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The Role of Non-Terrestrial Systems in the 6G ecosystem

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2nd International Summit on Sensors and Sensing Technology

From SatCom to NTN

Satellite Communications

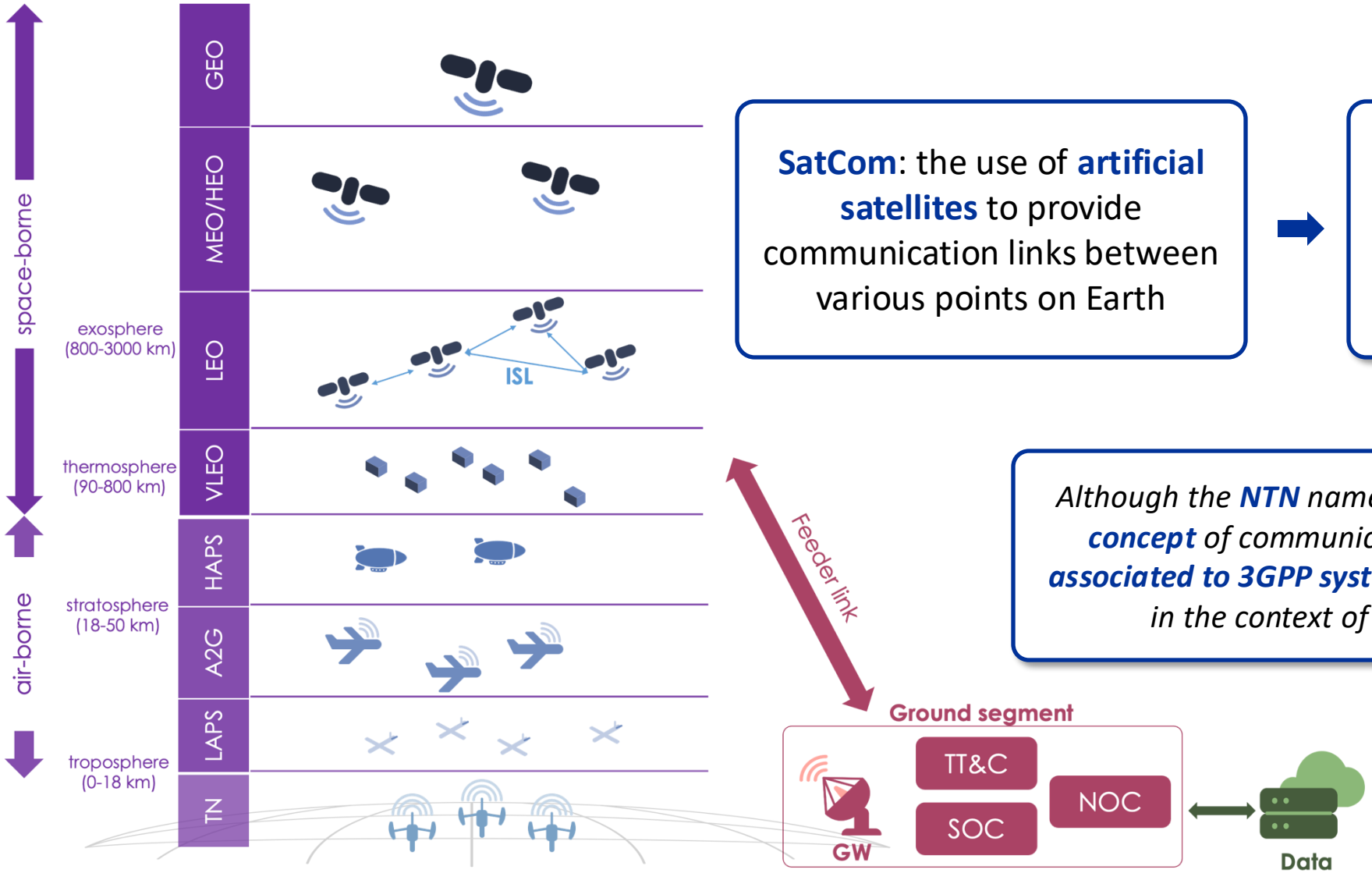
Non-Terrestrial Networks

What's so fancy about NTN?

The Role of Non-Terrestrial Systems in the 6G ecosystem

From Satellite Communications to Non-Terrestrial Networks

From SatCom to NTN

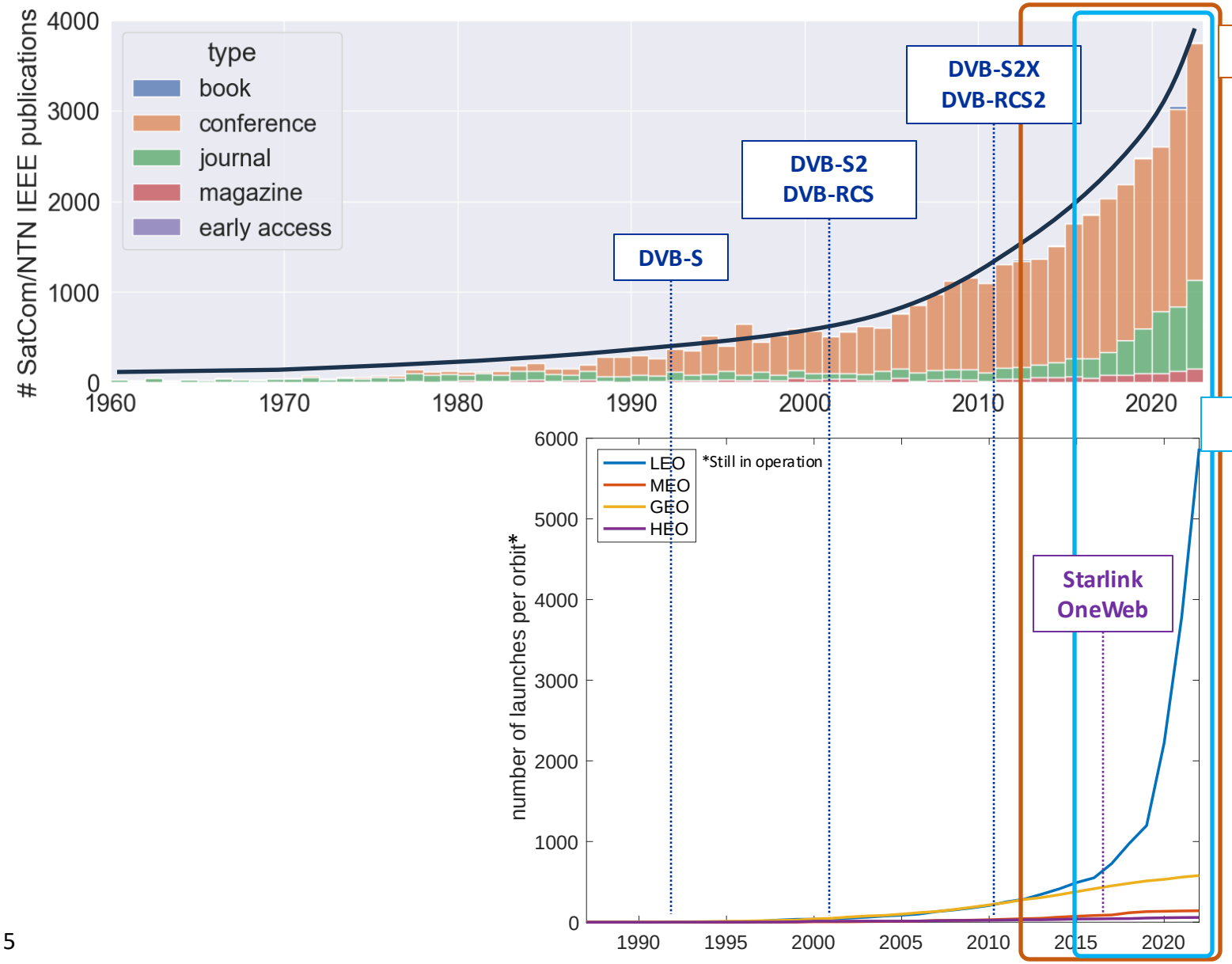


SatCom: the use of **artificial satellites** to provide communication links between various points on Earth

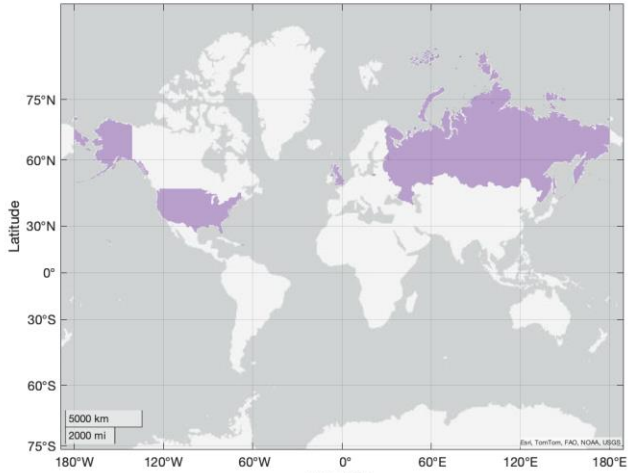
NTN: the use of **space-/air-borne platforms** organized in a connected infrastructure to provide wireless services on Earth

*Although the **NTN** name refers to a **wider and more general concept** of communication systems, it is now commonly **associated to 3GPP systems** because it has been initially used in the context of the 3GPP NR standardization.*

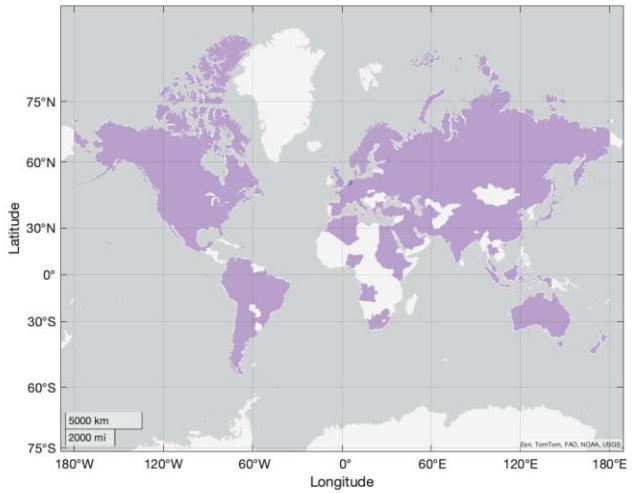
From SatCom to NTN (nothing happens overnight)



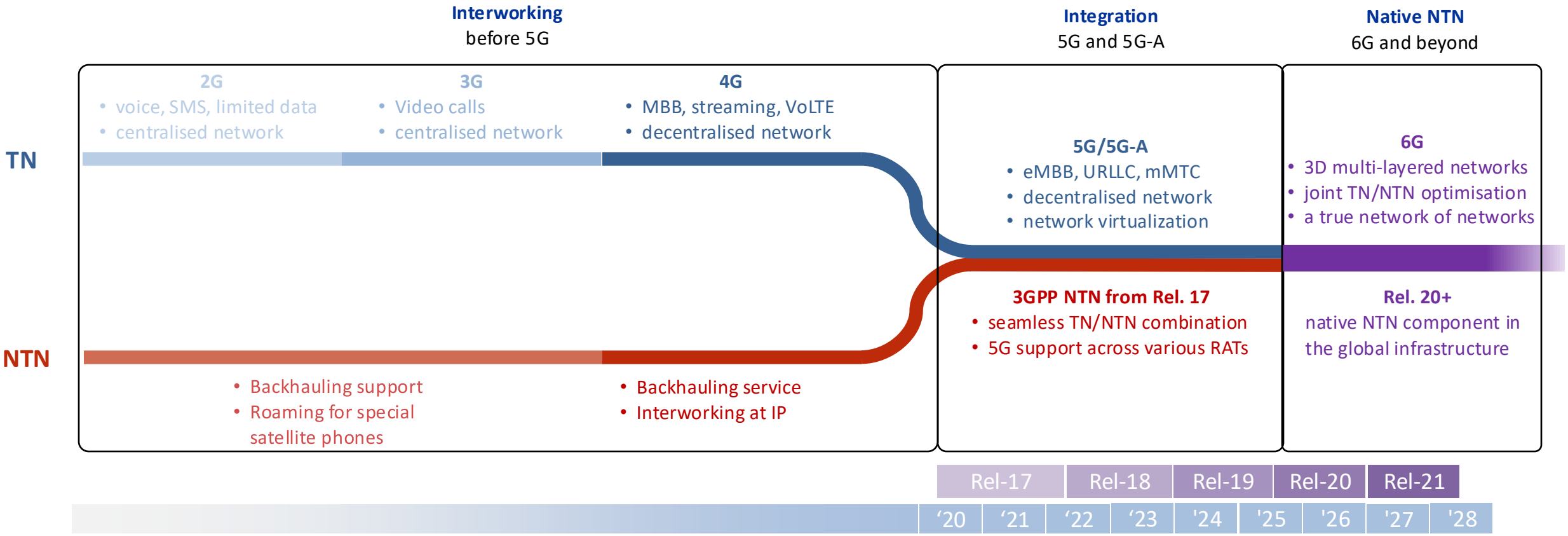
1974-1990



1990-2023



Non-Terrestrial Networks: a path to unification



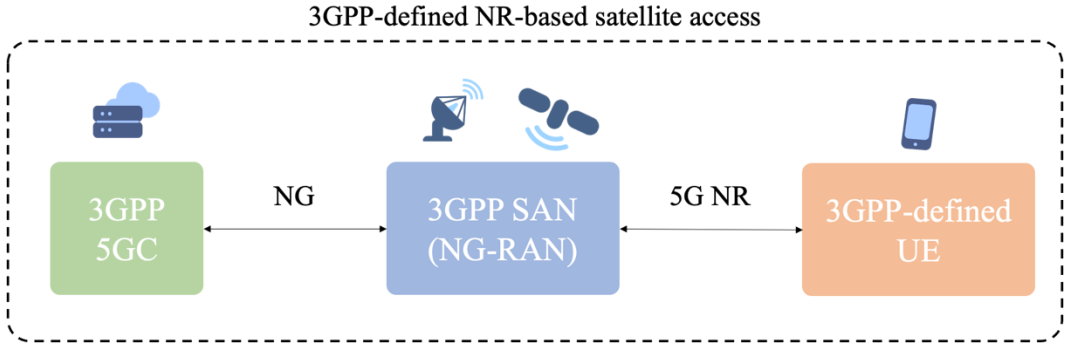
Interworking: legacy **SatCom** systems were typically **based on industry-driven technical specifications** leading **to proprietary architectures and protocol stacks** → difficult a posteriori interactions with terrestrial systems

The Role of Non-Terrestrial Systems in the 6G ecosystem

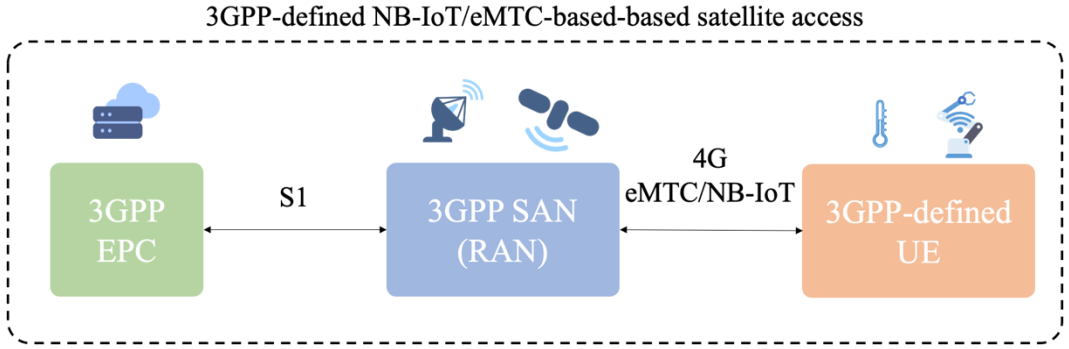
NTN yesterday

NTN Rel. 17: 3GPP-defined solutions

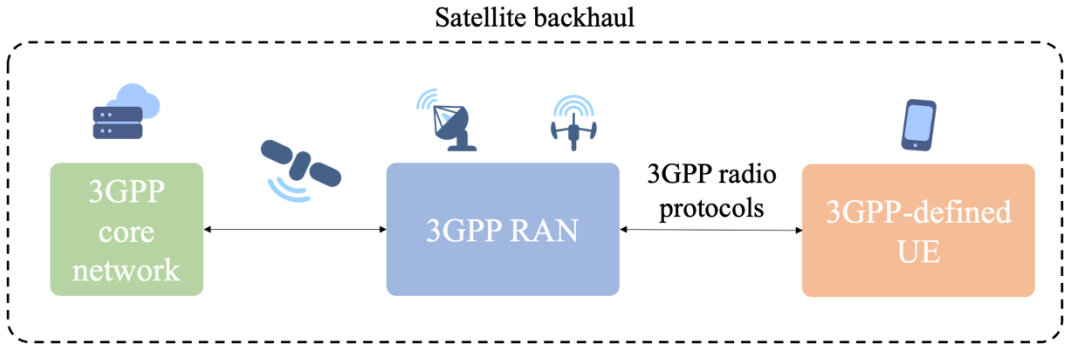
Satellite Access Node: on-ground non-NTN infrastructure
gNB functions + gateway + feeder link + NTN payload



SAN connected to the 5GC for eMBB-s and HRC-s to 3GPP-compliant UEs



SAN compatible with E-UTRA connected to the 4G EPC for mMTC-s to LTE-based UEs

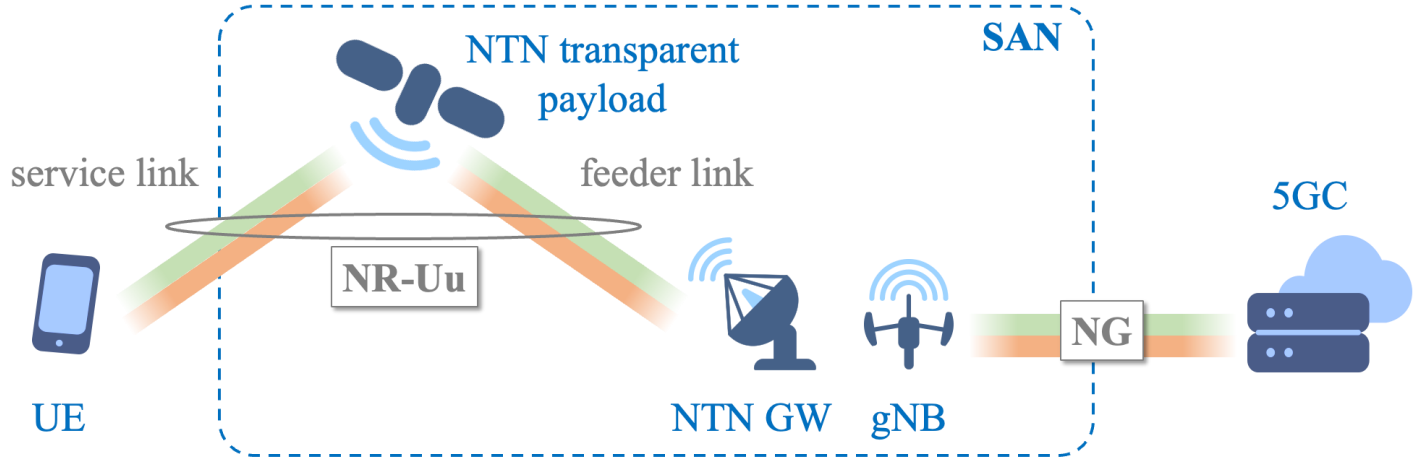


NTN component used as a transport network providing connectivity between the 3GPP CN and its users

NTN Rel. 17: overview

- NTN-based GEO/LEO with implicit HAPS/ATG compatibility

- Main characteristics
  - **transparent payload** architecture
  - **Earth-fixed**, **Quasi-Earth-fixed**, **Earth-moving**
  - **FR1**: S-band and L-band
  - **handheld** terminals **with GNSS** capabilities
    - BW: 30 MHz (DL) / 360 kHz (UL)
    - SCS: 15 kHz, 30 kHz
  - **SIB19** introduced for NTN
    - ephemeris, common TA, PDSCH/PUSCH offset, additional synchronisation and cell information



Band	UL (UE-to-SAN)	DL (SAN-to-UE)	Duplexing
n256	1980-2010 MHz	2170-2200 MHz	FDD
n255	1626.5-1660.5 MHz	1525-1559 MHz	FDD
n1	1920-1980 MHz	2110-2170 MHz	FDD HAPS

NTN Rel. 18: overview

- First specification dedicated to 5G-Advanced (+ submission of the NTN RIT to ITU-R WP4B reported in TR 37.911)

- NR radio protocols
  - **FR2** and mobile/nomadic **VSAT**
  - **network verification of the GNSS** coordinates determined by the UE
  - optimise NTN-NTN and TN-NTN **mobility procedures** in idle/connected modes
  - **UL coverage enhancements**
  - **30 MHz** channel in **FR1**

Band	UL (UE-to-SAN)	DL (SAN-to-UE)	Duplexing	
n256	1980-2010 MHz	2170-2200 MHz	FDD	
n255	1626.5-1660.5 MHz	1525-1559 MHz	FDD	
n254	**1610-1626.5 MHz**	**2483.5-2500 MHz**	**FDD**	
n512	**27.5-30 GHz**	**17.3-20.2 GHz**	**FDD**	CEPT ECC Decision(05)01 and ECC Decision (13)01
n511	**28.35-30 GHz**	**17.3-20.2 GHz**	**FDD**	USA subject to FCC 47 CFR part 25
n510	**27.5-28.35 GHz**	**17.3-20.2 GHz**	**FDD**	Earth Station operations in the USA subject to FCC 47 CFR part 25. No ESIM currently.

- Services and architectures
  - **discontinuous coverage scenarios**: MM, paging, power saving, determination of periods without visibility [TR 23.700-28]
  - **backhauling**: challenges and solutions [TR 23.700-27]
  - **security and privacy** issues for mobility management and power saving in discontinuous coverage [TR 33.700-28]
  - charging aspects for satellite/backhaul access [TR 28.844]

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NTN today

NTN Rel. 19: overview

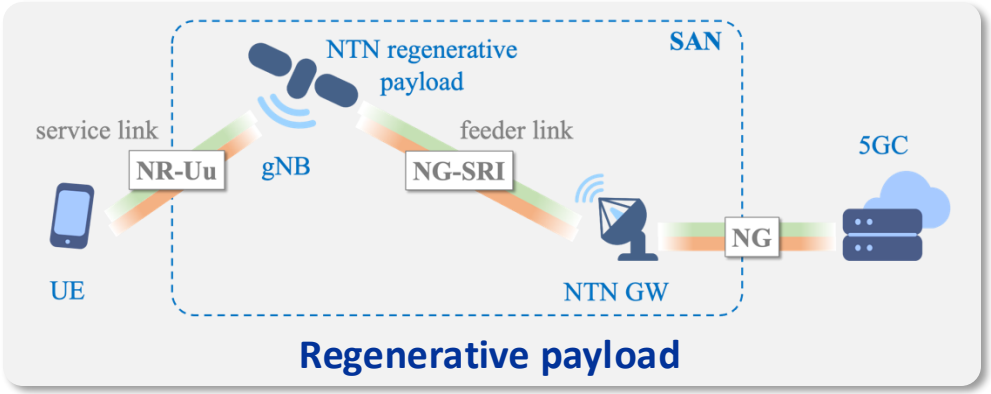
- NR radio protocols
  - DL **coverage enhancements** (*e.g.*, additional payload parameters for GSO/NGSO constellations in FR1/FR2)
  - UL **capacity enhancements** in FR1
  - **broadcasting services via NTN**: signalling information of the intended service area
  - **RedCap** UEs for NR-NTN **in FR1**
  - **regenerative payloads** (initial focus on full gNBs on-board)
  - **Ku-band**, **S-band** (n252/n252), **extended L-band** (n251/250)
  - **HPUEs** for **FR1-NTN:** 26, 29, 31 dBm

- Approved: December 2023
- Target completion: December 2025

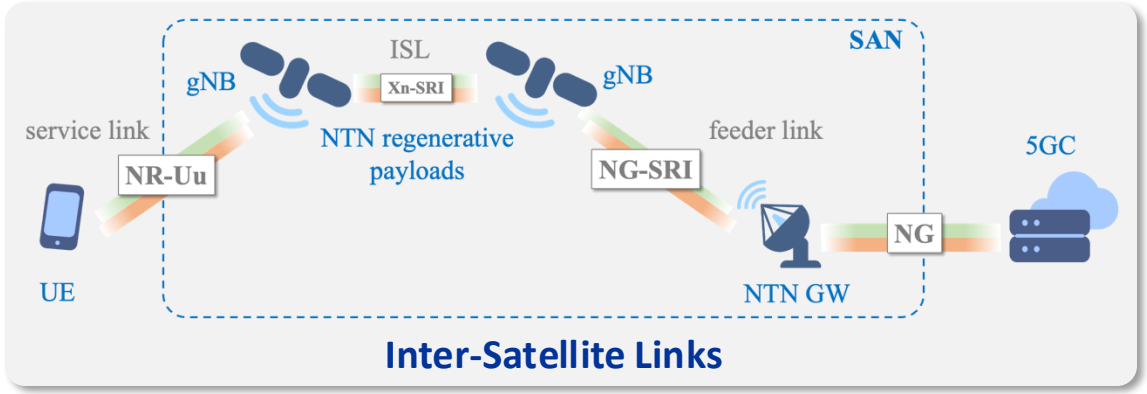
- Services and architectures
  - study of additional use cases (additional components, requirements, security) for 5G over NTN
    - **regenerative payloads**
    - **Store & Forward operations**
    - **UE-Satellite-UE communications**
  - **management aspects**: new use cases, NTN-NTN/TN-NTN mobility and service continuity, E2E management in NTN
  - **application layer solutions for satellite access** and the usage of NTN for **mission critical** scenarios

- Other potential topics might be added

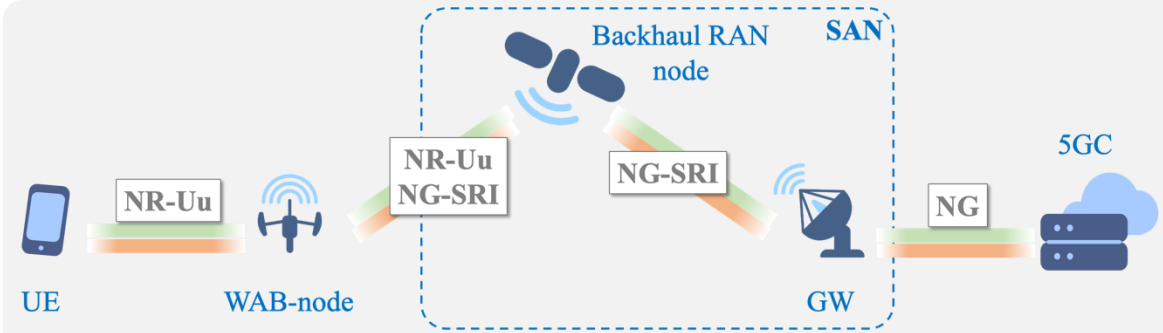
NTN Rel. 19: architecture evolution

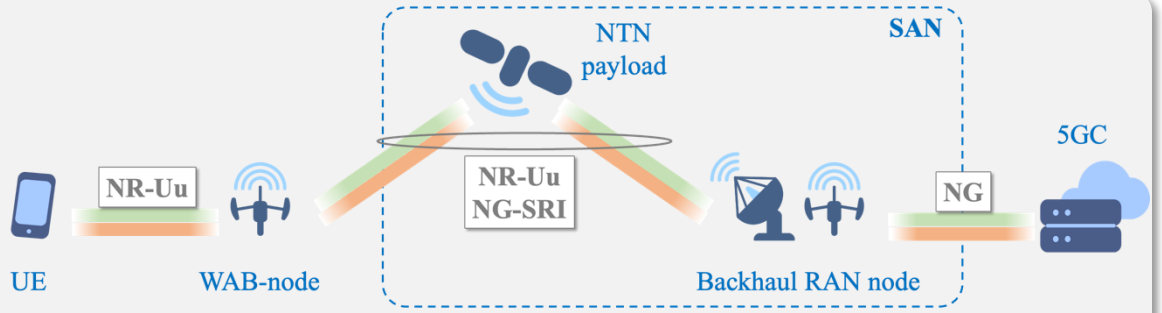


Regenerative payload



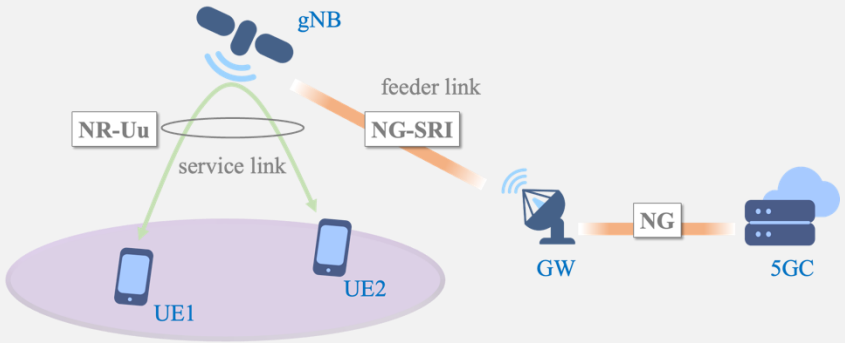
Inter-Satellite Links

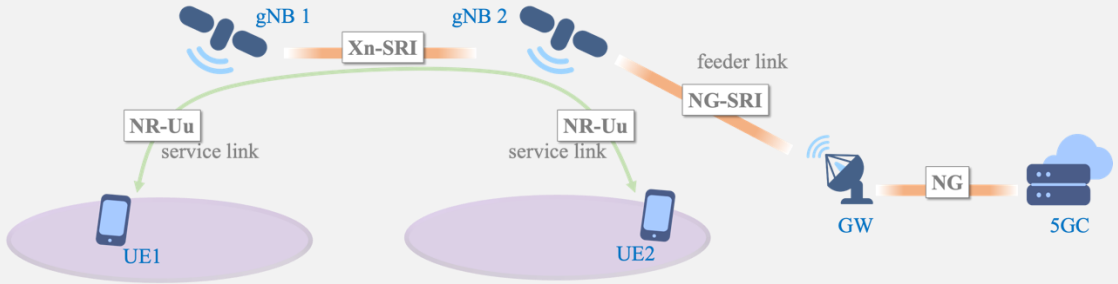




Wireless Access Backhaul

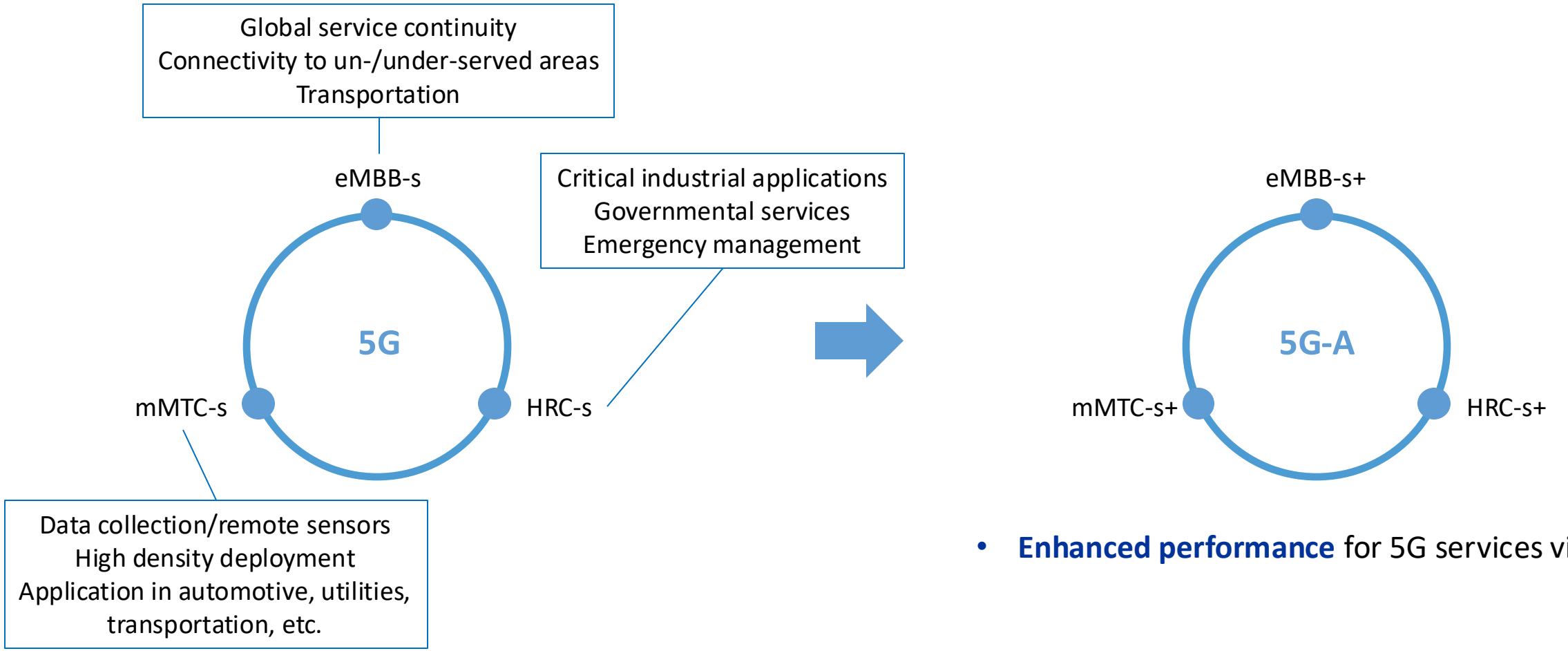
UE-Sat-UE





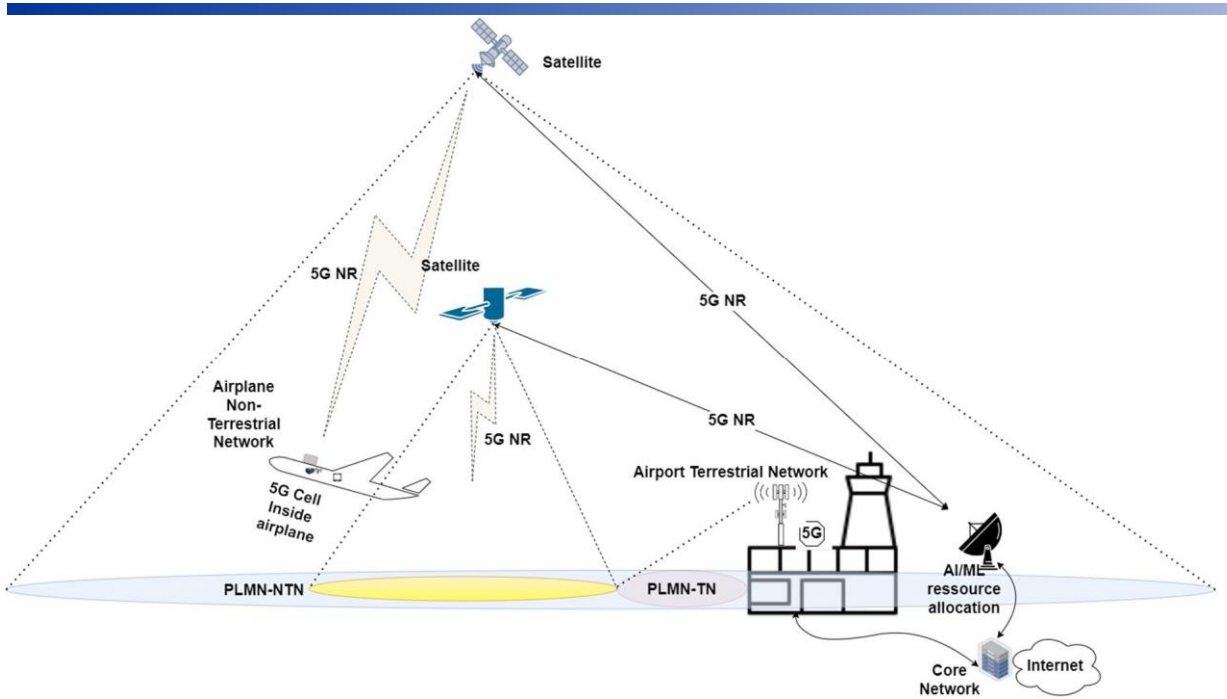
5G/5G-Advanced services via NTN

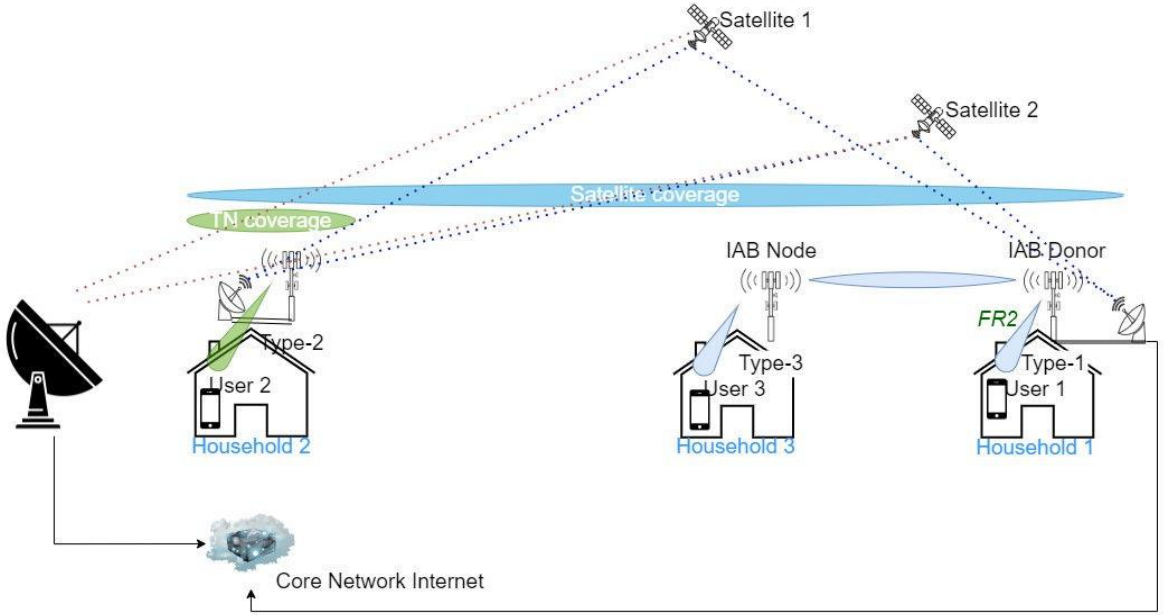
- NTN can bring an added value in terms of service **continuity**, **ubiquity**, and **scalability**



- **Enhanced performance** for 5G services via NTN

5G/5G-Advanced services via NTN: dual connectivity examples





Airway scenario

- TN/NTN switching during boarding operations
- In-flight entertainment via NTN

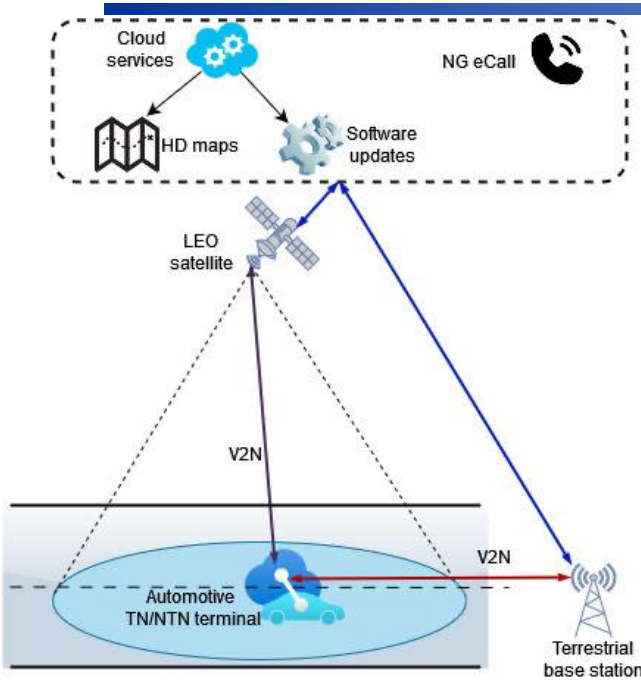
Similar scenarios can be implemented for railway and maritime transportation

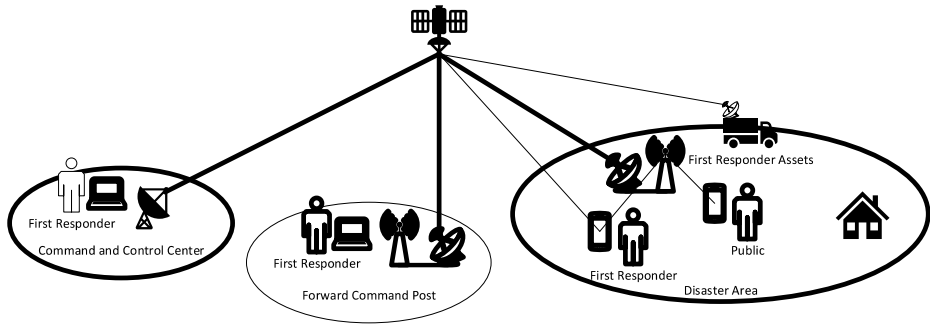
Residential broadband

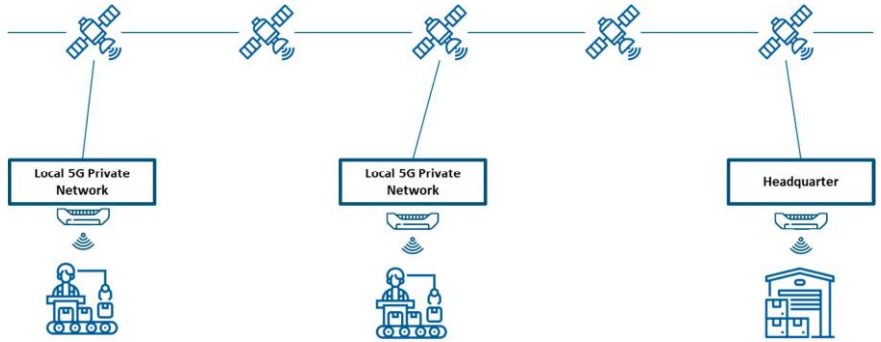
- QoS-driven selection of GEO/LEO
- IAB connectivity via NTN
- TN-to-NTN offloading for energy saving

Source: EC SNS-JU Project 5G-STARDUST, Deliverable D2.1, "Scenarios, use cases, and services," August 2023. Available: https://www.5g-stardust.eu/deliverables/

5G/5G-Advanced services via NTN: service distribution examples







Connected vehicle

- V2N solutions for SW updates, HD map transmission, NG eCalls

PPDR

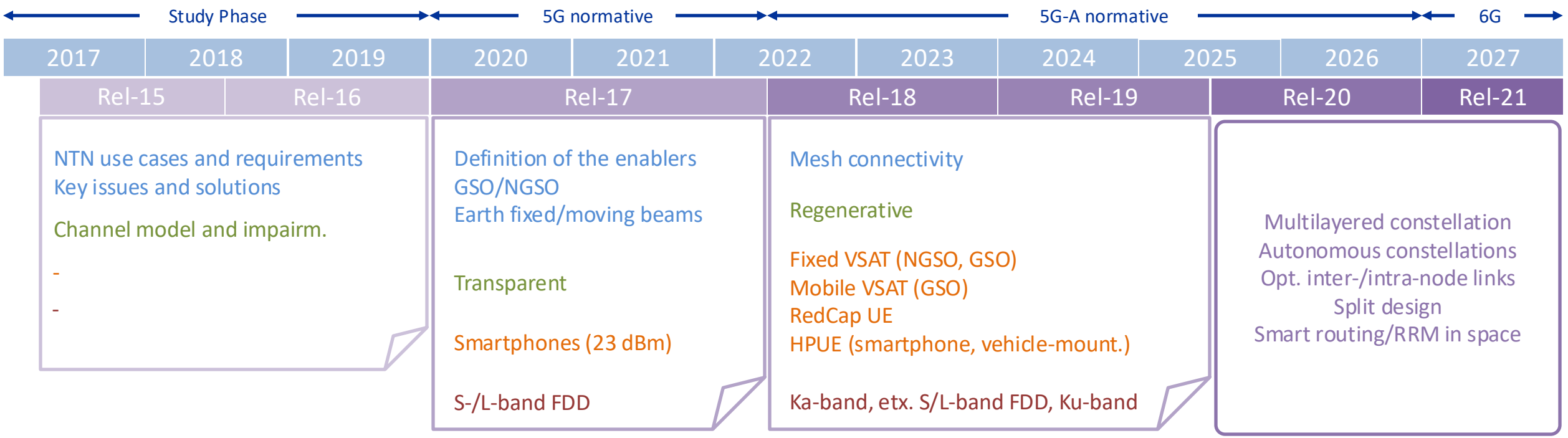
- Aftermath of a disaster
- Public Safety operations in un-/under-served areas
- Connectivity to
  - first responders
  - population in distress

Global private networks

- Integrate company-wide connectivity islands
- Guarantee secure and reliable communications

Source: EC SNS-JU Project 5G-STARDUST, Deliverable D2.1, "Scenarios, use cases, and services," August 2023. Available: https://www.5g-stardust.eu/deliverables/

NTN roadmap



System architecture

RAN aspects

Targeted terminals

Spectrum

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

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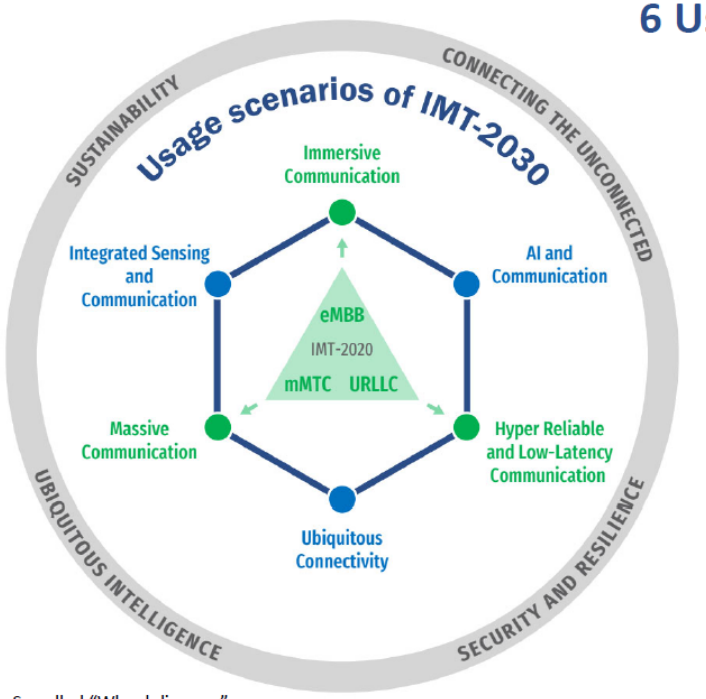
NTN tomorrow

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

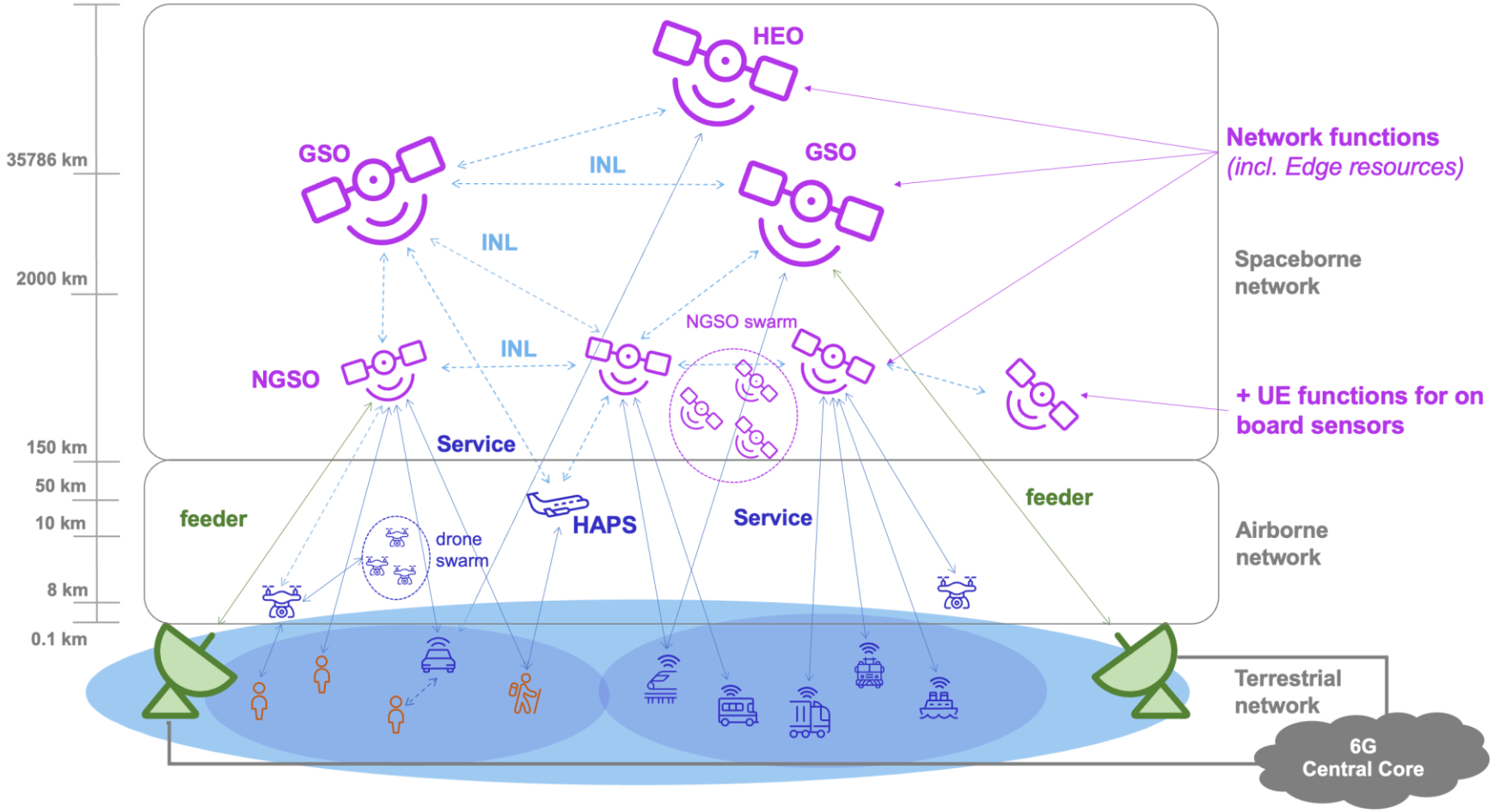
Sustainability, Connecting the unconnected, Ubiquitous intelligence, Security/resilience

- August 2024: **New Study on 6G Use Cases and Service Requirements (FS_6G-REQ)**
- Identified **use case families**
  - Integrated Sensing and Communications
  - Ubiquitous Connectivity
  - Immersive Communications
  - Massive Communications
  - + others?

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

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 research areas

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

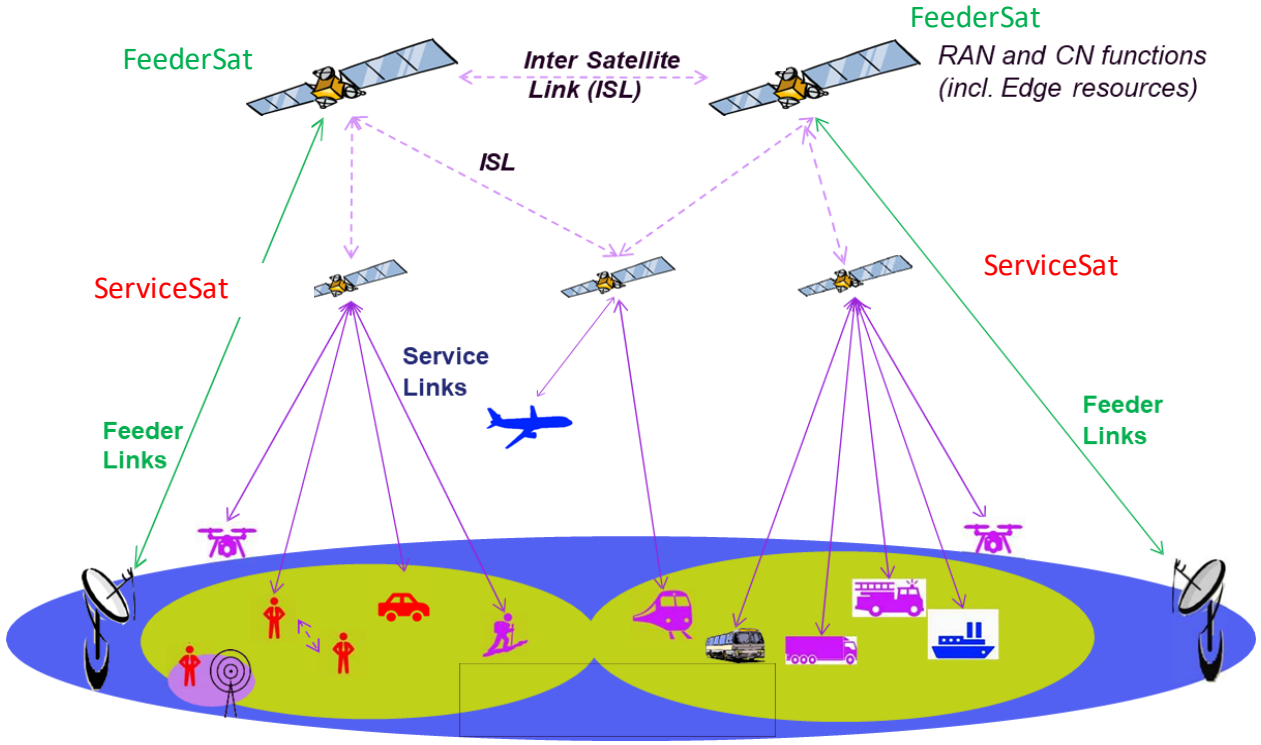
Active antennas for link budget and flexible coverage, regenerative flexible payload, high-parallel and energy efficient HW (open-HW/Open-SW), Optical devices

6G NTN Architecture

It will encompass heterogeneous nodes (also at the same altitude):

- nodes with higher computational capabilities (larger platforms)
- nodes with lower computational capabilities (smaller platforms)

- Example of non-uniform constellation
  - 600 km altitude
  - Near-polar inclination (~87°)
  - 45° min user elevation angle
  - at least 1 satellite always visible
  - at least 10 s of overlap between 2 satellites
  - 366 **FeederSats** (large platform)
    - 14 planes and 24 sats/plane
  - 1269 **ServiceSats** (smaller platform)
    - 27 planes and 47 sats/plane



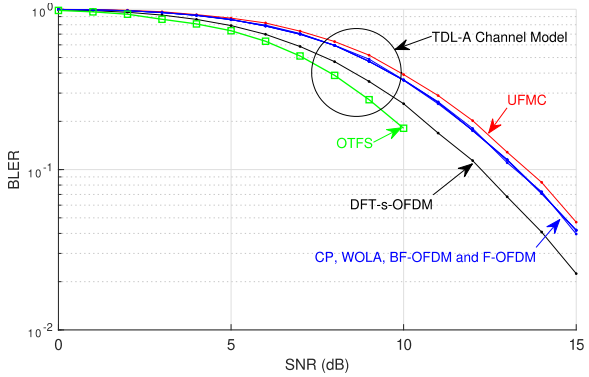
FeederSat:
- larger platform, no user link, only GW connection and OISL to ServiceSat and other Feedersat

ServiceSat:
- smaller platform (RU only), no feeder link, only user link and OISL to a FeederSat

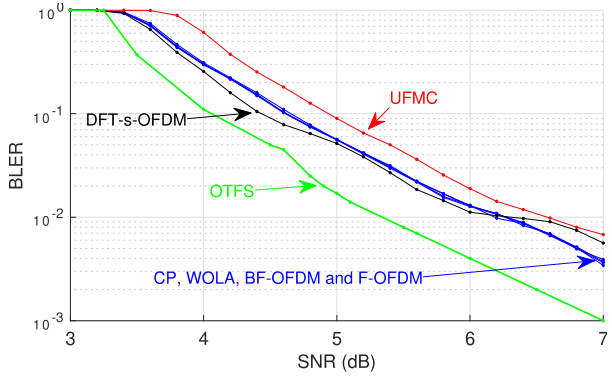
Source: SNS JU Project 6G-NTN, D3.5 "Archihitectural Solutions," March 2024. Available: https://www.6g-ntn.eu/public-deliverables/

Waveform: evolution or revolution?

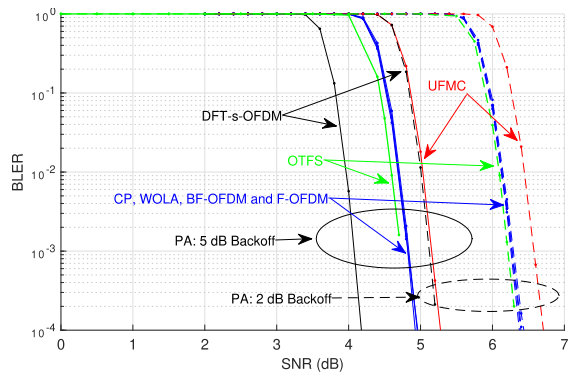
- Potential new/adapted waveforms addressing NTN features, e.g., CP-OFDM, DFT-s-OFDM, WOLA-OFDM, OTFS



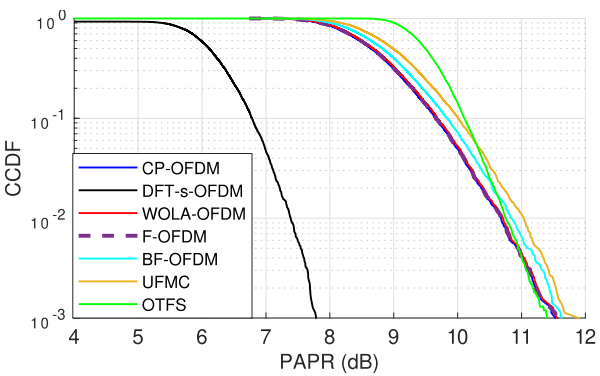
C band, NTN-TDL-A



Q/V band, PN



Q/V band, IBO = 2 and 5 dB

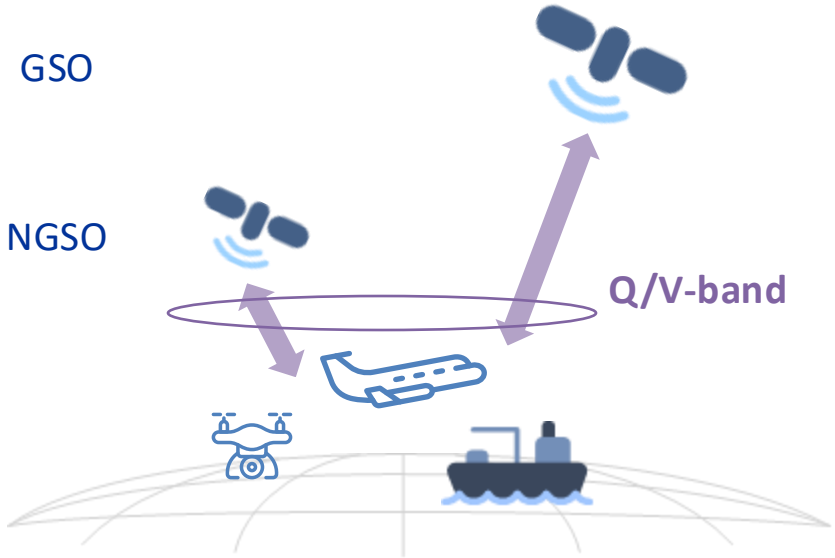


PAPR

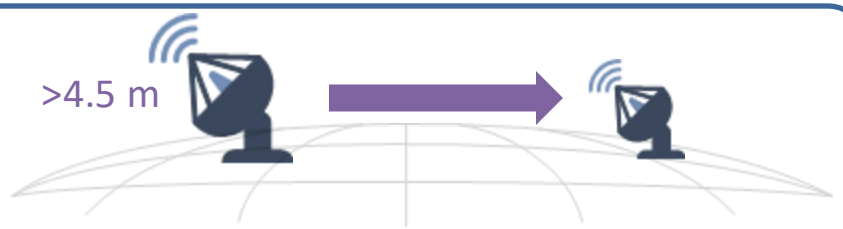
- DFT-s-OFDM shows better performance when HPA is implemented because of its reduced PAPR
- PN strongly impacts the performance of all waveforms
- Higher robustness of OTFS to PN and multipath, but increased complexity
- Assumption: no receiver optimization… yet

Source: SNS JU Project 6G-NTN, D4.1 "Report on unified and data driven air-interface for 6G-NTN," June 2024. Available: https://www.6g-ntn.eu/public-deliverables/

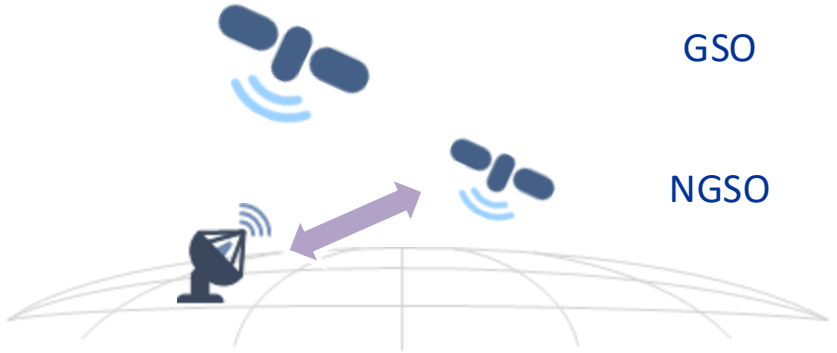
ITU-R WRC-27: Ku, Q/V, W



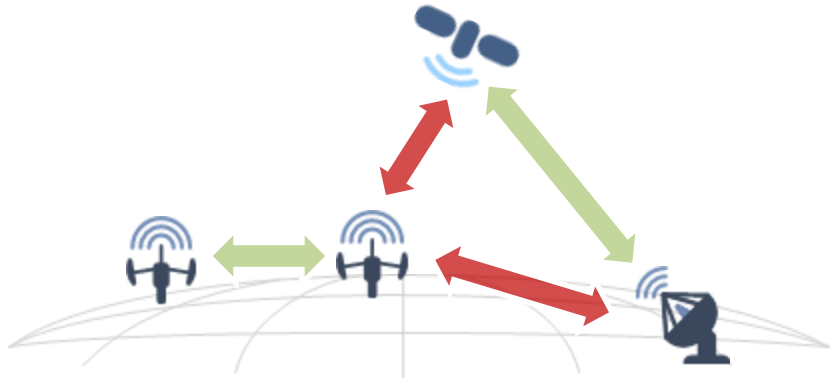
Aeronautical and maritime ESIM in Q/V band 47.2-50.2 GHz and 50.4-51.4 GHz - both GSO and NGSO



Allow FSS Earth Stations in the band 13.75-14 GHz with smaller antennas



Additional NGSO feeder links 51.4-52.4 GHz

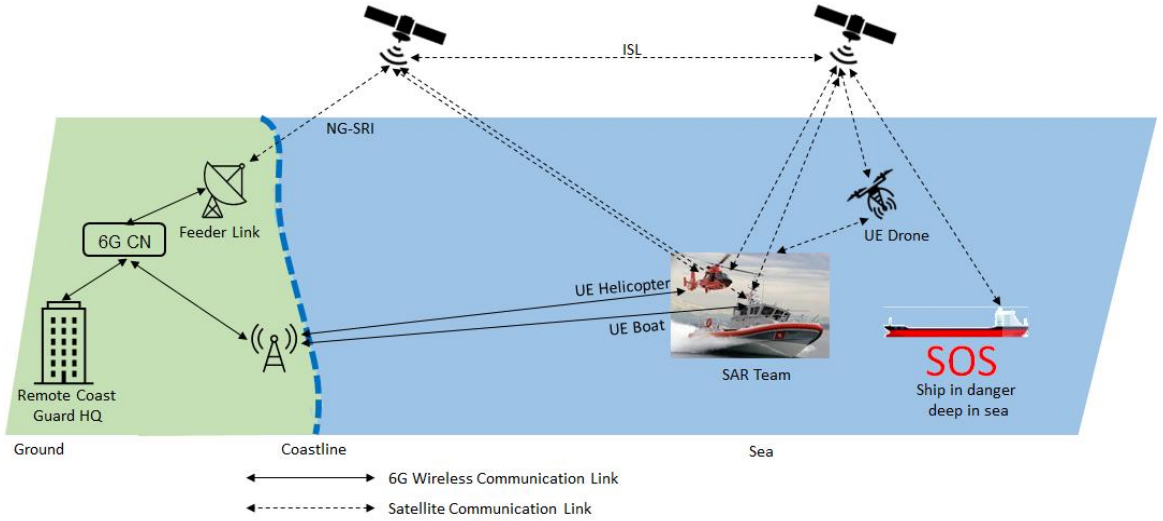


New pfd/epfd limits in 71-76 GHz and 81-86 GHz to protect fixed and mobile services

Source: F. Zeppenfeldt, "Non-Terrestrial Networks and regulation," Special Session "Bringing 6G from vision to reality in Europe – the key role of regulation in research," EuCNC 2024.

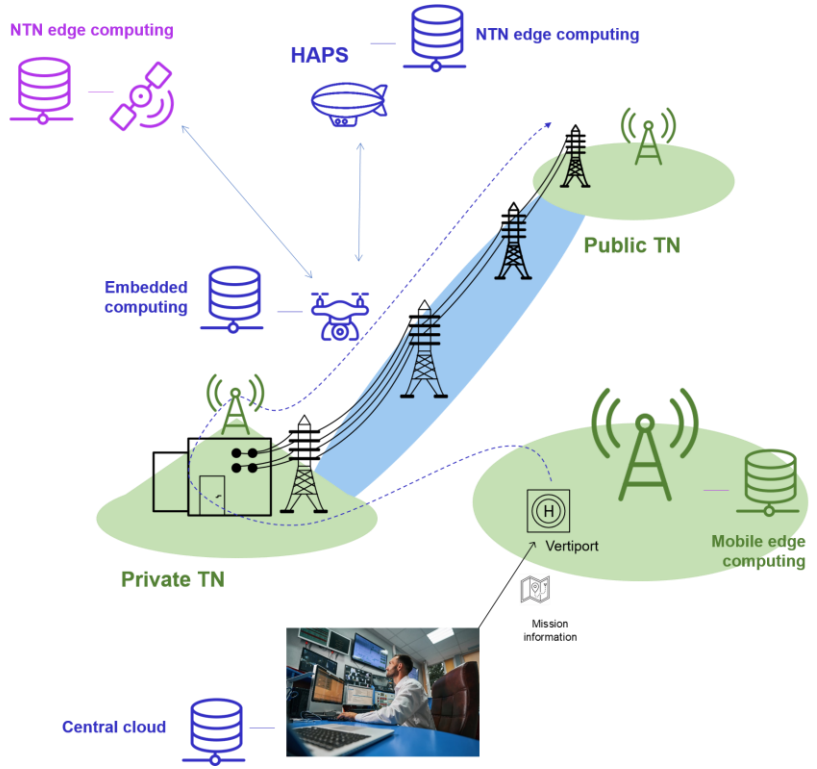
Performance enhancement of existing services or new ones!

6G services via NTN



Maritime coverage for S&R intervention

- Combined TN/NTN connectivity to coordinate maritime S&R operations
- Coast Guard intervention with
  - TN coverage and UAV
  - only NTN coverage
  - multi-link support for reliable roaming (figure)
  - seamless handover to different feeder links for NTN



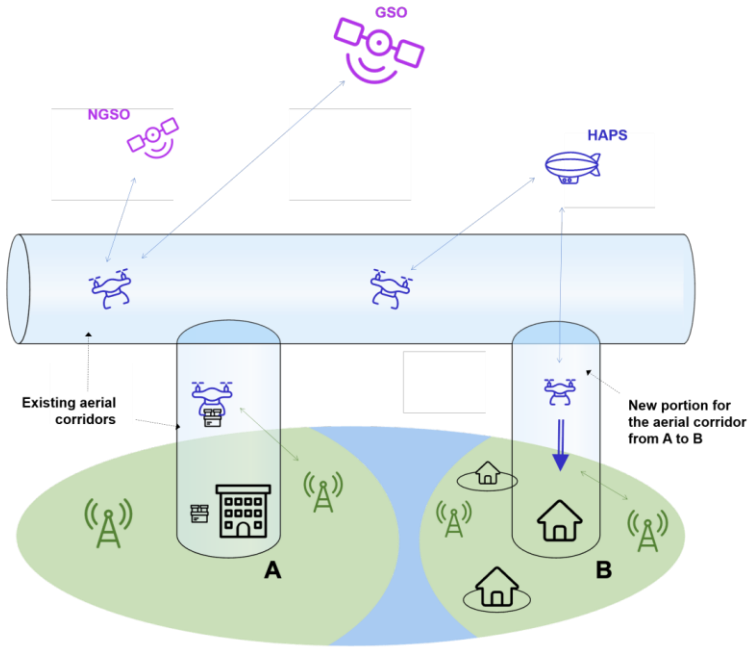
Autonomous power line inspection using drones

- connectivity for a fully autonomous remote UAV operation to monitor the safety, reliability, and integrity of wires, electrical substations, and other power generation assets

Source: SNS JU Project 6G-NTN, D2.1 "Use case report," March 2023. Available: https://www.6g-ntn.eu/public-deliverables/

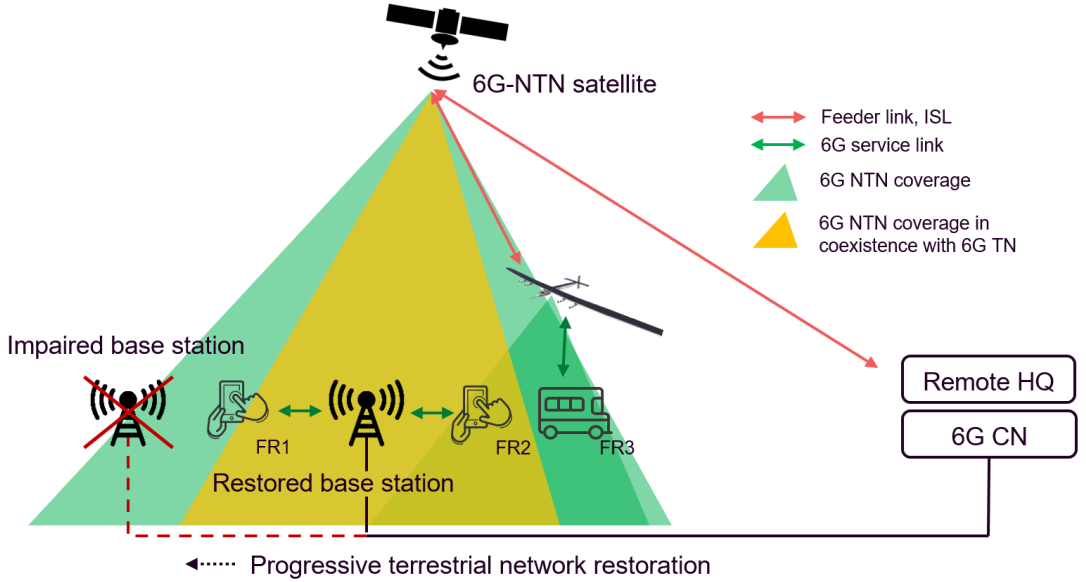
Performance enhancement of existing services or new ones!

6G services via NTN



Urban Air Mobility

- support connectivity in urban environments for automated goods delivery (business, health, citizen, emergency) and human transportation
  - on-demand creation of aerial corridors (figure)
  - anti-collision and autonomous deconfliction
  - emergency situation management



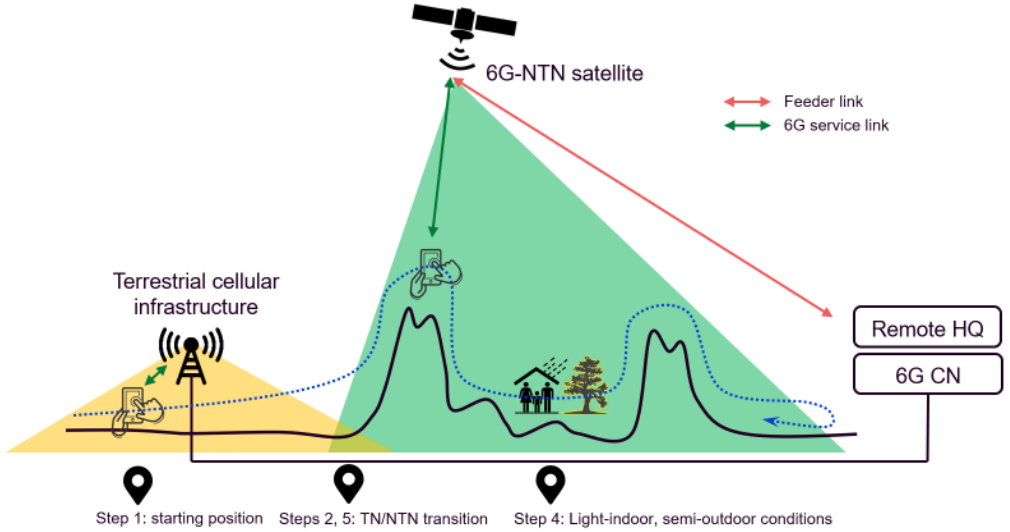
Adaptation to PPDR or temporary events

- provide connectivity in PPDR scenarios or for temporary planned events
  - support first responders communications
  - support greater public communications

Source: SNS JU Project 6G-NTN, D2.1 "Use case report," March 2023. Available: https://www.6g-ntn.eu/public-deliverables/

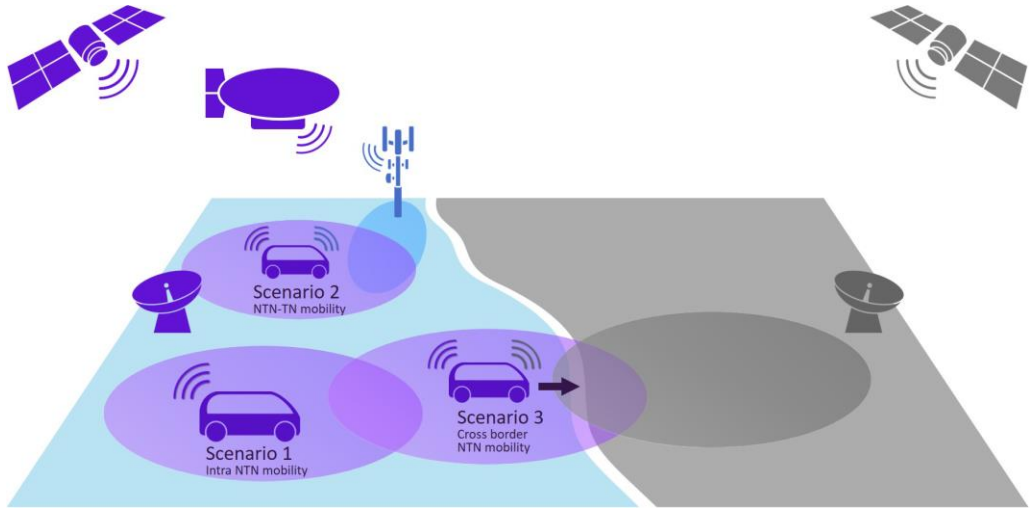
Performance enhancement of existing services or new ones!

6G services via NTN



Consumer handheld connectivity and positioning in remote areas

- provide positioning services in remote areas, and improve the QoE and support seamless transition from/to TNs, also in light indoor conditions



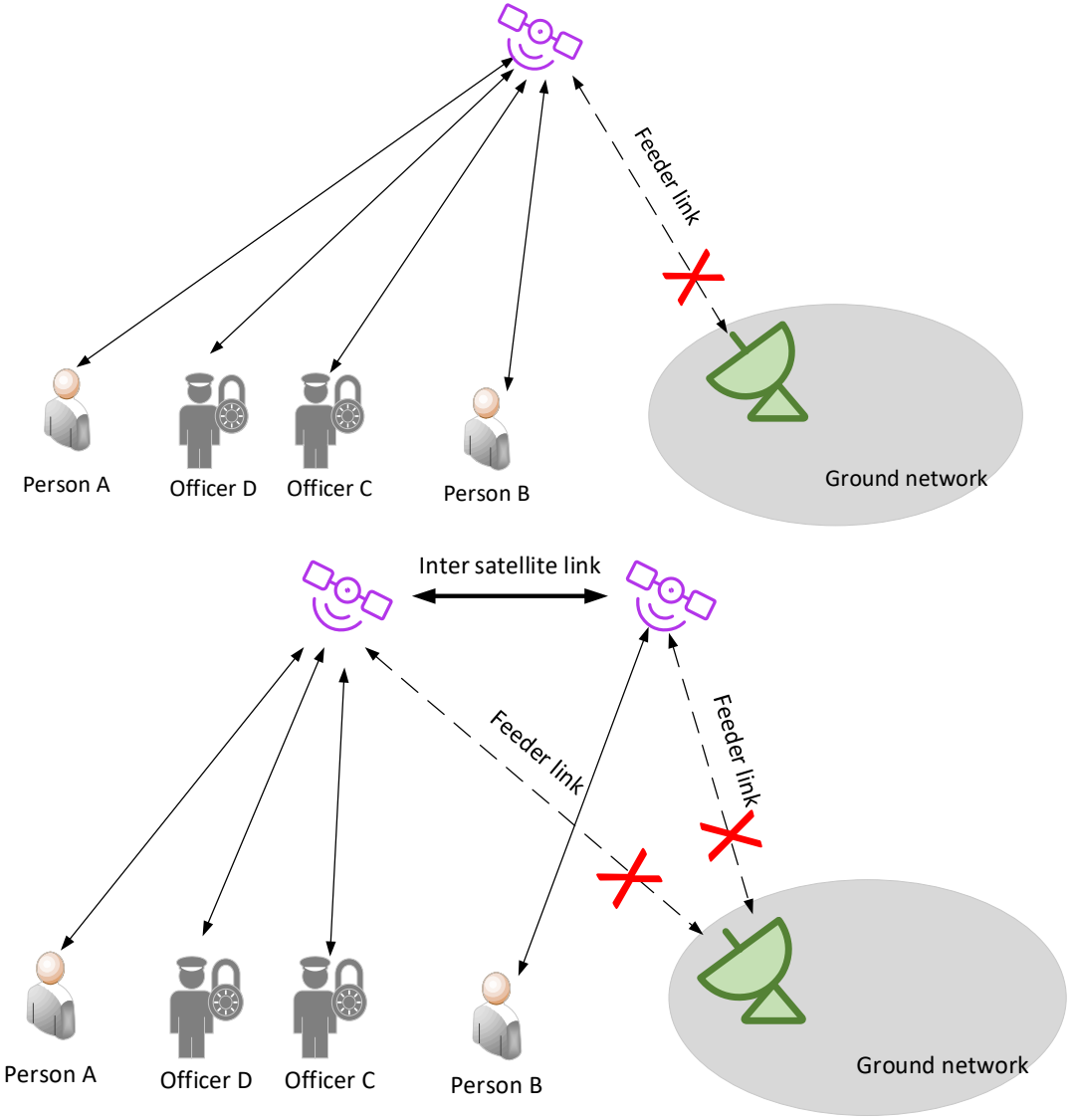
Continuous bidirectional data stream in high mobility

- offer alternative, reliable connectivity for the automotive sector in case of TN coverage loss
  - NTN only usage
  - NTN-TN switching usage
  - NTN-NTN switching in cross-border usage

Source: SNS JU Project 6G-NTN, D2.1 "Use case report," March 2023. Available: https://www.6g-ntn.eu/public-deliverables/

Performance enhancement of existing services or new ones!

6G services via NTN



Direct mesh communications over NTN

- support direct connectivity among users without requiring a feeder link
  - Public Safety
  - Maritime
  - IoT
  - Defense
  - Automotive

Source: SNS JU Project 6G-NTN, D2.1 "Use case report," March 2023. Available: https://www.6g-ntn.eu/public-deliverables/

6G NTN standardisation: an educated guess

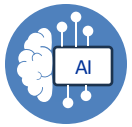
- Potential objectives
  - connectivity in areas not covered by TN
  - improving the coverage performance of direct connectivity, possibly in light indoor conditions
  - reducing the energy consumption through smart TN-NTN routing
  - higher accuracy positioning services beyond TN coverage
  - deterministic 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

Conclusions

- The integration of an NTN component into 5G is a reality since Rel. 17: the first milestone of a long path started more than 20 years ago → **a new beginning**

- The strict interaction of **research, industries, and standardisation/regulatory bodies** is a key to success

- NTN will be a native component in 6G infrastructures
  - **mega-constellations represent a sustainability** (financial/environmental) **challenge** for 6G → new paradigms being explored
  - **(r)evolutionary** technologies are needed to achieve a fully unified 6G air interface

What's so fancy about NTN?

Truly achieve global **service continuity, ubiquity, and resiliency**

Cost reduction through economy of scale for the satellite industries by accessing global standards

Support for **new/enhanced applications and services**

On-going NTN projects

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

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@6Gntn

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/

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

@5G_Stardust

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/

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