SNS JU 6G Architecture WG

Vision for 6G Architecture

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EuCNC 2025, Hexa-X-II Workshop, 03 June 2025

EUCNC | 6G Summit
Poznan, Poland • 3-6 June 2025

How to architect the 6G System?

The Ancient Theater of Epidaurus
(4th Century BC)

A modern Auditorium
(21st Century AC)

The 6G Architecture builds upon the 5G Architecture

6G E2E Architecture White Paper v1.0: Timeline

Arch WG First White Paper from SNS JU

3GPP 6G WS

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	6G concept				6G req.	6G study	6G specs		6G v2	
3GPP	Rel 17		Rel 18		Rel 19	Rel 20	Rel 21		Rel 22	
ITU-R	ITU Report on Future Technology Trends		Vision of IMT towards 2030 and beyond	Report on IMT feasibility above 100GHz	Technical performance requirements	Requirements and evaluation criteria	Technology Proposals for "IMT-2030"		"IMT-2030" specifications	

WRC-23 Agenda Item on New Bands

WRC-27 New Bands

1st 3GPP spec

Commercial Deployment

55+ SNS JU Projects

6G E2E Architecture White Paper v1.0: Structure

- Introduction & Motivation **(Marco Gramaglia, Ömer Bulakci, Xi Li, Tasos Gavras: Overall Editors)**
  - Include the gap analysis and cite the 6G Vision Paper
  - Include also Trials Input: Tech Gap Analysis & Main Use Cases
- 6G System Blueprint (**Marten Ericson, Sylvaine Kerboeuf**)
  - Big Picture
  - Modular Architecture Design
- Dedicated Chapters based on IMT 2030 Framework
  - Extensions (**Marco Gramaglia, David Larrabeiti**)
    - Integration of Overarching Concepts
  - Ubiquitous Networks (**Mir Ghoraishi, Agapi Mesodiakaki**)
  - AI & Communications (**Marten Ericson, Tasos Gavras, Harilaos Koumaras**)
    - Automation, Management & Orchestration
  - ISAC (**Xi Li, Sebastian Robitzsch**)
- Overarching Chapters
  - Security, Resiliency, Privacy and Trustworthiness (**Rodrigo Asensio, Antonio Skarmeta, Harilaos Koumaras**)
  - Sustainability (**Tasos Gavras, Agapi Mesodiakaki**)
  - Network Exposure (**Dimitris Tsolkas**)
    - Programmability, Monetization/Motivation
  - 6G Architectural Definition **(Marco Gramaglia)**

- Foundation stemming from 6G-IA Vision Paper
- Tech Gap analysis from SNS JU Stream C/D Projects

- Baseline Description of the System View
- Migration & Interworking

- Architectural Extension based on IMT 2030 Framework

- Overarching cross-domain technology areas

- Outcome Architectural Definition built upon the system blueprint

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6G Architecture Definition

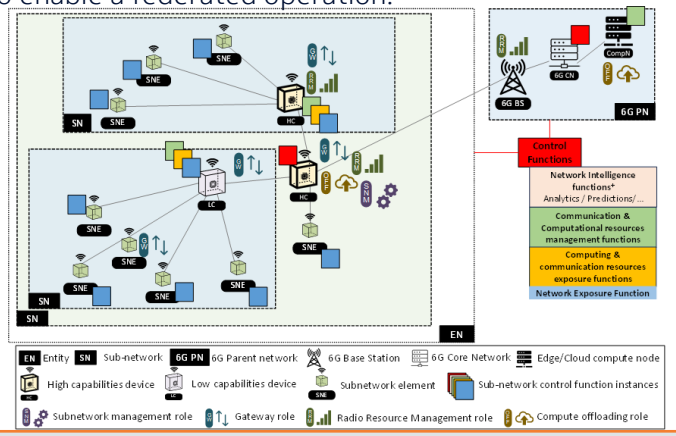
- Interworking and migration
- Modular Architecture Design
  - Multi Layered Architectures for NTN integration
  - Time Critical and Deterministic Networking Integration
  - Integration of Sensing and Digital Twinning
  - Integration of Overarching Topics: Sustainability, Security and Trust
  - Global Service Based Architecture
- Cloud Continuum Management
- Zero Trust for interoperability and Global Operation
- AI driven network management and orchestration

g cross-domain
areas

White Paper Chapter 3 Highlights: Extensions

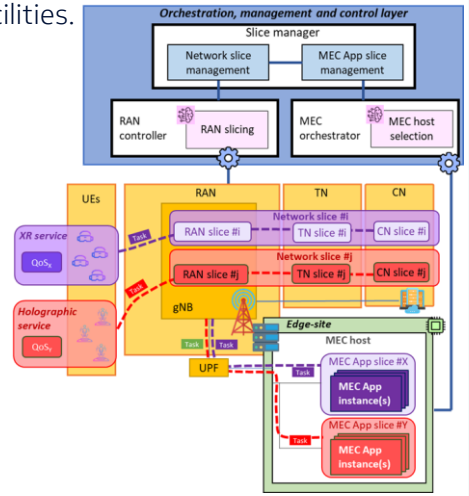
Integration of Overarching concepts

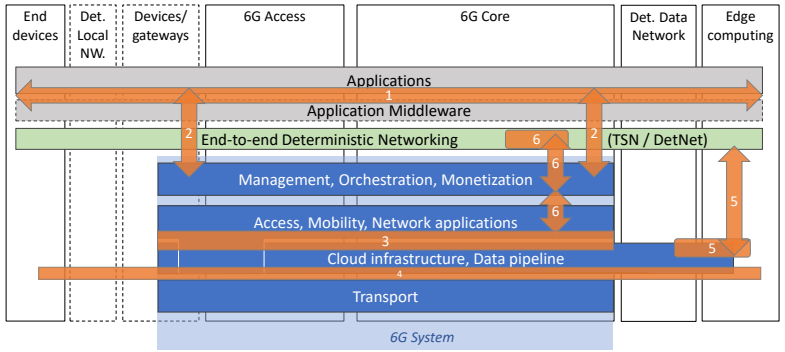
- **Resource management in the Compute Continuum**
  - The heterogeneity of resources available at the edge will need to be managed according to the service characteristics to bring the correct configuration
- **Sustainability for the Compute Continuum**
  - Besides the proper configuration for meeting the service requirement, the optimal utilization of resources in required to minimize the consumption footprint
- **Zero Trust Interaction**
  - Traditional services shall be managed in a flexible way, overcoming inefficient interactions through a zero-trust layer
- **Sub-network Integration**
  - The concept of 6G network of networks shall be enforced to enable a federated operation.



Integration of 6G Network Paradigms

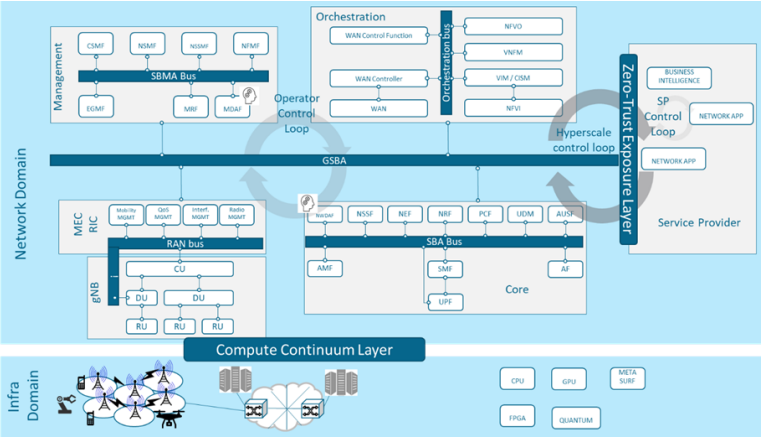
- **Network slicing and MEC**
  - Many latency sensitive application require the integration of edge computing facilities.
- **Deterministic networking**
  - Time dependable communications are fundamental for many services such as robotics and XR.





Service Based Architecture

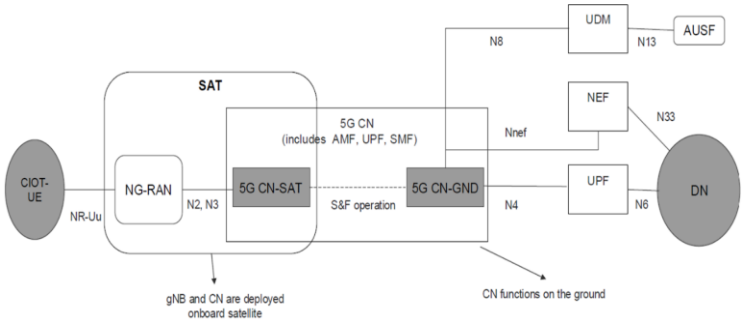
- **Extension of the Service Based Architecture as an architectural option**
  - The implementation of the service-based architecture in the 5G core enabled new functionality that could be leveraged for the 6G design, as well
  - Management, Orchestration, & possibly RAN could benefit for a data driven approach based on the SBA



Chapter 4 Highlights: Ubiquitous Networks

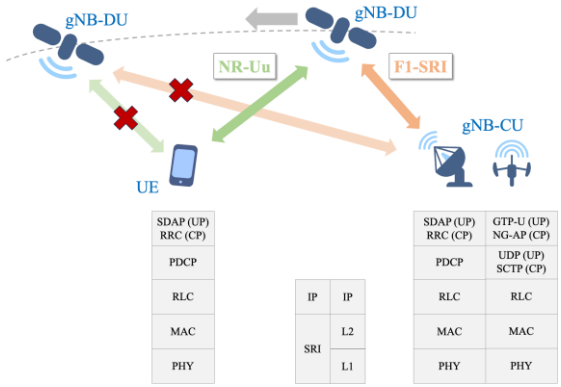
Distribution of Core Network Between Terrestrial and Non-Terrestrial Layers

- The main challenge of low-density LEO constellations lies in their discontinuous service & feeder link.
- Key procedures like Attach/Detach, Tracking Area Update, data transmission, & Paging need modifications due to signalling timers that control mobility and sessions, particularly for NAS procedures.
  - These adjustments must be completed within the limited visibility period of satellites.
- This architecture involves distributing core network functions as AMF, UPF, and SMF between satellites (5G CN-SAT) and the ground (5G CN-GND), ensuring seamless connectivity and efficient operations despite service interruptions.



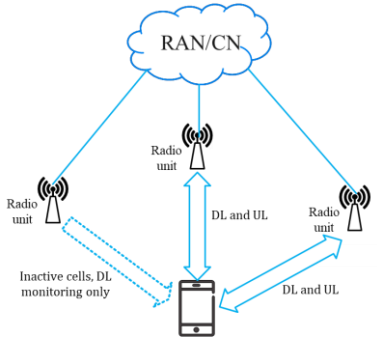
Distributed NG-RAN for 5G/6G Unified NTN Networks

- To increase flexibility, scalability, & enhanced E2E network management and orchestration, and less complexity for the Satellite system: efficient functional split for NTN 6G systems!
- The gNB-CU is in charge of managing the UE context and requests the gNB-DU to allocate/modify the radio resources for that user.
- The radio resources are then managed by the gNB-DU based on their availability. As such, the CU and DU are always belonging to the same gNB when the F1 interface connecting them is established.
- As soon as the NTN node goes beyond the visibility of the serving gateway, the gNB-DU would disconnect from its gNB-CU and, thus, beak the gNB requiring the creation of a new one resulting in the interruption of all its connections.



Multi-Connectivity for 6G Ubiquitous Coverage

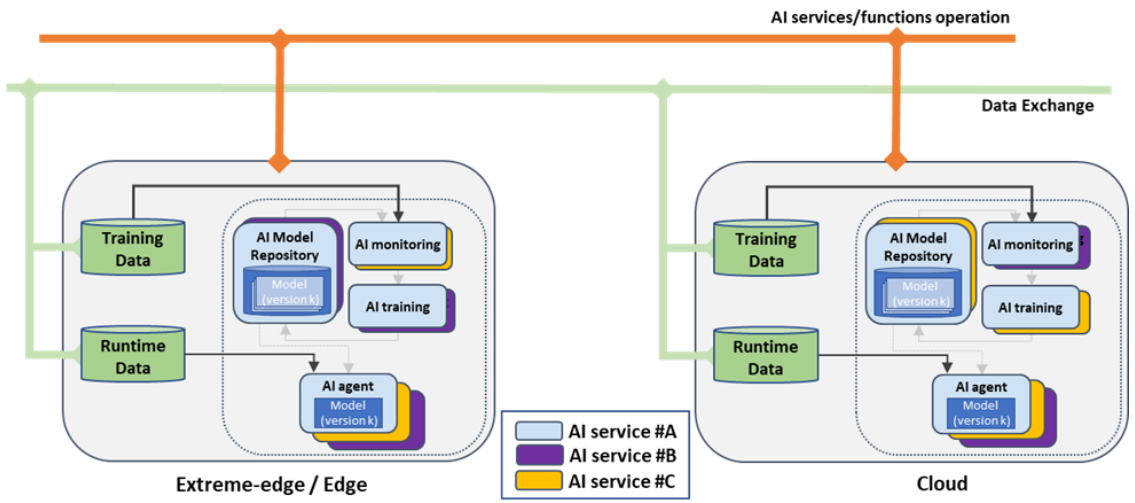
- A new Carrier Aggregation (CA) / Dual Connectivity (DC) scheme is proposed for 6G, aiming at decoupling Downlink (DL) and Uplink (UL) (e.g., two DL connections and one UL connection) & inherent use of inactive connections.
- For the inactive connections, the UE only needs to sparsely monitor the control signalling from the network.
- The advantages are lower delays in establishing the DC, increased the robustness of the system, and faster addition of extra cells.
- The concept oof Subnetworks in 6G, formed voluntarily by UEs based on mutual trust, will also be useful in extending the coverage and creating a seamless communication system.



Chapter 5 Highlights: AI & Communications

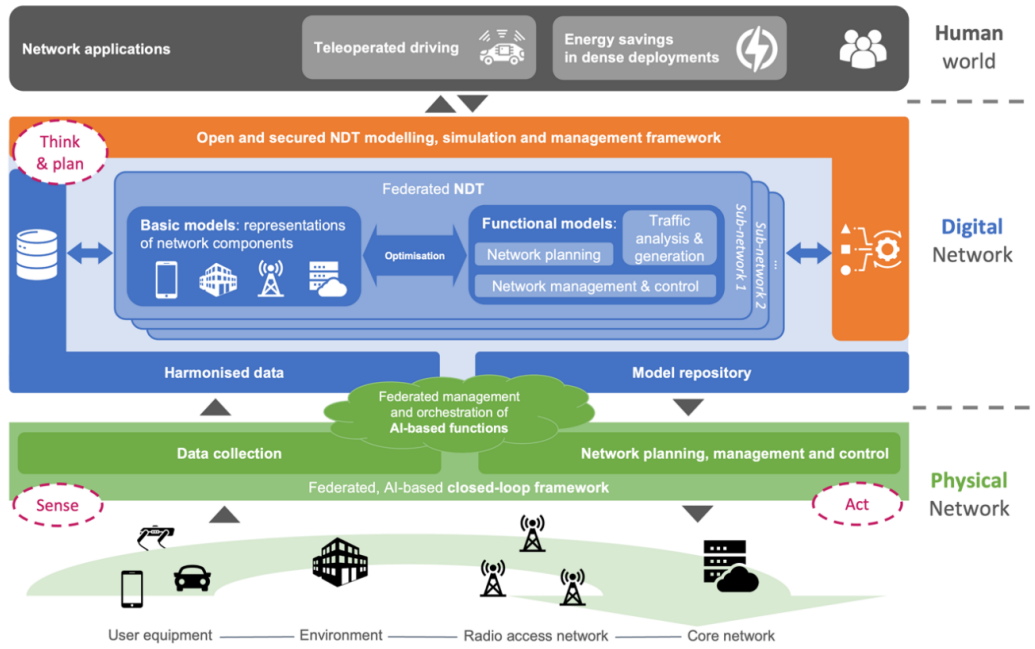
Intelligent Plane

- Several solutions **for AI/ML framework or Intelligent plane** to support AIaaS in-network and exposed outside the network (see AI/ML framework figure below).
- Other areas here:
  - **Intents & goals driven communication**
    - higher-level languages (such as express intents for network configuration or semantic communication) can be used to control the network
  - **M&O**
    - Using AI to enable autonomous network management



Digital Twin

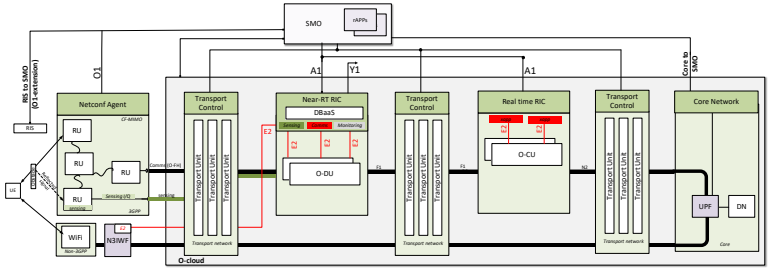
- **Digital twin (DT)**
  - Enable a virtual environment where, e.g., AI-driven network functions can be developed, tested
  - DT can support automation, real-time decision-making, and dynamic resource allocation



Chapter 6 Highlights: ISAC

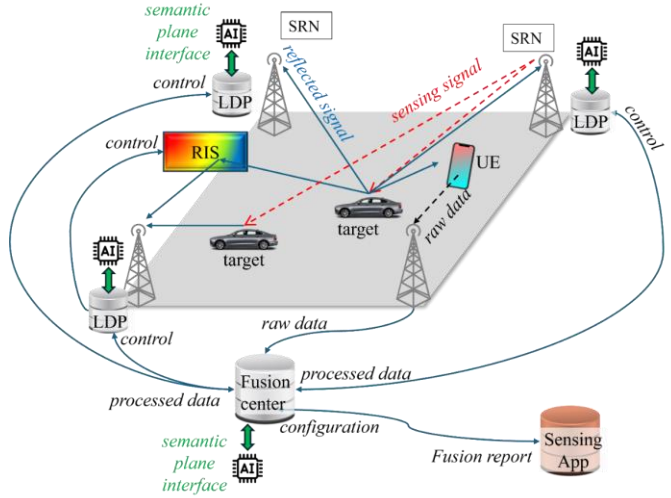
Integration of Non-3GPP & 3GPP Sensing

- Extending the 3GPP RAN system to allow the **integration of 3GPP & non-3GPP (e.g., Sub-6, Wi-Fi, mmWave, THz) tech** into a single ISAC system.
- **Adoption & possible extension of non-3GPP Inter-Working Function (N3IWF)** to provide the necessary access & authentication protocols with new features that allow the non-3GPP networks to securely expose sensing data to RIC.
- **Developing sensing xApps** to fuse the incoming sensing streams (IQ echo streams and Wi-Fi sending data). The processed sensing data can be exploited to optimize RAN or can be exposed to various vertical applications.
- The sensing output is also passed to **the Service Management and Orchestration (SMO)** that decides the optimal network resource configuration to support both communication & sensing services.



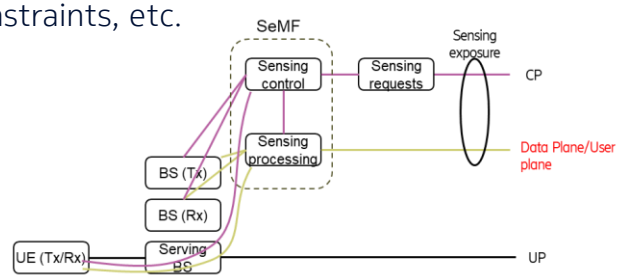
Distributed ISAC Architecture

- To enable **distributed and cooperative sensing**, involving collection and exploitation of data sensed by multiple heterogeneous devices as well as tracking many heterogeneous (and mobile) targets, including both passive and active UEs, over a large area.
- Introduction of a **semantic plane** for managing the extraction, interpretation, and transmission of contextual meaning, and handling dynamic adaptation of meaning in changing environments, maintaining coherence across distributed nodes, and optimizing network's overall performance.

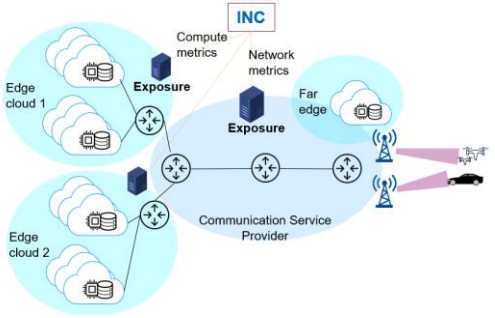


Sensing Service Provisioning & Exposure

- Introduction of **a Sensing Management Function (SeMF)** for facilitating an efficient coordination of sensing procedures, including **sensing control and sensing processing**, considering sensing requirements, sensing capabilities, sensing constraints, etc.



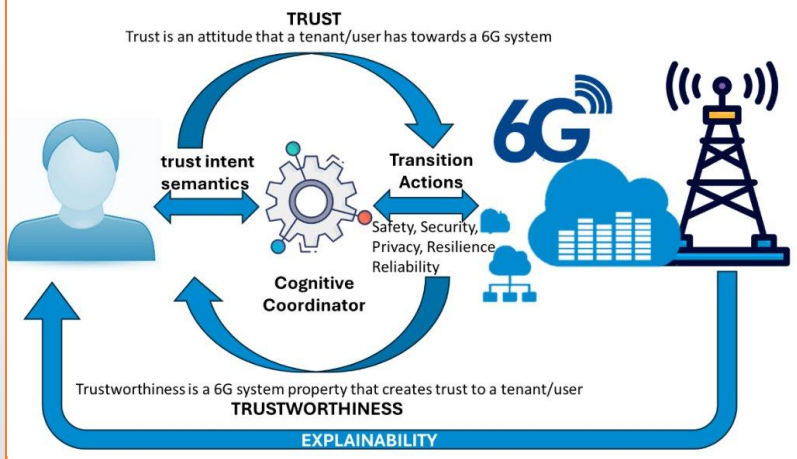
- **Integration of Network and Compute (INC)** to perform coordinated optimization for the sensing services, considering the trade-off between network metrics and compute metrics of the ISAC applications.



Chapter 7 Highlights: Security, Resiliency, Privacy &Trust

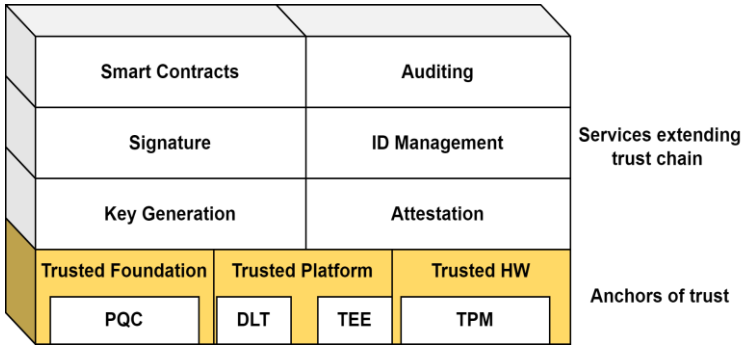
Trustworthiness Framework

- **Trust is an attitude that a tenant has towards a 6G system.** In contrast, trustworthiness is a system property that creates trust to the 6G tenant/user.
- **"Trustworthiness"** refers to a **holistic** approach, including safety, security, privacy, resilience and reliability as trustworthiness dimensions
- The **trustworthiness dimensions** (i.e., Safety, Security, Privacy, Resilience and Reliability) come at a cost in terms of usability, agility, or swiftness.
- A **balance between the various dimensions** is reflecting the **user intent**, trust requirements and expectations.
- **Explainability** is a fundamental tool to build trust between stakeholders. Allows to understand how and why measures have been applied to address specific needs.



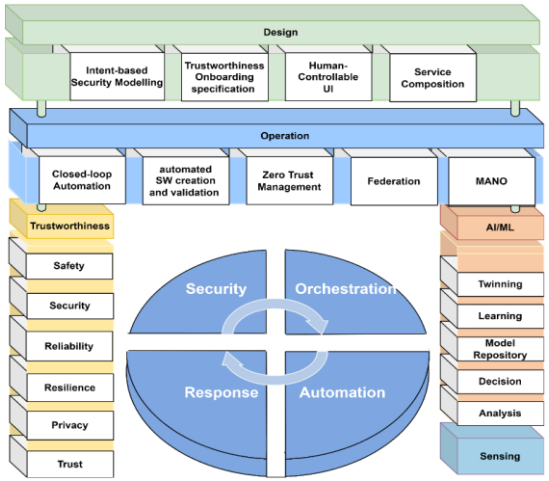
Chain of trust

- Anchors of trust are proven solutions that have been rigorously validated as trustworthy.
  - **Trusted Foundation**: Mathematical basis used to build trusted solutions. In 6G, complex mathematical challenges lead to trusted PQC protection schemes.
  - **Trusted Platforms**: while DLT ensures data integrity and tamper resistance through distributed consensus mechanisms across multiple replicated nodes. TEE offers a confidential computing platform and also enables remote attestation **of** software integrity.
  - **Trusted Hardware**: Dedicated modules integrated into systems that perform cryptographic operations and securely store unique keys, serving as the system's root of trust.
- Use these anchors of trust as the foundation to extend the chain of trust, addressing the specific security needs of higher system layers.



Overarching Layers

- **Design Layer**: This layer infuses trust into the architecture by providing the means to use 6G under the needs of service, users and the own network.
- **Operation Layer**: Focused on real-time management, it ensures closed-loop automation with, resource management, continuous monitoring, proactive threat detection, and automated responses.
- **AI/ML Layer**: Requirements-driven decision-making and adaptive trust management, offering digital twin evaluations and a model repository for instantiating, sharing, and updating AI models.
- **Sensing:** Integrates network and environmental data to provide situational awareness, continuously informing metrics.

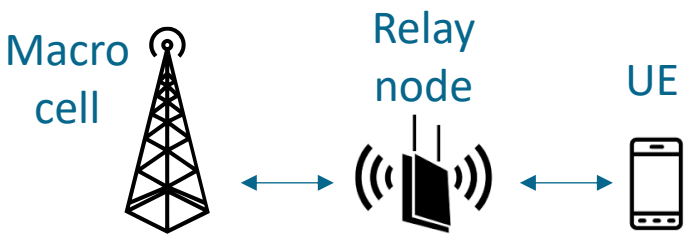


Chapter 8 Highlights: Sustainability

RAN sustainability advancements

Relay nodes contribute to a sustainable, energy-efficient wireless network infrastructure

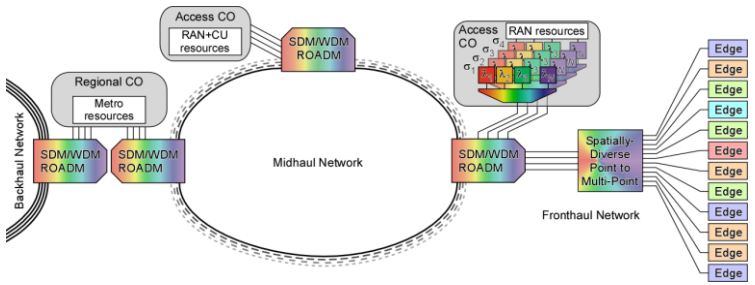
- Relay nodes in B5G RAN networks enhance sustainability by:
  - Mitigating signal blocking & increasing coverage in high-density areas.
  - Decrease the number of required base stations:
    - Lower energy consumption.
    - Decrease capital (CAPEX) and operational costs (OPEX).
- Energy efficiency improvements:
  - UE transmits lower power when connected to a relay.
  - Conserves battery life for user devices.
  - Studies show up to 90% energy savings with relays.
- Further AI/ML optimization of relay operation:
  - Improves relay functionalities.
  - Further energy consumption reduction.
  - Enhances overall system performance.



Transport network sustainability advancements

Transport network advancements reduce OPEX & contribute to the development of sustainable and energy-efficient network infrastructures

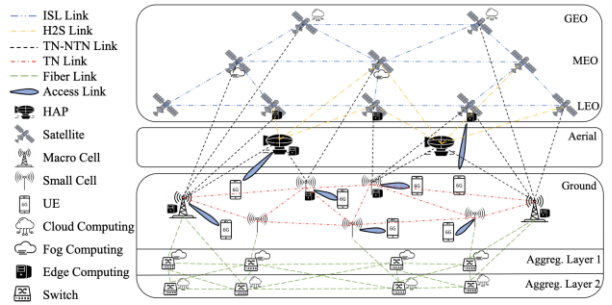
- Scalability challenges in 6G necessitate innovative optical X-haul network technologies.
- Optical X-haul network technologies:
  - Provide ultra-high-speed, energy-efficient all-optical bypasses.
  - Significantly reduce power consumption and OPEX.
  - Enhance overall network performance.
- Energy savings through:
  - Integration of multiple optical switching granularities.
  - Dynamic bandwidth adaptation for higher spectrum efficiency.
- Dynamic functional splits and passive traffic distribution elements enable adaptation to varying traffic requirements → improve energy usage efficiency.



E2E network sustainability advancements

Unification of Terrestrial and non-Terrestrial 6G Networks (TN-NTNs) has potential for sustainability advancements

- Current networks are reaching their limits→ need for unified TN-NTNs (terrestrial, aerial and space layers).
- Maximizing sustainability in unified 6G networks:
  - Energy efficiency maximization.
  - Reduce Total Cost of Ownership (TCO).
  - Decrease energy consumption.
- Efficient joint network, compute and storage resource allocation strategies needed that:
  - Address all related constraints (e.g., power, capacity, flow conservation).
  - Enable real-time decision-making, while induing low complexity.
  - Maximize sustainability related metrics.
  - Jointly consider the user association, traffic routing and network function placement problems.

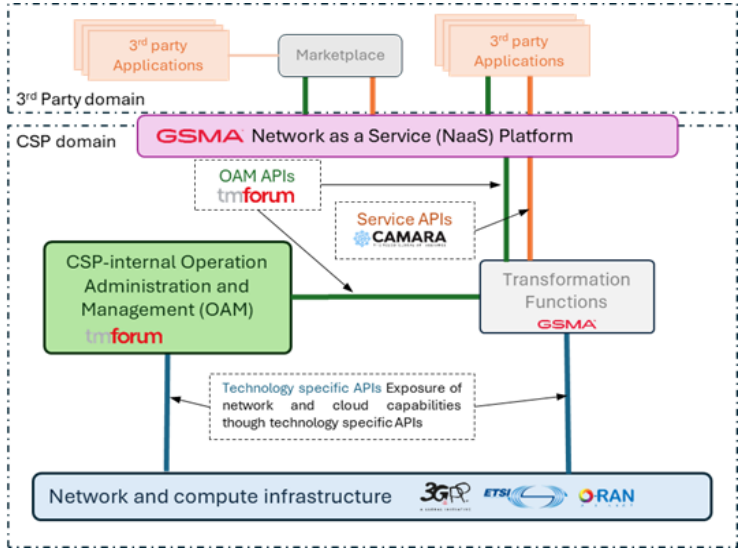


Chapter 9 Highlights: Network Exposure Capabilities

Network Exposure with APIs

Network exposure capabilities through the emerging ecosystem of network Application Programming Interfaces (APIs).

- The **Service APIs** provide a purpose-specific capability to third parties (e.g., CAMARA APIs)
- The **OAM APIs** offer programmable access to Operation, Administration and Management (OAM) capabilities.
- The **Technology-specific APIs** refer to operator internal APIs offering programmable access to telco infrastructure and network, service and IT capabilities.

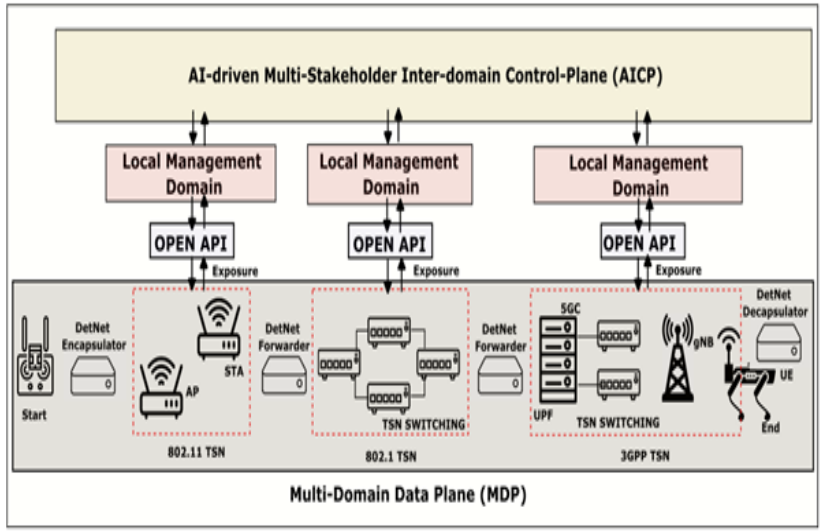


Mutli-domain exposure for DetNets

By unifying control and data planes of multiple domains, AI driven deterministic networks can be enabled.

The following principles should be met.

- AI-driven Multi-Stakeholder Inter-Domain Control-Plane (AICP)
- Support of Multi-Domain Data Plane (MDP)
- Interoperability Between Domains
- Scalable and Extensible architecture/implementation



Network Representation Aspects

Network Digital Twins (NDT)

The **digital twinning** concept brings real time monitoring and prediction capabilities down to the network infrastructure. Towards 6G, the integration of the NDT, is expected to operate across three distinct layers: the physical network, the digital network, & a federated simulation framework.

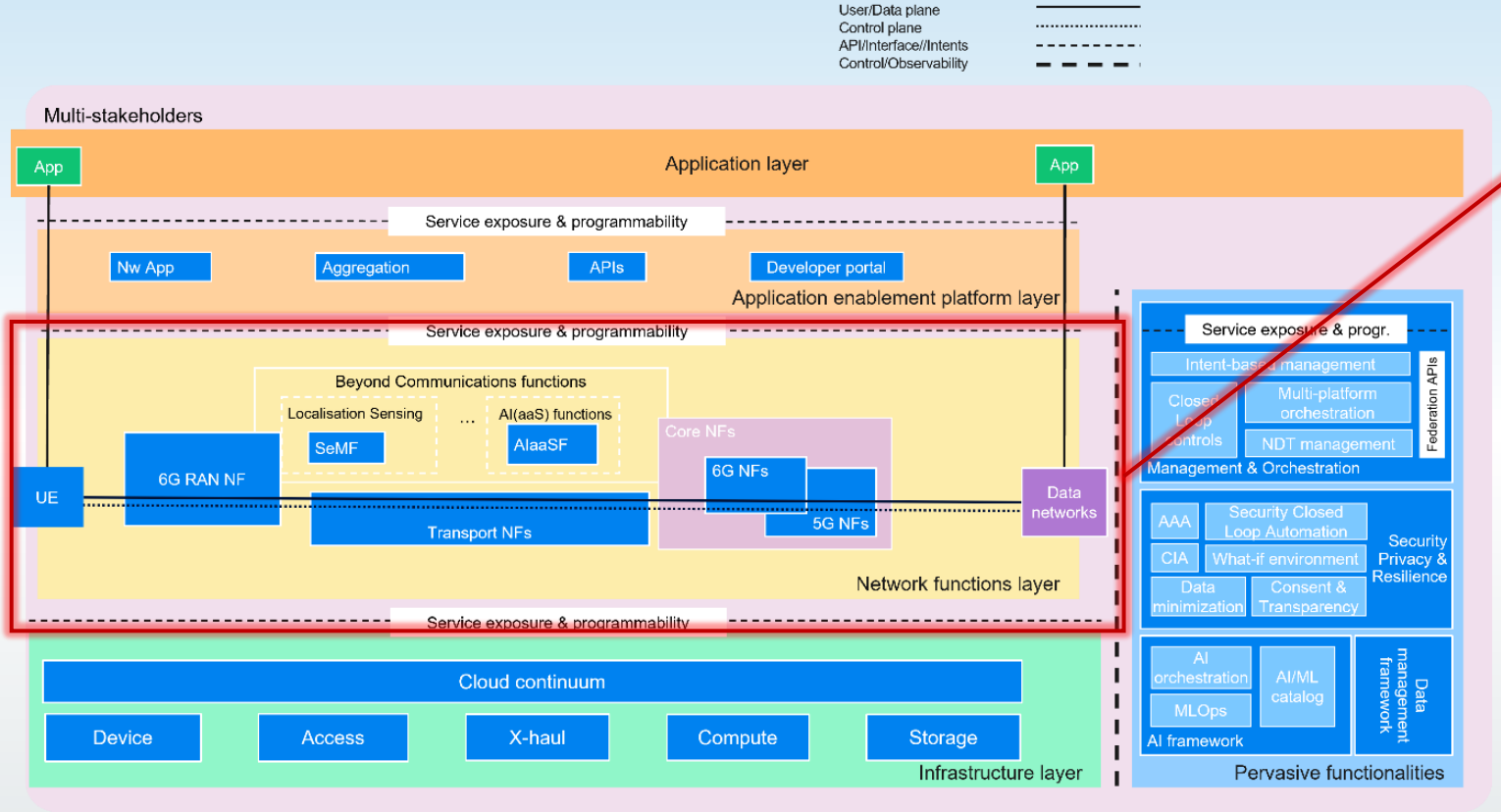
User Centric Architecture

Network services shall be recentred on users, following a user-centric approach, distinguishing characteristics of the 6G architecture, enabling user-definition, user-configuration, and user-control. The **user-centric architecture** in 6G will alter how users, network services, and apps now communicate, which will have an influence on the ownership of personal digital assets, network access, and mobility management.

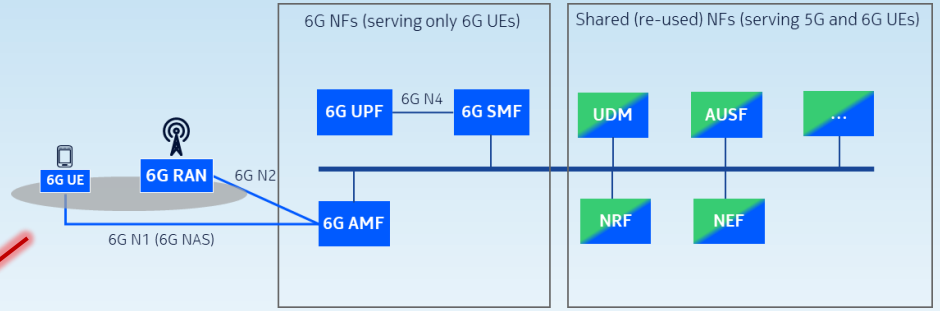
Isolated Trial Networks

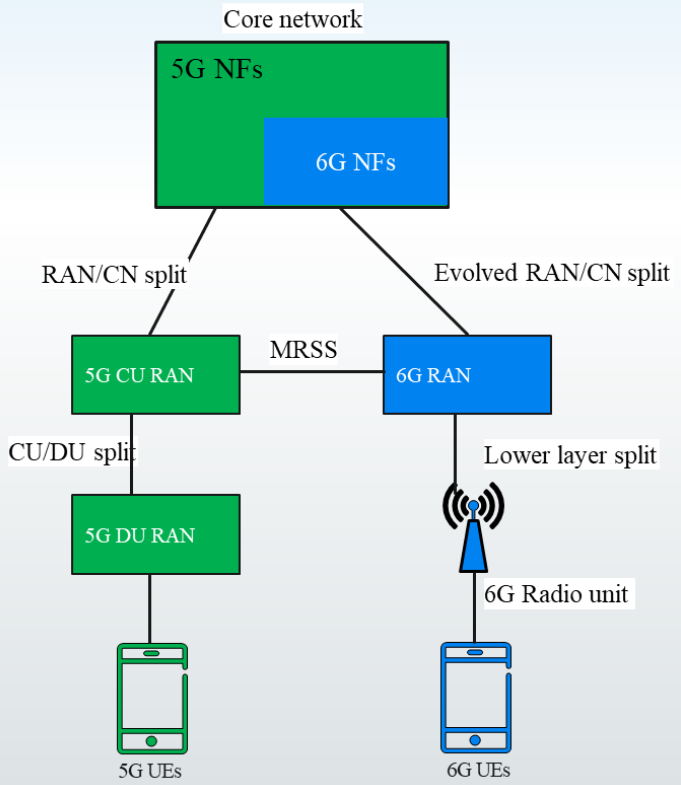
When it comes to network exposure for experimentation purposes, network and compute infrastructure should facilitate medium- to long-term experiments without frequent manual reconfiguration and giving experimenters access to internal network configuration. A **Trial Network** (TN) represents an end-to-end network with physical and virtual components dedicated to experimentation purposes. The TNs are fully configurable, manageable, controllable and automatically deployable networks combining virtual, physical, and emulated resources.

System Aspects: Modular Architectural Design & Migration



6G System Blueprint





5G→ 6G Migration

Various Project Partner Contributions submitted to the 3GPP 6G WS (link)

6G Architecture WG: Call 1 Projects

6G SNS IA 6G SNS ARCHWG

6G Architecture WG: Call 2 Projects

PROTEUS 6G

SAFE-6G

iTrust6G

ORIGAMI

ECO eNET

6G TWIN

6G SNSES

6G4SOCIETY

6GEWOC

NATWORK

6G DISAC

GOALS

INSTINCT

OPTI-6G

6G INTENSE

elastic

6G-Path

ENVELOPE

6G SUNRISE

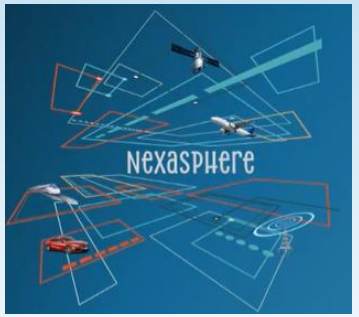
SEE-6G

6G SNS IA 6G SNS ARCHWG

6G Architecture WG: Call 3 Projects (Onboarding)

MULTIX

SUSTAIN 6G



6GARROW

未来 6G-Mirai

6G-VERSUS

unity-6G

55

6GSNS

6TH GENERATION SMART NETWORKS & SERVICES

6GSNS ARCHWG

THANK YOU FOR YOUR ATTENTION

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