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# Evolving Non-Terrestrial Networks from 5G to 6G

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*"New Perspectives for the Integration of Terrestrial and Non-Terrestrial Networks for 6G Systems"*

# Acknowledgements

Statements and opinions given in this presentation are the expressions of the author(s), only. Responsibility for the content of this presentation rests upon the author(s), not the European Union and the granting authorities, nor the Projects' Partners.

6GNTN

Design and validate NTN's key technical, regulatory, and standardisation enablers for the integration of TN and NTN components into 6G, focusing on multidimensional network infrastructure, multi-constraint RANs, and multi-user terminals

https://www.6g-ntn.eu

info@6g-ntn.eu

https://www.linkedin.com/company/6g-ntn/

@6Gntn

5G stardust

Deliver a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access

https://www.5g-stardust.eu/

info@5g-stardust.eu

https://www.linkedin.com/company/5g-stardust/

@5G_Stardust

RESTART ITA NTN

Design a 3D multi-layered communication architecture for integrated T/NT networks, by designing advanced transmission technologies and conceiving innovative methodologies for the orchestration of communication and computational resources

https://www.fondazione-restart.it/projects/s11-ita-ntn/

fondazione-restart@pec.it

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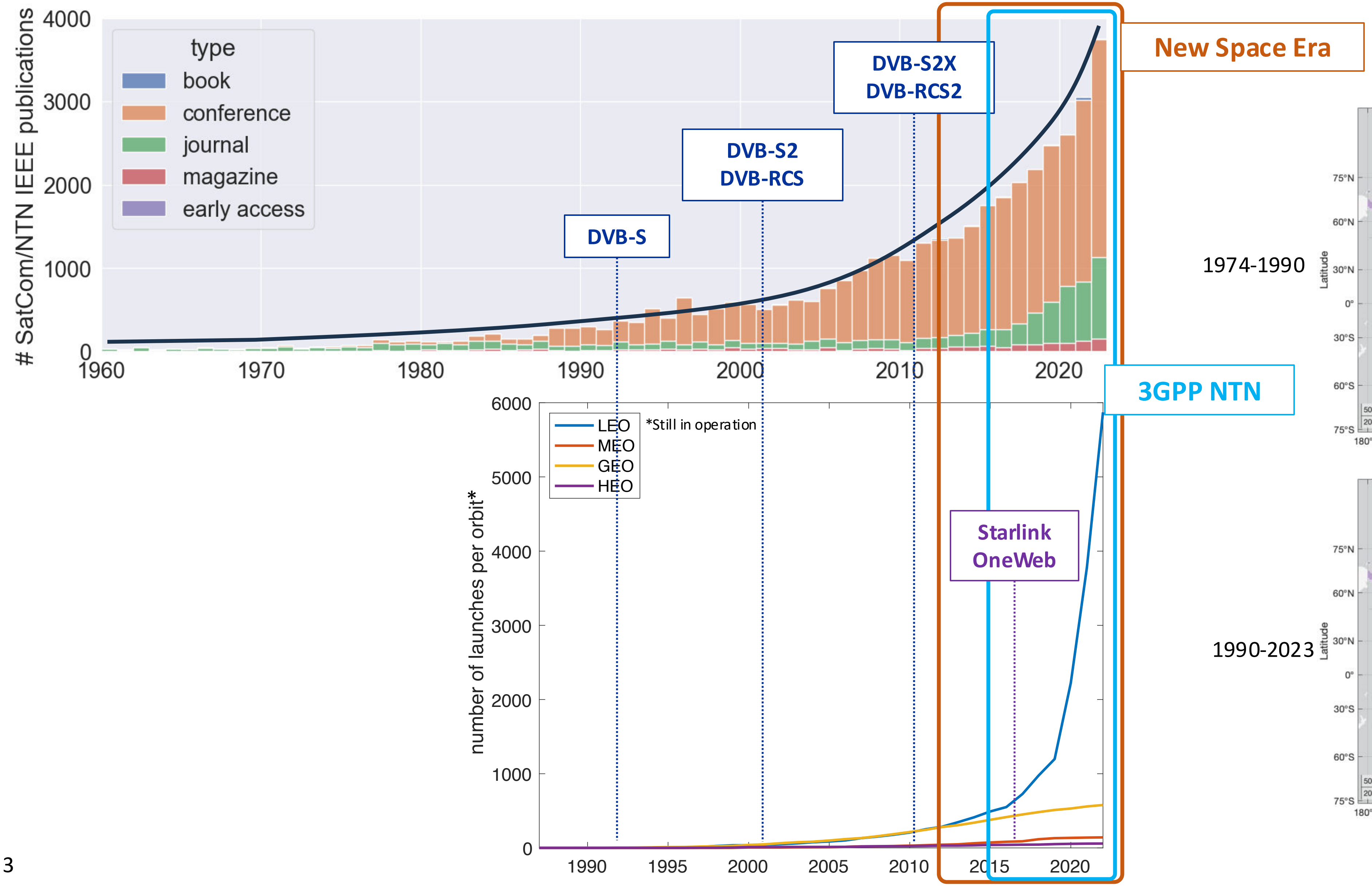
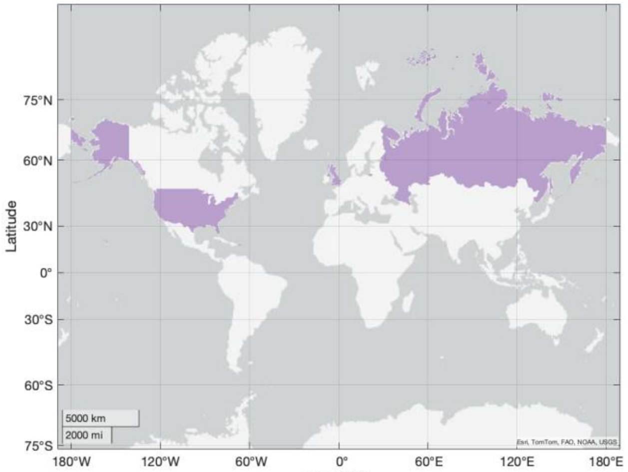
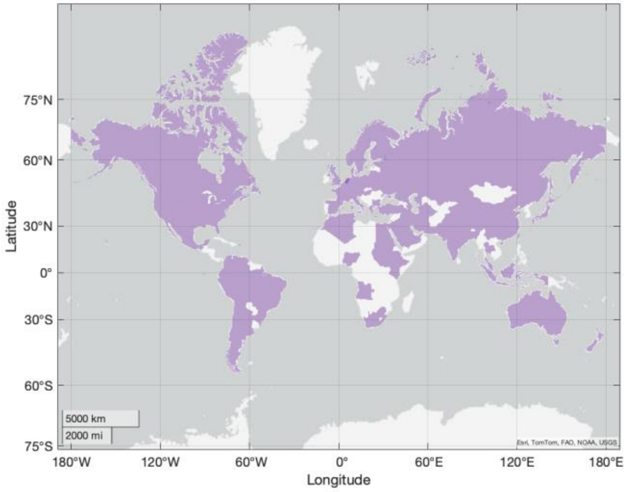
# From SatCom to NTN (nothing happens overnight)




1974-1990




1990-2023



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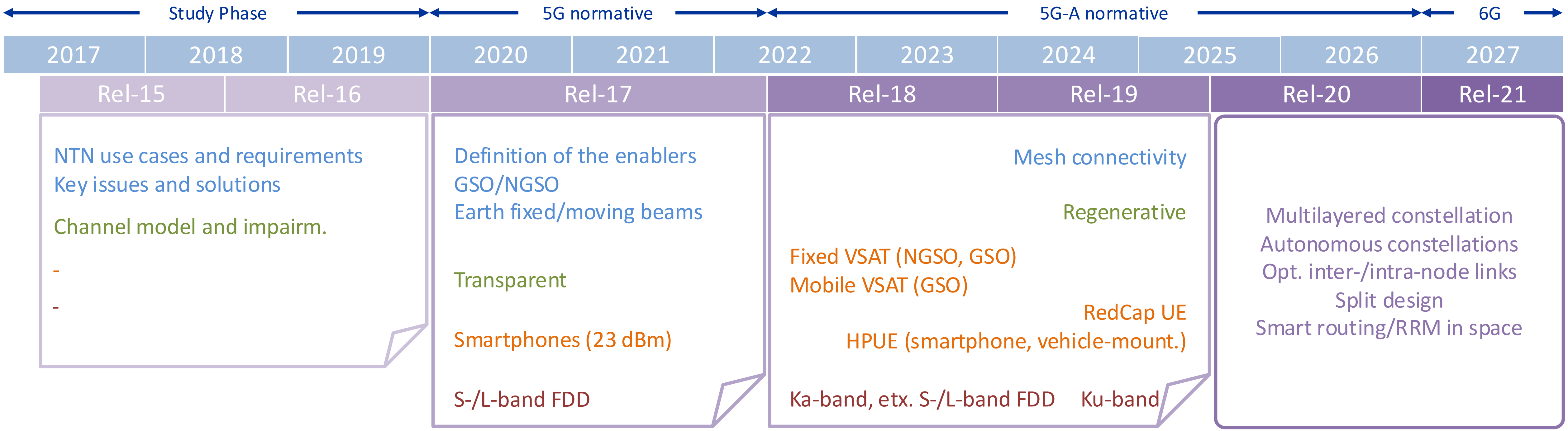
# NTN roadmap




System architecture

RAN aspects

Targeted terminals

Spectrum

- Solutions for indirect connectivity: IAB → WAB
- Multi-Connectivity de-prioritised and not yet developed
- Functional split solutions most likely to flow into Rel. 20-21

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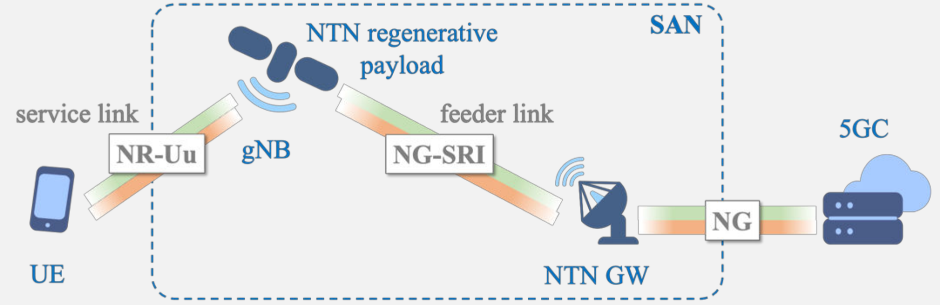
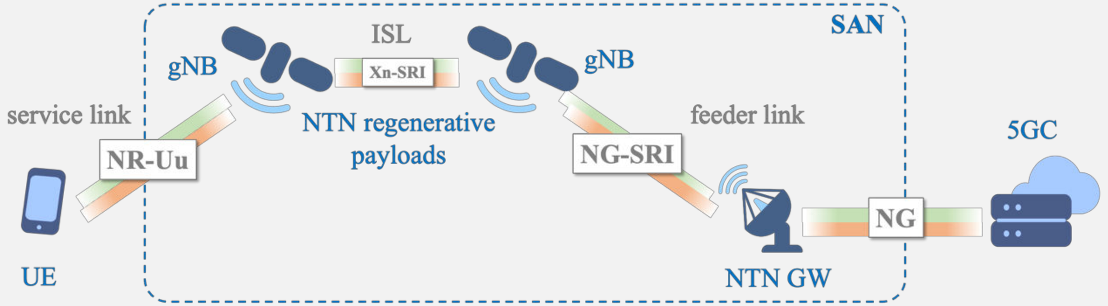
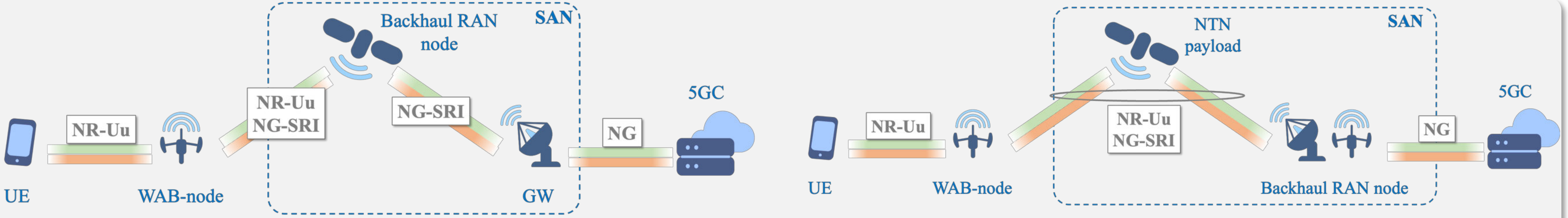
# NTN Rel. 19: architecture evolution




Regenerative payload

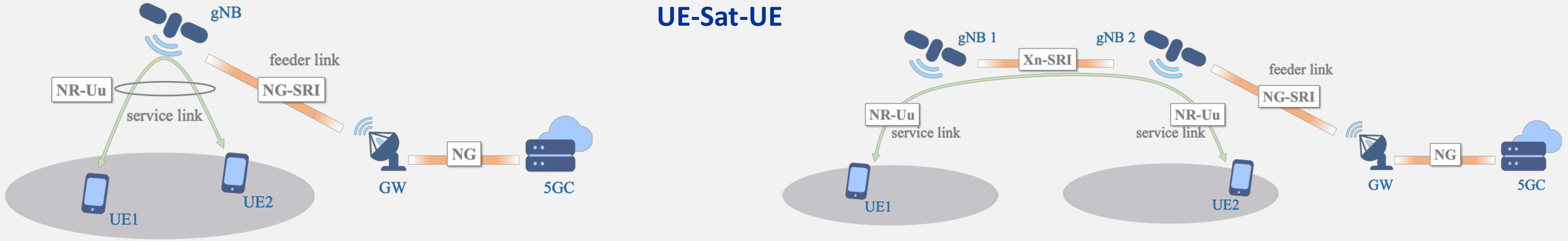



Inter-Satellite Links



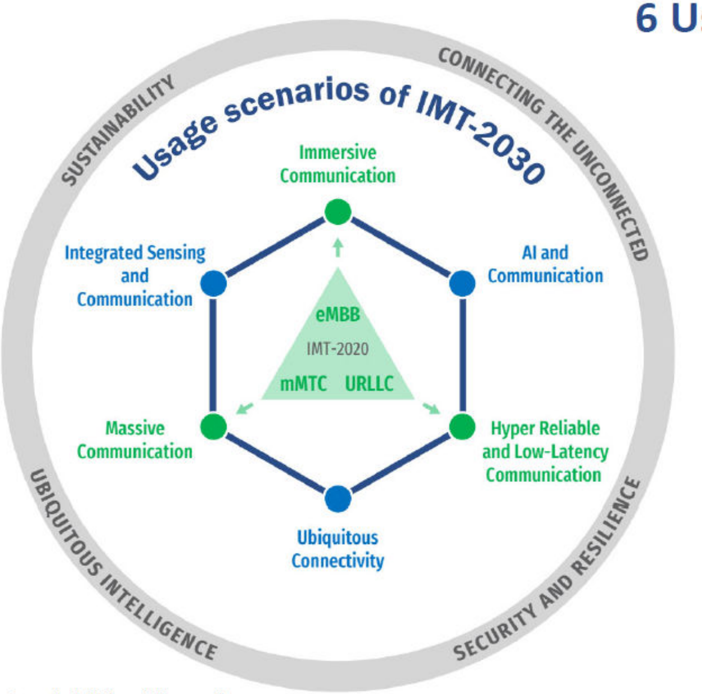

Wireless Access Backhaul

UE-Sat-UE



# 6G: from integration to a native NTN component

ITU-R IMT-2030




So called "Wheel diagram"

## 6 Usage scenarios

Extension from IMT-2020 (5G)

- eMBB ➡ Immersive Communication
- mMTC ➡ Massive Communication
- URLLC ➡ HRLLC (Hyper Reliable & Low-Latency Communication)

New

- Ubiquitous Connectivity
- AI and Communication
- Integrated Sensing and Communication

4 Overarching aspects:

*act as design principles commonly applicable to all usage scenarios*

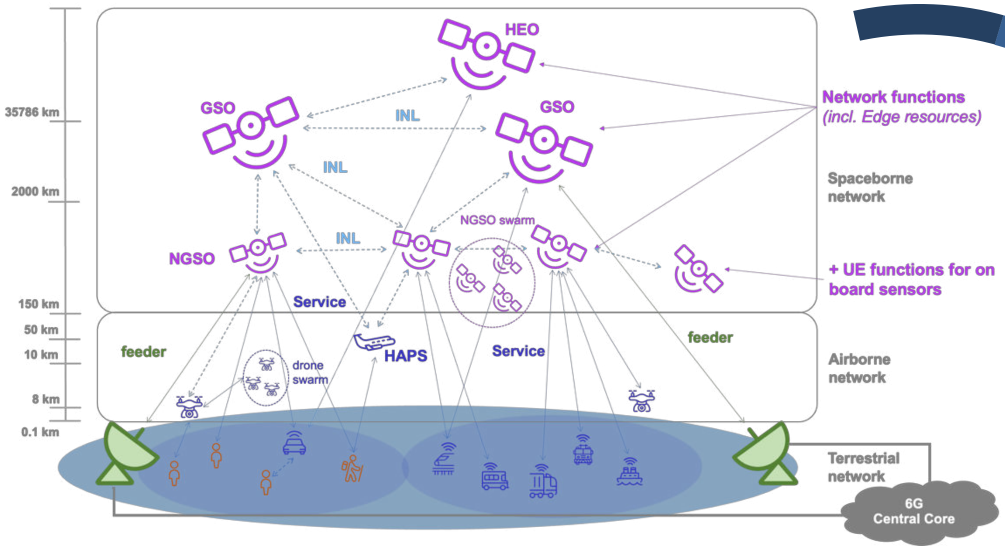
Sustainability, Connecting the unconnected, Ubiquitous intelligence, Security/resilience

- August 2024: **New Study on 6G Use Cases and Service Requirements (FS_6G-REQ)**
  - identify the high-level principles and use cases, with potential requirements, for IMT-2030
- December 2024: **New Study on 6G Scenarios and Requirements**
  - investigate a candidate set of minimum technical performance requirements based on ITU-R M.2160

*Source: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx*

NTN will be pivotal to provide a **ubiquitous, continuous, flexible, and resilient infrastructure**

# 6G: from integration to a native NTN component




**3D Multi-dimensional, Multi-layer, Multi-band 6G architecture**

**Architecture and system design**

Multilayered constellation from GEO to drones, Innovative and autonomous constellations, optical inter and intra node-links design, traffic-driven coverage, mesh infrastructure

**Networking, edge computing and communications**

Softwarisation, virtualisation, & orchestration of network resources, dynamic functional split for resource efficiency, advanced IP, routing in the sky, resource management, integrated edge communication and computing

**Radio interface and waveforms**

Unified waveforms, non-orthogonal techniques to increase the connection density, novel RA procedures to allow multiple transmissions per beam, beyond Shannon communication.

**Spectrum Usage and Access: new spectrum and sharing**

Multipoint transmission from the sky, cell-free MU-MIMO, distributed and swarm-based beamforming, Coordinated and uncoordinated sharing, inter and intra layer, Q/V and above

**Positioning**

NTN based positioning (<10cm)

**AI/ML**

Network and system orchestration, Self-organizing architecture, RRM, Network traffic and channel forecasting, PHL design and management, Intra system semantic Communications

**Antennas and components**

Active antennas for link budget and flexible coverage, regenerative flexible payload, high-parallel and energy efficient HW (open-HW/Open-SW), Optical devices

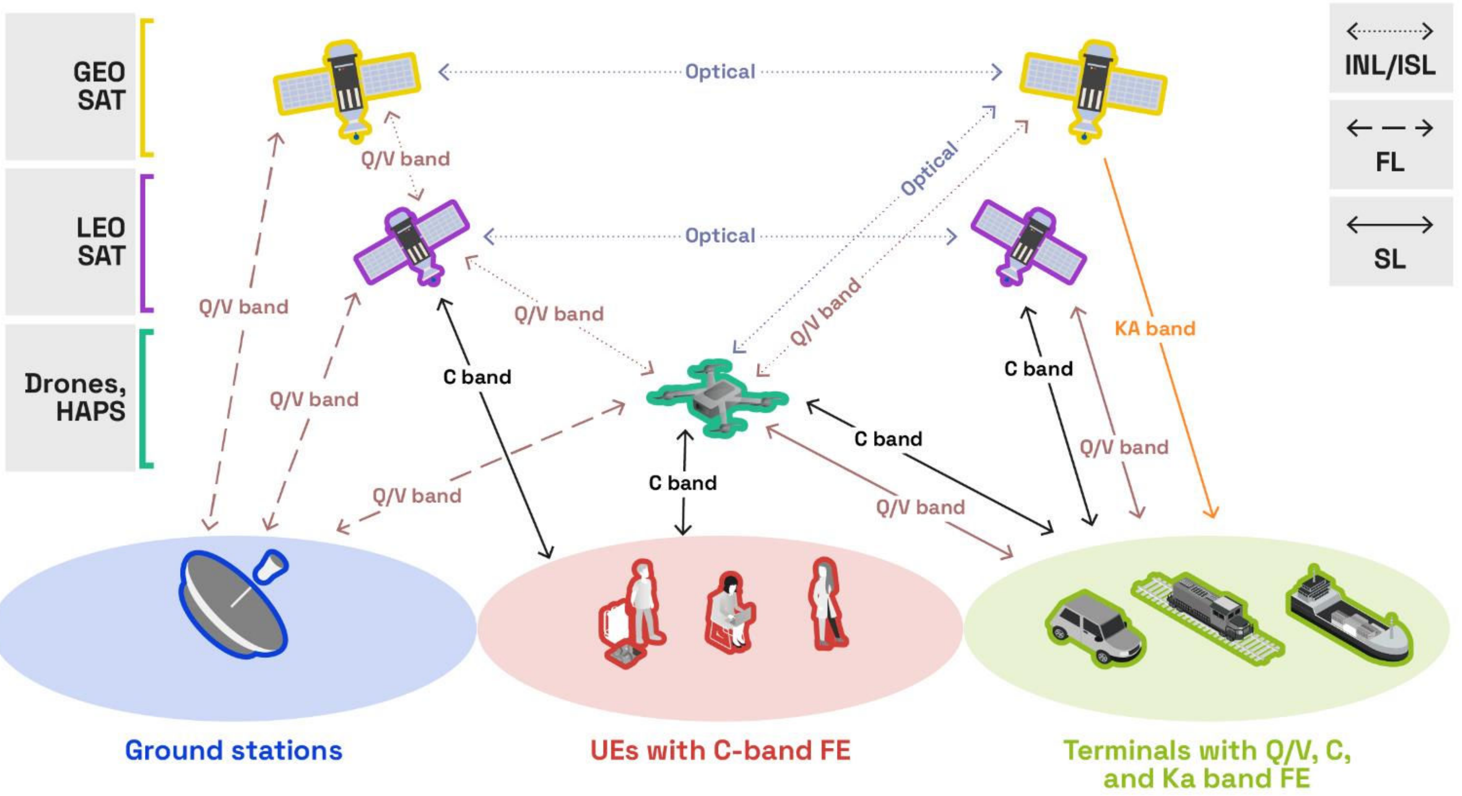


*Source: A. Guidotti et al., "Role and Evolution of Non-Terrestrial Networks Toward 6G Systems," in IEEE Access, vol. 12, pp. 55945-55963, 2024, doi: 10.1109/ACCESS.2024.3389459*

# 6G-NTN: multi-multilayer and multi-band 6G architecture

## Deterministic nodes with fixed and predictable orbits

- GSO platforms
  - broadcast & multicast for fixed ground stations
  - broadband access, *e.g.*, backup coverage or complementary capacity for hot-spots (latency tolerant)
  - non-delay sensitive traffic offloading from the NGSO
  - control and management planes to the NGSO in case of no feeder links / ground segment
  - backup in case of lower constellations failures
- NGSO platforms
  - broadband access to handhelds and VSAT-like UE




## Flexible nodes "opportunistically" deployed

- HAPs or (heavy) drones
  - capacity to specific areas with no TN, *e.g.*, disaster/emergency
  - additional capacity for sudden traffic increase, *e.g.*, concerts, sport events w/wo TN coverage

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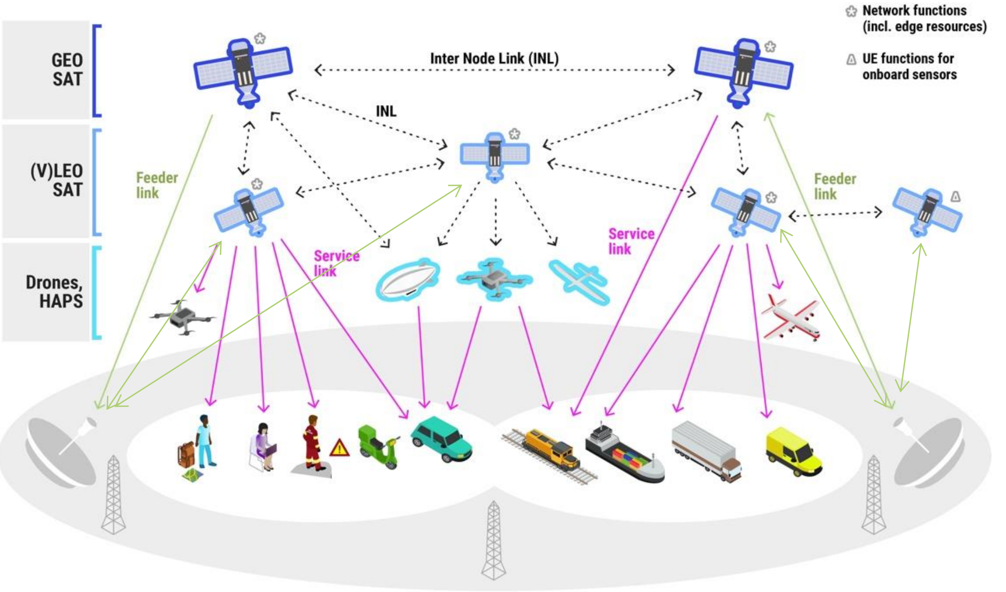
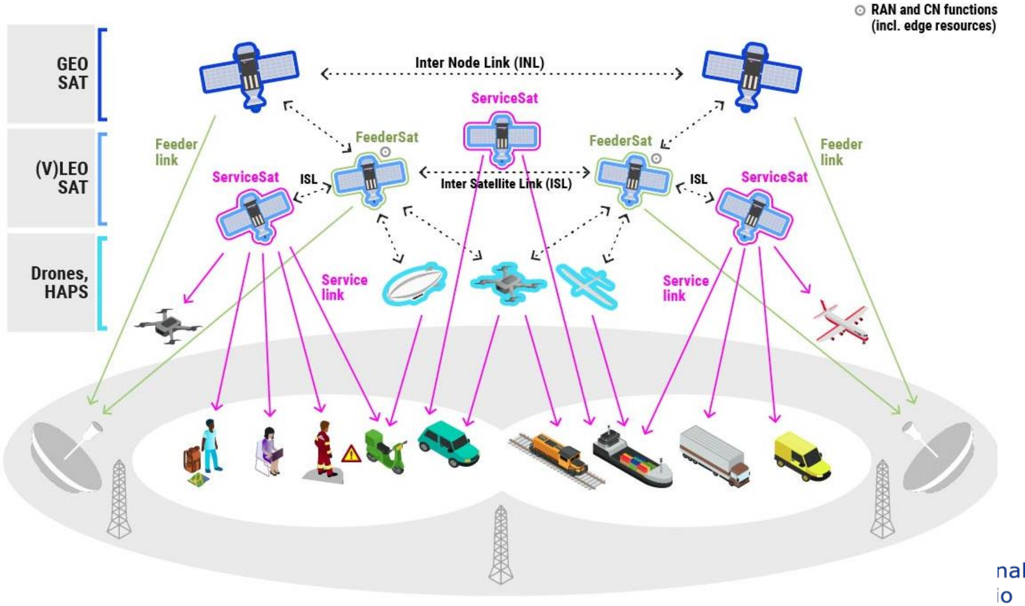
# 6G-NTN: architectural solutions

- **Conventional architecture – <u>homogeneous</u> satellites**
  - all satellites have the same functionalities
    - User link to UEs (multibeam)
    - 2 feeder links (redundancy and/or seamless ground station handover)
    - 4 OISL to 4 adjacent satellites (same and adjacent orbital planes)
    - 1 Ka-band payload for the ISL to GEO satellites
    - all RAN and, possibly, some CN functionalities




- **Distributed architecture – <u>heterogeneous</u> nodes (same altitude)**
  - **Feeder Nodes** with higher computational capabilities
    - 2 Feeder links to GW / no user link to UE
    - 4 OISLs to 4 service nodes
    - 2 OISLs to 2 feeder nodes
    - 1 Ka-band payload for the ISL to GEO satellites
    - Most of RAN/CN functionalities
  - **Service Nodes** with lower computational capabilities
    - User link to UEs (multibeam) / no feeder link to GW
    - 1 OISL to 1 feeder node
    - Minimum RAN functionalities (RU)




*Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.*

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# Architecture sizing: example

| Architecture | | sat/planes | planes | sat/type | total sat |
|---|---|---|---|---|---|
| Conventional | | 47 | 27 | - | 1269 |
| Distributed | Feeder | 14 | 24 | 366 | 1635 |
| | Service | 47 | 27 | 1269 | |

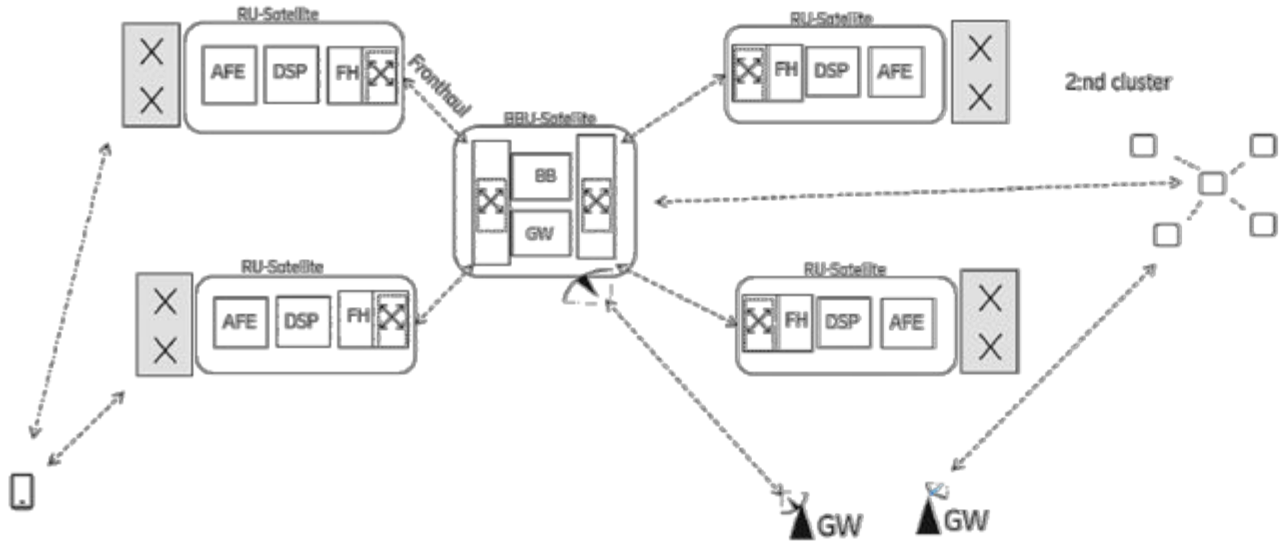
- Assumptions
  - altitude: 600 km
  - near-polar inclination (~87°)
  - 45° minimum user elevation angle
  - at least 1 satellite always in visibility
  - at least 10 s of overlap between 2 satellites
  - 2 constellations: C-band + Q/V-band
    - only for the service satellites
    - the feeder satellites are the same, with 8 ISLs

*Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.*

# Distributed architecture: considerations

- Platform sizing
  - RAN functional split in space (feeder/service satellite)
  - optimization of power budget and payloads volume
    - Feeder satellites w/o power amplifiers for user link → power/volume available for computation
    - Service satellites lower computational load → smaller platform, higher power for user link power amplifiers, antennas, etc.

- Example of functional split in a distributed architecture: Lower Layer Split
  - Service satellites (1269)
    - analog and digital front-ends, receiver beamforming, CP removal, FFT transforms
  - Feeder satellites (366 sat)
    - up to CN functionalities




*Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.*





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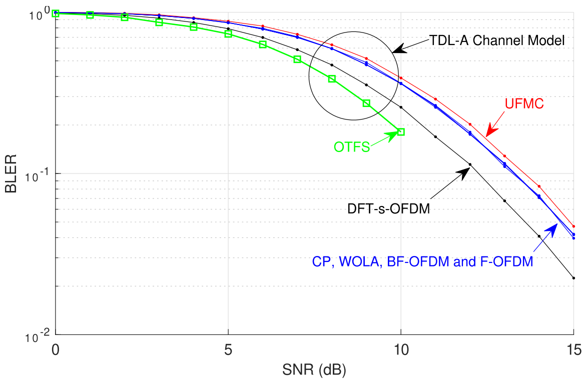
# 6G-NTN: radio interface design drivers

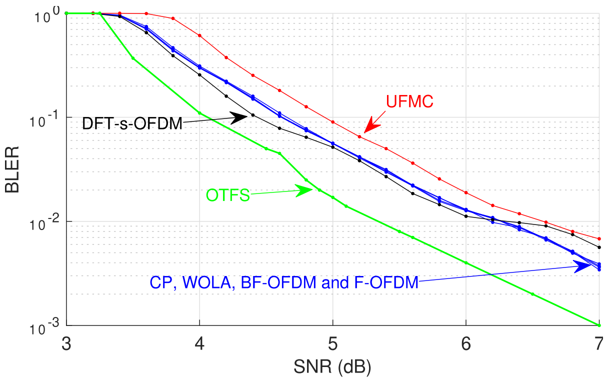
| Radio interface design drivers | Rationale |
|---|---|
| Multi carrier waveform enhancements | **Relaxed synchronization requirements** (GNSS-free operations)<br>Downlink **PAPR reduction** for spectral efficiency maximization in simplified platform (single channel HPA) |
| Advanced modulation, coding and multiple access schemes | **Low SNR regimes** enabling the support of challenging radio link conditions, *e.g.*, light indoor |
| Design flexible UL/DL framing structure | Flexibility **for frame structure adaptation** to satellite orbit, frequency range, etc.<br>Overhead reduction (limited multi-paths conditions ) |
| TDD support | **Unpaired spectrum** may be allocated to NTN (LEO/vLEO platform) |
| Full duplex | **Spectrum usage** maximization |
| Reference signals for robust synchronization, access procedures, and positioning | GNSS free operation, support **reliable network-based solution** for **Positioning, Navigation and Timing** services (<10cm) |
| Support of broadcast and multicast | Leverage **large coverage area** of satellites (multilayered architecture) |
| Support for AI driven radio resource control | **Dynamic optimization** of the **radio interface** configuration (*e.g.*, modulation, coding, power, signal occupancy, interleaving depth, HARQ) according to the radio link conditions |
| Spectrum sharing between TN and NTN | Co-channel spectrum sharing between TN and NTN |
| Joint communication and sensing | Provide low to medium resolution **sensing capabilities** directly integrated into the **waveform design** |

# Waveform: evolution or revolution?

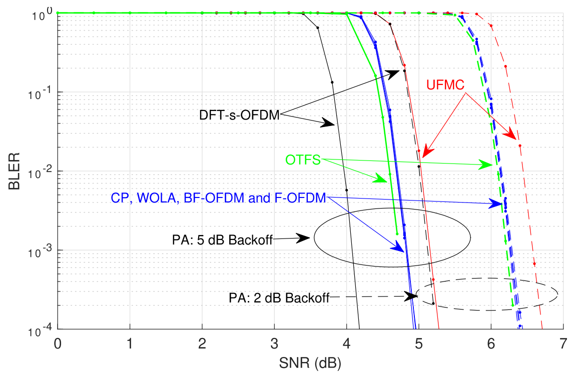
- Potential new/adapted waveforms addressing NTN features, *e.g.*,
  - CP-OFDM, DFT-s-OFDM, WOLA-OFDM, OTFS, BF-OFDM, UFMC, F-OFDM



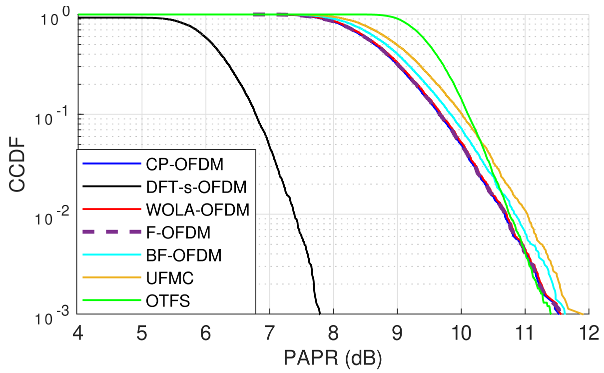

C band, NTN-TDL-A




Q/V band, PN




Q/V band, IBO = 2 and 5 dB




PAPR

- DFT-s-OFDM shows better performance when HPA is implemented because of its reduced PAPR
- PN strongly impacts the performance of all the waveforms
- Higher robustness of OTFS to PN and multipath. Higher receiver complexity
- Assumption: no receiver optimization… yet

*Source: Amatetti et All, '6G NTN in C and Q/V-Bands: Link Budget Analysis and Waveforms Performance' – Globecom 2024*

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# 6G NTN standardisation: an educated guess

- Potential objectives
  - connectivity in areas not covered by TN
  - improving the coverage performance of direct connectivity, possibly in light indoor conditions
  - reducing the energy consumption through smart TN-NTN routing
  - higher accuracy positioning services beyond TN coverage
  - deterministic and lower delays through interconnected nodes at very low altitudes

**new waveforms** with flexible channel bandwidth and low PAPR

- extend the link margin (e.g., light indoor)
- support ISAC
- support NOMA in high density scenarios

definition of **new/enhanced radio procedures** to support new architectures and technologies

definition of **advanced routing protocols** in multi-dimensional networks, with variable inter-node conditions

**AI-driven RRM** supporting NTN-TN spectrum sharing solutions

support TN/NTN and NTN/NTN **Multi-Connectivity**

support of **functional split architectures** across the feeder link and on INLs

# Conclusions

- **TN/NTN native unification in 6G**
- **Evolutionary and revolutionary technologies** are needed to achieve a true **fully unified 6G air interface**
  - flexible and natively integrated waveforms
  - networking, edge computing and communications
  - efficient Spectrum Access and new spectrum
  - GNSS free operation
  - light indoor operations, *e.g.*, improved link budget, extended/additional coding schemes
  - AI based NTN and NTN supported AI
- **Megaconstellations represent a sustainability** (financial/environmental) **challenge**: smart and sustainable design paradigms needed, *e.g.*, **distributed architecture**
  - functional split in space
  - software defined regenerative payload for flexibility and adaptivity
  - routing in space for resilience, security, cost reduction (ground segment simplification), load balancing
  - mesh architecture
- **Components** need to be addressed
  - antennas, *e.g.*, VSAT type at Q/V band
  - optical ISL
  - computational platform for SW defined payload, AI support, etc. (open HW/Open SW)
  - …

*Source: A. Vanelli-Coralli, "Exploring the Future: Challenges and Innovations in 6G Non-Terrestrial Network", Mobile Korea 2024*

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