COMPUTER & ELECTRONIC ENGINEERING

3GPP and NTN

Non-terrestrial networks (NTN)

- https://www.3gpp.org/technologies/ntn-overview (Joern Krause, 3GPP MCC)

- Non-terrestrial networks (NTN) are networks or segments of networks that use either Uncrewed Aircraft Systems (UAS) operating typically between 8 and 50km altitudes, including High Altitude Platforms (HAPs) or satellites in different constellations to carry a transmission equipment relay node or a base station:
  - LEO (Low Earth Orbit): Circular orbit in altitudes of typ. 500-2.000km (lower delay and better link budget but larger number of satellites needed for coverage)
  - MEO (Medium Earth Orbit): Circular orbit in altitudes of typ. 8.000-20.000km
  - GEO (Geostationary Earth Orbit): Circular orbit 35.786 km above the Earth's equator (Note: Due to gravitational forces a GEO satellite is still moving within a range of a few km around its nominal orbital position).
  - HEO (Highly Elliptical Orbiting): Elliptical orbit around the earth.

Architecture

- Two types of modes or "payload" can be distinguished:
  - Non-regenerative payload (also called "bentpipe payload" (considering the path from the gateway via spaceborne/airborne platform to the UE) or "transparent mode"): A spaceborne/airborne platform with no on-board processing capabilities that changes the frequency carrier of the received uplink RF signal, filters and amplifies it before transmitting it on the downlink, i.e. the platform corresponds to an analogue RF repeater;
  - Regenerative payload (or non-transparent mode): a spaceborne/airborne platform that has on top of RF filtering, frequency conversion and amplification also on-board processing capabilities (for demodulation/decoding, switching and/or routing, coding/modulation) so this spaceborne/airborne platform has base station functions on board.

Characteristics (I)

- Non-terrestrial networks (NTN) have a number of characteristics that require adaptations in comparison to terrestrial networks (TN) (see TR 38.811) including:
  - Motion of the space/aerial vehicles: Only for GEO the satellite stays rather stable over the earth like in terrestrial networks. For LEO and MEO the satellites are moving with high velocity which leads to moving cell patterns, higher Doppler shifts/variations, faster propagation delay variations requiring enhanced beam management (based on information about the predictable movement of the satellite (ephemeris) and the location/movement of the UE, the satellite network could know which beam and satellite covers the UE best).

Characteristics (II)

- As the moving cells may also cross country borders or cover areas with no territorial claims also regulatory aspects need to be taken into account (see TR 22.926).
  - Altitude (delay): Satellites operate in much higher altitudes than base stations of TNs which lead to longer latency (which needs to be taken into account in e.g. RACH, timing advance, HARQ, power control, MAC/RLC) due to larger propagation delays (TN: usually <1ms; GEO: up to a few 100ms) and it also impacts the link budget esp. in UL where the transmit power of the UE is limited.
  - Cell sizes: NTN networks have larger cell sizes than TNs which could lead to higher variations of the propagation delays, stronger near far effects.
  - Troposheric impacts: relevant above 6 GHz; like absorption, esp. relevant for higher frequencies (>10GHz) and low elevations (troposphere is the lower part of the atmosphere; below ~12km).
  - Ionospheric impacts: relevant below 6GHz, reflection and absorption effects (also latitude dependency); (ionosphere is the upper part of the atmosphere; above ~80km; in which solar radiation creates layers of plasma due to ionisation).

Architecture examples (1)

- Figures 4 and 5 show corresponding examples of Non-Terrestrial Network (NTN) architectures with a VSAT (Very Small Aperture Terminal) or a handheld/IoT device on the earth that communicates via a service link (also called user link) with a platform in the air or in space. This platform may communicate directly with a gateway on earth or at first via IAL (Inter Aerial Link) or ISL (Inter Satellite Link) via other platforms in the air or in space.

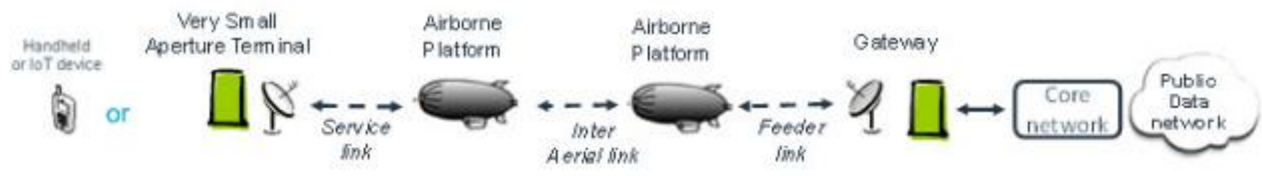


Figure 4: Aerial access network (with IAL) with a service link operating in frequency bands above 6 GHz [source: TR 38.811]

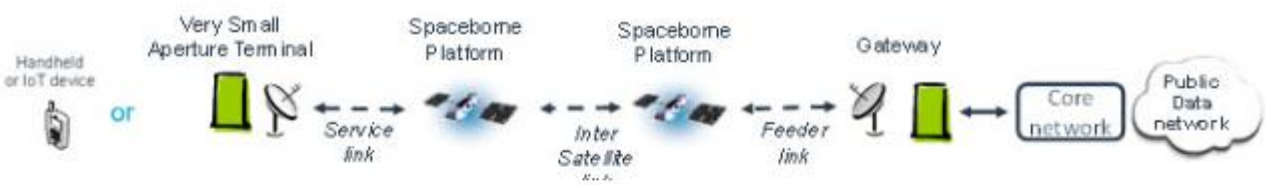


Figure 5: Satellite access network (with ISL) with a service link operating in frequency bands above 6 GHz [source: TR 38.811]

Architecture examples (2)

- Instead of serving UEs directly via airborne/spaceborne platforms it is also possible that the Service link is arranged between an airborne/spaceborne platform and a relay node (using a VSAT) on the earth where the relay node then serves UEs. So the NTN Terminal would then be this relay node.

- If the airborne platform has the base station (gNB) on board (regenerative payload), then the NTN Gateway at the end of the feeder link can be a router to the Core network which connects to the public network.

- In case of transparent/bent pipe payload the NTN Gateway at the end of the feeder link would be the base station (gNB) since the airborne platform operates just like a remote radio head relaying the signals.

- The usage of inter-satellite links (ILS) requires regenerative payload.

Antenna beams

- In case of Non-Geostationary Satellite Orbit (NGSO), i.e. LEO or MEO, the spaceborne platform will move around the earth faster than the earth rotation which means that at some point in time the feeder link will need to change to another gateway and also that for service continuity the NTN terminal will need to be served by a different spaceborne platform.

- Regarding the beams from the satellite you can distinguish beams that move with the satellite (also called "moving beams") from steerable beams (i.e. by using e.g. beamforming techniques the satellite has the capability to steer a beams towards fixed points on earth (also called "earth fixed beam") for the time of the visibility of the satellite).

- The feeder link between the NTN gateway and the satellite is also called Satellite Radio Interface (SRI).

NR NTN satellite bands defined in 3GPP (TS 38.101-5)

Table 1: NR NTN satellite bands defined in 3GPP (see TS 38.101-5)

REL	WI	NR 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 $F_{DL,low}$ – $F_{DL,high}$	Remarks
REL-17	NR_NTN_solutions	n256	1980 – 2010 MHz	2170 – 2200 MHz	FR1, FDD, S-band
REL-17	NR_NTN_solutions	n255	1626.5 – 1660.5MHz	1525 – 1559 MHz	FR1, FDD L-band
REL-18	NR_NTN_LSband	n254	1610 – 1626.5MHz	2483.5 – 2500MHz	FR1, FDD, LS-band
REL-18	NR_NTN_enh	n512*, n511*, n510*	27.5 – 30.0GHz 28.35 – 30.0GHz 27.5 – 28.35GHz	17.3 -20.2GHz 17.3 -20.2GHz 17.3 -20.2GHz	FR2, FDD, Ka-band

Table 2: LTE NTN bands (driven by IOT/MTC support):

REL	WI	LTE 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 $F_{DL,low}$ – $F_{DL,high}$	Remarks
REL-18	LTE_NBIOT_eMTC_NTN_req	256	1980 -2010 MHz	2170 -2200 MHz	FDD, S-band
REL-18	LTE_NBIOT_eMTC_NTN_req	255	1626.5 – 1660.5MHz	1525 – 1559 MHz	FDD, L-band
REL-18	IoT_NTN_FDD_LS_band	254	1610 – 1626.5MHz	2483.5 – 2500MHz	FDD, LS-band
REL-18	IoT_NTN_extLband	253	1610 – 1626.5MHz	1518 - 1525MHz	FDD, extL-band

A brief historical perspective

- Pre-Release 15
- in 3GPP 4G standards the satellite aspects were limited to the support of location services via satellite (GPS, Galileo, GLONASS, BeiDou, NavIC ...).
- In 3GPP Release 14 studies of use cases and requirements for 5G considered the extension of terrestrial networks via satellite and non-terrestrial networks.The main driving factors for considering non-terrestrial access were to:
  - Allow for the provision of services for those areas where the terrestrial service is not available and also for those services that can be more efficiently supported via satellite, like multicasting/broadcasting of similar content over a large area ("service scalability").
  - Provide better coverage in less densely populated/rural areas, on the sea, in high altitudes/airborne vehicles, in disaster zones where terrestrial networks could not operate reliably ("service ubiquity").
  - Reduce vulnerability/higher resiliency of non-terrestrial networks.
  - Reduce costs through a common radio interface for terrestrial and non-terrestrial networks via economies of scale and to provide service continuity.

Release 15 (first 5G standardization)

- Although stage 1 TS 22.261 of Release 15 added a 5G requirement regarding multiple access technologies: "The 5G system shall be able to support mobility between the supported access networks (e.g. NG-RAN, WLAN, fixed broadband access network, 5G satellite access network).", time constraints meant that it was not yet possible to standardize satellite support in REL-15.

- Nevertheless, a Release 15 Technical Specification Group (TSG) RAN led study item (SI) "Study on NR to support non-terrestrial networks" (FS_NR_nonterr_nw) with TR 38.811 was working on:
  - Summarizing the use cases.
  - Adapting the 3GPP channel model (developed in REL-14 TR 38.901 under the 5G REL-14 SI FS_NR_newRAT) for non-terrestrial networks.
  - A detailed description of the deployment scenarios for non-terrestrial networks and corresponding analysis of necessary adaptations to support operation via Satellite or HAPS in NR.

enhanced Mobile Broadband (eMBB):

- 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 (although potentially limited in capability compared to the primary network connection).
- 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.

massive Machine Type Connection (mMTC)

- Global connectivity between IoT devices (sensors/actuators) and NTN network
- Connectivity to a base station serving IoT devices of a local area network

Deployment scenarios

- GEO and Ka-band (higher GHz range) with VSAT relay as NTN node and transparent payload
- GEO and S-band (lower GHz range) with handheld UEs as NTN node and transparent payload
- LEO and S-band (lower GHz range) with handheld UEs as NTN node & regenerative payload
- LEO and Ka-band (higher GHz range) with VSAT relay as NTN node & regenerative payload
- HAPS in S- or Ka-band with handheld UEs as NTN node & regenerative payload

Release 16

Stage 1 requirements

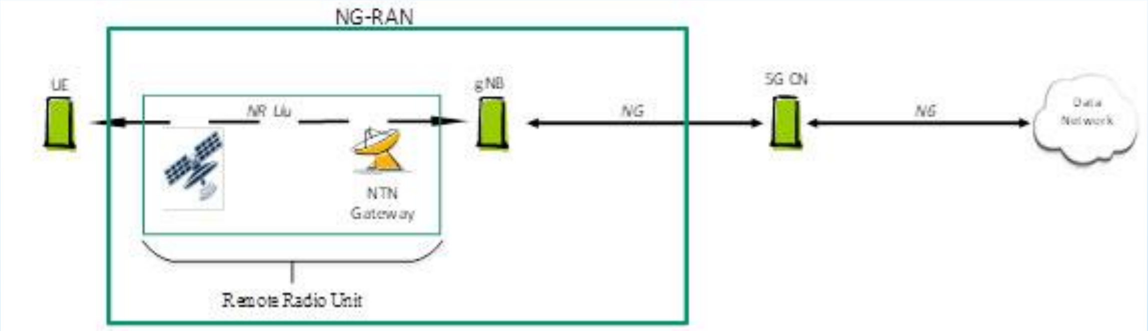
- Roaming between terrestrial and satellite networks
- Broadcast and multicast with a satellite overlay
- Internet of Things with a satellite network
- Temporary use of a satellite component
- Optimal routing or steering over a satellite
- Satellite transborder service continuity
- Global satellite overlay
- 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 remote service centre to off-shore wind farm

Study Item (SI) FS_NR_nonterr_nw

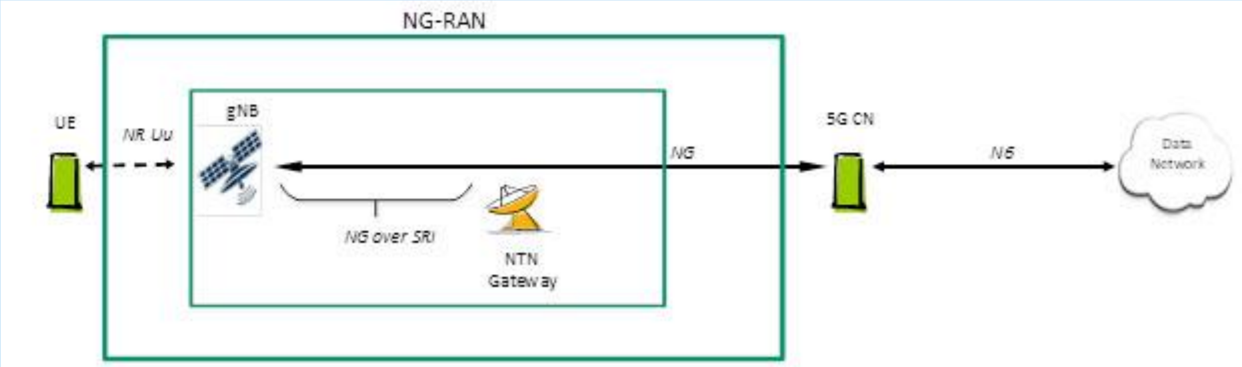
- Impacts on RAN protocols/architecture.
- More precisely:
  - Satellite access (with transparent GEO satellite and LEO based non-terrestrial access network (moving beam on earth), i.e. UAS/HAPS based access was considered here as a special case of NTN with lower Doppler and variation rate
  - Usage 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.

Cases (I)

- Transparent satellite based NG-RAN architecture (gNB on earth) [source: TR 38.821]

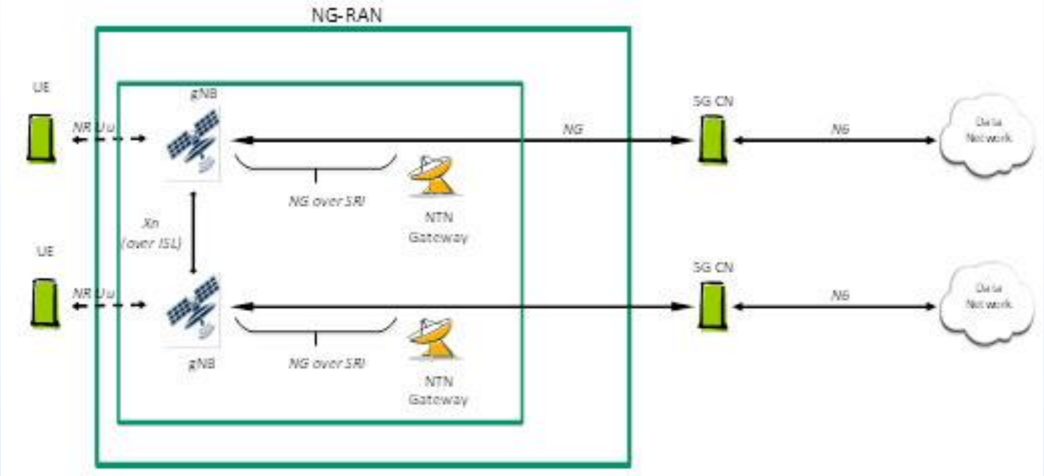


- Regenerative satellite based NG-RAN architecture without ISL (gNB on satellite) [source: TR 38.821]

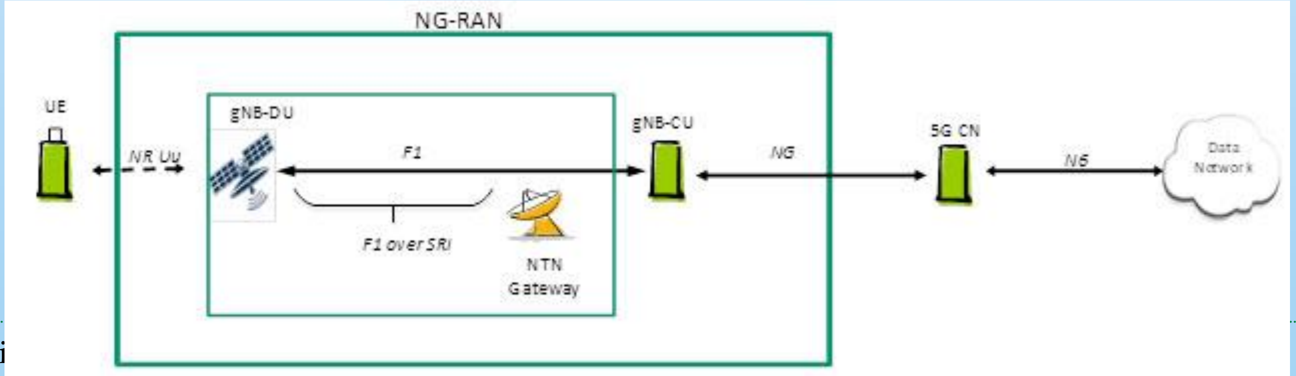


Cases (II)

- Regenerative satellite based NG-RAN architecture without ISL (gNBs on satellites) [source: TR 38.821]



- Regenerative satellite based NG-RAN architecture without ISL (gNB-Distributed Unit on satellite and gNB-Central Unit on earth).



WG RAN1 (Physical Layer)

- Timing relationship enhancements.
- Enhancements on UL time and frequency synchronization.
- Enhancement on the PRACH sequence and/or format in the case pre-compensation of timing and frequency offset is not done at UE side.
- Beam management and BWP operation for NTN with frequency reuse including signaling of polarization mode.
- Feeder link switch impact on physical layer procedures in case of LEO scenarios
- Number of HARQ processes, support of enabling / disabling of HARQ feedback.

WG RAN2 (Higher Layers)

- MAC enhancements (for random access, timing advance, DRX, Scheduling Request, HARQ)
- RLC enhancements (for status reporting, sequence numbers)
- PDCP enhancements (SDU discard, sequence numbers)
- 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.
- 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.
- Other mobility enhancements: additional Conditional Hand-Over (CHO) triggering conditions, enhancements to mobility configuration , measurement configuration/reporting, service continuity TN to NTN and NTN to TN.
- RACH procedure: inclusion of assistance information with trade-off between latency gain and UL overhead.

3GPP working groups

TSG RAN Radio Access Network	TSG SA Service & System Aspects	TSG CT Core Network & Terminals
RAN WG1 Radio Layer 1 (Physical layer)	**SA WG1** Services	**CT WG1** User Equipment to Core Network protocols
RAN WG2 Radio layer 2 and Radio layer 3 Radio Resource Control	**SA WG2** System Architecture and Services	**CT WG3** Interworking with External Networks & Policy and Charging Control
RAN WG3 UTRAN/E-UTRAN/NG-RAN architecture and related network interfaces	**SA WG3** Security and Privacy	**CT WG4** Core Network Protocols
RAN WG4 Radio Performance and Protocol Aspects	**SA WG4** Multimedia Codecs, Systems and Services	**CT WG6** Smart Card Application Aspects
RAN WG5 Mobile terminal conformance testing	**SA WG5** Management, Orchestration and Charging	
RAN AH1 ITU-R Ad Hoc	**SA WG6** Application Enablement and Critical Communication Applications	

Release 17 (June 22) (Introduction 1)

- The first release with normative requirements for NTN in 3GPP specifications
- The " Integration of satellite components in the 5G architecture” work item adds or enhances a number of features in 5GCore architecture in order to support Non-Terrestrial Networks (NTN), for several use cases:
  - Coverage extension: Many commercial activities, such as agriculture, mining, forestry take place outside inhabited areas. Coverage extension with satellite networks is useful to enable e.g. voice communication, video monitoring, and remote control in uncovered or under-covered areas.
  - Internet of Things: many Internet-of-Things applications relate to monitoring of assets (e.g. ships, trains, trucks), infrastructure (e.g. bridges, pipelines, railway track), or the environment (e.g. agriculture sensors). In many IoT applications, only small amounts of data are exchanged and communication is optimized for low power usage. Satellite communication should also be able to address these requirements.
  - Disaster communication: Public safety authorities have a responsibility to provide assistance in case of natural disasters. This requires communication, also in cases where because of that disaster the cellular infrastructure is damaged. Satellite communication can be used as fall back for these cases. Ideally the user equipment (UE) and way of working when cellular networks are available should also be usable with satellite access.

Release 17 (Introduction 2)

- Global roaming: Applications like tracking and tracing of containers need to be available globally across satellite and terrestrial networks. When a container is in a harbour or transported on a truck, using a terrestrial cellular network is probably most efficient. However, when the container is on a ship in the middle of an ocean, only satellite communication is possible.
- Broadcasting: Satellite communication is particularly suitable to broadcast the same information over a very wide area. This can also be used in context of 5G mobile edge applications (e.g. mobile gaming), where application content needs to be available in many different edge locations.

Release 17 (WG SA1-I)

- WG SA1-TS 22.261 (see also SP-200569 CR0428rev4) (System level)
  - The 5G system shall support service continuity between 5G terrestrial access network and 5G satellite access networks owned by the same operator or owned by different operators having an agreement (clause 6.2.3).
  - A 5G system with satellite access shall enable roaming of UE supporting both satellite access and terrestrial access between 5G satellite networks and 5G terrestrial networks (clause 6.2.4).
  - UEs supporting satellite access shall support optimized network selection and reselection to PLMNs with satellite access, based on home operator policy (clause 6.2.4).
  - The 5G system shall be able to support mobility between the supported access networks (e.g. NG-RAN, WLAN, fixed broadband access network, 5G satellite access network) (clause 6.3.2.1).
  - The 5G system shall be able to provide services using satellite access (clause 6.3.2.3).

Release 17 (June 22) (WG SA1-II)

- A 5G system with satellite access shall support different configurations where the radio access network is either a satellite NG-RAN or a non-3GPP satellite access network, or both (clause 6.3.2.3).
- A UE supporting satellite access shall be able to provide or assist in providing its location to the 5G network (clause 6.3.2.3).
- A 5G system with satellite access shall be able to determine a UE's location in order to provide service (e.g. route traffic, support emergency calls) in accordance with the governing national or regional regulatory requirements applicable to that UE (clause 6.3.2.3).
- The 5G system with satellite access shall be able to support low power MIoT type of communications (clause 6.3.2.3).
- The 5G system with satellite access shall support the use of satellite links between the radio access network and core network, by enhancing the 3GPP system to handle the latencies introduced by satellite backhaul (clause 6.4.2.1).
- A 5G system with satellite access shall be able to support meshed connectivity between satellites interconnected with intersatellite links (clause 6.4.2.1).
- A 5G system with satellite access shall be able to select the communication link providing the UE with the connectivity that most closely fulfils the agreed QoS (clause 6.5.2).

Release 17 (June 22) (WG SA1-III)

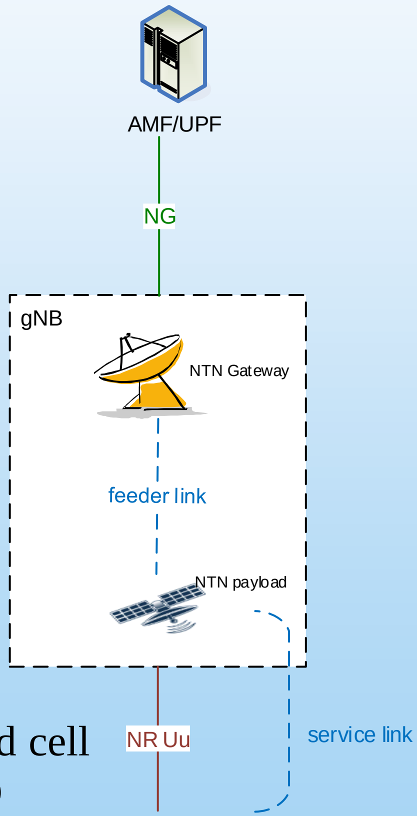
- A 5G system with satellite access shall be capable of supporting simultaneous use of 5G satellite access network and 5G terrestrial access networks (clause 6.5.2).
- A 5G system with satellite access shall be able to support both UEs supporting only satellite access and UEs supporting simultaneous connectivity to 5G satellite access network and 5G terrestrial access network (clause 6.5.2).
- A 5G system with satellite access shall be able to optimise the delivery of content from a content caching application by taking advantage of satellites in supporting ubiquitous service, as well as broadcasting/multicasting on very large to global coverages (clause 6.6.2).
- A 5G system with satellite access shall be able to support relay UE's with satellite access (clause 6.9.2.5).
- A 5G system with satellite access shall support mobility management of relay UEs and the remote UEs connected to the relay UE between a 5G satellite access network and a 5G terrestrial network, and between 5G satellite access networks (clause 6.9.2.5).
- A 5G system with satellite access shall support joint roaming between different 5G networks of a relay UE and the remote UEs connected to that relay UE (clause 6.9.2.5).

Release 17 (June 22) (WG SA1-IV)

– The 5G system shall support multicast/broadcast via a 5G satellite access network, or via a combination of a 5G satellite access network and other 5G access networks (clause 6.13.2).
– A 5G satellite access network shall support NG-RAN sharing (clause 6.21.2).
– The 5G system shall support mechanisms to determine the UE’s position-related data for period when the UE is outside the coverage of 3GPP RAT-dependent positioning technologies but within the 5G positioning service area (e.g. within the coverage of satellite access) (clause 6.27.2).
– A 5G satellite access network connected to 5G core networks in multiple countries shall be able to meet the corresponding regulatory requirements from these countries (e.g. Lawful Interception) (clause 8.6).
– The 5G core network shall support collection of charging information based on the access type (e.g. 3GPP, non-3GPP, satellite access) (clause 9.1).
– In a 5G system with satellite access, charging call records associated with satellite access(es) shall include the location of the associated UE(s) with satellite access (clause 9.1).

Overall architecture and general aspects

- As illustrated in the figure, non-terrestrial access is provided by means of an NTN payload, i.e. a network node on-board a satellite or HAPS, and an NTN Gateway interconnected by a feeder link, the UE accessing NTN network services through the NTN payload via a service link.
- The NTN payload transparently forwards the radio protocol received from the UE (via the service link) to the NTN Gateway (via the feeder link) and vice-versa. A gNB may serve multiple NTN payloads while an NTN payload may be served by multiple gNBs.
- Three types of service links are supported:
  - Earth-fixed: provisioned by beam(s) continuously covering the same geographical areas all the time (e.g., the case of GSO satellites);
  - Quasi-Earth-fixed: provisioned by beam(s) covering one geographic area for a limited period and a different geographic area during another period (e.g., the case of NGSO satellites generating steerable beams);
  - Earth-moving: provisioned by beam(s) whose coverage area slides over the Earth surface (e.g., the case of NGSO satellites generating fixed or non-steerable beams).



- With NGSO satellites, the NTN gNB can provide either quasi-Earth-fixed cell coverage or Earth-moving cell coverage, while gNB operating with GSO satellite can provide Earth fixed cell coverage.

WG SA2

- Study on architecture aspects for using satellite access in 5G.
- Addressed problems
  - Mobility management with large satellite coverage areas
  - Mobility Management with moving satellite coverage areas
  - Delay in satellite
  - QoS with satellite access
  - QoS with satellite backhaul
  - RAN mobility with NGSO regenerative-based satellite access
  - Regulatory services with super-national satellite ground station
- Normative solutions
  - 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 framework for the 5G System (5GS)

WG SA5

- Study on management and orchestration aspects with integrated satellite components in a 5G network" (FS_5GSAT_MO) which resulted in TR 28.808
- Issues
  - Reference management architectures for integrated satellite components
  - Use cases, potential requirements and solutions
    - related to network slice management
    - for the management of satellite components
    - for monitoring of satellite components
- Normative work
  - Specify/extend SON (Self Organizing Network) concepts to allow for moving non-terrestrial gNBs
  - Adapt the performance measurements which make use of the HARQ process, which may be unavailable when using satellite RAN
  - Extend the 5G Network Resource Model (NRM) to support satellite components, for example by adding ServiceProfile attributes
  - Specify the approach to use load balancing between terrestrial RAN and non-terrestrial RAN to guarantee service continuity and reliability

TSG RAN

- Assumptions:
  - Only transparent payload
  - Operating band using FDD in frequency range FR1 (i.e. 410MHz - 7125MHz); resulting in 2 new bands n255 (L-band) and n256 (S-band) in TS 38.101-5/TS 38.108
  - Handheld devices with power class 3 are supported
  - UEs with GNSS capabilities are assumed
  - Earth-fixed tracking areas with earth fixed or moving cells (see TR 38.821 clause 7.3.1.3; TS23.501 clause 5.4.11.7)
- For HAPS operation it was concluded:
  - NR operating band n1 (FDD: UL: 1920 - 1980MHz, DL 2110 - 2170MHz) can be applied
  - Wide Area BS class is applicable as in TS 38.104 without additional changes
  - NR UEs as defined by TS 38.101-1 can support HAPS deployments with no additional chsnges.

Timing, Synchronization and HARQ enhancements (WG RAN1) (I)

- The network broadcasts ephemeris information and common Timing Advance (common TA) parameters in each NTN cell. Since NTN capable UEs are expected to be all GNSS-capable, they shall acquire a valid GNSS position as well as the satellite ephemeris and common TA before connecting to an NTN cell.

- To achieve uplink synchronisation, before performing random access, the UE shall autonomously pre-compensate the Timing Advance, as well as the frequency Doppler shift by considering the common TA (information from the gNB), the UE position, the satellite position and satellite velocity through the satellite ephemeris. In connected mode, the UE shall continuously update the Timing Advance and frequency pre-compensation. If the UE does not have a valid GNSS position and/or valid satellite ephemeris, it does not communicate with the network until both are regained. The UEs may be configured to report Timing Advance at initial access or in connected mode. In connected mode triggered reporting of the Timing Advance is supported.

Timing, Synchronization and HARQ enhancements (WG RAN1) (II)

- While the pre-compensation of the instantaneous Doppler shift experienced on the service link is to be performed by the UE for the uplink, the management of Doppler shift experienced over the feeder link is left to the network implementation.
- To accommodate the propagation delay in NTNs, several timing relationships are enhanced by a Common Timing Advance (Common TA) and two scheduling offsets Koffset and kmac. Common TA is a configured offset that corresponds to the Round Trip Time (RTT) between the Reference Point (RP) and the NTN payload. Koffset is a configured scheduling offset that approximately corresponds to the sum of the service link RTT and the common TA. kmac is a configured offset that approximately corresponds to the RTT between the Reference Point (RP) and the gNB.
- To mitigate the impact of HARQ stalling in NTN, the HARQ feedback can be disabled in the presence of ARQ re-transmissions at the RLC layer (e.g., in GSO satellite systems) and/or the number of HARQ processes for re-transmissions at the MAC layer can be increased to 32 (e.g., in NGSO satellite systems).

Mobility Management (WG RAN2) (I)

- To enable mobility in NTN, the network provides serving cell's and neighbouring cell's satellite ephemeris needed to access the target serving NTN cell in the handover command.
- UE supports mobility between NTN and Terrestrial Network (i.e. from NTN to Terrestrial Network (hand-in) and from Terrestrial Network to NTN (hand-out)), but is not required to connect to both NTN and Terrestrial Network at the same time. It may also support mobility between radio access technologies based on different orbit (GSO, NGSO at different altitude).
- Triggering conditions upon which a UE may execute Conditional Hand-Over (CHO) to a candidate cell, have been introduced: event A4, time-based trigger condition, location-based trigger condition. The two last conditions are configured together with one of the measurement-based trigger conditions. Location is defined by the distance between UE and a reference location. Time is defined by the time between T1 and T2, where T1 is an absolute time value and T2 is a duration started at T1.

Mobility Management (WG RAN2) (II)

- For the measurements the network can configure multiple SS/PBCH Block Measurement Timing Configuration (SMTCs) in parallel per carrier and for a given set of cells depending on UE capabilities using propagation delay difference and ephemeris information. It can also configure measurement gaps based on multiple SMTC.
- The adjustment of SMTCs is possible: Under network control based on UE assistance information if available for connected mode and under UE control based on UE location and satellite assistance information (e.g., ephemeris, common TA parameters) for idle/inactive modes.
- In the quasi-earth fixed cell scenario, UE can perform time-based and location-based measurement in RRC_IDLE/RRC_INACTIVE. The timing and location information associated to a cell are provided via system information. They refer respectively to the time when the serving cell is going to stop serving a geographical area and to the reference location of serving cell.

Mobility Management (WG RAN2) (III)

- A Tracking Area corresponds to a fixed geographical area. Any respective mapping is configured in the RAN. The network may broadcast multiple Tracking Area Codes (TAC) per PLMN in a NR NTN cell in order to reduce the signalling load at cell edge, in particular for Earth-moving cell coverage. A TAC change in the System Information is under network control and may not be exactly synchronised with real-time illumination of beams on ground.
- Regarding the UE location aspects, upon network request, after AS security is established in connected mode, a UE should report its coarse UE location information (most significant bits of the GNSS coordinates, ensuring an accuracy in the order of 2 km) to the NG-RAN if available.

NG-RAN signalling (WG RAN3) Access Network Architecture

- The Cell Identity, indicated by the gNB to the Core Network as part of the User Location Information corresponds to a Mapped Cell ID, irrespective of the orbit of the NTN payload or the types of service links supported. It is used for Paging Optimization in NG interface, Area of Interest and Public Warning Services.
- The Cell Identity included within the target identification of the handover messages allows identifying the correct target radio cell as well as for RAN paging.
- The mapping between Mapped Cell IDs and geographical areas is configured in the RAN and Core Network. The gNB is responsible for constructing the Mapped Cell ID based on the UE location info received from the UE, if available. The mapping may be pre-configured (e.g., up to operator's policy) or up to implementation.
- The gNB reports the broadcasted TAC(s) of the selected Public Land Mobile Network (PLMN) to the Access and Mobility Management Function (AMF) as part of UE Location Information (ULI). In case the gNB knows the UE's location information, the gNB may determine the Tracking Area Indicator (TAI) the UE is currently located in and provide that TAI to the AMF as part of ULI.

Switch-over (RAN3)

- A service link switch refers to a change of serving satellite.
- A feeder link switch over is the procedure where the feeder link is changed from a source NTN Gateway to a target NTN Gateway for a specific NTN payload. The feeder link switch over is a Transport Network Layer procedure. Both hard and soft feeder link switch over are applicable to NTN.
- Service and feeder link switch overs apply mostly for the case of NGSO

NG-RAN signalling (RAN3)

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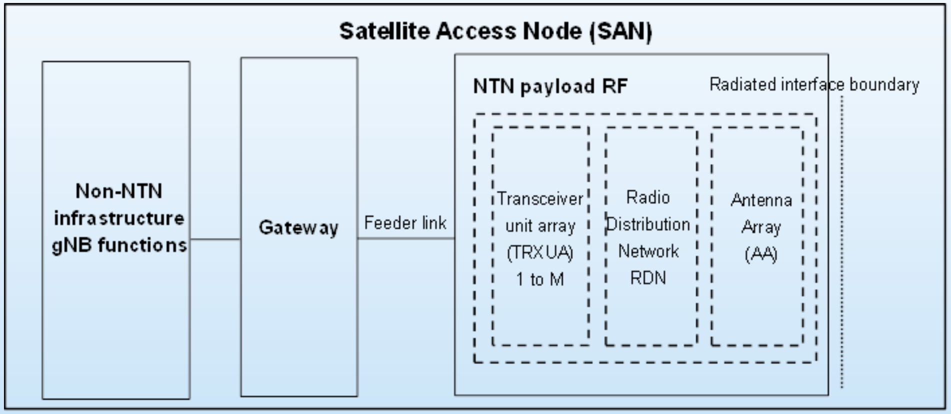
RF performances and RRM requirements (RAN4)

- The figure illustrates the satellite access node which encompass on ground non-NTN infrastructure gNB functions, gateway and feeder link and the RF functions of the NTN payload.



- The considered operating bands in frequency range FR1 are defined in the table.

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
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD

NB-IoT/eMTC support for Non-Terrestrial Networks

- The "NB-IoT/eMTC support for Non-Terrestrial Networks (NTN)" work item specifies enhanced features necessary for the support of Bandwidth reduced Low complexity (BL) UEs, UEs in enhanced coverage and NB-IoT UEs by Non-Terrestrial Networks (NTN).
- SA and CT aspects of NB-IoT/eMTC Non-Terrestrial Networks in EPS provide minimum essential functionality for the Rel-17 UE and the network to support satellite E-UTRAN access in WB-S1 mode or NB-S1 mode with CIoT EPS optimization. The functionality is largely aligned with that of Rel-17 NR Non-Terrestrial Networks in 5GS, with the exception of discontinuous coverage that is addressed only within the present work item in Rel-17

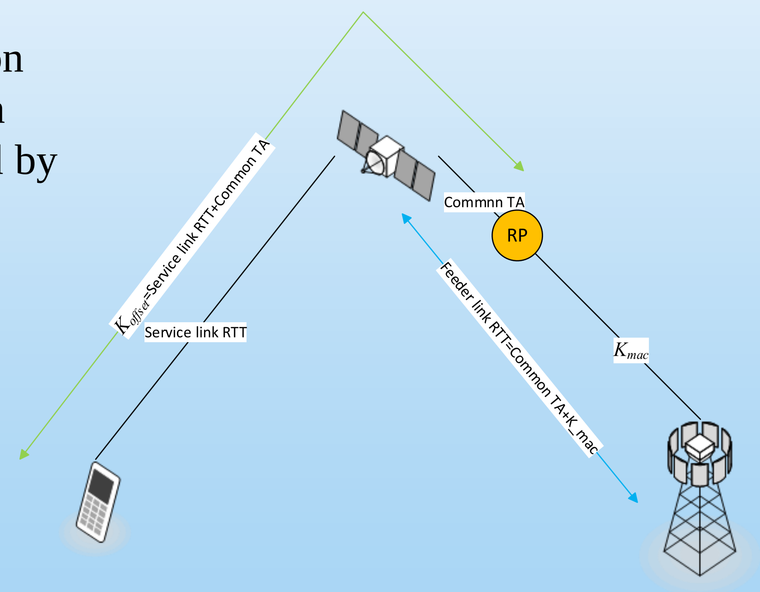
Timing and Synchronization

- The network broadcasts ephemeris information and common Timing Advance (common TA) parameters in each NTN cell. A UE shall acquire its GNSS position as well as the satellite ephemeris and common TA before connecting to an NTN cell. To achieve uplink synchronisation, before performing random access, the UE shall autonomously pre-compensate the Timing Advance, as well as the frequency doppler shift by considering the common TA, the UE position and the satellite position through the satellite ephemeris. In connected mode, the UE shall continuously update the Timing Advance and frequency pre-compensation, but the UE is not expected to perform GNSS acquisition. The UE does not perform any transmissions due to outdated satellite ephemeris, common TA or GNSS position based on timers. In connected mode, upon outdated satellite ephemeris and common Timing Advance, the UE re-acquires the broadcasted parameters and upon outdated GNSS position the UE moves to idle mode. The UEs may be configured to report Timing Advance at initial access or in connected mode. In connected mode triggered reporting of the Timing Advance is supported.
- For downlink synchronization in case of NB-IoT, the two LSB of the ARFCN (absolute radio-frequency channel number) is signalled in MIB for bands for which a 200 kHz channel raster is not supported, and the legacy 100 kHz raster is used. Otherwise, for bands for which a 200 kHz channel raster is supported, there is no signalling of ARFCN information in MIB.

Timing and Synchronization

- Downlink and uplink timings are frame aligned at the uplink time synchronization reference point (RP). To accommodate the long propagation delays in NTN, the timing relationships are enhanced by the support of two scheduling offsets.

- Uplink segmented transmission is supported for uplink transmission with repetitions. The UE shall apply UE pre-compensation per segment of UL transmission of PUSCH/PUCCH/PRACH for BL UEs and UEs in enhanced coverage and NPUSCH/NPRACH for NB-IoT from one segment to the next segment. The configuration of uplink transmission segment is indicated on SIB for initial access and can be re-configured by RRC signalling..



Discontinuous coverage and assistance information

- As a satellite moves on a specified orbit, for example in case of a NGSO satellite, the satellite beam(s) coverage area may move and cover different portions of a geographical area due to the orbital movement of the satellite. As a consequence, a UE located in the concerned geographical area may experience a situation of discontinuous coverage, due to e.g., a sparse satellite constellation deployment.
- The network may broadcast assistance information relating to the serving satellite and other satellites of the constellation to enable UEs to predict upcoming satellites fly-over periods and save power during periods of no coverage. The broadcast assistance information includes SGP4 ephemeris elements based on the TLE (Two-Line Elements) sets industry standard. Additional assistance information, such as coverage footprint parameters and cell radius, may also be optionally broadcast by the network.
- Predicting out of coverage and in coverage periods is up to UE implementation. When out of coverage, the UE is not required to perform Access Stratum (AS) functions.
- In the Core Network, discontinuous coverage is handled by means of Tracking Area- or RAT-specific configuration of the MME such that the MME is able, via existing functionality (namely periodic TAU timer, mobile reachable timer, implicit detach timer and high latency communication), to ensure that when the UE is unreachable, a) the UE does not trigger NAS transaction or detach from the network and b) mobile-terminated data destined to the UE can be stored in the network.

Release 17/18

- Reference scenarios (Vanelli Coralli)

	Release 17		Release 18
	Direct connectivity (<7 GHz)		**Indirect connectivity(above 10 GHz)**
Targeted terminals	**IoT devices**	**handset (smart-phones) and car/drone mounted devices**	**VSAT and/or ESIM**
Service	**Narrowband** **hundreds of kbps**	**Wideband** **few Mbps**	**Broadband** **hundred Mbps**
3GPP Radio interfaces	**4G NB-IoT/eMTC**	**5G New Radio**	**5G New Radio**
Example of applications	*Professional: utilities (smart grids, water distribution, oil & gas), agriculture*	*Consumer market Professional markets: Automotive, public safety, utilities, agriculture, Defense*	*Professional markets: Telco (e.g. Backhaul), IPTV service providers, Satellite News Gathering, Transport (aeronautical, maritime, railway), public safety, defense*

Release 18

- WG RAN4
  - Release 18 WI "30 MHz Channel Bandwidth for NR NTN (non-terrestrial networks) in FR1 (frequency range 1)" (NR_NTN_CBW_30MHz-Core) was adding the channel bandwidth of 30MHz to the already supported channel bandwidths of 5MHz, 10MHz, 15MHz and 20MHz for the operating bands n255 (L-band) and n256 (S-band) for the Satellite Access Node (SAN) and the UE and added corresponding requirements.
- WG SA2
  - The Release 18 "Study on 5GC enhancement for satellite access Phase 2" (FS_5GSAT_Ph2) was looking at mobility management and power savings in case of discontinuous coverage (i.e. a UE may have access to satellite service coverage only at specific time and places) and resulted in TR 23.700-28. Dynamic support of discontinuous coverage is required for initial NGSO constellation deployment but as well to support evolution of the constellations such as loss of satellites, different releases supported in a given constellation. So this SI looked into mobility management, paging enhancements, UE power savings, procedures to determine and coordinate the UE unreachability period.

Release 18

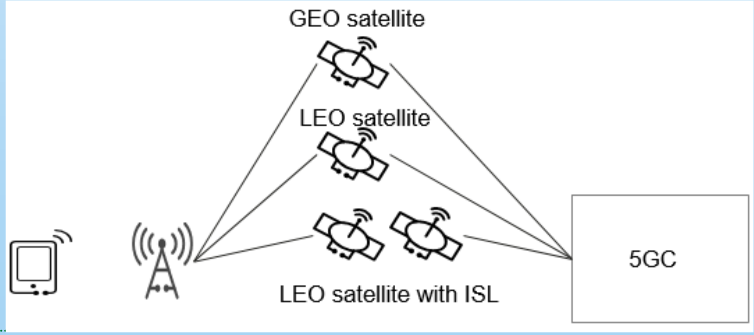
- WG SA3
  - Release 18 SI "Study on Security Aspects of Satellite Access" (FS_5GSAT_Sec) was looking at security/privacy issues for mobility management and power savings in case of discontinuous coverage and identified only one issue in TR 33.700-28: satellite coverage availability information could be received by 5GC/EPC from different potential sources, e.g. the OAM, the AF/external server (e.g. Coverage Map Server). While the sources like the OAM could be trusted, the sources like the AF/external server may not always be trusted. It concluded that satellite coverage information is provisioned to the AMF by O&M only. Hence no normative work is needed on AF authorization.
- WG RAN4
  - Release 18 WI "Introduction of the satellite L-/S-band for NR" (NR_NTN_LSband) was specifying a new FDD NTN band (called band n254) on top of the bands n255 (L-band) and n256 (S-band) that were introduced in Release 17 WI NR_NTN_solutions: For band n254 the UE is transmitting at 1610-1626.5MHz (UL, L-band) and the Satellite Access Node (SAN) is transmitting at 2483.5-2500MHz (DL, S-band).

Release 18

- The WG RAN2 led Release 18 WI "NR NTN (Non-Terrestrial Networks) enhancements" (NR_NTN_enh) had the goal to enhance NTN related features introduced in earlier releases (esp. REL-17):
  - Coverage enhancement: To improve NR uplink coverage in NTN: PUCCH repetition for Msg4 HARQ-ACK; PUSCH DMRS bundling enhancement so that UE can maintain phase continuity in case of timing drift.
  - Network verified UE location (compare REL-18 SI FS_NR_NTN_netw_verif_UE_loc): some UE and gNB Rx/Tx time measurements are defined in order to allow verification of the UE location
  - NTN-TN and NTN-NTN mobility and service continuity enhancements: e.g. SIB19 in TN to include NTN-specific parameters for NTN neighbour cells; to improve NTN-TN mobility the SAN may broadcast in a system information block a list of geographical TN areas with associated frequency information; improved trigger conditions (time-based/location based) for conditional handover; satellite switch with re-sync
  - NR-NTN deployment in above 10 GHz bands: e.g. new bands n510, n511, n512 in 20-30GHz range (Ka-band) will be introduced; Rx/Tx requirements for selected VSAT UE class/types and SAN for the Ka band; RRM for electronically-steered beam UEs (type 1) and mechanically-steered beam UEs (type 2).

Release 18

- The WG SA2 Release 18 SI "Study on Support of Satellite Backhauling in 5GS" (FS_5GSATB) is looking at satellite based backhaul which is important for remote area or mission critical scenarios, in case it is not possible to build terrestrial backhaul connections. It discussed solutions for 3 key issues and captured the results in TR 23.700-27:
  - Dynamic satellite backhaul i.e. problems in case of multi-hops of ISL or backhaul connections are over different satellites and terrestrial networks like packet delivery latency, bandwidth of the backhaul, packets out-of-sequence.
  - Satellite Edge Computing via UPF (User Planar Function) on board of the satellite to reduce latency and minimize the backhaul resources consumption.
  - Local Data Switching via UPF on-board of the satellite to reduce end to end delay for UEs in a communication.



IoT NTN enhancements (1)

- Rel-18's "IoT_NTN_enh" further enhances the IoT_NTN, with functionalities in three major areas: (1) Performance (HARQ and GNSS enhancements), (2) Measurement & mobility enhancements in idle as well as connected mode, and (3) Enhancements in discontinuous coverage. It also complements the work done by SA2 study on 5GC enhancements for satellite access Phase 2.
- The following functionality is introduced to improve performance:
  - HARQ feedback Enabling/Disabling: HARQ feedback of downlink packets can be enabled or disabled per HARQ process by dedicated RRC signalling and/or DCI based indication to mitigate the impact of HARQ stalling in NB-IoT/eMTC NTN. Disabling HARQ feedback allows scheduling a HARQ process with a downlink packet before one HARQ RTT has elapsed since last scheduled, which allows lower layer latency and higher data rates per UE. Disabling HARQ feedback can be configured even for NB-IoT with single HARQ process. For HARQ process with DL HARQ feedback disabled, the UE will not start the corresponding DL HARQ RTT timer. The (re)starting of downlink drx-inactivity timers are adjusted depending on configuration of HARQ enabling/disabling status, single or multiple TB scheduling and HARQ Ack bundling.

IoT NTN enhancements (2)

- In the uplink two HARQ modes: HARQ mode A and HARQ mode B are introduced and configured per HARQ process basis. UL HARQ mode configuration is based on RRC signalling. For HARQ process in HARQ mode B, UE will not start the corresponding UL HARQ RTT timer. For NB-IoT NTN with single HARQ process in HARQ mode B, the UE will start/restart drx-inactivity timer in the subframe containing the last repetition of the corresponding PUSCH transmission. HARQ mode B is not applicable for UL transmission using PUR. For eMTC new LCP restrictions are introduced corresponding to HARQ enabling/disabling. UE (re)starts drx-InactivityTimer accordingly based on the configured UL HARQ mode.

IoT NTN enhancements (3)

– Improved GNSS operations: During long connection times and for reducing GNSS measurements impact on UE power consumption, a UE supporting improved GNSS operations can be triggered to perform or configured to autonomously perform its GNSS acquisition If ul-TransmissionExtensionEnabled is configured, a time duration starts at the end of GNSS validity duration and a UE can perform autonomously GNSS acquisition using an autonomous gap starting at the end of the time duration, or the UE can be triggered to perform GNSS acquisition before the end of the time duration. This allows a UE in RRC_CONNECTED to apply UE pre-compensation of satellite delay and Doppler to maintain UL synchronization for UL transmission in an NTN cell. While network can trigger connected UE to perform GNSS measurement using DL MAC CE, UE autonomous GNSS-triggering measurement will be configured by RRC dedicated signalling. If there is neither network trigger nor network configuration of UE autonomously GNSS measurement, UE moves to RRC_IDLE after GNSS becomes invalid. UE will report the GNSS validity duration by using a UL MAC CE and assumes the GNSS location is valid upon successful GNSS measurement. Network enables this reporting of GNSS position fix duration, in SIB2 and in dedicated signalling (for handover).

IoT NTN enhancements (4)

- Moreover, for measurement and mobility enhancements:
  - New time-based and location-based triggers are introduced. UE can start intra/inter frequency measurement in connected mode before the specific time. A serving cell reference location and a distance threshold / radius for UE is introduced to detect when to trigger connected mode measurements. A new SIB is introduced for the network to broadcast the neighbor cell/satellite information. Satellite ids are introduced for serving and neighbor satellites. Location-based measurement initiation can also be optionally used in idle mode for cell re-selection purposes.
  - For CHO in eMTC NTN, time and location-based trigger conditions may be configured independently (i.e., without a jointly configured measurement condition).

IoT NTN enhancements (5)

- In addition, in case of discontinuous coverage,
  - An enhancement to RRC Release is introduced. UE may directly go to RRC_IDLE after RLF is triggered if there is not enough time for the UE to finish the procedure of RRC re-establishment due to the discontinuous coverage.
  - Based on the conclusion of SA2 study, a new cause value "Release due to discontinuous coverage" is introduced for the S1AP UE Context Release Request procedure. There is no need to enhance the existing S1AP procedure to support the tracking area reported by RAN before AN release. In this release, the paging enhancement for power saving and mobility management enhancement for discontinuous coverage are not pursued. In addition, IoT NTN has also aligned with the progress of NR NTN on the mobility issues, such as the introduction of time-based CHO over X2. While the progress of NW verified UE location in NR NTN is not considered in IoT NTN, since this topic is out of scope on IoT NTN.

IoT NTN enhancements (6)

- Finally, for UE’s RRM core requirements the following are identified: for NB-IoT and eMTC UEs in IDLE mode, cell re-selection requirements for location-based measurement triggering are specified; for NB-IoT and eMTC UEs in CONNECTED mode, RAN4 specified the requirements for neighbour cell measurements and the corresponding measurement triggering before RLF; for NB-IoT and eMTC UEs in CONNECTED mode, RAN4 specified the RRM requirements considering the GNSS reacquisition; for eMTC UEs in CONNECTED mode, RAN4 specified the Conditional Handover requirements for location-based and time-based events.

Release 19

- The Release 19 WG RAN2 led WI "Non-Terrestrial Networks (NTN) for Internet of Things (IoT) Phase 3" (NR_NTN_Ph3) has the following objectives which will be considered in 2024/2025:
  - DL coverage enhancements targeting support for additional reference satellite payload parameters covering both GSO and NGSO constellations operating in FR1-NTN or FR2-NTN
  - Uplink capacity/throughput enhancement for FR1-NTN
  - Signaling of the intended service area of a broadcast service (e.g. MBS broadcast) via NR NTN
  - Support of regenerative payload (i.e. 5G system functions on board the NTN vehicle)
  - Support RedCap UEs with NR NTN operating in FR1-NTN bands

Release 19

- WG SA1 Release 19 SI "Study on satellite access - Phase 3" (FS_5GSAT_Ph3) studies use cases and requirements for further enhancements of the 5G system over satellite (see TR 22.865):
  - Store and Forward (S&F) Satellite operation for delay-tolerant communication service: to provide communication service for UEs under satellite coverage without a simultaneous active feeder link connection to the ground segment (esp. relevant for delay-tolerant IoT services via NGSO space segment).
  - UE-Satellite-UE communication: In some scenarios, UEs need to communicate using satellite access without going to the ground network in order to avoid long delays and limited data rate as well as reducing the consumption of backhaul resources.(Note: REL-17 and REL-18 assumed transparent mode for the satellite access.)
  - GNSS independent operation: to provide satellite access to UEs without GNSS receiver or with no access to GNSS services (note: For REL-17 and REL-18 only GNSS capable UEs are supported.)
  - Positioning enhancements for satellite access: 3GPP positioning methods are needed in some scenarios for UEs using only satellite access.

Release 19

- Corresponding normative stage 1 requirements were captured in TS 22.261 in WG SA1 Release 19 WI "Satellite access Phase 3" (5GSAT_Ph3).
- WG SA2 Release 19 SI "Study on Integration of satellite components in the 5G architecture Phase 3" (FS_5GSAT_ARCH_Ph3) is based on the WG SA1 SI and will study:
  - Regenerative payload generic architecture
  - Store and Forward satellite operation
  - UE-satellite-UE communication enhancements for 5GS, supporting NR NTN NGSO constellation with and without ISL, with feeder link available (at least for session establishment)
- Results will be documented in TR 23.700-29.
- WG SA3 Release 19 SI "Study on Security Aspects of 5G Satellite Access Phase 2" (FS_5GSAT_SEC_Ph2) will study security and privacy key issues of:
  - Regenerative payload in 5GS & EPS
  - Store and Forward satellite operation for NR NTN (5GS) and IoT NTN (EPS)
  - UE-satellite-UE communication enhancements for 5GS
- Results will be documented in TR 33.700-29.

Release 19

- WG SA5 Release 19 SI "Study on Management Aspects of NTN Phase 2" (FS_NTN_OAM_Ph2) will study the following aspects:
  - Management capabilities to support new network architecture or functions for satellite regenerative payloads, considering different types of satellite constellations (both GSO and NGSO).
  - Management requirement, usecase and solution to support Store and Forward (S&F) satellite operation and UE-Satellite-UE communication.
  - Requirements and potential solutions to support end to end management (including RAN domain and CN domain) in NTN scenarios, such as coordinate with non-3GPP part (e.g. Satellite Control System, Transport System) to provide the NTN specific requirements.
  - Management enhancement for NTN-TN and NTN-NTN mobility coordination and better service continuity.
- Results will be documented in TR 28.874.

Release 19

- WG SA6 Release 19 SI "Study on application enablement for Satellite access enabled 5G Services" (FS_5GSAT_APP) will study:
  - Application layer solutions for satellite access: using satellite access characteristics, supporting predictable discontinuous /intermittent connectivity patterns between UEs and AS/AFs for IoT services with satellite access, supporting delivery of content from a content caching application
  - Usage of satellite communication for Mission Critical services (to provide better user experience, identify key issues, deployment models and develop solutions)
- Results will be documented in TR 23.700-01.

Release 19

- Further information
- 3GPP TR 23.700-29 V1.0.0 (2024-06) "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects;
  Study on integration of satellite components in the 5G architecture; Phase (Release 19)

3GPP TR 33.700-29 V0.5.0 (2024-10)
Technical Report
3rd Generation Partnership Project; **Technical Specification Group Services and System Aspects;** **Study on Security Aspects of 5G Satellite Access** **in the 5G architecture;** **Phase 3** **(Release 19)**