Multi-Access Edge Computing (MEC) over NTN for beyond 5G & 6G

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1.0	30/09/2025	Revised final version

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Executive Summary

The scope of this document is to describe the main standardization and IPR Management of MECON project.

This task will identify specific technical aspects that deserve standardization and compliance with other complementary frameworks and platforms. The purpose is to pursue a coherent and synergic action that remains aligned with the project implementation, without harming commercial opportunities for partners. Moreover, this task will also ensure efficient management of IPR. A specific plan for the use and dissemination of knowledge will be provided and periodically updated. Background and foreground will be regulated in the Consortium Agreement (CA).

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Abbreviations

3GPP - 3rd Generation Partnership Project

5G NR - 5G New Radio

5G-NR LL - 5G New Radio Light (also known as RedCap)

ACM - Adaptive Coding and Modulation

BER - Bit Error Rate

CA – Consortium Agreement

CDMA - Code Division Multiple Access

DSS - Dynamic Spectrum Sharing

ECEF - Earth-Centered, Earth-Fixed

EIRP - Equivalent Isotropic Radiated Power

EMI - Electromagnetic Interference

FAR - False Alarm Rate

FDMA - Frequency Division Multiple Access

FRF - Frequency Reuse Factor

FSO - Free Space Optics

FSS - Fixed Satellite Services

GCC - Ground Control Center

GEO - Geostationary Earth Orbiting

GNB - next Generation Node B

GNSS - Global Navigation Satellite System

G/T - Gain-to-Noise Temperature

GW - Gateway

HAPS - High Altitude Platform Station

HEO - Highly Elliptical Orbiting

IoT - Internet of Things

IPR – Intellectual Property Rights

ISL - Inter-Satellite Links

ITU - International Telecommunication Union

LEO - Low Earth Orbiting

LOS - Line of Sight

Mbps - Mega bit per second

MEO - Medium Earth Orbiting

MS - Mobile Services

MSS - Mobile Satellite Services

NCC - Network Control Center

NAS-MM - Non-Access Stratum Mobility Management

NAS-SM - Non-Access Stratum Session Management

NLOS - Non-Line of Sight

NGEO - Non-Geostationary Earth Orbiting

NFV - Network Functions Virtualization

NSA - Non-Standalone

NTN - Non-Terrestrial Network

OFDMA - Orthogonal Frequency Division Multiple Access

QoE - Quality of Experience

QoS - Quality of Service

RAN - Radio Access Network

RF - Radio Frequency

RFI - Radio Frequency Interference

RTD - Round Trip Delay

Rx - Receiver

SA - Standalone

SAR - Synthetic Aperture Radar

SBA - Service-Based Architecture

SC-FDMA - Single Carrier Frequency Division Multiple Access

SDN - Software Defined Networking

SDR - Software-Defined Radio

SNR - Signal-to-Noise Ratio

SRI - Satellite Radio Interface

TLE - Two-Line Element

TDMA - Time Division Multiple Access

TT&C - Telemetry, Tracking, and Command

UAS - Unmanned Aircraft System

UAV - Unmanned Aerial Vehicle

UE - User Equipment

URLLC - Ultra-Reliable Low-Latency Communications

VLEO - Very Low Earth Orbit

VNF - Virtual Network Function

VSAT - Very Small Aperture Terminal

1   Introduction - 3GPP Standardization for Non-Terrestrial Networks (NTN)

As the demand for global connectivity continues to grow, terrestrial cellular networks alone are insufficient to provide seamless coverage, particularly in remote, rural, maritime, and aerial regions. To address this challenge, Non-Terrestrial Networks (NTN) have emerged as a critical extension of terrestrial mobile networks, enabling connectivity via satellites, high-altitude platforms (HAPS), and other spaceborne and airborne systems. This document will focused on Non-transparent NTN over LEO satellite constellations.

Recognizing the significance of NTN in the evolution of mobile communication, the 3rd Generation Partnership Project (3GPP) has incorporated NTN support into its 5G and beyond (6G) standardization efforts, defining technical specifications that integrate satellite communications with terrestrial cellular networks. These standardization efforts aim to ensure interoperability, service continuity, and efficient spectrum utilization across terrestrial and non-terrestrial infrastructures.

This document provides an overview of the 3GPP NTN standardization framework, focusing on key specifications, architecture, protocols, and enhancements introduced in 3GPP Releases 15, 16, 17, 18, 19 and beyond. It also highlights how NTN technologies support critical applications such as IoT, emergency communication, broadband services, and global connectivity expansion.

By defining NTN standards, 3GPP enables mobile network operators, satellite providers, and equipment vendors to develop unified, scalable, and future-proof solutions that extend the reach of mobile networks to underserved and unconnected regions worldwide.

2   3GPP standardization for NTN

Here is a brief description of the main characteristics and enhancements specified in each 3GPP release related to NTN (Non-Terrestrial Networks).

2.1   Release 15

While initial specifications enabled non-standalone 5G radio systems integrated in previous-generation LTE networks, the scope of Release 15 expands to cover 'standalone' 5G, with a new radio system complemented by a next-generation core network. It also embraces enhancements to LTE and, implicitly, the Evolved Packet Core (EPC). This crucial waypoint enables vendors to progress rapidly with chip design and initial network implementation during 2019.

2.1.1   Main Features Specified in 3GPP Release 15

3GPP Release 15, finalized in 2018, was the first set of 5G New Radio (5G NR) standards. It introduced the foundation for 5G networks, focusing on increased speed, lower latency, and support for a variety of use cases.

1. 5G New Radio (NR)

- Introduction of 5G NR, a new radio access technology for 5G.
- Support for Standalone (SA) and Non-Standalone (NSA) modes.
    - NSA Mode: Uses LTE as an anchor for 5G.
    - SA Mode: Operates independently with a new 5G Core (5GC).

2. Enhanced Mobile Broadband (eMBB)

- Designed to increase data speeds, enabling applications like 4K/8K video streaming, VR, and AR.
- Higher spectral efficiency and support for mmWave frequencies (above 24 GHz).

3. Ultra-Reliable Low-Latency Communication (URLLC)

- Enables mission-critical applications such as autonomous driving, remote surgery, and industrial automation.
- Supports latency as low as 1 millisecond (ms) with 99.999% reliability.

4. Massive Machine-Type Communication (mMTC)

- Supports Internet of Things (IoT) applications with low power, long battery life, and high device density.
- Can support 1 million IoT devices per square kilometer.

5. New Frequency Bands and Carrier Aggregation

- Introduced two frequency ranges for 5G:
    - FR1 (Sub-6 GHz): 450 MHz – 6 GHz (better coverage, lower capacity).
    - FR2 (mmWave): 24 GHz – 52 GHz (ultra-fast speeds, shorter range).
- Carrier aggregation to combine multiple frequency bands for increased capacity.

6. Massive MIMO & Beamforming

- Massive Multiple-Input Multiple-Output (Massive MIMO) with up to 256 antennas for improved spectral efficiency.

- Beamforming to focus signals directly toward users, reducing interference.

7. Network Slicing
- Virtualization of network resources to create multiple logical networks for different applications (e.g., IoT, gaming, enterprise services).

8. Vehicle-to-Everything (V2X) Communications
- Enhancements for connected vehicles, supporting direct communication between vehicles, infrastructure, and pedestrians.

9. Integration with LTE (EPC Core & Evolved LTE)
- NSA mode allows 5G NR to work with existing LTE networks via the Evolved Packet Core (EPC).
- Enhancements to LTE to improve gigabit speeds and latency while transitioning to 5G.

10. Multi-RAT and Interworking
- Ensures smooth handover between 5G, LTE, and Wi-Fi.
- Improves device connectivity and service continuity across multiple network types.

3GPP Release 15, marked the initial standardization of 5G New Radio (NR). However, it did not specifically address Non-Terrestrial Networks (NTN), such as satellite communications. NTN-related features were introduced later, starting with Release 16.

2.1.2 Typical use cases of NTN networks in Rel. 15 are:
- NTN broadband connectivity to cells or relay nodes in underserved areas in combination with terrestrial wireless/cellular or wire line access featuring limited user throughput.
- NTN broadband connectivity between the core network and cells in un-served areas (isolated areas), also to restore connection to public data network in case of disaster relief or for public safety.
- NTN broadband connectivity between the core network and the cells on board a moving platform (e.g. aircraft or vessels or trains), including cases where NTN provides connectivity to a local terrestrial network on board of the moving platform.
- Network resilience: Secondary/backup connection to prevent complete connection outage for critical network links.
- NTN to interconnect various 5G local access network islands not otherwise connected
- Broadcast/Multicast service via NTN e.g. to off load popular content from the terrestrial mobile network infrastructure.

2.1.3 Release 15 consideration for MECON:
All essential and critical features of 3GPP Release 15 have been considered for MECON, including network entry procedures, enhanced Mobile Broadband (eMBB), IoT, network slicing, and beamforming. However, features such as Ultra-Reliable Low-Latency Communications (URLLC), carrier aggregation, Vehicle-to-Everything (V2X), and Non-Standalone (NSA) mode are beyond the scope of this project.

2.2 Release 16

List of the main NTN related features:
- Roaming between terrestrial and satellite networks
- Broadcast and multicast with a satellite overlay

- Internet of Things with a satellite network
- Temporary use of a satellite component
- Optimal routing or steering over a satellite
- Satellite transborder service continuity
- Global satellite overlay
- Indirect connection through a 5G satellite access network
- 5G Fixed Backhaul between NR and the 5G Core
- 5G Moving Platform Backhaul
- 5G to Premises
- Satellite connection of the remote service centre to the off-shore wind farm
- Satellite access (with transparent GEO satellite and LEO based non-terrestrial access network (moving beam on earth), i.e. UAS/HAPS based access was considered here as a special case of NTN with lower Doppler and variation rate
- Usage scenarios: pedestrians or users on board of a vehicle (high speed train, airplane).

The considered reference scenarios were GEO, LEO with steering beams, LEO with moving beams and all for the transparent payload case and the regenerative payload case.
For the concept of MECON, we consider Regenerative LEO cases with fixed and moving beams.

Figures 7 to 10 how the satellite access could be integrated in the 5G radio architecture in different scenarios:
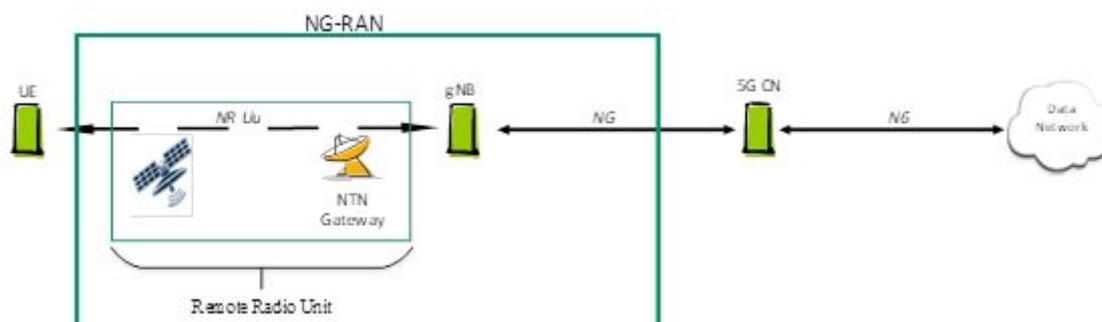
Figure 1:Transparent satellite-based NG-RAN architecture (gNB on earth) [source: TR 38.821].

Control Plane (CP) and User Plane (UP) of NR Uu are terminated on the ground/on earth (longer round-trip time (RTT) needs to be taken into account).
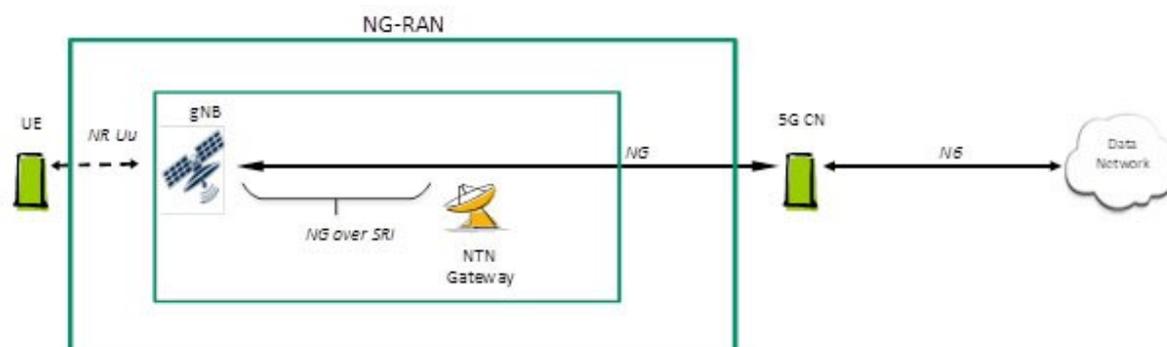
Figure 2: Regenerative satellite-based NG-RAN architecture without ISL (gNB on satellite) [source: TR 38.821].

NR-Uu radio interface is on the service link between the UE and the satellite.
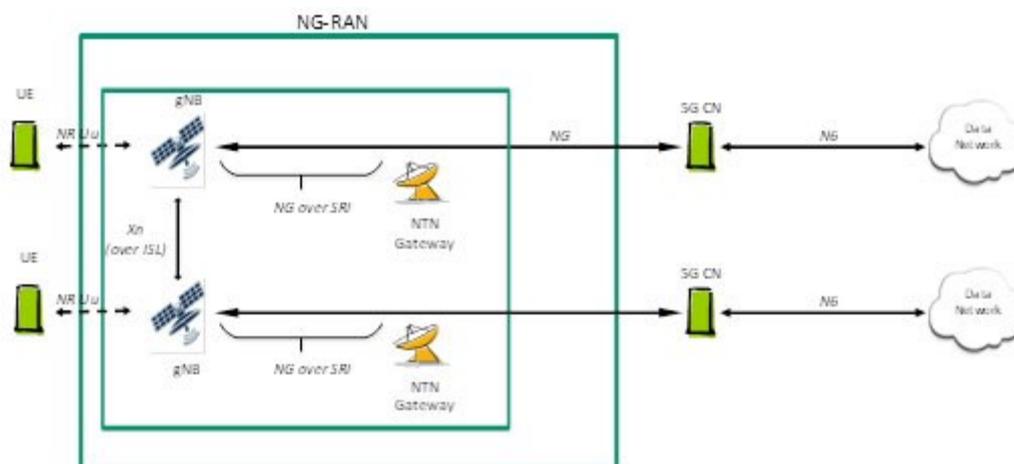
Figure 3: Regenerative satellite-based NG-RAN architecture without ISL (gNBs on satellites) [source: TR 38.821].

a UE (served by a gNB on board a satellite) could access the 5GCN also via ISL which is a transport link between satellites. So not necessarily 2 connections to the data network are needed.
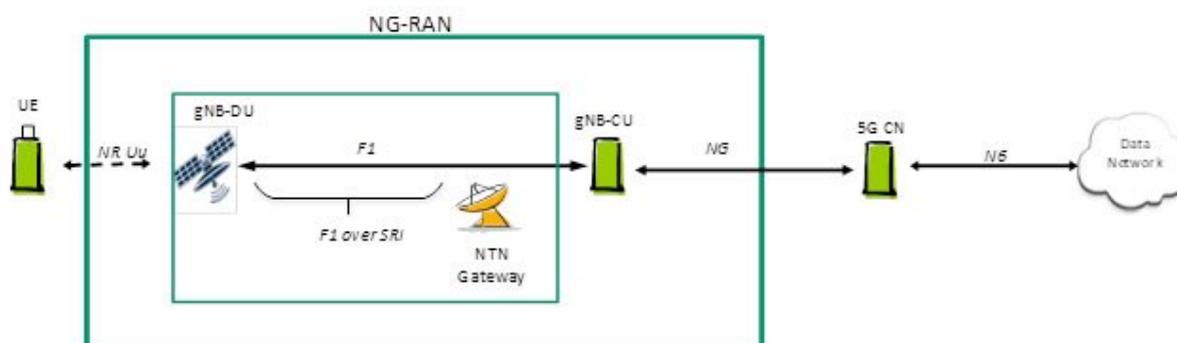
Figure 4: Regenerative satellite-based NG-RAN architecture without ISL (gNB-DU on satellite and gNB-CU on earth) [source: TR 38.821].

It illustrates how a split of the gNB functionality into CU (central unit) and DU (distributed unit) would look like. The feeder link/SRI between NTN gateway and satellite would then transport the F1 protocol. As RRC and other Layer3 processing are terminated in the gNB-CU on ground corresponding timing impacts are the consequence (worse for GEO than for LEO). It would be possible that the DU on board different satellites is connected to the same CU on ground.

Apart from NTN-TN service continuity scenarios, also multi-connectivity scenarios were considered in which one UE is served:

- In parallel, by an NTN (transparent or regenerative payload) and a terrestrial network (TN).
- In parallel, by 2 NTNs (both transparent or both with regenerative payload) – (with at least partial coverage overlap) in order to improve performance (like data rate or reliability) in certain scenarios. This scenario is beyond the scope of the MECON project.

Main focus issues:
1. Timing relationship enhancements
2. Enhancements on UL time and frequency synchronization

3. Enhancement on the PRACH sequence and/or format in the case pre-compensation of timing and frequency offset is not done at UE side
4. Beam management and BWP operation for NTN with frequency reuse, including signalling of polarization mode
5. Feeder link switch impact on physical layer procedures in case of LEO scenarios
6. Number of HARQ processes, support ɒof enabling/disabling HARQ feedback.
7. Offset-based solutions for timer adaptations are preferred, earth fixed tracking area is recommended
8. Enhancements for random access, timing advance, DRX, Scheduling Request, HARQ,
9. **Idle mode** enhancements: additional assistance information for cell selection/reselection (e.g. UE location, satellite Ephemeris information), earth-fixed tracking area to avoid frequent TAU, NTN cell specific information in SIB.
10. **Connected mode** enhancements: reduce service interruption during Hand-Over due to large propagation delay, tackle frequent handover and high handover rate due to satellite movement, improve handover robustness due to small signal strength variation in regions of beam overlap, compensate for propagation delay differences in the UE measurement window between cells originating from different satellites.

Only item 6 is considered in the MECON project.

2.3 Release 17

Rel-17 focused on basic connectivity using bent-pipe architectures.

2022 was the year in which Release 17 was functionally frozen.

Release 17 highlights

*   Sidelink enhancements,
*   Reduced capability (Redap) NR devices,
*   NR operation extended to 71GHz,
*   Further enhancements on MIMO for NR,
*   NR over Non terrestrial Networks (NTN),
*   IoT over NTN,
*   UE power saving enhancements for NR,
*   Enhancements to Integrated Access and Backhaul for NR,
*   Enhancement of RAN slicing for NR,
*   RF requirements enhancement for NR FR1,
*   RF requirements for NR FR2,
*   Coverage and positioning enhancements,
*   NR and slicing QoE,
*   Enhanced support of non-public networks,
*   Support for uncrewed aerial systems,
*   Support for edge computing in 5GC,
*   Proximity-based services in 5GS,
*   Access traffic steering, switch and splitting (ATSSS),
*   Network automation for 5G (Phase 2).

With the increasing utilization of UAVs for various purposes, the systems in the aerial ecosystem, along with their supporting telecommunications networks, are under increasing strain to cope with this growing demand. To coordinate aerial manned and unmanned activities, various entities, depending on the

country or region, establish regulations to ensure safety, efficiency, and integration within national and global airspace. Part of those entities are the International Civil Aviation Organization (ICAO) and national aviation authorities like the Federal Aviation Administration (FAA) in the U.S. or the European Union Aviation Safety Agency (EASA) in Europe.

2.4 Release 18

Release 18 Rel-18 introduces advanced features such as regenerative payloads, mobility enhancements, IoT support, and specifies further improvements of the 5G-Avanced system. These improvements consist both in enhancements of concepts/Features introduced in the previous Releases and in the introduction of new topics.

Rel. 18 specifies gNB functions to be executed onboard the satellite (e.g., MAC, RLC, PDCP layers), enabling regenerative satellite operation (Key documents: TR 38.821, TR 38.863).

 Rel. 18 defines two main functional split models: Option 2 with F1 split and option 7.2 (High Layer ↔ Low Layer split in DU). For the concept of the MECON project, we consider the Option 2 split model, as well as the entire gNB onboard.

Key improvements to (source TR 21.918):

- Further integrate Satellite (NTN) access (introduced in Rel-17) in the 5G System (5GS).
- Support of Internet of Things (IoT), Machine-Type Communication (MTC), including by satellite coverage.
- Sidelink, Proximity, Location and Positioning.
- Supporting industrial needs (Verticals, Industries, Factories, Northbound APIs)
- Multicast and Broadcast Services (MBS)
- Network Slicing
- Uncrewed Aerial Vehicles (UAV).
- Extended DRX/eDRX for long idle cycles, and Adapted RRC timers for delay tolerance for NB-IoT and Battery Powered NTN devices.
  - Idle cycles: Up to 10 minutes
  - RRC inactivity: >1 sec tolerance

- Energy Efficiency (EE).
- Artificial Intelligence (AI)/Machine Learning (ML).
- eXtended, Augmented and Virtual Reality (XR, AR, VR), Immersive communications.
  KPIs:
- Beam switch time target: ≤100 ms
- Handover success rate ≥99%
- IoT Battery life target: 10+ years
- Geo-positioning measurements (Key document: TR 38.855):
  - <100 m (with GNSS)
  - <1 km (without GNSS, TDOA-only)
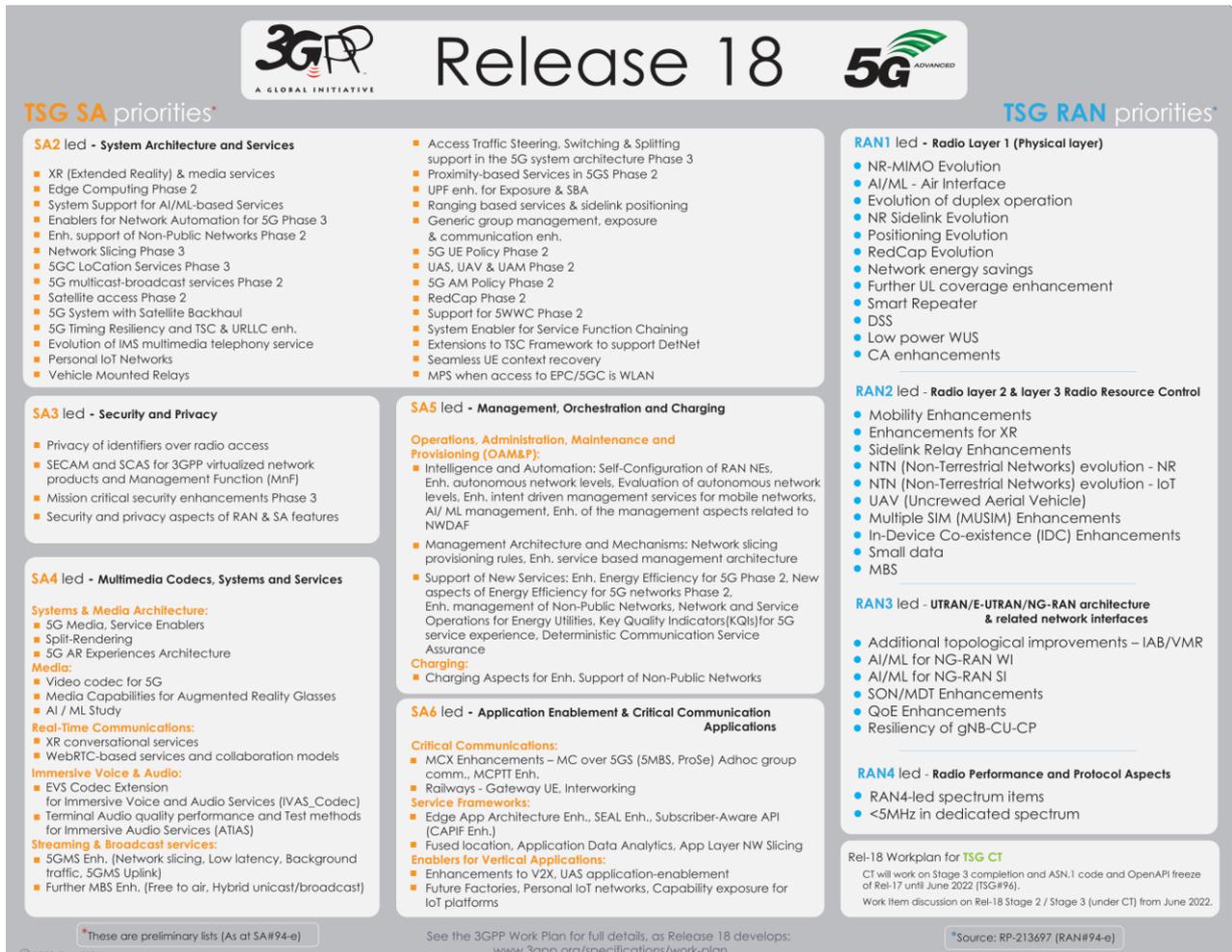
Figure 5: 3GPP Release 18 TSG SA and RAN priorities overview.

2.5 Release 19

In 3GPP Rel-19, significant advancements are being made to enhance NTN, building upon the foundational work of previous releases.

Rel. 19 major topics include TN and NTN:
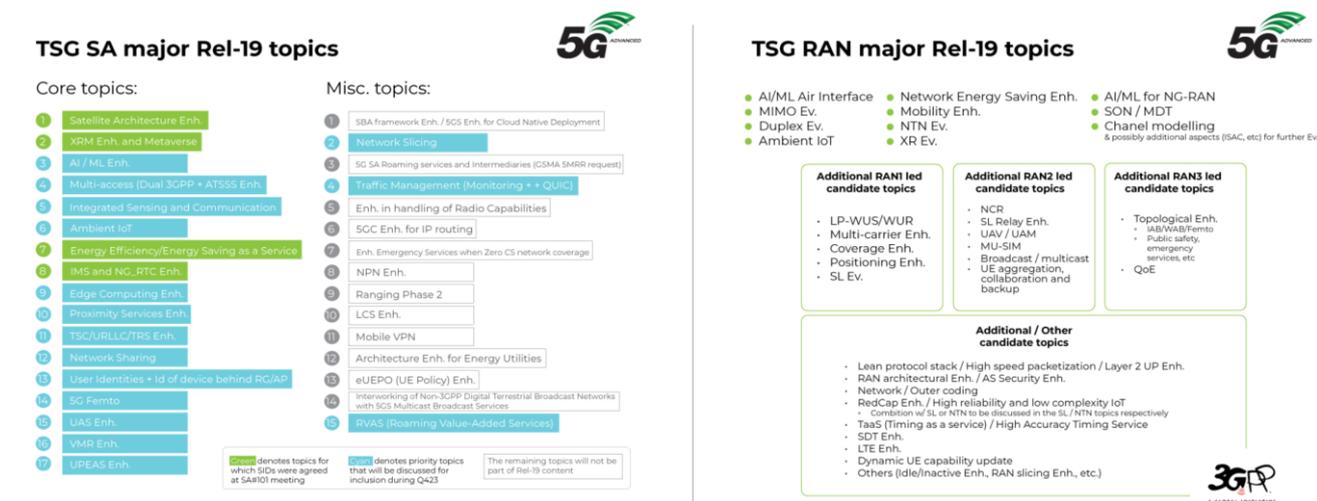
Figure 6: Major Rel-19 topics, include TN and NTN.

The key NTN-related features in Rel-19 include:

2.5.1 Support for Regenerative Payloads

Rel-19 introduces support for regenerative payloads, where satellites host complete or partial gNB functionalities onboard. This contrasts with the earlier transparent (bent-pipe) architectures, where satellites merely acted as relays. Why a gNB payload was a much better option than a gNB-DU payload, including the following key points (Reference: This development marks a milestone in integrating satellite technologies into 5G, as highlighted by Ericsson.

- o gNB on board fully leverages all available 5G RAN functionality specified since Rel-15.
- o The reuse of Xn means that gNB on board natively supports inter-satellite links, inter-satellite mobility, UP routing and S&F.
- o In the case of gNB-DU on board, it would not be possible to natively support feeder link switch or S&F.
- o In the case of gNB-DU on board, it would not be possible to leverage a standardized direct inter-satellite interface for e.g. inter-satellite mobility. Such an interface is not specified by 3GPP, which means it would have to be proprietary and could therefore increase the development cost.
- o From a signaling point of view, a gNB-DU on board would be suboptimal. The RRC termination would be in the gNB-CU on the ground, and frequent DU-CU interactions over the F1 interface on the feeder link would be required – much more so than with a gNB on board.
- o The perceived advantage of having only a gNB-DU on board is questionable: the gNB-DU hosts all the RF and physical layer functions, so it accounts for most of the complexity and power consumption in a gNB. "Carving out" a gNB-CU from a payload, then, does not accomplish much.

2.5.2 Enhancements for IoT over NTN

Rel-19 focuses on further enhancements to support **Internet of Things (IoT)** devices over NTN.

- **Key Features:**
  - o **Store and Forward (S&F) Operations:** Supports scenarios where satellites store data and forward it when in range of ground stations, beneficial for delay-tolerant IoT applications.
  - o **Uplink Capacity Enhancements:** Techniques such as multiplexing multiple UEs via orthogonal cover codes (OCC) and reducing signaling overhead to improve uplink capacity.

2.5.3 Integration with Terrestrial Networks

Rel-19 emphasizes seamless integration between NTN and terrestrial networks to ensure consistent and reliable connectivity.Key Aspects:

- o Enhancements to support handovers and service continuity between terrestrial and non-terrestrial networks.
- o Mechanisms to enable efficient spectrum utilization between satellite and terrestrial components.
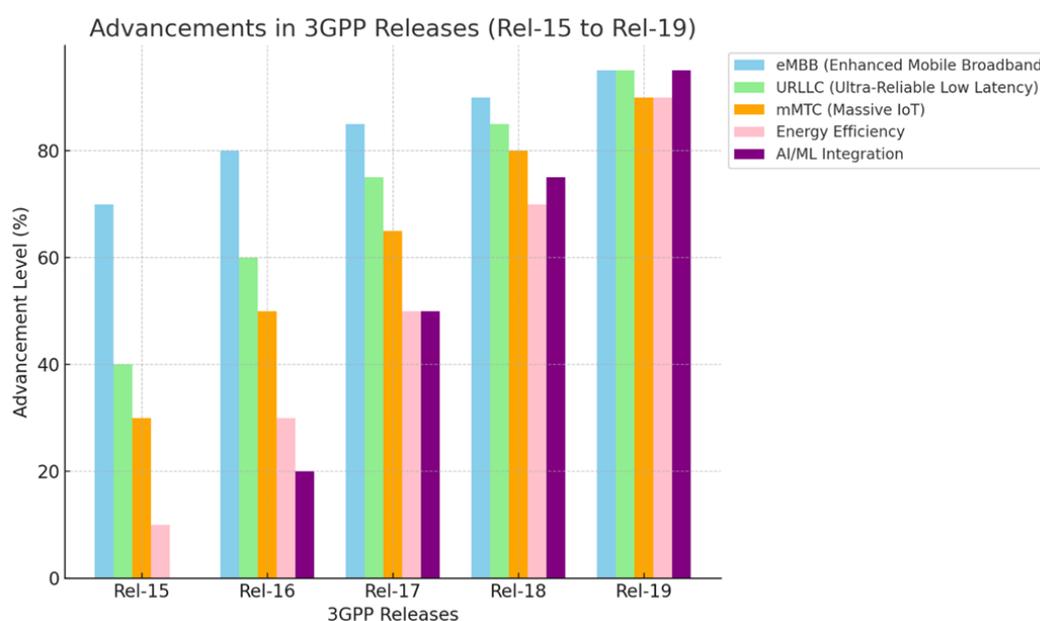
Figure 7: Advancements in 3GPP Releases, from Rel-15 to Rel-19.

2.5.4 AI/ML Integration for NTN

Rel-19 explores the application of **Artificial Intelligence (AI)** and **Machine Learning (ML)** to optimize NTN operations, among others:

- o **Beam Management:** Using AI/ML for adaptive beamforming and dynamic beam selection to enhance link reliability. Wikipedia+2LinkedIn+2ericsson.com+2
- o **Resource Allocation:** Predictive analytics for efficient spectrum and power allocation based on traffic patterns. LinkedIn

2.5.5 Extended Frequency Support

Rel-19 extends frequency band support for NTN operations, including bands beyond 10 GHz, such as the Ka-band, to accommodate higher data rates and increased capacity.

- **Reference:** The extension to higher frequency bands is part of the ongoing enhancements in 3GPP standards.

These features collectively aim to enhance the capabilities of Non-Terrestrial Networks, ensuring they can seamlessly integrate with terrestrial systems and support a wide range of applications, from broadband connectivity to IoT services in remote areas.

Here's a detailed breakdown of how 3GPP Release 19 enables TN-NTN (Terrestrial-Non-Terrestrial Network) interworking via O-RAN's open interfaces, based on the latest standardization efforts and technical documents:

2.5.6 Key Focus Areas in Release 19

Release 19 prioritizes seamless integration of terrestrial (TN) and non-terrestrial (NTN) networks by formalizing O-RAN's role in managing hybrid architectures. Key enhancements include:

- Unified RAN Control: O-RAN's RAN Intelligent Controller (RIC) orchestrates TN-NTN handovers, beamforming, and interference mitigation.
- Regenerative Payload Support: Satellites with onboard processing (e.g., DU functions) leverage O-RAN's Option 7.2 functional split to optimize latency and resource usage.
- Dynamic Spectrum Sharing: O-RAN's E2 interface enables real-time coordination between ground stations and satellites for efficient spectrum/power allocation.

2.5.7 O-RAN Interfaces Enabling TN-NTN Interworking

Interface	Role in TN-NTN Interworking	Example Use Case
E2	Connects RIC to CU/DU for real-time control (e.g., beam adjustments during satellite handovers).	Mitigates interference between TN cells and LEO satellites.
A1	Guides RIC with policy updates (e.g., traffic prioritization for emergency NTN services).	Prioritizes maritime/aviation traffic during congestion.
O1	Manages lifecycle of NTN components (e.g., software updates for regenerative payloads).	Remote firmware updates for satellites via O-Cloud.
Open Fronthaul	Standardizes DU-RU communication for hybrid TN-NTN base stations.	Integrates satellite-based RUs with terrestrial DUs.

2.5.8 Technical Innovations in Release 19

A. Enhanced Mobility Management

- Conditional Handover (CHO): Uses RIC-driven xApps to predict and execute TN↔NTN handovers based on UE location/signal strength.
- L1/L2 Measurements: Supports CSI-RS (Channel State Information Reference Signals) for NTN-specific beam tracking, improving handover accuracy.

B. AI/ML-Driven Optimization

- DQN Models: Allocate RAN functions (CU/DU/RU) between ground and satellite systems dynamically.
- Interference Mitigation: xApps analyze NTN beam patterns to minimize cross-link interference.

C. Support for Regenerative Payloads

- Onboard DU Processing: Satellites handle Layer 2 functions (e.g., scheduling), reducing reliance on ground stations for latency-critical tasks.
- O-Cloud Integration: Extends cloud-native orchestration to satellite payloads via O-RAN's SMO (Service Management and Orchestration).

2.5.9 Real-World Implementations

- Mavenir & Terrestar: Demonstrated NB-IoT over GEO satellites using O-RAN's E2/O1 interfaces for mobility management.
- ESA's Spacetime Project: Integrates O-RAN with NTN steerable-beam systems, enabling mesh networks for hybrid TN-NTN coverage.

2.5.10 Challenges Addressed

Challenge	O-RAN Solution
High Latency (LEO/GEO)	Near-RT RIC optimizes functional splits (e.g., CU on ground, DU on satellite).
Frequent Handovers	AI-driven CHO reduces signaling overhead by 40%.
Vendor Lock-In	Open fronthaul interfaces enable multi-vendor NTN deployments.

2.5.11 Future Outlook (6G Preparation)

Release 19 lays the groundwork for 6G NTN by:

- Standardizing AI-native RICs for predictive TN-NTN resource management.
- Expanding network slicing to prioritize NTN traffic (e.g., emergency services).
- Enabling multi-hop Sidelink relays for off-grid NTN connectivity.
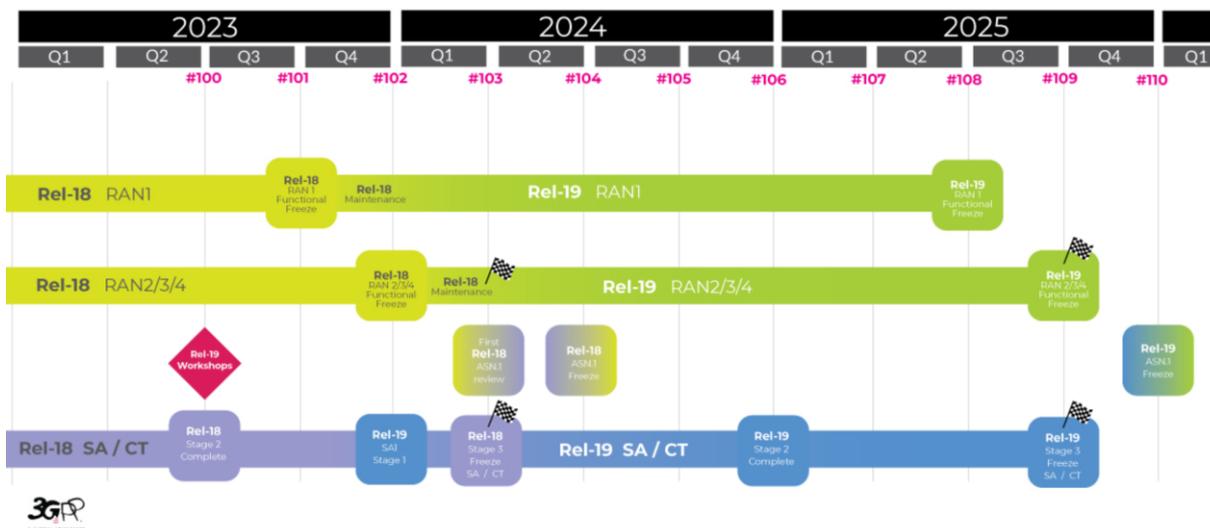
2.5.12 Rel. 19 timeline

Figure 8: Release 19 timeline.

2.6 Spectrum allocation in Rel. 19

In **3GPP Rel-19**, several enhancements have been made to support new frequency bands and bandwidths for both terrestrial and Non-Terrestrial Networks (NTN). Below are the key specifications with numerical values.

2.6.1 Terrestrial Networks: Introduction of Upper Mid-Band Frequencies

- Frequency Range: 7.125 GHz to 24 GHz.
- Channel Bandwidths: Specific channel bandwidths for these frequencies are under study in Rel-19. Historically, for Frequency Range 1 (FR1) up to 7.125 GHz, channel bandwidths include 5 MHz to 100 MHz.
- For Frequency Range 2 (FR2) starting from 24.25 GHz, bandwidths include 50 MHz to 400 MHz. The new upper mid-band frequencies are expected to have channel bandwidths defined within this range. Wikipedia

These enhancements in Rel-19 aim to provide greater flexibility and capacity for both terrestrial and non-terrestrial 5G networks, accommodating the growing demand for higher data rates and expanded coverage.

2.6.2 NTN-Specific Spectrum and Bandwidths (3GPP Rel-17 to Rel-19)

NTN operates under both **FR1** and **FR2**, covering S-band, L-band, Ku-band, and Ka-band. Here's the breakdown:

1. S-Band / L-Band (Low-frequency, legacy satellite + NTN IoT)

Uplink	~1.6 – 2.2 GHz
Downlink	~1.4 – 2.0 GHz
Examples	Bands: n255, n256 (NB-IoT NTN)
Bandwidth	Typically 5 MHz, 10 MHz (NB-IoT, LTE-M)

- Designed for **low-data rate NTN** (IoT, NB-IoT)
- Used in GEO/MEO satellites
- Good propagation and indoor penetration

2. Ka-Band (High-throughput broadband NTN)

Uplink (Earth → satellite)	27.5 – 31 GHz
Downlink (Satellite → Earth)	17.7 – 21.2 GHz
Potential Bands	Future FR3 band proposals
Bandwidths	Up to 400 MHz (FR2), potentially more with aggregation

- Used in broadband satellite systems (e.g., Starlink, Viasat, OneWeb)
- High capacity, suitable for eMBB over NTN
- More vulnerable to rain fade

3. Ku-Band (Rel-19 Enhancement Focus)

Uplink (Earth → satellite)   12.75 – 14.5 GHz

Downlink (Satellite → Earth) 10.7 – 12.75 GHz

Use Cases   Direct-to-device (D2D), broadband over LEO

Bandwidths   Typically 50 MHz – 100 MHz per carrier (FR2 format)

- Targeted in Rel-19 for NTN-NR and NTN-IoT
- Better atmospheric performance than Ka-band
- Used in OneWeb, SES, and other LEO constellations

4. 3GPP Designated NTN NR Bands (FR1/FR2)

n255   1.6 – 2.2 GHz   NB-IoT NTN GEO

n256   1.4 – 1.6 GHz   NB-IoT NTN GEO

n510 (proposed) ~12.75 – 14.5 GHz NTN-NR   LEO/MEO

n511 (proposed) ~10.7 – 12.75 GHz NTN-NR   LEO/MEO

Bands n510/n511 are expected to be fully specified or refined during Rel-19/20 activities.

5. Channel Bandwidths per Band Class

< 2 GHz (FR1)   5 MHz, 10 MHz, 20 MHz

S-/L-band NTN IoT Narrowband (180 kHz for NB-IoT)

Ku-band (Rel-19)   50–100 MHz per carrier

Ka-band (FR2)   100–400 MHz (up to 800 MHz w/ CA)

Key 3GPP Specifications Covering NTN Spectrum & Bandwidth

TR 38.811	Channel models for NTN	Covers LEO, GEO, link budgets
TS 38.104	NR BS RF requirements	Defines spectrum and bandwidth
TS 36.104	E-UTRA BS requirements	For NB-IoT/LTE-M over NTN
TR 38.821 / 863	Solutions & study on NTN NR	Architecture, spectrum scenarios
TS 38.101-1/-2	UE requirements (FR1/FR2)	Includes NTN-supported bands

2.7 Release 20

Structured summary of key 5G-Advanced enhancements in 3GPP Release 20, based on the latest industry insights:

1. AI/ML-Driven Network Optimization

- AI at the Air Interface: First-time integration of AI/ML for real-time radio performance improvements, including dynamic beamforming and interference management.
- Network-Wide AI: Enhanced automation for energy efficiency, load balancing, and mobility management using intent-based AI solutions.
- Predictive Analytics: AI-driven traffic forecasting to optimize energy consumption and resource allocation.

2. Energy Efficiency & Sustainability

- Dynamic QoS Adjustments: Services adapt based on energy availability (e.g., reduced video quality during low power).
- Carbon Footprint Reporting: Networks track and report emissions for specific services (e.g., IoT fleets or connected vehicles).
- Advanced Sleep Modes: RedCap devices and base stations use ultra-low-power states to reduce energy use.

3. Enhanced Mobility & Handover

- Near-Zero Interruption Handovers: Layer 1/2 triggered mobility (LTM) reduces service disruption to <10 ms for XR, IIoT, and URLLC use cases.
- NTN Integration: Improved handovers between terrestrial and non-terrestrial networks (satellites, HAPS) for global coverage.

4. Non-Terrestrial Network (NTN) Advancements

- Direct-to-Device Satellite Connectivity: Enables smartphones to communicate directly with LEO/MEO satellites for emergency services and IoT.
- Multi-Orbit Support: Seamless interoperability between LEO, MEO, and GEO constellations for resilient global coverage.
- Reduced GNSS Dependency: Enhanced uplink synchronization for areas with poor satellite visibility.

5. RedCap & IoT Enhancements

- Reduced Device Complexity: Supports 5-MHz bandwidth and 10 Mbps speeds for wearables, industrial sensors, and video surveillance.
- Ambient IoT: Devices powered by RF energy harvesting (light, motion) for smart logistics and industrial monitoring5.
- Enhanced Uplink: Improved throughput for XR/AR/VR applications and industrial automation.

6. XR & Immersive Communications

- QoS Prioritization: Guaranteed low latency (<5 ms) and high reliability for XR traffic.
- ATSSS Integration: AI-driven traffic steering across 5G, Wi-Fi, and NTN for uninterrupted XR experiences.

7. Security & Reliability

- Post-Quantum Cryptography (PQC) Readiness: Upgraded encryption standards to counter quantum computing threats.
- Resilient Timing: Sub-microsecond synchronization for industrial automation and smart grids, reducing GPS dependency.

8. MIMO & Spectrum Efficiency

- Sub-Band Full Duplex (SBFD): Simultaneous uplink/downlink in the same frequency band to double spectral efficiency.
- Massive MIMO Upgrades: 256-antenna arrays and improved beamforming for higher capacity and coverage.

9. Sidelink & Device-to-Device (D2D)

- Relay Support: UE-to-UE relaying extends coverage for autonomous vehicles and emergency services.
- V2X Enhancements: Sidelink operates in new frequencies (e.g., 6 GHz) for low-latency vehicle communication.

10. Positioning Accuracy

- Sub-10 cm Precision: Indoor/outdoor positioning for logistics, AR-assisted surgery, and autonomous robotics.
- Carrier Phase Measurement: Improved non-line-of-sight (NLOS) accuracy for industrial asset tracking.

2.8   Release 20 Timeline

- Finalization: Mid-2025 (18-month roadmap).
- 6G Preparation: Lays groundwork for 6G's AI-native networks, ubiquitous NTN, and immersive XR.

2.9   Key Use Cases Enabled

- Mission-Critical IoT: Smart grids, remote surgery, and autonomous factories.
- Global Connectivity: Satellite-direct smartphones and disaster recovery.

Release 20 bridges 5G-Advanced and 6G, prioritizing AI integration, global NTN coverage, and ultra-reliable low-latency communication for emerging industries.

CU-DU split was introduced in Rel-15 and is a distinctive feature of NG-RAN. 6G studies are expected to start in 3GPP in Rel-20 (during 2025), and a potential future 6G RAN node can be expected to leverage a different split architecture, so at this point it does not seem justified to envisage the CU-DU split in 6G. Therefore, a gNB-DU payload and its required ground segment may prove challenging in terms of a possible evolution path toward 6G. This is not so (or at least less so) in the case of a gNB payload.

The figure below shows the evaluation path from Rel.-15 to Rel.-19 and 6G.
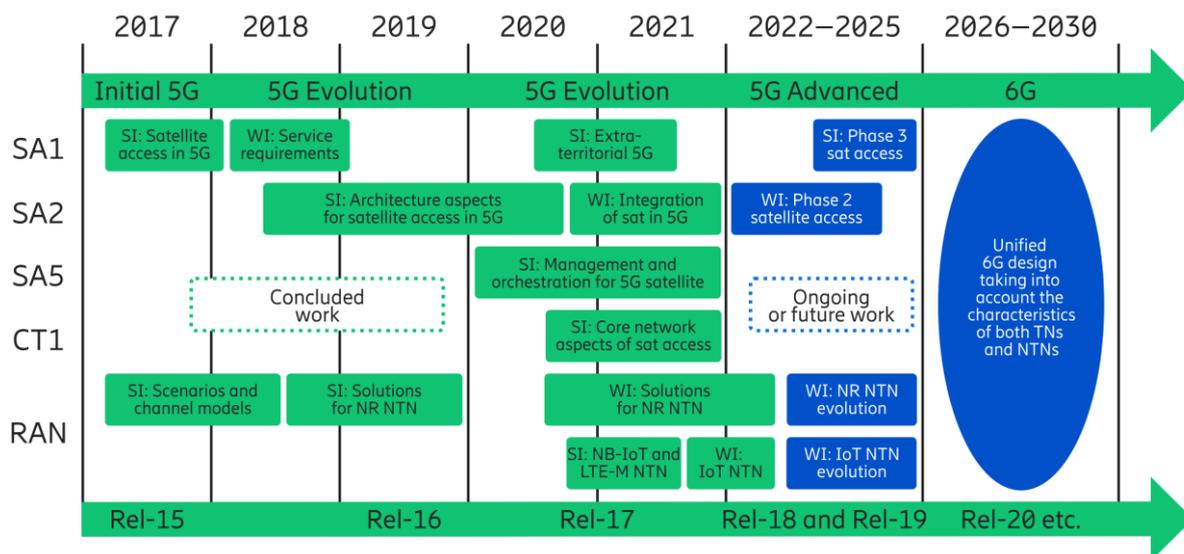
Figure 9: Evolution path toward 6G (from Ericsson).

RIS – Standards status (2025)

3GPP has **not** adopted a RIS study item in Rel-18/19; NCR (network-controlled repeaters) progressed in Rel-18 instead. Active work is in **ETSI ISG RIS** (use cases/KPIs, evaluation). Translation: deployments are vendor/research-driven today, not 3GPP-NR normative.

3   Intellectual Property Rights (IPR)

In this section are specified the rules applied to IPR management during the project execution and the rules applied to the consortium partners regarding IP rights, sharing, use and access.

3.1 Definitions

▪ Access Rights: means licences and user rights to Foreground or Background.

▪ Access Rights needed: means in the case of the implementation of the Project, when without the granting of such Access Rights, the performing of the work assigned to the recipient Party would be impossible, unfeasible and unworkable, detained or retarded, or involve considerable additional or extra financial and/or human resources. In the case of use of own Foreground, it means that without the granting of such Access Rights, would be technically or legally impossible to exercise such a use.

▪ Application Programming Interface (API): means a particular set of rules and specifications that Software programs can follow to communicate with each other; it serves as an interface between different Software programs and facilitates their interaction, like the way the user interface facilitates interaction between humans and computers.

▪ Background: means information which is held by a Party prior to its accession to this agreement, as well as the intellectual property rights pertaining to such information, including the application that has been filed before its accession to this agreement, which is needed for carrying out the Project or for using Foreground.

▪ Dissemination: means disclosure of Foreground by any appropriate means other than that resulting from the formalities for protecting it and including the publication and presentation of Foreground in any medium.

▪ Direct utilization: means when the owner of the Foreground uses it in further research, commercial or industrial exploitation, namely in its own activities.

▪ Fair and reasonable conditions: means appropriate conditions including possible financial terms considering the specific circumstances of the request for access, for example the actual or potential value of the Foreground or Background to which access is requested and/or the scope, duration or other characteristics of the use envisaged.

▪ Foreground: the tangible and intangible results which are generated under the project, including pieces of information, materials and knowledge and whether or not they can be protected. It includes intellectual property rights (e.g. copyrights, industrial designs, patents, plant variety rights), similar forms of protection (e.g. rights for databases) and know how or trade secrets (e.g. confidential information).

▪ Grant Agreement: means the contract signed between a Party and its National Entity.

▪ Indirect utilization: means the use of Foreground made by other Party (which is not the owner) by means of assignment of rights or granted licences.

▪ Intellectual Property Rights (IPR):

   o   means patent, patent applications and other statutory rights in inventions;

   o   copyrights (including without limitation copyrights in Software);

   o   rights for databases, registered design rights, applications for registered design rights, unregistered design rights and other statutory rights in designs;

- and other similar or equivalent forms of statutory protection and undisclosed or confidential information, trade secrets and know-how.

▪ Software: a set of instructions capable, when incorporated in a machine-readable medium, of causing a machine having information-processing capabilities to indicate, perform or achieve a particular function, task or result.

▪ Use: means the direct or indirect use of Foreground in further research activities other than those covered by the Project, or for developing, creating and marketing a product or process, or for creating and providing a service.

3.2 Intellectual property rights, use and dissemination

With respect to the ownership of Foreground, Access Rights, the IPR management follows rules of next subsections, which are according to the provisions of Consortium Agreement.

3.2.1 Foreground ownership

Foreground resulting from the project is owned by the project Party generating it. To accomplish with the obligations resulting from the Consortium Agreement, Parties shall reach an agreement with their employees and other contracted personnel as soon as the latter may be entitled to claim rights to Foreground (subcontractors, students, end-users actively involved in the project etc.). Such agreements may include a formal transfer of ownership or granting of appropriate access rights with a right to sublicense.

3.2.2 Foreground joint ownership

When Foreground is generated jointly by Parties and their respective share cannot be ascertained they shall have jointly ownership on such Foreground, unless the Parties agree on a different solution.

In case of joint ownership, the joint owners shall establish an agreement regarding the allocation and terms of exercise of that joint ownership. The joint owners have the entire freedom to agree among themselves on alternative regimes of the allocation and terms of exercise of the joint ownership.

Arrangements concerning joint ownership, including its shares, protection measures, distribution of responsibilities, costs and profit sharing, territorial division and possibilities of transfer should be negotiated separately and be subject to separate agreements.

3.2.3 Foreground protection

Foreground capable of industrial or commercial application, shall be protected by adequate and effective means by its owner having due regard to its legitimate interest and of the other Parties, particularly those commercial.

Where a Party which is not the owner of the Foreground invokes its legitimate interest, it must, in any given instance, show that it would suffer disproportionately great harm.

3.2.4 Foreground transfer conditions

Each Party may transfer ownership of its own Foreground to any legal entity, subject to the following conditions:

(i) Where a Party transfers ownership of Foreground, it shall pass on its obligations regarding that Foreground to the assignee, including the obligation to pass them on to any subsequent assignee;

(ii) Subject to its obligations concerning confidentiality, as in the context of a merger or an acquisition of a large part of its assets, if a Party is required to pass on its obligations to provide access rights, it shall give at least 30 days prior notice to the other Parties of the envisaged

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transfer, together with sufficient information concerning the envisaged new owner of the Foreground to permit the other Parties to exercise their access rights;

(iii) Parties recognize, at the same time, that in the contest of a merger or an acquisition of an important part of its assets, a Party may be subject to confidentiality obligations which do not permit it to give the full established prior notice for the transfer;

(iv) following notification in accordance with the previous paragraph (ii), any other Party may object within 30 days of the notification or within a different time-limit agreed in writing between all Parties, to any envisaged transfer of ownership on the grounds that it would adversely affect its access rights. If any of the other Parties demonstrate that their access rights would be adversely affected, the intended transfer shall not take place until agreement has been reached between the Parties concerned;

(v) each Party, nonetheless, may identify specific third parties to whom it can potentially transfer the ownership of its Foreground in Annex "**Foreground List Rights and Assignments**" of Consortium Agreement. The other Parties hereby waive their right to object to a transfer to the listed third parties.

3.2.5 Foreground use

The project partners should use the Foreground which they own or ensure that it is used.

3.2.6 Access rights

The Parties defined in the Consortium Agreement Annex "**Background IP list**" the Background which may be subject to Access Rights of other Parties.

For the avoidance of doubt, all Background not listed in Consortium Agreement Annex "**Background IP list**" shall be, accordingly, excluded from Access Rights.

The Party which owns the Background may expand at anytime the existing list by adding further Background to the Consortium Agreement Annex "**Background IP list**".

However, any limitation to Consortium Agreement Annex "**Background IP list**" after signature of the Consortium Agreement requires an acceptance of the IPR board composed by **project management team (PMT) + ethics committee (ET)**.

All requests for Access Rights needed shall be made in writing to the owner, with also a communication to the **IPR board**.

The granting of Access Rights shall be made conditional on the acceptance of specific conditions aimed at ensuring that these rights shall be used only for the intended purpose, subject to appropriate confidentiality obligations and with the respectful and safeguard of the legitimate interests of the granting Party.

Without prejudice to their obligations regarding the granting of Access Rights, Parties shall inform each other as soon as possible of any limitation to the granting of Access Rights to Background, or of any other restriction which might substantially affect the granting of Access Rights.

Exclusive licenses for specific Foreground or Background may be granted subject to written confirmation by all the other Parties that they waive their Access Rights thereto.

Unless otherwise agreed by the owner of the Foreground or Background, Access Rights shall confer no entitlement to grant sublicenses.

Without prejudice to the previous paragraphs, any agreement providing Access Rights to Foreground or Background to Parties or third parties shall be such as to ensure that potential Access Rights for other Parties are maintained.

Parties shall inform each other as soon as possible of any limitation to the granting of Access Rights to Background or of any other restriction which might substantially affect the granting of Access Rights.

3.2.7   Access for implementation

Access Rights needed to the Foreground for the performance of the own work of a Party under the Project must be granted on a royalty-free basis, only during project duration.

Access Rights needed to Background for the performance of the own work of a Party under the Project shall be granted on a **Royalty-Free Basis or on Fair and Reasonable Conditions**.

3.2.8   Access rights to use

Access Rights to Foreground if Needed for Use of a Participant's own Foreground shall be granted on **Royalty-Free Basis or on Fair and Reasonable Conditions**.

Access Rights to Background if Needed for Use of a Participant's own Foreground shall be granted on **Royalty-Free Basis or on Fair and Reasonable Conditions**.

A request for Access Rights may be made up to 6 months (six months) after the end of the Project, or after the termination of the requesting Participant's participation in the Project.

3.2.9   Access rights for affiliates

An affiliated entity established in a Member State or Associated country shall also enjoy Access Rights to Foreground or Background under the same conditions as the Party to which it is affiliated.

Access Rights require that access is needed to use own Foreground, the above paragraph only applies to the extent that ownership of Foreground was transferred to an affiliate entity established in a Member State or Associated country.

Further arrangements with Affiliated Entities may be negotiated in separate agreements.

3.2.10 Access rights concerning project partners leaving the consortium

The termination of the participation of a Party shall in no way affect the obligation of the Party to grant Access Rights to the remaining Parties in the same Project.

A Party leaving the Consortium shall have Access Rights to the Foreground developed until the date of the termination of its participation. The period of time to request Access Rights should be the same as the one set in section **3.2.6** "Access Rights to Use". However, in case of a Defaulting Party, Access Rights granted to it shall cease and its right to request Access Rights shall end immediately at the moment of decision of the **IPR board** composed by **project management team (PMT) + ethics committee (ET)**to terminate Defaulting Party's participation in the Consortium.

For the avoidance of doubt, Defaulting Party according to the Consortium Agreement means a Party which the board composed by **project management team (PMT) + ethics committee (ET)** has identified to be guilty of irregularity according with the Consortium Agreement.

3.2.11 Additional access rights

Grant of additional Access Rights to those covered by the Consortium Agreement should be negotiated separately and be subject to separate agreements.

3.2.12 Provisions for access to software

For the avoidance of doubt, the general provisions for Access Rights provided for in Sections **3.2.6**, **3.2.7**, **3.2.8**, **3.2.9, 3.2.10** and **3.2.11** are applicable also to Software.

3.2.13 Dissemination

Each Party shall ensure that the Foreground of which it has ownership is disseminated as swiftly as possible.

Dissemination activities shall be compatible with intellectual property rights, confidentiality, and the legitimate interests of the owner of the Foreground.

At least 30 days prior notice of any dissemination activity shall be given to the other Parties concerned and **IPR board**, including sufficient information concerning the planned dissemination activity and the data envisaged to be disseminated.

Following notification, any of those Parties may object within 30 days of the notification to the envisaged dissemination activity if it considers that its legitimate interests in relation to its Foreground or Background could suffer disproportionately great harm.

No Party shall disseminate Foreground of other Party, even if such Foreground is linked to its own Foreground, unless the other Party previously approves of such an activity in writing.

For the avoidance of doubt, the rules applicable for the dissemination activities of the Party's own Foreground apply as well for the dissemination of other Party's Foreground.

3.3 Non-disclosure of information, confidentiality and privacy

During the Project and for a period of 5 years after its completion, the Parties undertake to preserve the confidentiality of any data, documents or other material that is identified as confidential in relation to the execution of the project.

For the avoidance of doubt, any written confidential information should be identified as such on each page.

When confidential information was communicated orally, its confidential character must be confirmed by the disclosing Party in writing within 30 days after disclosure.

4   References:

1.   Non-Terrestrial Networks (NTN) (https://www.3gpp.org/technologies/ntn-overview)

2.   3GPP Releases (https://www.3gpp.org/specifications-technologies/releases)

3.   How we reached a common vision on the architecture for 5G non-terrestrial networks in 3GPP Rel-19 (https://www.ericsson.com/en/blog/2024/10/ntn-payload-architecture)

Pure Satellite/NTN specific specifications:

4.   TR 38.811, "Study on New Radio (NR) to support non-terrestrial networks", REL-15 SI FS_NR_nonterr_nw, RAN

5.   TR 22.822, "Study on using satellite access in 5G", REL-16 SI FS_5GSAT, SA1

6.   TR 38.821, "Study on solutions for NR to support non-terrestrial networks (NTN)", REL-16 SI FS_NR_NTN_solutions, RAN3

7.   TR 23.737, "Study on architecture aspects for using satellite access in 5G", SI FS_5GSAT_ARCH, SA2; note: SI started in REL-16 but ended in REL-17

8.   TR 38.863, "Non-terrestrial networks (NTN) related RF and co-existence aspects", REL-17 WI NR_NTN_solutions, RAN4

9.   TS 38.101-5, "NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements", REL-17 WI NR_NTN_solutions, RAN4

10. TS 38.108, "NR; Satellite Access Node radio transmission and reception", REL-17 WI NR_NTN_solutions, RAN4

11. TS 38.181, "NR; Satellite Access Node conformance testing", REL-17 WI NR_NTN_solutions, RAN4

12. TS 38.521-5, "NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance", REL-17 WI NR_NTN_solutions_plus_CT-UEConTest, RAN5

13. TR 38.882 "Study on requirements and use cases for network verified UE location for Non-Terrestrial-Networks (NTN) in NR", REL-18 SI FS_NR_NTN_netw_verif_UE_loc, RAN

14. TR 37.911, "Study on self-evaluation towards the IMT-2020 submission of the 3GPP Satellite Radio Interface Technology", REL-18 SI FS_IMT2020_SAT_eval, SA1

15. TR 22.926, "Guidelines for extraterritorial 5G Systems (5GS)" REL-18 SI FS_5GET, SA1

16. **Generic specifications including Satellite/NTN aspects:**

17. TS 22.261, "Service requirements for the 5G system", stage 1 spec from SA1

18. TS 23.501, "System architecture for the 5G System (5GS)", stage 2 spec from SA2, esp. clauses 5.4.10 and 5.4.11

19. TS 38.300, "NR; NR and NG-RAN Overall description; Stage-2", RAN2, esp. clause 16.14

20. Note: Stage 3 aspects are distributed over several specifications (like any other 3GPP feature).

21. **Other references:**

22. "NTN & Satellite in Rel-17 & 18", by Munira Jaffar & Nicolas Chuberre, see also 3GPP Highlights newsletter no.3, page 24