The evolution of NTN from 5G to 5G-Advanced and the path to 6G

Workshop on "Non-Terrestrial Networks for 6G Systems" (NTN6G)

11th IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE) 2023

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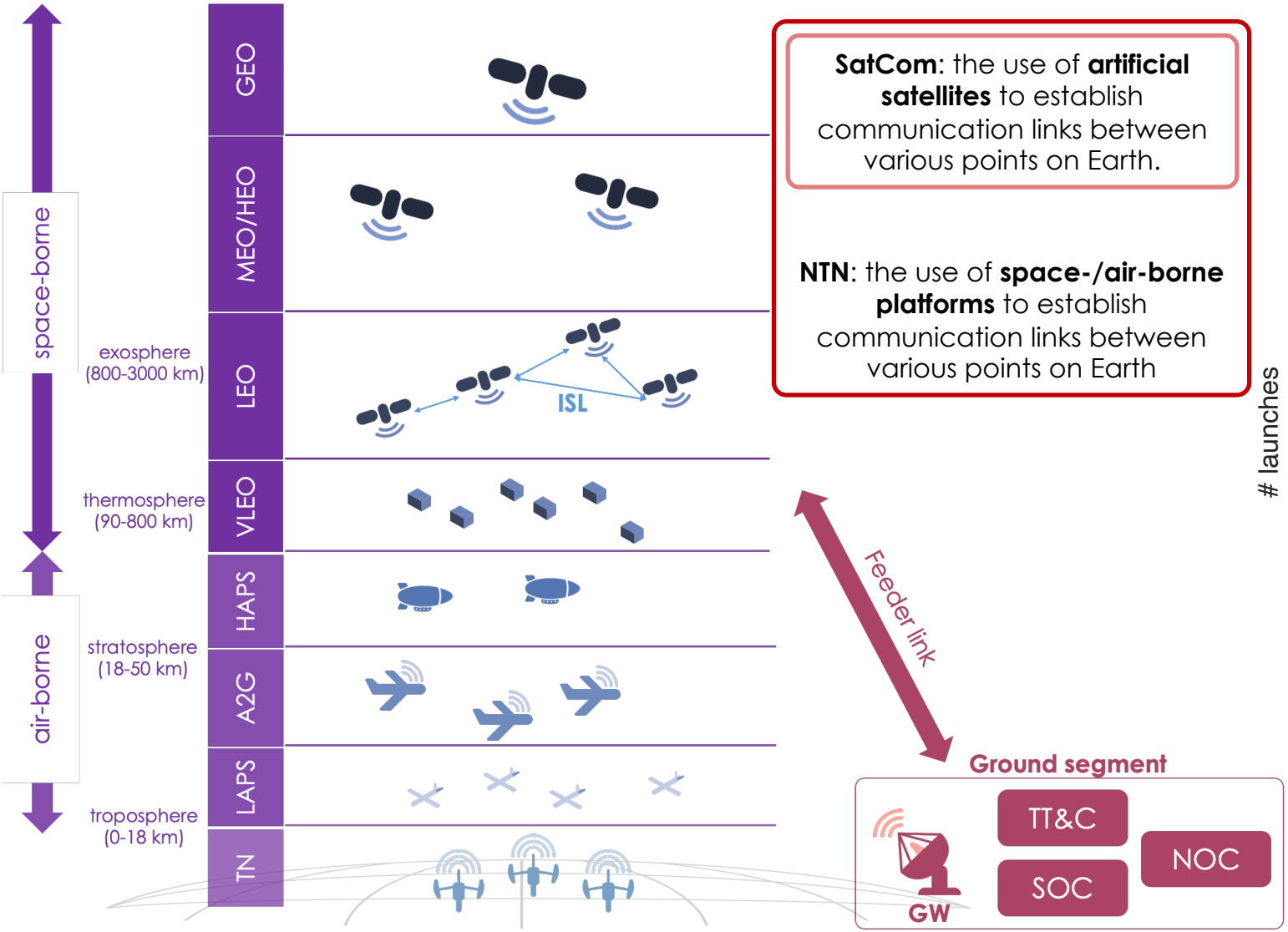
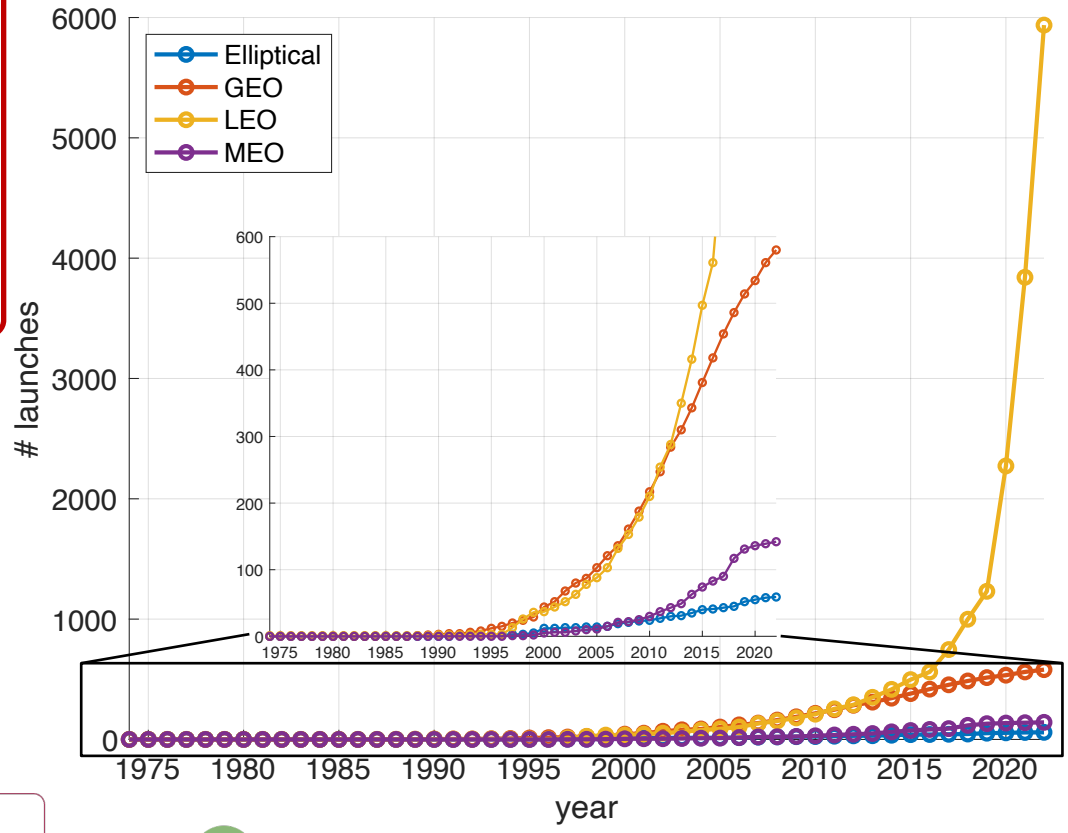
From SatCom to NTN



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

NTN: the use of **space-/air-borne platforms** to establish communication links between various points on Earth



Source: https://www.ucsusa.org/resources/satellite-database

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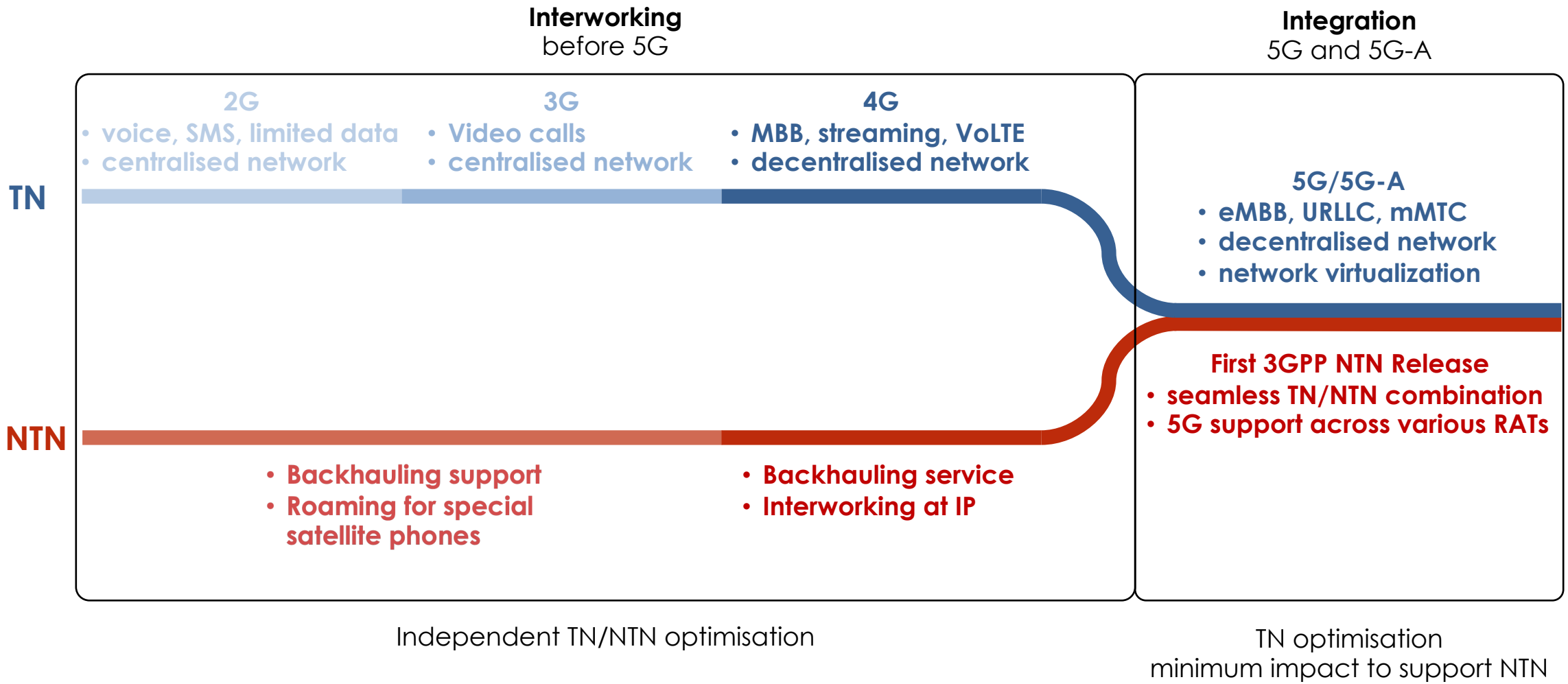
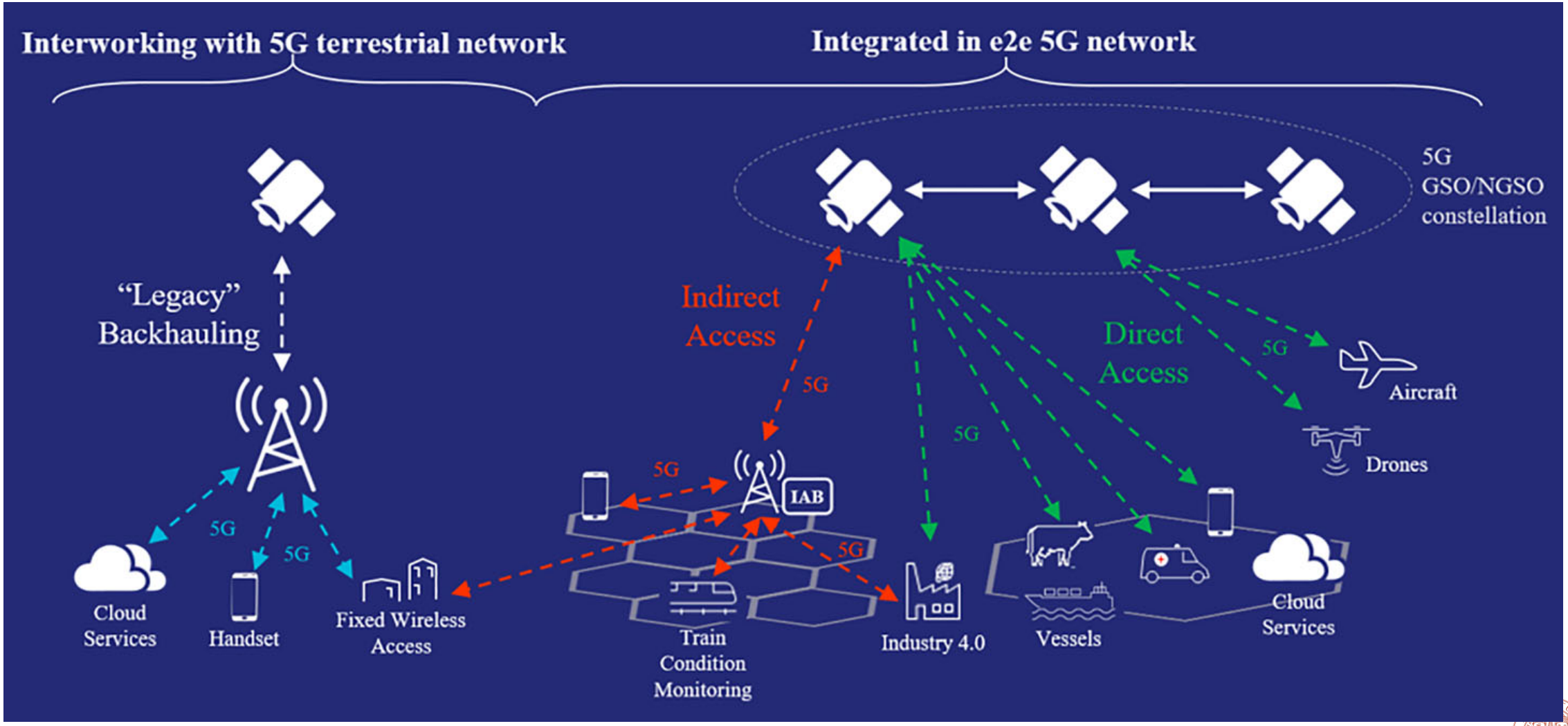
TN/NTN convergence



Source: GSOA, White Paper, "Satellite Communications and their role in enabling 6G," October 2022.

NTN: from interworking to integration

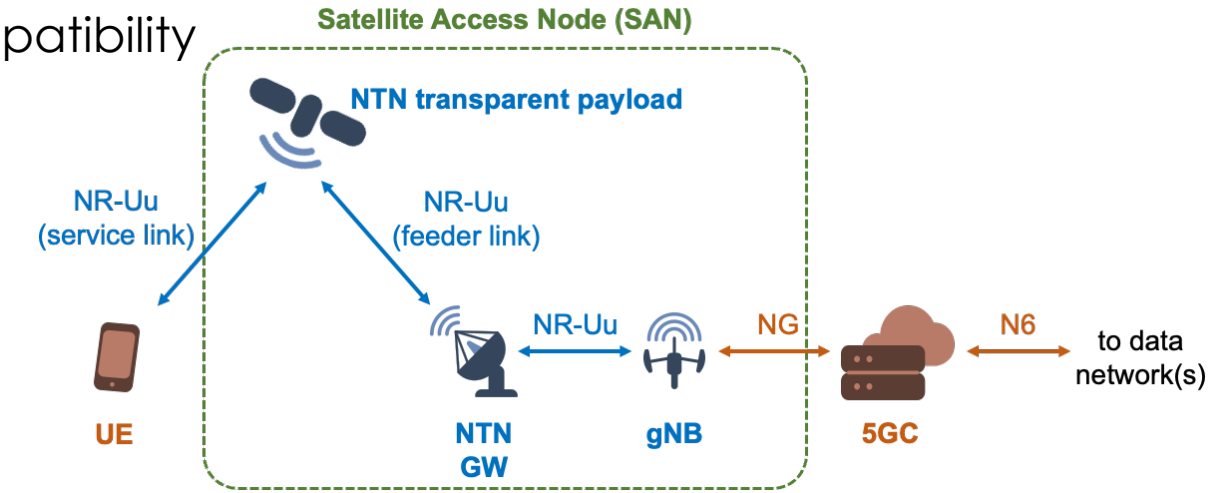


Source: El Jaafari M, Chuberre N, Anjuere S, Combelles L., "Introduction to the 3GPP-defined NTN standard: A comprehensive view on the 3GPP work on NTN," Int J Satell Commun Network. 2023;41(3):220-238. doi:10.1002/sat.1471

3GPP NTN in Rel. 17

- NTN-based GEO/LEO with implicit HAPS/ATG compatibility
- Main characteristics
  - **transparent payload architecture**
  - coverage type
    - **Earth-fixed**
    - **Quasi-Earth-fixed**
    - **Earth-moving**
  - **FR1**: S-band and L-band
  - **handheld** terminals **with GNSS** capabilities
  - **FDD**
  - **Earth-fixed tracking**

- **Massive normative work** to **adapt** the NR system to the **NTN characteristics**



RAN1: Physical layer
- Timing relationship
- UL time and frequency synchronization
- Enhancements on HARQ
- Polarization signaling for VSAT/ESIM

RAN3: Access network architecture
- Network Identity handling
- Registration Update and Paging Handling
- Cell Relation Handling
- Feeder Link Switch-Over (NGSO)
- Aspects Related to Country-Specific Routing

SA2: System level
- Mobility management with huge cell size
- UE location and support of regulated service
- QoS class for GEO satellite links
- Impact of satellite backhauling

RAN2: Access layer
- User Plane: RACH aspects, Other MAC aspects (e.g. HARQ), UP: RLC, PDCP
- System information broadcast
- Control Plane: Tracking Area Management, Idle/connected mode mobility, UE Location Service

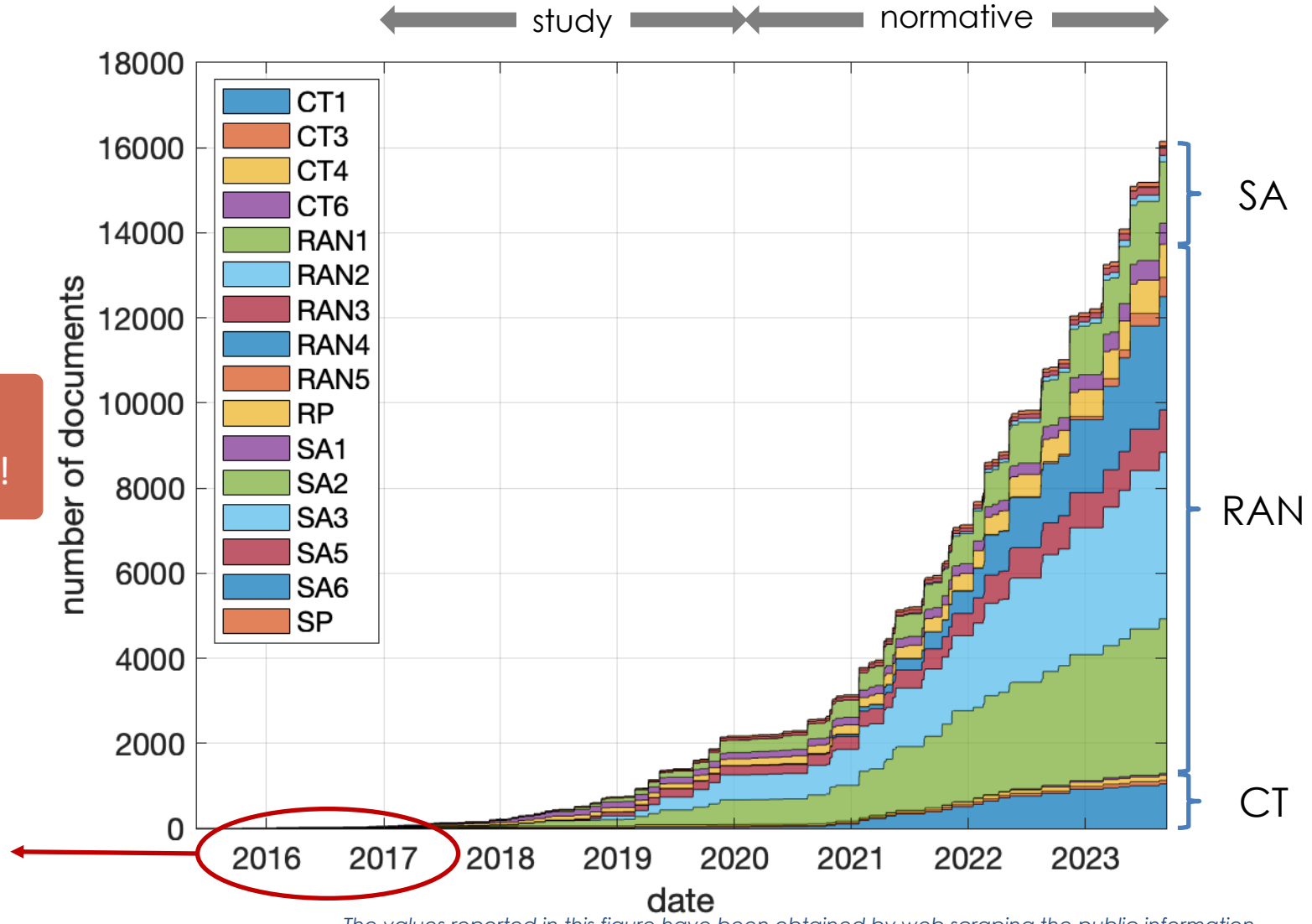
RAN4: RF & RRM performance
- New bands
  - TN/NTN coexistence
  - Satellite Access Node, UE
- RRM: e.g. timing compensation (idle, connected mode), GNSS accuracy

CT1: Network protocols
- PLMN (re)selection
- NAS timers

Source: Mohamed El Jaafari, "3GPP NTN standardization: status and prospect," ASMS/SPSC conference, September 2022.

3GPP NTN standardisation effort

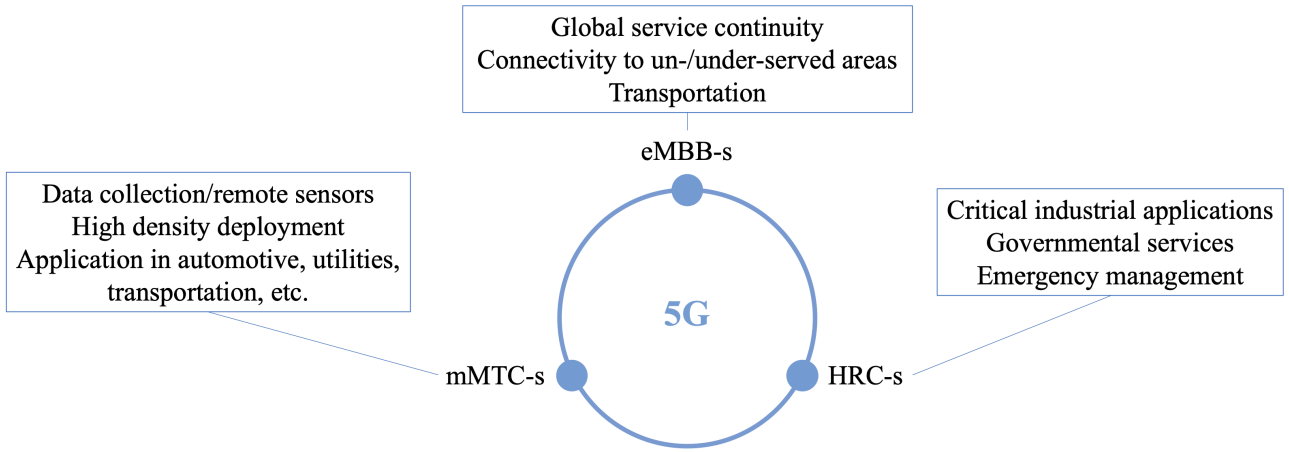
The inclusion in Rel. 17 made NTN skyrocketing!



<100 contributions in 2016-2017

The values reported in this figure have been obtained by web scraping the public information available on the 3GPP website in August, 2023, with a tool proprietary of the University of Bologna. As such, the exact values might be subject to variations, without impacting the general trends.

5G NTN services

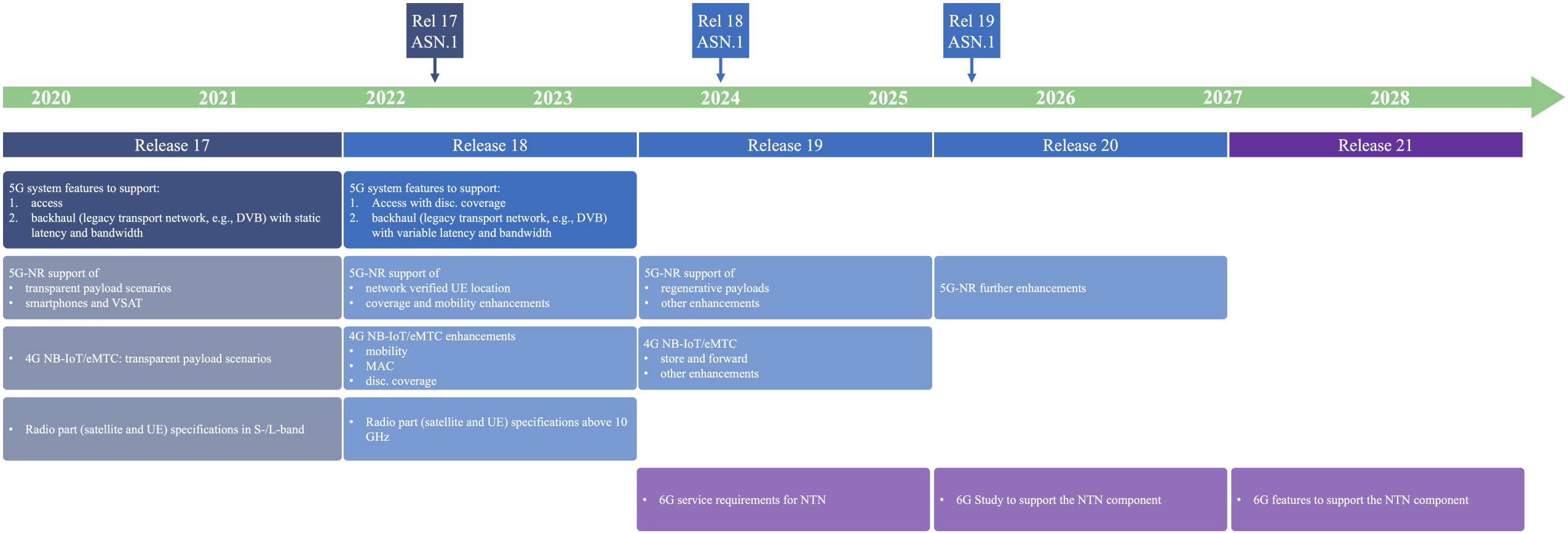


Source: A. Guidotti et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," submitted to IEEE Access, 2023

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
Dedicated providers					
Space X	2016 LEO (0)	MNO spectrum/ 2GHz MSS	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
AST SpaceMobile	243 LEO (1)	MNO spectrum	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
Lynk	5000 LEO (3)	MNO spectrum	Pre Rel-17 3GPP	2Q2023	Messaging, LDR (low-data rate)
Sateliot	250 LEO (1)	2.0GHz MSS	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Ligado	1 GEO	L-band	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Partnerships					
T-Mobile/SpaceX	2016 LEO (0)	MNO spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video
AT&T/AST	243 LEO (0)	MNO spectrum	3GPP-Rel 12	2024	Messagign, Data, Voice, Video
Mediatek/ Skylo/Bullitt	6 GEO (Inmarsat)	L-band	3GPP-NTN	1Q2023	Messaging
Skylo/ Ligado/Viasat	1 GEO (Ligado)	L-band	3GPP-NTN	2H2023	NB-IoT, Messaging, LDR

Source: 5G Americas, White Paper, "Update on 5G Non-Terrestrial Networks," July 2023.

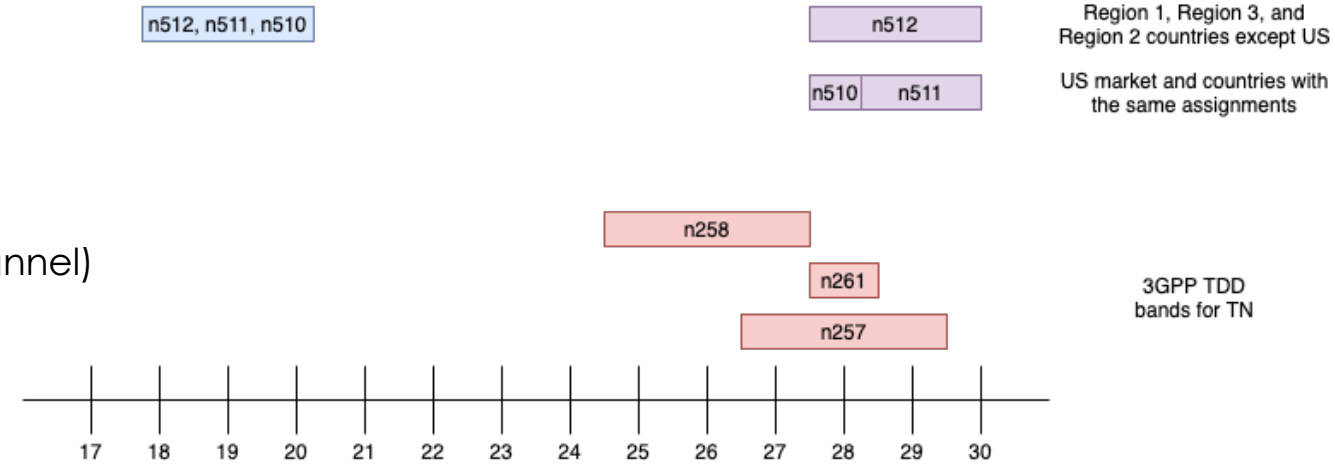
3GPP NTN beyond Rel. 17



Source: A. Guidotti et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," submitted to IEEE Access, 2023

NTN Rel. 18: main features

- Enhancements to the **NR radio protocols** to
  - **support FR2** and mobile/nomadic **VSAT**
    - evaluations based on transparent payloads (IAB/regenerative FFS)
    - co-existence analysis on-going (adjacent channel)
  - allow the **network verification of the GNSS** coordinates determined by the UE
  - optimise **mobility procedures** in both idle and connected modes



Source: ESA EAGER Project, White Paper, "Architectures, services, and technologies towards 6G Non-Terrestrial Networks," February 2023.

Source: EC HORIZON-JU-SNS-2022 Project 5G-STARDUST, D3.1 "System Requirements Analysis and Specifications," July 2023.

- Enhancements to the **NB-IoT/eMTC radio protocols** to
  - optimise **mobility procedures**
  - improve the support of small constellations providing **discontinuous service** over a given area

NTN Rel. 19: potential topics

- Coverage enhancements (DL and possibly UL)
- NTN/TN mobility enhancement in connected mode (e.g., CHO)
- Support of HD mode RedCap UE (Reduced Capabilities) in FR1

NR-NTN improved service experience

- Support of regenerative payloads (i.e., with ISL)
- Support of UEs with GNSS independent operation for uplink time and frequency synchronization in NTN based access (idle/connected modes)

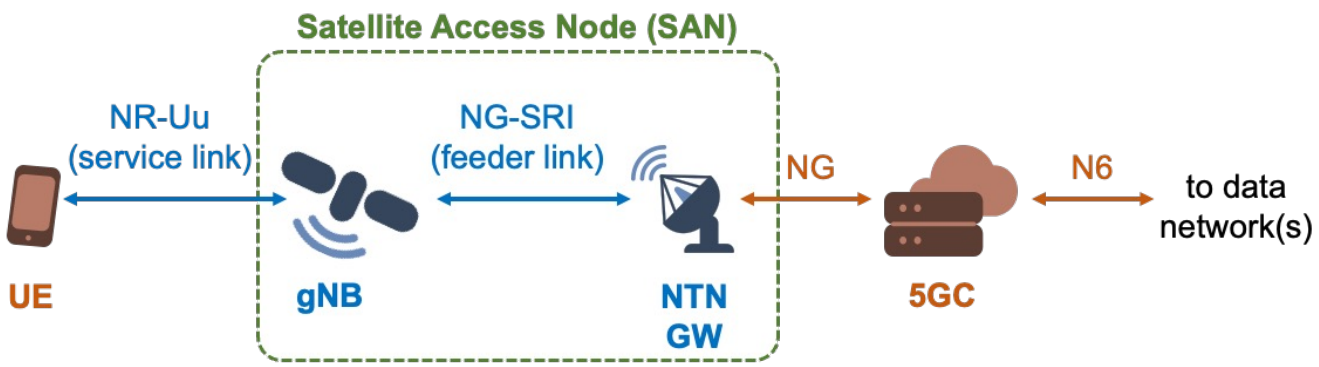
NR-NTN new capabilities

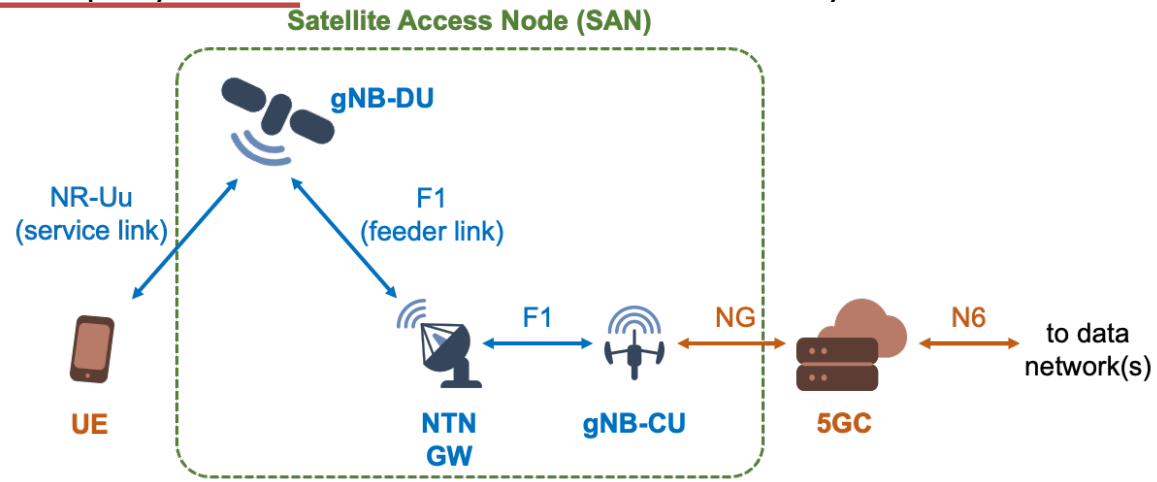
- Regenerative payload = Store and Forward (i.e., eNB + ePC network elements)

IoT-NTN new capabilities

NTN Rel. 19: architecture

- Architecture evolution in three directions: regenerative payloads, IAB, Multi-Connectivity





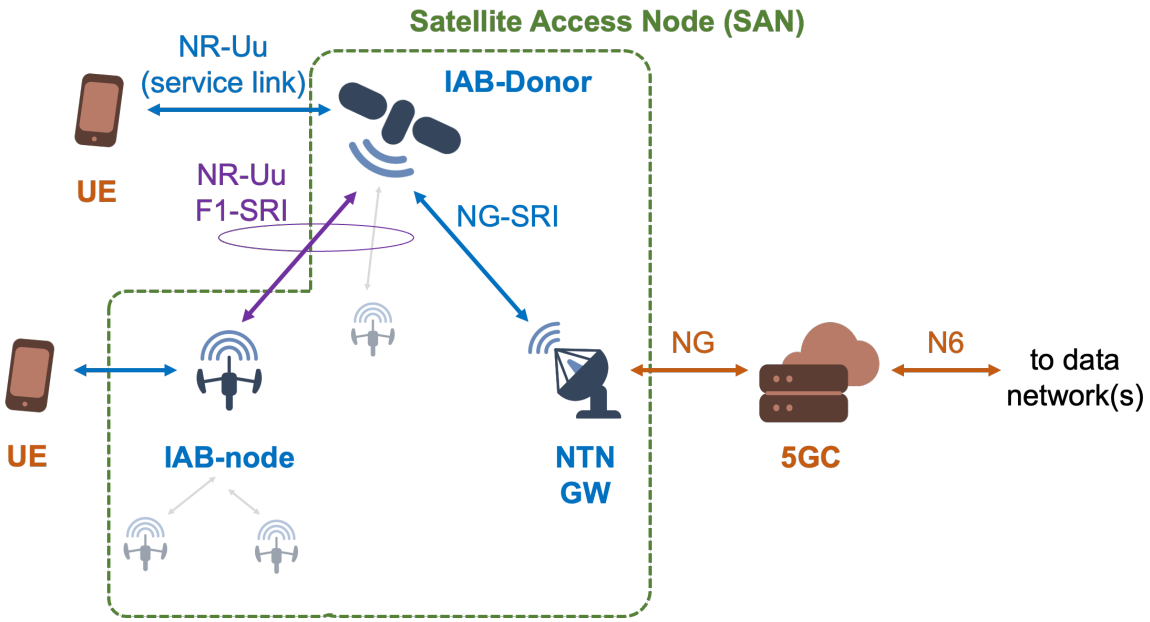
- **Full gNB on-board**
  - all protocols up to SDAP/RRC are terminated on-board
  - the feeder link SRI (PHY+MAC) shall carry the NG upper layers
  - routing schemes and algorithms now also involve the GW and the NTN payload
- **Functional split**
  - scalable solution based on NFV/SDN for system tailoring
  - challenges related to F1
  - only opt.2 split is full-3GPP

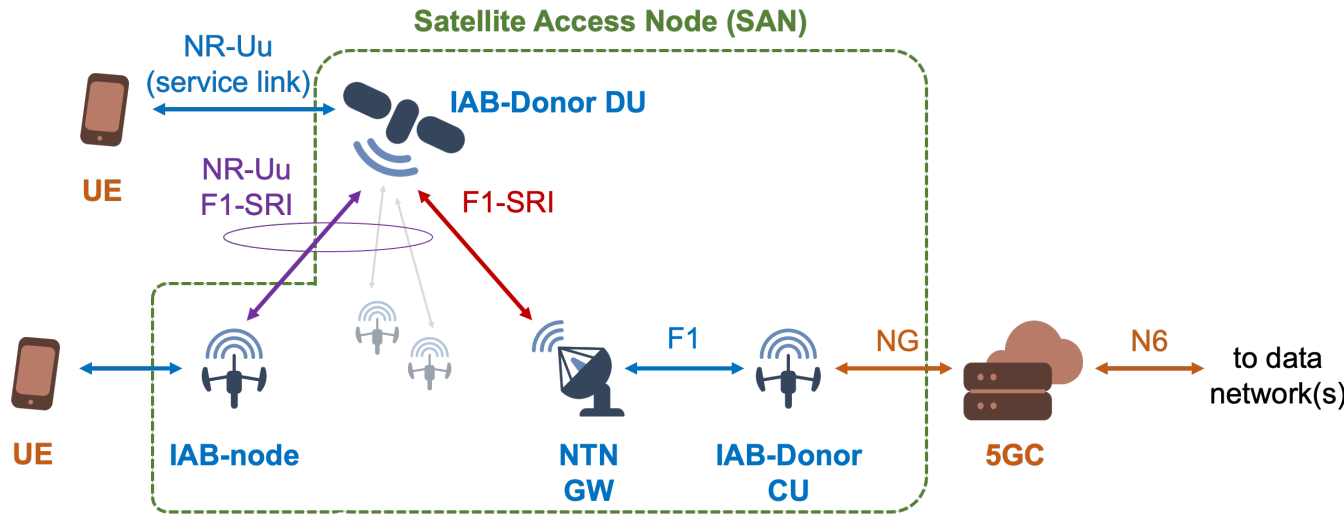
Source: ESA EAGER Project, White Paper, "Architectures, services, and technologies towards 6G Non-Terrestrial Networks," February 2023.

Source: EC HORIZON-JU-SNS-2022 Project 5G-STARDUST, D3.1 "System Requirements Analysis and Specifications," July 2023.

NTN Rel. 19: architecture

- Architecture evolution in three directions: regenerative payloads, IAB, Multi-Connectivity





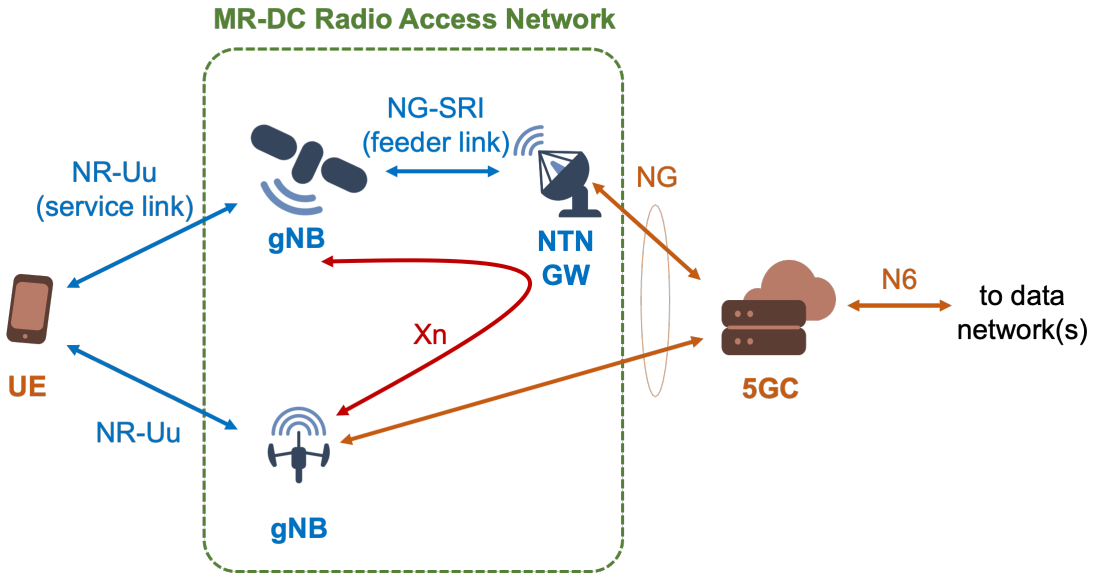
- **Regenerative payload: full Donor on-board**
  - both direct and indirect connections are possible
  - challenges related to F1-SRI on the service link
  - challenges related to NG-SRI on the feeder link
  - BAP on the service link

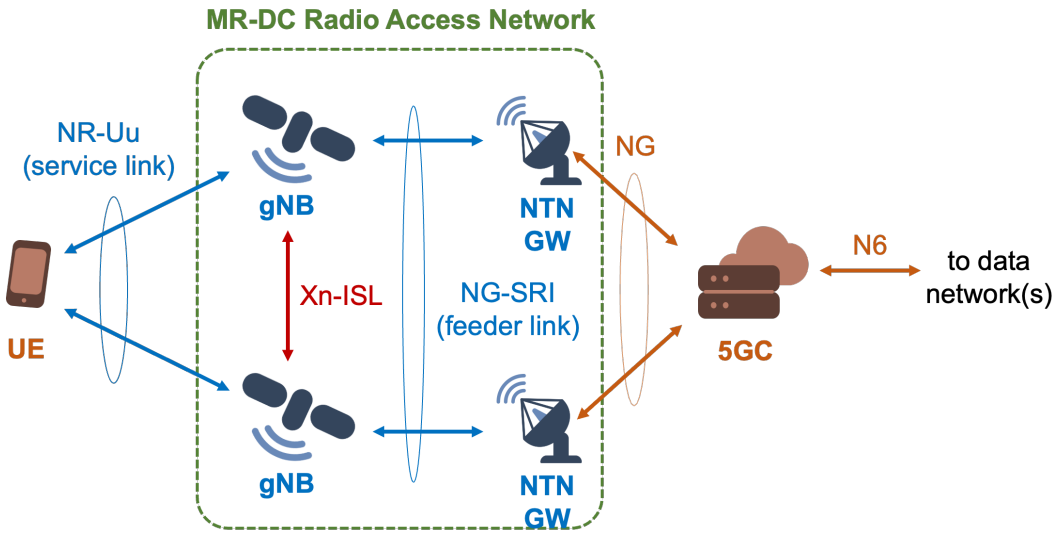
- **Regenerative payload: Donor-DU on-board**
  - both direct and indirect connections are possible
  - challenges related to F1-SRI on the service and feeder links
  - BAP on the service link

Source: EC HORIZON-JU-SNS-2022 Project 5G-STARDUST, D3.1 "System Requirements Analysis and Specifications," July 2023.

NTN Rel. 19: architecture

- Architecture evolution in three directions: regenerative payloads, IAB, Multi-Connectivity





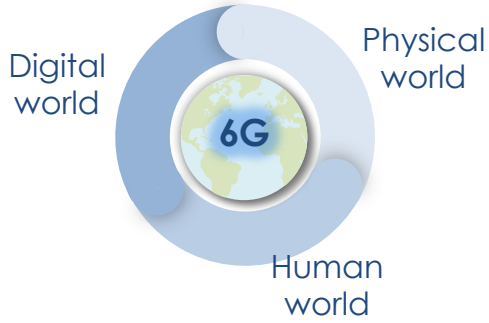
- **TN-NTN with regenerative payload**
  - challenging due to the different channel characteristics
  - NG-SRI on the feeder link
  - Xn-SRI on the feeder link
  - both TN-gNB and NTN-gNB can be elected MN

- **NTN-NTN with regenerative payload**
  - the NTN nodes do not necessarily belong to the same orbit (challenging)
    - e.g., low-latency through LEO and large throughput through GEO
  - NG-SRI on the feeder link
  - Xn over ISLs

Source: EC HORIZON-JU-SNS-2022 Project 5G-STARDUST, D3.1 "System Requirements Analysis and Specifications," July 2023.

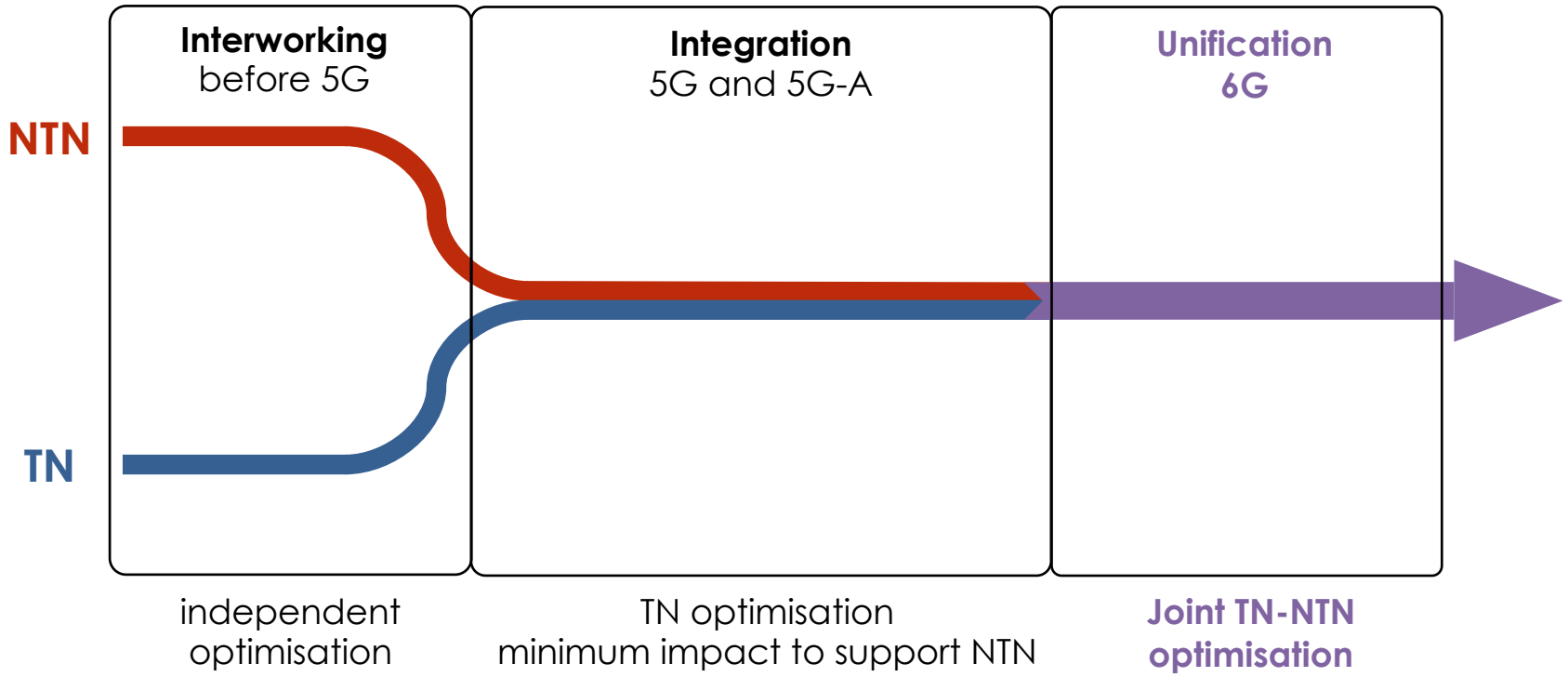
The role of Non-Terrestrial Networks in 6G

- 6G systems are expected to achieve more than "just" extremely fast connectivity
  - digital twinning between domains: convergence of the physical, human, and digital worlds
  - connected intelligence
  - immersive communications: high-resolution visual/spatial, tactile/haptic, and other sensory data



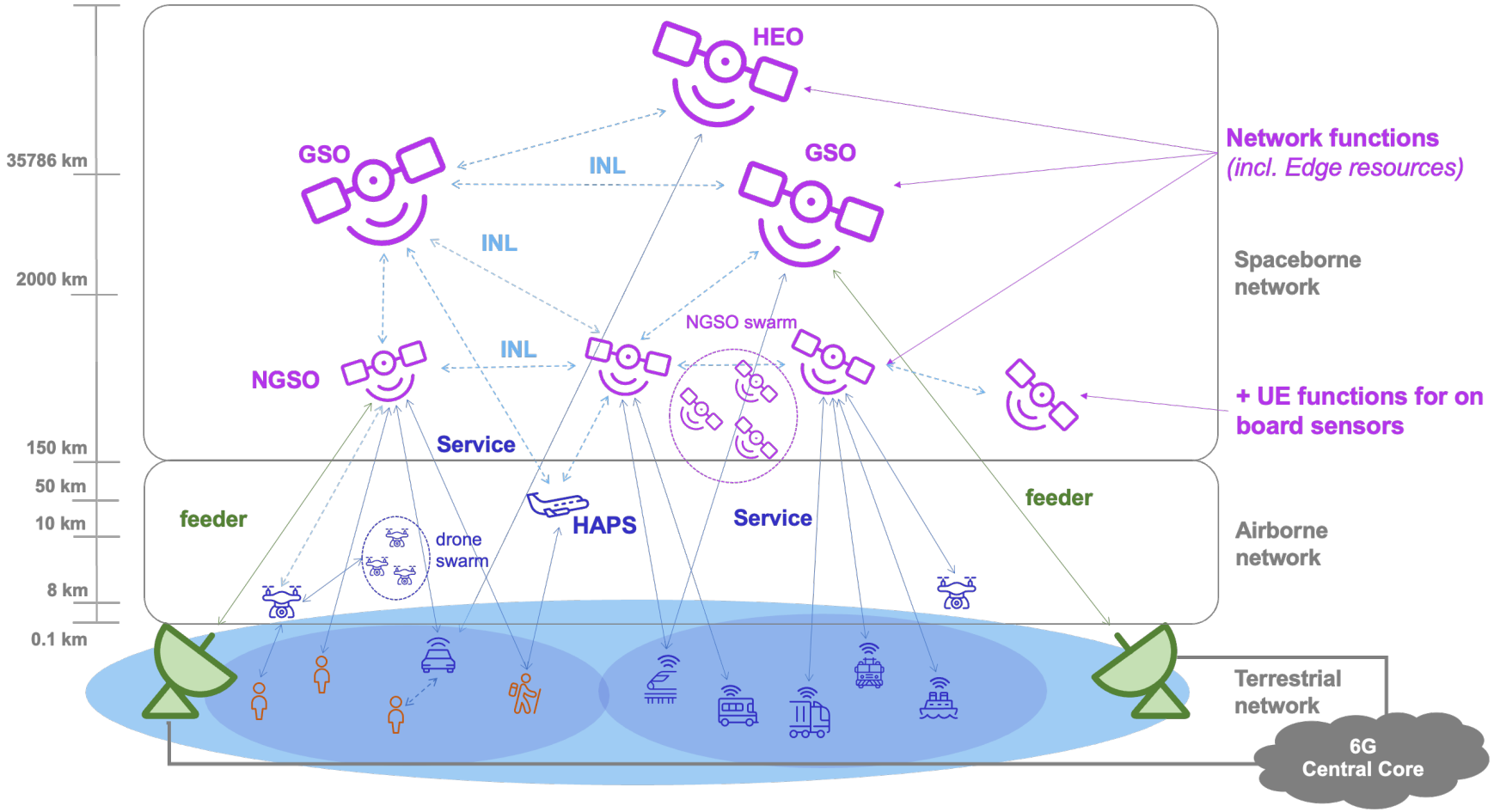
- Non-Terrestrial Networks will be pivotal to provide a ubiquitous, continuous, flexible, and resilient infrastructure for
  - **Direct connectivity** to smart phones outdoor and in light indoor/in-vehicle (emergency communications)
  - **Connectivity mobile platforms** (trains/planes/ships/drones/HAPs)
  - **Broadcast/multicast**
  - **Low latency communications to support vertical markets** (railway, automotive, aeronautical, etc)
  - **Network-based positioning**
  - **IoT applications** (global NB-IoT/mMTC coverage, remote/control monitoring of critical infrastructures, smart good tracking)

The role of Non-Terrestrial Networks in 6G



- The current NTN standardization framework provides a solid ground for NTN integration into 5G
- 5G-A will introduce enhancements with additional capabilities and increased performances
- **6G will target a fully unified T-NT infrastructure based on multi-dimensional multilayer architecture**

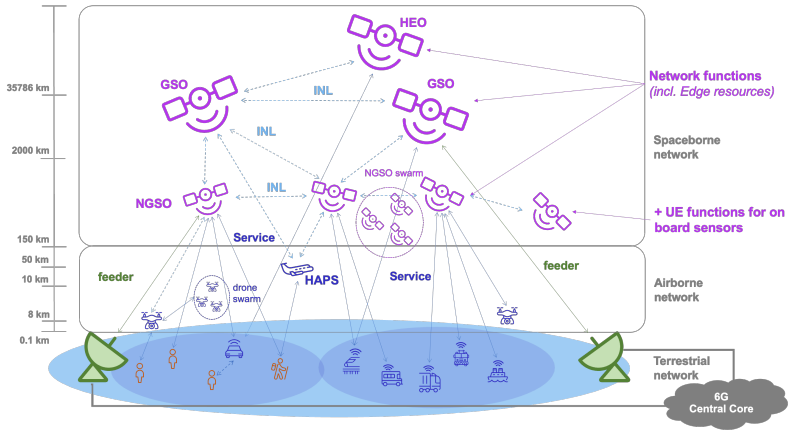
The role of Non-Terrestrial Networks in 6G



- No distinction between TN and NTN nodes: they are all nodes of the same infrastructure, to be jointly optimised and exploited

Source: A. Guidotti et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," submitted to IEEE Access, 2023

The role of Non-Terrestrial Networks in 6G



Architecture and system design

Multi-layered constellation from GEO to drones, Innovative LEO and vLEO orbits, optical inter and intra node-links design, cell-free MU-MIMO, traffic-driven coverage

Networking, edge computing and communications

Softwarization, virtualization, and orchestration of network resources, functional split, advanced IP, routing in the sky, resource management, integrated edge communication and computing

Flexible and integrated waveforms

Low PAPR and low OOBE solutions, Non-orthogonal techniques to increase the connection density, novel RA procedures to allow multiple transmissions per beam, multipoint transmission from the sky, distributed beamforming

Dynamic Spectrum Access and new spectrum

Coordinated and uncoordinated sharing among different access technologies, inter and intra layer, higher frequency bands, Q/V and above

Positioning

Network based positioning

AI/ML

Network and system orchestration, Radio Resource Management, Network traffic forecasting, Physical layer management, Channel estimation

Antennas and components

Active antennas for link budget and flexible coverage, Refracting RIS for indoor coverage, regenerative payload, high-parallel energy efficient HW, Optical devices

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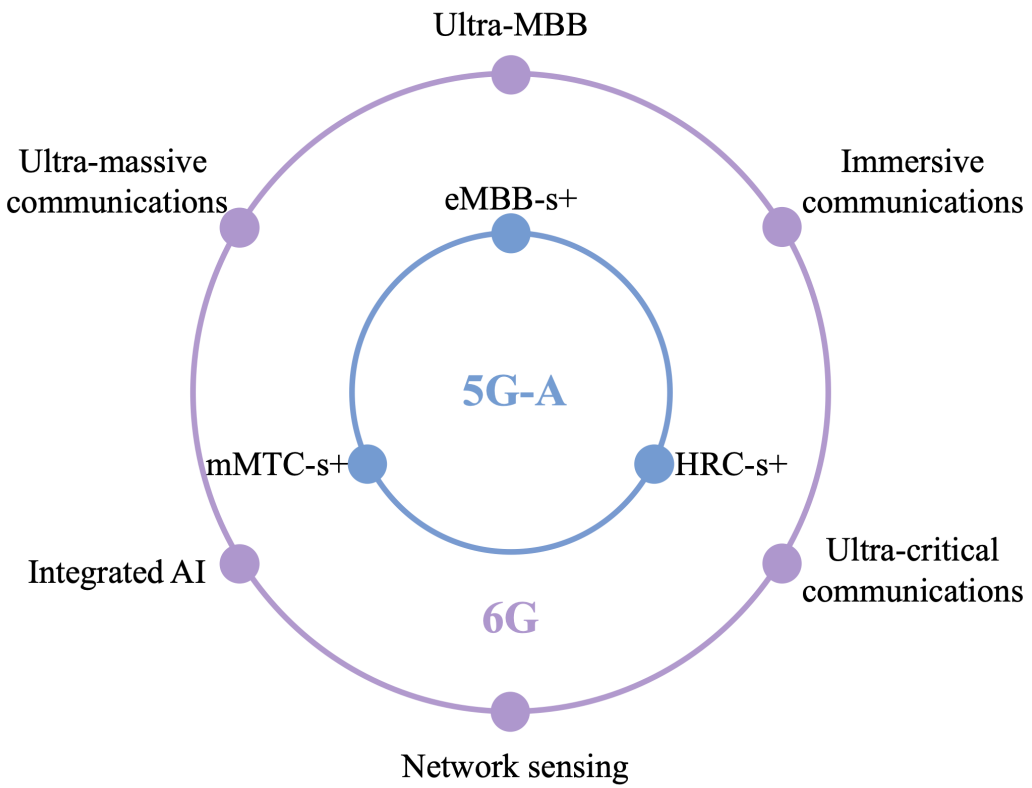
The role of Non-Terrestrial Networks in 6G



6G NTN key elements

Source: A. Guidotti et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," submitted to IEEE Access, 2023

Conclusions

- The integration of an NTN component into 5G is a reality since Rel. 17
- However, both **evolutionary and revolutionary technologies** are needed towards a true fully integrated NT-T system infrastructure for 5G-Advanced and 6G communication systems
- **NTN** will play a **pivotal** role in future fully unified systems, leading to a **ML-MO-MB 6G NTN**

For future NTN systems, we need to make a further technology leap now!

Current funded projects on NTN…

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

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

https://twitter.com/6Gntn

https://www.eagerproject.eu

https://www.linkedin.com/company/eager-project/

https://twitter.com/eagersatcom

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

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

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