NTN from 5G to 6G: Standardization and Sustainability Aspects

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40 min

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Content

>Views on the 5G NTN standard and the lessons learned

>A perspective of NTN in the 6G context

>Considerations on sustainability aspects.

NTN in 5G lessons learned

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Rational for initiating standardisation activity in NTN at 3GPP (1/2)

>Vision

- SatCom is **a shrinking niche market.**
- **Open new market opportunities** through the integration in the mobile eco system
- **Users** want to **escape from service provider's lock:** limited services and terminal diversity
- **Satellite Network Operators** want to **escape from network vendor lock**

>Conditions for success

- **Minimum impact** on UE, RAN and core network
- Being able to **address the consumer market:** smart phones, cars
- A **single technology framework** to address **all SatCom services** and markets

Rational for initiating standardisation activity in NTN at 3GPP (2/2)

>Foreseen added value of SATELLITE IN 5G

- 1/ Foster the roll out of **5G service in unserved areas** (e.g. isolated/remote areas, on board aircrafts or vessels) and underserved areas (e.g. sub-urban/rural areas),
- 2/ **Reinforce the service reliability**: robust service delivery for M2M/IoT devices or for passengers on board moving platforms, service availability anywhere
- 3/ Enable **network scalability with multicast/broadcast** for data delivery towards network edges.

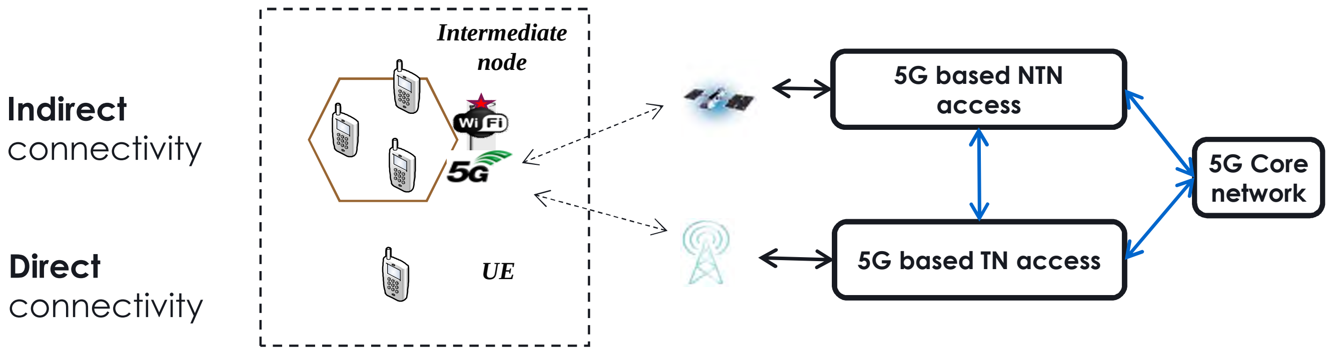
3GPP defined Non-Terrestrial Network in 5G: Overview

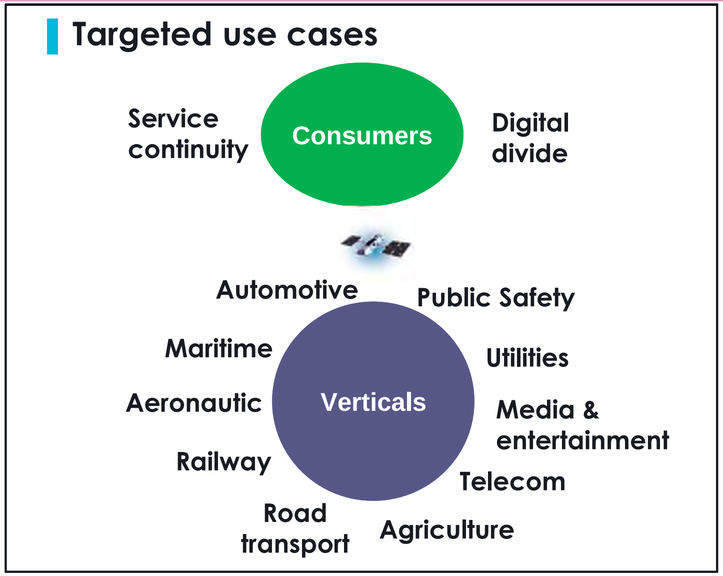
<u>3GPP NTN:</u> the **first and true global and open standard for all SatComs** (*any device, orbit, service, frequency bands, beam size/type*) and **supported by the 3GPP eco system** (satellite, mobile and vertical stakeholders)

<u>NTN added value wrt TN</u>: service continuity and reinforced reliability/availability

3 NTN reference scenarios wrt terminal types:
- **IoT devices** (Narrowband: hundreds of kbps) in < 7 GHz
- **Smartphones**/vehicle (Wideband: few Mbps) in < 7 GHz
- **Flat panel antenna terminal** on moving platforms (Broadband: hundreds of Mbps) in > 10 GHz

*Radio Access Network: **mobility** across the access technologies*





Common 5G technology framework to best manage (Perf., QoS, Security, Slicing) across the access technologies

GNSS = Global Navigation Satellite System
FDD = Frequency Division Duplexing

3GPP NTN standard in 5G: Release 17 and beyond main features

- Addressing specific NTN issues
  - **Any orbit:** Propagation, Extended & variable delays & Doppler
  - **Any payload:** Transparent/Regenerative
  - **Any radio cells:** any size, Earth fixed/moving, possibly cross borders.
  - **Any frequency bands:** satellite service allocated below 6GHz and above 10 GHz
  - **Service continuity between Terrestrial Network and NTN.**

UEs with GNSS capabilities

FDD/TDD

Earth fixed Tracking area

Implicit compatibility to support HAPS (High Altitude Platform Station) and ATG (Air To Ground) scenarios

NTN impact on the SatCom eco system

3GPP : a framework enabling

- Economy of scale / Global market
- Multi vendor interoperability
- Open certification of User Equipment
- Continuous innovation of services and capabilities
- Backward capabilities ensured between the releases of a given generation

NTN standard designed to support

- any device, orbit, service, frequency bands, beam size/type
- natively 5G features (e.g. slicing, QoS, Security, energy saving)
- Minimum impact on legacy 5G system (UE, RAN and Core network level)
- global service continuity, improved QoE and reliability through multi connectivity / mobility across
  - terrestrial & satellite access; NGSO and GSO access
- spectrum coexistence (adjacent band) of satellite with mobile systems

NTN->SatCom : From a shrinking niche market to a segment of a global market

3GPP Standardisation activities to support NR-NTN development

Topic	Releases					
	Rel-15	Rel-16	Rel-17	Rel-18	Rel-19	Rel-20
Freeze date	June 2015	July 2020	June 2022	June 2024	Dec 2025	
Service requirements	5G NTN Use cases and service requirements				Mesh connectivity (UE-SAT-UE communication) GNSS independent operation,	5G Advanced: - Multi-orbit satellite networks - Resilient Notification - Enh. Emergency communications by satellite - Enh KPIs 6G: introducing 'Ubiquitous' connectivity as a 6G pillar
System architecture		Study key issues	Enablers for the support of Satellite	-	Regenerative payload UE-SAT-UE communication Mesh connectivity Dual steer (GSO/NGSO, TN/NTN)	

3GPP Standardisation activities to support NR-NTN development

Topic	Releases					
	Rel-15	Rel-16	Rel-17	Rel-18	Rel-19	Rel-20
Radio Access network aspects	Channel model for 0.5 – 100 GHz	Study key issues	Support of NGSO/GSO, Earth fixed/moving beams	Verified UE location, UL coverage enh, TN/NTN and NTN/NTN mobility enh	DL coverage enh, broadcast (MBS) enhancements, UL capacity enh, E-UTRAN TN to NR NTN inter-RAT mobility, Regen payload (gNB on board) Channel bandwidth < 5 MHz	
Targeted terminals	-	-	Smart phones (23 dBm)	Fixed VSAT for GSO/NGSO, Mobile VSAT only for GSO	RedCAP UE, High power Tx UE (Smart phones + vehicle mounted) Mobile VSAT for NGSO	
Frequency bands	-	-	S, L bands in FDD mode	Extended L band, Ka band in FDD mode	Ku band in FDD mode	
Application Enablers					Application enablement for satellite access enabled 5G services.	

3GPP Standardisation activities to support IoT-NTN development

Topic	Releases			
	Rel-17	Rel-18	Rel-19	Rel-20
Completion date (Core)	June 2022	March 2024	June 2025	-
Service requirements			Store and forward	- IMS call over GEO (IoT NTN) - Enh. Emergency communications for IoT NTN - Enh. KPIs
System architecture	-	Discontinuous coverage	Store and forward	-
Radio Access network aspects	Support of NGSO/GSO, Earth fixed/moving beams,	Mobility enh Performance enh Discontinuous coverage	Store & Forward Uplink capacity enhancements Further Mobility enhancements Support of TDD with NB-IoT Support emergency broadcast messaging using the mechanisms for PWS	-
Targeted terminals	Power class 3 devices (23 dBm)	-	High power Tx UE	-
Frequency bands	S, L bands in FDD mode	Extended L band	L band in TDD mode	-

3GPP NTN technology is being rolled-out

Deployment scenarios	**A**	**B**	**C**	**D**	**E**	**F**
Service	IoT-NTN, Messaging & voice			Broadband		
3GPP NTN RAT	IoT-NTN	IoT-NTN	IoT-NTN	NR-NTN	NR-NTN	NR-NTN
Orbit	GSO	NGSO	NGSO	NGSO	GSO	NGSO
Duplex mode	FDD	FDD	TDD	FDD	FDD	FDD
Payload	Transparent	Transparent/Regenerative			Transparent	Regenerative
Bands	Below 7.125 GHz (e.g. L/S bands)				Above 10 GHz (e.g. Ku/Ka band)	
Targeted devices	IoT & Smartphones (D2D)			Smartphones	Fiexed and Mobile VSAT	
Potential SNOs	*EchoStar Viasat/Inmarsat Ligado TerreStar Solutions Thuraya*	*Sateliot OQT EchoStar OmniSpace*	*Iridium*	*Echostar, MSS-A*	*Hispasat Intelsat, JSAT, KTSAT, Ovzon Eutelsat Group*	*SpaceRISE Eutelsat Group*

Earliest service opening for each scenario (and related 3GPP releases)

2024	2025	2026	2027	2028	2029	2030
A *Rel-17*	B *Rel-17/18*	C *Rel-19*	E *Rel-18/19*	D *Rel-17/18*		F *Rel-18/19*

NTN in 5G versus other satellite access technology

STRENGTHS

- Strong **interest from user groups** including verticals and mobile network operators.
- A potential **large supply chain** for user equipment and network element to drive the cost down.
- A SatCom **market segregated between respectively network and terminal vendors**.
- **Interoperability between NTN and TN**: spectrum coexistence (adjacent band), mobility, multi connectivity
- Support of **regulatory services** (emergency call, Lawful intercept, Warning ,...)

OPPORTUNITIES

- Technology **enabling new roles for satellite communication systems** integrated in cellular network
    - Contribution to the ubiquitous connectivity, resiliency and possibly the sustainability of the mobile system.
- Fast availability of **NTN capable smartphones for satellite networks** operating in FR1 bands (below 7GHz)
- Early D2D service to IoT and smartphone devices with IoT-NTN

WEAKNESSES

- **D2D: Slow deployment of NTN** capable space infrastructure
- **BB** in bands above 10 GHz**:**
    - **GNSS resilient operation** is yet missing
    - **Availability of the needed NTN capable chipsets** may require additional work in 3GPP Rel-20.
    - **Potential performance degradation** compared to legacy/proprietary satellite radio interfaces on the downlink (e.g. wrt DVB-S2x) in specific deployment scenarios

THREATS

- For D2D, **3GPP but non NTN capable access technology** may compete in the short term with the 3GPP defined NTN technology in order to address already commercialised user equipment.

NTN in 5G/5GA system: Key recommendations

> Aggregate the demand for UEs across several industrial satellite network programs

- to ensure the availability and affordability of chipset/front-end of terminal devices as well as the necessary support of NTN features in network solutions (RAN and core networks).

> Develop the necessary test cases for the certification of NTN capable UE.

NTN in 6G context

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An evolving market context for Satellite communications

Trends	New SatCom roles / impacts on operation
from service to user centric approach	Space segment shall **adapt to the targeted UE** which shall **adapt to the usage constraints** e.g. Pedestrian, Automotive, Drone use cases
The « **fast response time** » requirement	NGSO: Reinforced role GSO: restricted to back-up or more ?
telecom networks increasingly at the **basis of the (digital) economy**	from **coverage extension** to **network resiliency** / Multi orbit infra (with ISL)
Spectrum scarcity	Towards **Spectrum sharing** with Mobile Service
Sustainability	Towards converged space infrastructures (Telecom, navigation, observation) / **Multi orbit**, **Multi mission** satellite systems ?

NTN targeted market segments (see 3GPP S1-241041)

Consumer market:

- Includes connectivity to **smartphones or wearable devices & cars**;
- Need for guaranteed coverage;
- By 2030, at least:
  - 7.5% of the total number of mobile subscribers (5.2Bn) expected to be NTN;
  - 5% of the new cars (~75 million per year) are expected to be NTN capable.

Enterprise market:

- Need for services in rural areas or less developed areas and moving platforms;
- Unique UE for both NTN/TN;
- Similar use cases to today (e.g. office, media & entertainment);
- As the technology becomes cheaper and compact and easier to access, the adoption is expected to rise.

Vertical markets:

- Utilities, agriculture (e.g. sensors), transport (aeronautic, maritime, railway), governmental users (e.g. broadband communication);
- Specific requirements: e.g. sensor data collection over a wide area, **autonomy, security, resilience and mobility**;
- Several millions of users are expected to require satellite connectivity.

6G-NTN: 2 family use cases

- Satellite **connectivity to smart phones and IoT devices** (D2D) in frequency bands **up to 8 GHz**
  - enhanced performances compared to 5G (data rate, coverage, throughput, ..)

- Satellite **connectivity to vehicle/building mounted devices** (Flat Panel Antenna) in frequency bands **above 10 GHz** (e.g. Ku, Ka, Q/V band).
  - Terminal (SWAP) adapted to vehicles from the automotive, public safety, transport (aeronautic, railways, drone, maritime), utilities, agriculture and media & entertainment sectors are assumed.

NTN in 6G: Service Requirements (via satellite access network)

Improved user experience

- **Improved service continuity** over the coverage
  - Enhanced NTN/TN mobility/multi connectivity especially in connected mode
- **Improved coverage**
  - Provision of emergency services (at least SMS) via satellite in light indoor/in vehicle conditions
  - Mobility in sub-urban/dense forest (i.e. several hundred ms fading duration)
- **Support of device diversity**
  - Handheld/IoT, vehicle/drone mounted
- **Improved data rate/throughput**

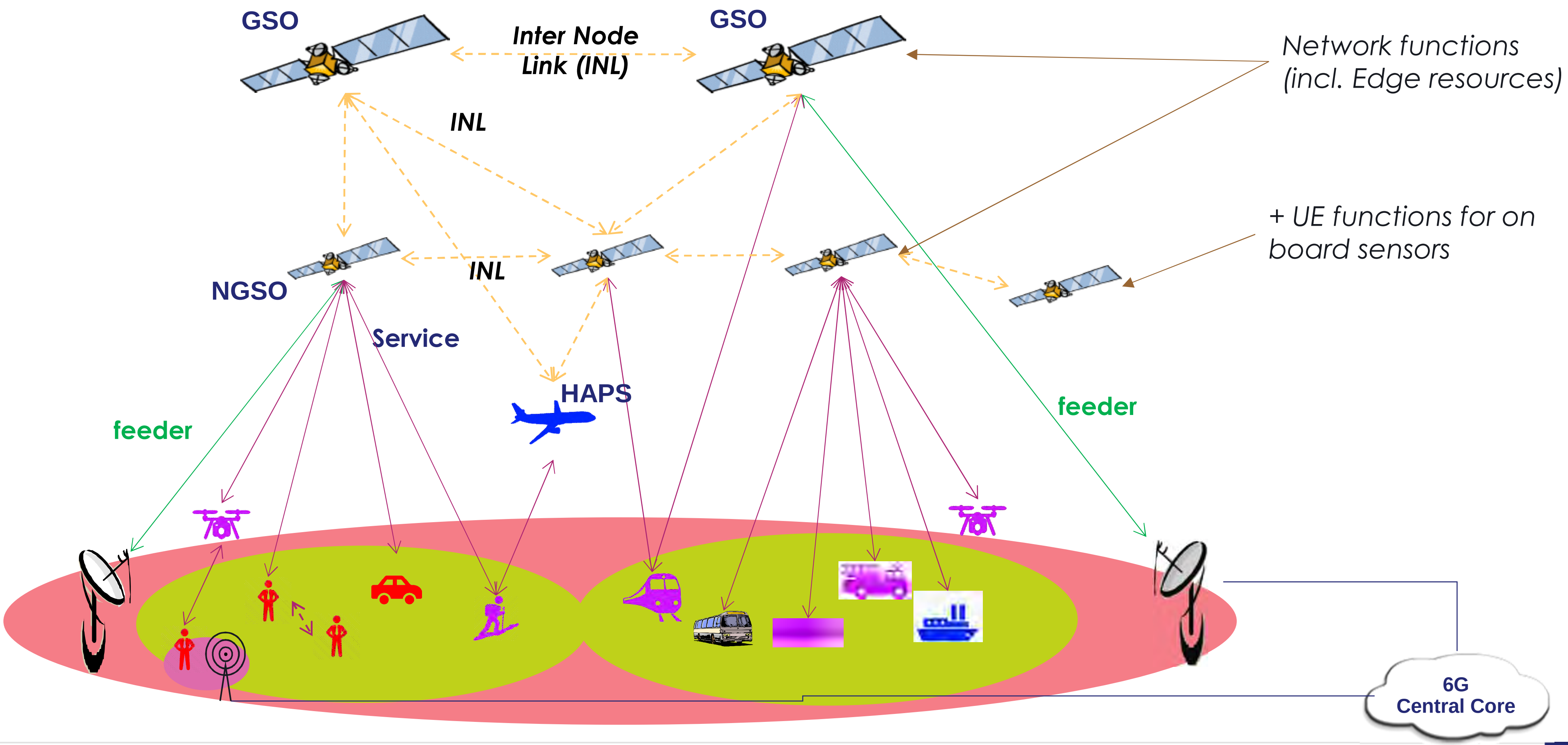
Improved network capabilities

- **Resiliency**
  - GNSS independent operation (i.e. initial access, ..)
  - GNSS independent capability for the UE to determinate its location
  - Service continuity with respect to temporary failure of a given node (e.g. NGSO, GSO, HAPS, TN node);
  - Fast set-up of an autonomous network over a specific region via satellite(s) and/or HAPS with no or intermittent connectivity to core networks (e.g. for crisis response)
- **Sustainability**: Minimise overall consumption
  - Energy based access network selection: under traffic or zero traffic conditions
- **Overall spectrum usage efficiency**
  - Multi access technology spectrum coexistence (i.e. NTN/TN)

NTN in 6G: Possible performances

Target service performances	NTN in 5G (As per 3GPP &/or ITU-R IMT2020 satellite requirements)	NTN in 6G
Peak data rate (DL/UL) wrt smartphones & low cost IoT devices	1/0.1 Mbps (Outdoor only) @ up to 3 km/h	Outdoor conditions: Tens of Mbps @ up to 250 km/h Light indoor/in car conditions: At least Short Message Service capability
Peak data rate (DL/UL) wrt Vehicle or drone (flying and surface) mounted devices	[50/25] Mbps @ up to 250 km/h (with 60 cm aperture)	Hundreds of Mbps (Outdoor only) @ up to 250 km/h (with <20 cm equivalent aperture)
Peak data rate (DL/UL) wrt Large Aeronautic, maritime platforms mounted devices	[50/25] Mbps @ up to 1000 km/h	Thousands of Mbps (Outdoor only) @ up to 1200 km/h (with <60 cm equivalent aperture)
Location service (target accuracy and acquisition time) in outdoor conditions only	respectively 1 meter and < 100 seconds (reliability through Network verification)	respectively 100 meter (TBC) @ 95% reliability through RAT dependent positioning method
Coverage	Outdoor only	Maximum Coupling Loss able to address light indoor/In car

NTN in 6G : 3D Network architecture concept



Multi-multilayer & multiband 6G architecture

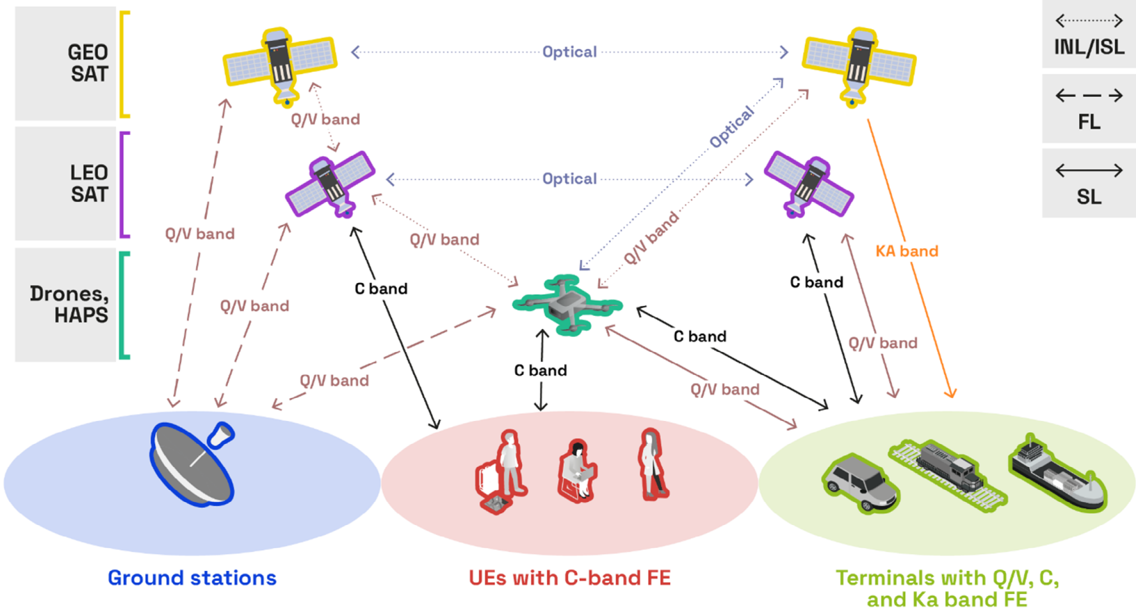
Deterministic nodes (predictable orbits)

GSO platforms

- broadcast & multicast for fixed ground stations
- broadband access
  - backup coverage in case of lower constellation satellite(s) failures
  - complementary capacity for non-delay sensitive traffic offloading
    from the NGSO.
- Control and management planes to the NGSO in case of no feeder links / ground segment

NGSO platforms

- broadband access to handhelds and/or VSAT-like UEs



"Opportunistically" deployed nodes

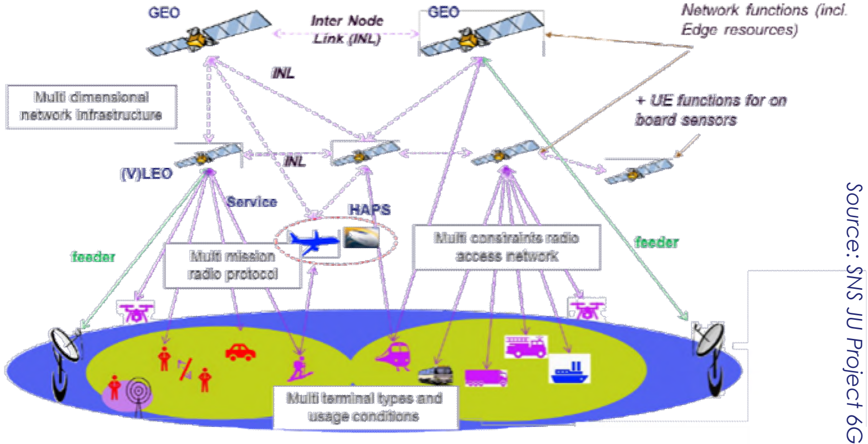
HAPs or drones (heavy drones)

- 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

NTN in 6G: architectural solutions

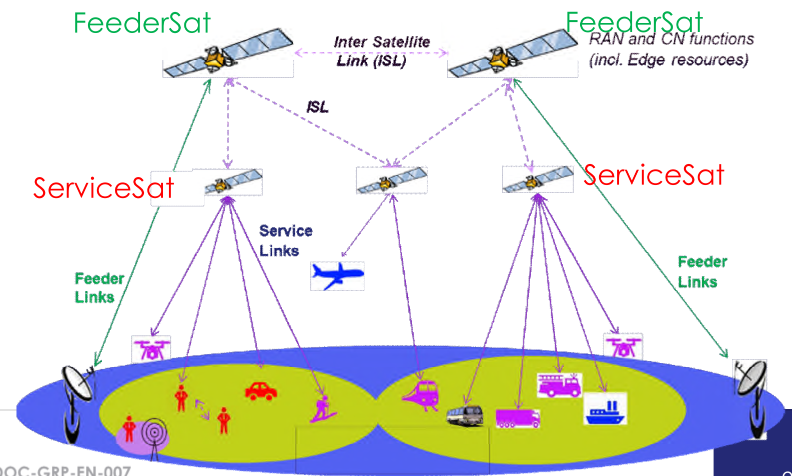
> Conventional architecture – homogeneous satellites

- 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 ISL to GEO satellites
  - All RAN and, possibly, some CN functionalities



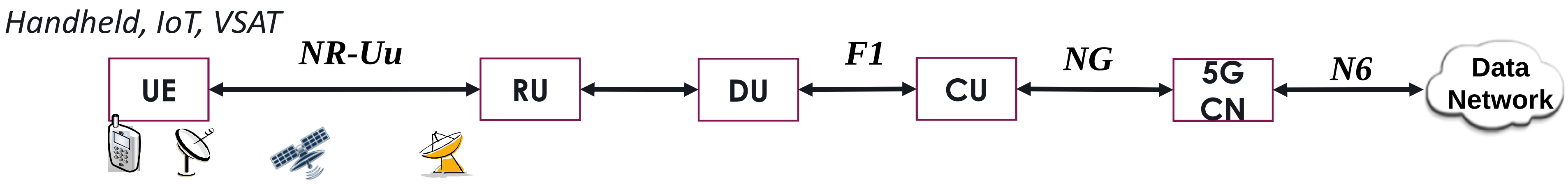
> Distributed architecture – heterogeneous nodes (same altitude)

- Feeder Nodes with higher computational capabilities
  - 2 Feeder links to GW / no user link to UE
  - 4 OISLs to 4 service nodes
  - 2 OISLs to 2 feeder nodes
  - 1 Ka-band payload for the ISL to GEO satellites
  - Upper layers RAN functionalities/CN functionalities
- Service Nodes with lower computational capabilities
  - User link to UEs (multibeam) / no feeder link to GW
  - 1 OISL to 1 feeder node
  - Lower PHY functionalities (RU)

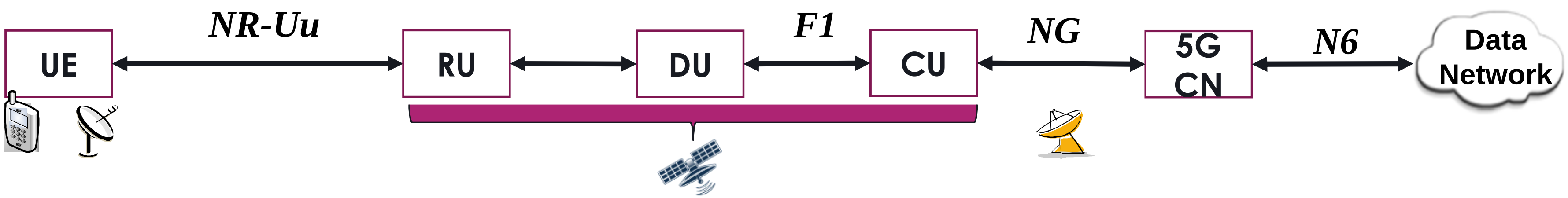


Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 202

NTN functional architecture and mapping on space segment (1)

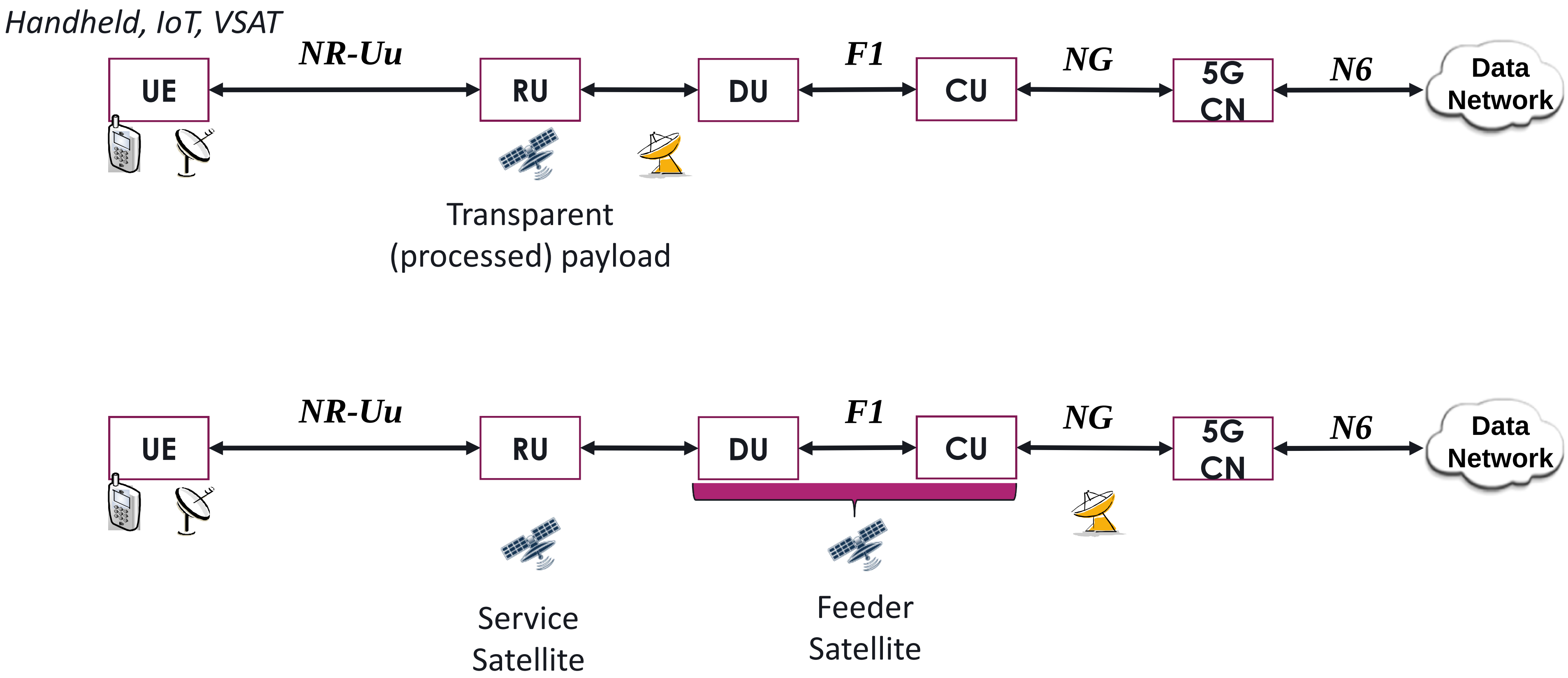


Transparent (RF) payload



Regenerative payload

NTN functional architecture and mapping on space segment (2)



6G radio interface: NTN related enablers (1/2)

Spectrum efficient and flexible waveform optimized for both terrestrial and non-terrestrial network components

Candidate radio interface features	Rationale
Multi carrier waveform enhancements	▪ OFDM evolution offering relaxed synchronization requirements. ▪ Supporting UE without GNSS capabilities (also referred as « GNSS free operation ». ▪ Mitigating specific satellite constraints: Reduce the Peak-to-Average Power Ratio (PAPR) on the downlink to maximize the spectral efficiency in case of reduced number of channels in a single on board amplifier.
Advanced modulation, coding and multiple access schemes	▪ Minimizing error rate performance under low SNR conditions. ▪ Enabling the support of extended Maximum Coupling Loss to mitigate challenging radio link conditions (e.g. to overcome building penetration loss).
Design flexible UL/DL framing structure	▪ Adapt the frame structure to satellite Orbit, frequency range etc… ▪ Reduce the overhead penalty since there are quasi no multi-paths in satellite propagation channel.

See details in 3GPP 6GWS-250040

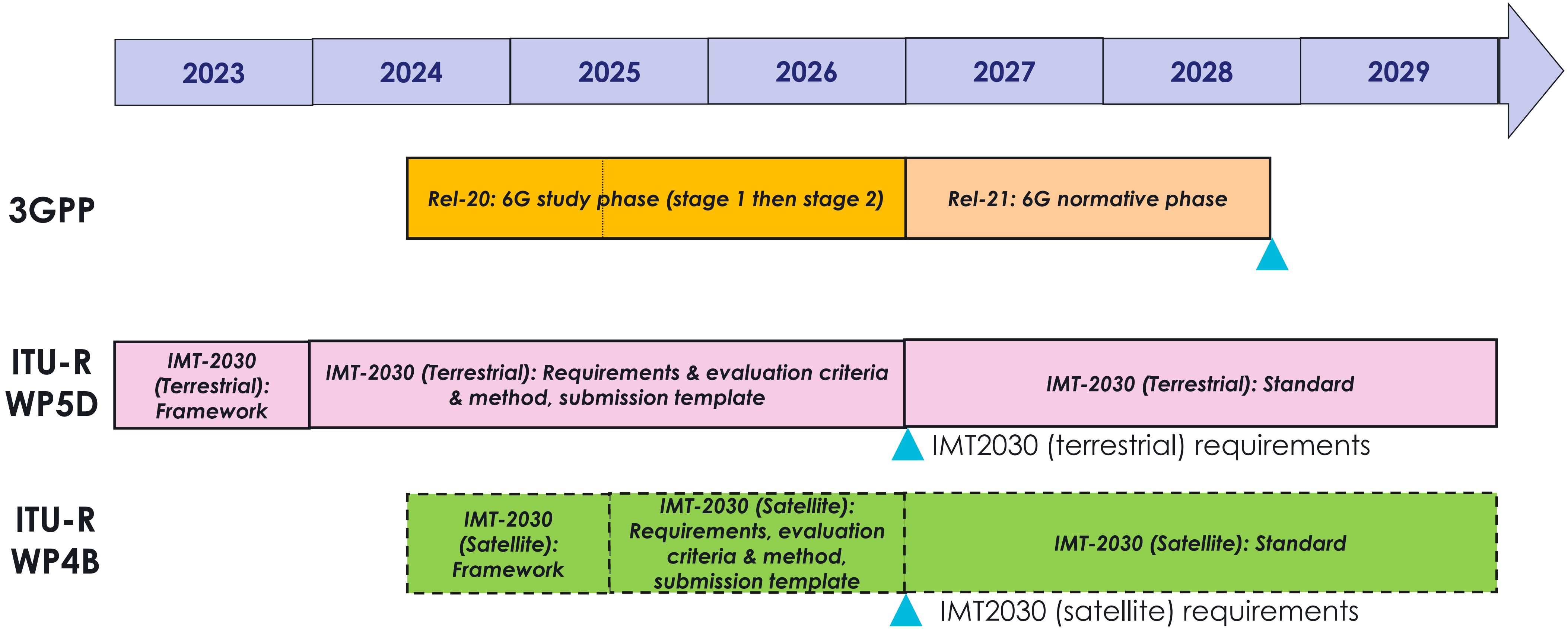
6G radio interface: NTN related enablers (2/2)

Candidate radio interface features	Rationale
Design appropriate robust reference signals for enhanced positioning	▪ Support reliable (i.e. trusted) network based solution for accurate and fast response Positioning, Navigation and Timing (PNT) service. ▪ Potential narrow-band synchronization signals could be also designed, where the PRS resources could be defined over multiple slots.
Support of broadcast and multicast	▪ Leverage the large coverage area of satellites
Enablers for Artificial Intelligence driven radio resource control	▪ Increase the "goodput" of a radio link through dynamic optimisation 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	▪ Revise the methodology of coexistence study and RF/RRM specification, and potentially consider adjacent channel coexistence between TN and NTN.
New spectrum	▪ Some additional MSS allocations may be granted at the WRC-2027 as per agenda items 1.12, 1.13 and 1.14. Moreover, some additional bands such as Q/V bands should be considered for broadband connectivity.
FDD and TDD support	▪ Adapted to paired and unpaired spectrum

See details in 3GPP 6GWS-250040

6G TN & NTN: 3GPP and ITU-R

TN = Terrestrial Network
NTN = Non Terrestrial Networks (Satellite, HAPS)



Calendar is driven by the terrestrial component of 6G !

NTN in 6G system: Key recommendations

> Hooks for 6G RAT to support NTN shall be defined in 6G from day one

- to enable ubiquitous connectivity with quasi seamless service continuity
- to contribute to the overall resiliency and sustainability of the 6G system.

> NTN shall operate without dependency to 3rd party system (e.g. GNSS)

What about sustainability ?

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Sustainability in NTN for 6G

> Mega constellation based satellite network:

- **a LEO space segment** able to provide global coverage but **oversized to meet a peak traffic demand over a specific geographical area** and setting high constraints on the coexistence with other constellations,
- **satellites with short lifetime** leading to high replacement rate,
- a relatively **high average power consumption of the terminal** due to continuous tracking of the successive serving satellites.

> Vs Multi orbit satellite network

- ***space segment level***
  - Take advantage of
    - GEO for broadcast/multicast traffic, and common signalling (e.g. idle mode)
    - MEO for navigation and broadband traffic
    - LEO for broadband traffic
  - Optimization of
    - LEO sizing (overall mass to be launched) to the average traffic demand
      - => off load to MEO or GEO the geographically localized and/or temporary peak traffic demand,
    - LEO and MEO space segment power and extended lifetime
      - => Beam deactivation when no traffic demand

- ***Terminal level***
  - Reduced Tx peak power
  - Energy saving:
    - served via the GSO space segment when in idle mode state. (no satellite tracking)

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Note that

- *the views expressed in this presentation may not necessarily be the ones of Thales Alenia Space*
- *Part of the content of this presentation leverages the outcomes of the Horizon Europe 6G-NTN R&D project*

Some references

- « 3GPP Non-Terrestrial Network: A Global Standard for Satellite Communication Systems », Special Issue of the International Journal of Satellite Communications and Networking, Pages: 217-301, Edited by Mohamed El Jaafari and Nicolas Chuberre, published by Wiley, May/June 2023,
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