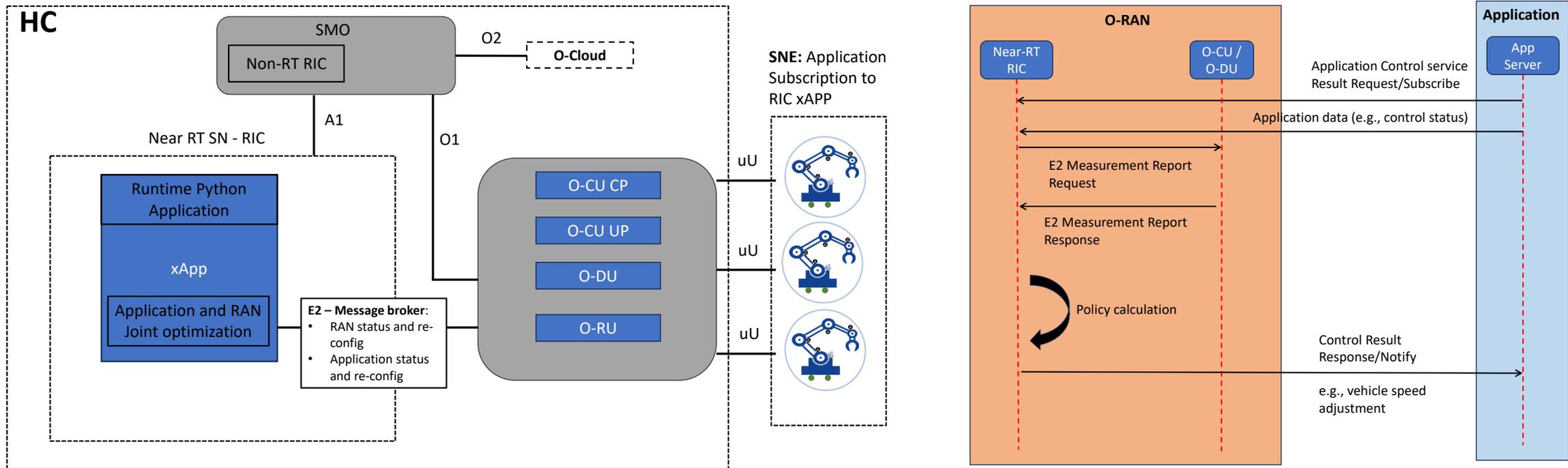
- Distributed interference management through AI/ML-based power control:
 - SNs operating in the same frequency bands
- High Capability (HC) devices of each SN broadcast Neuronal Network Information together with Channel State Information (CSI)
 - CSI feedback is utilized to make RRM decisions on power control
- Architecture enablers required for performing offline AI/ML model training and distributing the model to HC



Control & goal-oriented communications in subnetworks

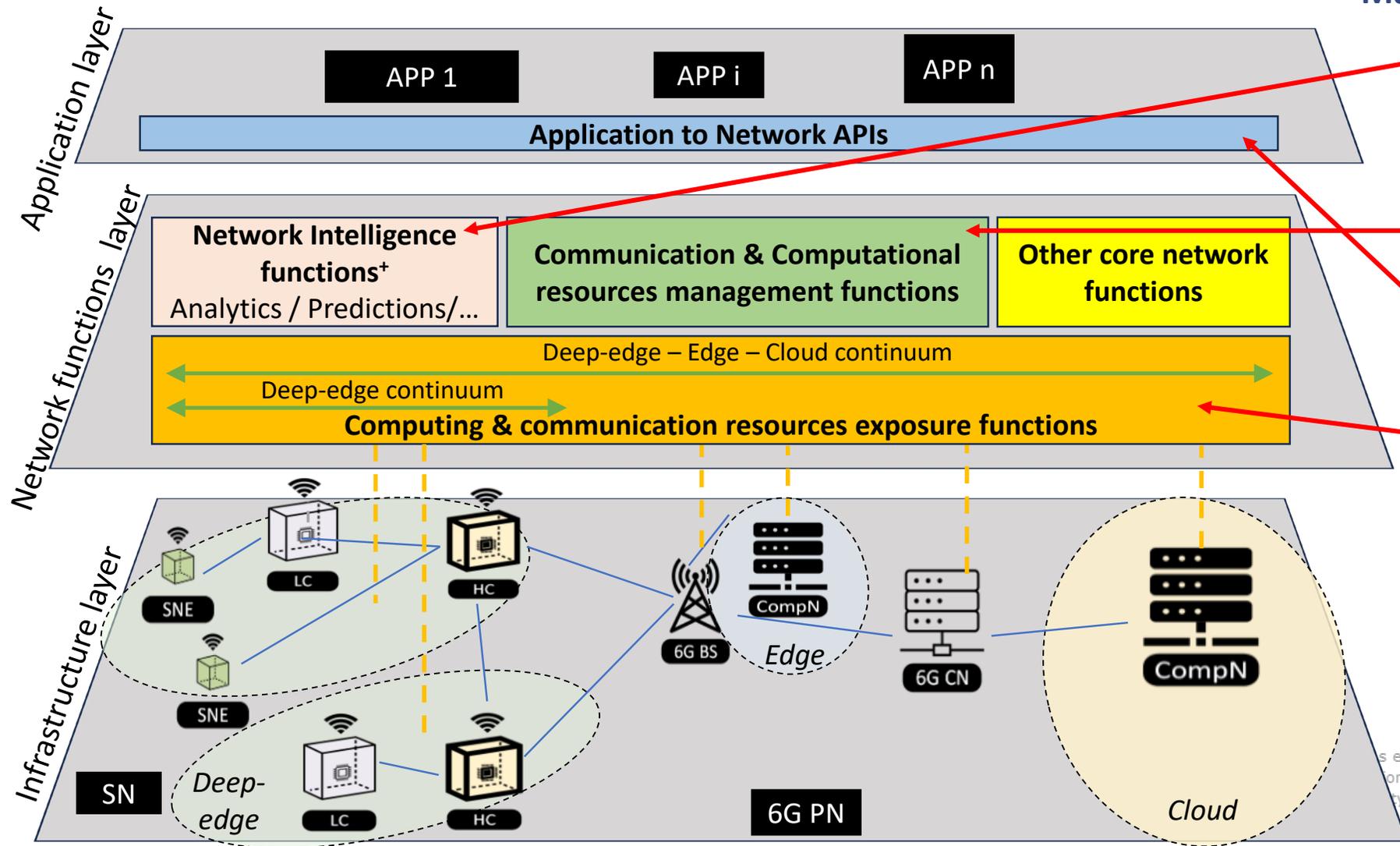


- Based on Open-Radio Access Network (O-RAN)
 - Instance of Near Real-Time RAN Intelligent Controller (Near-RT RIC) at High Capability (HC) device realizes a subnetwork O-RAN
 - Application data and channel state information are jointly utilized for the subnetwork operation
 - RAN&APP goal/decision-making made by a reinforcement learning agent in near real-time
 - Usage in 6G-SHINE: adjust robots' speed/trajectories to minimize their communications interference



Architecture enablers for dynamic computational offloading

- Logical service-based 6G system architecture for making an elastic continuum that enables joint scheduling of computing task and communication links



Main architecture extensions:

- Intelligence
NWDAF extend with predictions on the availability of CC
- Joint coordination /scheduling of CC
Extending Policy Control Function (PCF) to exploit available CC continuum

1. Continuum

NEF (network exposure functions) designed between NF (network functions) and AF (Application function). Our continuum requires extending exposing capabilities towards the infrastructure layer.

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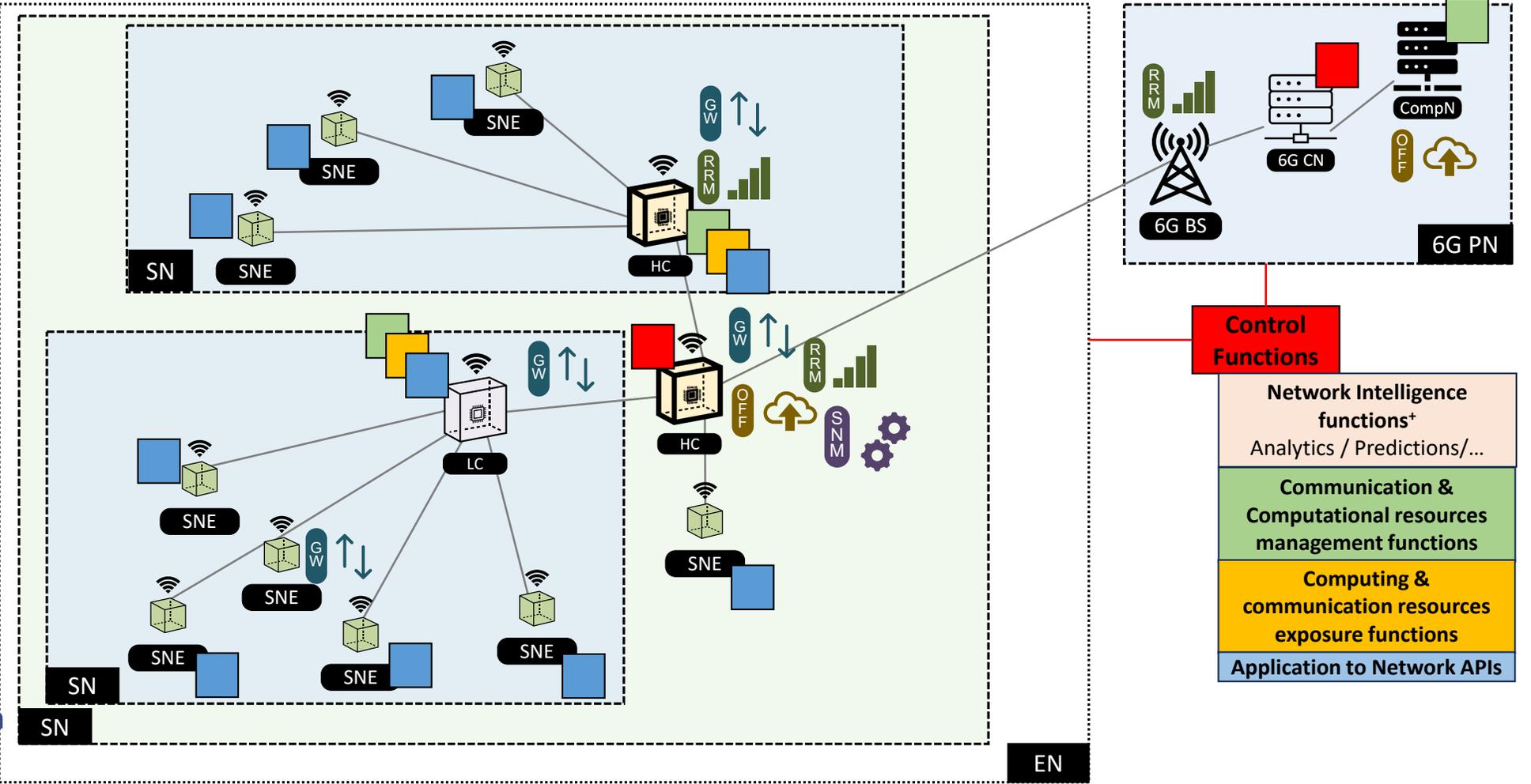
Architecture enablers for dynamic computational offloading

Mapping of architecture components to subnetwork elements

Flexible deployment of control functions through the end-to-end system (considering capabilities of devices)

&

Functional split/coordination between 6G parent network and SN (e.g. survivability)



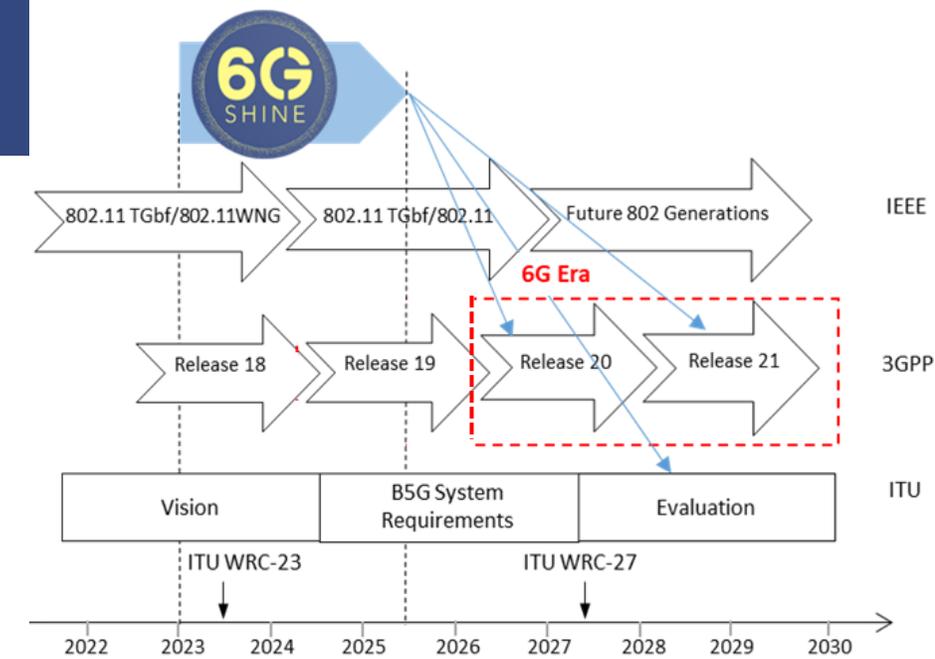
Control Functions

- Network Intelligence functions⁺
Analytics / Predictions/...
- Communication & Computational resources management functions
- Computing & communication resources exposure functions
- Application to Network APIs

EN Entity	SN Sub-network	6G PN 6G Parent network	6G Base Station	6G Core Network	Edge/Cloud compute node
High capabilities device	Low capabilities device	Subnetwork element	Sub-network control function instances		
Subnetwork management role	Gateway role	Radio Resource Management role	Compute offloading role		

Standardization impact

- 6G-SHINE counts on partners intensively participating in standardization to support transferring 6G-SHINE contributions to standardization bodies
 - Subnetwork architecture innovations could target R20-21
- Possibility of providing inputs already to 6G use cases & requirements for subnetworks – SA1
 - Existing 3GPP communication modes & topologies may not be optimal for 6GSHINE’s localized communication requirements :
 - Integration and operation of all sub-system devices through the 3GPP infrastructure can be cumbersome
 - Loss of the connection to the 3GPP network may lead to an outage of the sub-system, which is not tolerable for such sub-systems e.g., a car
 - Routing of sub-system traffic and management functions through public mobile networks leads to unnecessarily higher latency and network load



3GPP TSG- SA1 Meeting # 105
Athens, Greece, 26 Feb - 1 March 2024

S1-240121

Source: Robert Bosch GmbH
Title: New Study on 3GPP Subnetworks
Document for: Approval
Agenda Item: 7



- 6G-SHINE focuses on (consumer, industrial & in-vehicle) subnetworks, which have demanding KPIs and require innovative solutions to ensure sustainable support
- Innovative 6G architecture elements are necessary for realizing such subnetworks and their integration with the 6G ‘network of networks’ vision
 - Flexible subnetwork architecture with dynamic roles
 - Management node acting on behalf of the subnetwork nodes in the integration and interworking of the subnetwork with the 6G parent network
 - Architecture enablers for advanced RRM mechanism and goal-oriented comms in subnetwork and with the cooperation of the 6G parent network
 - Interfaces and exposure functions to extend the (communication & computing) continuum from the cloud to the subnetwork level
- Potential standardization for 6G use cases & requisites (R19) and R20-21 (architecture)



THANK YOU!

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