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UNIVERSITÀ DI BOLOGNA

Walking into 6G NTN

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Acknowledgements and disclaimer

6GNTN

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

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RESTART

Contribute to shape the evolution of Telecommunications in Italy, focusing on the main topics of Telecommunications, including all types of related systems and networks for both human and non-human users.

https://www.fondazione-restart.it/

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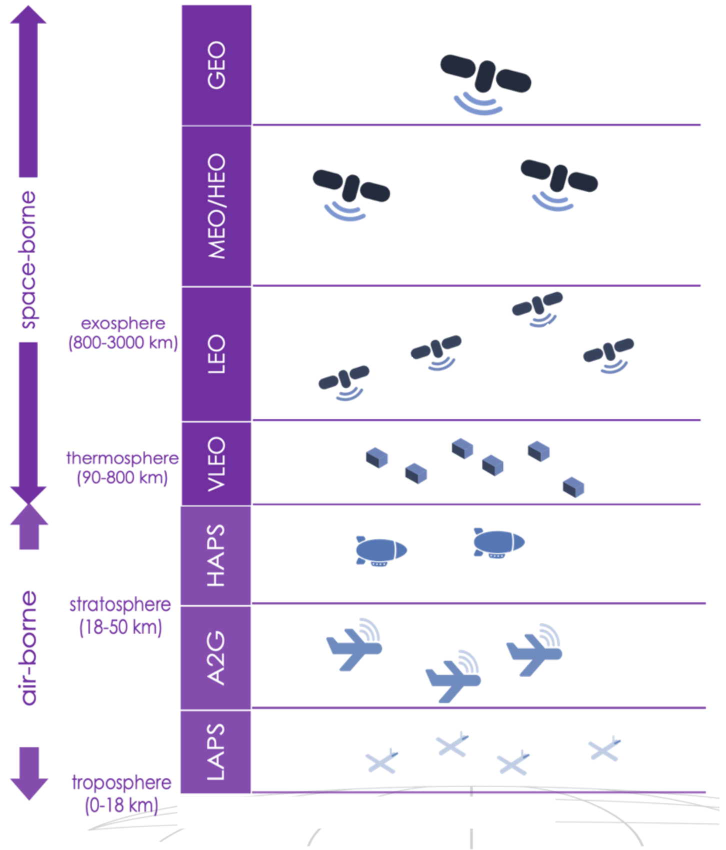
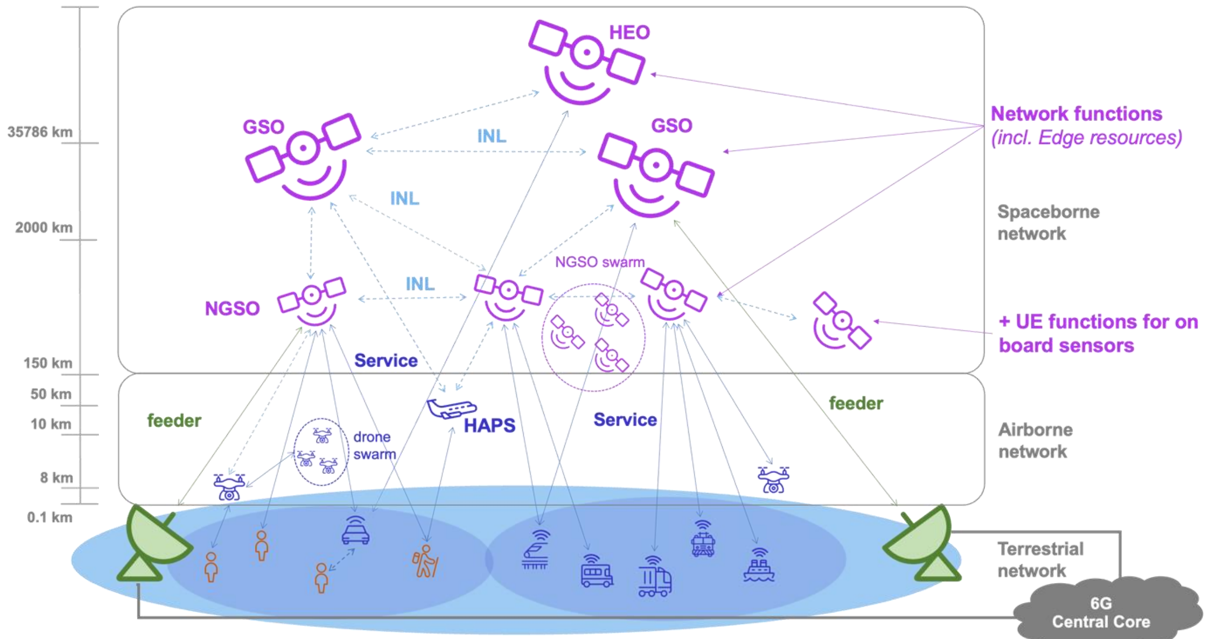
The path to Non-Terrestrial Networks and its evolution

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 referes to a **wider and more general concept** of communication systems, it is now commonly **associated to 3GPP systems** because it has been intially used in the context of the 3GPP NR standardization,*

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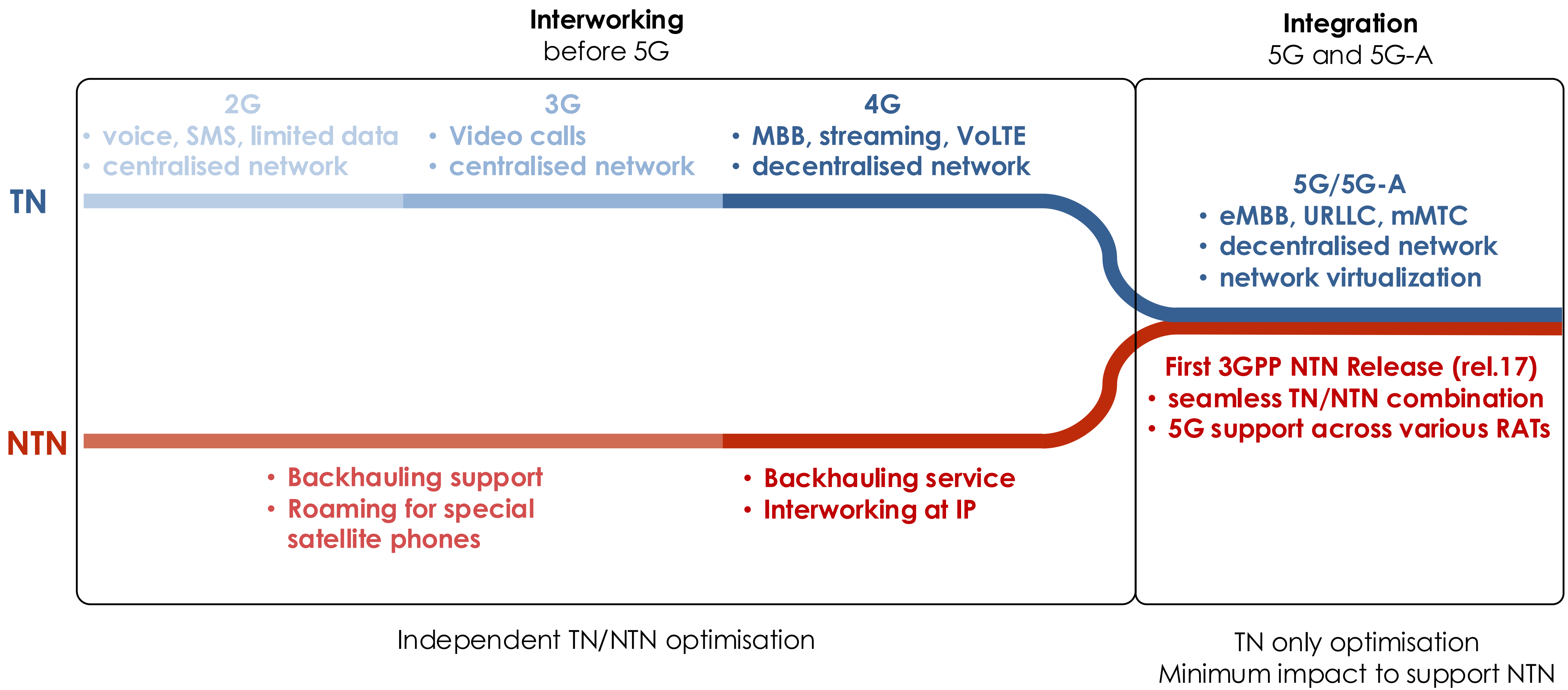
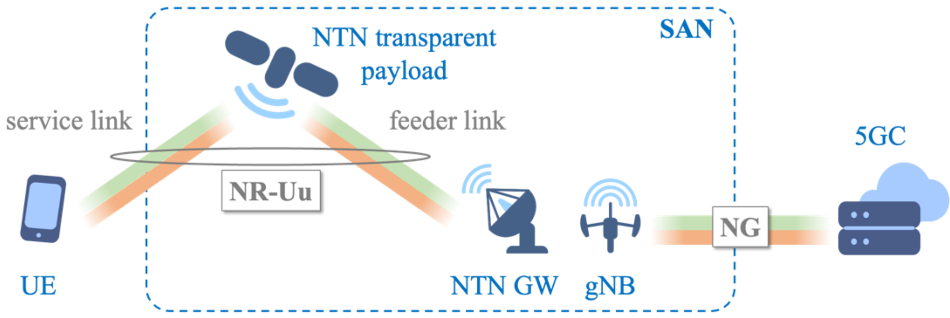
From interworking to integration



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

NTN Rel. 17: overview

- Main characteristics
  - GEO/LEO based with implicit HAPS/ATG compatibility
  - transparent payload architecture
- Coverage type
  - Earth-fixed: the beams continuously cover the same geographical area (e.g., GEO)
  - Quasi-Earth-fixed: the beams cover a geographical area for a period of time and a different area in the next period (e.g., NGSO with steerable beams)
  - Earth-moving: the beams cover a fixed area with respect to the satellite, i.e., beams move on the surface of the Earth along the satellite's movement on its orbit (e.g., NGSO without steerable beams)
- Spectrum in FR1: S-band and L-band
  - FDD
  - TDD unfeasible due to the large propagation delays on satellite links
- Handheld terminals with GNSS capabilities
  - The UE is capable of estimating its location and report it to the network
  - SIB 19 for satellite ephemerids



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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
n511	28.35-30 GHz	17.3-20.2 GHz	FDD
n510	27.5-30 GHz	17.3-20.2	FDD

- 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)

NTN Rel. 19: overview

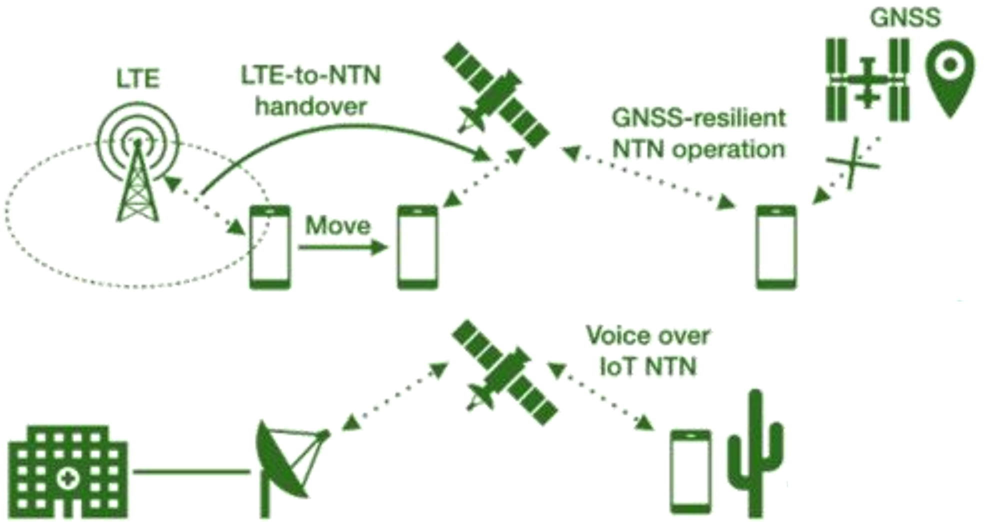
- NR radio protocols
  - DL **coverage enhancements** (*e.g.*, additional payload parameters for GSO/NGSO constellations in FR1/FR2)
  - UL **capacity enhancements** in FR1
  - **broadcasting services via NTN**: signalling information of the intended service area
  - **RedCap** UEs for NR-NTN **in FR1**
  - **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

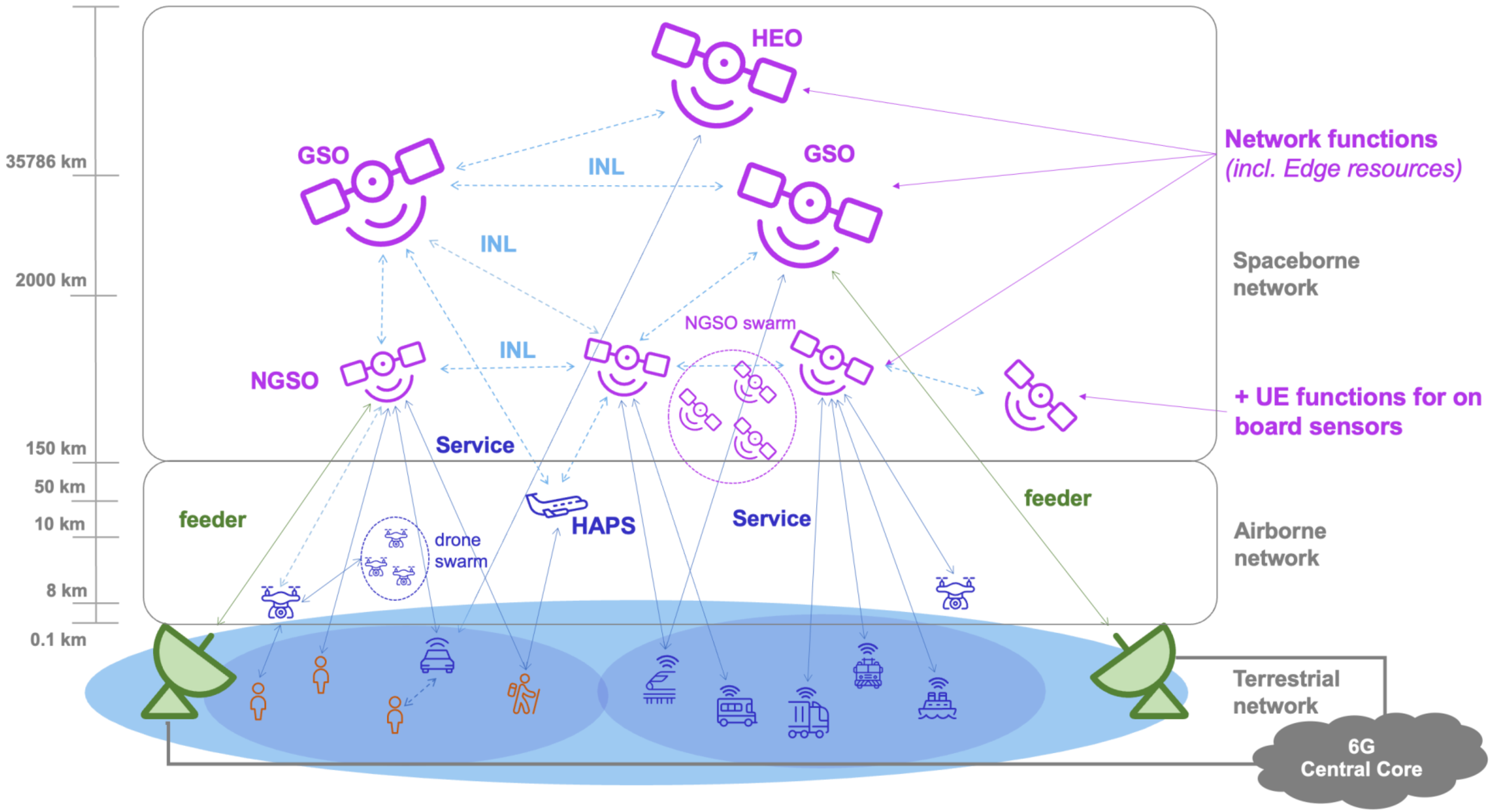
NTN Rel. 20: overview

- Last week 3GPP formally approved the scope of its Rel. 20
- Rel. 20 has dual-track strategy:
  - improve 5G-A capabilities
  - initiate preliminary studies for 6G
- In Rel. 20, 3GPP targets
  - **enabling voice calls over GEO satellites using NB-IoT technology** (RP-251867)
    - Several key enhancements to NB-IoT:
      - down-selection between control-plane and user-plane solutions for voice transport
      - support of semi-persistent scheduling for NB-IoT-NTN for DL and UL data transmission for voice packets
      - modifications to RRC connection setup procedure for NB-IoT-NTN
      - modifications for emergency call for voice over NB-IoT-NTN
      - UE transmit power higher than PC1 (e.g., up to 37dBm) for NB-IoT-NTN
  - enabling **GNSS-resilient NR NTN operation**
  - **service continuity through multi-orbit satellite access** (TR 22.887)



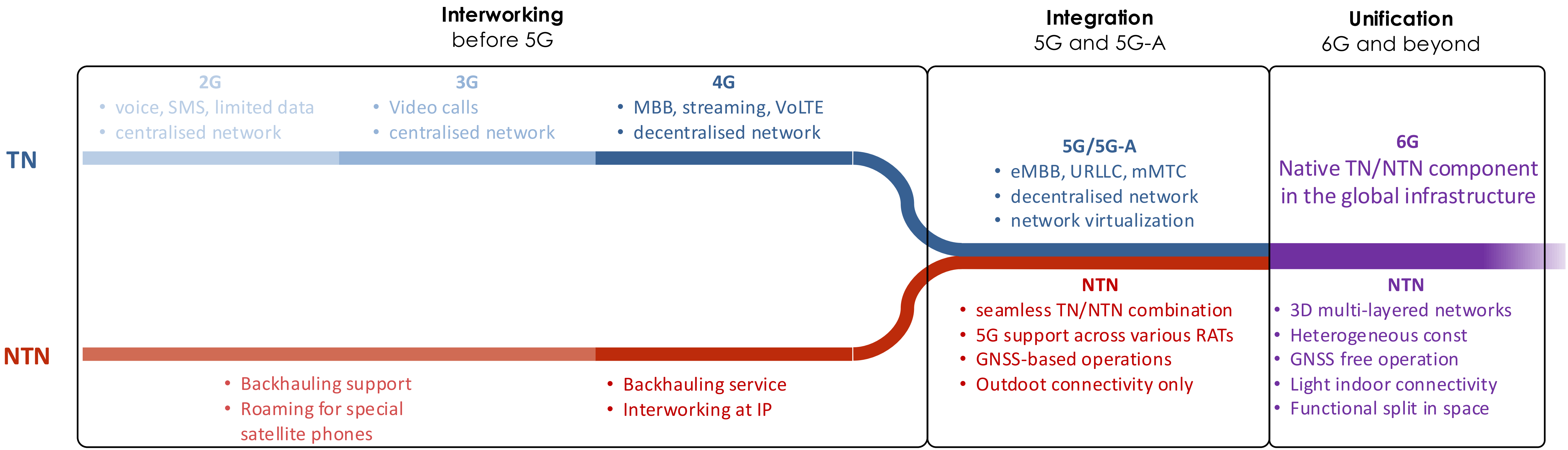
Source: NVIDIA, 'A Tale of Two Mobile Generations: 5G-Advanced and 6G in 3GPP Release 20' May 2025

The 3D multi-layered network



Source: A. Guidotti, A. Vanelli-Coralli et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," IEEE Access, 2024

The path to unification



Interworking
SatCom systems based on ad-hoc or proprietary architectures and protocol stacks: no integration with terrestrial systems

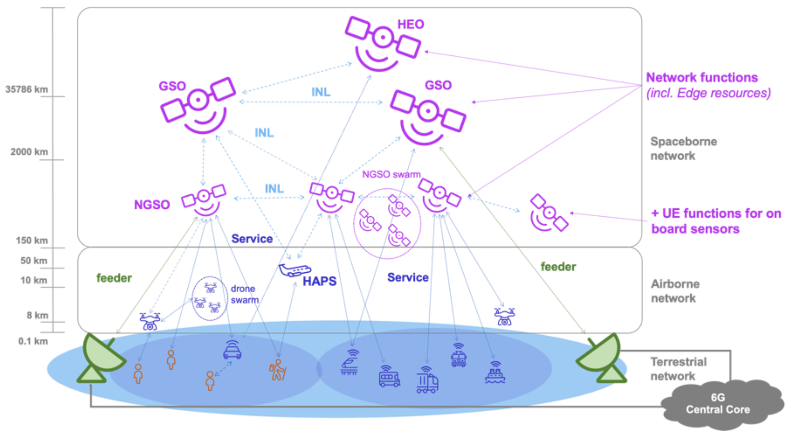
Integration
TN optimization plus new features to support NTN with minimum impact on TN (limited NTN optimization)

Unification
Joint TN/NTN design, optimization, and operations

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

6G NTN research challenges

6G NTN research areas



Architecture and system design

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

Networking, edge computing and communications

Softwarization, virtualization, and orchestration of network resources, flexible functional split for energy efficiency, advanced IP, routing in the sky, resource management, integrated edge communication and computing, self organizing infrastructure

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 and swarm-based 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 based on NTN (<10cm)

AI/ML

Network and system orchestration, Self organizing architecture, Radio Resource Management, Network traffic forecasting, AI based Physical layer design and management, Channel estimation,

Antennas and components

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

Source: A. Guidotti, A. Vanelli-Coralli et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," IEEE Access, 2024

6G-NTN architecture design

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

Softwarization, virtualization, & 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, Radio Resource Management, 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, A. Vanelli-Coralli et al., "Role and Evolution of Non-Terrestrial Networks towards 6G systems," IEEE Access, 2024

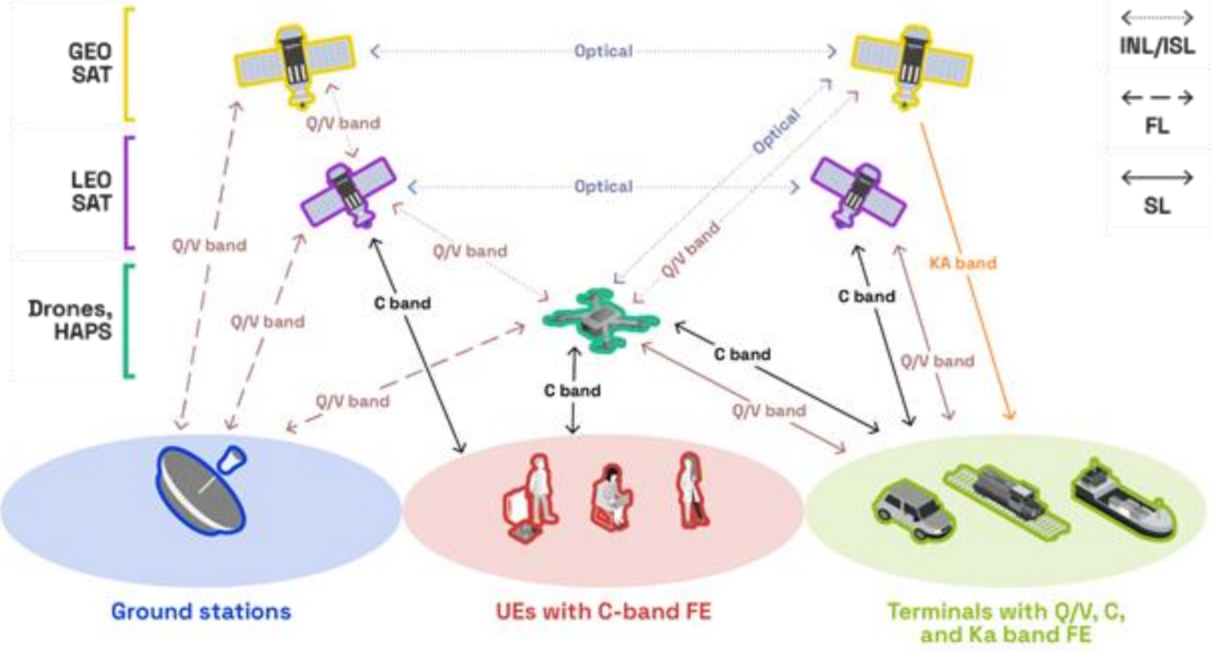
Nodes of the multi-dimensional, multilayered & multiband 6G architecture

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 UEs

Flexible nodes "opportunistically" deployed

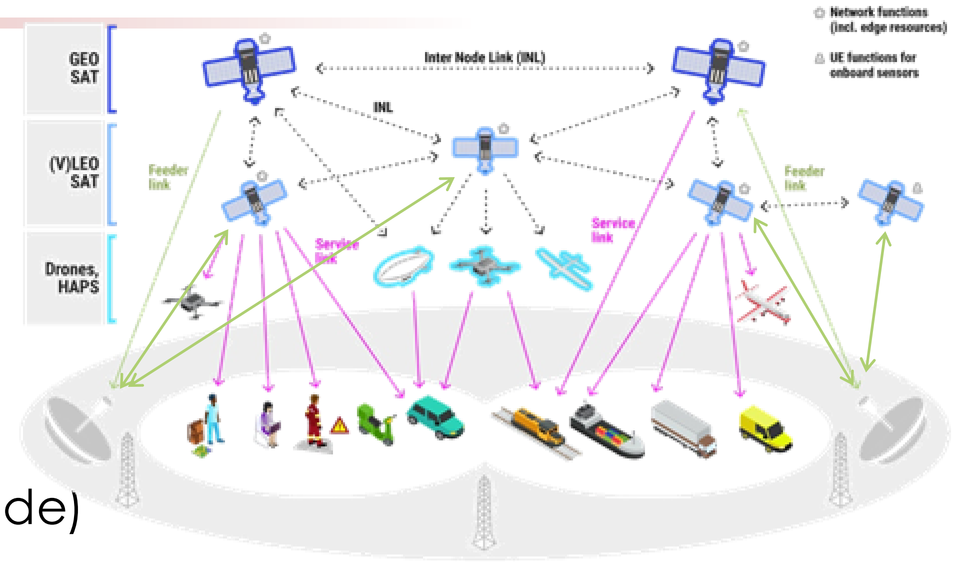
- HAPs or drones (heavy drones)
  - capacity to specific areas with no TN, e.g., disaster, emergency, etc
  - additional capacity for sudden traffic increase e.g., concerts, sport events w/wo TN coverage



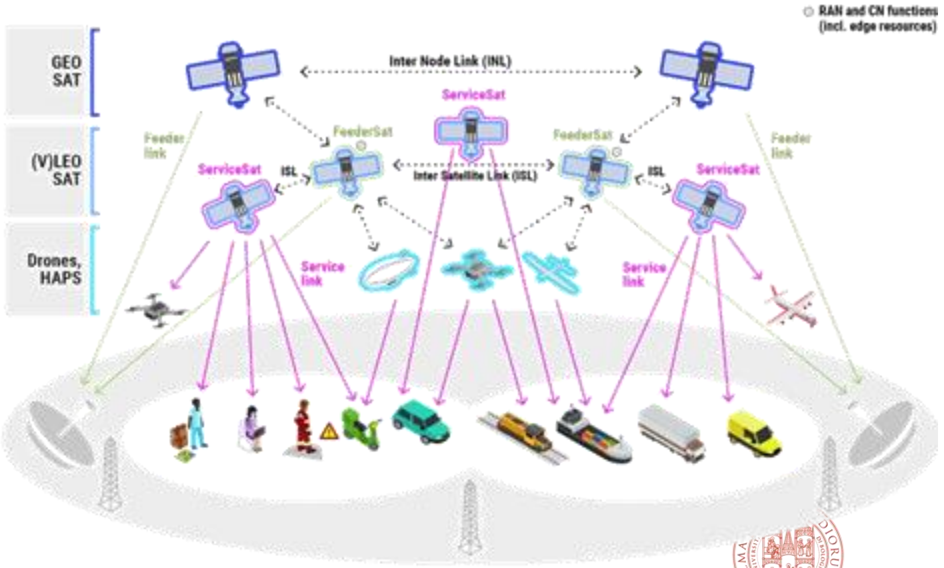
Source: 6G-NTN 'D3.1 Report on 3D multi layered NTN architecture'

6G-NTN architecture

- Conventional architecture – homogeneous 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 INL to GEO satellites
    - all RAN functionalities (Edge computing in space)



- Distributed architecture – heterogeneous nodes (same altitude)
  - **Feeder Nodes with higher computational capabilities**
    - 2 Feeder links to GW / no user link to UE
    - 4 OINLs to 4 service nodes
    - 2 OINLs to 2 feeder nodes
    - 1 Ka-band payload for the INL 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 OINL to 1 feeder node
    - Minimum RAN functionalities (RU)



Source: 6G-NTN 'D3.5 Report on 3D multi layered NTN architecture'

Constellation sizing

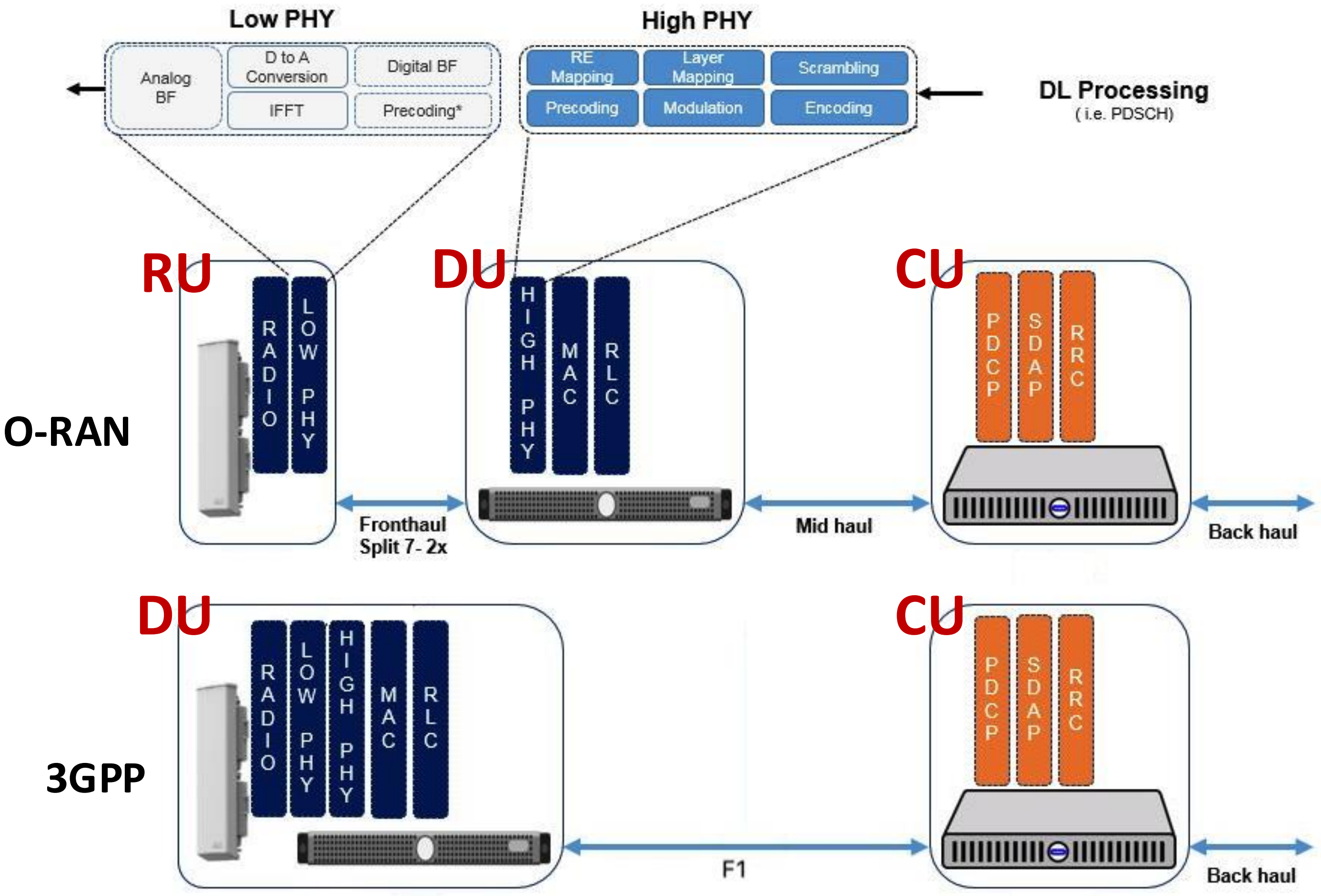
- Assumptions
  - Altitude: 600 km
  - Near-polar inclination (~87°)
  - 45° min user elevation angle
  - At least 1 satellite always visible
  - At least 10 s of overlap between 2 satellites
  - 2 constellations: 1 for C-band and 1 for Q/V band
    - only for the service satellites and satellites belonging to the conventional architecture
    - the feeder satellites are the same, with 8 ISLs

Architecture		Sat/ planes	# of planes	# of sat per type	Total # of sat
Conventional		47	27	-	1269
Distributed	Feeder	14	24	366	1635
	Service	47	27	1269	

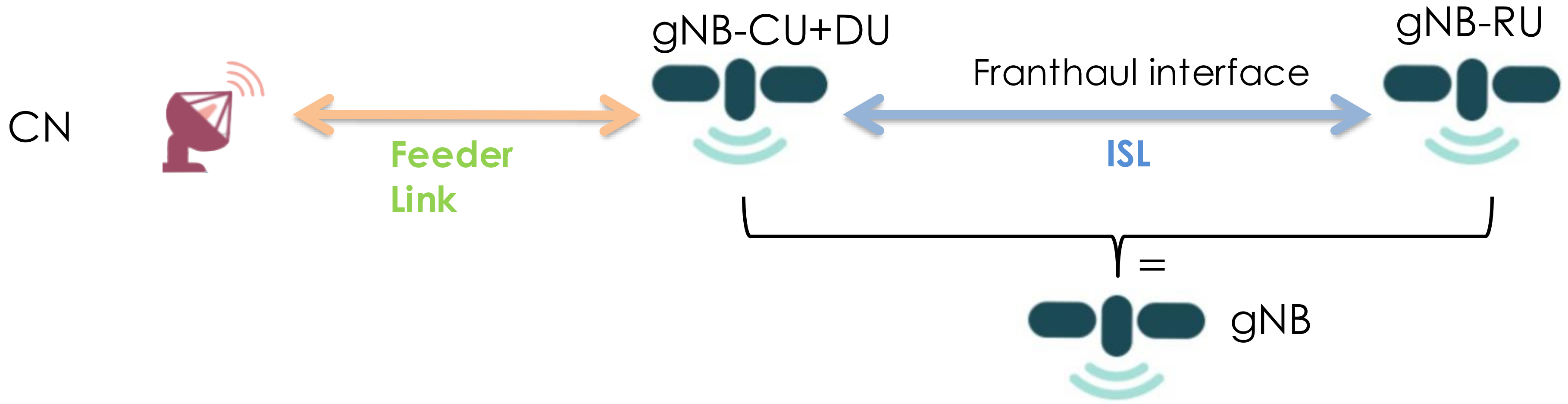
Source: 6G-NTN 'D3.1 Report on 3D multi layered NTN architecture'

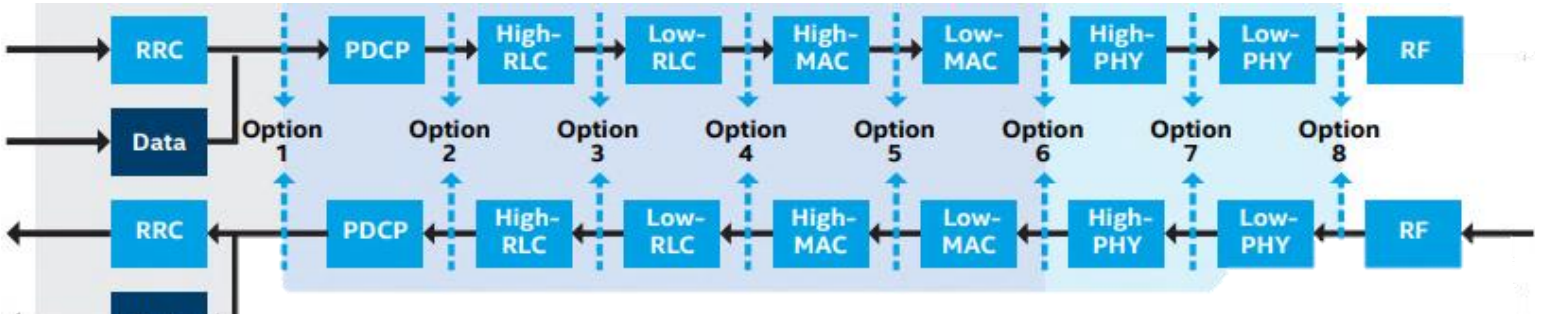
Functional architecture: what and where

- Distribution of the RAN functions between different network elements
  - 3GPP splits RAN in Central Unit (CU) and Distributed Unit (DU)
  - O-RAN adds a further split introducing the Radio Unit (RU)



Functional split for the distributed architecture





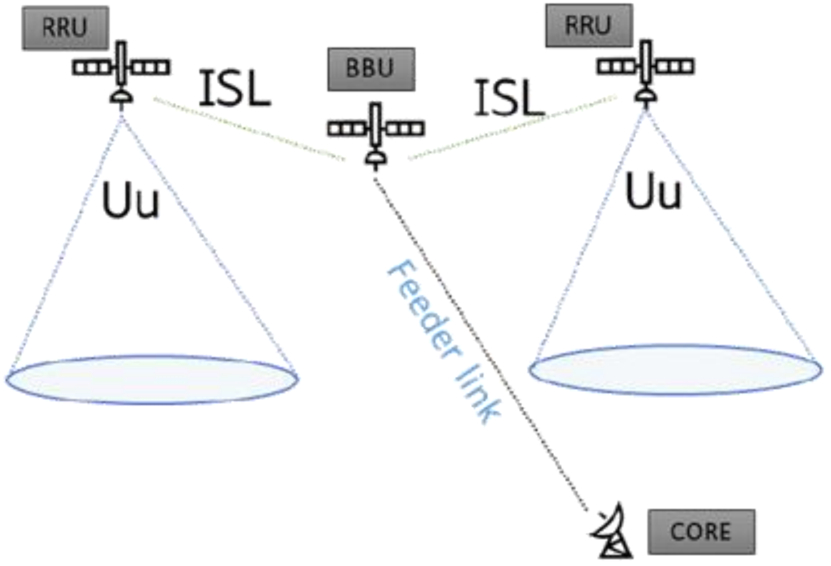
3GPP Split Options Intel

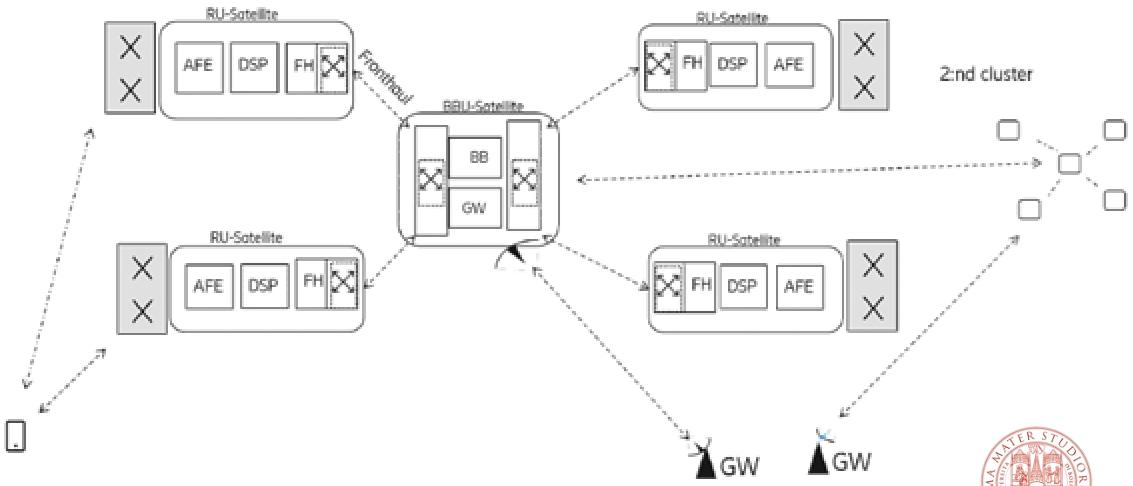
Increase NTN node required computational power

Increase interface required performances

Lower Layer Split in Space for the distributed architecure

- The feeder satellites contain the baseband unit (BBU) functionality
  - "baseband" includes the whole upper layers of the radio protocol stack
- Service satellites:
  - carry a RU
  - provide the service link to the user terminals on the ground.
- Physical layer processing functionalities are split between the feeder satellite and the service satellites.
- The connection from the feeder satellite to the service satellites in the cluster is done via OISLs supporting some variant of the fronthaul interfaces.





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

Lower Layer Split in Space: Adv. & Disadv.

- Advantages:
  - **Optimization of power budget and payloads** for the different roles of the satellites.
  - The feeder satellites carrying the BBU do not have to be equipped with multiple power amplifiers for the service link → power and payload volume can be allocated for computation parts.
  - The payload of the Service satellite carrying the RU will have more volume and power for the power amplifier, antennas, and beamforming network for the service link.

- Disadvantage:
  - No centralized scheduling will be possible:
    - feeder satellite will have its own scheduler

Constellation: some numbers beyond the sizing

Conventional Architecture

Subsystem	Power Consumption [W]	Power Consumption [% total]	Mass [kg]	Mass [% total]
RF FE and Beamforming	8400	93% - 88%	194	61%
Full Base Station	260 – 320	ca. 3%	40	13%
Optical Terminals (80mm)	4 x 100 – 200	4% - 8%	4 x 20+	25%
Total (best – worst cases)	9060 – 9520		314	

Distributed Architecture (Service Satellite)

Subsystem	Power Consumption [W]	Power Consumption [% total]	Mass [kg]	Mass [% total]
RF FE and Beamforming	7800	97% - 95%	173	76%
RU	60 – 120	ca 1%	30	13%
Optical Terminals (20mm)	2 x 75 – 130	2% - 3%	2 x 13	11%
Total (best – worst cases)	8010 - 8180		229	

Distributed Architecture (Feeder Satellite)

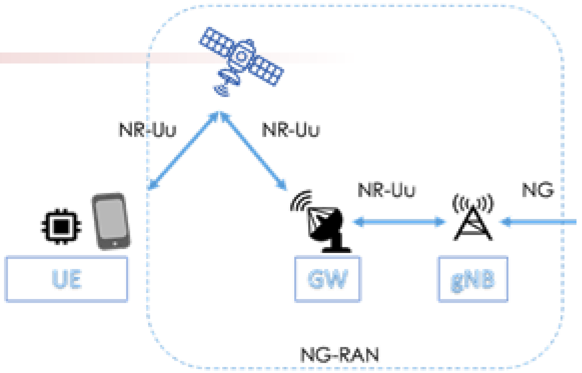
Subsystem	Power Consumption [W]	Power Consumption [% total]	Mass [kg]	Mass [% total]
RF FE (Feeder + ISLs)	370	19% - 8%	28	12% - 9%
Base Station w/o RU	800 – 2400	41% - 55%	40 – 120	18 - 39%
Optical Terminals (80mm)	8 x 100 – 200	41% - 37%	8 x 20+	70 – 52%
Total (best – worst cases)	1970 – 4370		228-308	

Source: 6G-NTN 'D3.6 Report on 3D multi layered NTN architecture'

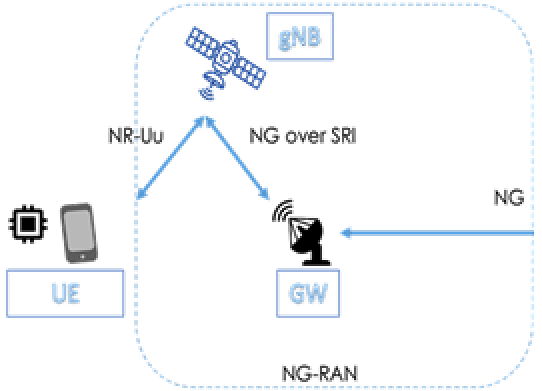
Conclusions

- The integration of an NTN component into 5G is a reality since Rel. 17 (2018).
- 6G target a native unified optimization of NTN to enable service improvements and market enlargement wrt 5G
- Both **evolutionary and revolutionary technologies** are needed to achieve a true **fully unified** 6G system:
  - **3D multidimensional multilayerd and multiband architecture**
    - Regenerative payloads, relay-based access, innovative and autonomous infrastructure, mesh architecture
  - **Technology evolution**
    - Flexible and natively integrated waveforms
    - Networking, edge computing and communications
    - Efficient Spectrum Access and new spectrum
    - NTN based positioning (no GNSS assumption)
    - AI based NTN and NTN supported AI
    - Antennas and components

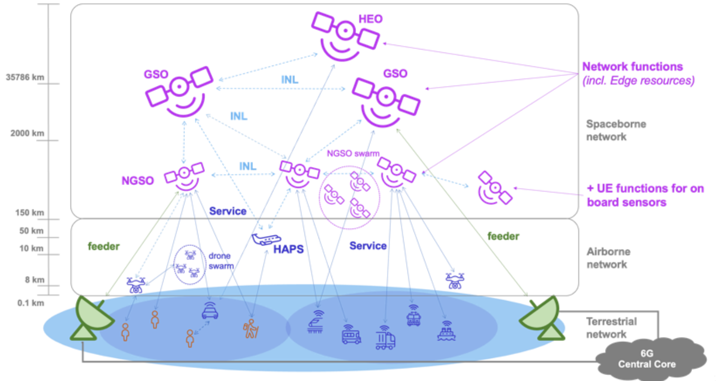
Rel.17/18



Rel.19



6G



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