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ASMS/SPSC Tutorial

From 5G NTN to 6G NTN – Standardization, Research, and Challenges

Advanced Satellite Multimedia Systems Conference & Signal Processing for Space Communications Workshop 2025
Sitges (Spain), February 26, 2025
Christian Rohde, Thomas Heyn, Alexander Hofmann, Sahana Raghunandan, Rainer Wansch
Communication Systems Division

Fraunhofer Institute for Integrated Circuits IIS

Standardization, Partnerships, and Associations

Contributions since 2015
(Satellite, V2X, Network Energy Saving, MIMO, Positioning, RedCap…)

ESA NTN-Forum

Non-profit organization, founded 1985, > 1136 employees, annual budget approx. 167.9 Mio €
16 locations in 12 cities: **Erlangen**, Nuremberg, Fuerth, Dresden, Ilmenau, …

AGENDA

1) From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

- NTN Aspects in Releases 15 to 19
- Spectrum for NR-NTN and IoT-NTN
- Relevant Public 3GPP Documents
- NTN Projects at Fraunhofer IIS – Standardization, Applications, Research

2) Key Techniques and Enablers of NTN

- Accomplished Work in 3GPP (Release 17 and 18) and Related Implementation Aspects
- Current work in 3GPP (Release 19)

3) R&D and Challenges of Future NTN Features

- 3D Networks and Ubiquitous Coverage → Open points for research and standards development
- Market needs

4) Conclusions

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From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

NTN Aspects in Releases 15 to 19

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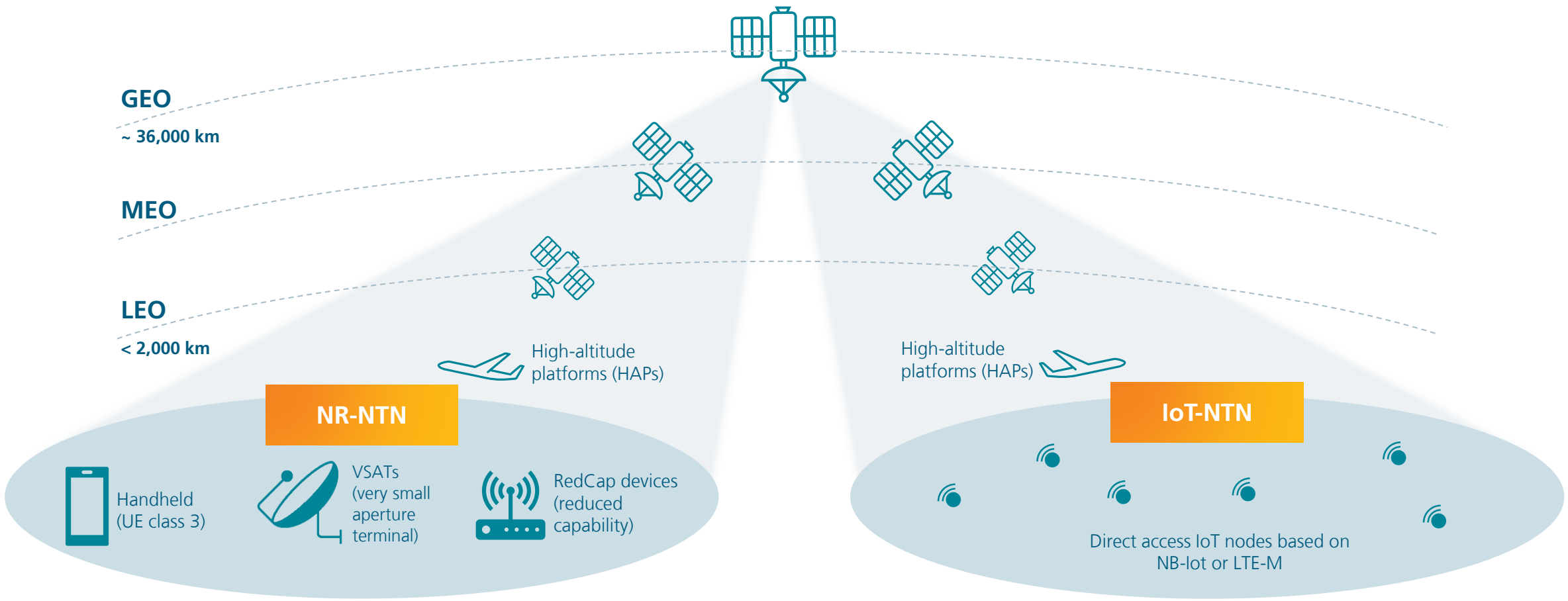
Non-Terrestrial Networks (NTN)

NTN Architecture



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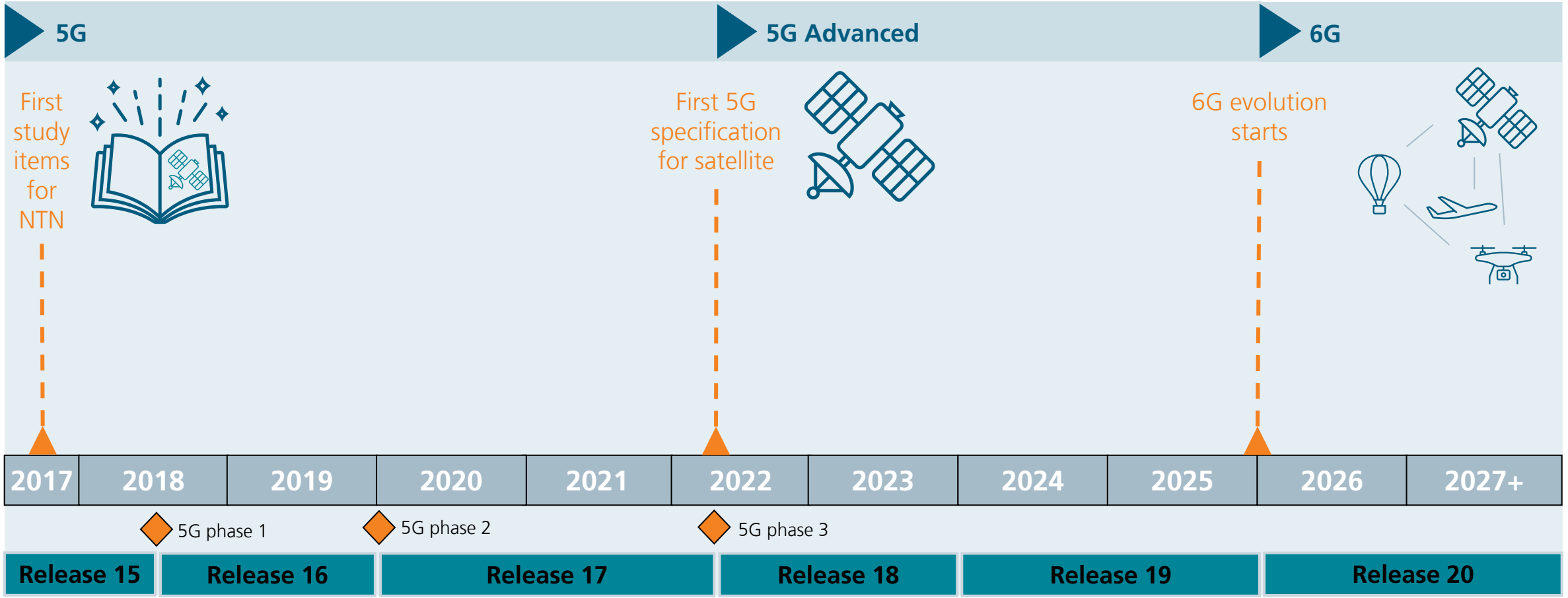
Non-Terrestrial Networks (NTN)

3GPP standardization timeline



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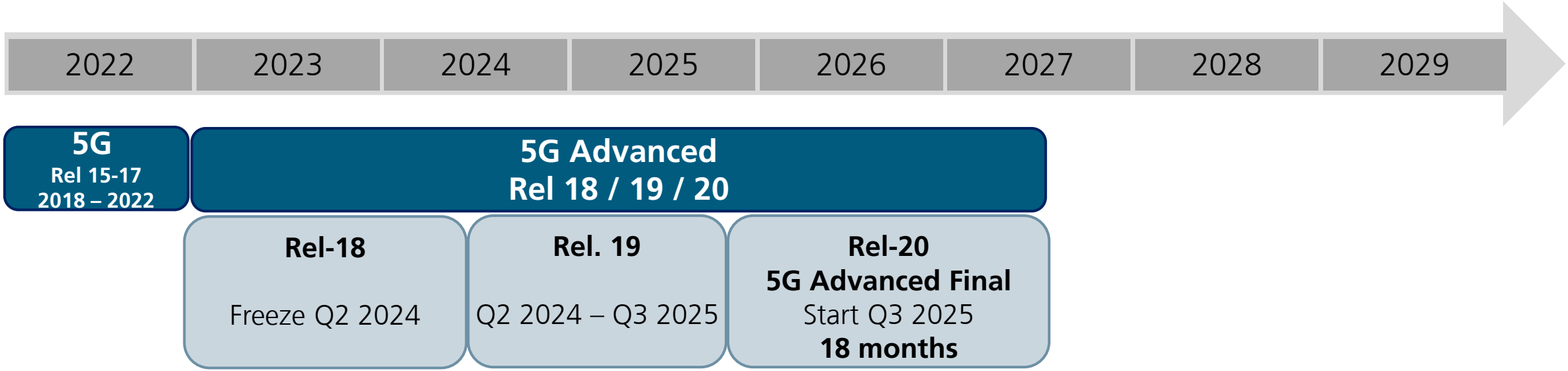
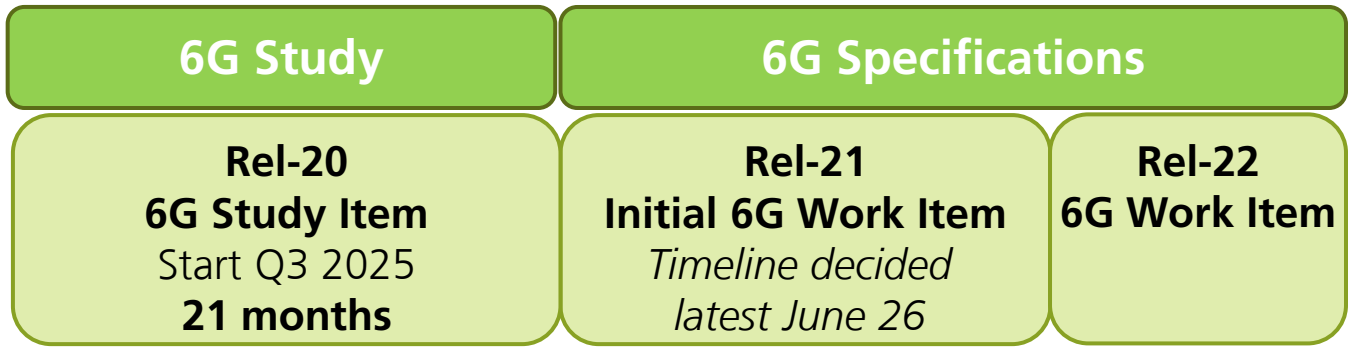
3GPP Radio Access Network (RAN) *

Timeline 5G-Advanced and 6G



With NTN from the 1st moment!

"6G should natively support satellite connectivity from the start and in a more user-centric fashion" [Ericsson, 04/2024]



* 3GPP RP-240823

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NTN in 3GPP – 5G-Advanced

Powerful standard for NR-NTN

Additional capabilities compared to prior releases

Aspect	Rel-17	Rel-18 *	Rel-19 **	Rel-20 Potential topics
Completion date (core part for RAN)	June 22	March 2024	June 2025	~March 2027
System architecture	**Transparent satellites (GEO, non-GEO**); Earth fixed/moving beams		**Regenerative payload (gNB on board; ISL),** mesh connectivity (UE-Sat-UE), beam management with NES features	Multi-orbit constellations?
Aspects in RAN	Adaptations for long latency / Doppler	**Network verified UE location**, UL coverage enhancements	DL coverage enhancements, broadcast, UL capacity enhancements, channel bandwidth <5 MHz	Intra-SAN Carrier Aggregation?
RAN - Mobility	Basic mobility based on terrestrial methods	**NR to NR enhanced mobility (CHO)** (only idle mode mobility in RAN4)	**LTE TN to NR NTN** idle mode **mobility (incl. 5G NSA deployments)** Connected mode mobility?	Connected mode mobility?
Terminals	**Smartphones** (Power 23 dBm) with GNSS	5 UE types with GNSS in Ka-band: Fixed **VSAT for GSO/NGSO** and mobile VSAT, but only for GSO (both with mechanical and electronic steering antennas)	RedCap UE in FR1; **High power UE** ≥ 26 dBm for handheld and non-handheld; Mobile VSAT for NGSO?	UE w/o GNSS? Mobile VSAT for NGSO?
Frequency bands (all FDD) TS 38.101-5	**FR1: S-band (n256),** **FR1: L-band (n255)**	FR1: Combined L-/S-Band (n254), **FR2: Ka-band (n510,511,512)**	**FR1: S-Band** (n25X)**,** 06/24 **FR1: extended L-Band** (n25X), 06/24 **FR2: Ku-Band** (n51X), 06/24	Other bands in FR1, incl TDD?

* 3GPP RP-240779 ** 3GPP RP-241667, RP-241689, RP-241661, RP-241690, RP-240924

NTN in 3GPP – 5G-Advanced

Capabilities of IoT-NTN

Additional capabilities compared to prior releases

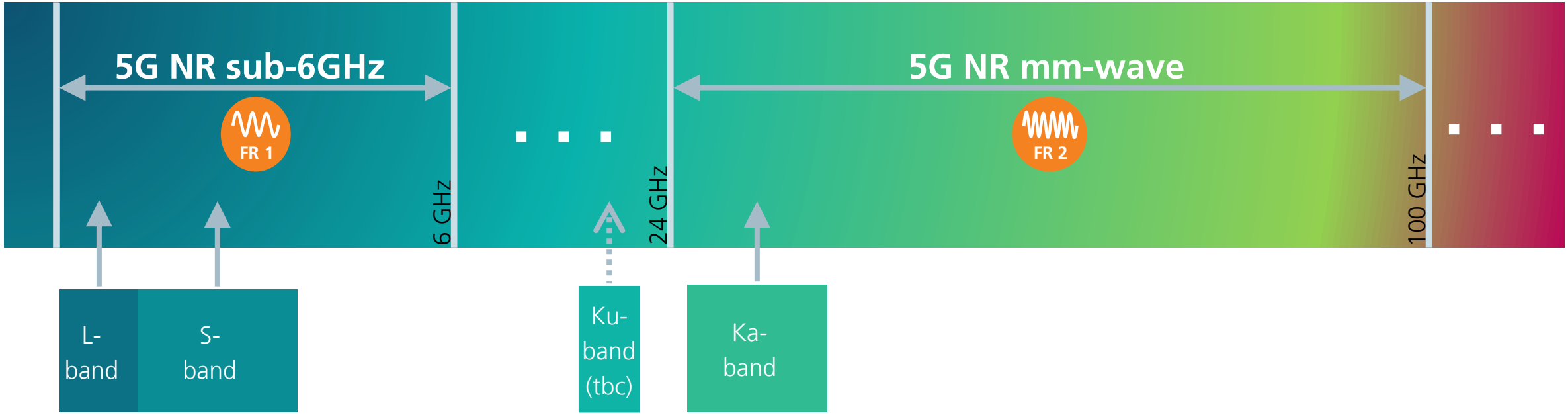
Aspect	Rel-17	Rel-18 (RP-231407)	Rel-19 (RP-240776)	Rel-20 Potential topics
Completion date (core part for RAN)	June 22	March 2024	June 2025	~March 2027
System architecture	**Transparent satellites (GEO, non-GEO), Earth fixed/moving beams**		**Regenerative payload** (gNB on board; ISL), mesh connectivity (UE-Sat-UE)	Voice over NB-IoT?
Aspects in RAN	Adaptations for long latency / Doppler	Performance enhancements (HARQ, GNSS operation)	**Support of Forward and Store; UL capacity enhancements** 09/24: **Half Duplex for TDD/FDD**	
RAN - Mobility	Basic mobility based on terrestrial methods	Mobility enhancements, enhancements of discontinuous coverage		
Terminals	UE with GNSS, Power 23 dBm		**High power UE ≥ 26 dBm**	UE w/o GNSS?
Frequency bands (all FDD) TS 36.108	**FR1: S-band (256), FR1: L-band (255)**	Combined L-/S-Band (254) **FR1: Extended L-band (253)**	**TDD band in FR1**	Other bands in FR1, incl TDD?

From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

Spectrum for NR-NTN and IoT-NTN

Non-Terrestrial Networks (NTN)

Frequency bands for NTN



Specified NTN satellite frequency bands

Frequency range 1 (FR 1): n254, n255, n256

Frequency range 2 (FR 2): n510, n511, n512

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Non-Terrestrial Networks (NTN)

FR1 & FR2 Frequency Bands for NTN (R18)

Requirements throughout the RF specifications are in many cases defined separately for different frequency ranges (FR). The frequency ranges in which NTN satellite can operate according to this version of the specification are identified as described in Table 5.1-1.

Table 5.1-1: Definition of NTN frequency ranges

Frequency range designation	Corresponding frequency range
FR1-NTN (Note 1)	410 MHz – 7125 MHz
FR2-NTN (Note 2)	17300 MHz – 30000 MHz
NOTE 1: NTN bands within this frequency range are regarded as a FR1 band when references from other specifications. NOTE 2: NTN bands within this frequency range are regarded as a FR2 band when references from other specifications.	

Source: 3GPP TS 38.101-5: "User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements (Release 18)"

Non-Terrestrial Networks (NTN)

FR1 & FR2 Frequency Bands for NTN (R18)

Specified NTN satellite frequency bands in FR1:

NTN satellite operating band	Uplink (UL) operating band Satellite Access Node receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) operating band Satellite Access Node transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n254	1610 – 1626.5 MHz	2483.5 – 2500 MHz	FDD
NOTE:	**NTN satellite bands are numbered in descending order from n256.**		

Specified NTN satellite frequency bands in FR2:

Satellite operating band	Uplink (UL) operating band SAN receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) operating band SAN transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n512[1]	27500 MHz - 30000 MHz	17300 MHz - 20200 MHz	FDD
n511[2]	28350 MHz - 30000 MHz	17300 MHz - 20200 MHz	FDD
n510[3]	27500 MHz - 28350 MHz	17300 MHz - 20200 MHz	FDD

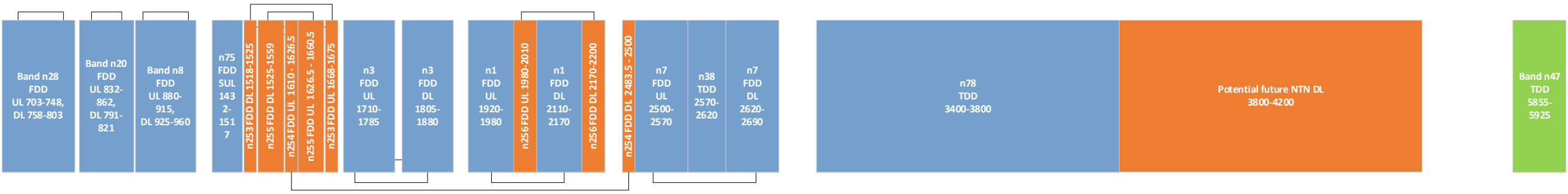
NOTE 1: This band is applicable in the countries subject to CEPT ECC Decision(05)01 and ECC Decision (13)01.
NOTE 2: This band is applicable in the USA subject to FCC 47 CFR part 25.
NOTE 3: This band is applicable for Earth Station operations in the USA subject to FCC 47 CFR part 25. FCC rules currently do not include ESIM operations in this band (47 CFR 25.202).

Source: 3GPP TS 38.101-5: "User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements (Release 18)"

Non-Terrestrial Networks (NTN) in 6G

Limited available Spectrum in FR1

- NTN needs more spectrum in FR1, that services can scale!
  - Only fragmented total 80.5 / 81.5 MHz UL/DL (n254, n255, n256) *
  - For smartphones, automotive, logistics…
  - Opening C-Band would be great (currently FSS)
  - TN/NTN spectrum sharing is another option…
- FR2 has much more spectrum available:
  - Ka-band: 2500 / 2900 MHz UL/DL
  - Ku-band: 1250 / 2050 MHz**



* 3GPP TS 38.101-1, 38.101-5

** 3GPP RP-241690

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From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

Relevant Public 3GPP Documents

3GPP Working Groups

Technical Standardization Groups (TSG)

Project Co-ordination Group		
TSG RAN **Radio Access Network**	**TSG SA** **Service & System Aspects**	**TSG CT** **Core Network & Terminals**
RAN WG1 Radio Layer 1 specifications	**SA WG1** Services	**CT WG1** MM/CC/SM (lu)
RAN WG2 Radio Layer 2 & 3 specifications	**SA WG2** Architecture	**CT WG3** Interworking with external networks
RAN WG3 Interface specifications	**SA WG3** Security	**CT WG4** MAP/GTP/BCH/SS
RAN WG4 Radio Performance & Protocol aspects	**SA WG4** Codec	**CT WG6** Smart Card Application Aspects
RAN WG5 Mobile Terminal Conformance Testing	**SA WG5** Telecom Management	
RAN WG6 Legacy RAN radio and protocol	**SA WG6** Mission-critical applications	

3GPP Standardization

5G Working Method for 3GPP Releases

Step 1

TDocs submitted → Study Items (SI)

Results of **Study Item**

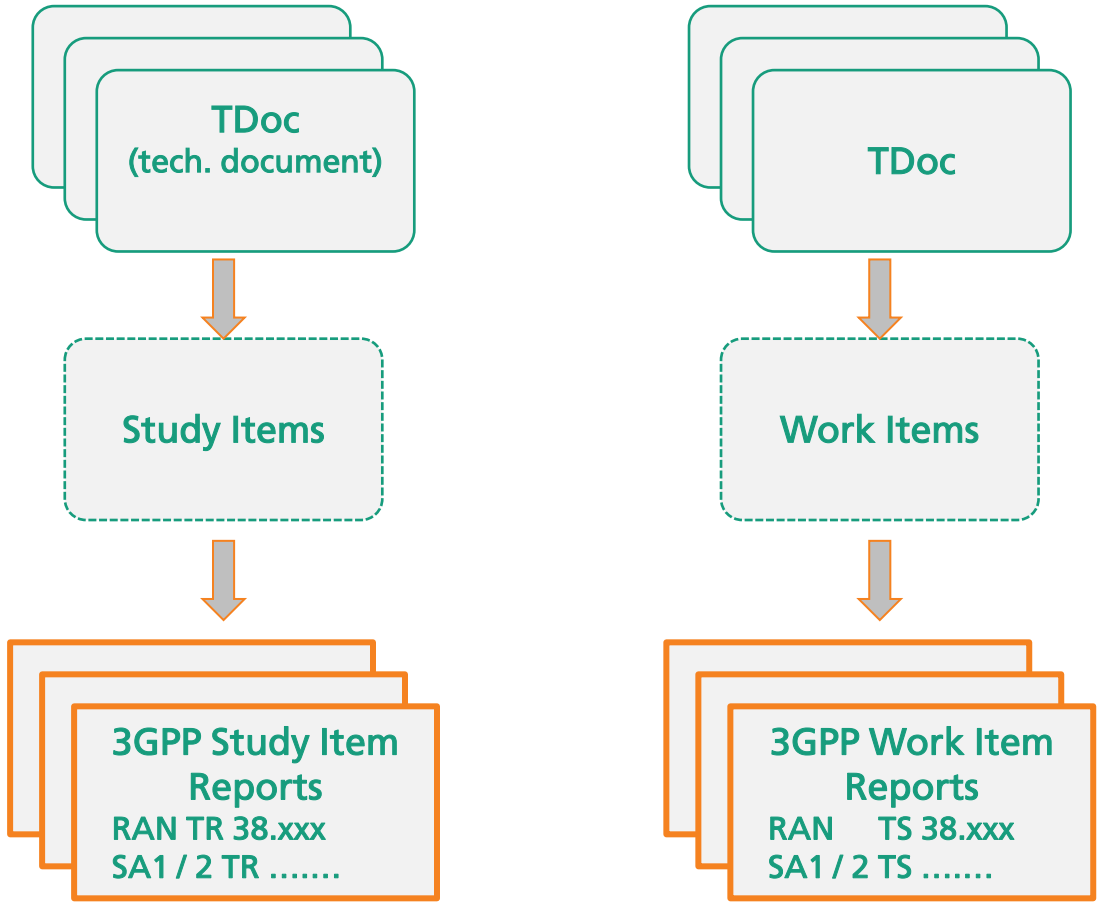
→ **Technical Report (TR)**

Step 2

TDocs submitted → Work Items (WI)

Results of **Work Item**

→ **Technical Specification (TS)**



3GPP Standardization

3GPP Specification Series and Reports (3G and beyond)

From: http://www.3gpp.org/specifications/specification-numbering

Main specification series	Content	Examples
21.XYZ	General Requirements	TR 21.905 Vocabulary for 3GPP specifications TR 21.915 Release 15 description
22.XYZ	Service aspects, use cases, detailed requirements „Stage 1“	TR 22.811
23.XYZ	Technical realization „Stage 2“	TS 23.501 5G System architecture
26.XYZ	CODECS	
33.XYZ	Security aspects	
36.XYZ	LTE Radio Technology	TS 36.201 LTE physical layer overview
37.XYZ	Multiple radio access technology aspects	TR 37.885 V2X use cases for LTE and NR
38.XYZ	New Radio technology	TS 38.201 NR physical layer overview

3GPP Standardization

3GPP Specification Series, Reports, TDocs

Where to find….

Public Specification series:

LTE: http://www.3gpp.org/DynaReport/36-series.htm **or easier** ftp://ftp.3gpp.org/Specs/
NR: https://www.3gpp.org/dynareport?code=38-series.htm

Public TDoc's from all the working group meetings:

ftp://ftp.3gpp.org/tsg_ran/
ftp://ftp.3gpp.org/tsg_sa/
ftp://ftp.3gpp.org/tsg_ct/

One directory per meeting, e.g. last RAN#80 plenary: ftp://ftp.3gpp.org/tsg_ran/TSG_RAN/TSGR_80/
→ all ~800 TDoc's from La Jolla/US meeting
Email discussions (for 3GPP members only)

Individual email lists for all 3GPP working groups
Subscription via ETSI portal

3GPP Standardization

3GPP Specification Series, Reports, TDocs

Excerpt for NR:

spec number	title	notes
TS 38.101	NR; User Equipment (UE) radio transmission and reception	**SPECIFICATION WITHDRAWN**
TS 38.101-1	NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone	
TS 38.101-2	NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone	
TS 38.101-3	NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios	
TS 38.101-4	NR; User Equipment (UE) radio transmission and reception; Part 4: Performance requirements	
TS 38.101-5	NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements	
TS 38.104	NR; Base Station (BS) radio transmission and reception	
TS 38.106	NR repeater radio transmission and reception	
TS 38.108	NR; Satellite Access Node radio transmission and reception	
TS 38.133	NR; Requirements for support of radio resource management	
TS 38.141	NR; Base Station (BS) conformance testing	**SPECIFICATION WITHDRAWN**
TS 38.141-1	NR; Base Station (BS) conformance testing Part 1: Conducted conformance testing	
TS 38.141-2	NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing	
TS 38.151	NR; User Equipment (UE) Multiple Input Multiple Output (MIMO) Over-the-Air (OTA) performance requirements	
TS 38.161	NR; User Equipment (UE) TRP (Total Radiated Power) and TRS (Total Radiated Sensitivity) requirements; Range 1 Standalone and Range 1 Interworking operation with other radios	
TS 38.181	NR; Satellite Access Node conformance testing	
TS 38.201	NR; Physical layer; General description	
TS 38.202	NR; Services provided by the physical layer	
TS 38.211	NR; Physical channels and modulation	
TS 38.212	NR; Multiplexing and channel coding	
TS 38.213	NR; Physical layer procedures for control	
TS 38.214	NR; Physical layer procedures for data	
TS 38.215	NR; Physical layer measurements	
TS 38.300	NR; NR and NG-RAN Overall description; Stage-2	

From 5G to 6G - Evolution of Releases and Increasing Support of NTN Features

NTN Projects at Fraunhofer IIS – Standardization, Applications, Research

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NTN Projects @ Fraunhofer IIS

Standardization, Applications, Research

Finished: **Fraunhofer 6G-SENTINEL**
TN+NTN System Level Simulator (HAPS…), …

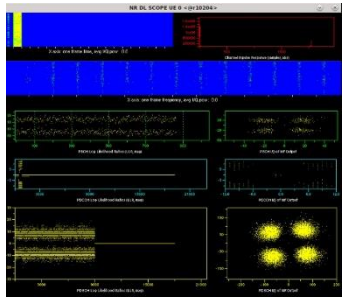
BMBF 6G-RIC
Energy efficient waveforms for TN/NTN

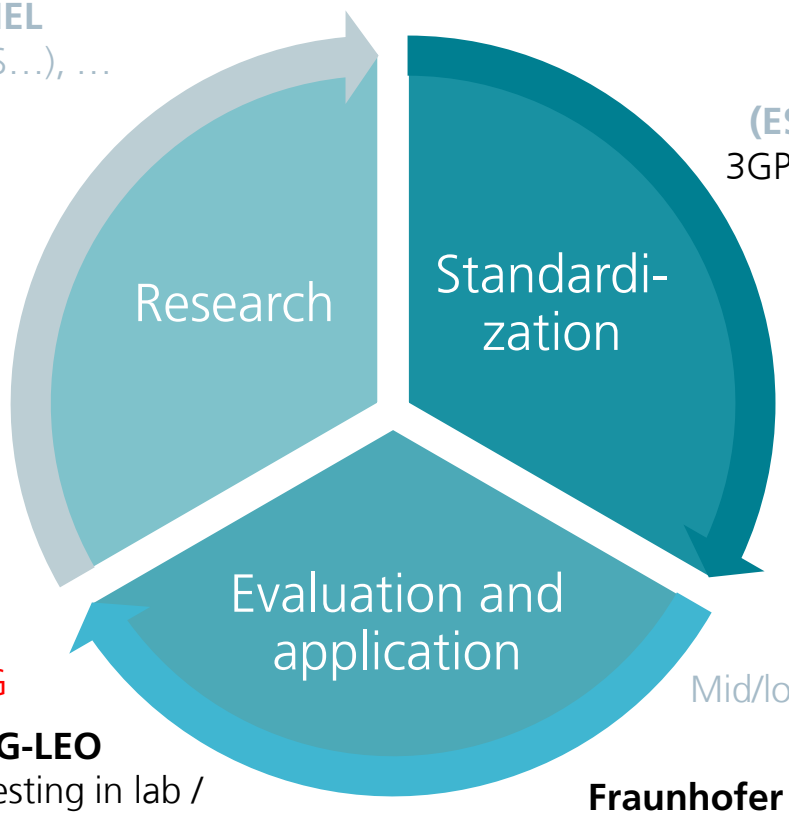
CelticNext 6G-SKY
Holistic 3D-architecture, 6G demos

EU TRANTOR
Functional split, H2SAT experiments

DLR 5G-AUTOSAT-KI
TN/NTN Networks with AI, lab demos

New: ESA 6G-LINO *
Experimental LEO satellite for 6G





(ESA ALIX), ESA HELENA
3GPP standardization support

Finished: **ESA 5G-IS**
Mid/long term Infrastructure Study

ESA 5G-GOA/5G-LEO
Realtime Prototyping/testing in lab / over-the-air / over satellite

Fraunhofer On-Board Processor
H2SAT Space lab on Ka-Band GEO satellite

© Fraunhofer IIS/Paul Pulkert

New: ESA SEVECODE
NTN/TN demonstrations of V2X applications

* https://www.tesat.de/news/press/943-esa-selects-tesat-for-6g-precursor

Bundesministerium für Wirtschaft und Klimaschutz
esa
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

NEW: ESA 6G LINO

6G Laboratory In Orbit

- **Start/Duration**
  - July 2024 / 29 months
- **Consortium**
  - Germany: Tesat, Airbus, **Fraunhofer IIS**, Dt. Telekom, (VTT)
  - UK: OpenCosmos, **Uni Surrey**
- **Purpose, Goals**
  - Deliver an in-orbit laboratory with a LEO satellite
  - Gaining knowledge on E2E connectivity and inclusion of satellites in TN
  - 6G applications can boost the technological potential of the European digital and aerospace industry and broadband connectivity even further.
- **Demo applications**
  - gNB-in-space & transparent payload
  - Handover scenarios (transparent payload)
  - Spectrum sensing incl. AI
  - **Contact us to test and demo your ideas in space!**

https://www.tesat.de/news/press/943-esa-selecs-tesat-for-6g-precursor

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Key Techniques and Enablers of NTN

Key Techniques and Enablers for Non-Terrestrial Networks (NTN)

Accomplished Work in 3GPP (Release 17 and 18) and Related Implementation Aspects

**5G NTN –
Initial updates in 3GPP Release 17 and 18 for non-terrestrial networks**

1. Initial NTN Support for gNB and UE: Configurable Timers and Timing Advance
2. Immediate Reuse of UL/DL HARQ Process ID and no Feedback
3. Enable 32 HARQ Processes in DL and UL
4. LEO Satellite Delay and Doppler-related Adjustment of UE Time Synchronization
5. Continuous Frequency Offset Estimation and Compensation at UE
6. Synchronization Sequence SINR (SS-SINR) in CSI reporting
7. SINR based adaptive modulation and coding (AMC)
8. Continuously updated System Information Block #19 (SIB19)

Techniques and Enablers for NTN (R17 + 18)

Initial NTN Support for gNB and UE: Configurable Timers and Timing Advance

Type: Specification

Challenge/Task: Round trip times (RTTs) over satellites much higher than in TNs

Context:

- Terrestrial networks (TNs) have timeouts in various RAN procedures for immediate detection of a bad link status.
- Closed loop control (gNB and UE) of timing advance (TA) for UL transmission

Solution:

- **Timeout values of RAN procedures extended** to cope with the increased RTT - especially GEO with RTT > 500 ms
- **Own location** (GNSS based) and data in System Information Block #19 (**SIB19**) **help UE to calculate the TA**.
  - NTN/ satellite specific info in SIB19: common timing advance (= delay of feeder link) + first and second derivatives
  - NTN: open loop mode or closed loop possible – TA command rate and loop ON/OFF is implementation specific of gNB
  - Configurable timeout of TA commands at UE but can be set to inf as well.
  - Implementation of TA control loop: larger time constants for the control loop needed!

Techniques and Enablers for NTN (R17 + 18)

Immediate Reuse of UL/DL HARQ Process ID and no Feedback

Type: Specification

Challenge/Task: Too long RTT for Hybrid Automatic Repeat request (HARQ) processes (waiting for positive or negative feedback)

Context:

- Each data code word gets a HARQ process ID and is split in so-called redundancy versions
- First version is sent immediately, and the other versions are sent on negative HARQ feedback from the receiving end
  = incremental redundancy → Works well only with instantaneous feedback
- Limited amount of HARQ processes: 16 per each UE handled by a gNB

Solution:

- Immediately reuse UL/DL HARQ process ID; do **not wait for feedback; no retransmissions** → "Disable HARQ Feedback"
- UE does not send ACKs/NACKs anymore, which saves resources in the PUCCH
- Deactivation especially important for GEO; ARQ process on RLC layer kept active

Techniques and Enablers for NTN (R17 + 18)

Enable 32 HARQ Processes in DL and UL

Type: Specification

Challenge/Task: 16 HARQ processes to few

Context:

- Expected HARQ feedback response time within 1 slot duration (max 1ms based on SCS config)
- Maximum 16 ms of transmission time can be covered which is too less for NTN (HAPs and LEOs)

Solution:

- Enable **32 HARQ processes** in DL and UL; feedback response time also configurable
- Not useful for GEO where deactivated. Deactivation now also available for TN and LEO
- Blind HARQ: gNB and UE negotiate the number of redundancy versions for initial transmission

Techniques and Enablers for NTN (R17 + 18)

LEO Satellite Delay and Doppler-related Adjustment of UE Time Synchronization

Type: Implementation / deployment

Challenge/Task: Timing synchronization relative to DL framing but LEO satellite delay and Doppler variation

Context:

- UE/gNB relative speeds rather low in TNs compared to LEO-based NTNs
- Much more variance of LEO satellite delay and Doppler than GEO

Solution:

- LEO satellite delay and Doppler-related adjustment by **fast adaptive time synchronization schemes** at NR UE

Techniques and Enablers for NTN (R17 + 18)

Continuous Frequency Offset Estimation and Compensation at UE

Type: Implementation / deployment

Challenge/Task: Initial synchronization under unknown Doppler (or residual Doppler) and tracking of changing Doppler

Solution:

- **Initial carrier frequency offset search pattern approach**
- Note that data from SIB19 is available only after successful synchronization
- **Use own location information** (GNSS based) **and SIB19 data**; calculation of uplink frequency offset based on location and satellite location and velocity vector (or Ephimeris data)
- DL Doppler can be pre-compensated by the satellite but common offset per beam/ cell, i.e. residual Doppler offsets

Techniques and Enablers for NTN (R17 + 18)

Synchronization Sequence SINR (SS-SINR) in CSI reporting

Type: Specification

Challenge/Task: Synchronization sequence SINR (SS-SINR) measurement in CSI reporting

Context:

- So far only Channel Quality Indicator (CQI) derived at UE and fed back (together with various MIMO-related values).
  → MIMO modes not applicable (yet). CQI mapping table to SINR values too rough? Potential overhead in PUCCH?
- Channel state indicator (CSI) only would be sufficient

Solution

- Specification of according **signalling field in CSI reporting**
- Rel. 17 feature holds for TN and NTN

Techniques and Enablers for NTN (R17 + 18)

SINR based Adaptive Modulation and Coding (AMC)

Type: Specification

Challenge/Task: Adaptive Modulation and Coding (AMC) based on SINR feedback

Context:

- AMC schemes:
  - A) UE reports the CQI values (same SINR mapping table for TN and NTN) and gNB decides Mod & Cod based on CQI
  - B) gNB tracks the HARQ FER statistic and decides Mod & Cod based on that
    → Often preferred method because more accurate and instantaneous.
- BUT in NTN: HARQ can be deactivated and gNB may get only the CSI reporting (with the SINR values)

Solution: Allow C) new AMC scheme based on SINR

Techniques and Enablers for NTN (R17 + 18)

Continuously updated System Information Block #19 (SIB19)

Type: Specification / Implementation

Challenge/Task: Make sure SIB19 is always up-to-date

Context:

- Transmission order: SSB (Synch System Block including PSS und SSS) -> SIB1-> SIB19 needed for initial access and updates
- New SIB for NTN = SIB19 since Rel.17 contains
  - Ephimeris data = satellite orbit position and data of the cell-serving satellite
  - Satellite location in space + velocity vector (equivalent to Ephimeris)
  - Latency on the feederlink (Common timing advance + 1. derivative + 2. derivative)
    → Used for transparent payloads, 0 for regenerative payloads
- Initial scenarios only GEO/GSO → Many parameters implemented as static

Solution: Assure continuously updated SIB19 for proper NGSO system deployment

Key Techniques and Enablers for Non-Terrestrial Networks (NTN)

Current work in 3GPP (Release 19)

Advancing 5G NTN – 3GPP Release 19 work on non-terrestrial networks

1. Support of **regenerative payload** (full gNB onboard)
2. Downlink **coverage enhancement** in NTN
3. Support of LTE to NR-NTN **mobility**
4. Uplink capacity/ throughput enhancement in NTN
5. Support of broadcast services in NTN
6. Support of HPUE (high power UE) for NR-NTN and IoT-NTN
7. Support of RedCAP UEs in FR1-NTN bands
8. Support of bandwidth less than 5 MHz for NTN

Techniques and Enablers for NTN (R19)

Regenerative Payload

Satellites with on-board processors serve as 5G base stations (gNB). Due to satellite movements base station mobility has to be taken into account.

Feeder link connection management

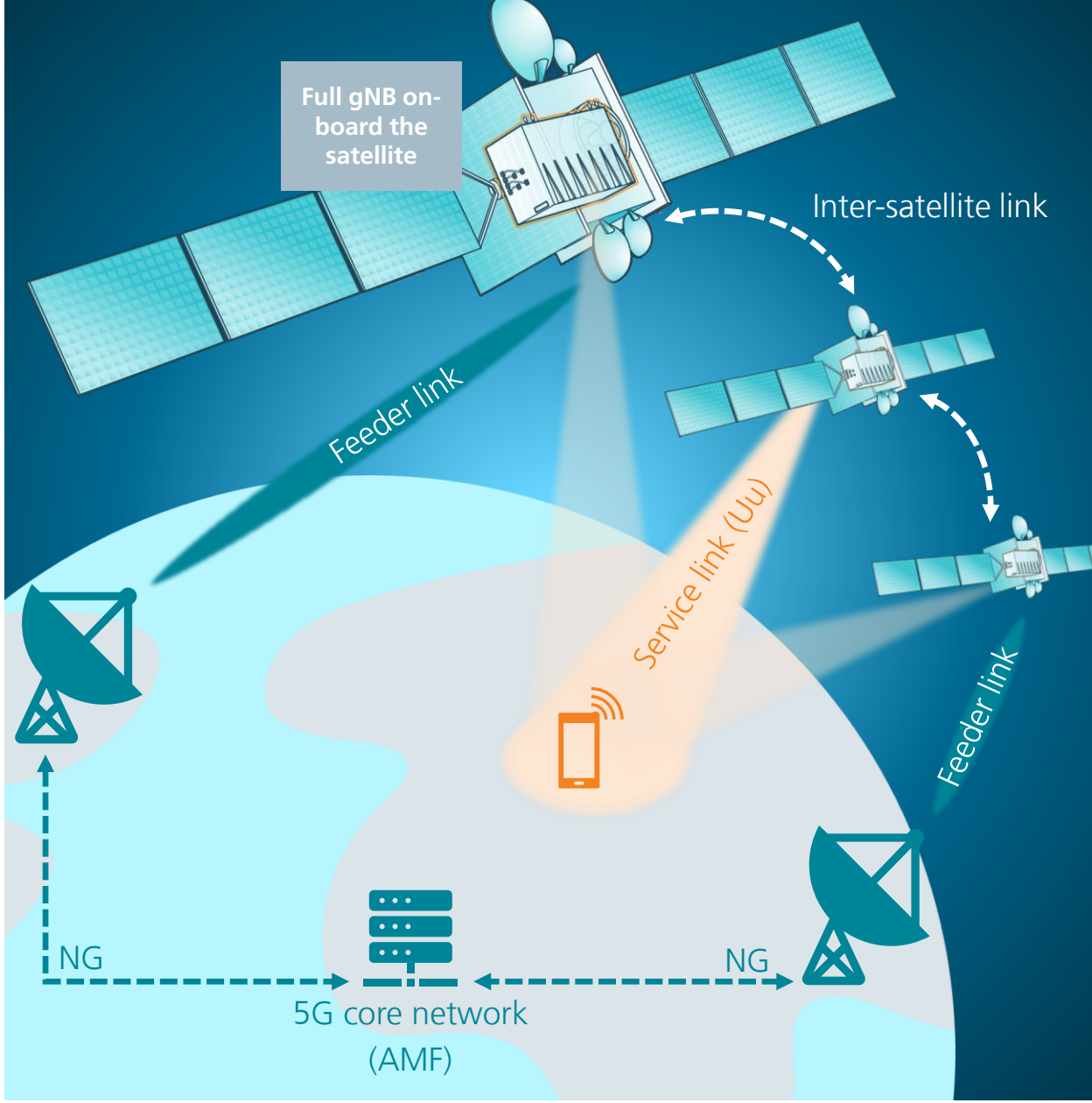
with focus on the NG interface to the core network (AMF) on ground

- NG suspend/resume
- NG removal/setup

Service link connection management

with focus on Uu interface between satellite and ground

→ new in Release 19: RRC inactive



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Techniques and Enablers for NTN (R19)

Downlink Coverage Enhancement

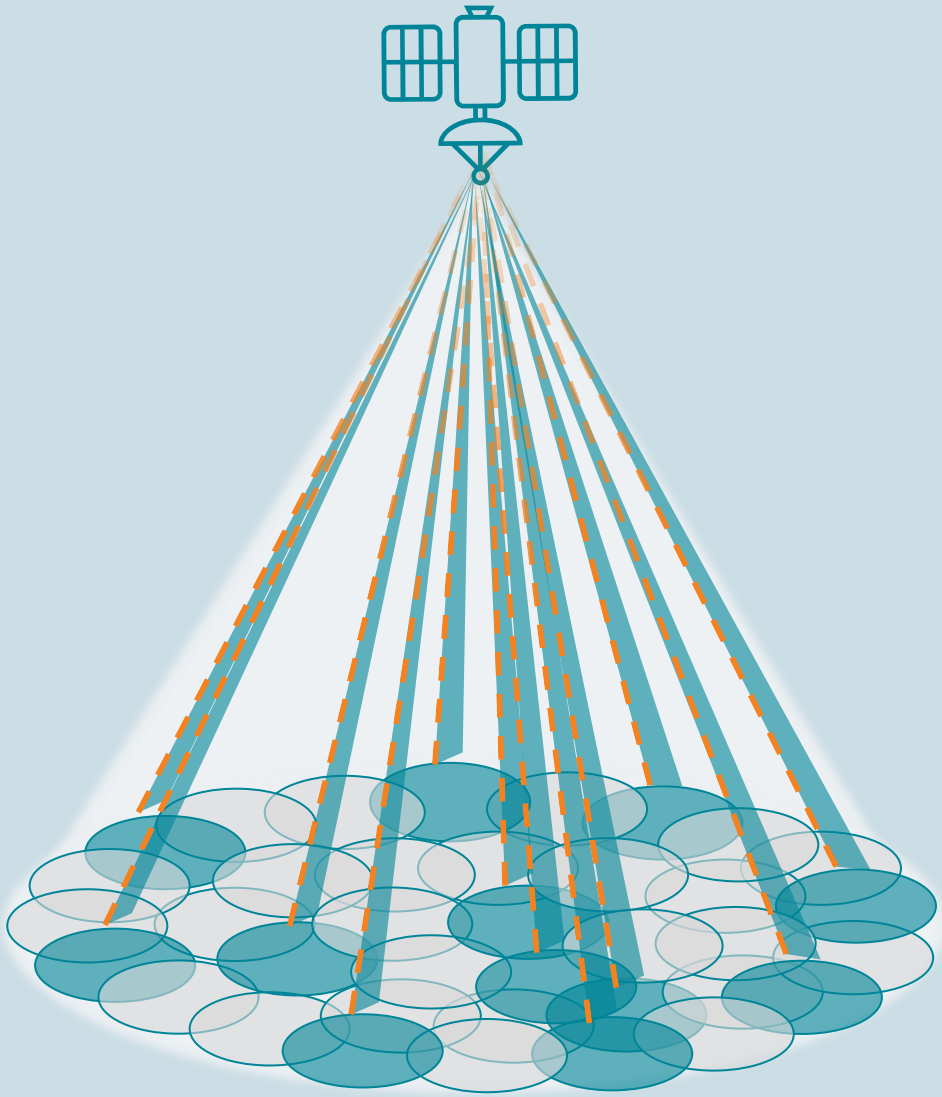
Downlink coverage enhancements are needed to accommodate power constraints, as satellites may not be able to have all beams active with nominal EIRP density at the same time.

System-level enhancements

Supporting dynamic and flexible beam sharing and switching mechanisms

Link-level enhancements

Improving downlink physical channels (PDSCH, PDCCH)



Techniques and Enablers for NTN (R19)

Handover

Reliable and smooth handover solutions enhance the mobility performance in NTN systems and ensure seamless connectivity.

Handover types

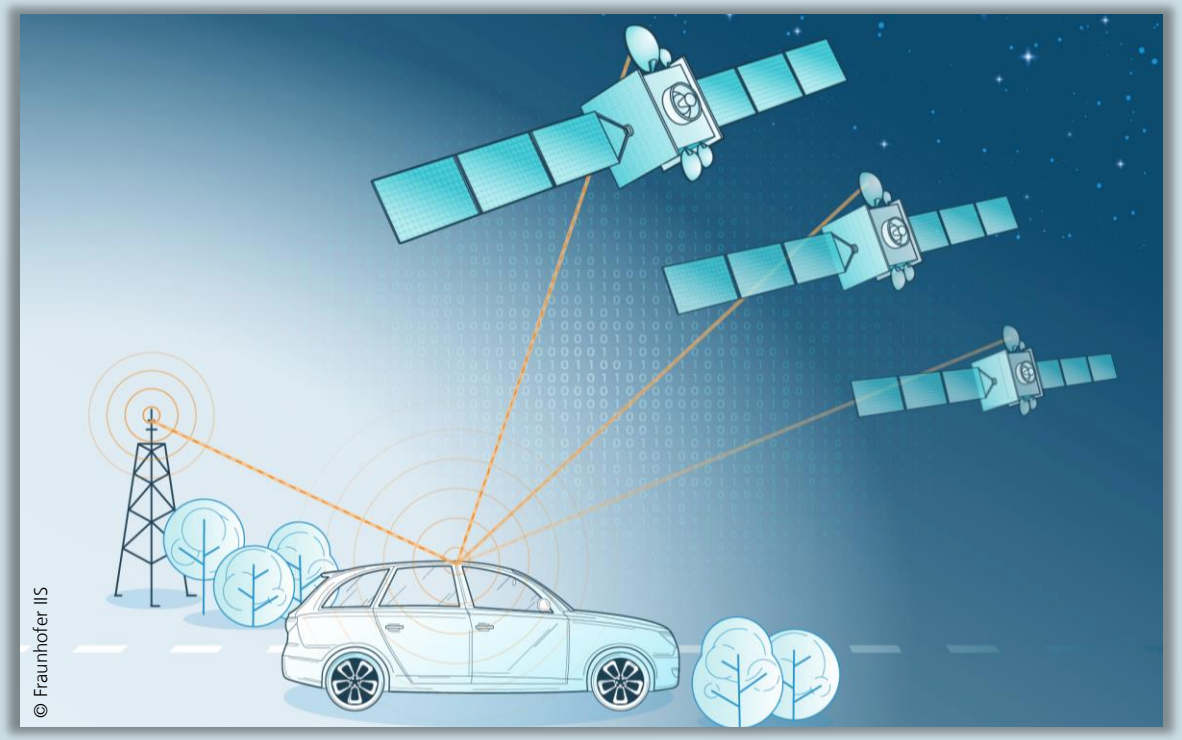
"Legacy" handover (HO)
- Signal strength-based

Conditional handover (CHO)
- Location-based
- Time-based

NTN handover in 3GPP

Release 18
- TN (5G) ↔ NTN (5G)
- NTN/NTN

Release 19
TN (LTE) ↔ NTN (5G)



1 Twofold mobility
- Moving satellites
- Mobile users

2 Two connectivity types
- Terrestrial network (TN) connectivity
- Non-terrestrial network (NTN) connectivity

3 Two types of handover scenarios
- TN↔NTN (terrestrial-to-satellite and vice versa)
- NTN↔NTN (satellite-to-satellite)

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R&D and Challenges of Future NTN Features

R&D and Challenges of Future NTN Features

3D Networks and Ubiquitous Coverage

NTN in 6G

Still lot of Research Challenges on Top of 5G-Advanced, e.g.

Mobility

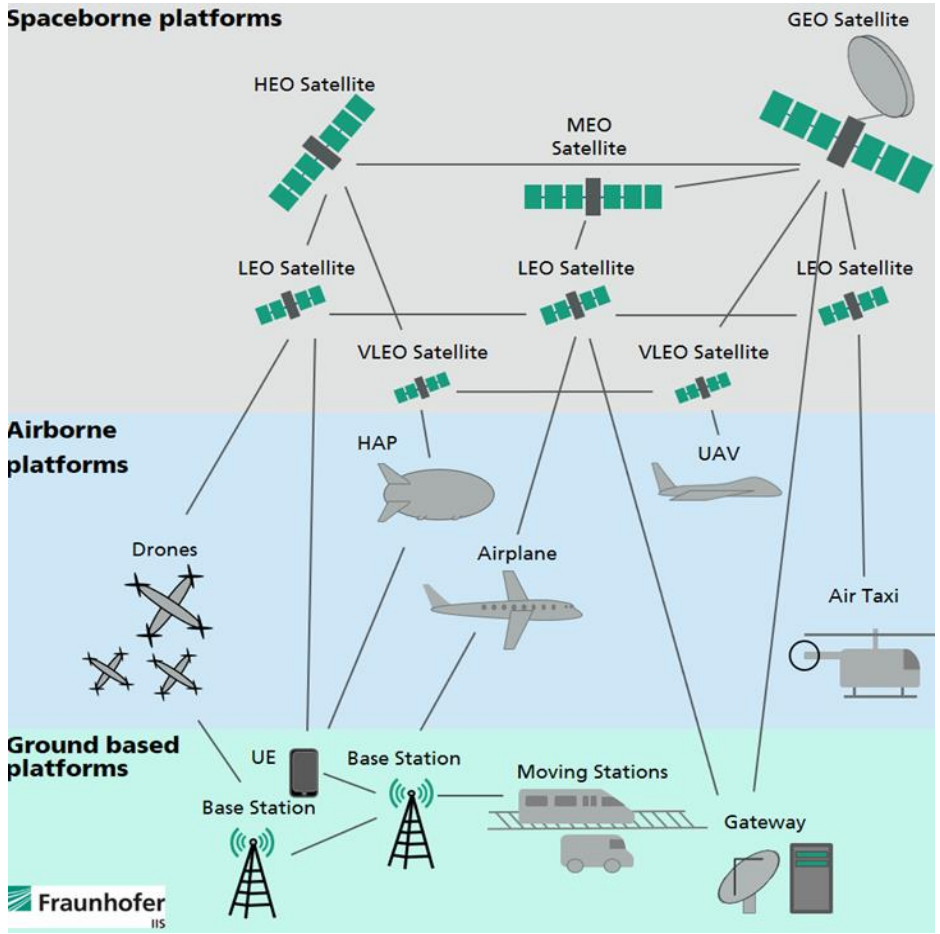
- **Seamless connectivity** in complex 3D networks (multi-orbit, HAPS, UAVs…)
- **QoS continuity** optimized with AI

Deployment

- **Spectrum in FR1!**
- **Spectrum sharing and resource allocation** of TN/NTN
- **Interference avoidance**, e.g., in multi-orbit scenario
- **Functional split** TN/NTN (3GPP / O-RAN), incl. ISL and On-board processing
- Efficient **antennas for Ku-/Ka-Band** (automotive, UAVs, maritime…)

Efficiency

- **Optimize waveforms** for higher throughput = revenues for SNOs
- **Single RAT** for IoT and wideband/broadband?
- **Beam management** with power limited satellites



Heterogeneous future 3D-networks

ETSI Conference “Non-Terrestrial Networks, a Native Component of 6G" 04/24

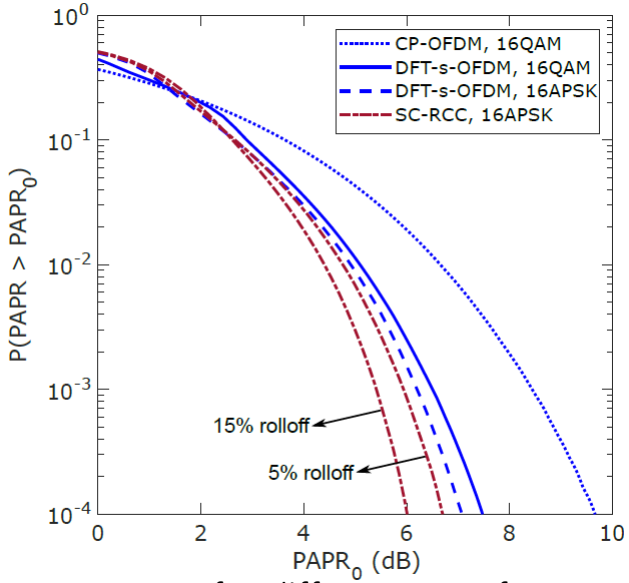
- **GNSS free operation of UEs** → resilience, cheaper devices
- Lean signaling
- Scalability and granularity (IoT, broadband)
- NTN based positioning

NTN in 6G
Efficiency

Trade-off waveforms

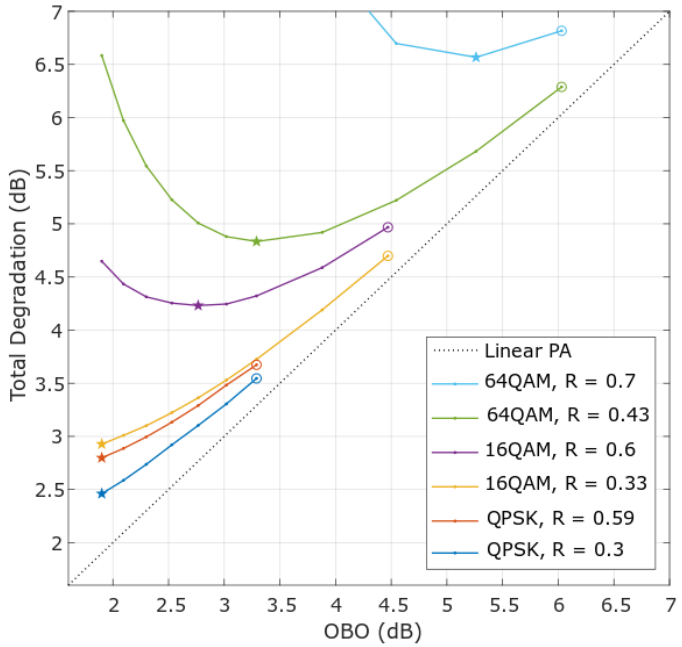
- ✓ Power-efficient waveform used in UL
- × DL: OFDMA with high PAPR
  - Higher OBO required, Total Degradation (TD) increases
  - Satellite is power limited
  - Reduced throughput and revenues

- Same challenge for terrestrial FR2
- But questionable, whether waveform changes are possible in 6G

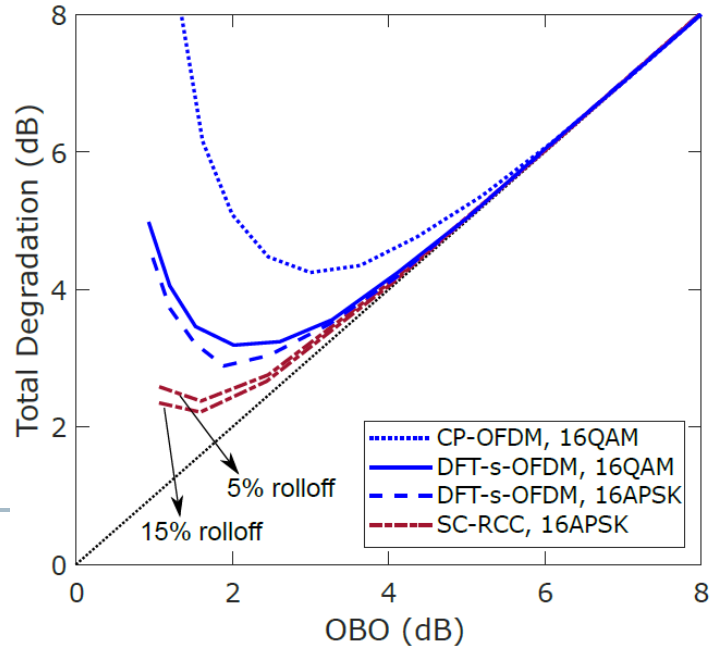


PAPR for different waveforms *

TD for different MCS of 5G-NTN DL **



TD for different waveforms *

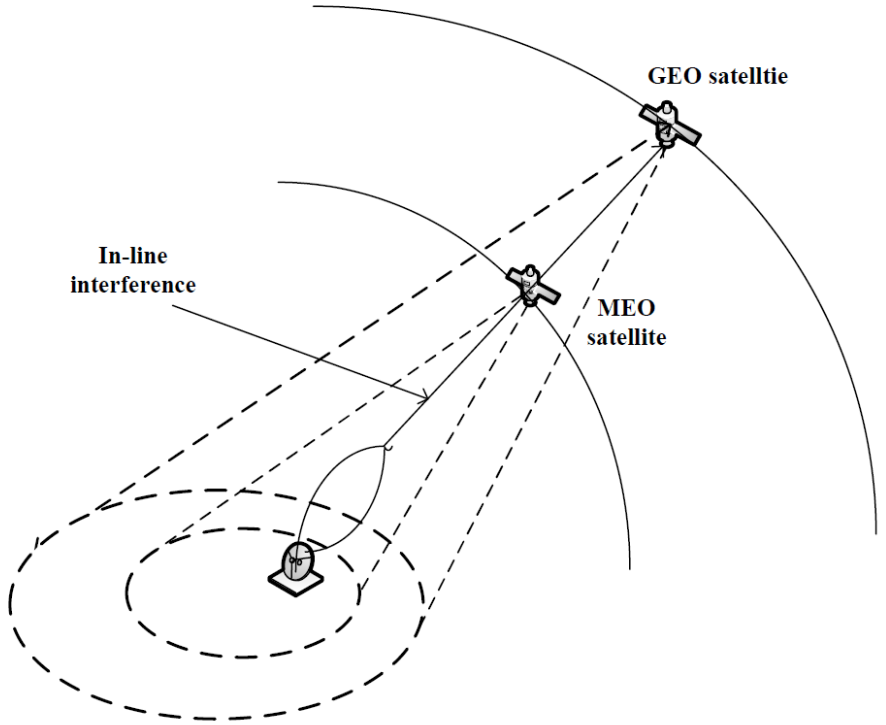


* G. George, S. Roy, S. Raghunandan, C. Rohde and T. Heyn, „5G New Radio in Nonlinear Satellite Downlink: A Physical Layer Comparison with DVB-S2X", IEEE 5G World Forum, 2021
** 3GPP R1-1908996, "Downlink Performance Evaluation in NTN", Fraunhofer IIS, HHI, Prague 2019-08

NTN in 6G
Interference

Challenges:

- In-line interference
  - Due to increasing number of constellations and satellites
- GNSS jamming
  - Jamming along borders / from trucks
    => harmful for planes, ships, ground users
  - UE up to Rel-19 assume GNSS capability to sync
  - Need for robust sync in 6G to support UE w/o GNSS



Example: In-line interference caused by NGSO systems (MEO or LEO) *

* 3GPP R1-1909000, "NTN Regulatory Aspects", Fraunhofer IIS, HHI, Prague 2019-08, see also annex in 3GPP TR 38.821

R&D and Challenges of Future NTN Features

Market Needs

Current Developments and Associated Activities in 5G/6G NTN

GSOA, 5GAA

GSOA: Deployment Considerations 12/23 ***

- Covering GEO, Non-GEO, large frequency range
- IoT-NTN and NR-NTN

3GPP NTN Based Satellite Network Deployment Plans

Matrix of industry initiatives/areas of interest led by satellite network operators for the different deployment scenarios:

	Narrowband connectivity to IoT devices (NTN-IoT in FR1)		Narrowband/Broadband connectivity to handheld devices (NTN-NR in FR1)	Broadband connectivity to non-handheld devices (VSAT) (NTN-NR in above 10 GHz Band)	
Space Segment	**Re-use of existing GSO**	**NGSO**	**NGSO**	**GSO**	**NGSO**
Operators	EchoStar Viasat-Inmarsat TerreStar Solutions	Sateliot EchoStar OmniSpace Viasat-Inmarsat	EchoStar OmniSpace Viasat-Inmarsat SES	Intelsat Eutelsat-Oneweb Viasat-Inmarsat SES	Intelsat Eutelsat-Oneweb Viasat-Inmarsat SES
Timeline Indication	2023-2025	2024-2029	2026-2029		

5GAA: Strong automotive interest in NTN, automotive demands

- **Seamless connectivity, even in areas w/o terrestrial coverage**!
- NTN towards new European Satellite Constellation IRIS^2
- 3GPP: Rel-19 workshop *, automotive terminal characteristics @FR1/FR2 **

NTN technical report now published: next slide

European Constellation IRIS2

- Will be based on 5G-NTN, more details to be announced

* 3GPP RWS-230164 ** LS to 3GPP RP-232733 *** LS to 3GPP RP-232732

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Current Developments and Associated Activities in 5G/6G NTN

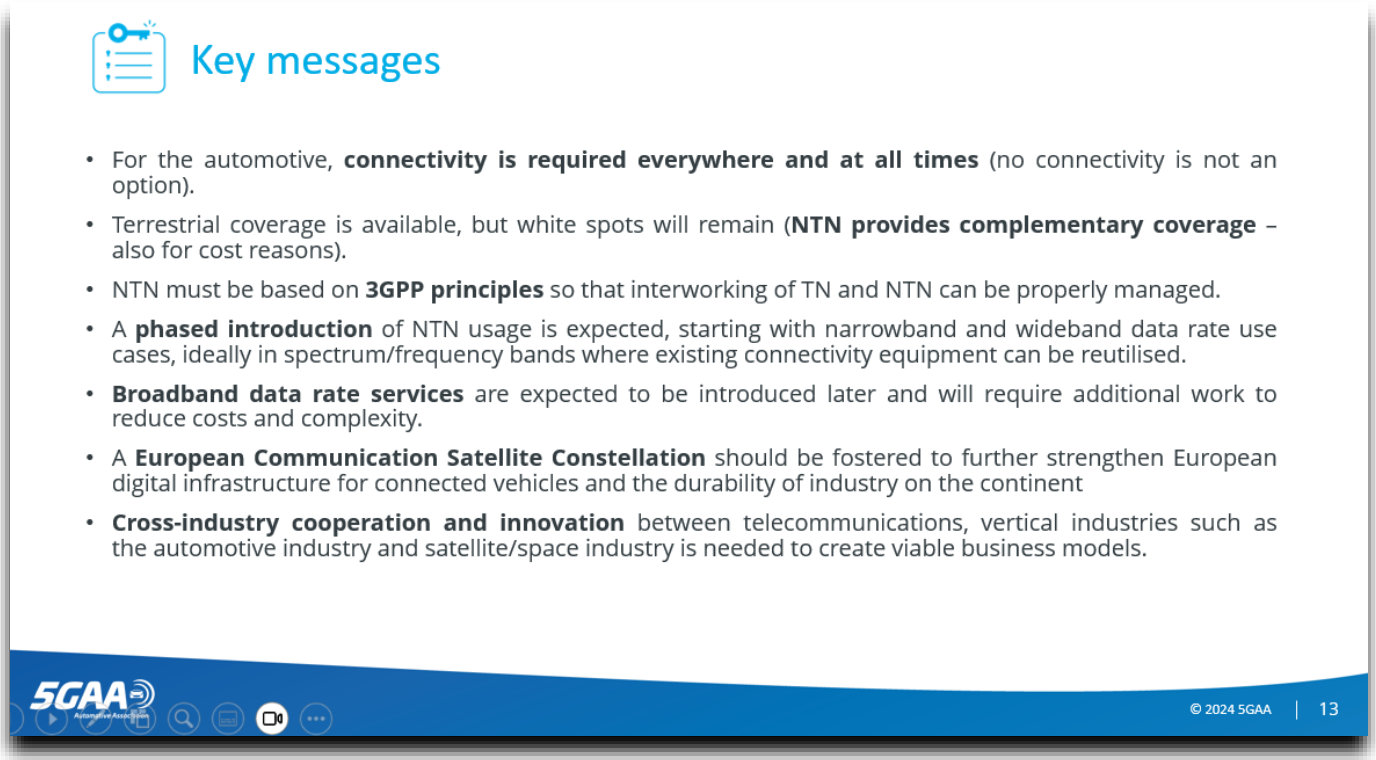
5GAA

5GAA: Detailed report on NTN on automotive demands, published 09/24

- **Seamless connectivity, even in areas w/o terrestrial coverage!**
- **Need for narrowband, wideband and broadband data rate services**
- Report with mobility aspects, antenna characteristics, spectrum needs…

https://5gaa.org/content/uploads/2024/09/5gaa-ntn-ras-technical-report.pdf

Key messages (BMW in sat conference in Bonn):



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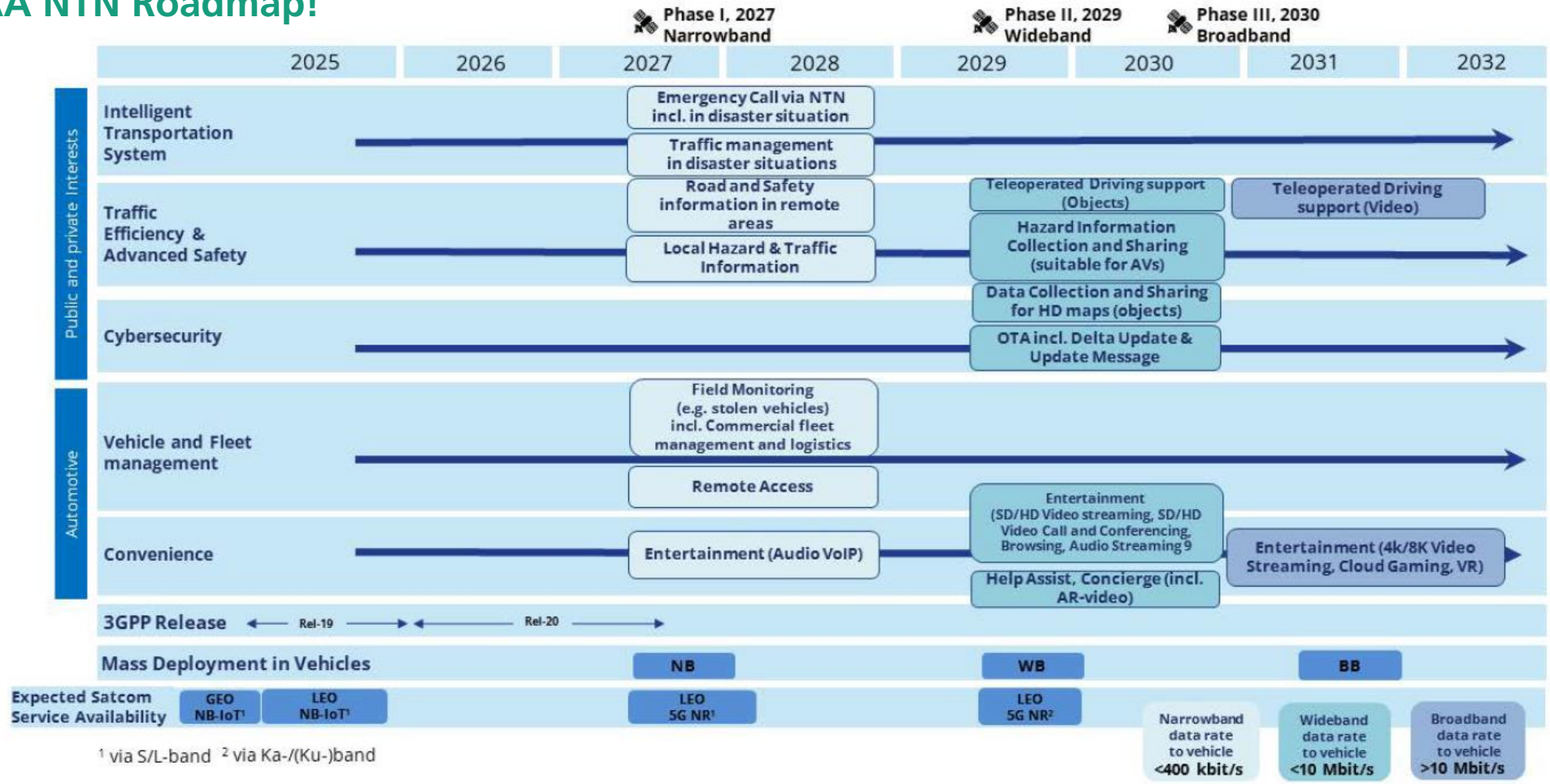
Current Developments and Associated Activities in 5G/6G NTN

5GAA

5GAA NTN Roadmap!



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Current Developments and Associated Activities in 5G/6G NTN

Seamless Air Alliance (SAA)

SAA Use Cases *

3GPP NTN use cases first defined by the Seamless Air Alliance are focused on cabin and cockpit connectivity:

- Internet Access for Passengers (Inflight Connectivity) (LEO, MEO, GEO)
- Multicast / Live Television for Passengers (GEO)
- Airline & Airport Administration and Operation (LEO and/or GEO)
- Hyperconnected ATM (LEO and/or GEO)

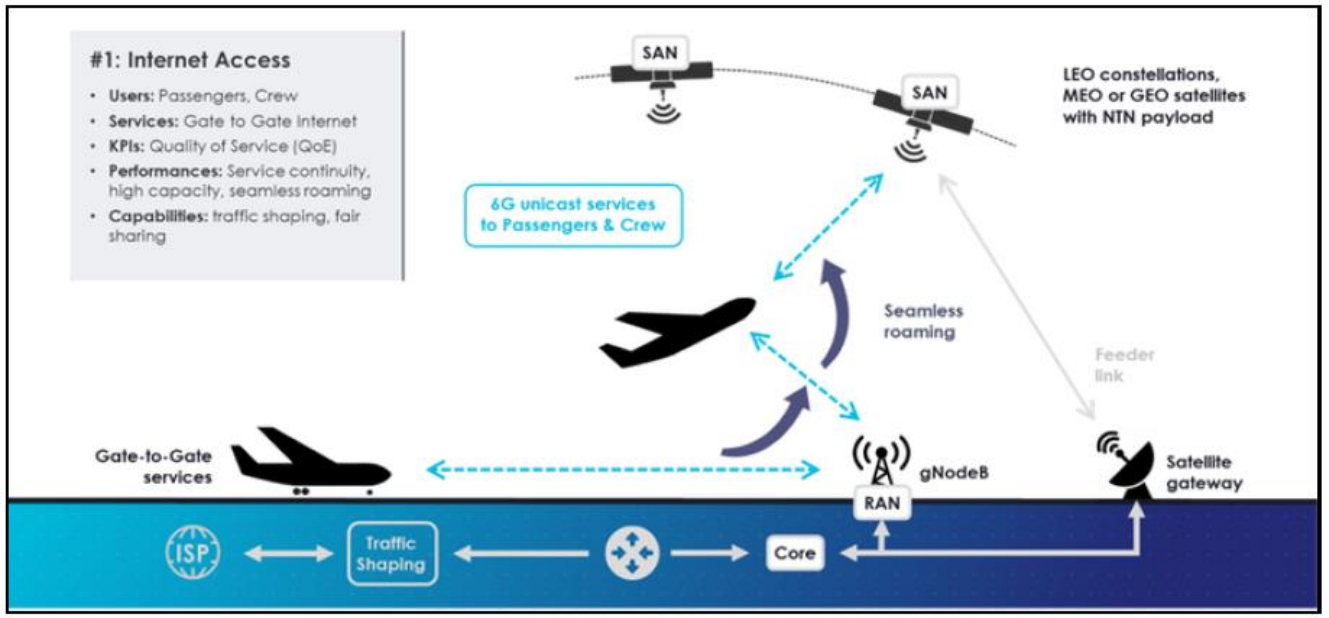


Figure 9-1 3GPP NTN Passenger Internet Access Use Case

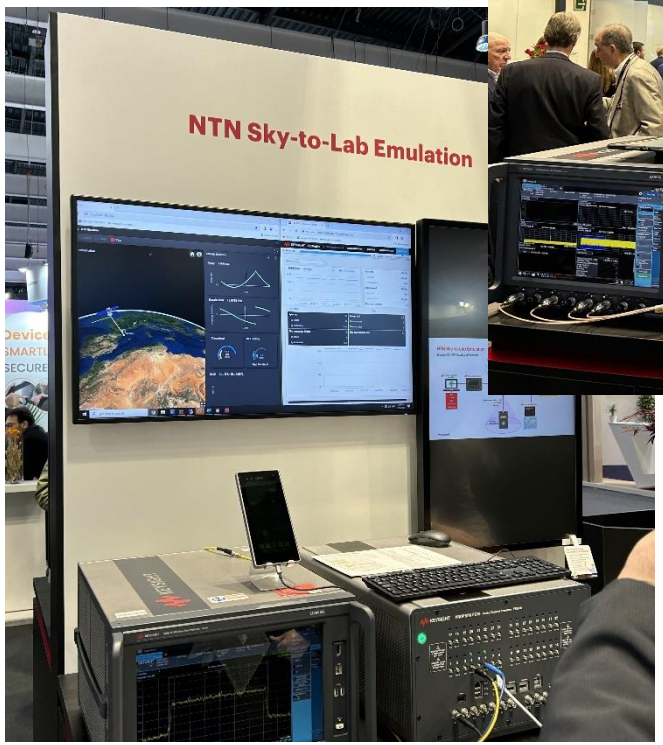
* Source: LS to 3GPP RP-240737

Mobile World Congress 2024, Barcelona

NTN related Demos

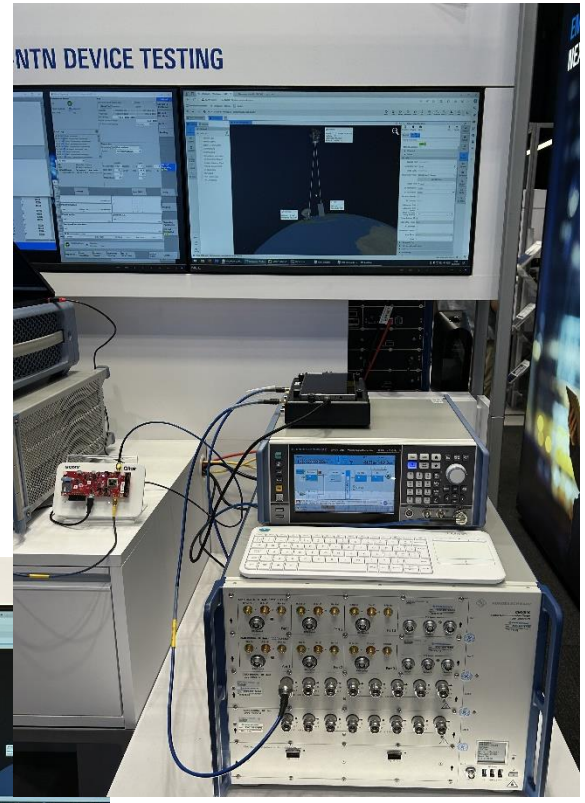
@Keysight

Qualcomm test mobile

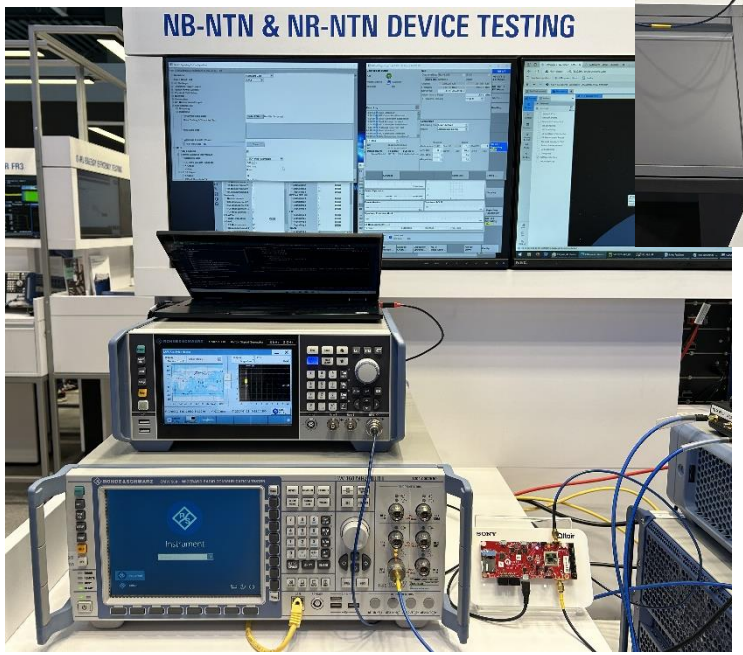


Mediatek NR-NTN test mobile

@Rohde&Schwarz



NR-NTN test mobile



Sony/Altair IoT-NTN module

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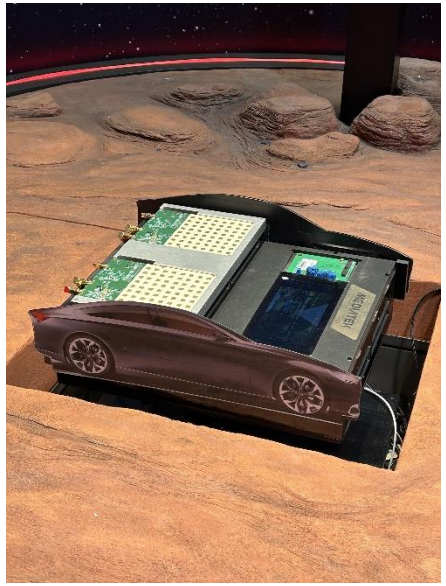
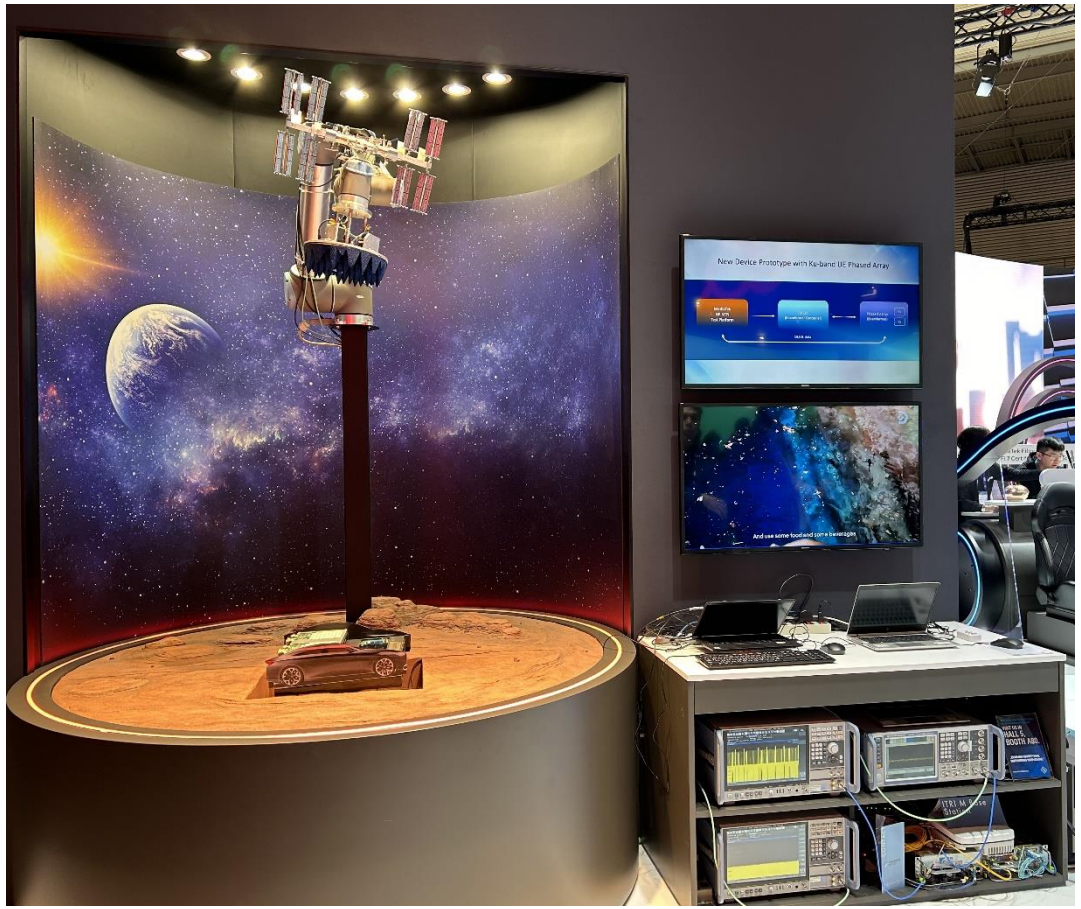
Mobile World Congress 2024, Barcelona

NTN related Demos

@Mediatek



Demonstrator setup for Ku-band, with R&S



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Quectel eval-board IoT-NTN for L/-S-Band

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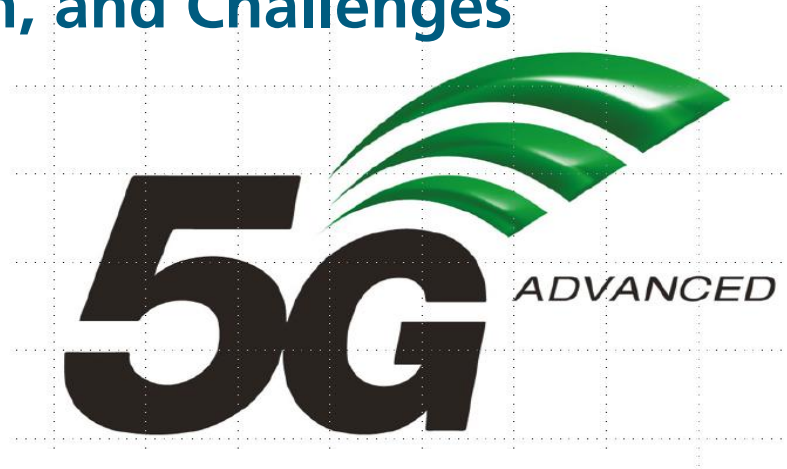
Conclusions

From 5G NTN to 6G NTN – Standardization, Research, and Challenges

Conclusions



5G and 5G-Advanced

- Already a powerful standard created by 3GPP
- Significant market interest, **standardization strongly industry driven**!
- Prototypes for 5G-NTN available
- Multiple deployments started or announced!
- Few additional features expected for Release 20

Towards 6G

- Several research challenges to be solved
- 6G Workshop by 3GPP in March 2025 will reveal company opinions!
- Let's shape NTN in 6G (-Standardization) together!

NTN was introduced in 5G step by step…

However in 6G, NTN integrates into 3D networks and represents a new central component!

→ Ubiquitous coverage anytime, anywhere, anyhow

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