



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Challenges and Innovations for future 6G NTN

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5th NTN Workshop: Towards a unified TN-NTN system

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"Guglielmo Marconi"

Credits to Partners, blame on me



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



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The role of NTN in 6G

Direct-to-Device connectivity to “smartphones”: service continuity and geographical coverage, including PPDR, operating below 7 GHz

Broadband and additional services connectivity to vehicle/static-mounted devices: vertical markets (e.g., automotive, public safety, transport, utilities, agriculture, etc.) operating above 10 GHz

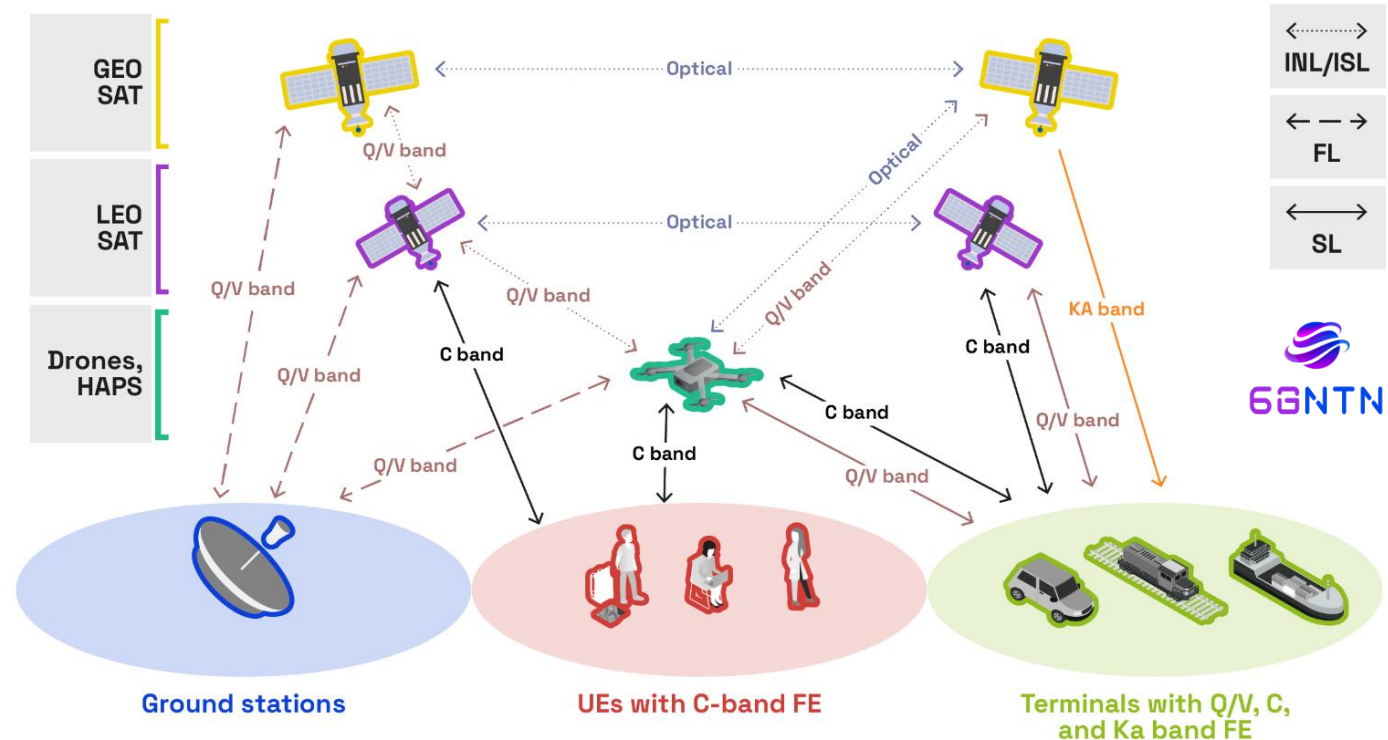
Multi-orbit / Multi-band Architectures

Deterministic nodes with fixed and predictable orbits

- GSO platforms
- NGSO platforms

Flexible nodes deployed “opportunistically”

- HAPs or (heavy) drones



Source: SNS JU Project 6G-NTN, D3.6 “Architectural Solutions,” December, 2024.

The role of NTN in 6G: research areas and open challenges



Lessons learnt



Need for **further R&I activities and demonstrations** for technologies we are already accustomed to



Consider TN and NTN not as two networks, but as **two components/elements of the same one**



Sustainability is a must: economic, technical, environmental challenges



Business and services

Consider the **multi-tenant/-stakeholder nature** of unified networks: new business/role models

Define a **comprehensive and clear business framework** for integrated TN-NTN services



R&I areas

Architecture and system design

Multi-layered 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

Virtualisation & orchestration of network resources, dynamic functional split, advanced IP, routing in the sky, enhanced RRM, integrated edge communication and computing

Radio interface and waveforms

Unified waveforms, non-orthogonal techniques, novel RA procedures (multiple transmissions per beam, GNSS-free operations), beyond Shannon communication, TDD

Spectrum Usage and Access: new spectrum and sharing

Multipoint transmission from the sky, CF MU-MIMO, distributed/federated BF, coordinated/uncoordinated sharing, inter/intra layer, Q/V and above

Positioning

NTN based positioning (<10cm), GNSS-resilient/-free operations

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



NTN radio interface: design drivers

Radio interface design drivers	Rationale
Multi carrier waveform enhancements	Relaxed synchronization requirements (GNSS free operations) 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. ... 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 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 communications and positioning	Support reliable NTN based solution for Positioning, Navigation and Timing (PNT) services (<10cm).
Joint communication and sensing	Provide low to medium resolution sensing capabilities directly integrated into the waveform design .



Limits of mega-constellations

The mega-constellation concept **might soon become unsustainable** from technical, economical, and environmental perspectives



Technical challenges

- antenna resolution capabilities
- spectrum management and coexistence
- production capabilities
- launching capabilities
- ...



Economical challenges

- launching cost
- infrastructure cost & management
- space crowding
- ...



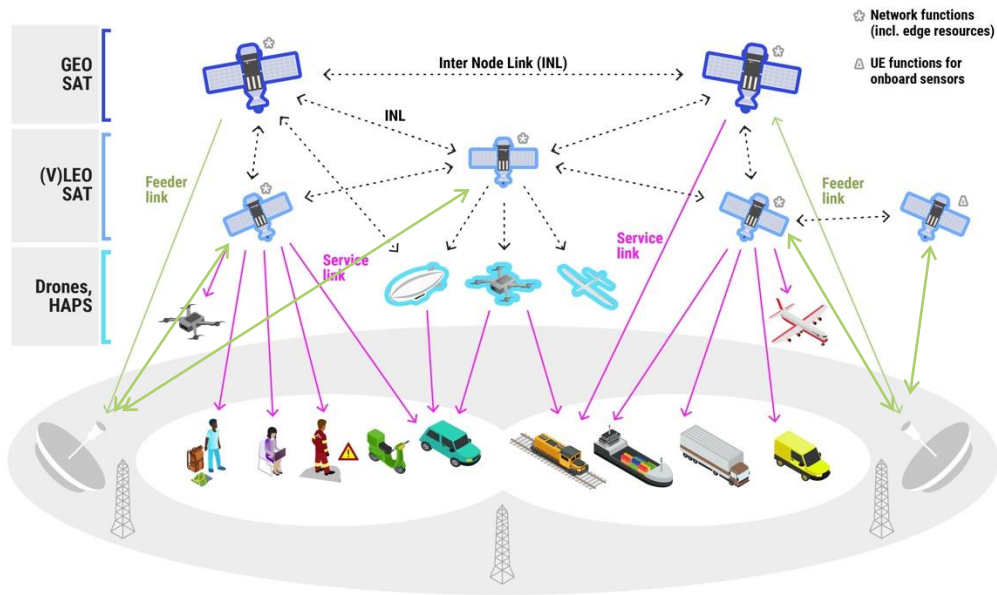
Environmental challenges

- environment footprint
- debris production
- Kessler effect
- ...

Can we do something better?



6G-NTN architectural solutions



Conventional architecture – homogeneous satellites

All nodes 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 and, possibly, some CN functionalities

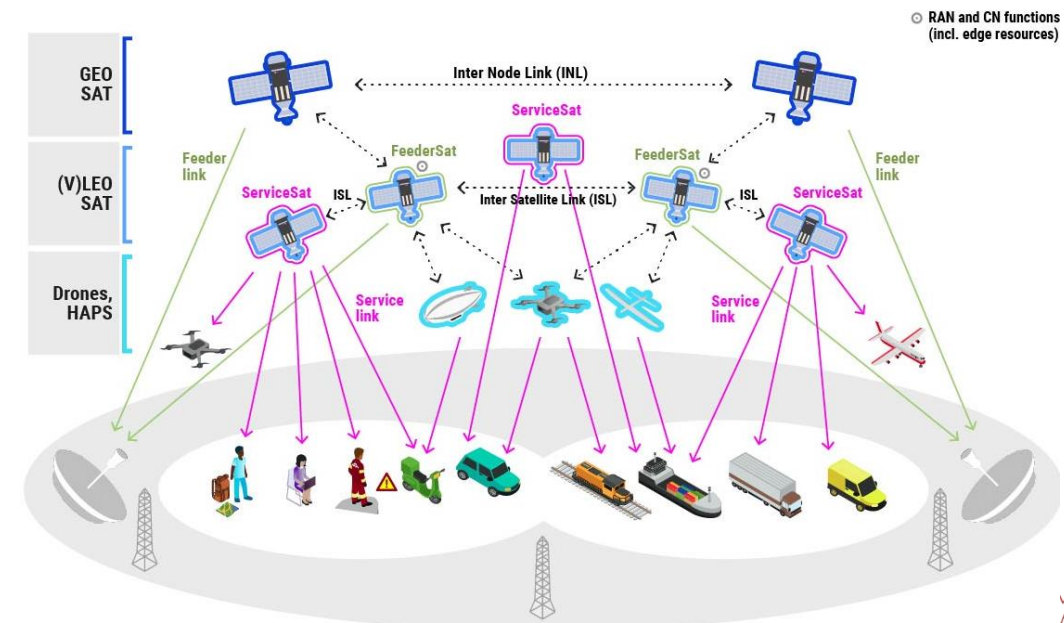
Distributed architecture – heterogeneous nodes (same altitude)

Feeder Nodes: higher computational capabilities for most of the RAN/CN functionalities

- 2 Feeder links to GW / no user link to UE
- 4 OINLs to 4 service nodes and 2 OINLs to 2 feeder nodes
- 1 Ka-band payload for the INL to GEO satellites

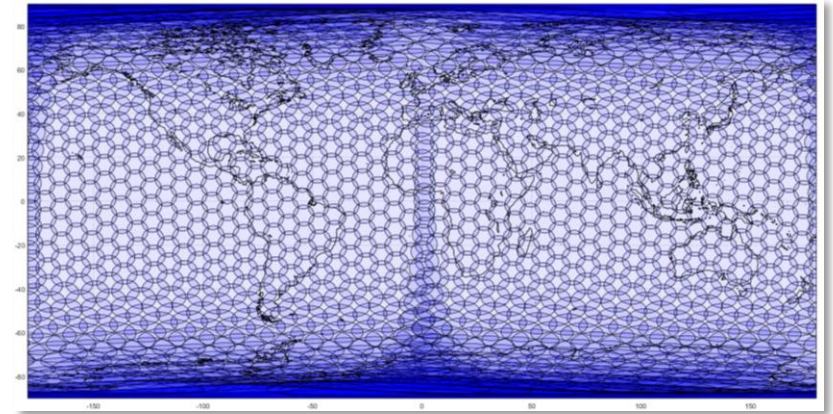
Service Nodes: lower computational capabilities for minimum RAN functionalities (RU)

- User link to UEs (multibeam) / no feeder link to GW
- 1 OINL to 1 feeder node



6G-NTN architectural solutions: sizing example

3GPP-compliant radio interface
Accurate Constellation design and sizing
D2D and 4G-like services (no fiber optic-like services)
Continuous and ubiquitous coverage



Assumptions

- Altitude: 600 km
- Near-polar inclination (~87°)
- ≥1 satellite always visible
- 10s overlap between satellites
- 45° min user elevation angle (max slant range 815 km)

Architecture		Sat/ planes	# of planes	# of sat per type	Total # of sat	Sat power per type	Total constell. power	Sat mass per type	Total constell. mass
Conv.		47	27	-	1269	9290 W	11.8 MW	314 kg	398 tons
Dist.	Feeder	14	24	366	1635	3170 W	11.4 MW	268 kg	389 tons
	Service	47	27	1269		8100 W		229 kg	

No need for Mega-constellation (tens of thousands satellites)
No need for billions of investments
Sustainable / integrated NTN architecture

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



Conclusions

6G targets a **native TN/NTN unification** in a multi-orbit/-layer/-band architecture

- both **evolutionary** and **revolutionary** technologies are needed to achieve a true **fully unified 6G air interface**

Key lessons from the 5G/5G-Advanced experience: we need to

- progress with further **R&I** activities and **demonstrations**
- really consider TN and NTN as two **elements of the same network**, with **inherent multi-tenancy**
- guarantee the system **economic, technical, environmental sustainability** (do we really need mega-constellations?)
- define a **comprehensive and clear business framework**

NTN requires a longer time to market: **anticipating** technology evolutions, standard definition, and system/service requirements **are winning factors in the ICT ecosystem**





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