SATCOM AND NTN: FROM DATA COMMUNICATION TO DATA INFRASTRUCTURE

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DIA Association, Addressing Grand Challenges Through Communication Systems

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DATACOM INDUSTRY ASSOCIATION

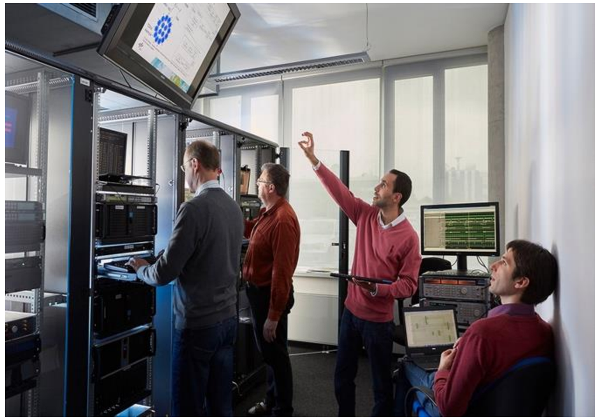
DLR

Where am I from?

DLR Institute of Communications and Navigation (KN)

More than **200 employees** at the DLR sites **Oberpfaffenhofen and Neustrelitz**

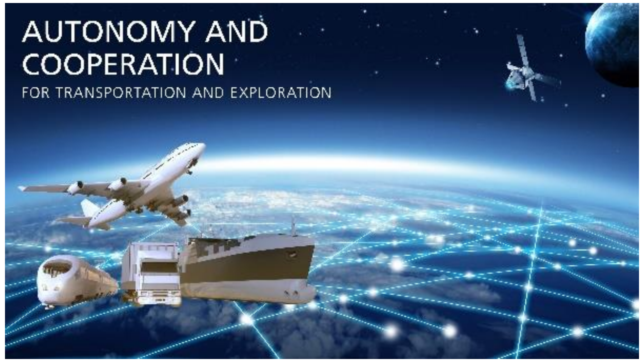
The institute is engaged in the design, analysis and realization of systems for communication and navigation for applications in the fields of space, aviation, transport and security.



The work ranges from the scientific fundamentals to technology demonstration in a real environment and technology transfer in cooperation with industry.

The Institute's work is oriented toward four missions that have a direct benefit for society and the economy.

DLR-KN main missions



GLOBAL CONNECTIVITY

GLOBAL POSITIONING

AUTONOMY AND COOPERATION

CYBERSECURITY

NTN (Related) Projects Overview

Systems / Architectural Studies

5G stardust

6GNTN

Agrarian
Farming on the Edge

European Commission

6GSNS

6G-TakeOff

SPONSORED BY THE
Federal Ministry of Education and Research

Technology Developments

esa
European Space Agency

- **RoPRO**

Routing for Megaconstellations

- **EDGECOLB**

Edge computing in space

- **QUICOPSAT**

QUIC protocol adaptations for SatCom

- **AIComS**

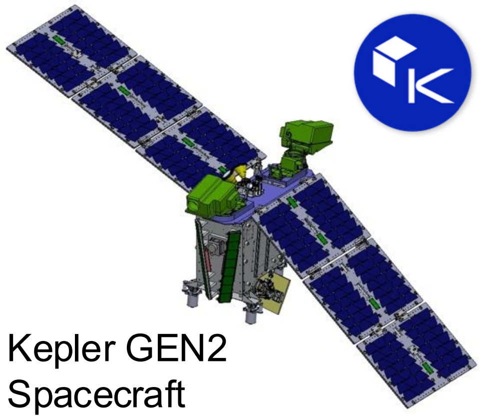
Develop AI/ML-based SW/HW for future NTN payloads

- **TRACK / 5G-InRail**

SatCom Component for FMRCS

Demonstrations

- **MIXELS – DEMONSTRATION OF AN EXPERIMENTAL 5G gNodeB IN SPACE**

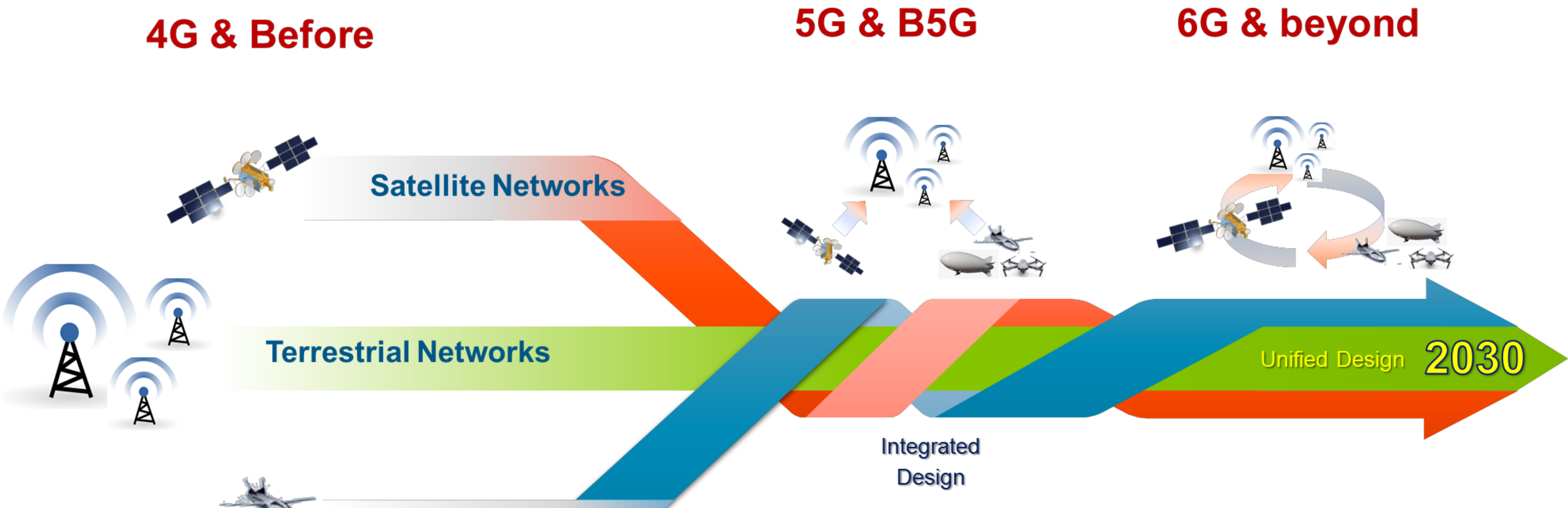


Kepler GEN2
Spacecraft

5G MIXELS

esa
European Space Agency

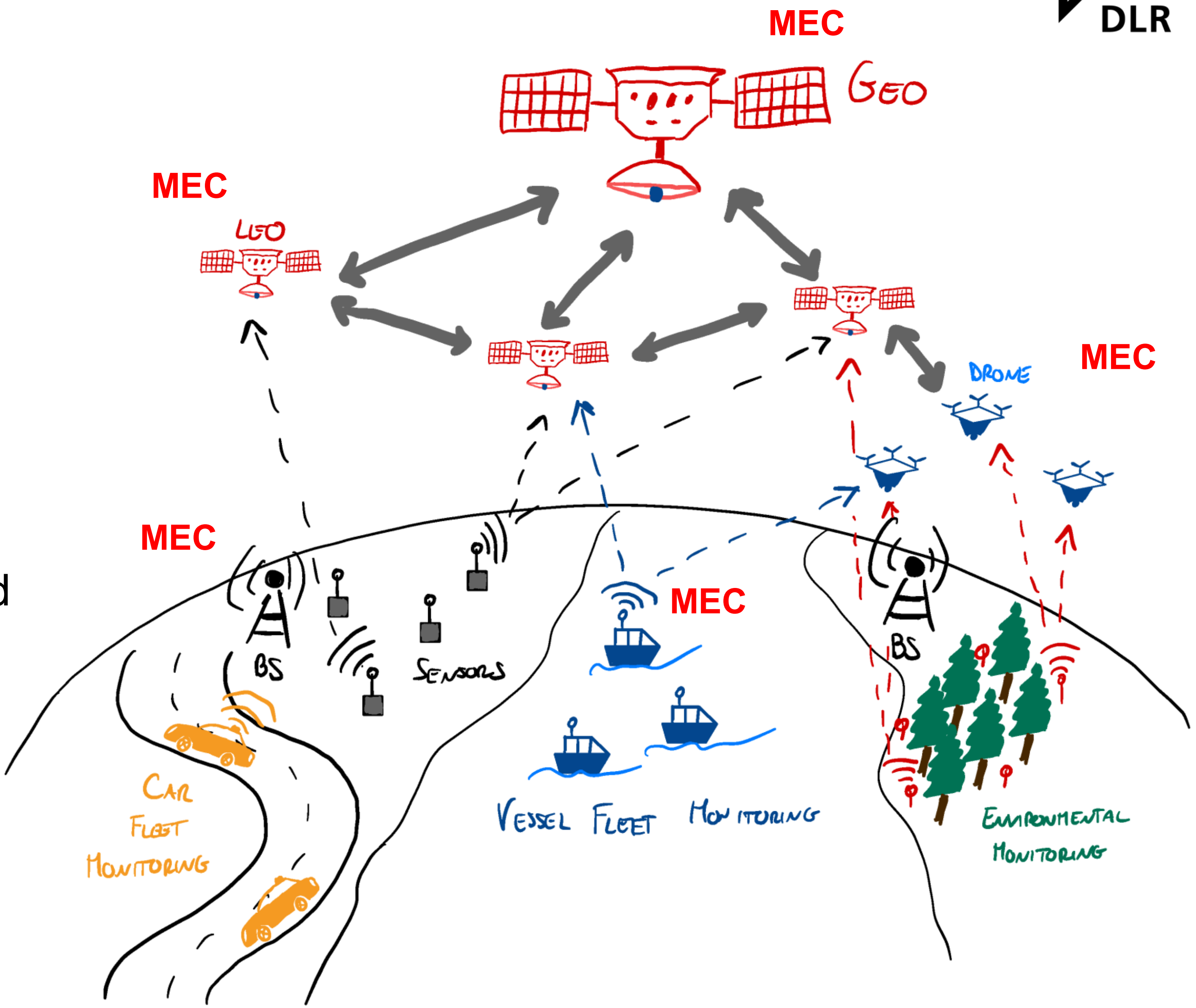
The outlook of NTN into 6G



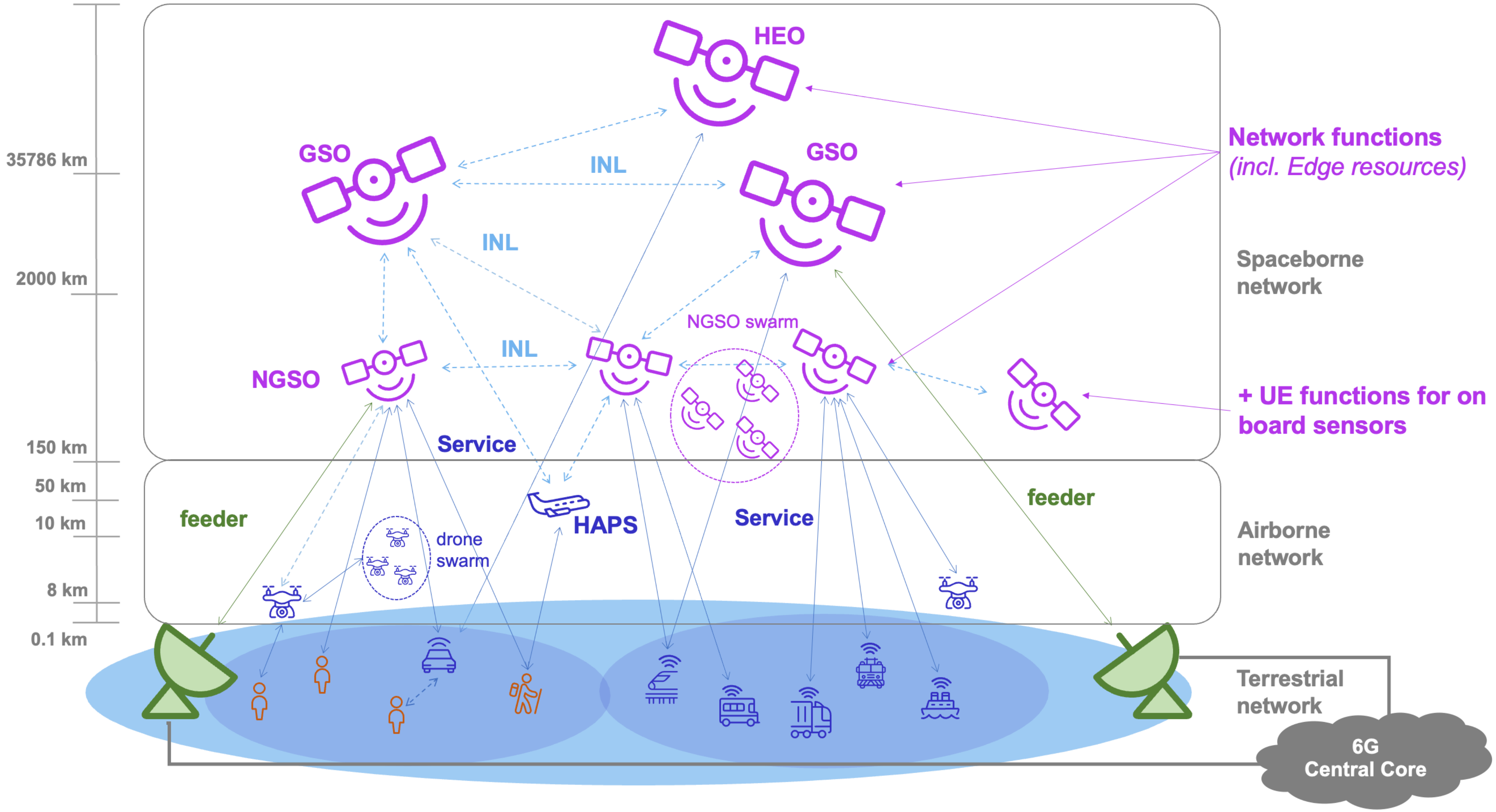
NTN as native component of 6G from DAY1

The 3D 6G Network Vision

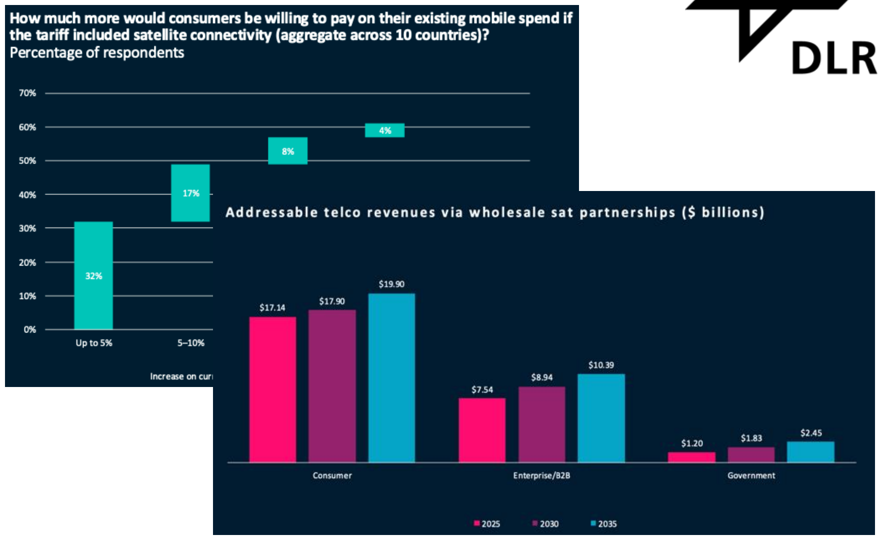
- **The 3D-Network** is a dynamic network with changing topology
- Each Domain (space, air, ground) has its own characteristics
- for NTN this depends on the orbit (GEO, MEO, LEO)
- Highly flexibel solutions are required for transmission opimization
- Its beneficial for (high demanding) MEC Apps and its developers to be aware about expected performance



▪ A multilayered architecture providing **ubiquitous, resilient coverage and service continuity**

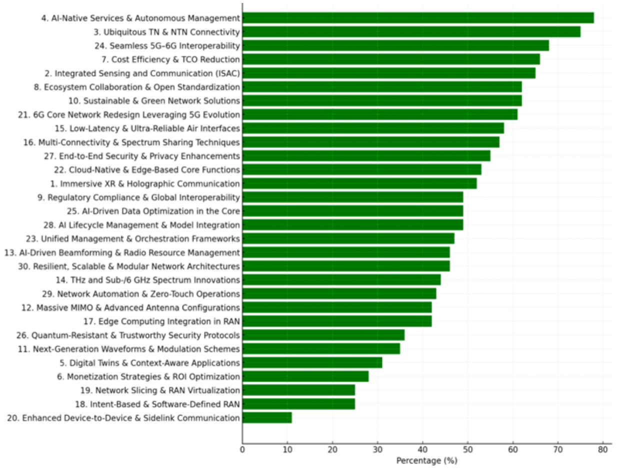


- MWC ’25: GSMA Intelligence Report
  - 60% of current users are ready to pay up to 5% increase to have NTN connectivity on their smartphone
  - NTN Global market will count up to 3% of telco total revenues (~30B$) in the next 10 years
    - Ubiquitous coverage and service continuity
    - Consumer, Enterprise and Government market



Source: GSMA Intelligence MWC2025, Satellite and NTN Summit

- 3GPP 6G Workshop (Incheon, SK) – March 10-11, 2025
  - 1800 attendees (750 in person)
  - 230 contributions
    - NTN in 75% of them
    - AI in 78% of them
  - NTN is second only to AI, and right after it



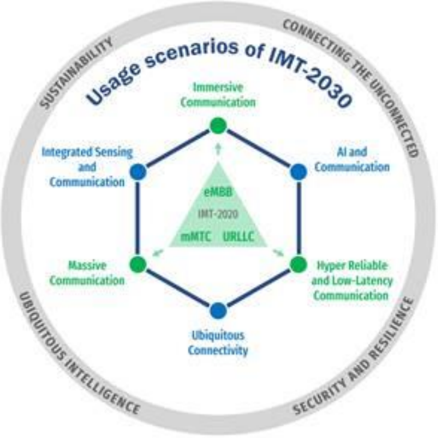
Source: APEX Standard , https://apexstandards.com/6gws.pdf?ref=NLT2

NTN will be a structural element of future 5G/6G

5G/5G-Advanced services via NTN: Rel. 20 trends

Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)	Area traffic capacity (UL)	Overall user density	Activity factor	UE speed	UE type
Pedestrian	[1] Mbps	[100] kbps	1,5 Mbps/km²	150 kbps/km²	[100]/km²	[1,5] %	Pedestrian	Handheld
Public Safety	[3,5] Mbps	[3,5] Mbps	TBD	TBD	TBD	N/A	100 km/h	Handheld
Vehicular connectivity	50 Mbps	25 Mbps	TBD	TBD	TBD	50 %	Up to 250 km/h	Vehicle mounted
Airplanes connectivity	360 Mbps/plane *[1 Gbps/plane]*	180 Mbps/ plane *[300 Mbps/plane]*	TBD	TBD	TBD	N/A *[40%]*	Up to 1000 km/h *[Up to 1500 km/h]*	Airplane mounted
Stationary	50 Mbps	25 Mbps	TBD	TBD	TBD	N/A	Stationary	Building mounted
Video surveillance	[0,5] Mbps	[3] Mbps	TBD	TBD	TBD	N/A	Up to 120km/h or stationary (note 4b)	Vehicle mounted or fixed installation
NB-IoT connectivity	[2] kbps	[10] kbps	8 kbps/km²	40 kbps/km²	[400]/km²	[1] %	[Up to 100 km/h]	IoT

Use-Cases for NTN in 6G



UC1: Maritime Coverage for search and rescue coast guard intervention

Coast Guard Intervention
1: with Terrestrial Coverage
2: without Terrestrial Coverage and with only NTN coverage
3: with Multi-link Support for Reliable Roaming
4: with Seamless Handover to Different Feeder Links for NTN connectivity

UC5: Consumer Handheld Connectivity and Positioning in Remote Areas

Emergency situation management

UC6: Continuous Bi-directional Data Streams in High Mobility

1: NTN only usage
2: NTN – TN switching usage
3: NTN – NTN switching in cross border usage

UC7: Direct Communication over Satellites

1: Public safety
2: Maritime
3: IoT
4: Automotive

UC2: Autonomous power line inspection using drones

1: Routine inspection
2: Manual inspection

UC3: Urban air mobility

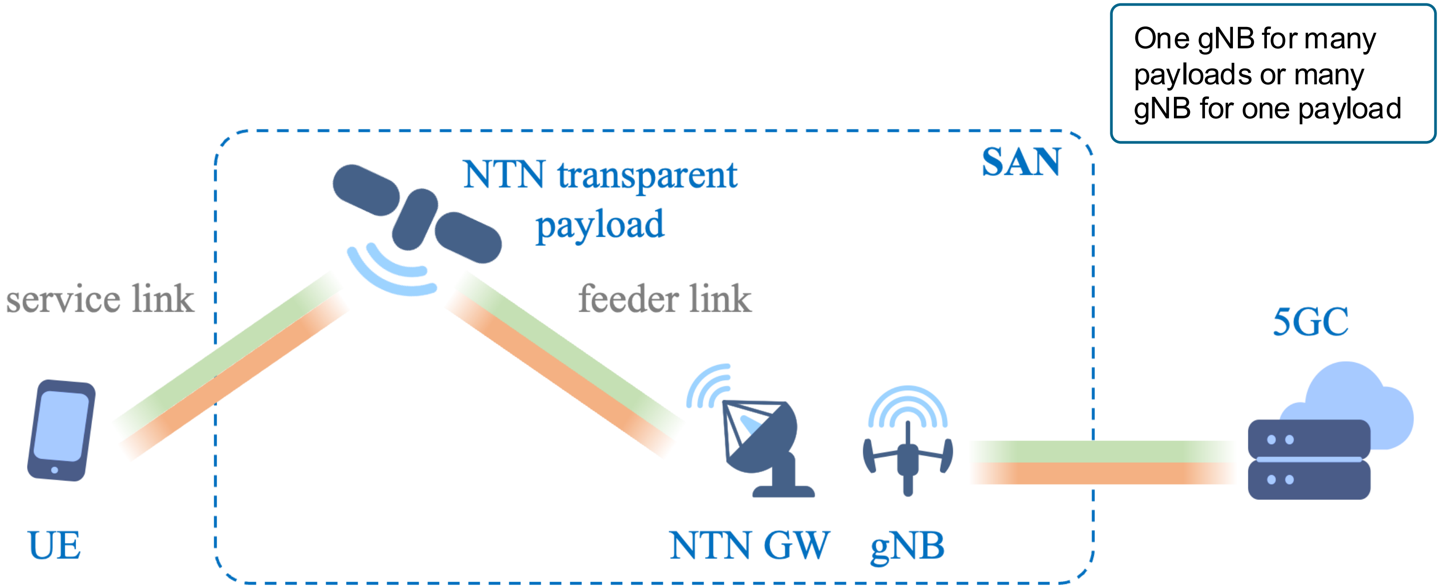
1: On-demand creation of aerial corridors for last-mile delivery
2: Anti-collision and autonomous deconfliction
3: Emergency situation management

UC4: Adaptation to PPDR or Temporary Events

1: First-Responder (FR) communications
2: Population communications in distress

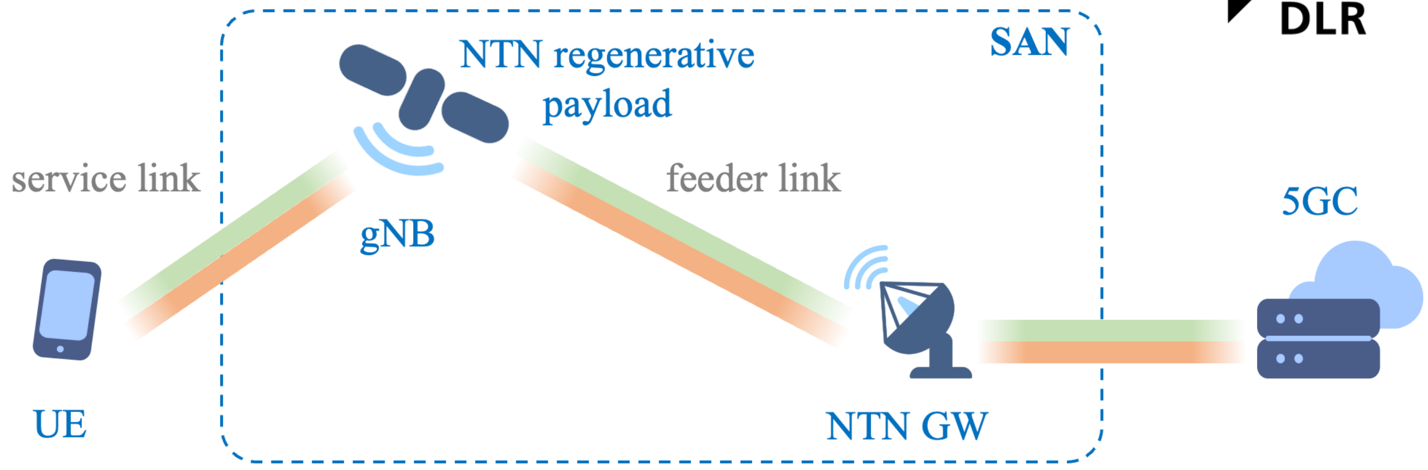
NTN Rel. 17: transparent payload architecture

- **Direct access** to **handheld** terminals
- Payload: **air-/space-borne RF repeater**
- gNB: conceptually at the GW
  - the full compatibility with 3GPP NR required **adaptations** to the **NR-Uu** interface (service + feeder)
  - all **protocols terminated on-ground**

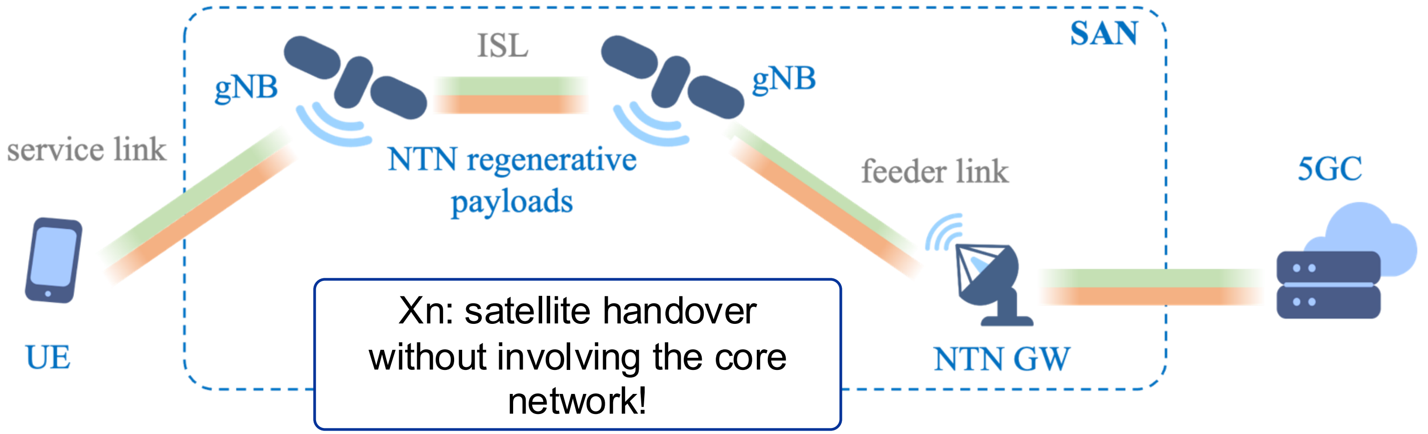


NTN Rel. 19: regenerative payloads

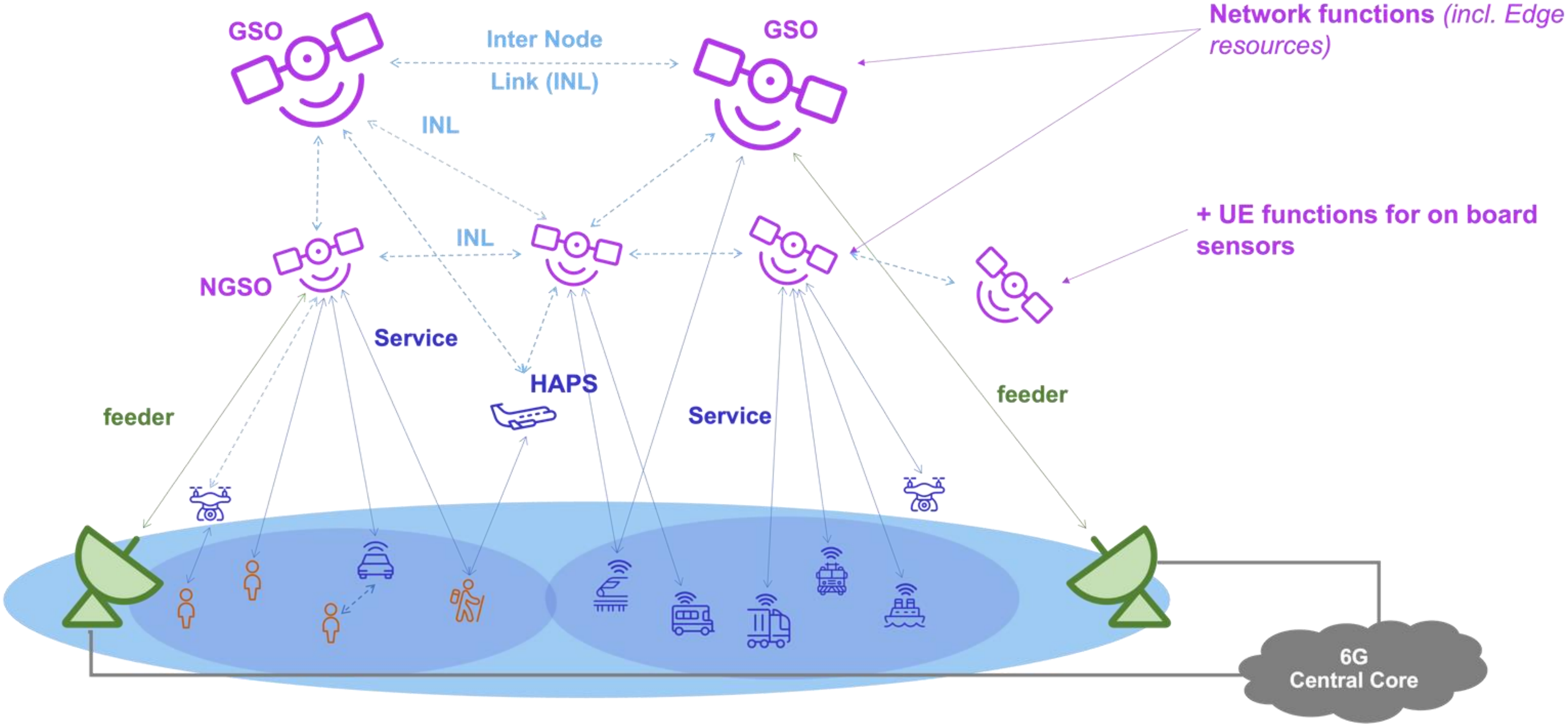
- **Direct access** to **handheld/VSAT** terminals via **regenerative** payloads
- Full gNB on-board
  - GW: a Transport Network Layer node
  - **NR-Uu protocols are terminated on-board**



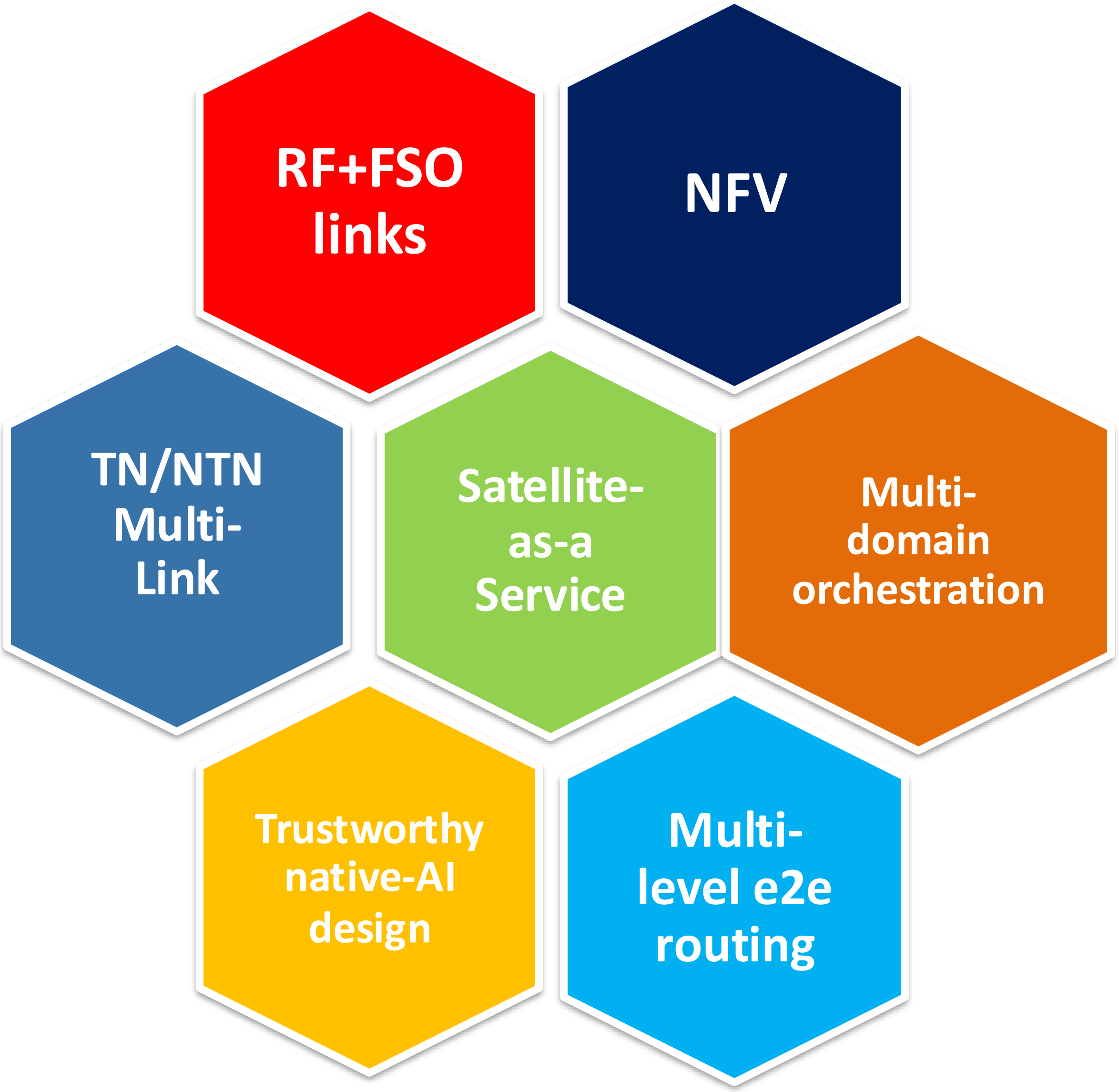
- GW + payload: implementation of the **SRI layers to carry NG**
- Up to SDAP (UP) and RRC (CP) terminated on-board → **reduced latency**
- PDU sessions and QoS flows: UPF-UE
  - NG tunnels: UPF-gNB incl. feeder link
  - Radio bearer on the service link



The Overall Networking Picture



The Main Building Networking Blocks

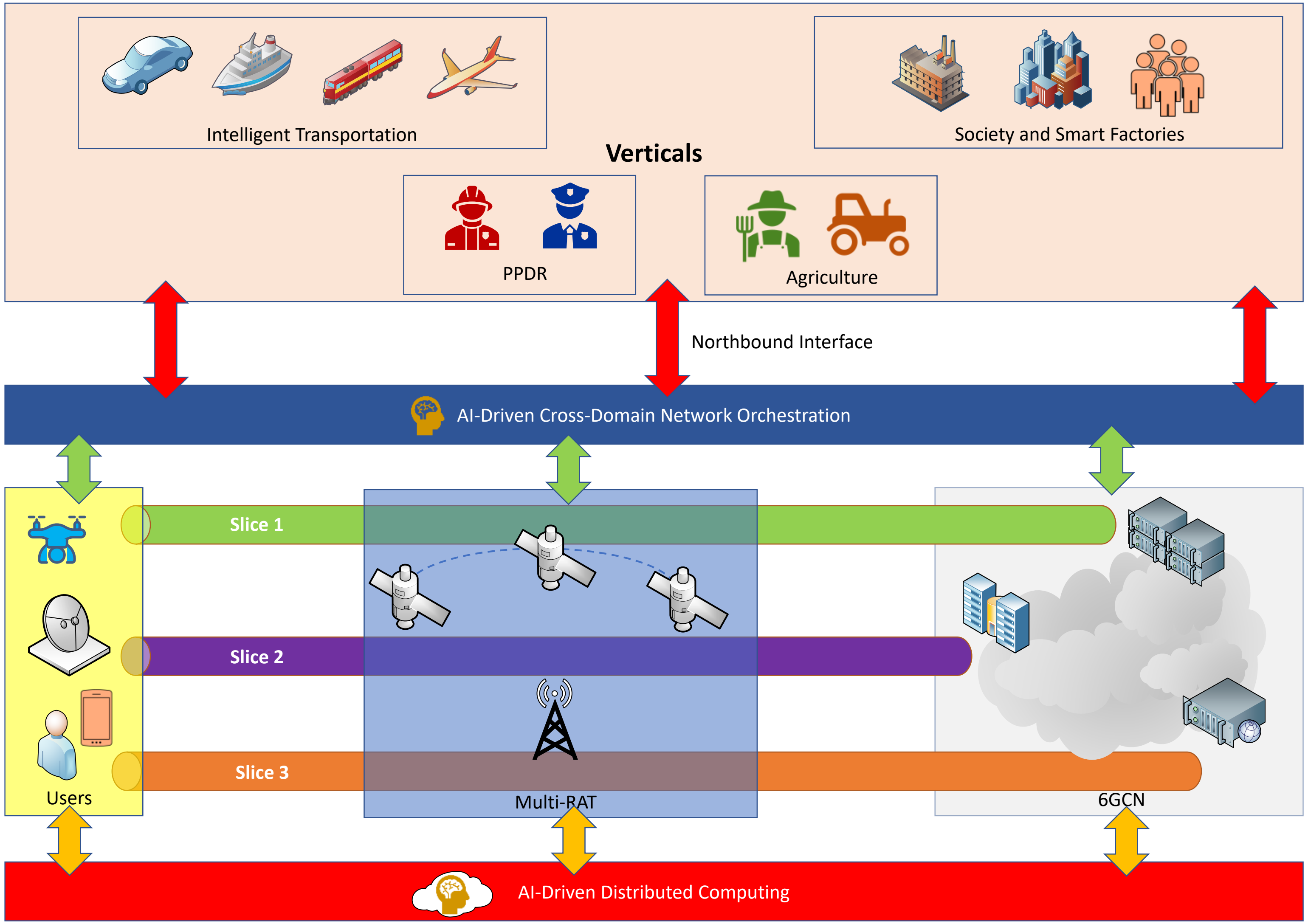


- Self-organised networking cabilities
- Zero-touch service management
- Network functions in space
- AI-as-a-Service in Space
- Satellite-as-a-Service (i.e. edge computing in space)
- Convergence of TN and NTN from a multi-link connectivity standpoint
- E2E connectivity through routing in space

Main Actors and Roles

RF+FSO links	Extended capacity
DTN	Resilience to distruption events
Multi-level/orbit network	Multi-service extended coverage
Semantic Comms	Goal-oriented comms for optimised capacity
Multi- domain orchestration	diversified user needs under very different operating conditions
Green abstraction interfaces	enabler to convey power control capabilities to management/control planes
Multi-level e2e routing	Congestion/load-balancing aware routing
Trustworthy native-AI design	Optimisation of TN and NTN segments jointly

A service-oriented architecture



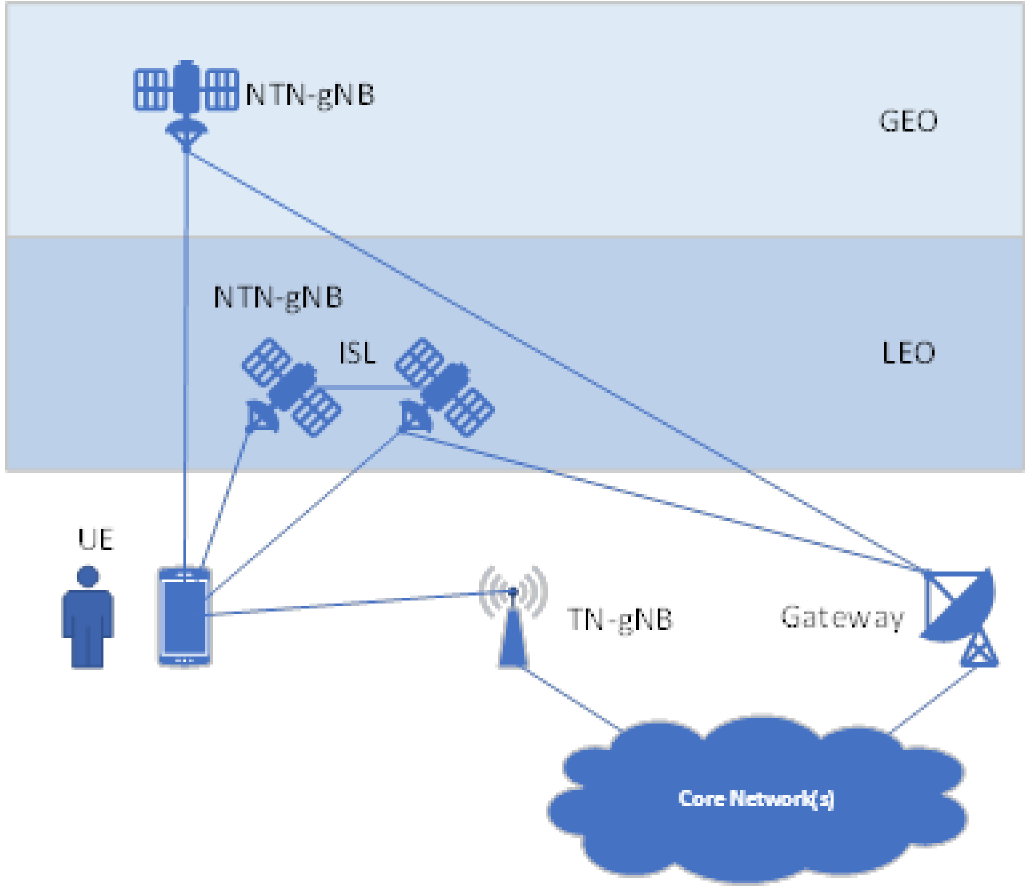
- Fully softwarised network architecture
- Intent-based networking paradigm
- AI based optimisation of
  - Network orchestration/slicing functions across TN and NTN segments
  - Distributed computing functionalities on ground and space towards edge-cloud continuum
- Self-organised networking architecture to cope with NTN-varying topology

NTN in 6G from DAY1: Way Forward

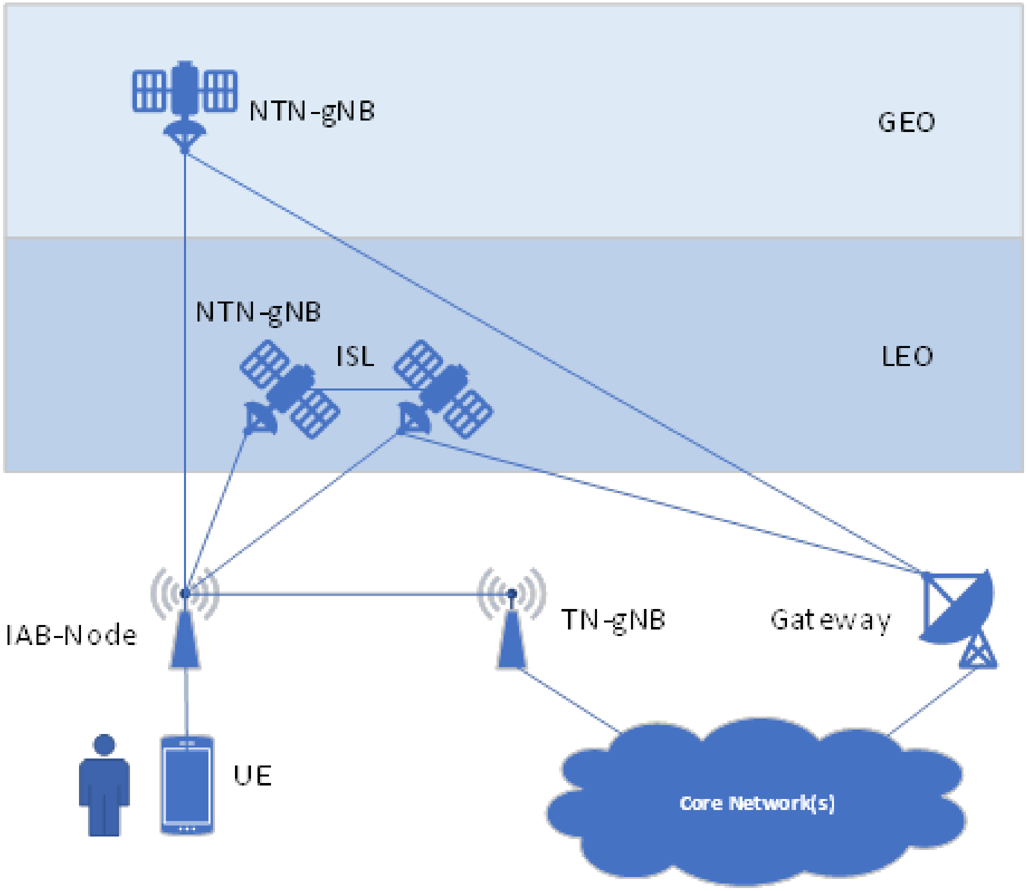
- **Service centric networking**
  - Optimal placement and coordination of service function chains among different elements of the space and ground segments
- **Orchestration of space networks as an integrated part of the 6G system**
  - Exploitation of Function-as-a-Service paradigms supported by AI techniques to correlate NTN-6G context data with network operations and achieve effective network orchestration
- **Edge/Cloud continuum**
  - Exploitation of space assets placed in different interconnected flying systems will be an added value to guarantee diversified and QoS-proof access to distributed computing and storage resources across the whole 6G network.
- **Dynamic end-to-end network slicing and resource allocation**
  - Effective service provisioning techniques across all protocol layers in order to enable a service assurance in multi-layer multi-orbit scenarios by means of AI-based complex dynamic control strategies
- **Distributed AI techniques**
  - Applied throughout the entire 6G-NTN network architecture to guarantee a flexible and effective service provisioning under the operational constraints imposed by the heterogeneity of NTN-6G network elements.

Multi-connectivity scenarios

Direct connection

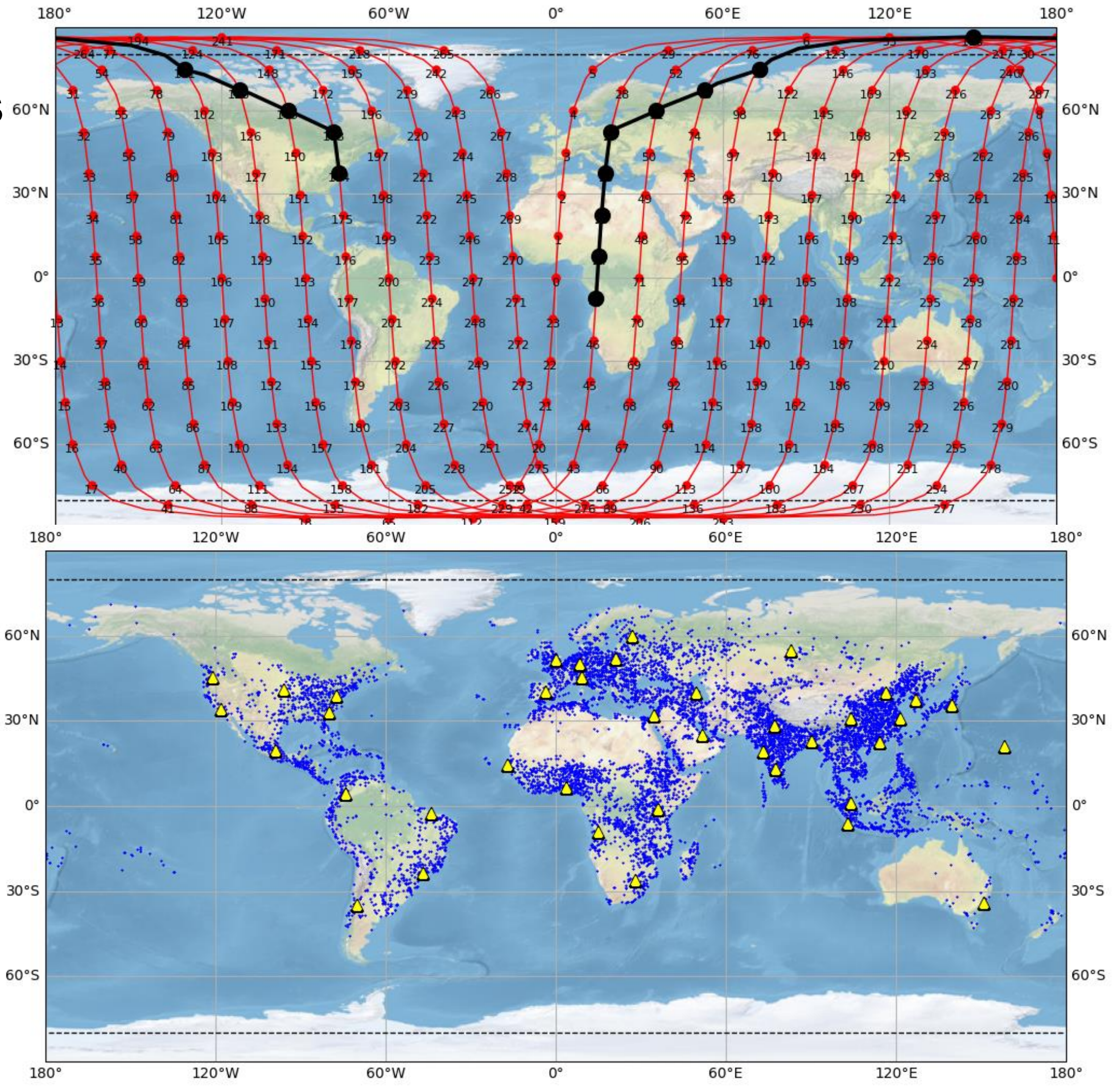


Indirect connection



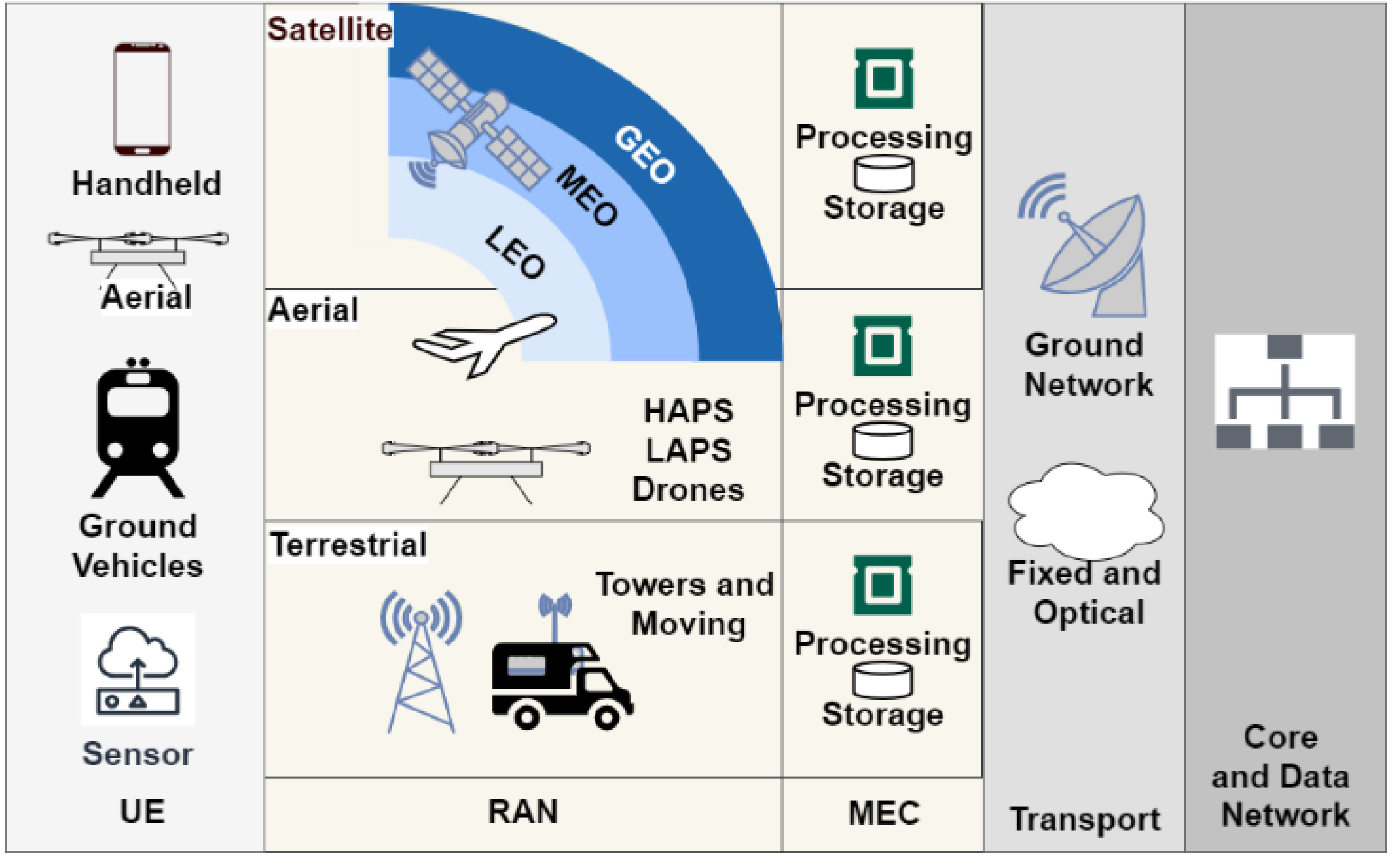
Routing Solutions for Satellite Constellations

- Source routing:
  - Ingress node calculates route to assumed egress
  - Minimum signalling, no link load information
- Segment routing:
  - More flexible – segment is instruction
- Fully-decentralized schemes:
  - Geographical routing
  - Distance-vector routing
- SDN-based:
  - Distributed SDN
  - Machine learning extensions



Roth MMH. Analyzing Source-Routed Approaches for Low Earth Orbit Satellite Constellation Networks. In: Proceedings of the 1st ACM Workshop on LEO Networking and Communication LEO-NET ’23. ACM 2023; New York, NY, USA:43–4

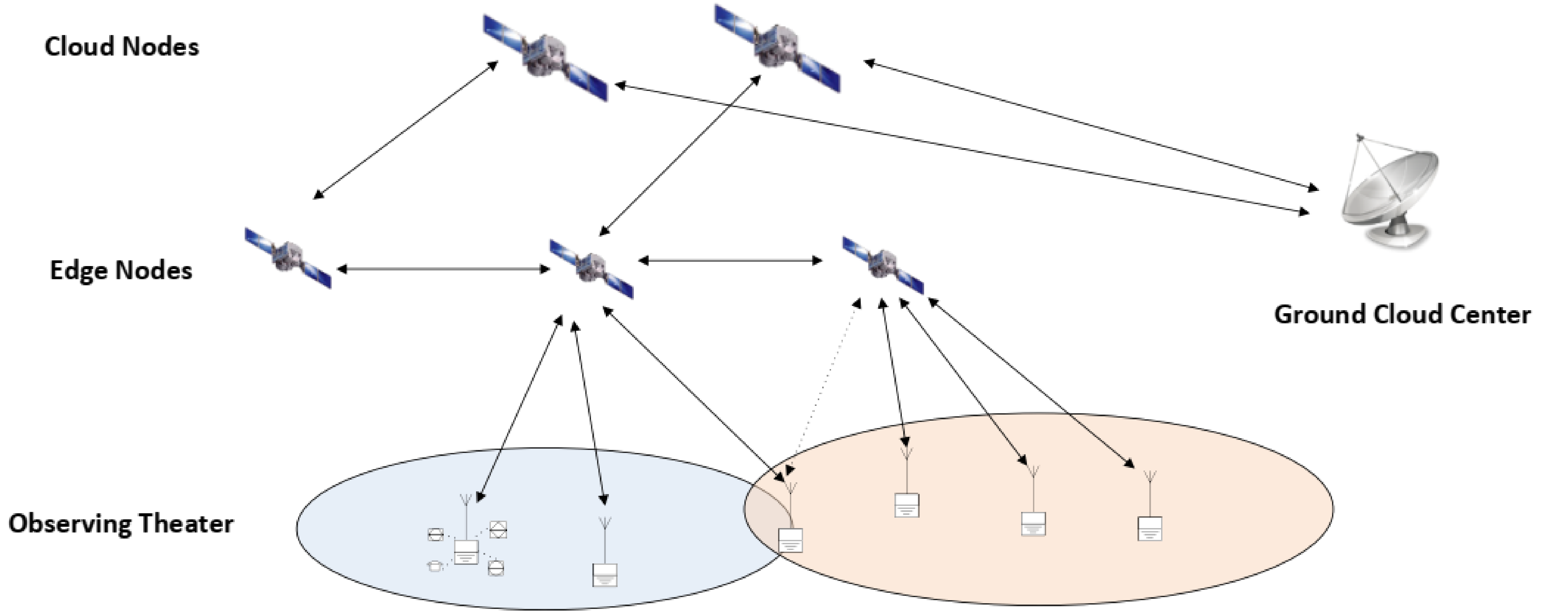
MEC-Platform Co-Located with the RAN



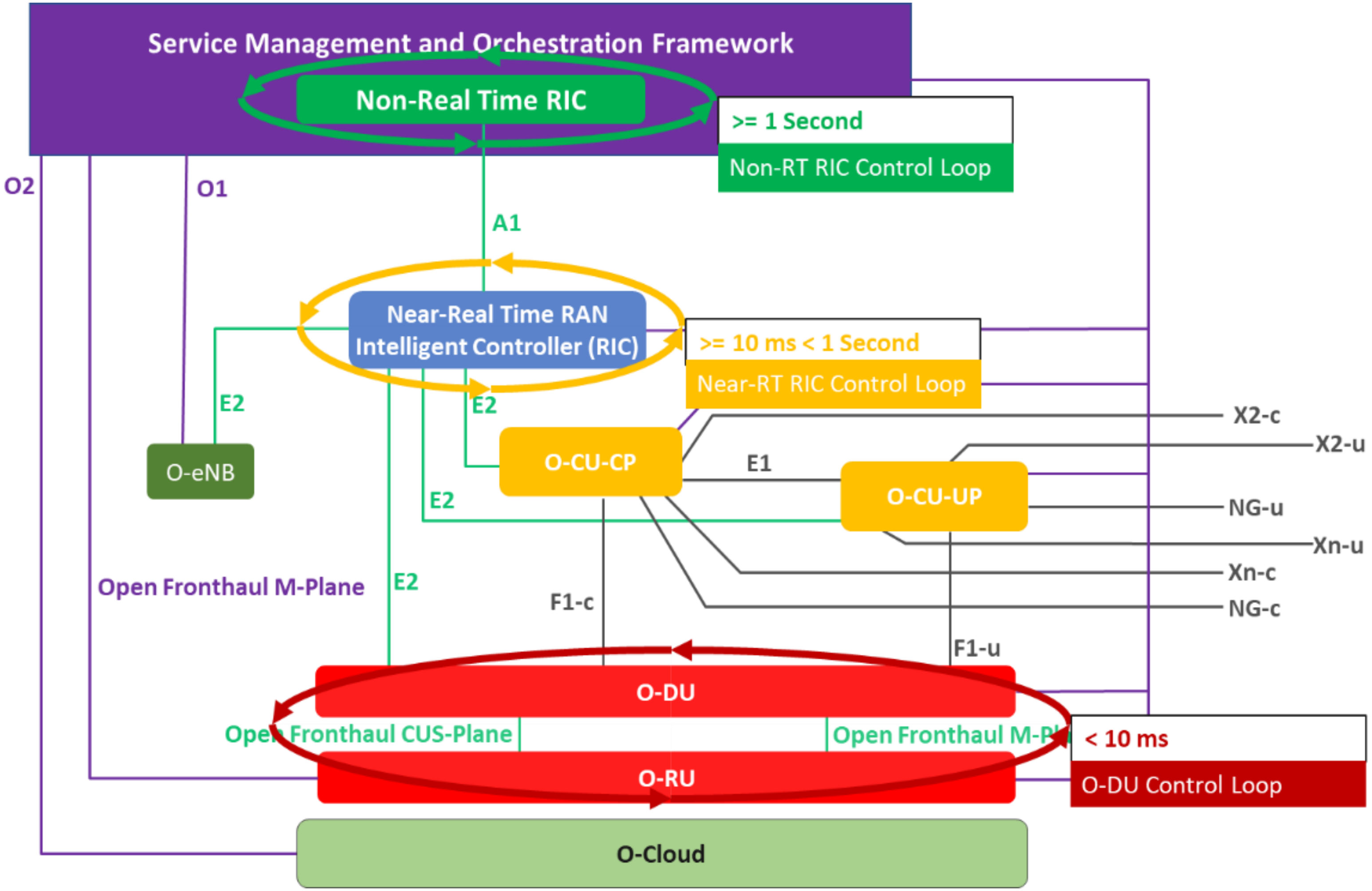
There are many options for MEC platform placement, we considered co-located with the gNB

Bringing services closer to the user by hosting the edge on-board flying nodes ➔ combining benefits of NTN and MEC

Edge Computing: Satellite as-an-edge Service!

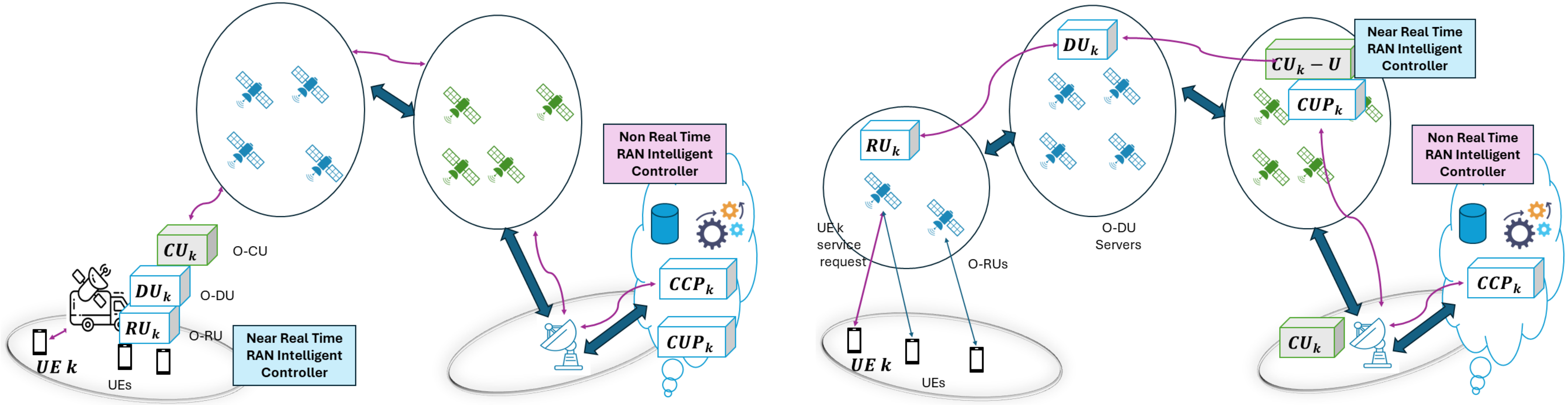


Power is nothing without control…



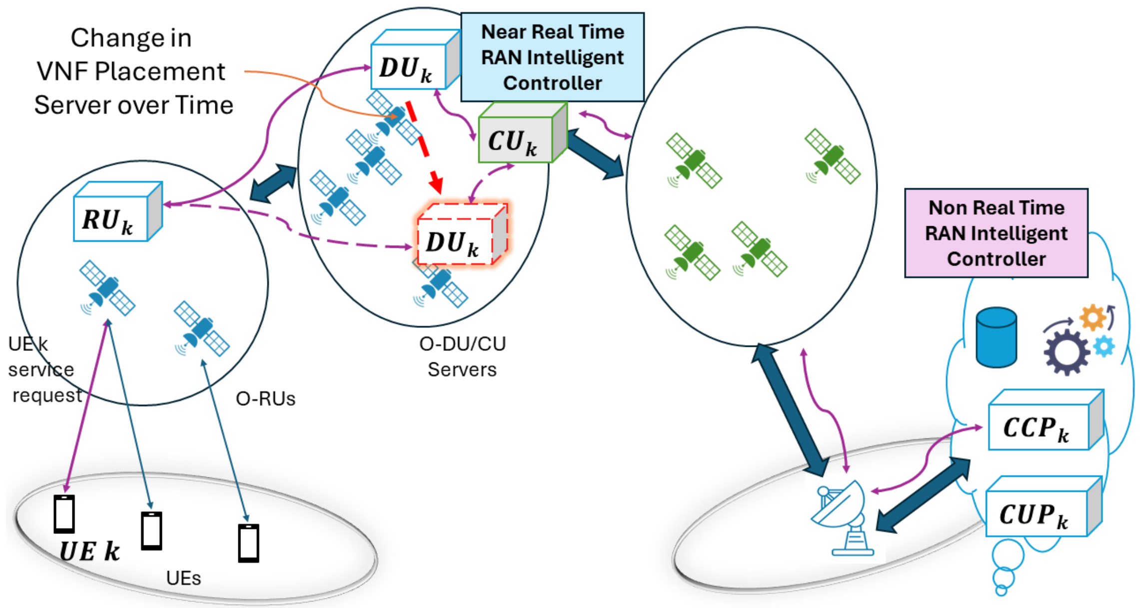
RAN Functions Deployment

- Several possible options for the deployment of the RAN functions
- The possible set of RAN functions including RU, DU, and CU correspond to the set of stack function functions of the O-RAN protocol.
- Core networking functions can be also deployed where the Core User Plane (CUP), and the Core Control Function (CCP) are considered

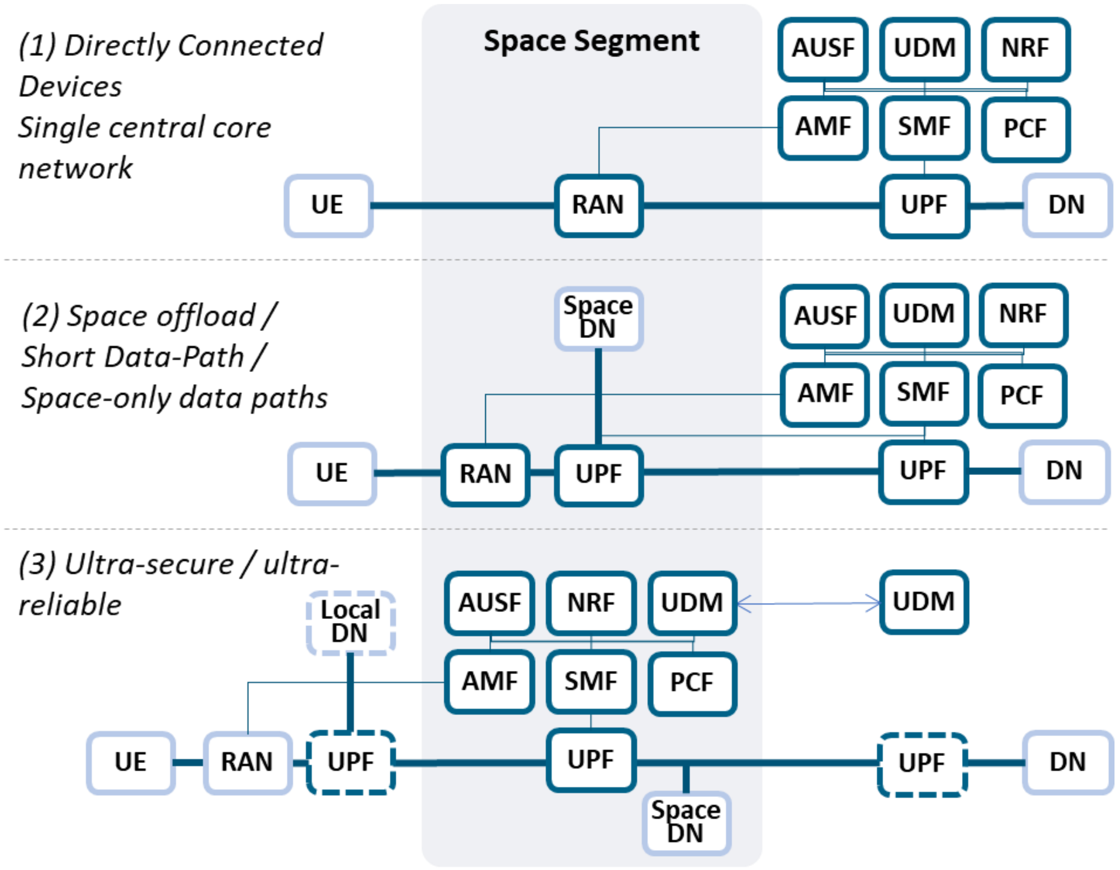


VNF Placement

RAN VNF Placement

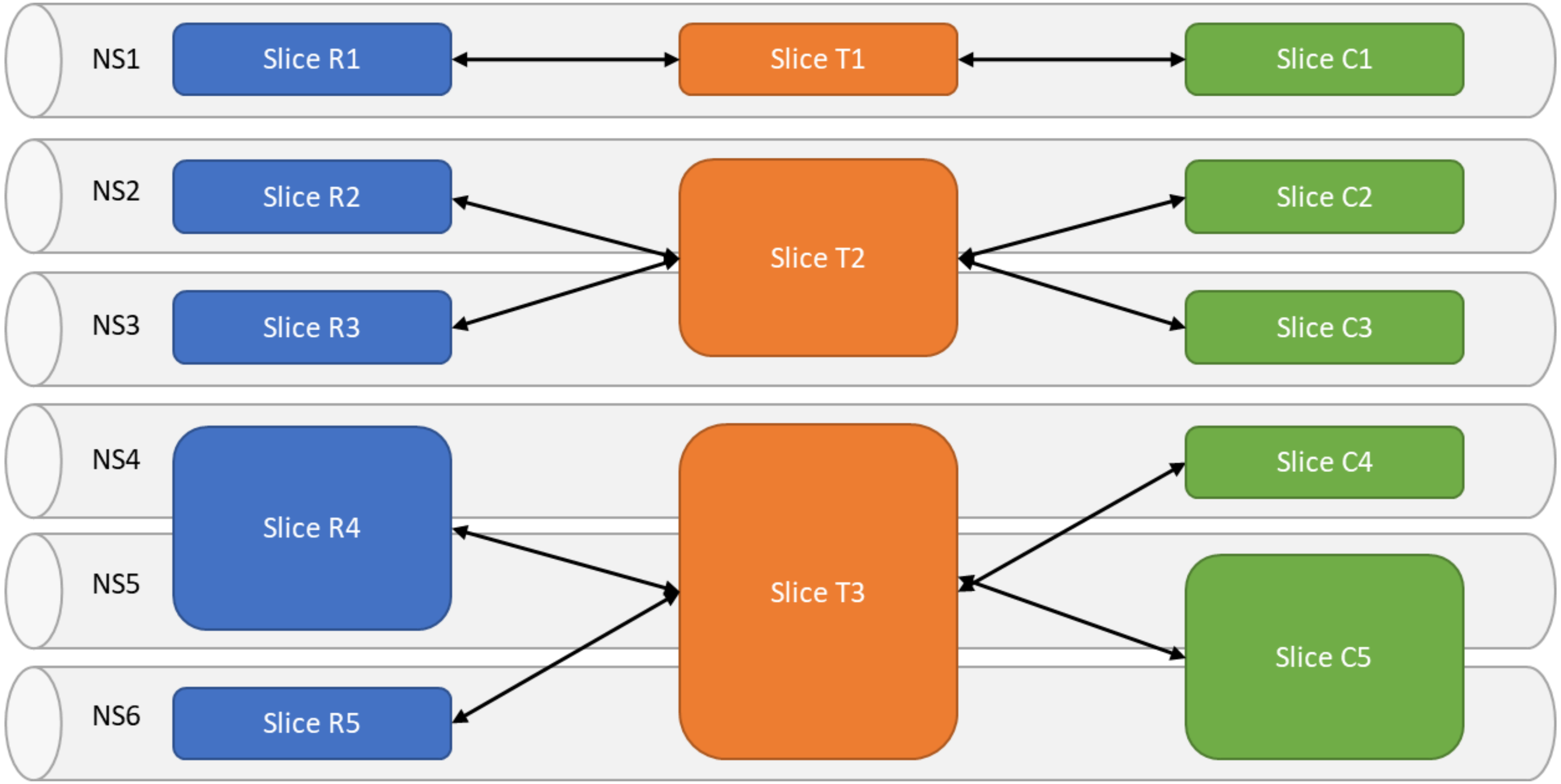


CORE NF Placement



Network Slicing

- End-to-end Network Slices - Dedicated and Shared



6G-NTN for Beyond Earth

Conclusions

- Satellite ecosystem is being to be „rebranded“ to be aligned with the actual needs of vertical and society in the forthcoming 6G landscape:
  - Convergence and unification with terrestrial networks infrastructure at different level, i.e. communication technology, infrastructure, operations
  - Data awareness to achieve more effective unification between TN and NTN and pave the way towards fruitfull business exploitation
- Important challenges still ahead in view of the modernisation of satellite systems:
  - Cost-benefits tradeoff
  - Physical limitations of space assets, e.g., SWaP constraints
  - Emergence and consolidation of new business model needed