NTN as enabler for holistic 6G architectures

Workshop on Communication in Extreme Environments for Science and Sustainable Development

ICTP, Trieste, Italy, November 20th-23rd 2023

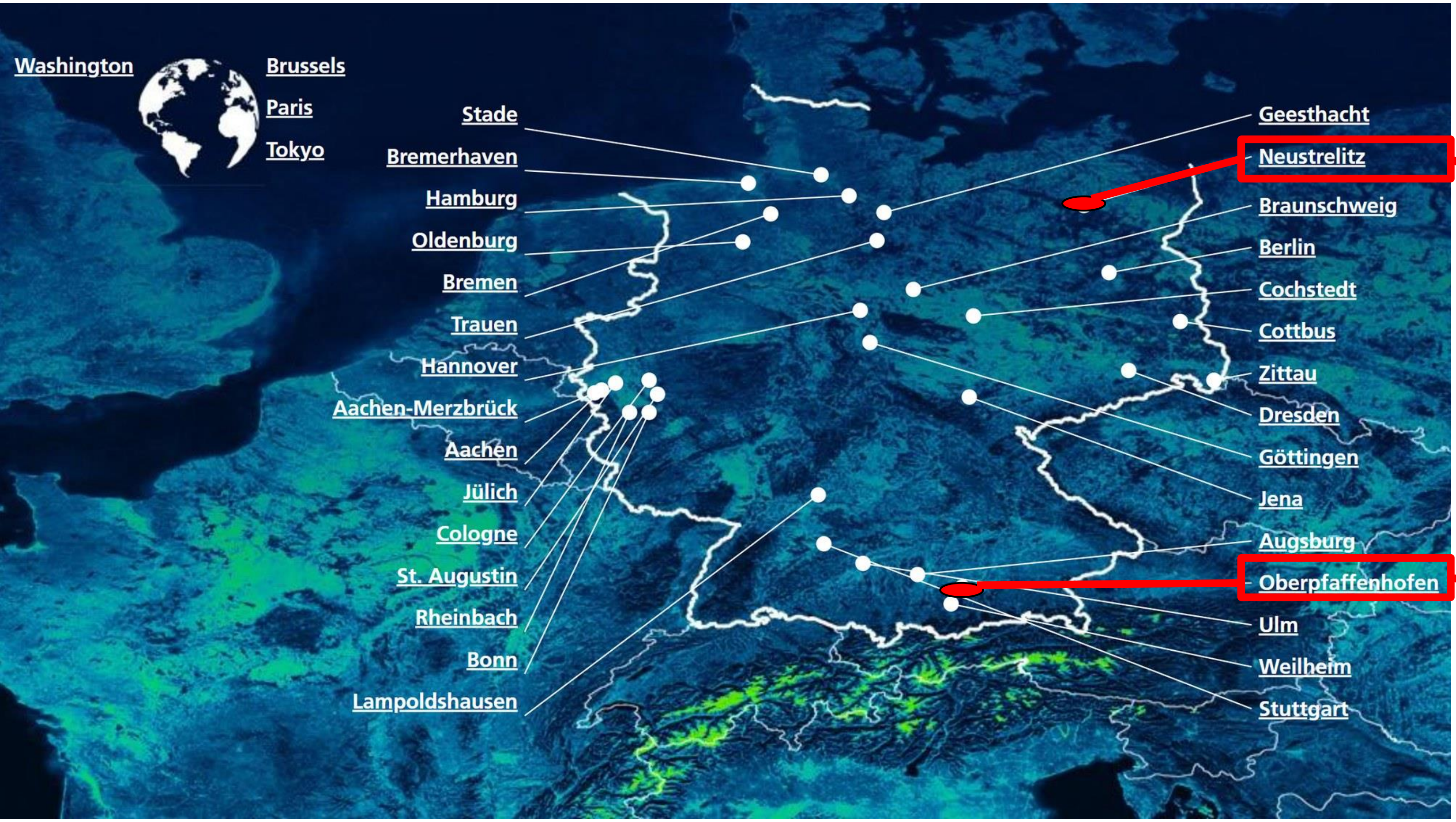
Speaker: Dr. Tomaso de Cola (DLR)

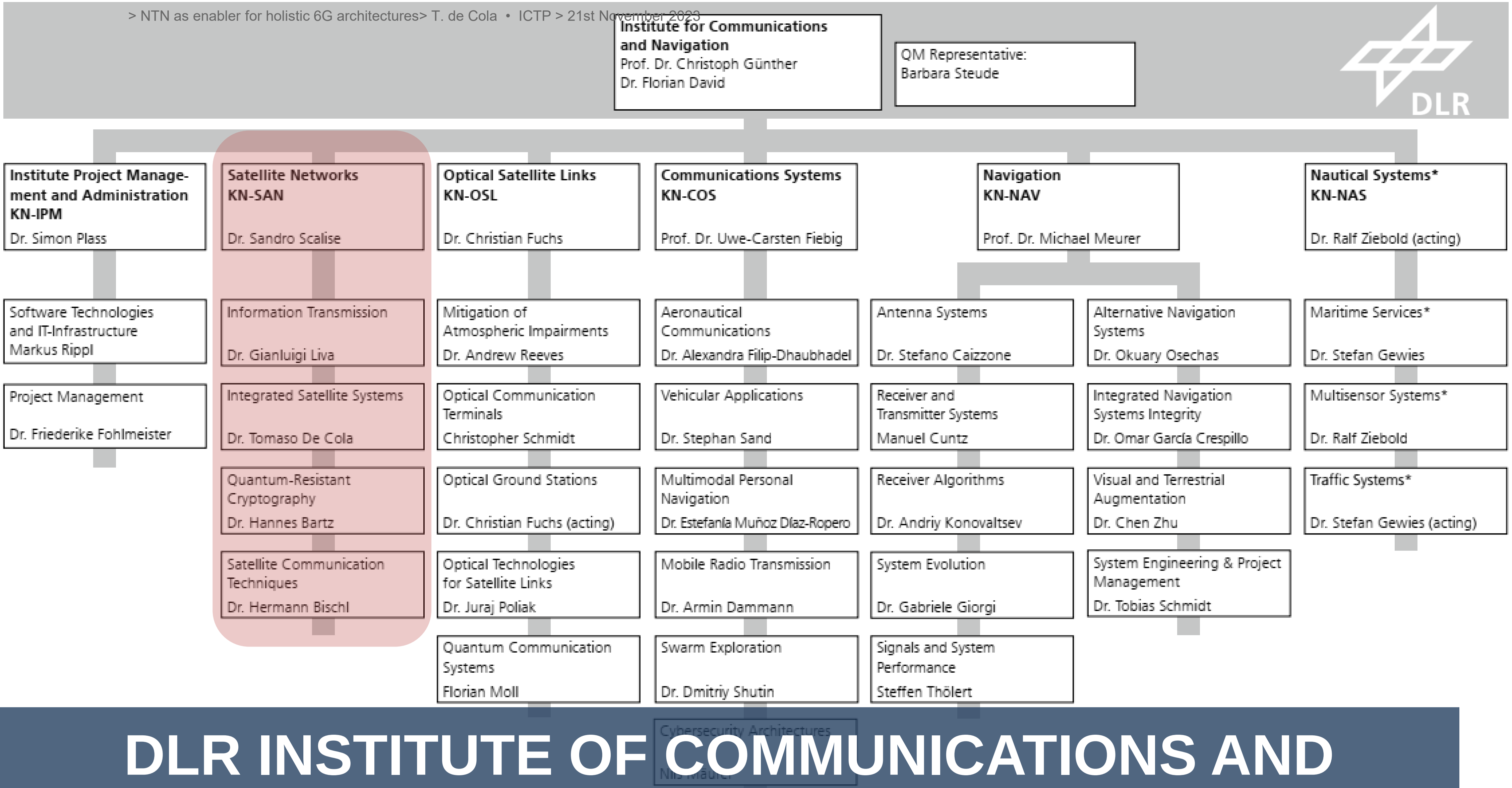
Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

DLR at a glance

- Research Institution
- Space Administration
- Project Management Agency

DLR – Institute of Communications and Navigation





DLR INSTITUTE OF COMMUNICATIONS AND NAVIGATION

* Site Neustrelitz

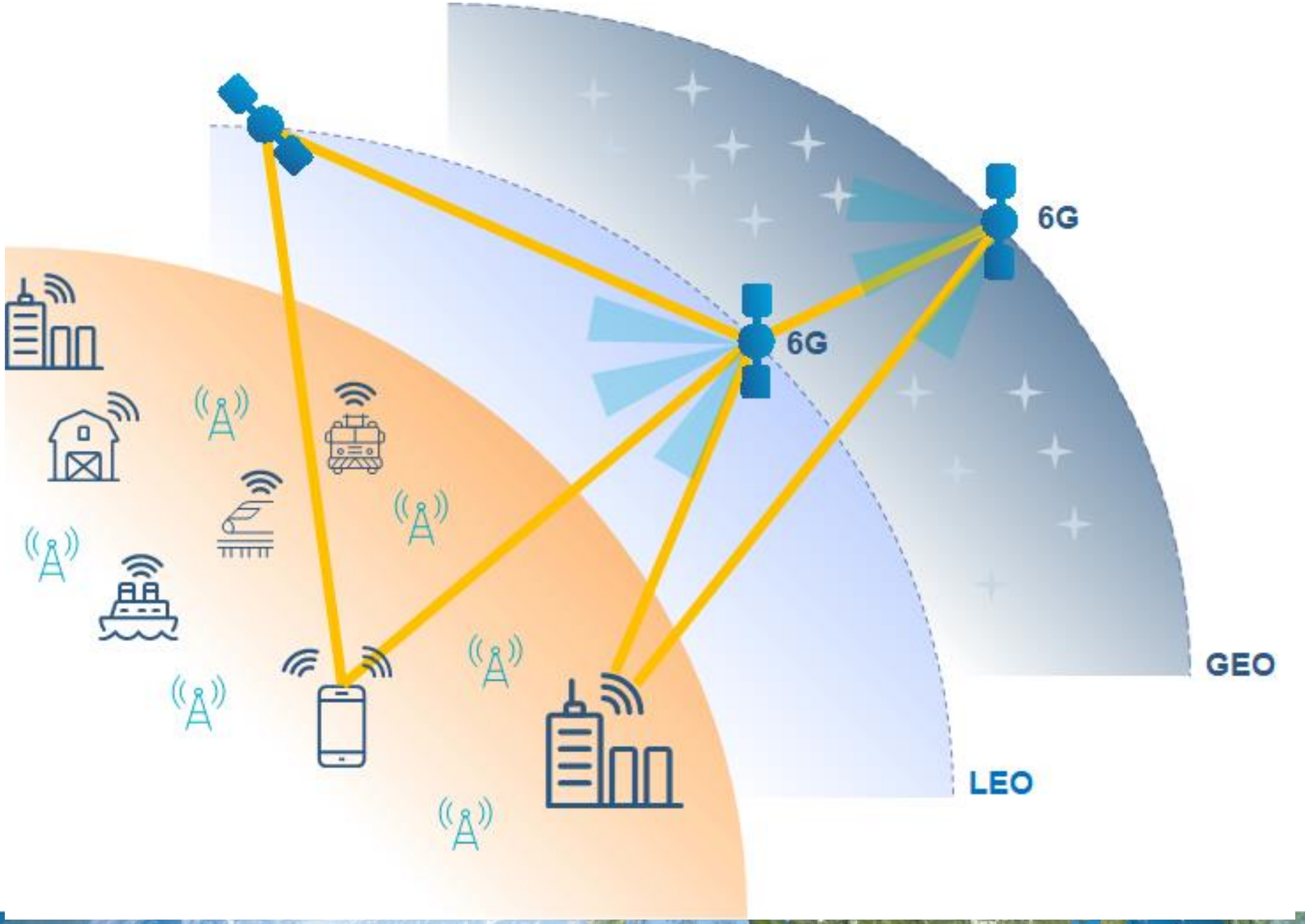
Satellite Networks Department in a Nutshell

Staff

- 28 Scientists + 1 DLR-DAAD and 1 Munich-Aerospace Fellows
- 4 Groups
  - Information Transmission (ITX)
  - Integrated Satellite Systems (INS)
  - Quantum-Resistant Cryptography (QRC)
  - Satellite Communications Techniques (SCT)

Main Research Topics

- Satellite Communications
  - Transmission Schemes for RF Userlinks (Broadband & Space IoT / mMTC)
  - Networking & Protocols for Non-Terrestrial-Networks Integration with 5G and 6G
- Selected „Quantum-Topics“
  - Quantum-Resistent Cryptography
  - Quantum Error Correction



Satellite Networks Department: Missions

- Satellite Communications
  - Transmission Schemes for RF Userlinks (Broadband & Space IoT / mMTC)
  - Networking & Protocols for Non-Terrestrial-Networks Integration with 5G and 6G
- Selected „Quantum-Topics“
  - Quantum-Resistant Cryptography
  - Quantum Error Correction

Satellite Networks Department: Expertise

Integrated Satellite Systems Group

- Integration of SatCom with other systems (5G/6G, GNSS, EO)
- Mobile Edge Computing
- Network Slicing and Orchestration
- DTN Protocols

Quantum-Resistant Cyptography Group

- Code-based Cryptosystems
- Efficient and Robust Encryption and Decryption Algorithms
- New Methods for the Cryptanalysis

Information Transmission Group

- Modulation and Error Control Coding
- Signal Processing
- Medium Access Control / Massive Multiple Access
- Quantum Error Correction

Satellite Communications Techniques Group

- Fade Mitigation Techniques
- Interference Management
- On-Board Processing Algorithms (Switching, Routing, etc…)
- Equalisation and Signal Pre-Distortion

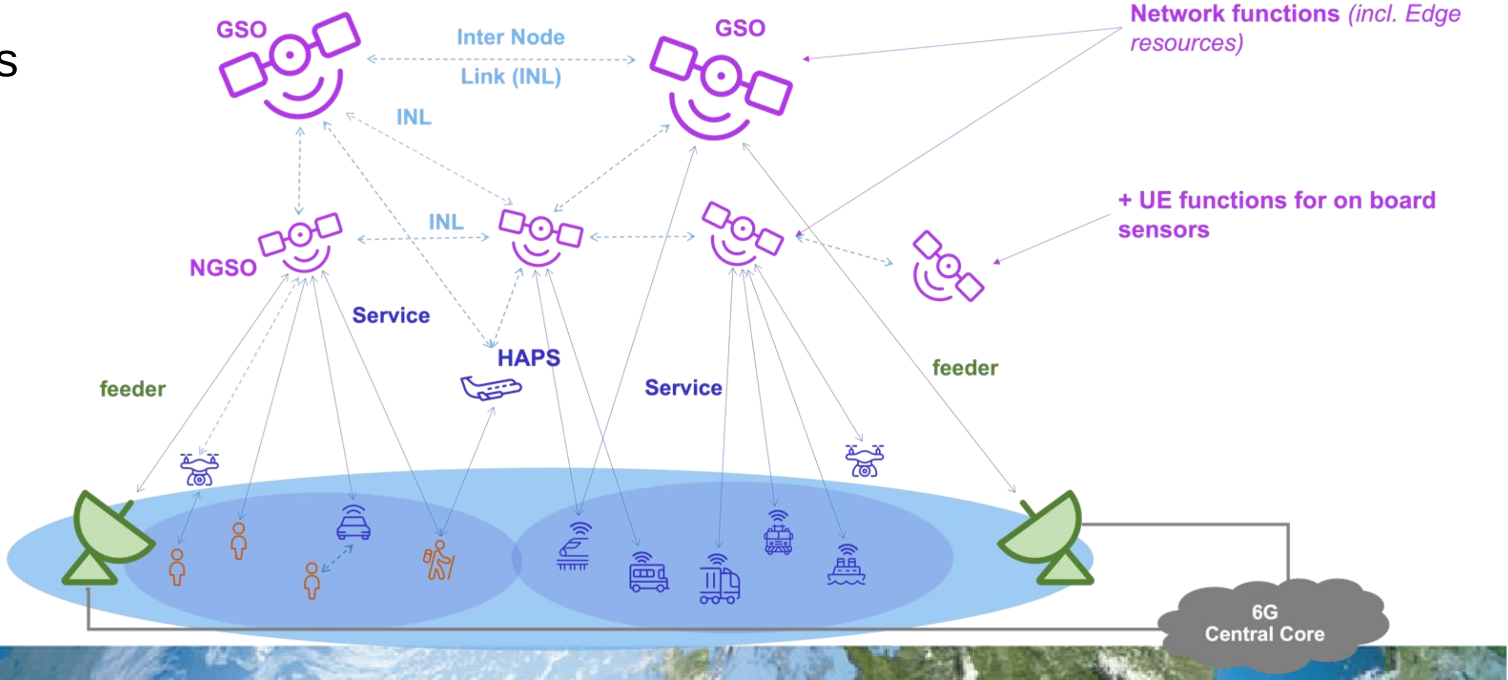
Satellite Communications: Context and Motivation

- Many "New Space" Initiatives → Coming back of constellations & "Democratization" of Space
- NTN (Non-Terrestrial Networks) Inclusion in 3GPP (5G / 6G)
- EU Secure Connectivity / IRIS^2 Initiative

→ Major technical innovations required

- Multi orbit concepts
- Regenerative / autonomous payloads (also for GEOs)
- No more "dedicated" waveforms?
- Optical ISLs and Feeder Links
- Resilience as essential asset

→ **Satellites as Intelligent, Reliable and Secure Networks Nodes**

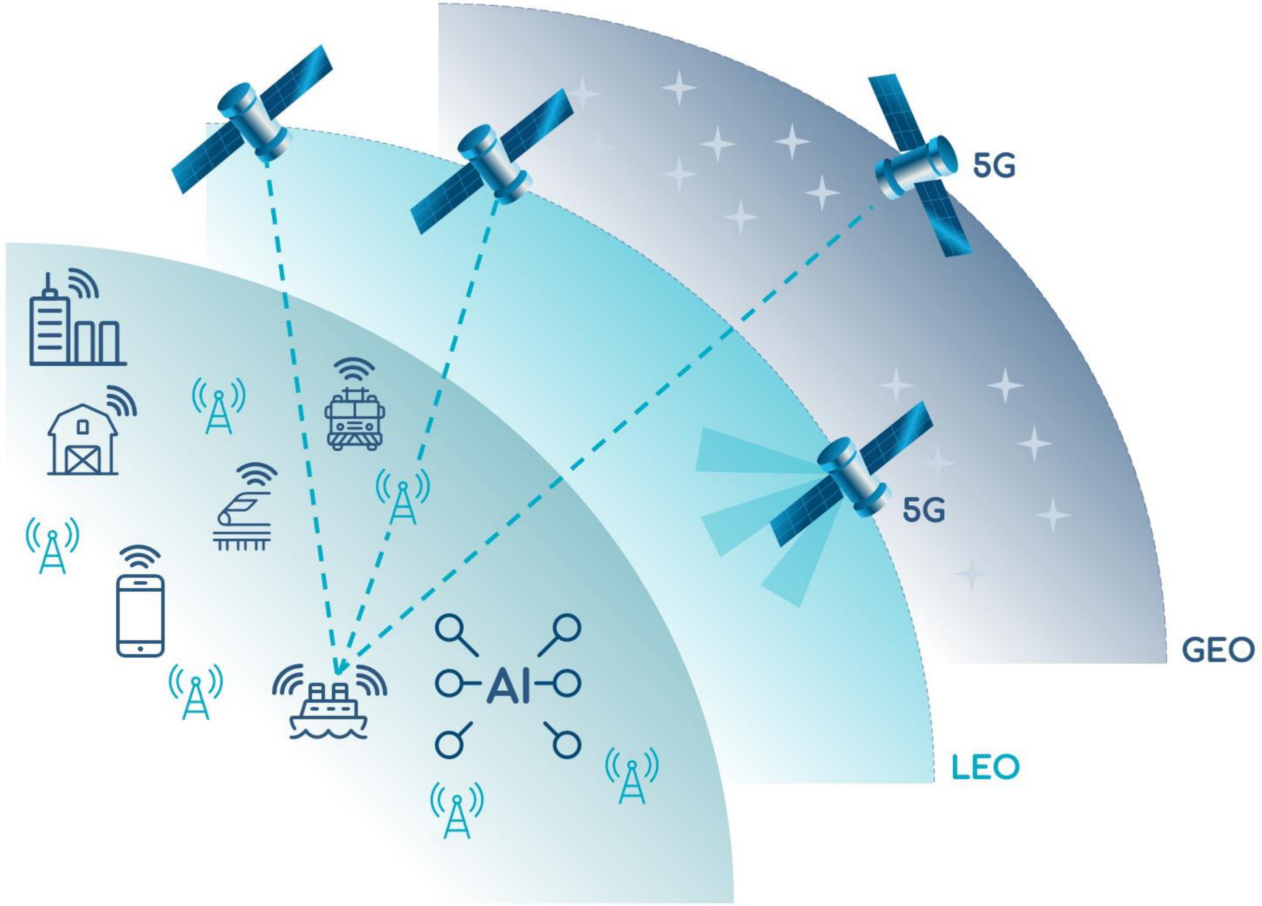


B5G NTN Projects at DLR KN

5G stardust

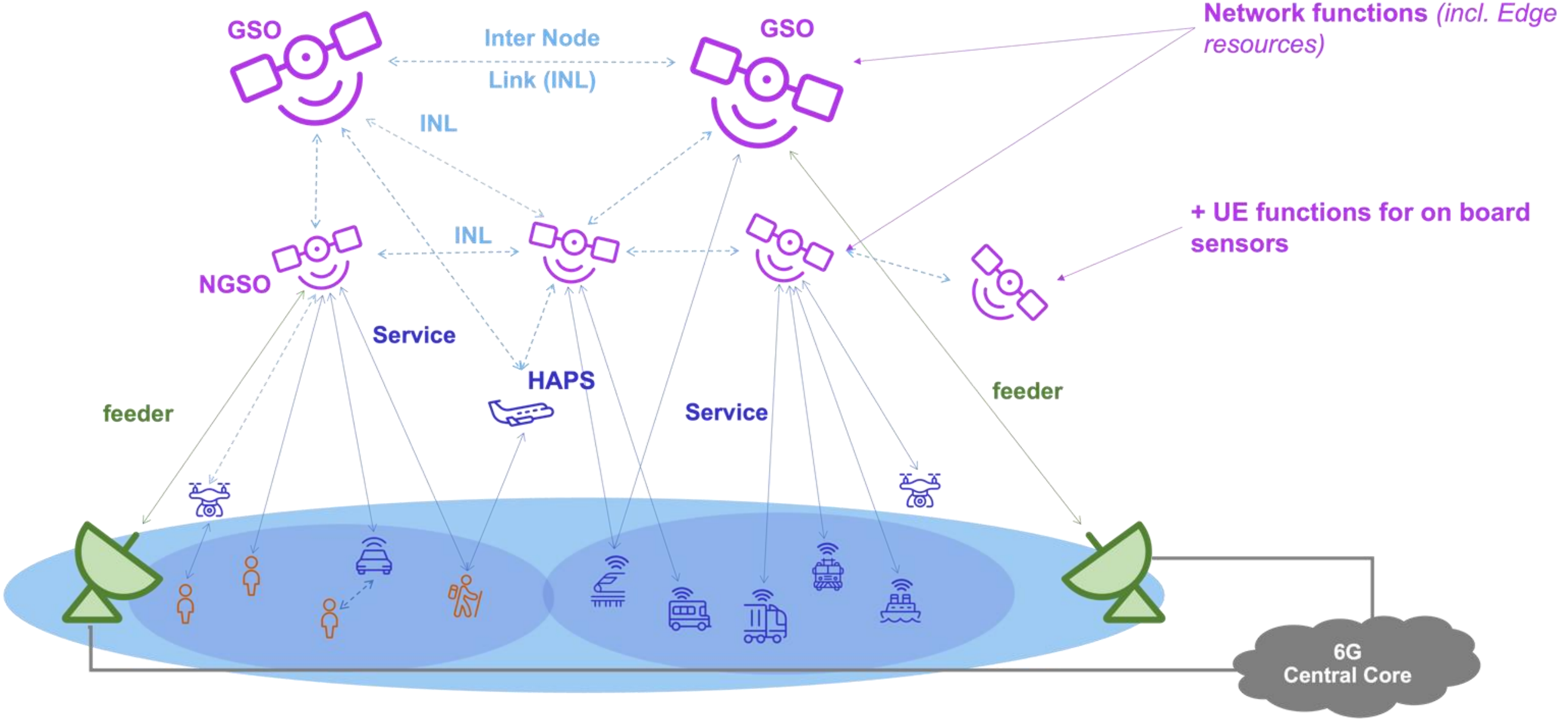
- Main mission:
  - Design, develop and demonstrate a deeper integration of TN and NTN:

- Enabling Technologies:
  - Regenerative payloads for GEO and NGSO systems
  - Unified radio interface for cost-effective converged TN/NTN multi-tenant networks
  - Softwarised self-organised network architecture
  - E2E AI-Driven Network Design



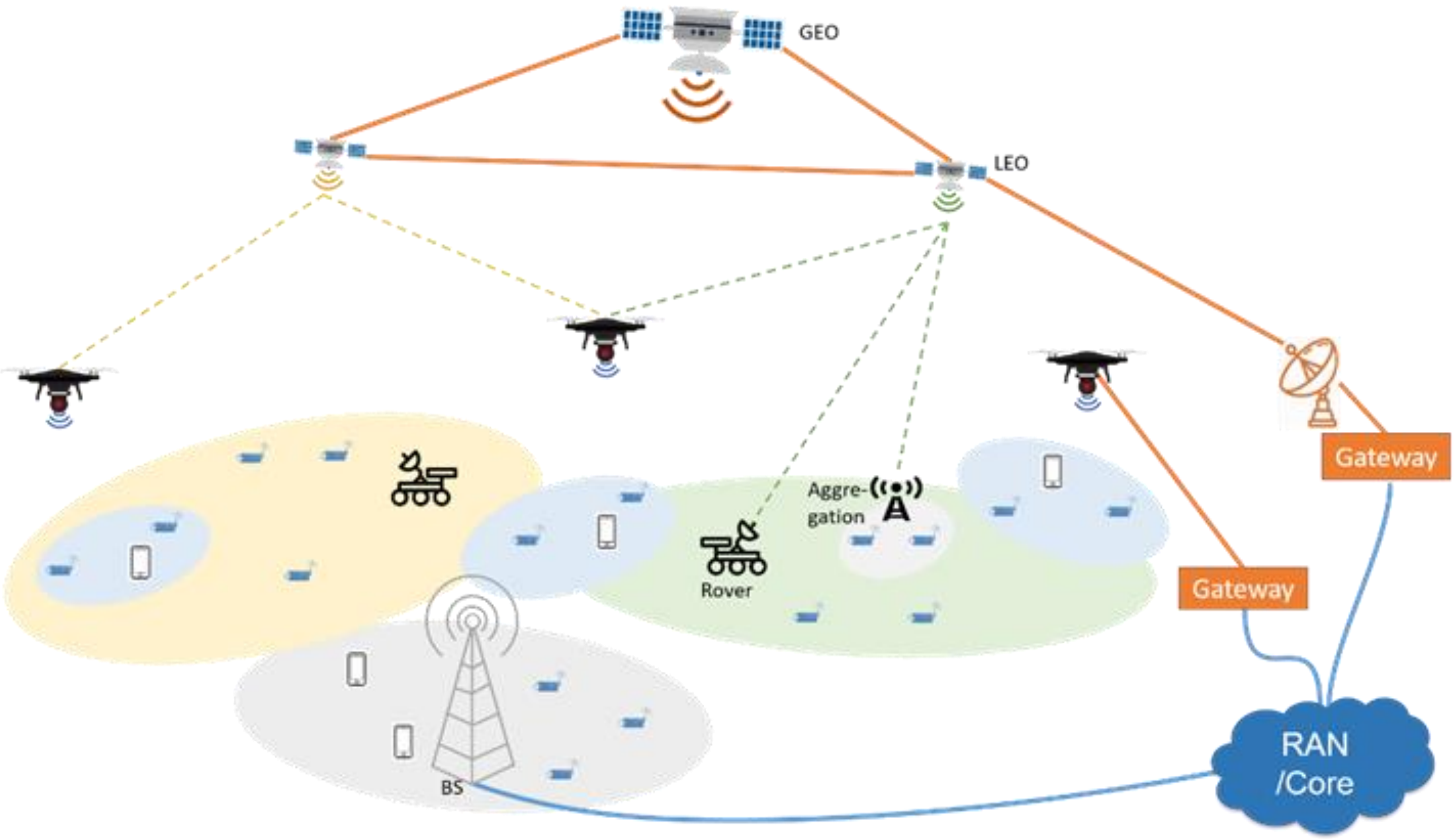
6G NTN Projects at DLR KN

6GNTN



6G NTN Projects at DLR KN

6G-TakeOff



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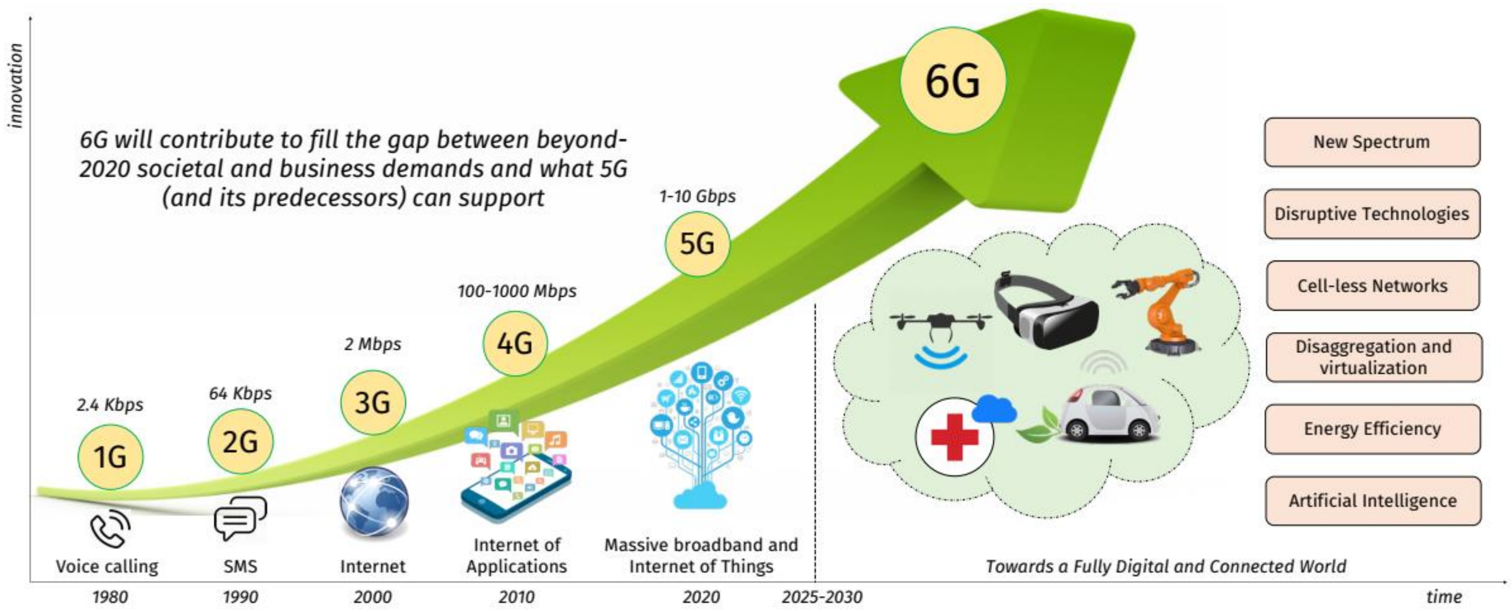
ICTP The Abdus Salam International Centre for Theoretical Physics

6G: Vision and Services

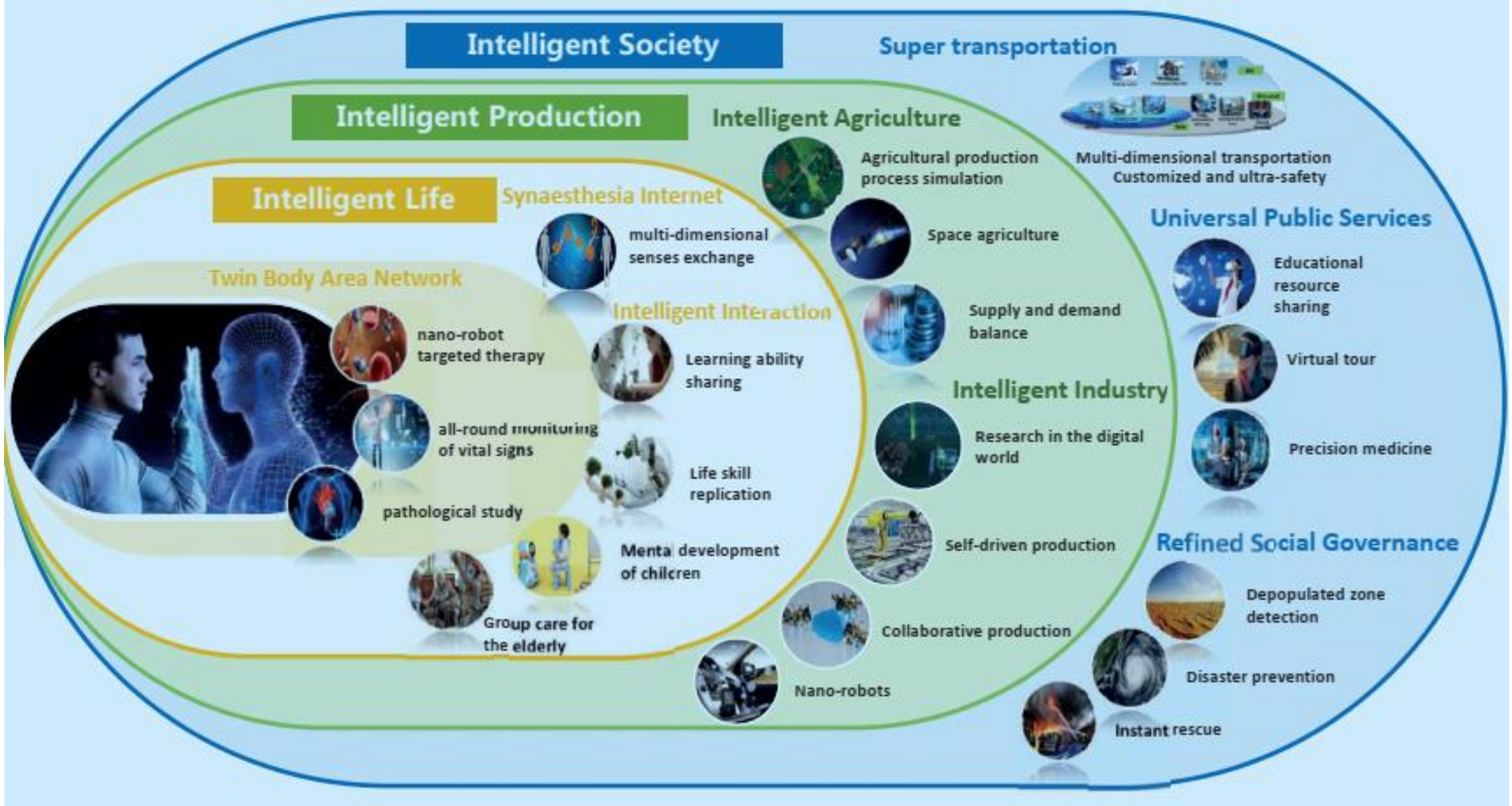
- B5G and 6G are expected to bring substantial evolution of the architecture and services envisioned for 5G:
  - Deep use of ML/AI concepts
  - New frequency bands (i.e. THz+)
  - Energy efficiency
  - Full system softwarisation
  - Edge computing capabilities on demand

- New services will be enabled:
  - AR/VR/MR
  - Holographic telepresence
  - E-health with haptic applications
  - Pervasive connectivity
  - Unmanned mobility
  - …



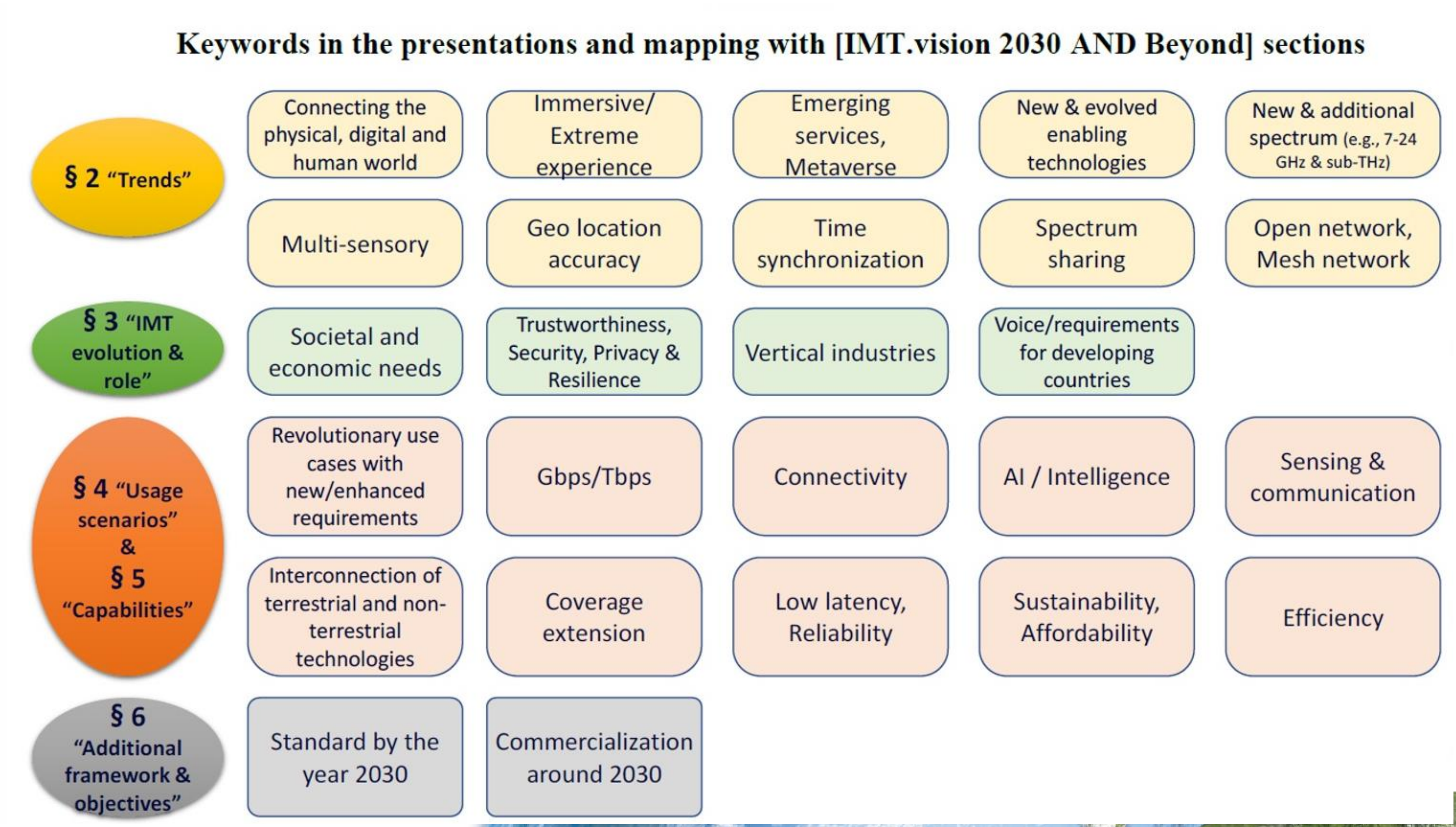
from M. Giordani *et al.*, "Toward 6G Networks: Use Cases and Technologies," in IEEE Communications Magazine, vol. 58, no. 3, pp. 55-61, March 2020 (with IEEE courtesy)

6G Use cases and Scenarios



Courtesy of IEEE:
G. Liu et al., "Vision, requirements and network architecture of 6G mobile network beyond 2030," in China Communications, vol. 17, no. 9, pp. 92-104, Sept. 2020.

IMT-2030 and Beyond Vision



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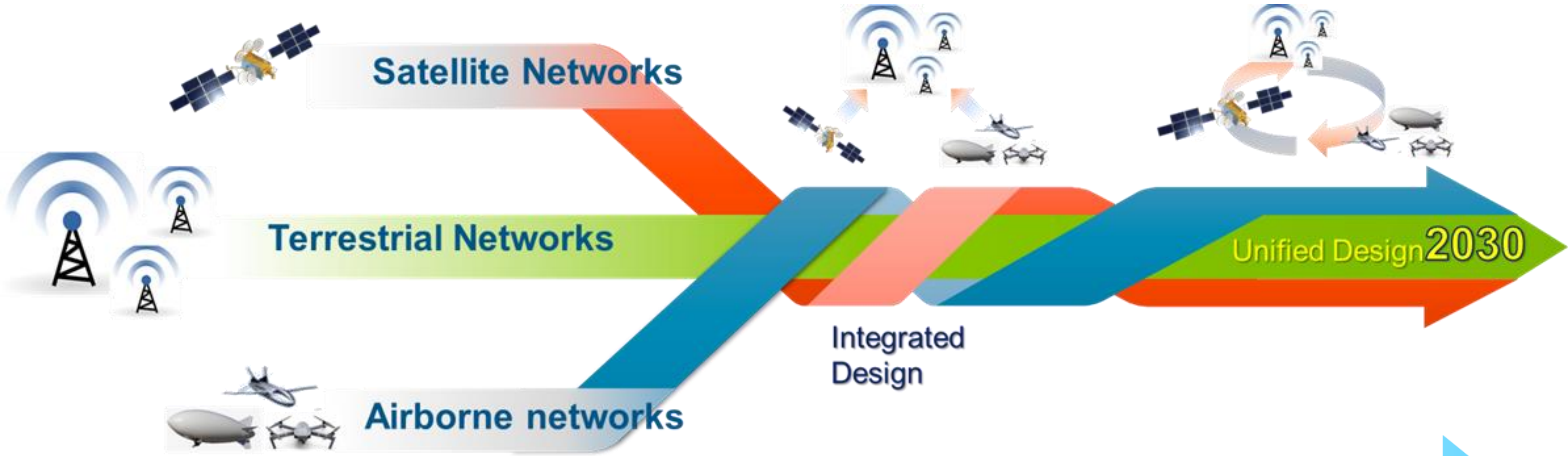
Unified 3D Networks

6G-TakeOff



4G & Before

Design optimized **independently** and exclusively for terrestrial networks

5G & B5G

Design optimized for terrestrial network component

Minimum impact to support integration of satellite for coverage and availability extension

6G & beyond

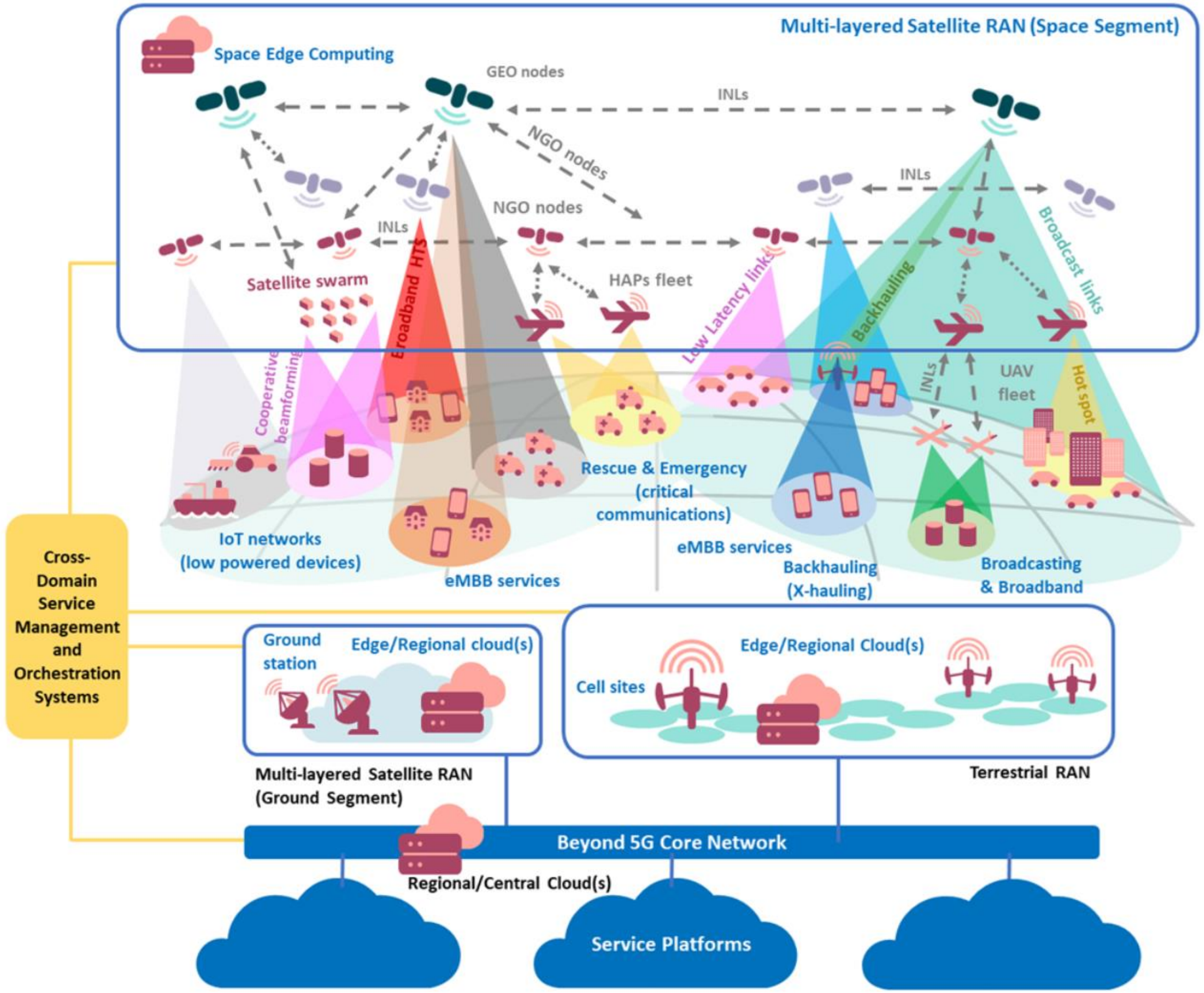
Design optimized for both terrestrial and space components against a set of common goals

DLR

NTN Reference Scenarios

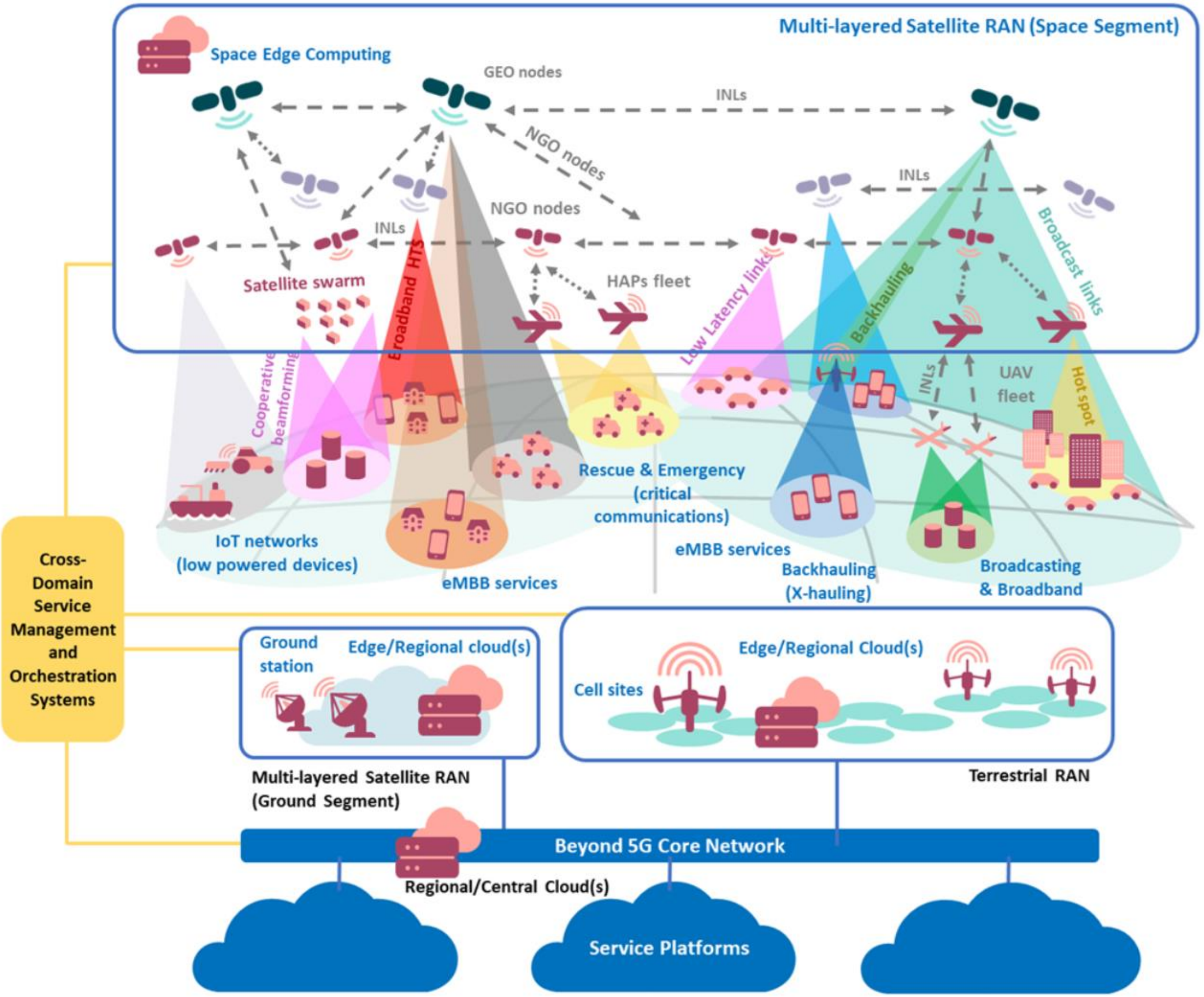
- Multiple Connectivity
  - Maritime and railway
    - LEO, GEO complement TN
  - Direct access (LEO),
    Integrated Access and Backhaul (IAB):
    - Fast network deployment
    - Temporary gap filler
  - Dual connectivity between LEO and GEO

- 3D Multi-orbit, multi-layer network:
  - Interconnected space assets
  - Mesh networks on ground and space



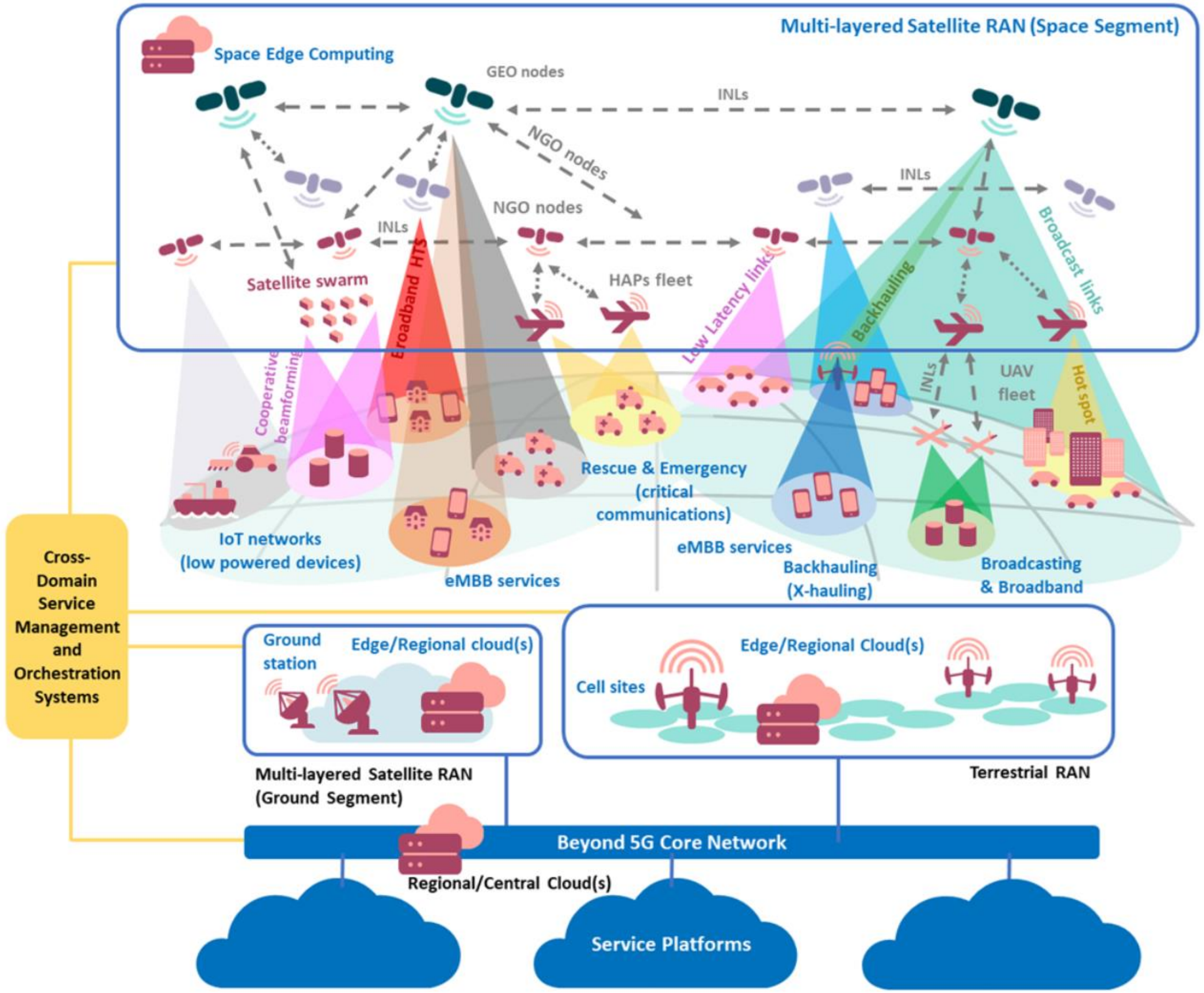
NTN Reference Scenarios

- Architecture & Service Distribution
  - Point-to-point LEO uRLLC V2X:
    - User Plane Functions
    - Multi-access Edge Computing
  - Public Protection and Disaster Relief:
    - Direct access, fast response
  - Distributed 5G/6G systems for private networks:
    - On-board control plane, terrestrial user plane → ultra-reliable signalling

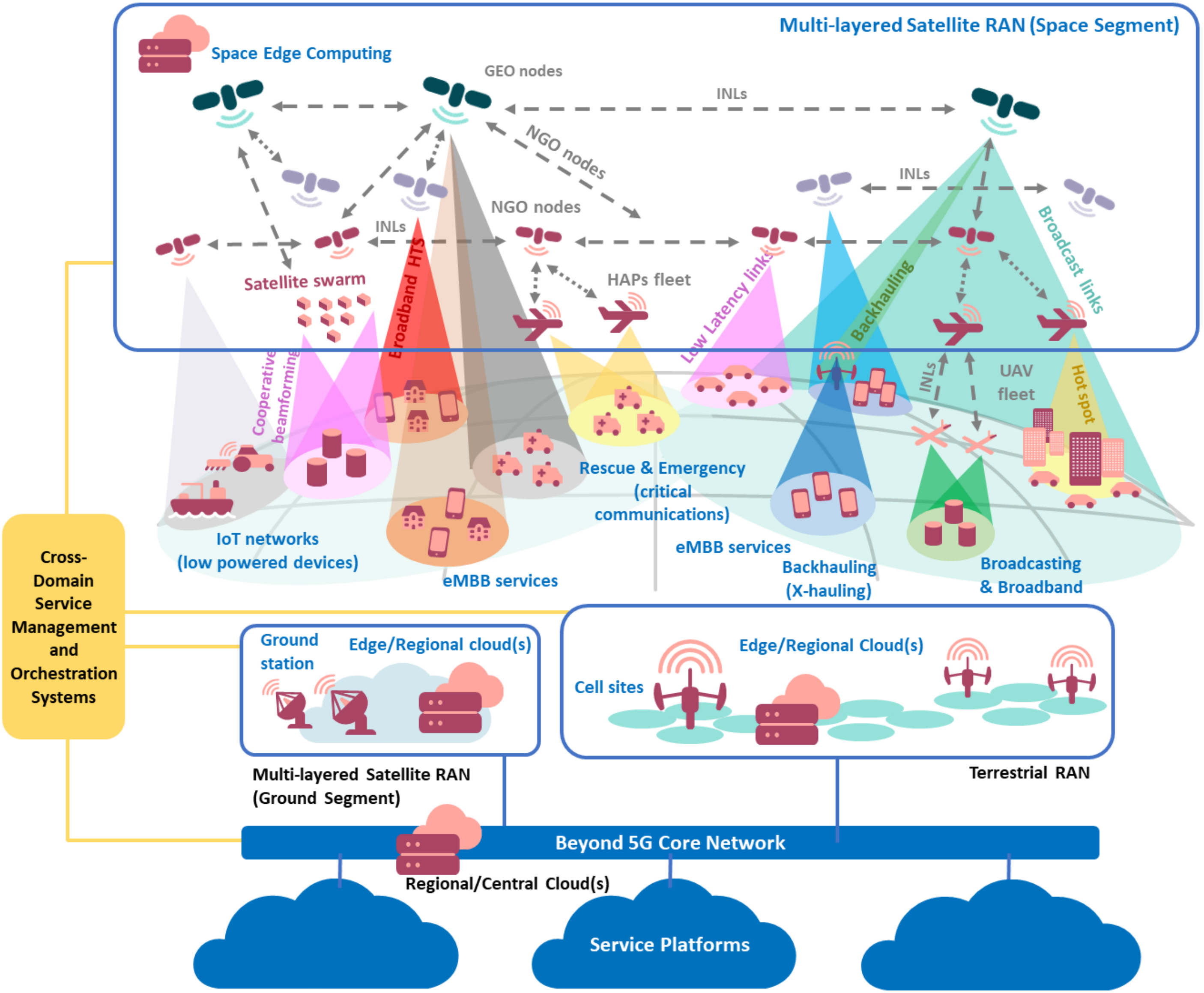


Network Architecture

- Dedicated space links (RF or optical)
  - Bridged to terrestrial counterparts
  - Direct interconnection to cellular terminal
  - Or to intermediate points, backhaul
- Cross-domain network orchestrator
  - Adoption of Open RAN
  - Radio Intelligent Controller
- Distributed learning strategies
  - Optimize performance
- Distributed network control & management
  - Timely, effective decision-making
  - Software Defined Networking
  - P4-based switch programming



6G-NTN in a Nutshell

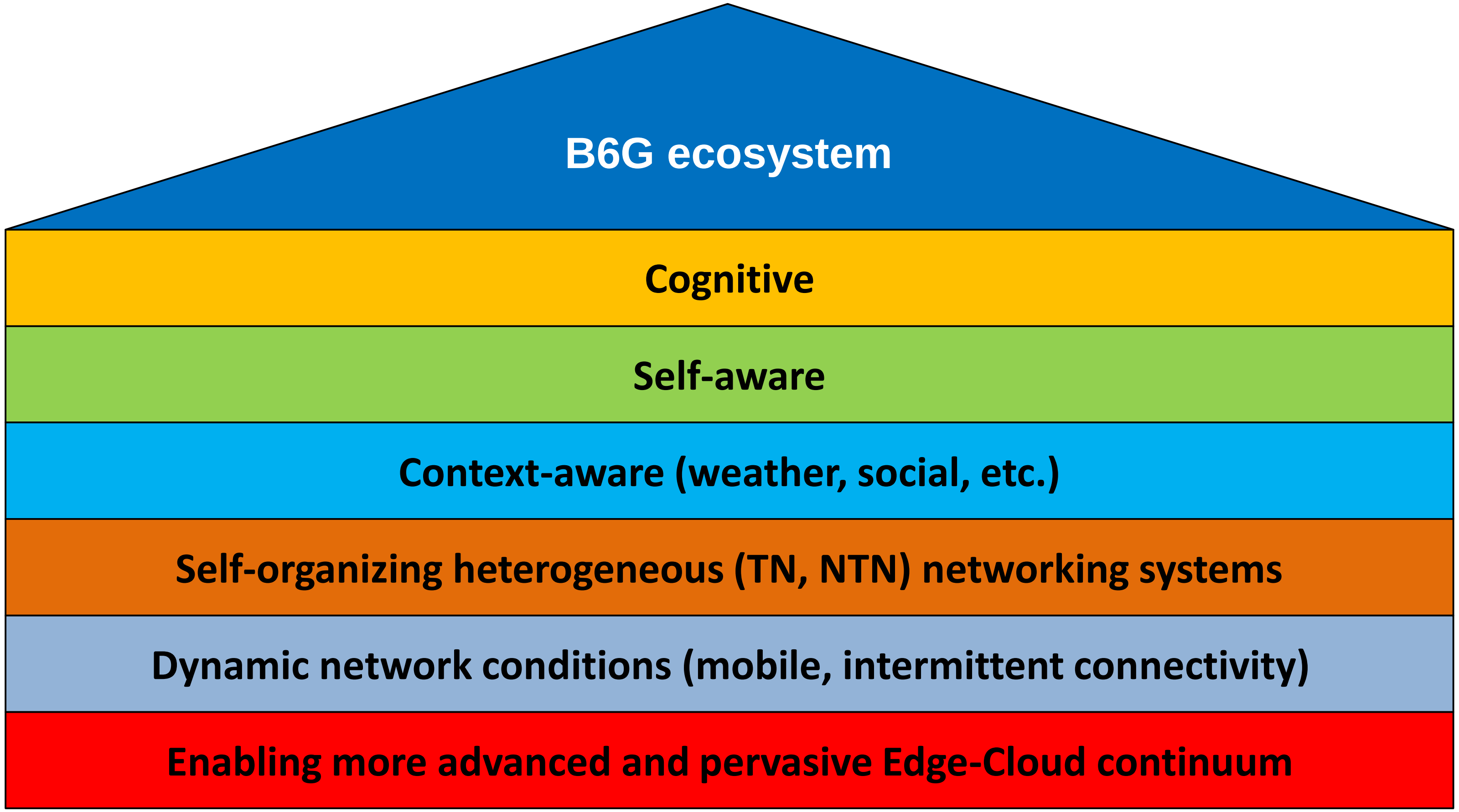


Multidimensional
Multi-layered
Unified

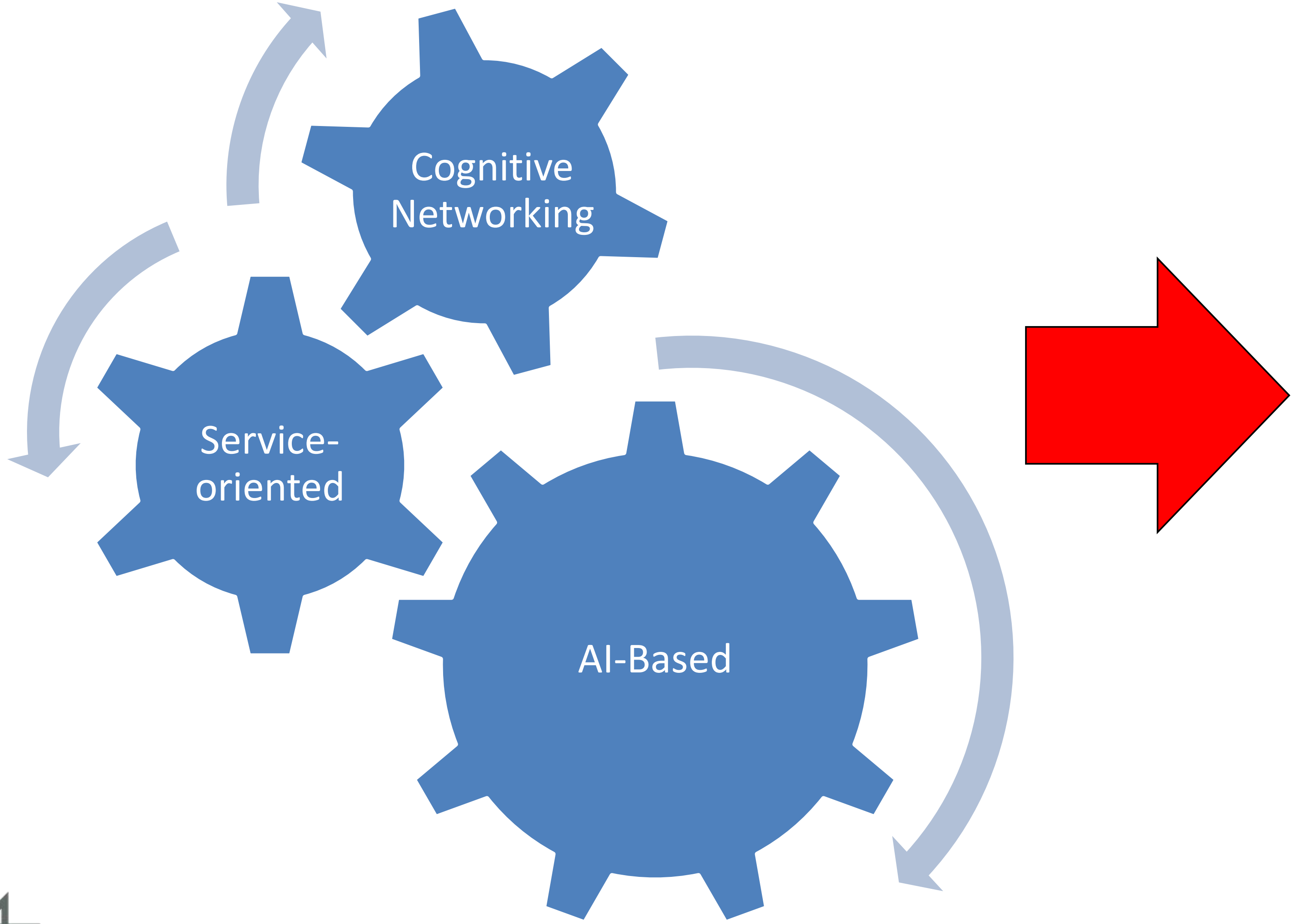
Achieved by means of

- **Unified and distributed-orchestration platform**
- **Full interoperability of the space segment to the integrated terrestrial wireless-wired network**
- **Full exploitation of the peculiarities of the space segment**

B6G+NTN Ecosystem: A Grand Vision

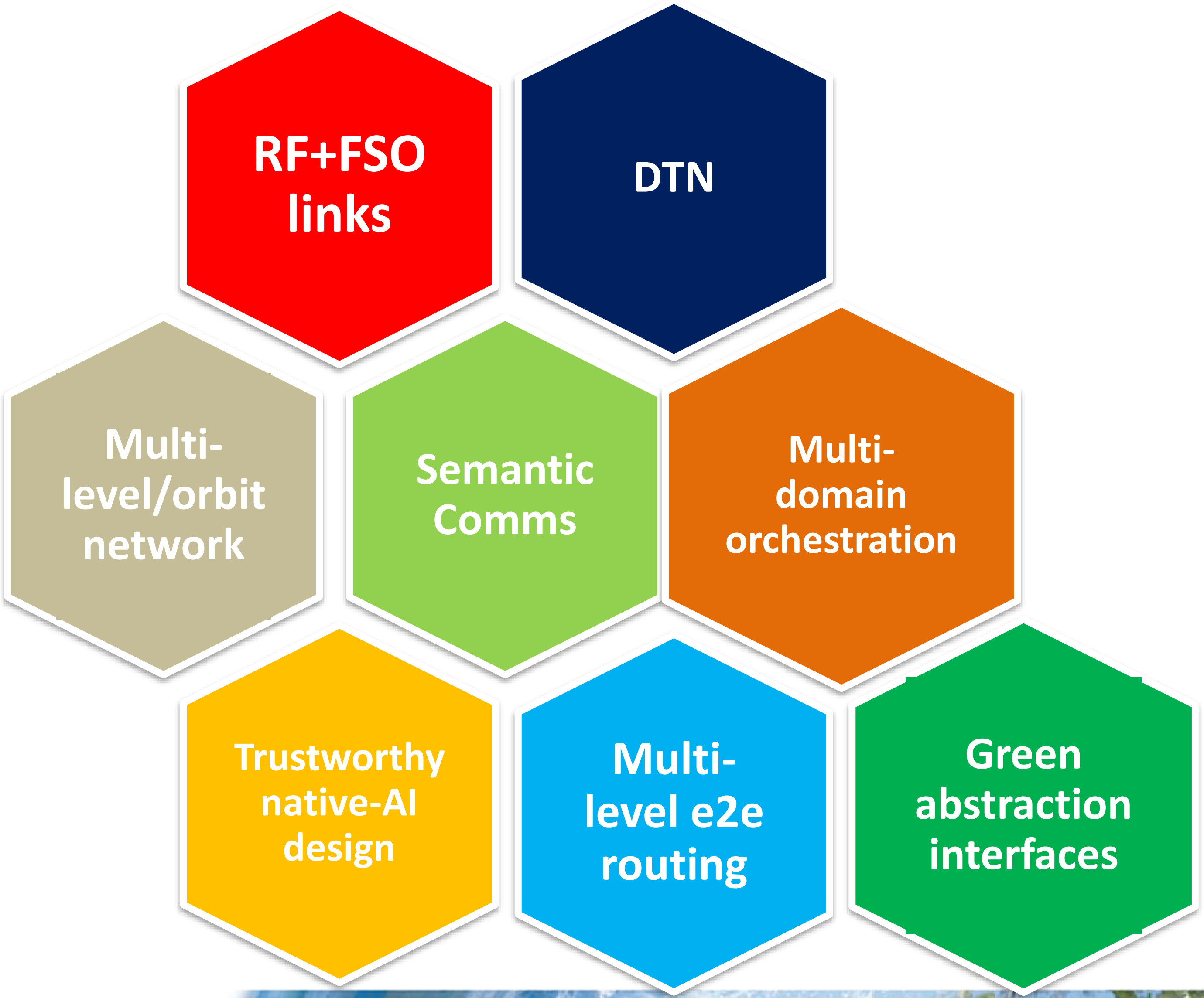


Networking Evolution for NTN boosted performance



- Future space networks to become cognitive by observing and acting autonomously
- Full automation of network management and configuration tasks,
- Service-based networking (e.g., routing, forwarding, caching)
- Intent-based Networking on ground and space networks

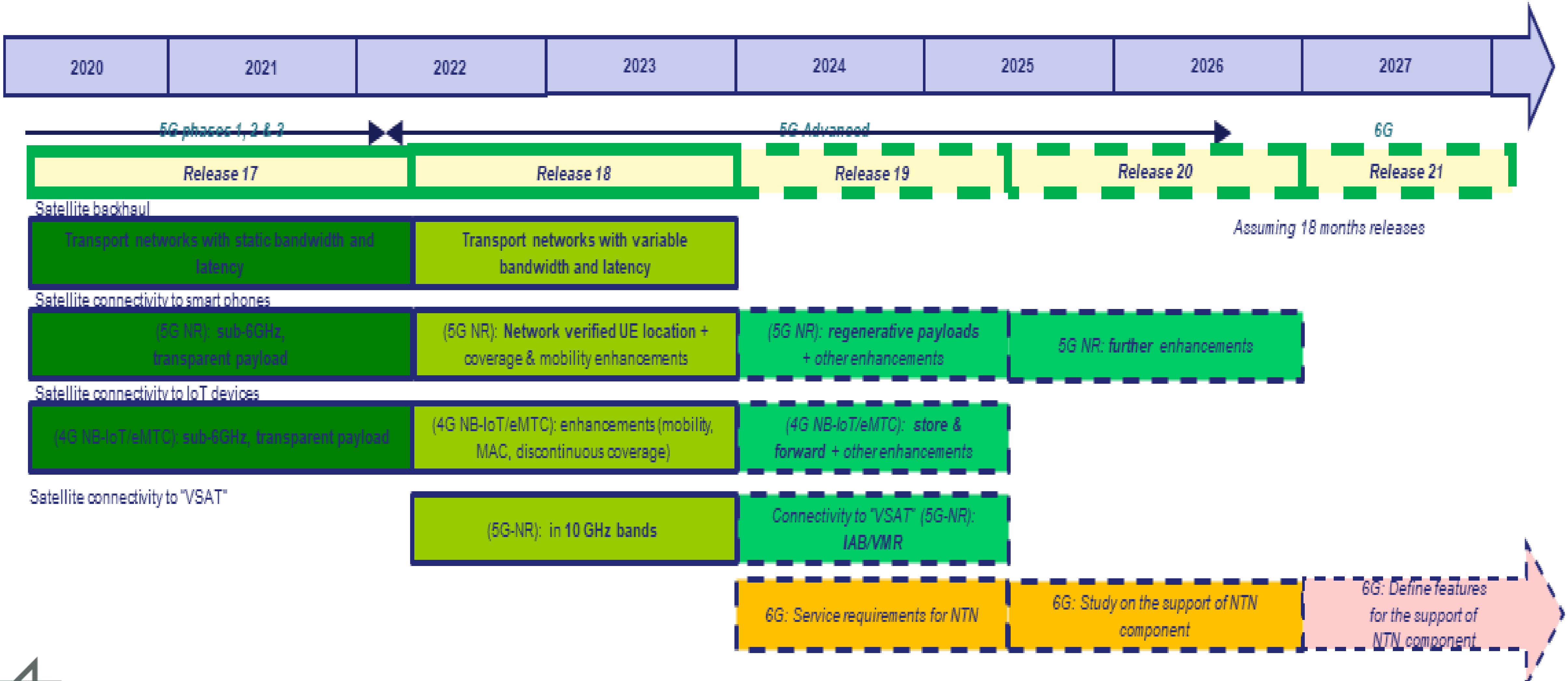
Main Building Blocks



Key characteristics

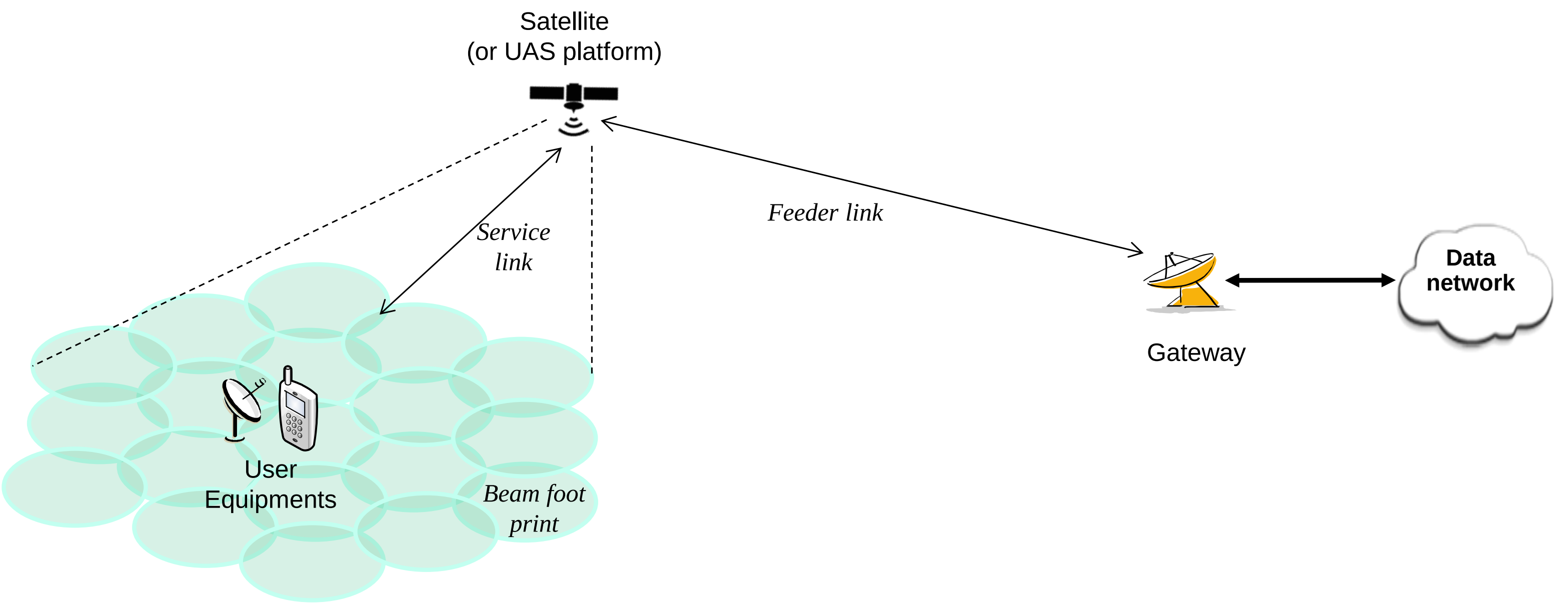
RF+FSO links	Extended capacity
DTN	Resilience to distruption events
Multi-level/orbit network	Multi-service extended coverage
Semantic Comms	Goal-oriented comms for optimised capacity
Multi- domain orchestration	diversified user needs under very different operating conditions
Green abstraction interfaces	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

3GPP standardisation with respect to NTN Roadmap



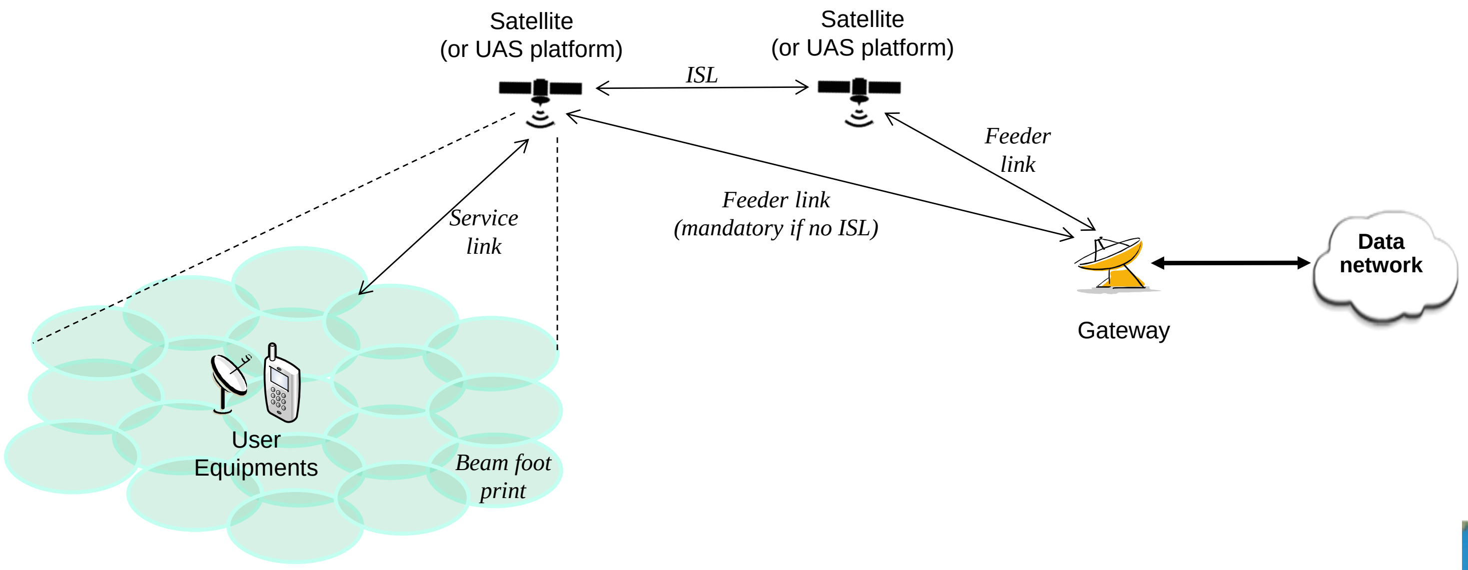
3GPP standardisation with respect to NTN

- Main scenarios:
  - Transparent



Field of view of the satellite (or UAS platform)

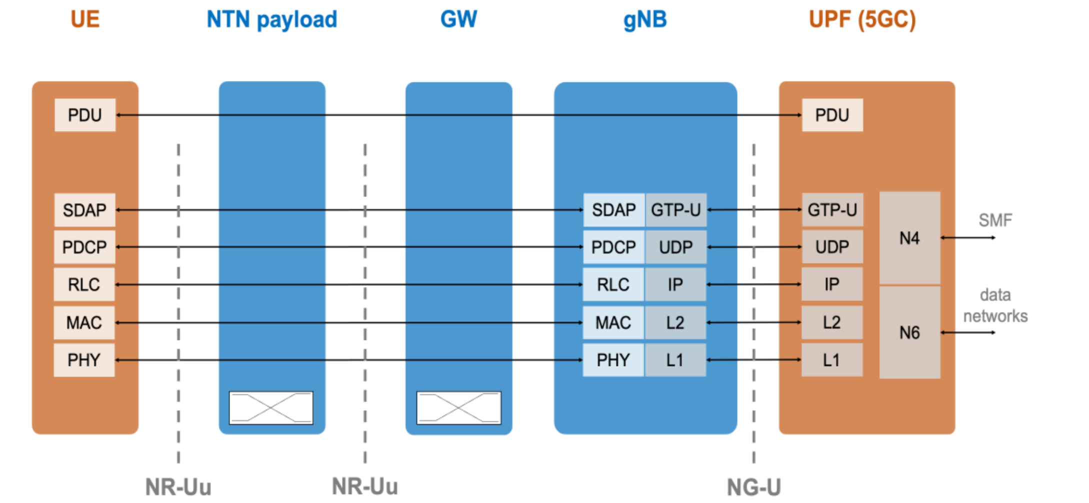
  - Regenerative

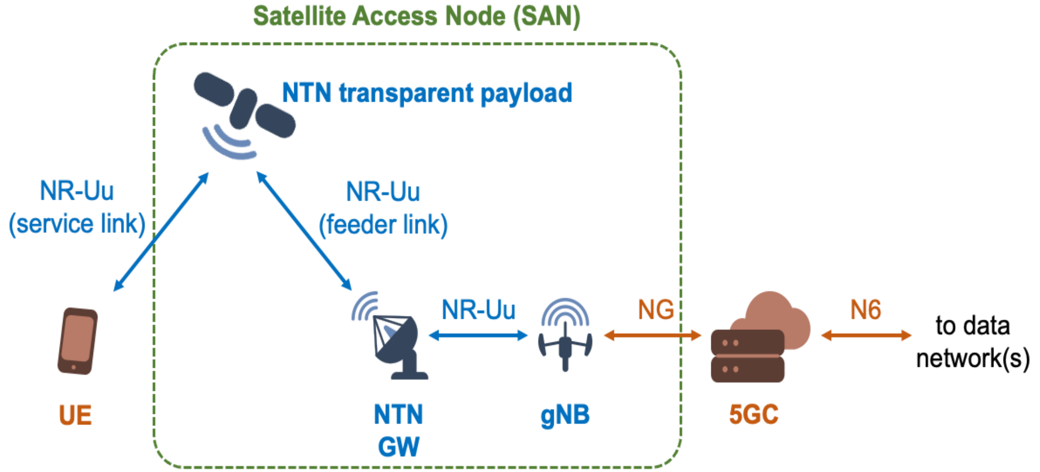


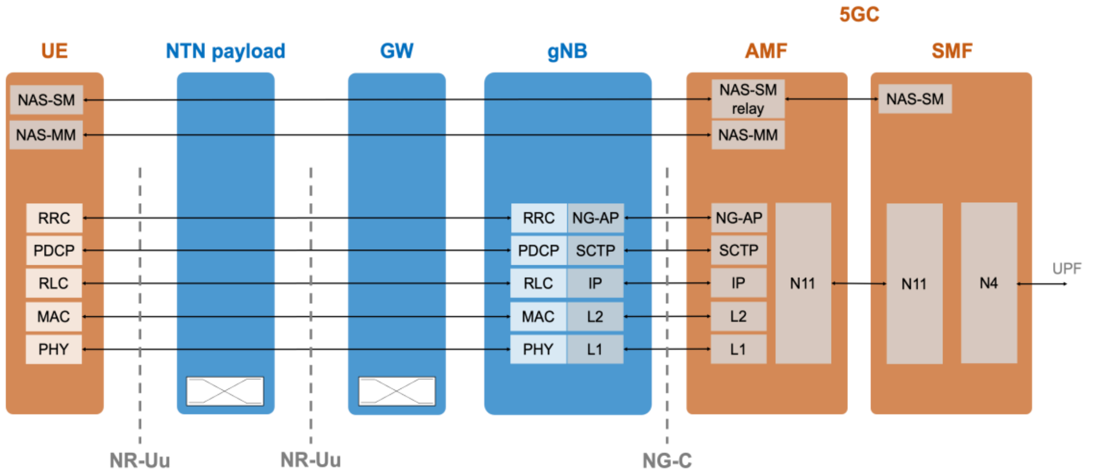
Field of view of the satellite (or UAS platform)

3GPP standardisation with respect to NTN

- NTN standardisation:
  - NTN in Rel. 17 contributed to a number of RAN specifications, aiming at defining the interfaces for the integration of NTN (transparent) into the rest of the 5G architecture
  - NTN in Rel. 18 is contributing to the extensions and enhancements of Rel. 17 specifications, still with satellite operating in transparent mode.
  - Protocol stacks being defined for user- and control-planes.

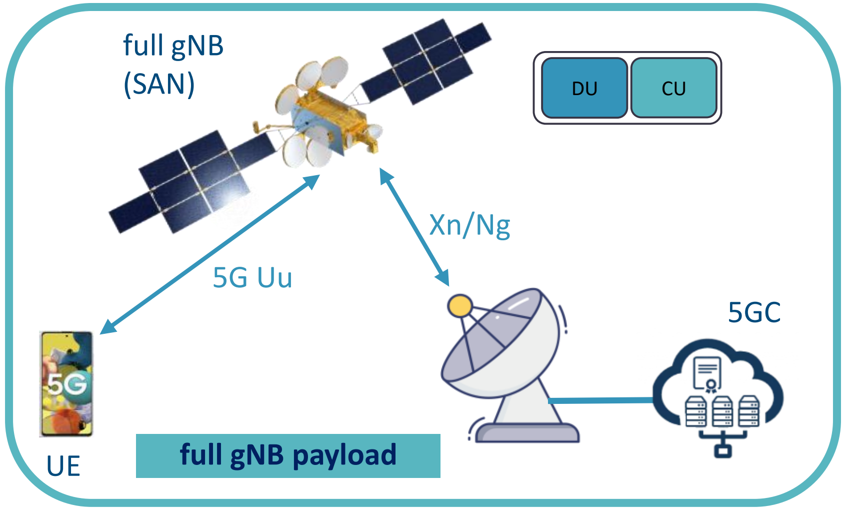




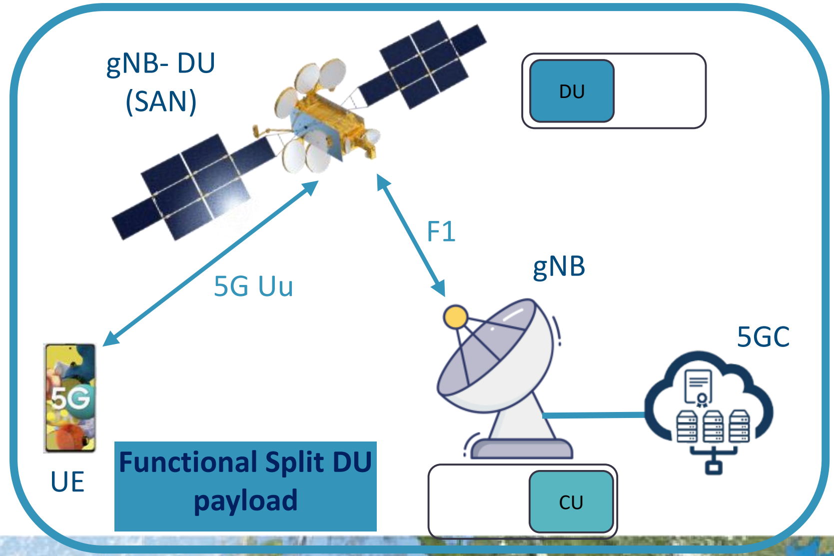


3GPP standardisation with respect to NTN

- Future Plans:
  - Rel. 19 is expected to elaborate the case of regenerative satellite payloads:
    - gNB fully implemented onboard or

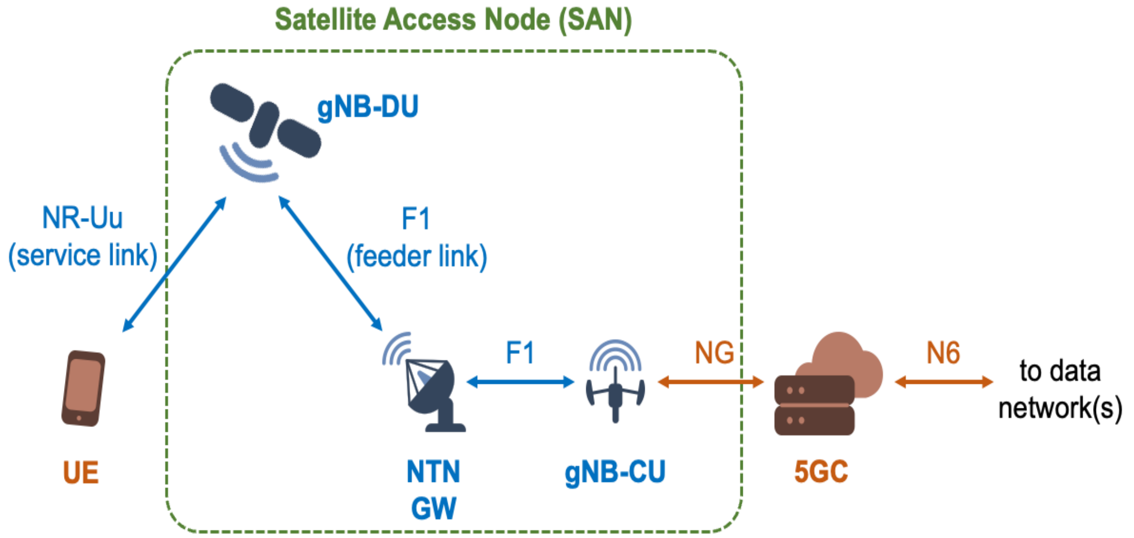


    - CU-DU splitting between ground and space segments



3GPP standardisation with respect to NTN

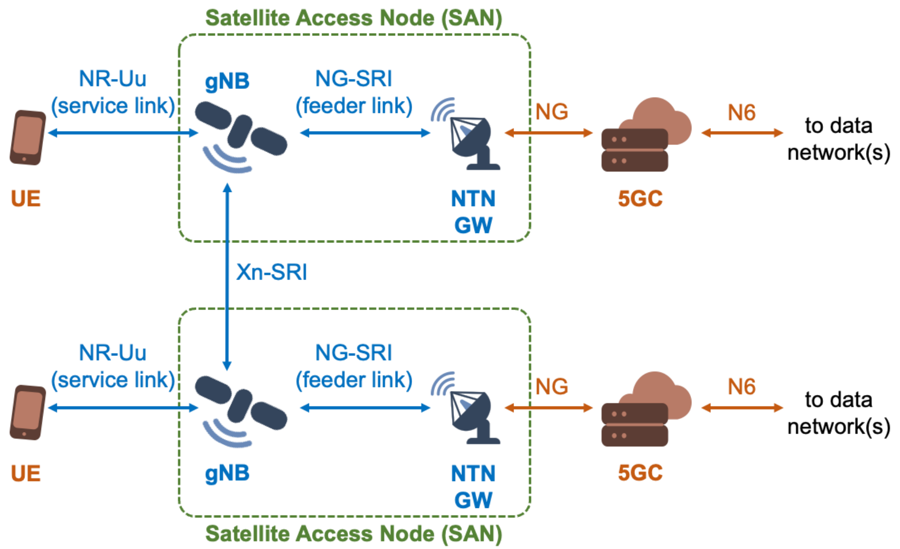
- Regenerative satellite connectivity:



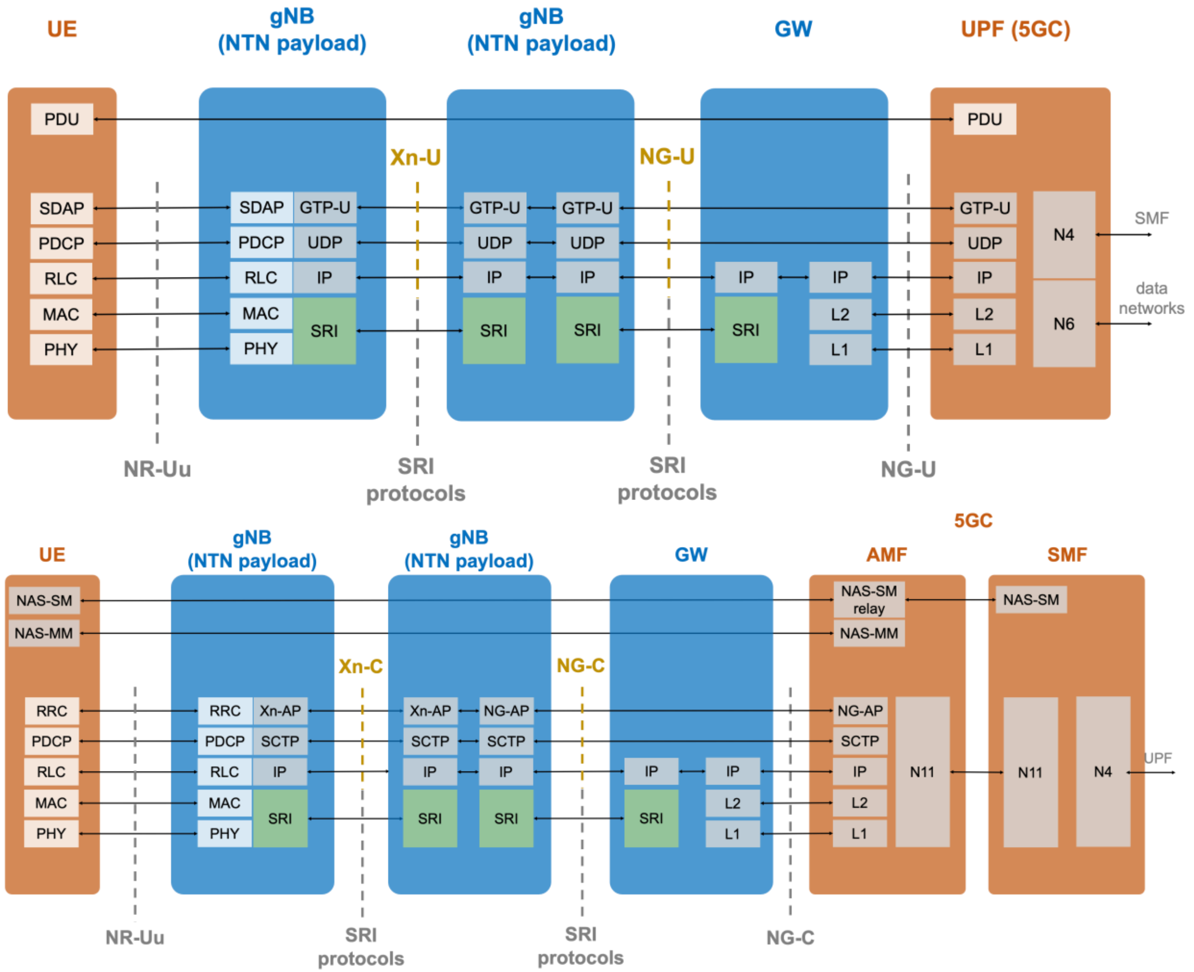
- Regenerative satellite protocol stacks:

3GPP standardisation with respect to NTN

- Satellite-to-satellite connectivity (e.g., constellation)

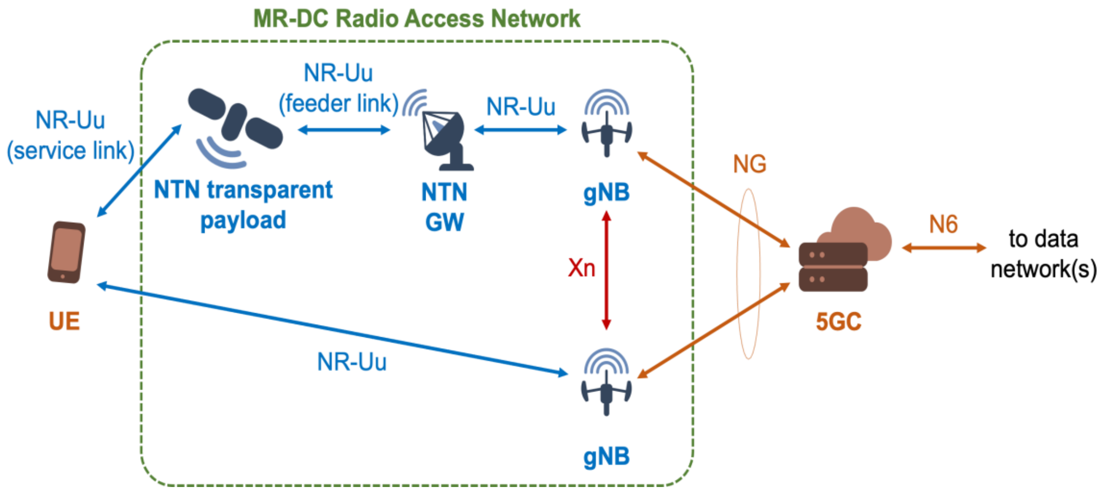


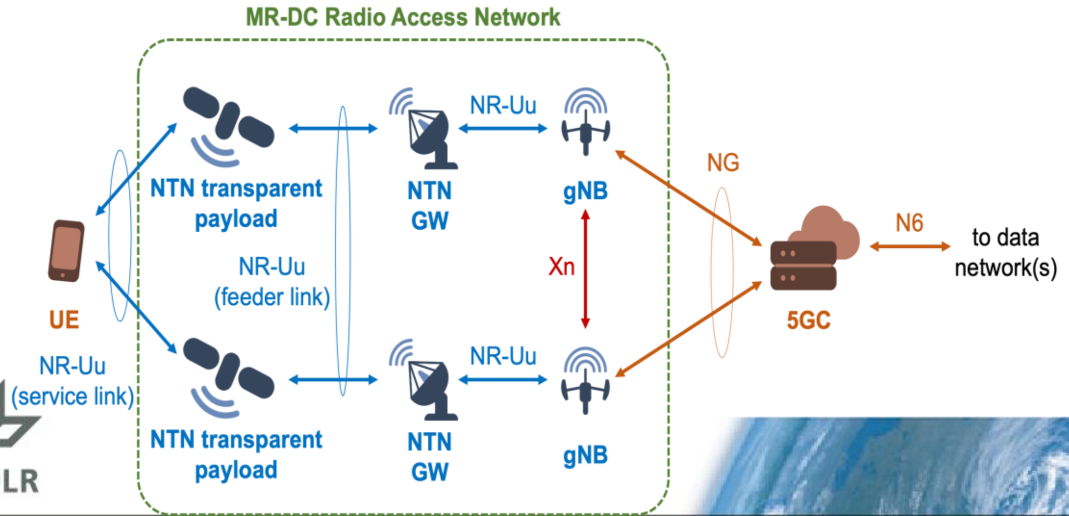
- Satellite-to-satellite protocol stacks



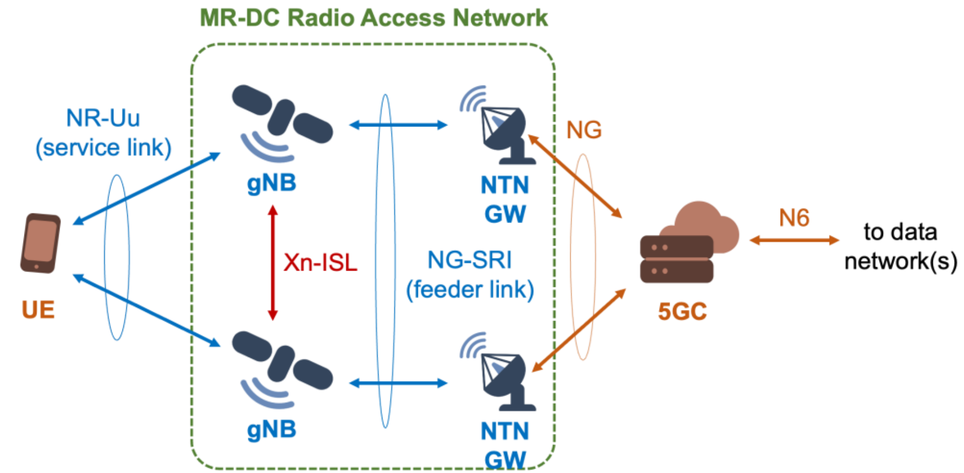
3GPP standardisation with respect to NTN

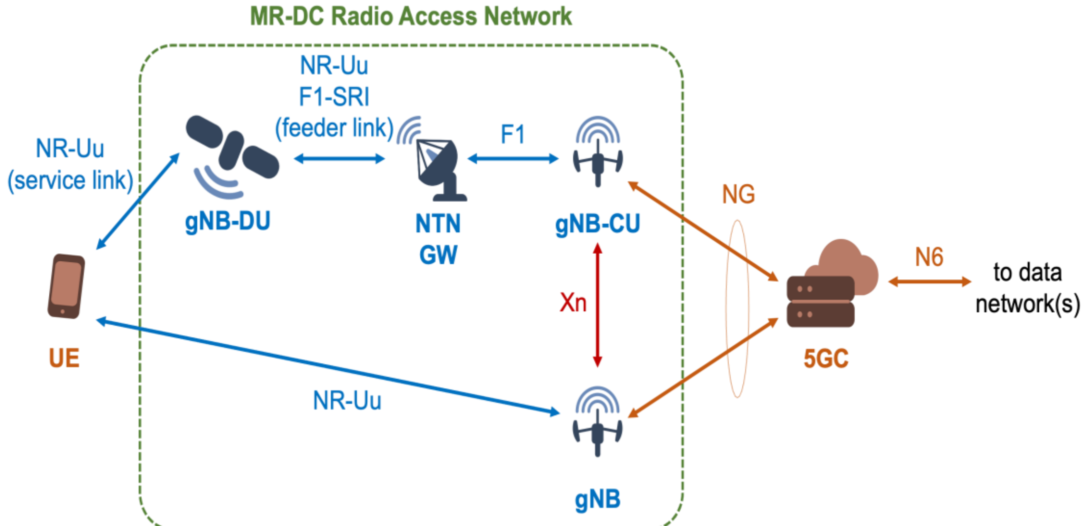
- Multi-connectivity scenarios (transparent)





- Multi-connectivity scenarios (regenerative)





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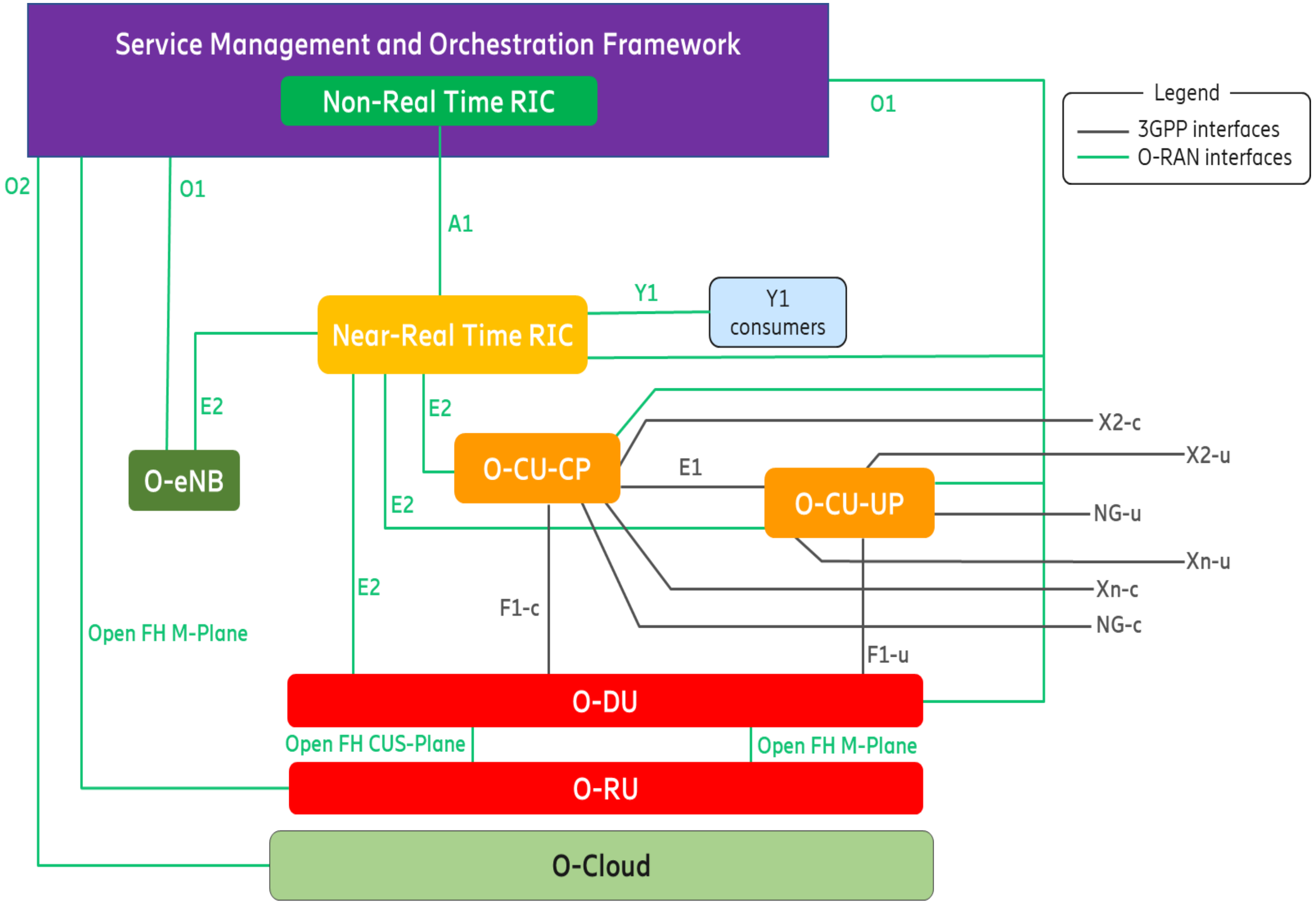
ORAN standardisation elements (relevant to NTN…)

- 3GPP and ORAN together to boost openness and network implementation:
  - A few open interfaces to allow advanced operations and interworking at user and control plane
  - Definition of two RAN Intelligent Controllers (RICs):
    - Non-Real Time
    - Near-Real Time



Open Points and Technical Challenges

- 3GPP with ORAN extensively studied and implemented for terrestrial networks, while NTN is a new perspective:
  - NTN is experiencing a new golden age, especially for the re-birdth of constellations
  - Many satellite implementations are still black bloxes so that adoption of ORAN is not straightforward
  - Short term evolution of NTN is towards the adoption of 5G-Advanced, for which the potentials of ORAN standards seem immediate (i.e. many initiatives at EU, ESA, and national level towards this goal)
  - Long term evolution of NTN is towards 6G, i.e. multi-orbit 3D networks, hence making the profitability of open standards even more profitable, but business models supporting such an openness still undefined
  - Future space nodes are expected to be smart nodes (i.e. not just regenerative satellite payloads), so that computation and intelligence on board will become a consolidated practice
  - But satellite nodes will still be severly constrained in power, mass, and computation, so that energy efficiency of ORAN functionalities and the overall integrated functions is a big question mark, subject to additional investigations
  - Many plans/ideas to launch satellites that will carry gNB, so that ORAN support seems particularly desirable and attractive, but the road towards an operational concept is still long.

Take-Home Message

Anytime, anywhere, any-device connectivity through full-fledged 6G+NTN networks requires more advanced networking paradigms towards unprecedented performance offered to hyperconnected EU society and industry

Bonus Material!

DLR

The Abdus Salam International Centre for Theoretical Physics (ICTP)

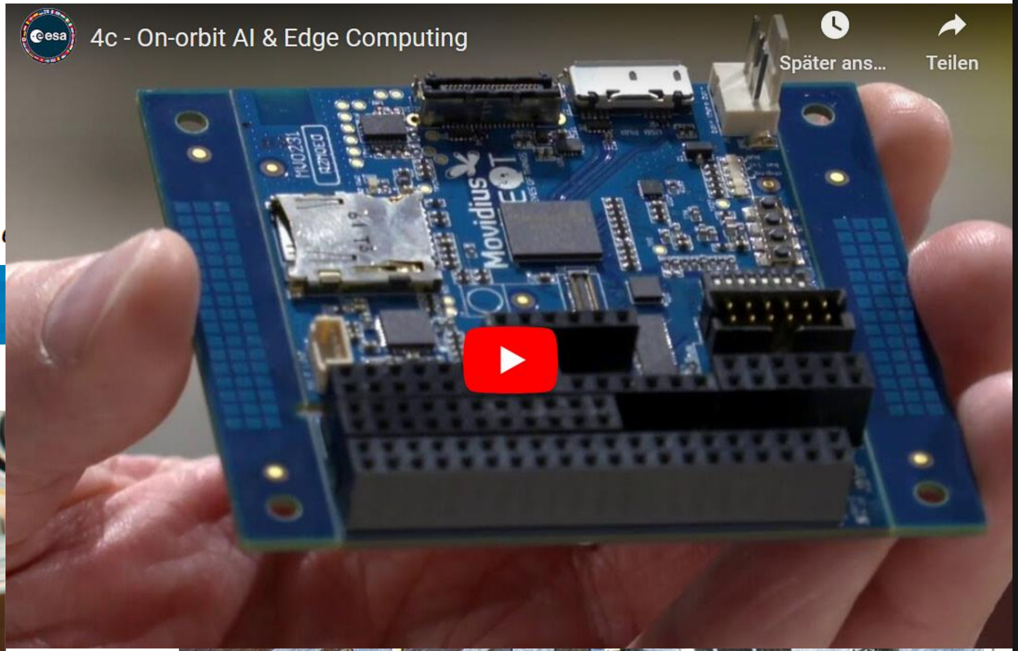

Distributed
Business
Decentralized
Sensors
Location
Precision
Servers
Content
Flexibility
EDGE
COMPUTING
Computation
Bandwidth
Instant Data
Analyzers
New
Nodes
Info
Simple
Improve
Latency
Paradigm
Response
Host
Real-Time
Delivery
Embedded

Buzzword or reality?

Orbital Edge Computing: Nanosatellite Constellations as a New Class of Computer System

Bradley Denby
bdenby@andrew.cmu.edu
Carnegie Mellon University

https://abstract.



From the Cloud to the Edge of Space

A vital component to the commercialization of space is high performance computing / micro datacenter in space.

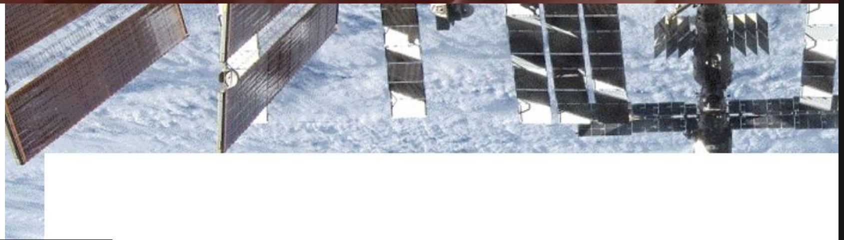
EDGE COMPUTING & MICRO DATACENTERS IN SPACE

SPOTLIGHT ON TRANSACTIONS

EDITOR RON VETTER
University of North Carolina Wilmington; vetterr@uncw.edu

Computer Architecture for Orbital Edge Computing

Daniel J. Sorin, Duke University



THALES ALENIA SPACE WITH HELP FROM MICROSOFT DEMONSTRATE ON-ORBIT COMPUTE TECHNOLOGIES ONBOARD THE INTERNATIONAL SPACE STATION TO GATHER UNMATCHED EARTH OBSERVATION INSIGHTS

HORIZON EUROPE

Advanced Space Cloud for European Net zero emissions and Data sovereignty

Fact Sheet

Project description

DE EN ES FR IT PL

Data centres… in space

Cameras and sensors from space are keeping close watch of events on the ground and transmitting this data to Earth. But sending data to the ground takes time. One solution is to launch data centres into orbit. This would reduce the exponential impact of digital technology on energy consumption and climate warming. The installation of large modular space infrastructures with robotic assembly, megawatt level space-based solar power, high throughput optical communications, low cost and reusable launchers is within reach. The EU-funded ASCEND project will introduce a pioneering new on orbit services system concept. This would make Europe a world leader in robotised and sustainable modular infrastructures as well as reusable launchers.

Show the project objective

Fields of science

engineering and technology > environmental engineering > energy and fuels > renewable energy > **solar energy**

natural sciences > computer and information sciences > **software**

Project Information

ASCEND
Grant agreement ID: 101082517

DOI
10.3030/101082517

Start date 1 January 2023
End date 30 April 2024

Funded under
Digital, Industry and Space

Overall budget
€ 2 047 882,50

EU contribution
€ 2 047 882,00

Coordinated by
THALES ALENIA SPACE FRANCE SAS
France

NEW Φ-LAB IN SWEDEN AND THE RISE OF EDGE COMPUTING IN SPACE

SHARE

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ARTIFICIAL INTELLIGENCE DIGITAL EARTH OBSERVATION
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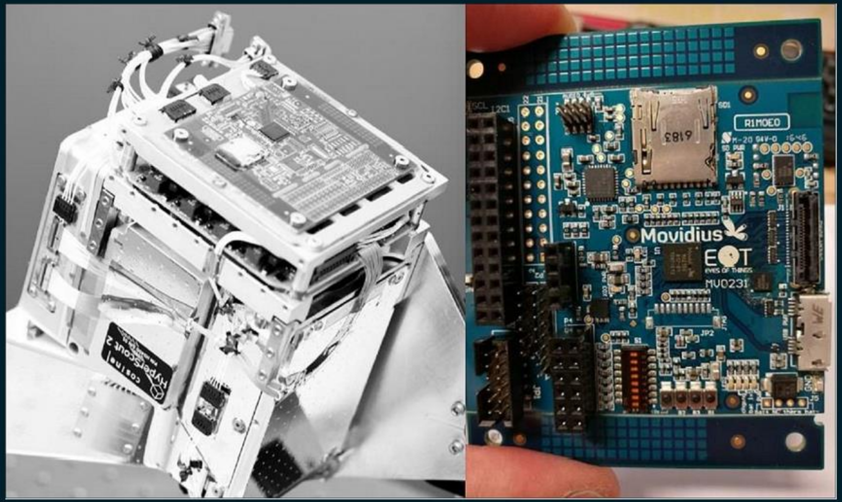
Building on its experience in fostering transformative innovations aimed at market adoption in the Earth observation (EO) sector, the model of Φ-lab@ESRIN is being replicated across Europe by ESA. Under the leadership of the newly established **Directorate of Commercialisation, Industry**

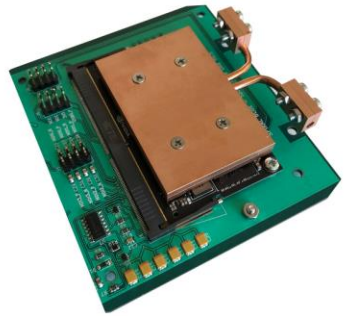
Examples of satellite use cases:

- Bringing data centre services into Earth orbit and beyond is an emerging trend, by this increasing autonomy and resilience in decentralised networks,
- Rapid extraction of information onboard Earth Observation (EO) satellites: possible use cases for AI and satellite data include the identification of flooding, illegal fishing, deforestation, algal blooms, or environmental disasters,
- Onboard pre-filtering or discarding cloud-covered or corrupted satellite images. A preliminary demonstration was performed in the frame of the Φ-sat-1 mission, enabling "smart" discarding of cloudy images.



The Intel-Movidius Myriad 2 board (right) mounted on the top of HyperScout-2 electronics stack (left) is an example of edge-computing platform used onboard Φ-sat-1 satellite to detect cloud-covered images (Credits: https://directory.eoportal.org/web/eoportal/satellite-missions/p/phisat-1).

SPACE EDGE COMPUTING



ENABLING AI IN SPACE

Spiral Blue is developing the Space Edge Computer - an onboard computing system that will give Earth observation satellites the ability to process images captured on the satellite itself. This has the potential to increase the capacity of an Earth observation satellites carrying Space Edge Computers by as much as 20x.

Space Edge Computers use the NVIDIA Jetson series, maximising processing power while keeping power draw manageable. They carry polymer shielding for single event effects, as well as additional software and hardware mitigations. We provide onboard infrastructure software to manage resources and ensure security, as well as onboard apps such as preprocessing, GPU based compression, cloud detection, and cropping. We can also provide AI based apps for object detection and segmentation, such as Vessel Detect and Canopy Mapper.

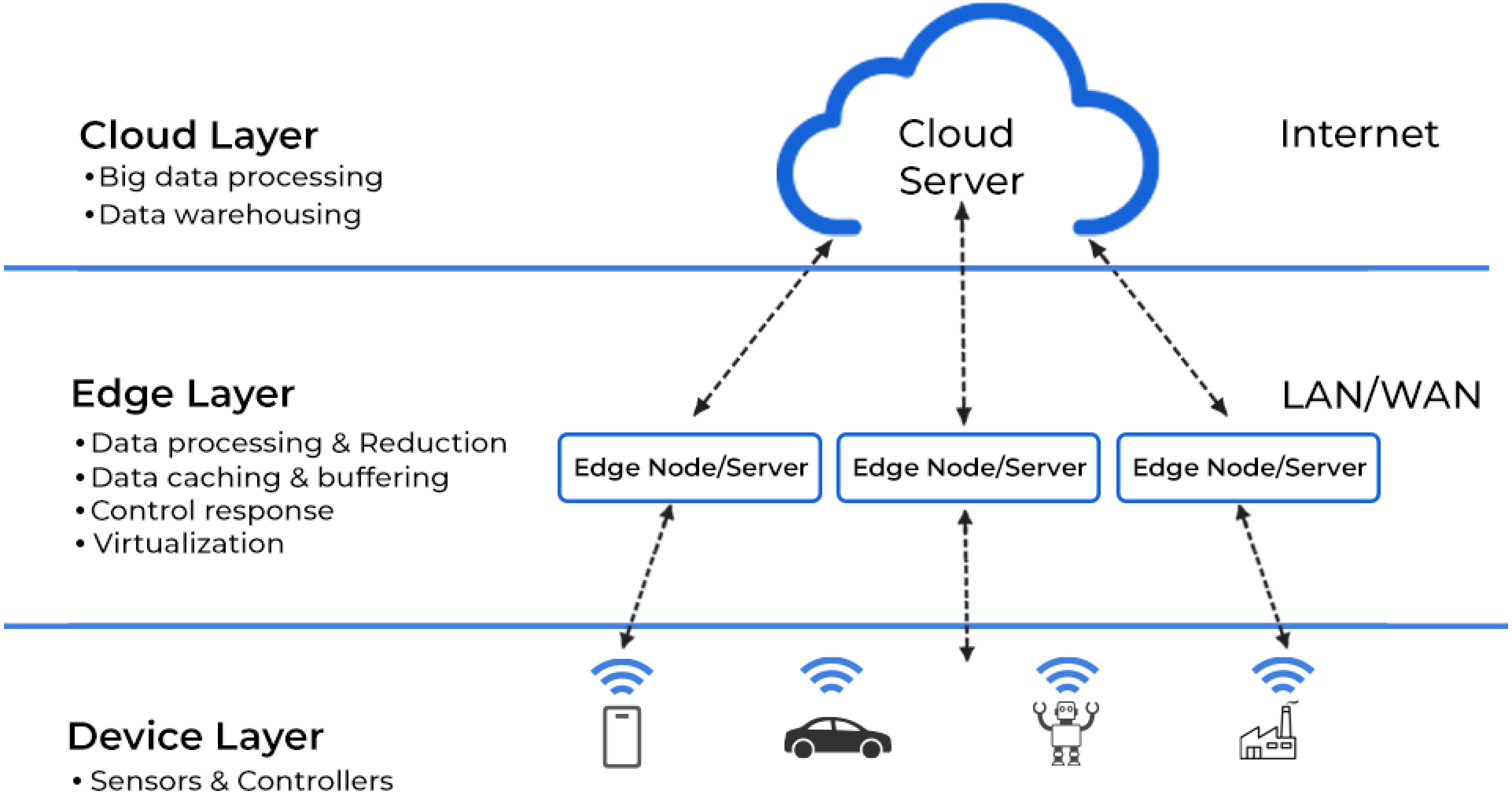
MEC in a nutshell

- MEC is the abbreviation for:
  - Mobile Edge Computing (as usual in the 3GPP terminology) → EDGEAPP in SA6
  - Multi-Access Edge Computing (as usual in the ETSI terminology) → MEC ISG and DECODE WG

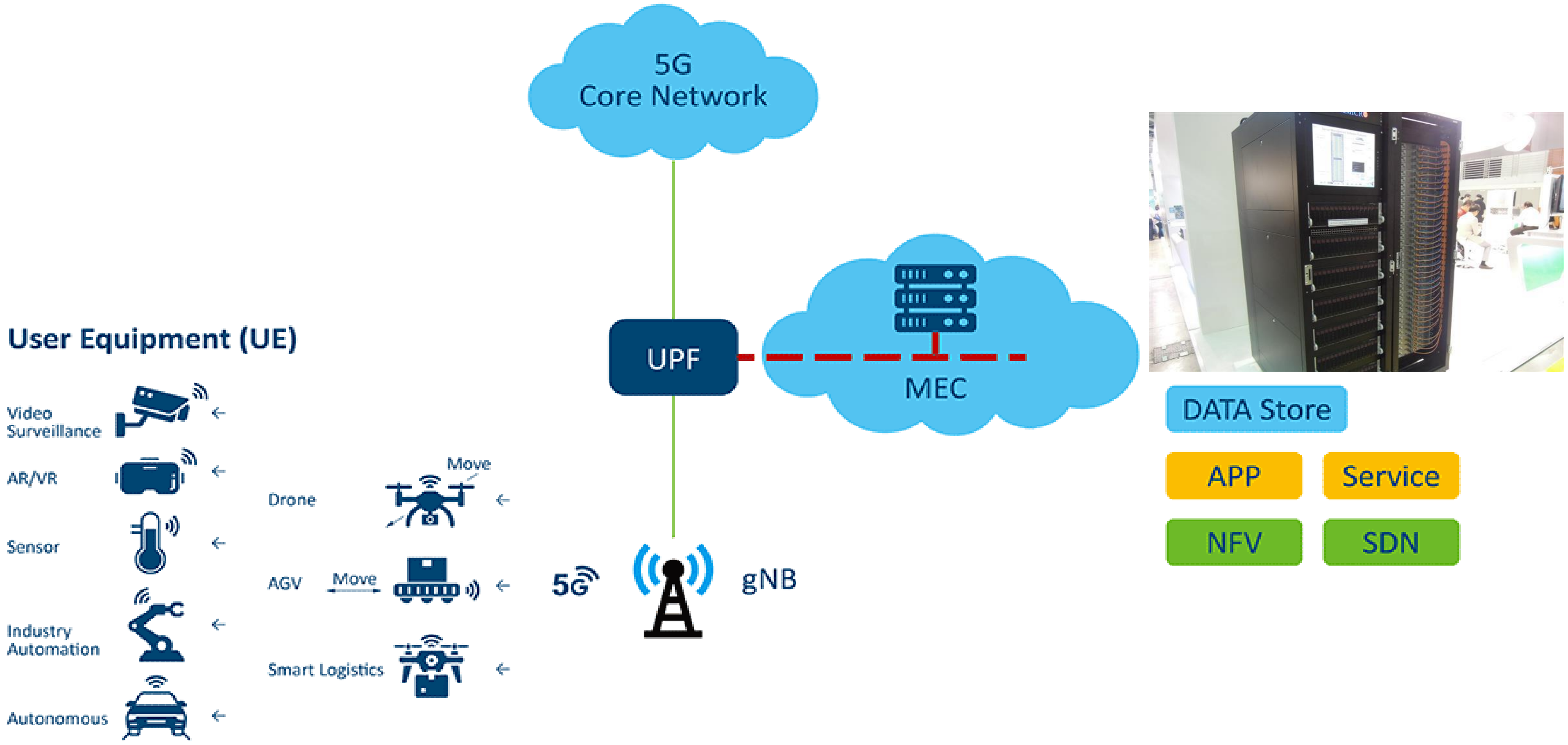
- The main mission of MEC is essentially to provide:
  - intelligence,
  - computation capability, and
  - data access directly at the edge of the network access

- The main objective of MEC is to enable more efficient low-delay and high throughput services, hence supporting use cases such as:
  - video analytics
  - location services
  - Internet-of-Things (IoT)
  - augmented reality
  - optimized local content distribution and data caching

EDGE COMPUTING ARCHITECTURE



Typical edge deployment in 5G….

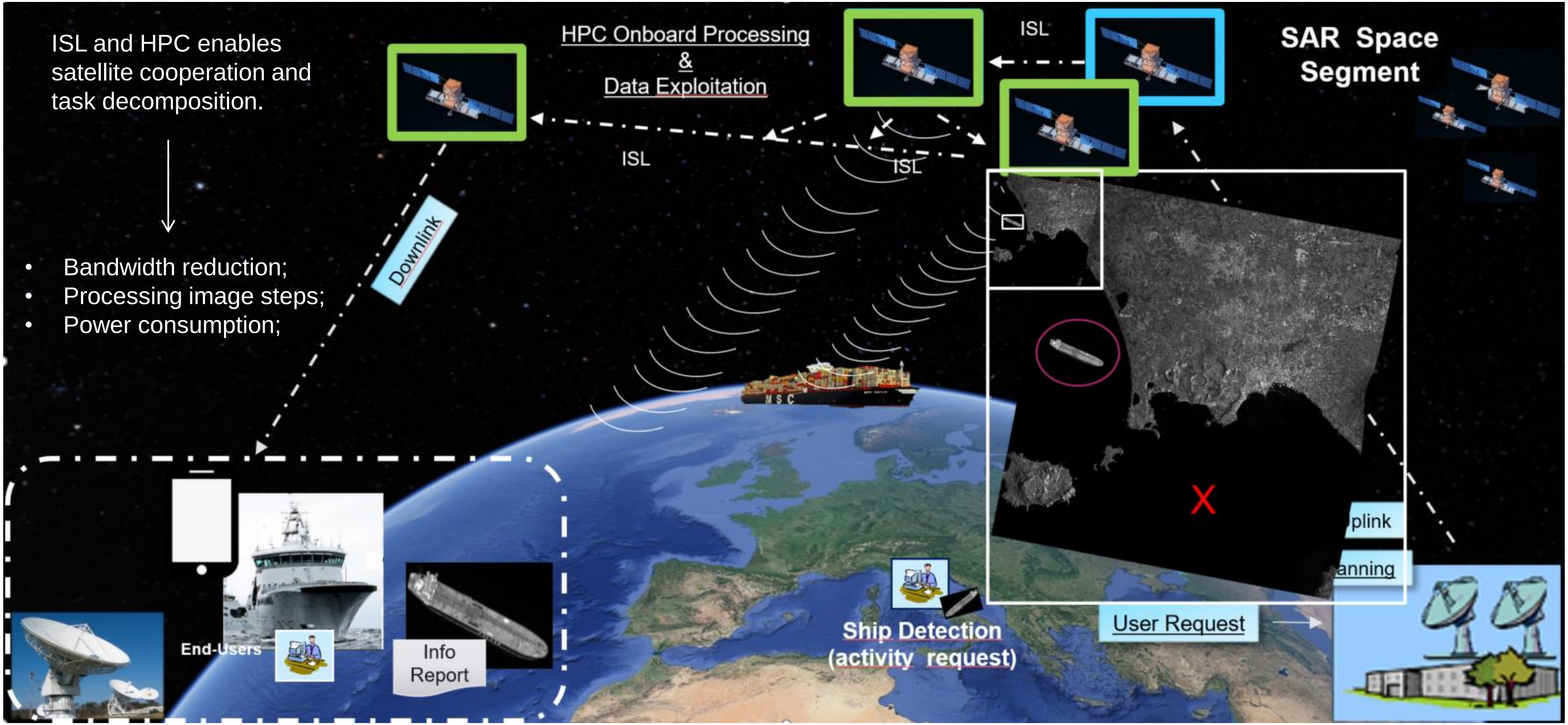


DLR

Satellite Opportunities for MEC
Overview

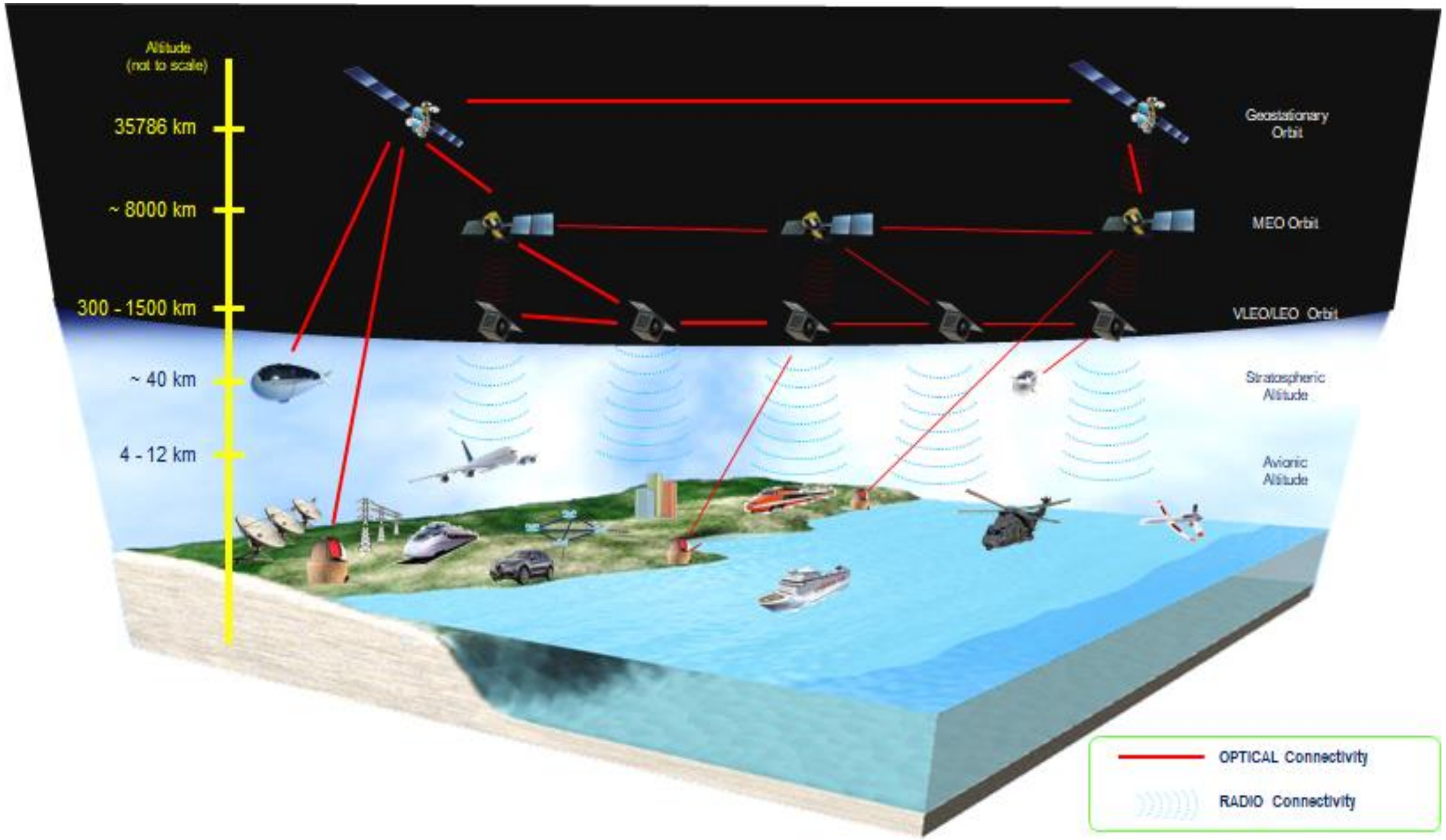
- MEC support particularly appealing to move data availability as much closer as possible to users, so as to reduce large latency typically experienced by satellite systems:
  - Combination of edge caching and intrinsic multicast capability of satellites to optimise content delay and content penetration
  - Integration of MEC functionalities directly in the satellite access segment
- MEC intended as “edge computing” to boost local computing (i.e., onboard satellite) to relief core network from excessive data distribution:
  - Support to IoT-based services by means of in-space edge computing
- MEC for possibly enabling low delay services (i.e., zero-perceived latency, relaxed uRLLC requirements) with LEO satellite constellations

Earth Observation Mission



(courtesy of Thales Alenia Space Italy)

Satellite Based Surveillance



(courtesy of Thales Alenia Space Italy)

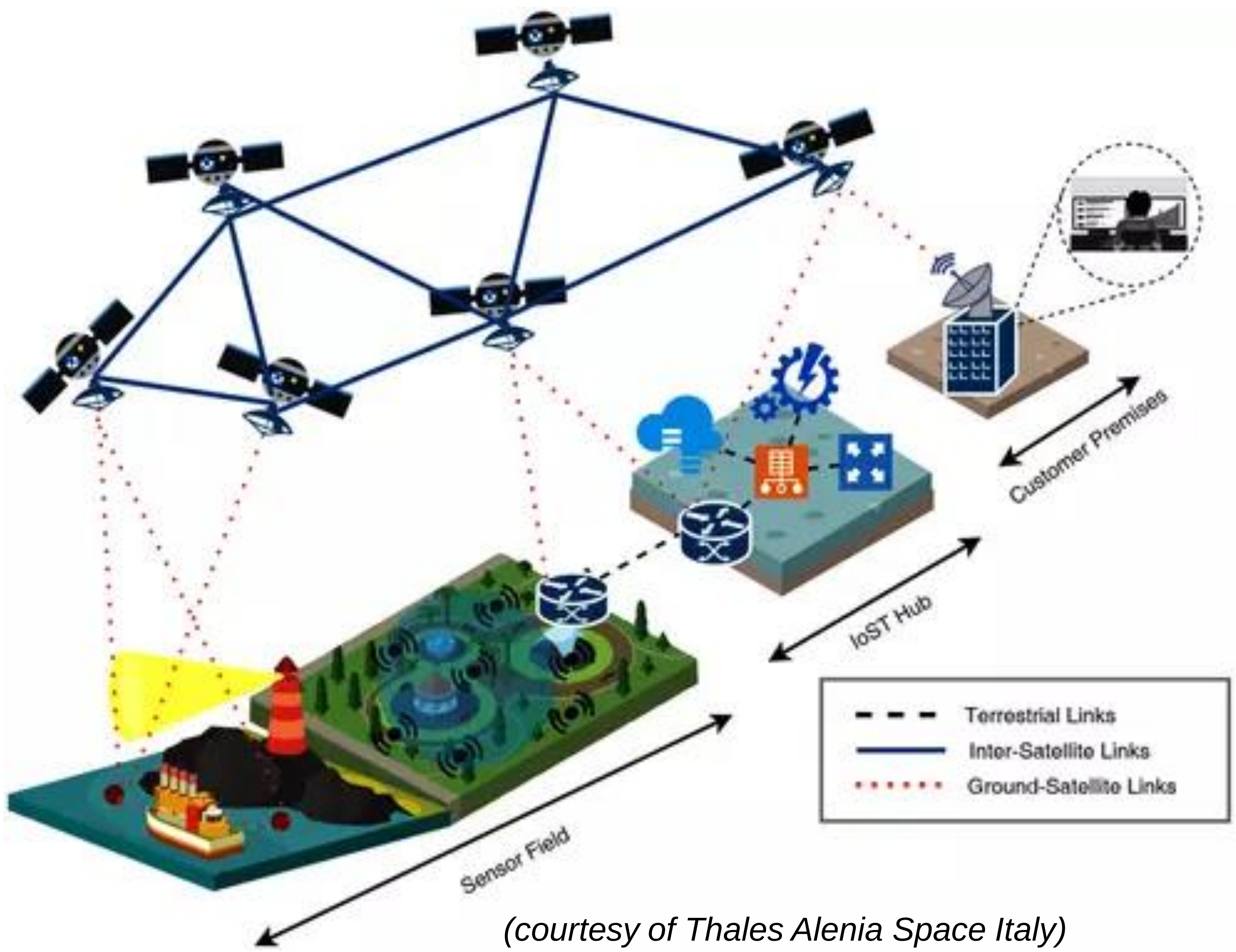
Computational tasks:

- Detection;
- Identification;
- Parameters estimation.

Critical parameters:

- Timeliness;
- Refresh rate of collected data.
- Real-time decision-making
- Latency (VLEO-LEO constellation).

IoT Service Communication



(courtesy of Thales Alenia Space Italy)

High deployments of IoT systems that have access to the network through a LEO satellite.

Edge computing

- Sending only relevant and actionable information to the cloud servers;
- Improved task completion;
- Energy consumption;
- Improved autonomy in the service (possible AI applications).

MEC and Satellite: A Marriage in Heaven?

- Though the attractive market and business opportunities, important technical challenges cannot be neglected:
  - The preferred satellite sytems are LEO constellations:
    - lower delays against GEO
    - increasing appeal of mega constellations
    - Large coverage
    - Possibly lower access delays in comparison to terrestrial edge/clouds infrastructure
  - But:
    - Visibility of satellite limited to a few minutes (5-10 minutes, depending on the system geometry)
    - Terrestrial edge and cloud infrastructures are typically fixed, whereas satellite are moving assets
    - Task assignment and satellite edge state has to migrate (or has to be replicated) across multiple neighbour satellites
    - Computing, storage, and power availability onboard satellites is limited
    - Satellites resources cannot be fully dedicated to specific edge computing tasks but must be shared across multiple services

Research problems (some of them…)

- Allocation of resources (link bandwidth, CPU, memory, power for running MEC)
- Joint routing and edge computing optimisation
- Load balancing towards effective edge computing deployment
- Distributed edge computing architectures towards optimised edge computing operations
- Energy (power) efficient edge computing functions
- Functional splitting conjugated with MEC optimised functions
- Optimised server placement
- …

Thank you for the attention!