Integrated TN/NTN architectures in 6G: opportunities and challenges

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One6G Lecture 11 - Non-Terrestrial Networks for 6G: Toward Seamless Network Convergence

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Credits to Partners, blame on me

- This presentation is partially based on the research outcomes of the 6G-NTN project funded under the European Union HE SNS JU program
- 6G-NTN objective is to **research and develop technical**, **regulatory**, and **standardization enablers** ensuring **native unification of the NTN component into the 6G** system for **vertical industries** and **consumer market**

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

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

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Views and opinions expressed are those of the Author only and do not necessarily reflect those of the European Union nor those of the Projects' Partners. Neither the European Union, the Projects' Partners, nor the granting authorities can be held responsible for them.

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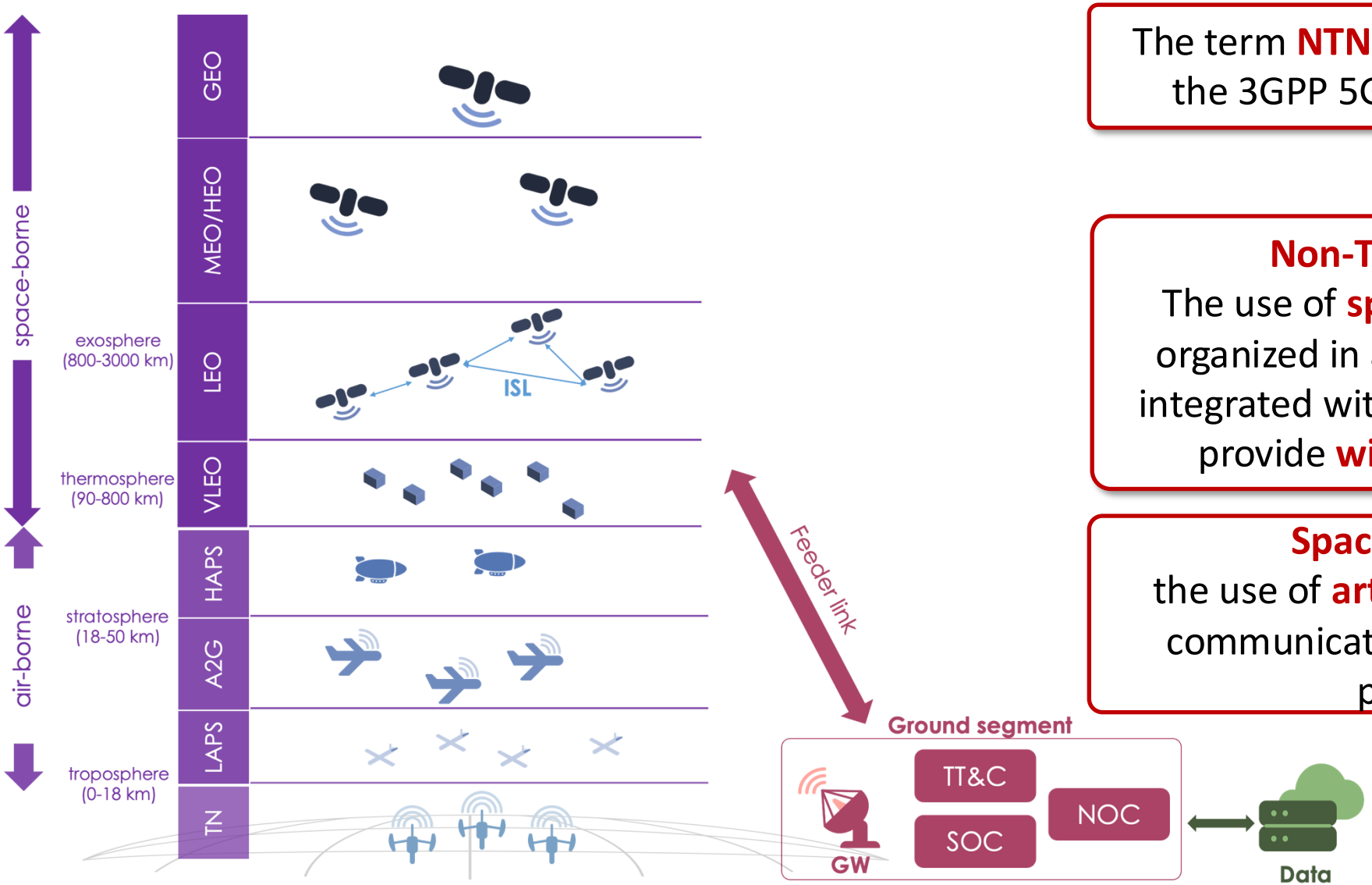
Outline

- **Nothing happens overnight** - From SatCom to NTN
- **Where we stand today** - 5G and 5G-Advanced NTN
- **Synergy not competition** - The Role of NTN in 6G
- **Leveraging standards and smart design for a sustainable NTN** - 6G NTN Architecture
- **Addressing NTN from day zero** – Radio Access Technology research areas
- **What did I say?** - My takeaways

NOTHING HAPPENS OVERNIGHT

From SatCom to Non-Terrestrial Networks

Non-Terrestrial Networks



The term **NTN originates** in the context of the 3GPP 5G Standardization (2016+)

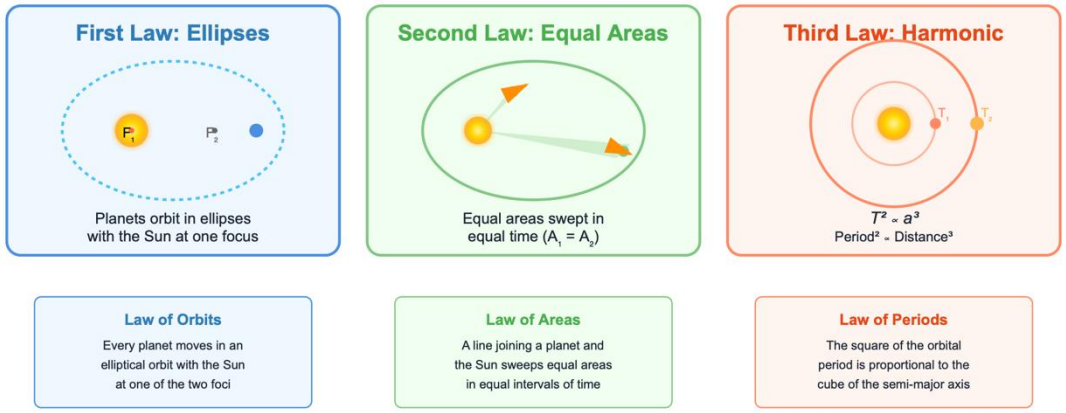
Non-Terrestrial Networks
The use of **space-/air-borne platforms** organized in a connected infrastructure integrated with the terrestrial network to provide **wireless services** on Earth

Space-borne = SatCom
the use of **artificial satellites** to provide communication links between various points on Earth

Space-borne NTN = Satellite Communications

A Satellite **orbits around the Earth** according to the **Keplerian Laws**

- Orbits are ellipses with the Earth in one of the foci
- Getting closer to the Earth (low altitudes), satellite's
  - speed increases
  - orbital period reduces
  - field of view reduces



What does this mean?

- The number of satellites needed for continuous and global coverage increases in low orbits

→ **Constellations**
- multiple satellites per orbit (plane)
- multiple orbits (planes)

- Large coverage beams
- Doppler/Delay effect
- Differential Doppler/Delay effect
- Multiple/frequent handovers
- …

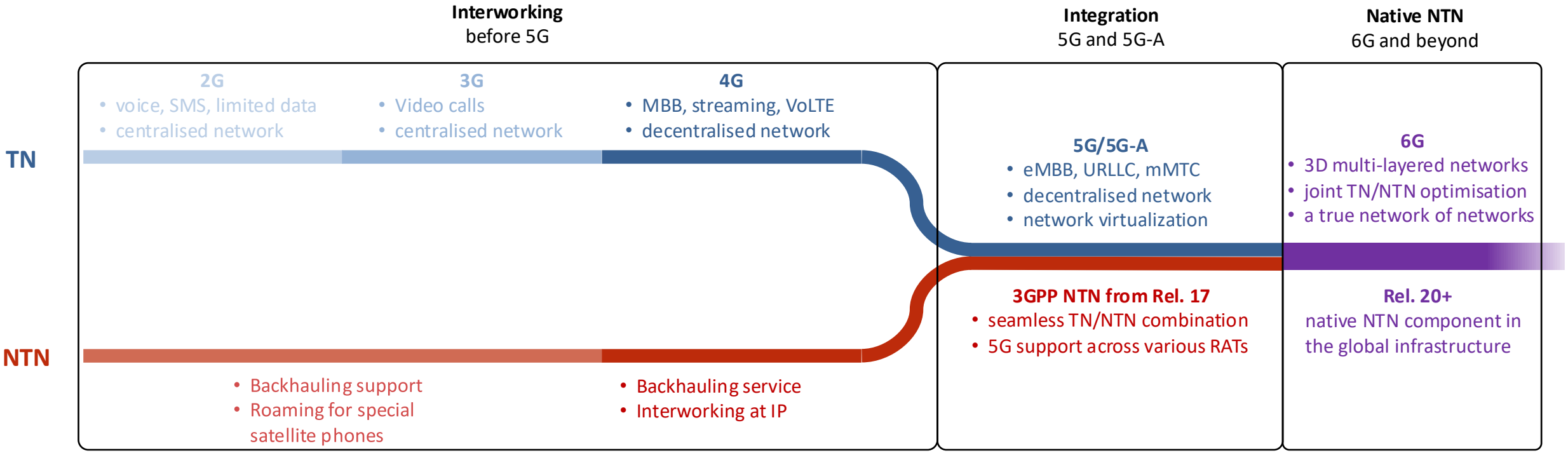
→ **Radio interfaces adaptation (3GPP)**
- Doppler/Delay compensation
- HARQ and timing adjustments
- Handover management
- Spectrum management
- …

WHERE WE STAND

5G AND 5G-ADVANCED NTN

TN-NTN: a path to unification

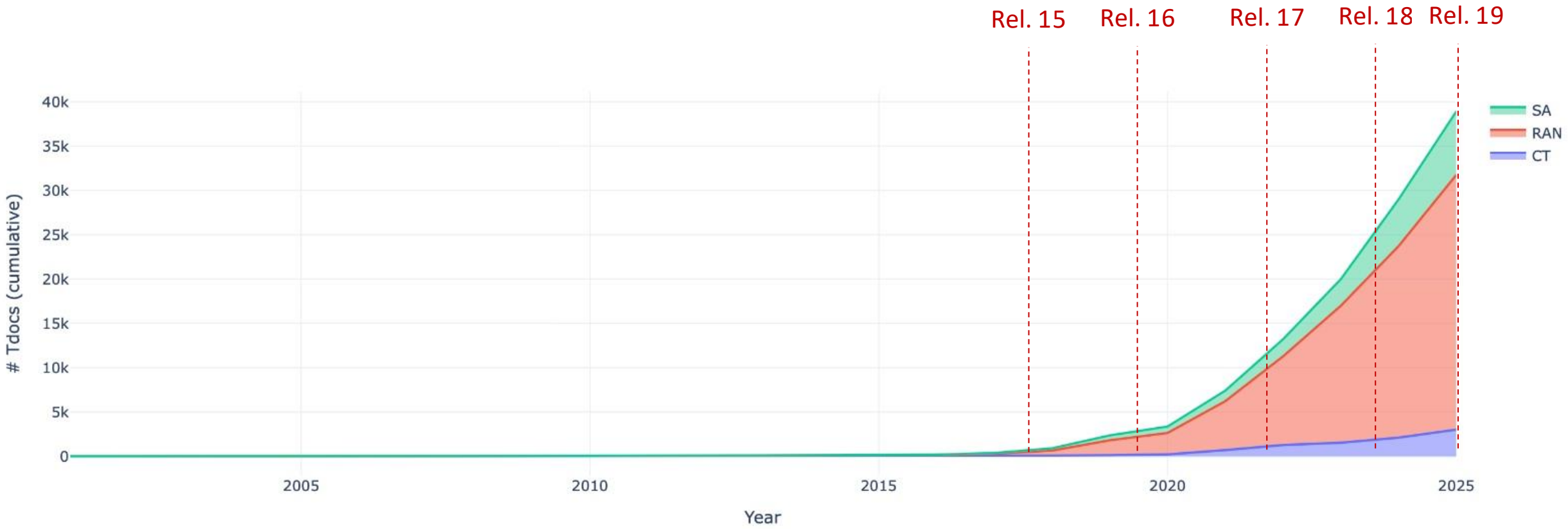
Legacy SatCom systems: typically based **on industry-driven technical solutions** that led to **proprietary architectures and protocol stacks** → difficult *a posteriori* interactions with terrestrial systems



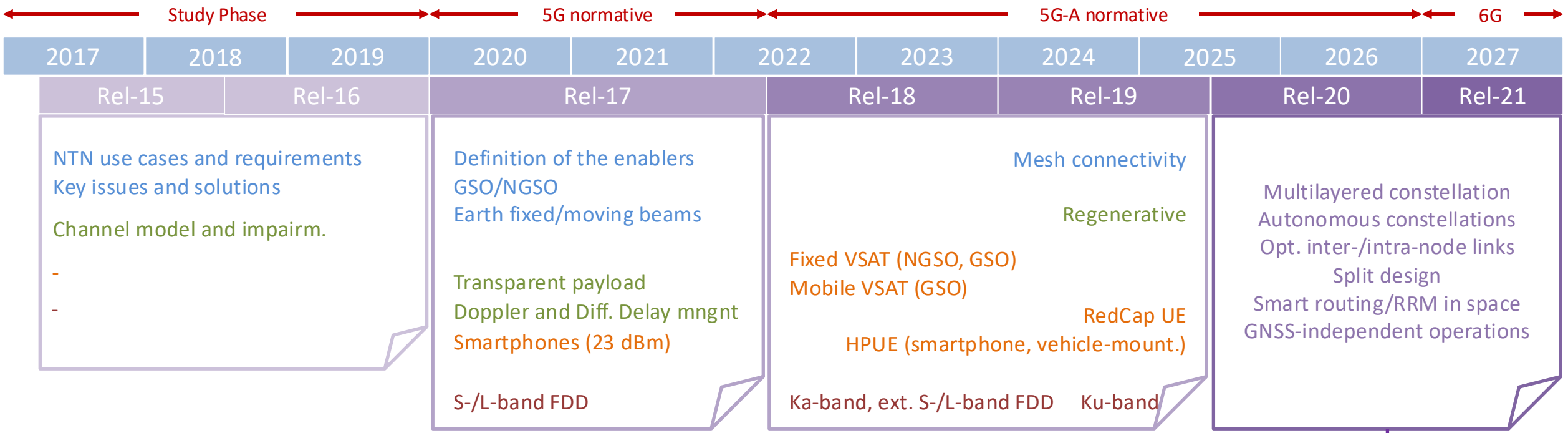
3GPP NTN: a massive joint effort between the stakeholders of both terrestrial and satellite industries allowing

- 3GPP specifications to provide **global service continuity and resiliency**
- satellite industries to access the **economy of scale** and reduce the **manufacturing costs**

NTN in 3GPP



System and RAN evolution in 3GPP



RP-251881: New SID: Study on 6G Radio → "Aim at a harmonized 6G Radio design for TN and NTN, including their integration" [June 2025]

- Ubiquitous connectivity and availability of services in remote/sparsely populated areas
- Improve network resiliency, especially when disasters disrupt TNs or damage undersea communication cables

System architecture

RAN aspects

Targeted terminals

Spectrum

System and RAN evolution in 3GPP: spectrum

Release 17

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

Release 18

	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
FR1	n254	1610-1626.5 MHz	2483.5-2500 MHz	FDD
FR2	n512	27.5-30 GHz	17.3-20.2 GHz	FDD
	n511	28.35-30 GHz	17.3-20.2 GHz	FDD
	n510	27.5-28.35 GHz	17.3-20.2 GHz	FDD

Extended FR1 + Ka-band

Extended FR1 + Ku-band

Release 19

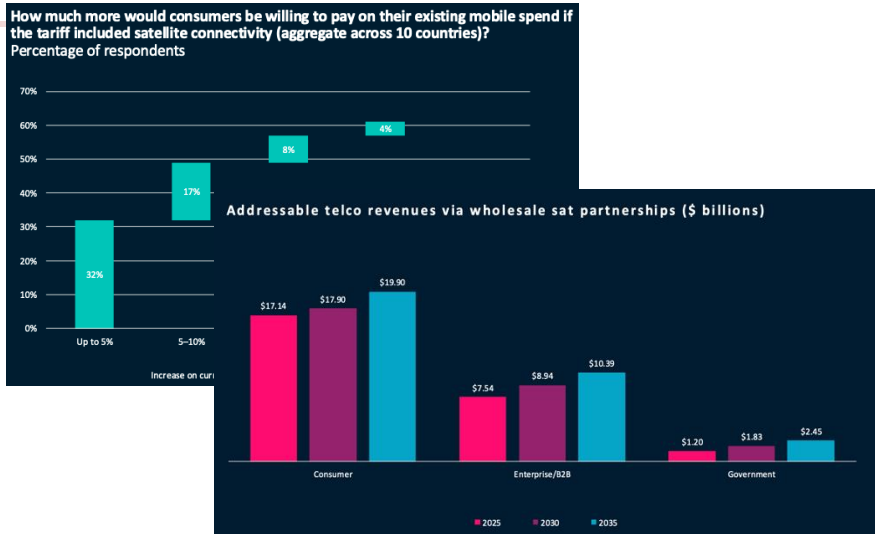
	Band	UL (UE-to-SAN)	DL (SAN-to-UE)	Duplexing
	n256	1980-2010 MHz	2170-2200 MHz	FDD
	n255	1626.5-1660.5 MHz	1525-1559 MHz	FDD
	n254	1610-1626.5 MHz	2483.5-2500 MHz	FDD
FR1	n253	1668-1675 MHz	1518-1525 MHz	FDD
	n252	2000-2020 MHz	2180-2200 MHz	FDD
	n251	1626.5-1660.5 MHz	1518-1559 MHz	FDD
	n250	1668-1675 MHz	1518-1559 MHz	FDD
	n248	14-14.5 GHz	10.70-12.75 GHz	FDD
	n247	13.75-14.00 GHz	10.70-12.75 GHz	FDD
	n512	27.5-30 GHz	17.3-20.2 GHz	FDD
	n511	28.35-30 GHz	17.3-20.2 GHz	FDD
	n510	27.5-28.35 GHz	17.3-20.2 GHz	FDD
FR2	n509	14-14.5 GHz	10.70-12.75 GHz	FDD
	n508	13.75-14.00 GHz	10.70-12.75 GHz	FDD

SYNERGY NOT COMPETITION

The role of NTN in 6G

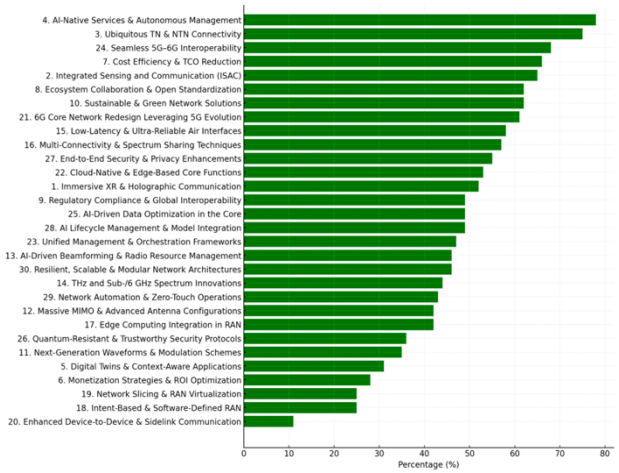
The role of NTN in 6G

- MWC'25: GSMA Intelligence Report
  - 60% of current users are ready to pay up to 5% increase to have NTN connectivity on their smartphone
  - NTN Global market will count up to 3% of telco total revenues (approx. 30B$) in the next 10 years
    - ubiquitous coverage and service continuity
    - Consumer, Enterprise and Government markets



Source: GSMA Intelligence MWC2025, Satellite and NTN Summit

- 3GPP 6G Workshop (Incheon, SK) – March 10-11, 2025
  - 1800 attendees (750 in person)
  - 230 contributions
    - NTN in 75% of them
    - AI in 78% of them
  - NTN is second only to AI, and right after it



Source: APEX Standard , https://apexstandards.com/6gws.pdf?ref=NLT2

NTN will be a structural element of future 6G communications

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

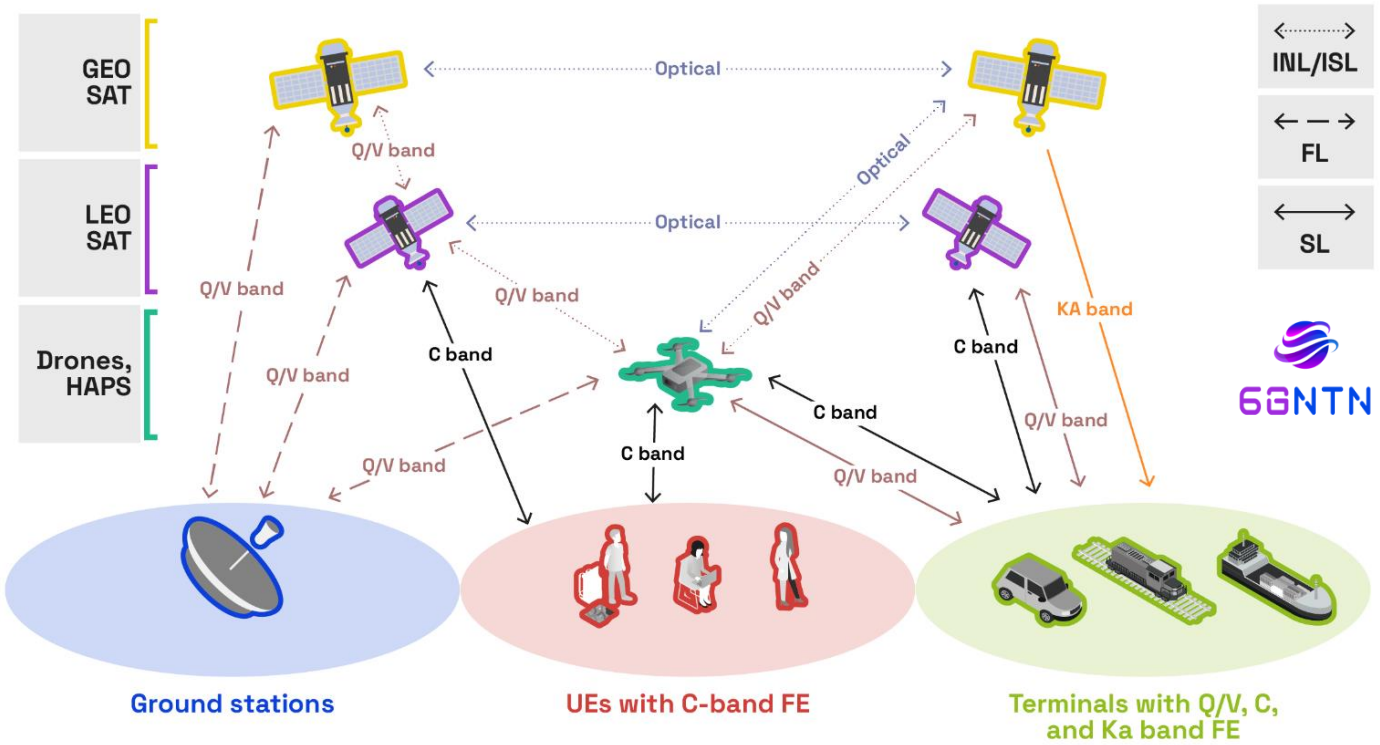
Multi-orbit / Multi-band Architectures

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.

LEVERAGING STANDARDS AND SMART DESIGN FOR A SUSTAINABLE NTN

The 6G NTN Architecture

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

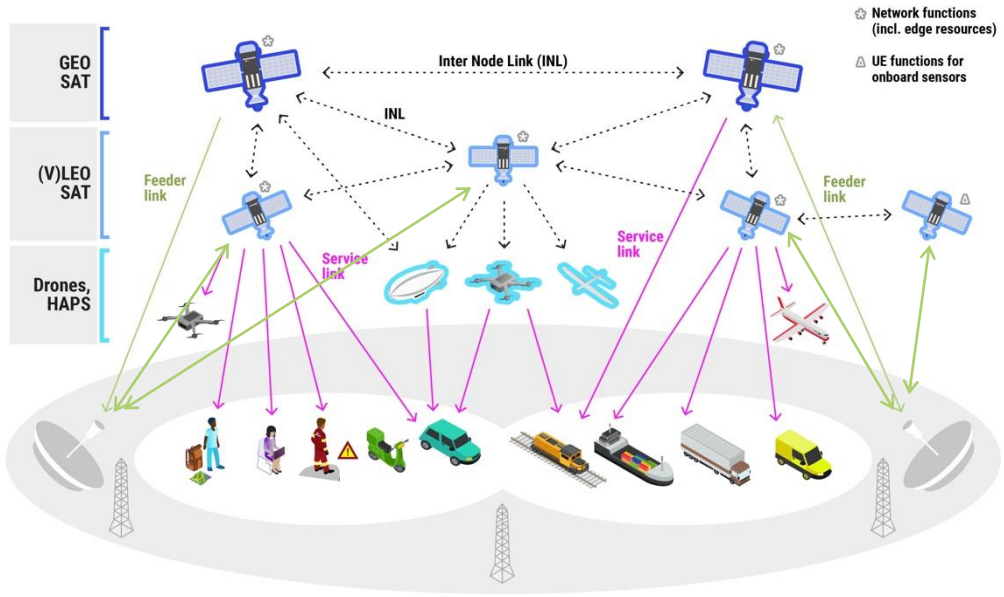
- launching cost
- infrastructure cost & management
- space crowding
- …

Environmental challenges

- environment footprint
- debris production
- Kessler effect
- …

Can we do something better?

6G-NTN architectural solutions: an example



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

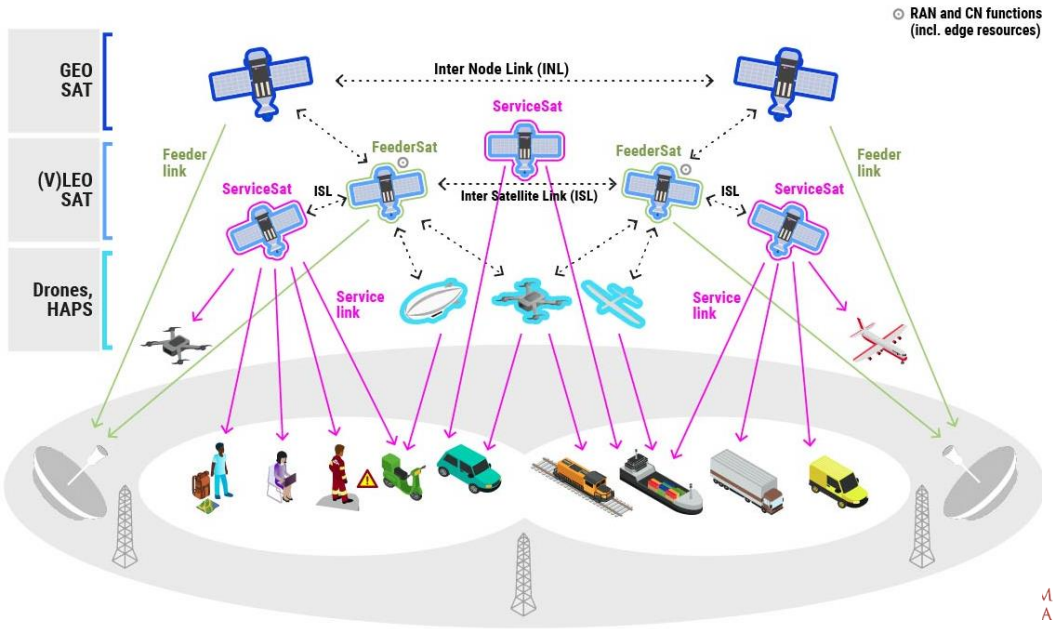
Distributed architecture – heterogeneous nodes (same altitude)

***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



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

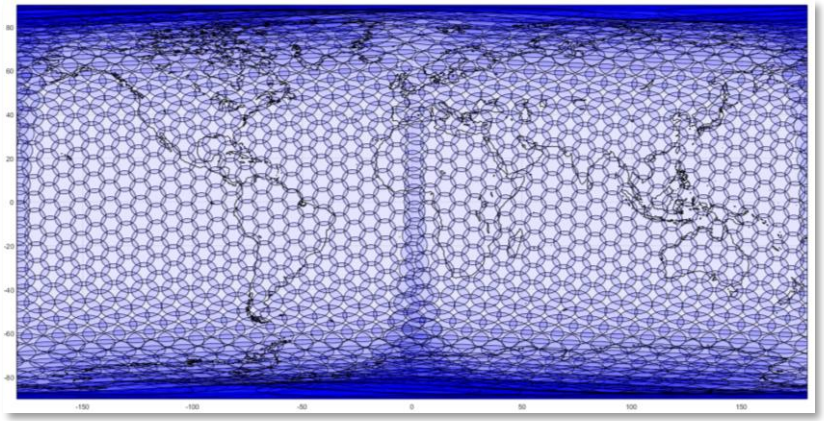
6G-NTN architectural solutions: sizing example

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.

ADDRESSING NTN FROM DAY ZERO

6G NTN Air Interface

NTN radio access technology research areas

Radio interface research areas	Rationale
Multi-carrier waveform enhancements	**Relaxed synchronization requirements** (GNSS-free operations) **PAPR reduction** for spectral efficiency maximization
Advanced modulation, coding and multiple access schemes	**Low SNR regimes** enabling the support of challenging radio link conditions, *e.g.*, light indoor coverage
GNSS-free operation	Improve **resilience and reliability** of the system, remove external dependences
AI-based PHY	Improve performance, resilience and flexibility
Flexible UL/DL framing structure	Flexibility **for frame structure adaptation** to satellite orbit, frequency range, etc. … Overhead reduction (limited multi-paths conditions)
TDD support	Use **unpaired spectrum** for LEO/vLEO platforms
Dynamic TN-NTN spectrum sharing	**Efficient co-channel spectrum sharing** between TN and NTN
Support for distributed beam forming	Improve coverage, capacity, and reliability (possible wupport from new waveform)
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**

WHAT DID I SAY?

Take away messages

My takeaways - What did he say?

Synergy not competition

- NTN is **a 3GPP integrated technology** ensuring **coverage and service continuity** with **inherent multi-tenancy**
- Two main scenarios **D2D below 7GHz** and **vehicle/static-mounted devices above 10GHz** for vertical markets
- There is a need for a sound **business/technical framework where MNOs, SNOs, and HNOs can successfully cooperate**

Leveraging standards and smart design for a sustainable NTN

- No need for unsustainable mega constellations if we build on **standard and technology solutions developed over decades specifically for SatCom (NTN)**
- Unlike Direct-to-cell, **3GPP NTN includes NTN-specific features** allowing **for full and seamless integration** with TN

Research Challenges/Areas

- Progress with R&I activities, demonstrations, and standardization
- **NTN specificities/peculiarities** to be considered from day zero in the standardization process (**challenges/opportunities**)
- Avoid revolutionary approaches**; let's not waste what has been done through the years**

What's next

- Beyond integration of communication and sensing: **communication, sensing, and navigation unification**
- NTN not as a mere pipe, but **as a source of data from space**

My takeaways - What did he say?

Synergy not competition

- NTN is **a 3GPP integrated technology** ensuring **coverage and service continuity** with **inherent multi-tenancy**
- Two main scenarios **D2D below 7GHz** and **vehicle/static-mounted devices above 10GHz** for vertical markets
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NTN represents the new/last frontier of wireless communications

An infrastructure able to allow people to connect, irrespectively of their geographically positions, political situation, and natural conditions

A true anywhere and anytime communication system

What's next

- Beyond integration of communication and sensing: **communication, sensing, and navigation unification**
- NTN not as a mere pipe, but **as a source of data from space**

THANK YOU

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