ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

The evolution of 3GPP NTN from 5G to 5G-Advanced and 6G

Space Softwarization: from Physical Layer to Services: a new paradigmatic vision of Space networks

Summer School "Frontier Technologies for Space 2.0 Communications"

August 30, 2023

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3rd Generation Partnership Project

- Standardization allows to specify the best possible technical solution given all the requirements from interested parties
  - operators, network infrastructure vendors, chipset makers, …

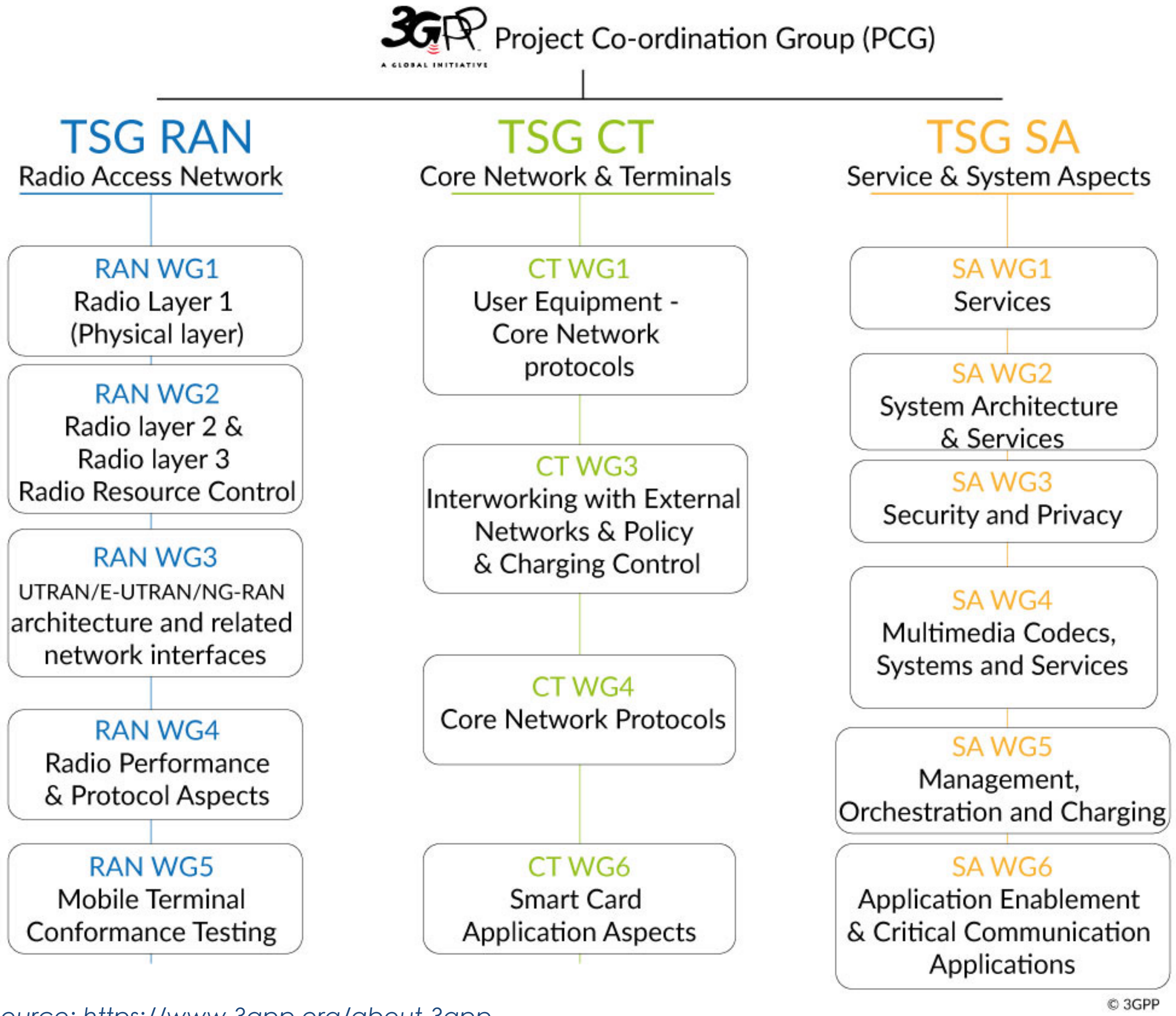
Our Partners		Country
ARIB	The Association of Radio Industries and Businesses (ARIB) www.arib.or.jp	Japan
atis	The Alliance for Telecommunications Industry Solutions (ATIS) www.atis.org	USA
CCSA	China Communications Standards Association (CCSA) www.ccsa.org.cn	China
ETSI	The European Telecommunications Standards Institute (ETSI) www.etsi.org	Europe
tsdsi India's Telecom SDO	Telecommunications Standards Development Society, India (TSDSI) http://tsdsi.org	India
TTA	Telecommunications Technology Association (TTA) www.tta.or.kr	Korea
TTC Telecommunication Technology Committee	Telecommunication Technology Committee (TTC) www.ttc.or.jp/e	Japan

- 3GPP: non-legal body grouping 7 Standard Developing Organisations to prepare, approve, and maintain global-level technical specifications
  - mobile communications technologies, including radio access, core network, and services
  - hooks for non-radio access to the core network and for interworking with non-3GPP networks
  - 3GPP specifications and studies are contribution-driven, by member companies, in WGs at the TSG level

- 840 individual members from the 7 SDOs

Source: https://www.3gpp.org/about-us/partners

3rd Generation Partnership Project



Source: https://www.3gpp.org/about-3gpp

- Regular WGs meeting + quarterly plenary TSG meeting for discussion and approval
- The progress of the standards is indicated in milestones denoted as **Releases**

collection of functionalities, providing developers with a stable platform for the implementation of features at a given point and allowing the addition of new functionalities in subsequent Releases

Source: https://www.3gpp.org/specifications/67-releases

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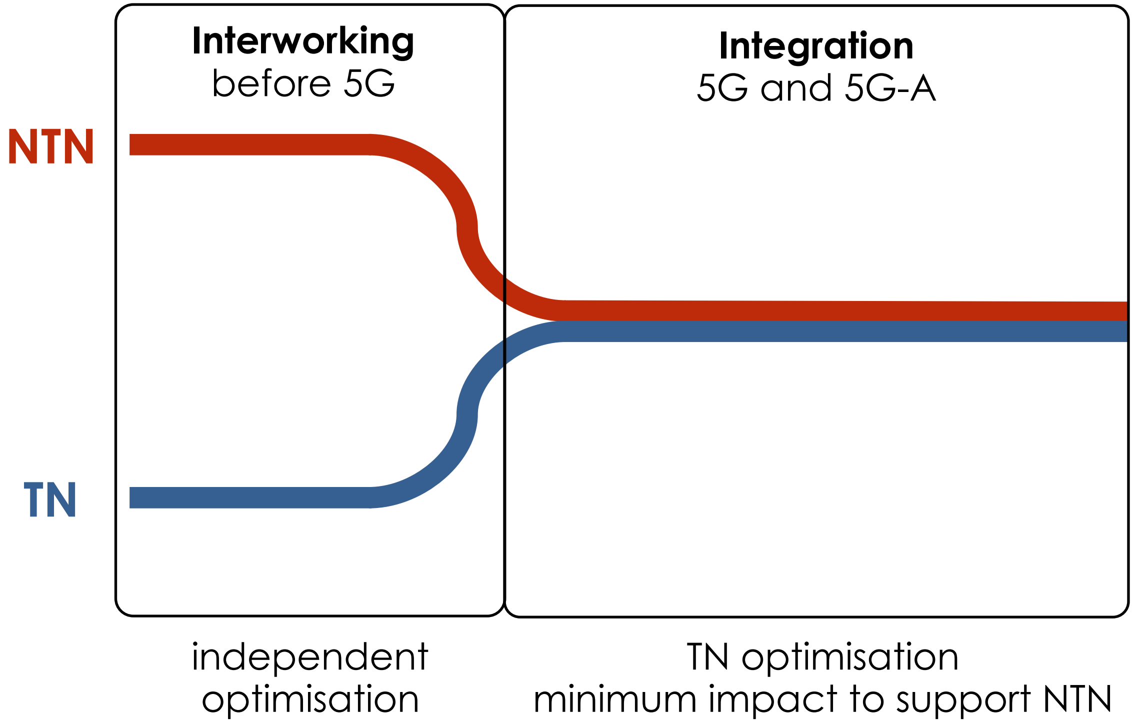
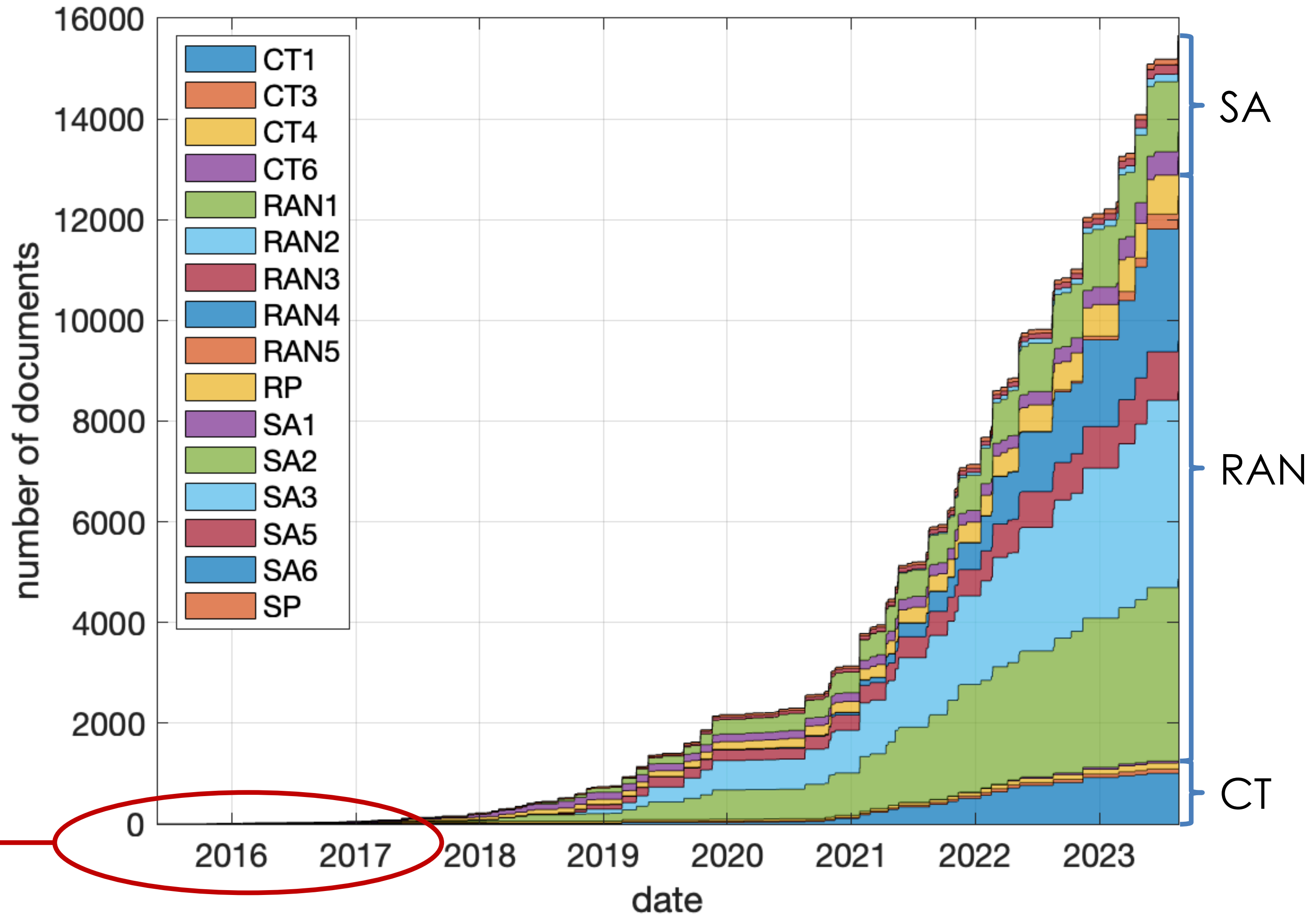
3GPP Non-Terrestrial Networks

- NTN standard: **the result of a joint effort** between stakeholders of both mobile and satellite industries with a two-fold benefit
  - true achievement of global service continuity and resiliency for 3GPP
  - access to the unified and global 3GPP ecosystem and possibility to exploit economy of scale for the satellite industries

- The NTN standard is also supported by **vertical stakeholders** aiming at
  - the seamless **combination** of satellite and mobile systems
  - the **support** of all 5G features across different RATs



3GPP Non-Terrestrial Networks

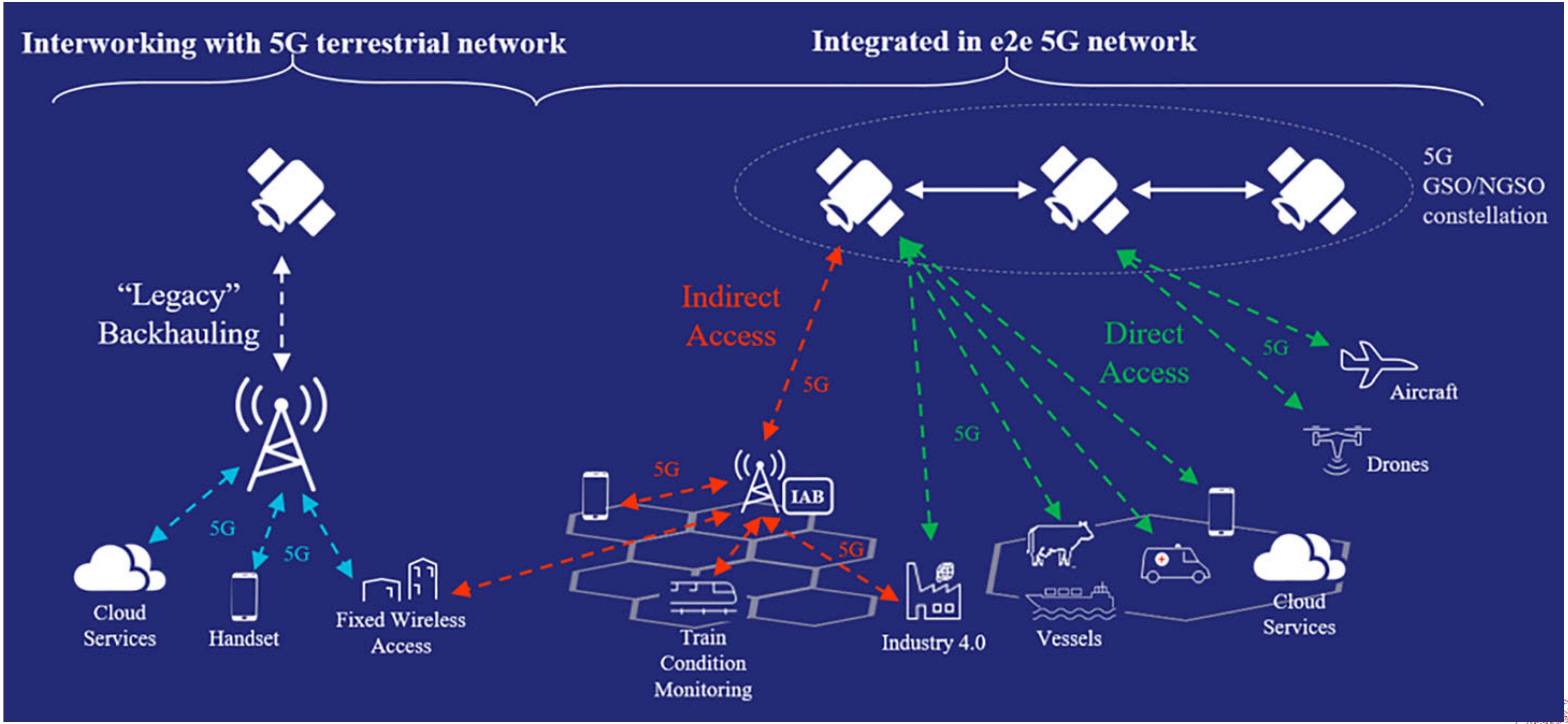


The inclusion in Rel. 17 made NTN skyrocketing!

<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.

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*

NTN scenarios and capabilities

- Support of three general scenarios, in which we can distinguish:
  - satellite access networks operating in FR1 → direct connectivity to
    - outdoor handheld terminals and/or car/drone mounted devices via 5G NR (wideband)
    - outdoor IoT devices via the 4G NB-IoT/eMTC standard (narrowband)
  - satellite access networks operating in FR2 → broadband connectivity to VSATs on rooftops and/or ESIMs on moving platforms

	Direct connectivity (FR1)		**Indirect connectivity (FR2)**
Targeted terminals	IoT devices	handheld (smart phones) and car/drone mounted devices	VSAT and/or ESIM
Service	Narrowband hundreds of kbps	Wideband few Mbps	Broadband hundred Mbps
Orbit	GSO and NGSO	NGSO	GSO and NGSO
3GPP Radio interfaces	4G NB-IoT/eMTC	5G New Radio	5G New Radio
Market applications	Professional: utilities, agriculture	Consumer Professional: automotive, Public Safety, utilities, agriculture, Defense	Professional: telco (*e.g.*, backhaul), IPTV, SNG, transportation, Public Safety, Defense

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

The road to NTN in Rel. 17

study phase — normative phase

Release 15

- 2017: initial RAN and SA SIs on NR to support NTN
- TSG RAN and RAN1 findings reported in TR 38.811

- use cases and scenarios
- NTN channel model
- potential key impact areas

Release 16

- 2018: necessary features and adaptations to support NR protocols in NTN
- findings reported in TR 38.821

- architectures
- challenges and solutions for L1, radio protocols, interfaces

Release 17

- 2020: WI on the NR enhancements to support NTN
- findings reported in the TS 38.xyz series

- 3GPP SA focused on the identification of use cases for NTN-based 5G aiming at
  - **service ubiquity and global connectivity**, by providing direct access to handset, home access, and IoT devices in under-/un-served areas solving the "0G" issue
  - **service continuity and resiliency**, by combining TN and NTN to serve mobile platforms
  - **service scalability**, by efficiently providing multicast/broadcast services (MBS) via NTN

NTN Study Phase

- Study phase: take into account the specific characteristics of satellite networks and channels, which create new technical challenges compared to legacy terrestrial networks

- This required adaptations to tackle issues related to
  - long propagation delays
  - large Doppler shifts and Doppler variations
  - generation of large moving cells on-ground

- Addressed NTN platforms
  - GSO or NGSO spaceborne satellites
  - airborne vehicles operating at altitudes typically between 8 and 50 km
    - HAPS
    - Unmanned Aerial Systems (LTA and HTA)

NTN Study Phase

	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5	Cellular (10 km Radius)
Platform orbit and altitude when relevant	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	Airborne vehicle up to 20 km	
Frequency band	Ka band	S band	S band	Ka band	S band (Below 6 GHz)	S band
Max One way Propagation delay (ms)	Bentpipe: 272.37 ms gNB on board: 135.28 ms	272.37 ms	14.204 ms	14.204 ms	1.526 ms	0.03333 ms
Max Differential delay (ms)	16 (between Edge of satellite coverage and Nadir)	16 (between Edge of satellite coverage and Nadir)	4.44 (between Edge of satellite coverage and Nadir)	4.44 (between Edge of satellite coverage and Nadir)	0.697 (between Edge of satellite coverage and Nadir)	0.00333(between cell centre and cell edge) equal to maximum delay
Max Doppler shift in kHz	For plane @ 20 GHz: +/- 18.51 kHz @30 GHz: +/- 27.7 kHz	For plane 1.851 kHz @ 20 GHz	+/- 48 kHz	@20 GHz : +/- 480 kHz @30 GHz : +/- 720 kHz	@ 2 GHz: +/- 100 Hz mainly due to platform motion	In case of UE on board a high speed train: +/- 925 Hz
% of the carrier frequency (Ratio of Doppler Shift over the central signal frequency	10^{-4} %	10^{-4} %	0.0024%	0.0024%		
Max Doppler variation in Hz/s.	Negligible	Negligible	-544 Hz/s @ 2 GHz	-5.44 kHz/s @ 20GHz (Downlink) -8.16 kHz/s @30 GHz (uplink)	Negligible	Negligible

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Platform orbit and altitude	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	UAS between 8 km and 50 km including HAPS
Carrier Frequency on the link between Air / space-borne platform and UE	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Around 2 GHz for both DL and UL (S band)	Around 2 GHz for both DL and UL (S band)	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Below and above 6 GHz
Beam pattern	Earth fixed beams	Earth fixed beams	Moving beams	Earth fixed beams	Earth fixed beams
Duplexing	FDD	FDD	FDD	FDD	FDD

Source: 3GPP TR 38.811, "Study on New Radio (NR) to support non-terrestrial networks (Release 15)," September 2020

NTN Study Phase

NTN characteristics	Technical issues	Impacted NR features	Potential areas of impact	Comments
Motion of the space/aerial vehicles	Moving cell pattern	Hand-over/paging	Higher layers impact	Paging and Hand-over procedures should be adapted to take into account the relative motion of the cell pattern with respect to the tracking area. Further analysis on tracking area design may need to be carried out. Mobility management is also to be considered.
	Delay variation	TA adjustment	Physical layer impact	Alignment of uplink signals may need to be considered.
	Doppler	Initial downlink synchronization	No impact	The preferred SCS values for Non-Terrestrial Networks may be respectively 60 KHz for frequency bands <6 GHz and 240 KHz for frequency bands > 6 GHz. However it can also operate with lower SCS value.
		DMRS time density	No impact	The preferred DM-RS configuration may be type 1 to cope with Doppler variation rate.
Altitude	Long latency	HARQ	Higher Layers & physical layer Impact	Need to adapt the HARQ specification. Deactivation and/or enhancements of NR HARQ can be considered.
		Physical layer Procedures (ACM, power control)	Physical layer impact	The operation/configuration of Adaptive power and coding/modulation control loop protocols may have to be adapted.
		MAC/RLC Procedures	Higher layers impact	Timers limit of MAC/RLC and higher layers loop protocols may have to be extended.

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

NTN Study Phase

NTN characteristics	Technical issues	Impacted NR features	Potential areas of impact	Comments
Cell size	Differential delay	TA in Random access response message	Physical layer impact	Doppler/Delay compensation technique can be implemented. Further analysis/simulations using the NTN channel model is needed. Adaptations of PRACH format and random access procedure may have to be considered.
		Random access	Physical layer impact	
Propagation channel	Impairments	DMRS frequency density	No impact	Non terrestrial network propagation channel may feature a frequency selective at most comparable with cellular channel.
	Impairments	Cyclic prefix	No impact	Non terrestrial network propagation channel may feature a worse delay spread at most comparable to cellular channels.
Duplex scheme	Regulatory constraints	Duplexing mode (TDD/FDD)	Higher layers impact	FDD is preferred especially for most satellite systems. TDD can be considered for HAPS and for LEO(*).
Satellite or aerial Payload performance	Phase noise impairment	PT-RS	Potential constraint on the operation to be further studied	Satellite Radio links are typically operated with relatively low order modulation scheme, in most of the cases up to 16QAM.
	Back-off	PAPR	Physical layer impact	Uplink: It is recommended to use DFT-S OFDM Downlink: Low PAPR scheme may improve performance. However not mandatory to support non-terrestrial networks.

(*) *Note: there is one LEO network that operates in TDD mode (IridiumNext).*

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

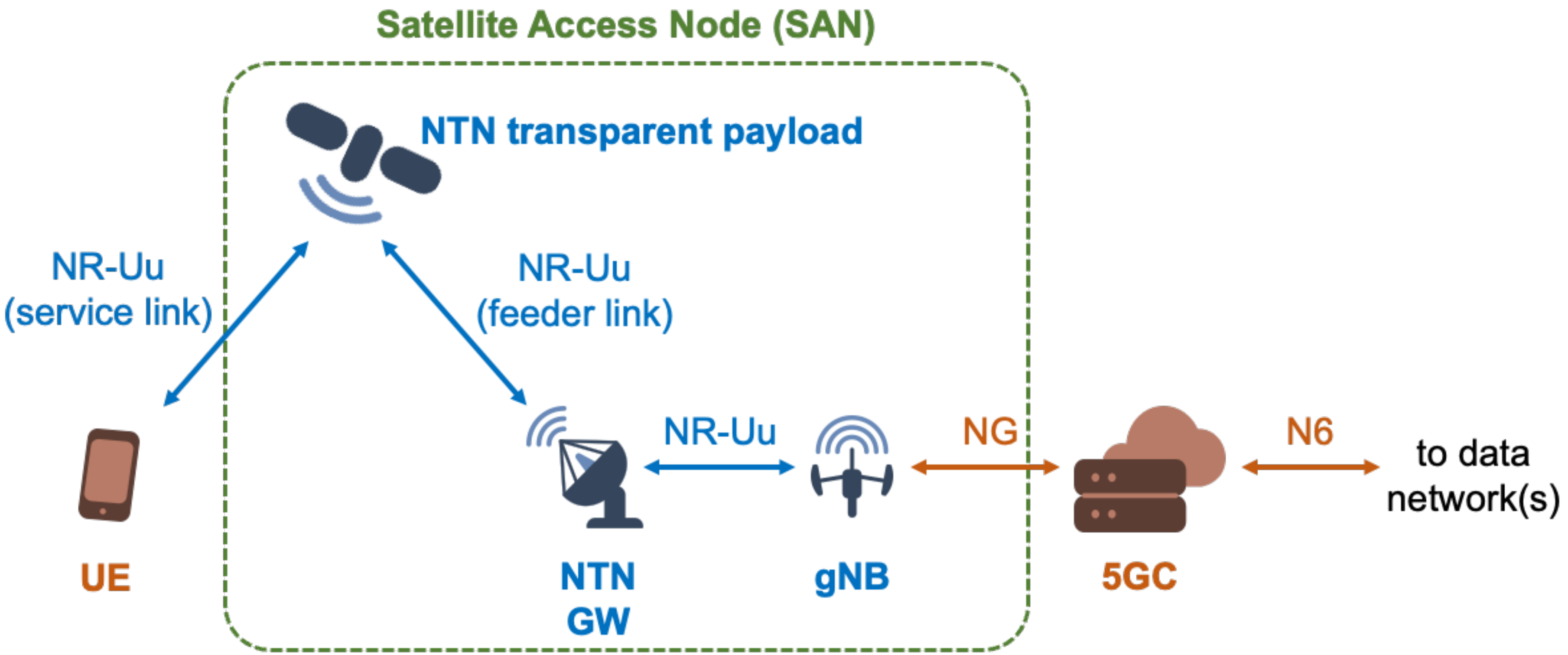
- Building on these outcomes, TR 38.821 reports the identified architectures and a detailed assessment of the impacts on L1, radio protocols, and interfaces

NTN Normative Phase: Rel. 17

- Focus on NTN-based GEO and LEO systems with implicit compatibility to support HAPS and ATG

- Main characteristics
  - **transparent payload architecture**
  - coverage type
    - **Earth-fixed**: the beams continuously cover the same geographical area all the time (e.g., GEO)
    - **Quasi-Earth-fixed**: the beams cover a geographical area for a limited period 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., they 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
  - **handheld** terminals **with GNSS** capabilities
    - the UE is capable of estimating its location and report it to the network
  - **FDD**
    - TDD unfeasible due to the large propagation delays on satellite links
  - **Earth-fixed tracking**
    - the Tracking Area (set of on.ground cells) is fixed on the Earth's surface, which requires an adaptive mapping between the gNB and the beams for NGSO (due to a feeder link switch)

NTN Rel. 17: architecture

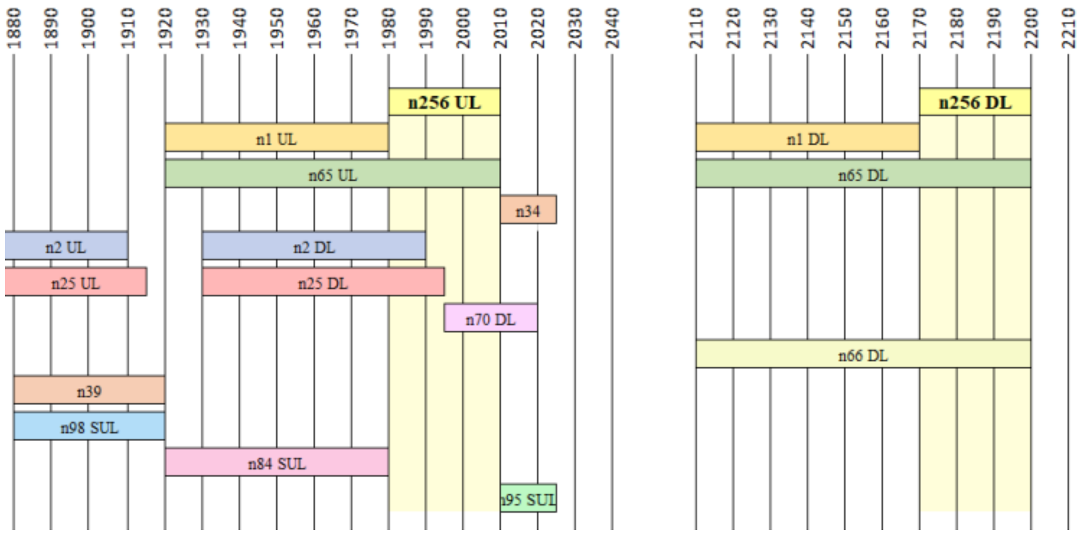


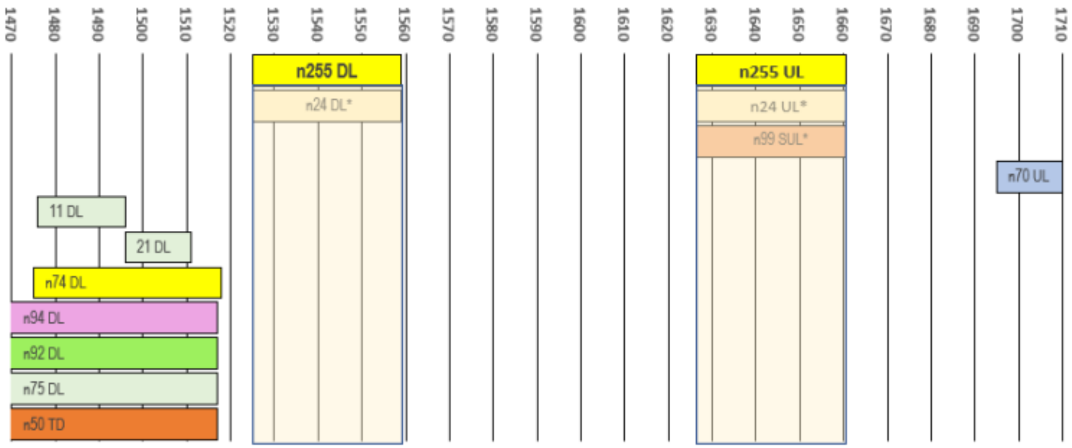
- Transparent payload → user and feeder link implementing the NR-Uu interface
- All protocols and procedures are terminated and managed on-ground
- Depending on the specific implementation, mutliple gNBs might be needed to manage a single NTN node

NTN Rel. 17: spectrum

- Deployment exclusively in FR1

Satellite operating band	UL operating band (UE-to-SAN)	DL operating band (SAN-to-UE)	Duplexing mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD





- n256 adjacent to n1 (FDD) and n34 (TDD) → co-existence analysis required
- full/partial overlap with n65, n2, n25, n70, n66 → possible limitations to n256 use in some countries
- RF requirements for NTN access in TR 38.863 for nodes compliant with TS 38.101-5 and TS 38.108
- max. 30 MHz on NTN DL/UL, a single handheld terminal can have 360 kHz on the UL
- SCS: 15 kHz or 30 kHz

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

NTN Rel. 17: impact on specifications

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.

NTN Rel. 17: impact on specifications

TABLE 5 3GPP RAN specifications updated for the integration of satellite components in the 5G.[a]

3GPP working group	3GPP RAN specifications
RAN1	**TS 38.211** Physical channels and modulation
	TS 38.213 Physical layer procedures for control
	TS 38.214 Physical layer procedures for data
RAN2	**TS 38.300** Overall description; Stage-2
	TS 38.304 User Equipment (UE) procedures in idle mode and in RRC Inactive state
	TS 38.306 User Equipment (UE) radio access capabilities
	TS 38.321 Medium Access Control (MAC) protocol specification
	TS 38.322 Radio Link Control (RLC) protocol specification
	TS 38.323 Packet Data Convergence Protocol (PDCP) specification
	TS 38.331 Radio Resource Control (RRC); Protocol specification
RAN3	**TS 38.401** NG-RAN; Architecture description
	TS 38.410 NG-RAN; NG general aspects and principles
	TS 38.413 NG-RAN; NG Application Protocol (NGAP)
	TS 38.423 NG-RAN; NG-RAN; Xn Application Protocol (XnAP)
RAN4	**TS 38.101-5**[b] User Equipment (UE) radio transmission and reception, part 5: Satellite access Radio Frequency (RF) and performance requirements
	TS 38.108 Satellite Access Node radio transmission and reception
	TS 38.133 Requirements for support of radio resource management
	TR 38.863 Non-terrestrial networks (NTN) related RF and co-existence aspects
	TS 38.104 Base Station (BS) radio transmission and reception
	TS 38.181 Satellite Access Node conformance testing; NTN specific characteristics

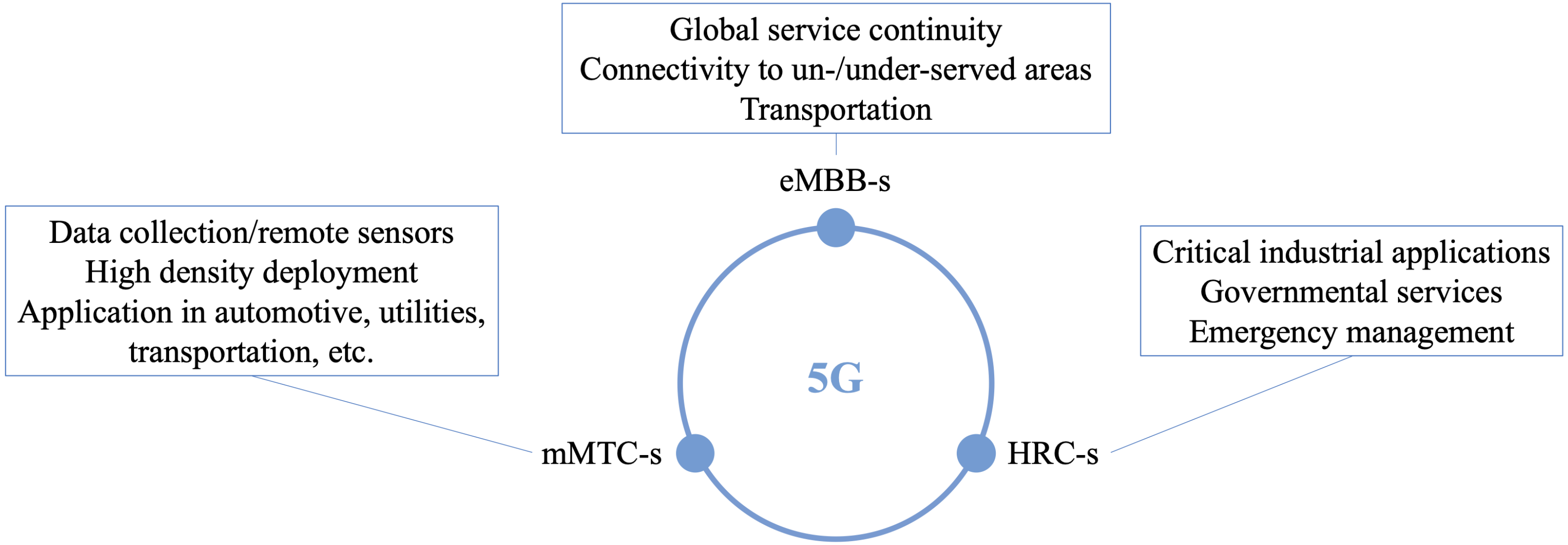
[a] 3GPP RAN specifications updated for NB-IoT/eMTC support for NTN are within 36 series: Replace 38 per 36 in Table 5.
[b] For IoT NTN: TS 36.102 Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception for satellite access.

TABLE 6 3GPP SA and CT specifications updated for the integration of satellite components in the 5G.

3GPP working group	3GPP SA specifications
SA1	**TS 22.261** Service Requirements for the 5G System
SA2	**TS 23.501** System architecture for the 5G System (5GS); Stage 2
	TS 23.502 Procedures for the 5G System (5GS), Stage 2
	TS 23.503 Policy and charging control for the 5G System (5GS), Stage 2
CT1	**TS 23.122** Non-Access-Stratum (NAS) functions related to Mobile Station (MS) in idle mode
	TS 24.501 Non-Access-Stratum (NAS) protocols for the 5G System (5GS), Stage3

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

5G NTN services



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

Broadband satellite service

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
Space X (Starlink)	12000+ (3580)	Ku-band	Proprietary	Yes	Broadband
OneWeb	648 (542)	Ku-band	Proprietary	TBD	Broadband
Kuiper	3236 (0)	Ka band	Proprietary	Estimated 2024	Broadband
Galaxy Space	1000 (7)	Q/V spetrum	Proprietary	TBD	Broadband
Boeing	147 NGSO (1)	V band	Proprietary	TBD	TBD
Inmarsat	14 GEO (14)	TBD	Proprietary	TBD	Broadband to IoT
Telesat	188 (2)	C, Ku, Ka bands	Proprietary	TBD	Broadband
Echostar	10 GEO (10)	Ku, Ka, S bands	Proprietary	Yes	Broadband
HughesNet	3 GEO (2)	Ka band	Proprietary	Yes	Broadband
Viasat	4 GEO (4)	Ka band	Proprietary	Yes	Broadband

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

IoT/D2C satellite service

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
Iridium	66 LEO	L-band	Proprietary	Yes	LDR/Messaging
Orbcomm	31 LEO	137-150 MHz	Proprietary	Yes	Assets tracking
GlobalStar	24 LEO	L/S-band	Proprietary	Yes	Assets tracking
Ligado	1 GEO	L-band	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT

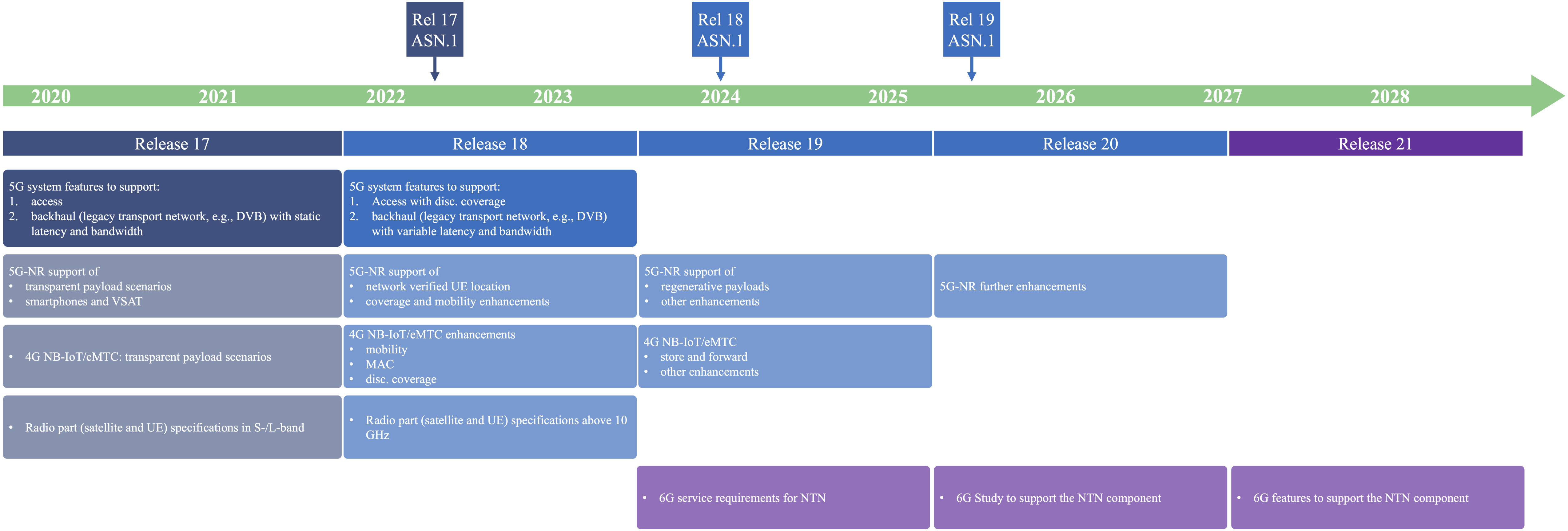
Source: 5G Americas, White Paper, "Update on 5G Non-Terrestrial Networks," July 2023.

IoT/D2C satellite service

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
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
Verizon/Kuiper	3236 (0)	Ka band	Proprietary	TBD	Ground sites backhaul - LTE and 5G
Apple/Globalstar	24 LEO	L-band, S-band	Proprietary	4Q2022	Emergency Messaging
Qualcomm/ Iridium	66 LEO	L-band	Proprietary	4H2023	Messaging
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
  - allow the verification of the GNSS coordinates determined by the UE
  - optimise mobility procedures in both idle and connected modes
- 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

Release 17

	Direct connectivity (FR1)		Indirect connectivity (FR2)
Targeted terminals	IoT devices	handheld (smart phones) and car/drone mounted devices	VSAT and/or ESIM
Service	Narrowband hundreds of kbps	Wideband few Mbps	Broadband hundred Mbps
Orbit	GSO and NGSO	NGSO	GSO and NGSO
3GPP Radio interfaces	4G NB-IoT/eMTC	5G New Radio	5G New Radio
Market applications	Professional: utilities, agriculture	Consumer Professional: automotive, Public Safety, utilities, agriculture, Defense	Professional: telco (*e.g.*, backhaul), IPTV, SNG, transportation, Public Safety, Defense

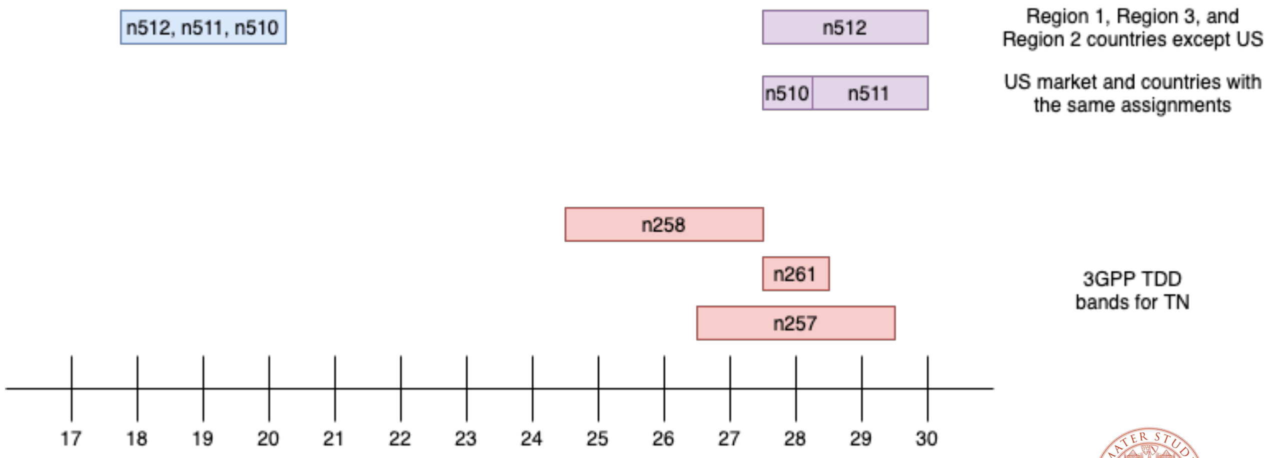
Release 18

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

NTN Rel. 18: spectrum

- Support of FR2 for VSAT only
  - evaluations based on transparent payloads (IAB/regenerative FFS)
  - configurations
    - 50, 100, 200 MHz channels + optional 400 MHz
    - SCS: 60 kHz or 120 kHz
  - co-existence analysis on-going (adjacent channel)

NTN Ka-band DL	17.7-20.2 GHz (n512, n511, n510)	For the Ka-band Downlink NTN band definition, define one NTN band covering the full harmonized Ka-band space-to-earth range of 17.7-20.2 GHz for Regions 1, 2 and 3.
NTN Ka-band UL	27.5-30.0 GHz (n512) 28.35-30.0 GHz (n511) 27.5-28.35 GHz (n510)	Define 3 NTN bands for Ka-band UL • one band covering the full harmonized Ka-band Earth-to-space range of 27.5-30.0 GHz applicable for Region 1, Region 3, and Region 2 countries except the US • additional two bands for the US/FCC market and countries deploying the same assignments: ◦ 27.5-28.35 GHz range ◦ 28.35-30.0 GHz range



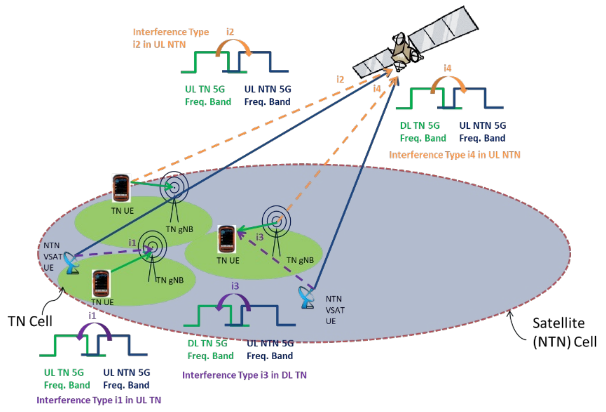
Source: ESA EAGER Project, White Paper, "Architectures, services, and technologies towards 6G Non-Terrestrial Networks," February 2023.

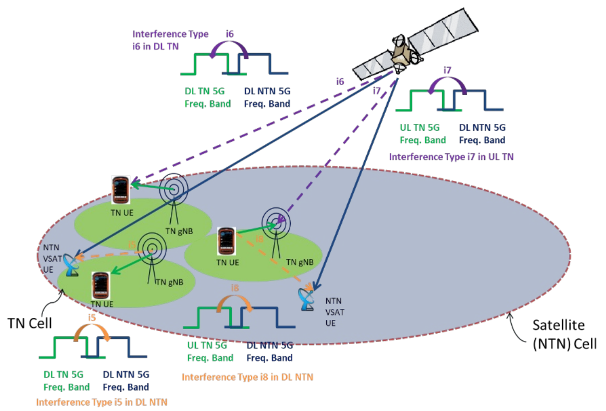
Source: EC HORIZON-JU-SNS-2022 Project 5G-STARDUST, D3.1 "System Requirements Analysis and Specifications," July 2023.

NTN Rel. 18: spectrum

- Co-existence scenarios currently considered

No.	Combination	Aggressor	Victim	Objective	NTN band
1	TN with NTN	NTN UL	TN UL	ACLR NTN UE to be varied/defined ACS TN gNB fixed	27 GHz
2	TN with NTN	TN UL	NTN UL	ACLR TN UE fixed ACS NTN SAN to be varied/defined	27 GHz
3	TN with NTN	NTN UL	TN DL	ACLR NTN UE to be varied/defined ACS TN UE fixed	27 GHz
4	TN with NTN	TN DL	NTN UL	ACLR TN gNB fixed ACS NTN SAN to be varied/defined	27 GHz
5	TN with NTN	TN DL	NTN DL	ACLR TN gNB fixed ACS NTN UE to be varied/defined	17 GHz
6	TN with NTN	NTN DL	TN DL	ACLR NTN SAN to be varied/defined ACS TN UE fixed	17 GHz
7	TN with NTN	NTN DL	TN UL	ACLR NTN SAN to be varied/defined ACS TN gNB fixed	17 GHz
8	TN with NTN	TN UL	NTN DL	ACLR TN UE fixed ACS NTN UE to be varied/defined	17 GHz





Source: 3GPP Tdoc R4-2309768, "Collection table for NTN co-existence in above 10GHz calibration results," WG4 Meeting # 107, May 2023.

Rel. 19: proposed topics for NR-NTN

Improve the service experience

- Coverage enhancements (DL and possibly UL)
- NTN/TN Mobility enhancement in connected mode (e.g., CHO)
- New Notification/Alert message for UE terminating calls with UE in poor SNR conditions preventing paging message reception
- Support of HD mode RedCAP UE (Reduced Capabilities) in FR1

New capabilities

- Support of Regenerative payloads (i.e., with ISL)
- Support of MBS (Multicast and Broadcast Services)
- Network-based positioning enhancements (NGSO & multi satellite visibility) for reliable UE location determination
- Support of UE with GNSS independent operation for uplink time and frequency synchronization in NTN based access (idle/connected modes)
- Asynchronous multi-connectivity (e.g., between two satellite access, i.e., NGSO and GSO; possibly between NTN/TN) for above 10 GHz only
- Support of discontinuous coverage (mitigating coverage holes during deployment/operation of constellation)

Rel. 19: proposed topics for IoT-NTN

Improve the service experience

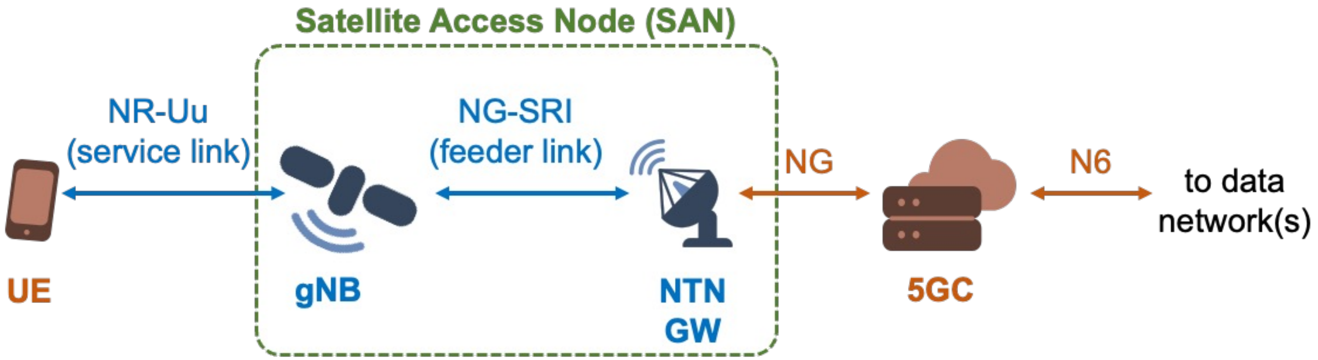
- NTN/TN mobility enhancement (signalling overhead optimization)
- Enhanced HARQ disablement (e.g. adaptative repetition scheme)

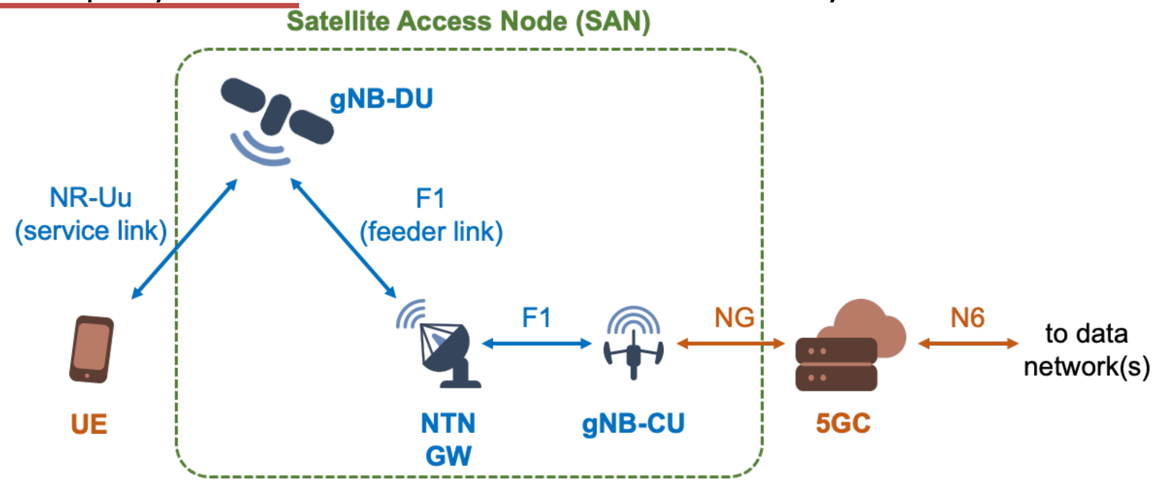
New capabilities

- Regenerative payload = Store and Forward (i.e., eNB + ePC network elements)
- Support of GNSS independent operation for uplink time and frequency synchronization in NTN based access
- 5GC supporting IoT-NTN

NTN Rel. 19: architecture

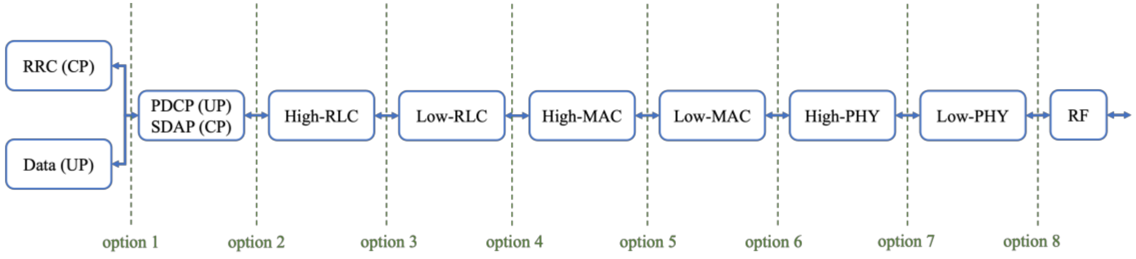
- Architecture evolution in three directions: regenerative payloads, IAB, Multi-Connectivity





- **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
    - the NG interface is logical
  - 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

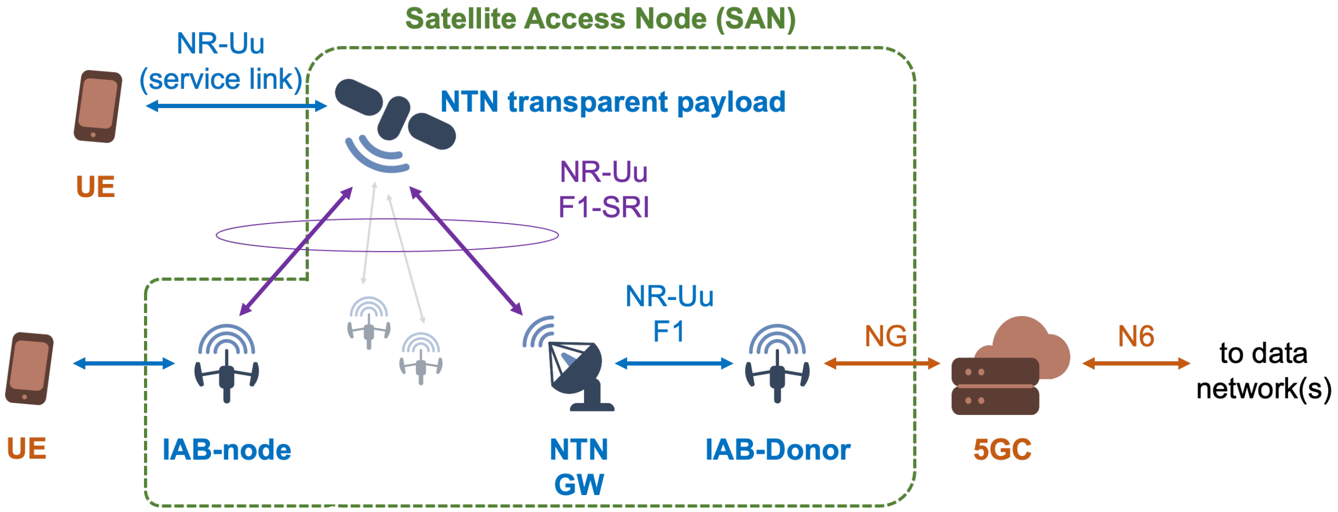


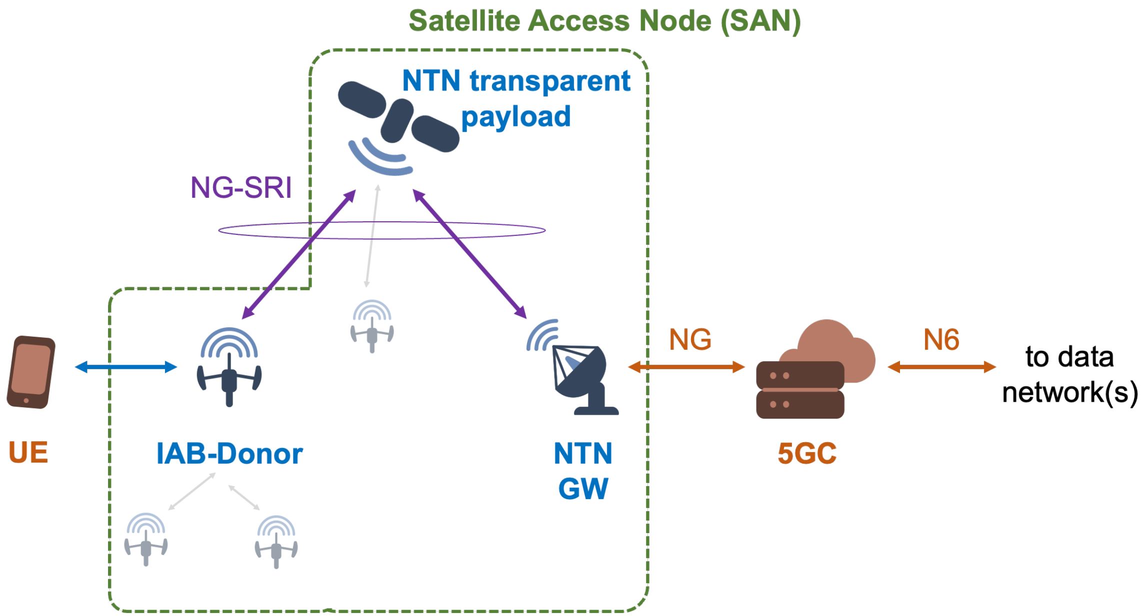
Source: ESA EAGER Project, White Paper, "Architectures, services, and technologies towards 6G Non-Terrestrial Networks," February 2023.

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



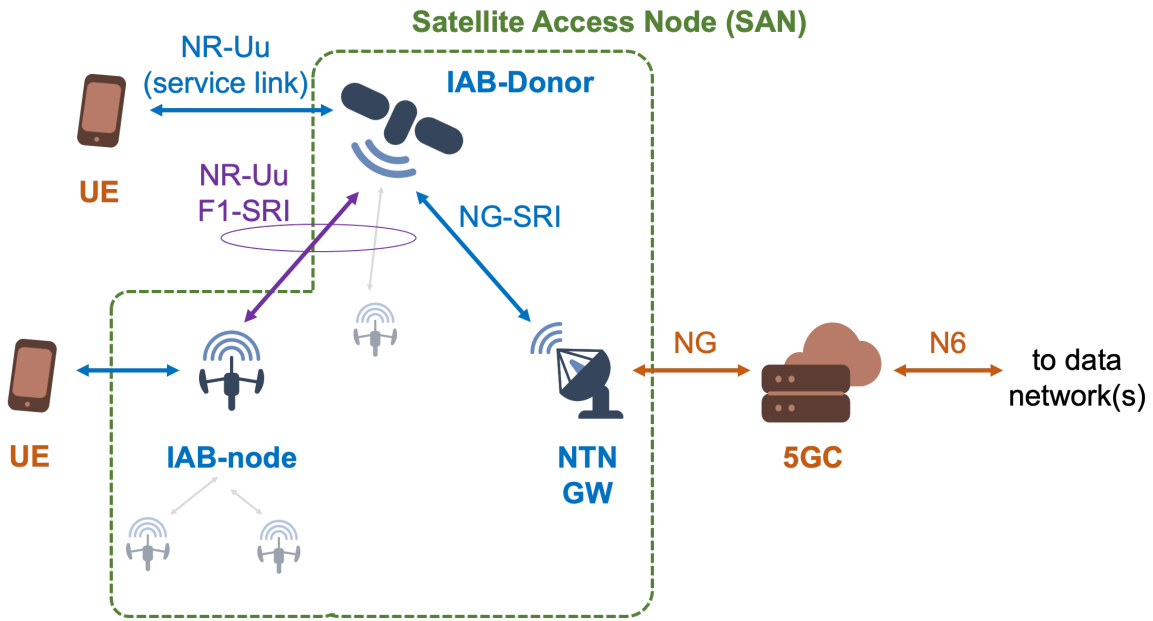


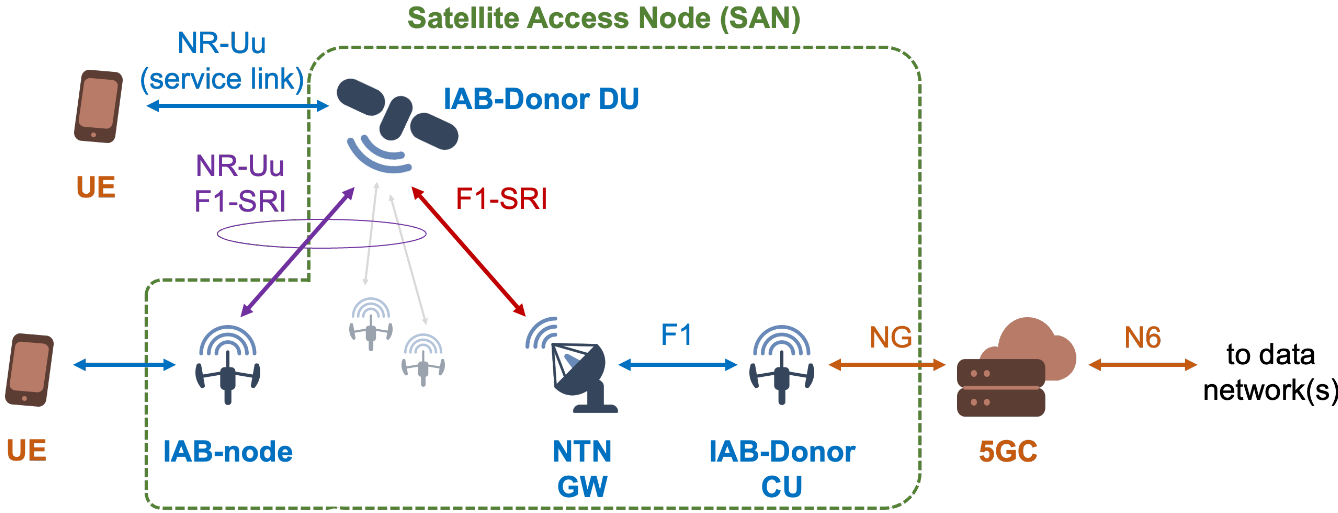
- **Transparent payload inside the IAB hierarchy**
  - both direct and indirect connections are possible
  - challenges related to F1-SRI
  - Backhaul Adaptation Protocol between RLC and IP
- **Transparent payload for backhaul**
  - only indirect connections are possible
  - challenges related to NG-SRI
  - no BAP on the feeder link

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





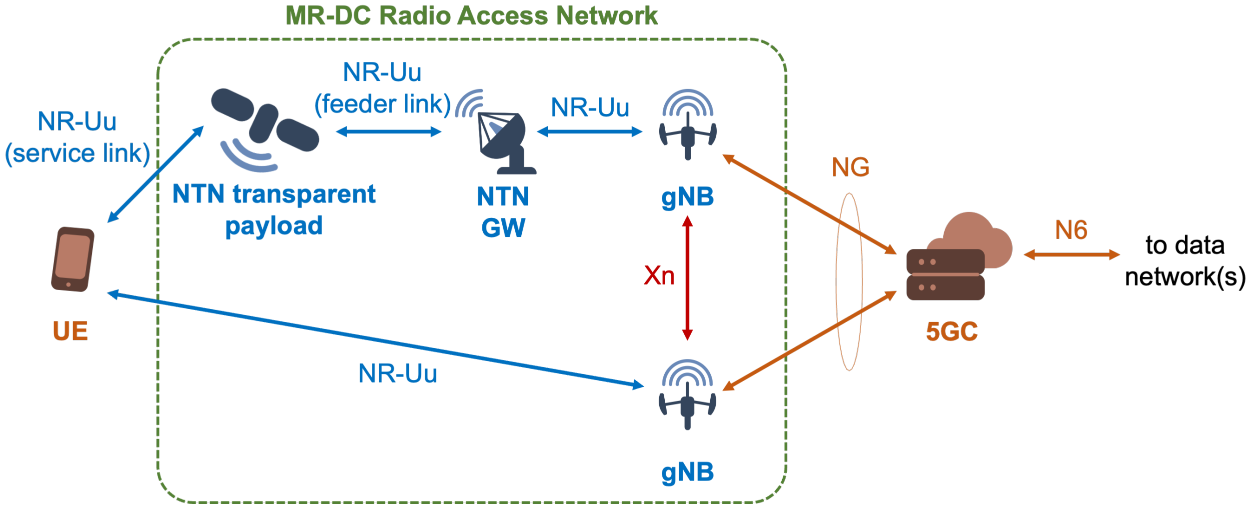
- **Regenerative payload: full Donor on-board**
  - both direct and indirect connections are possible
  - challenges related to F1-SRI on the service link
  - challenges related to NG-SRI on the feeder link
  - BAP on the service link

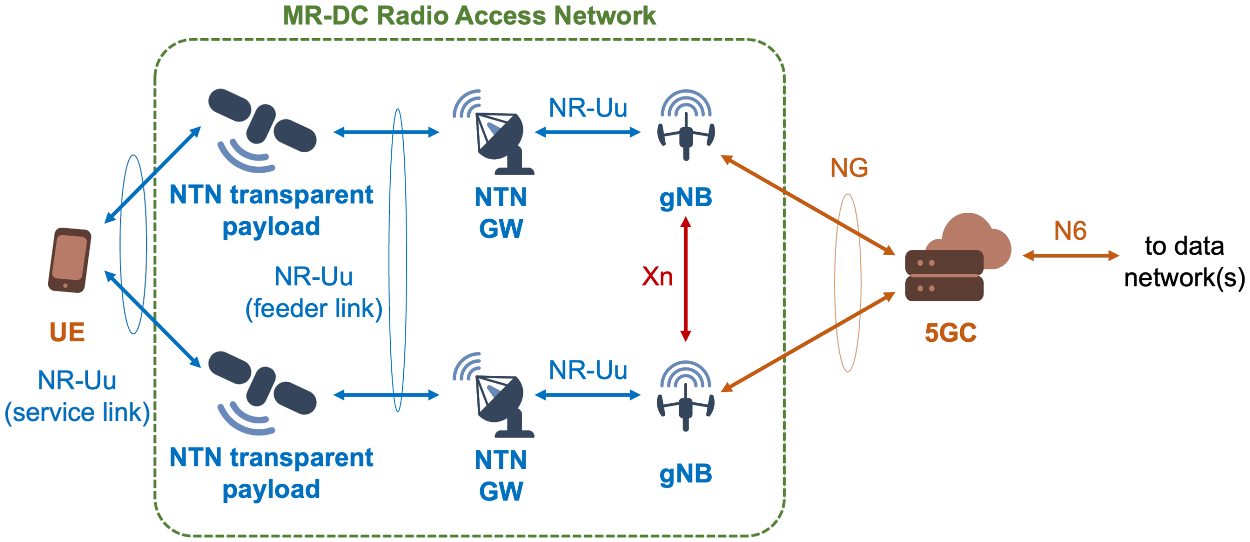
- **Regenerative payload: Donor-DU on-board**
  - both direct and indirect connections are possible
  - challenges related to F1-SRI on the service and feeder links
  - BAP on the service link

Source: 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





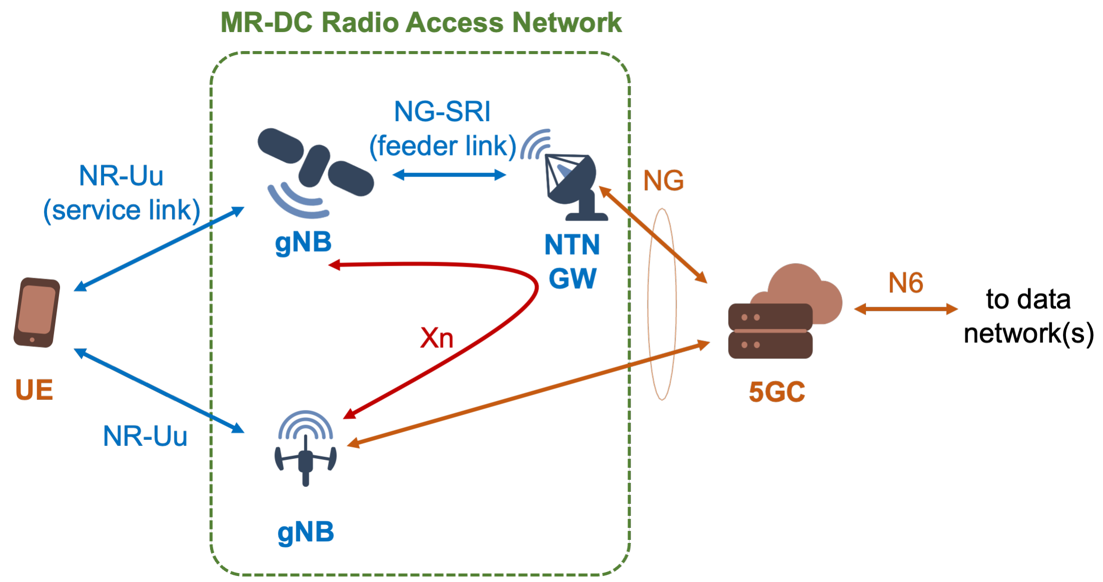
- **TN-NTN with transparent payload**
  - challenging due to the different channel characteristics
  - both TN-gNB and NTN-gNB can be elected MN
  - both gNBs on-ground

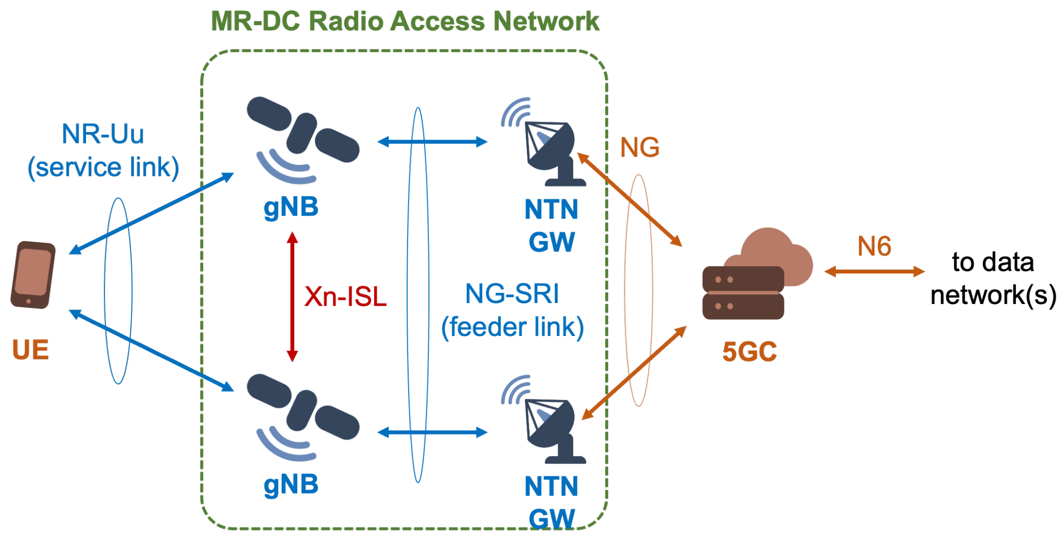
- **NTN-NTN with transparent payload**
  - the NTN nodes do not necessarily belong to the same orbit
    - e.g., low-latency through LEO and large throughput through GEO
  - both gNBs on-ground and possible MN

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





- **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

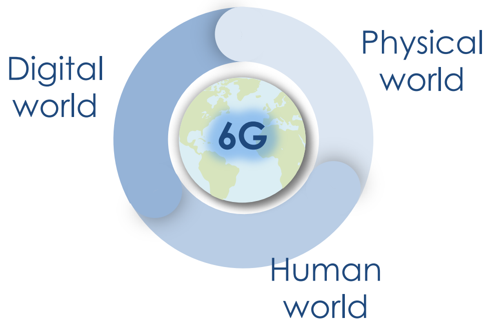
- **NTN-NTN with regenerative payload**
  - the NTN nodes do not necessarily belong to the same orbit (challenging)
    - e.g., low-latency through LEO and large throughput through GEO
  - NG-SRI on the feeder link
  - Xn over ISLs

Source: 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.

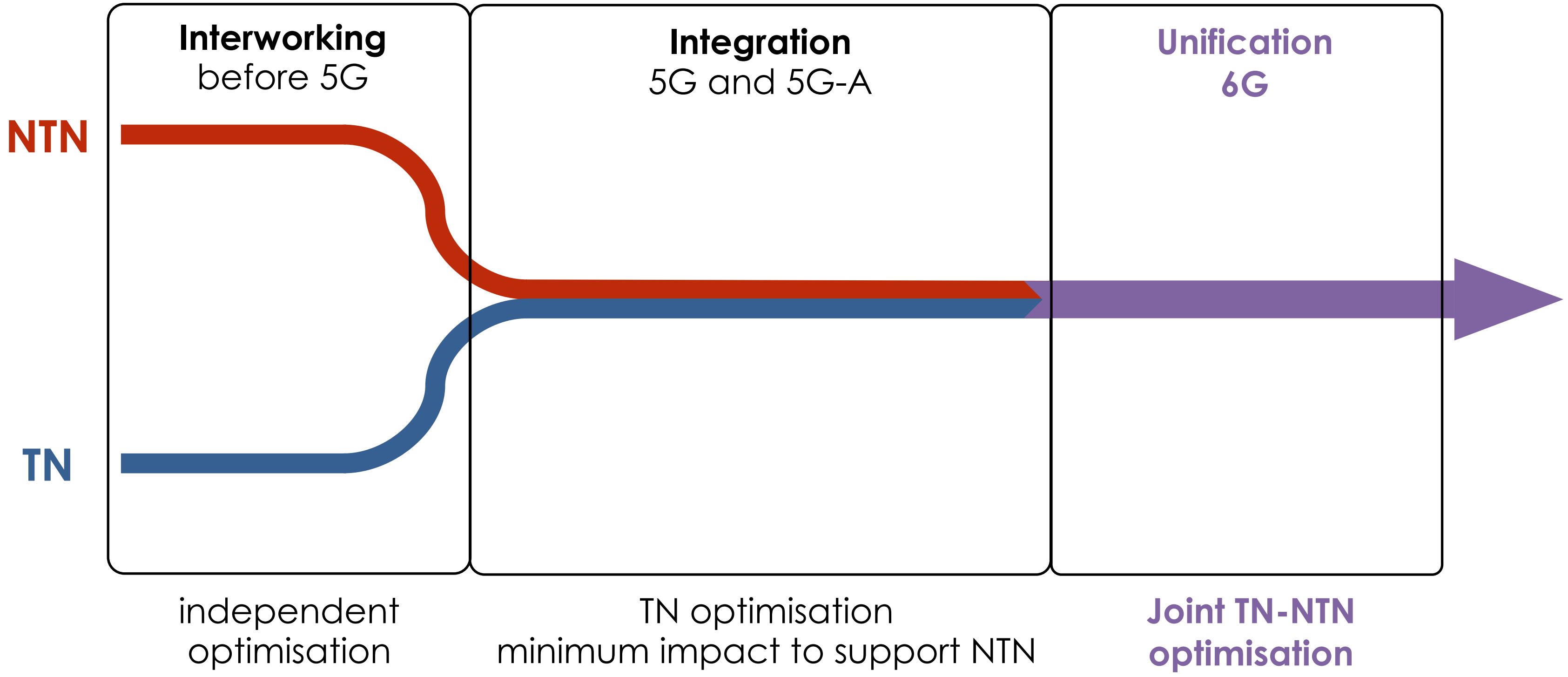
The role of Non-Terrestrial Networks in 6G

- 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



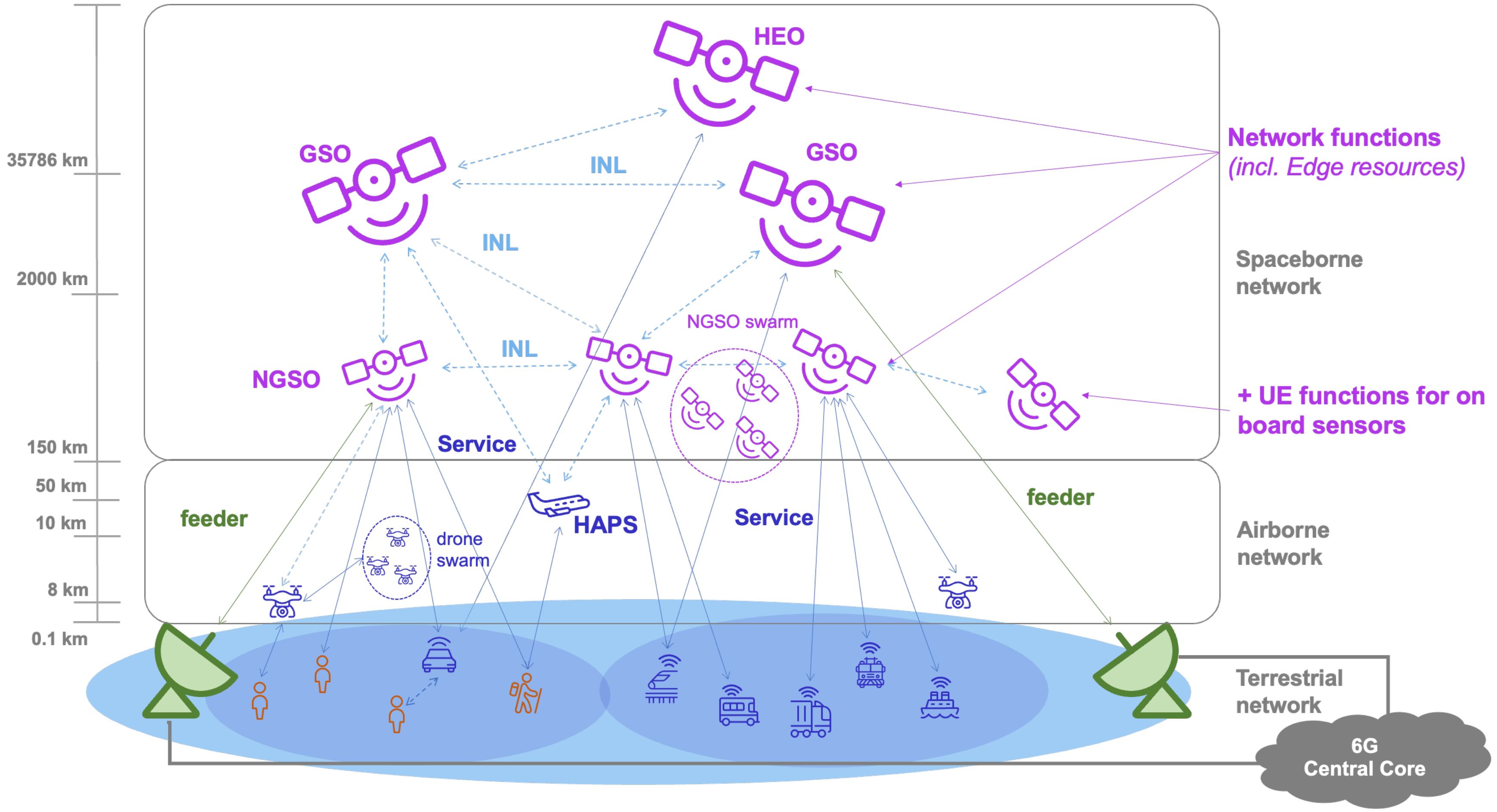
- Non-Terrestrial Networks will be pivotal to provide a ubiquitous, continuous, flexible, and resilient infrastructure for
  - **Direct connectivity** to smart phones outdoor and in light indoor/in-vehicle (emergency communications)
  - **Connectivity mobile platforms** (trains/planes/ships/drones/HAPs)
  - **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**

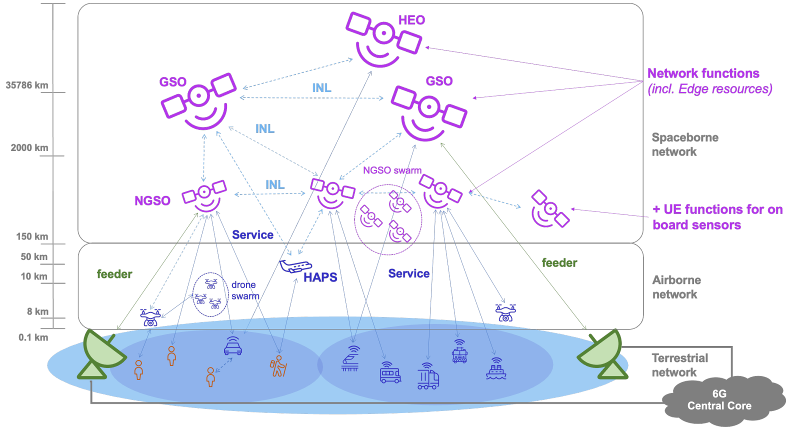
The role of Non-Terrestrial Networks in 6G



- 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

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

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

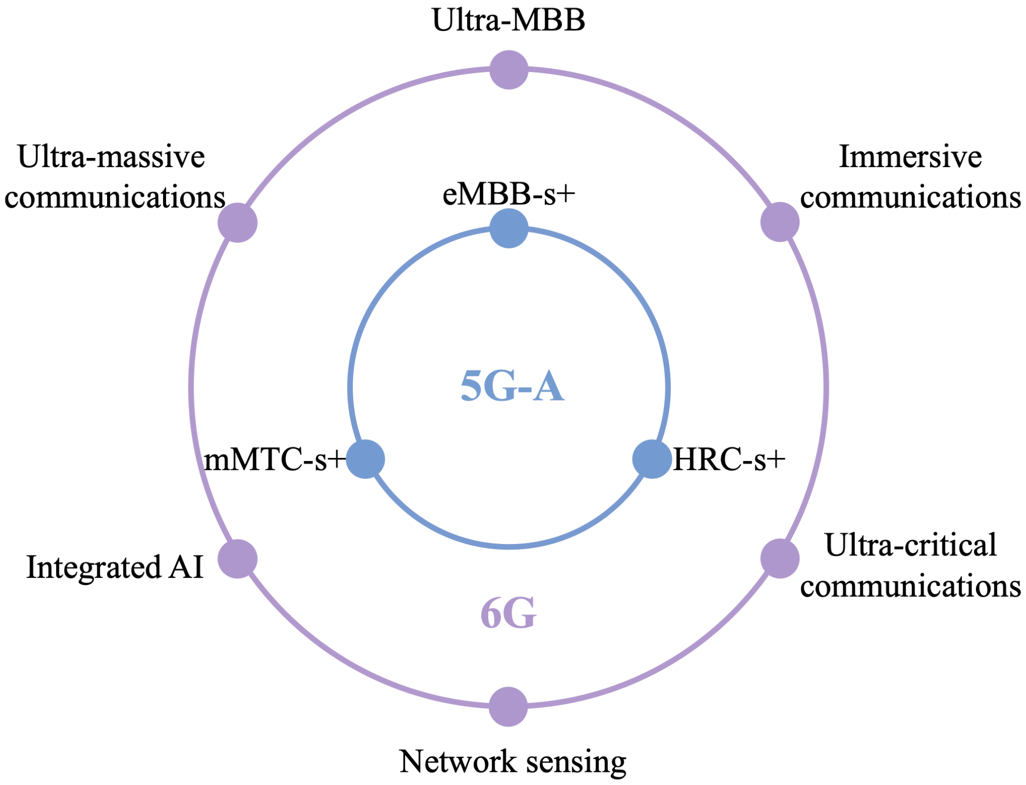
Network and system orchestration, Radio Resource Management, Network traffic forecasting, Physical layer management, Channel estimation,

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

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



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**
  - **Architecture evolution**
    - Regenerative payloads, relay-based access, MC
  - **Technology evolution**
    - Many technologies are candidate to be key enablers for 5G-A/6G NTN
      - NTN-NTN asynchronous MC and CA
      - UE without GNSS
      - Relay-based architecture for NTN
      - MU-MIMO
      - AI and ML
      - Next generation waveforms for PAPR reduction
      - Reflecting Intelligent Surfaces
      - …
- For **future** NTN systems, we need to make a further technology leap **now**

Current funded projects on NTN…

6GNTN

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

EAGER

https://www.eagerproject.eu
https://www.linkedin.com/company/eager-project/
https://twitter.com/eagersatcom

5GSTARDUST

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

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