Non-terrestrial Networks: Standardization in 5G NR

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Outline

- Standardization activity review for NTN in 5G NR
- Overview
  - Roles
  - Use cases
  - Architectures
  - Deployment scenarios
- RAN issues and related potential solutions
  - RAN1
    - Channel models
    - Main technical challenges and potential solutions
    - Etc.
  - RAN2/3/4
- Future standardization development of NTN in 5G NR

Standardization Activity: Rel-15

- First study item on NR to support Non-Terrestrial Networks (NTN) was approved in RAN#75
- The intent is to study the channel models (propagation conditions, mobility); define the deployment scenarios as well as the related system parameters, and identify any key impact areas that may need further evaluations.
- Objectives
  - Channel model: Study the feasibility of adapting the 3GPP channel model for non-terrestrial networks. If needed, identify and study new channel models. (RAN1)
  - Provide detailed description of deployment scenarios for non-terrestrial networks and the related system parameters such as architecture, altitude, orbit etc. (RAN Plenary)
  - For the described deployment scenarios, identity potential key impact areas on the NR. (RAN Plenary)

Standardization Activity: Rel-16

- A study item "Solutions for NR to support Non Terrestrial Network" has been approved in RAN#83,
- Objectives of PHY layer
  - Consolidation of potential impacts as initially identified in TR 38.811 and identification of related solutions if needed [RAN1]:
    - Physical layer control procedures (e.g. CSI feedback, power control)
    - Uplink Timing advance/RACH procedure including PRACH sequence/format/message
    - Making retransmission mechanisms at the physical layer more delay-tolerant as appropriate. This may also include capability to deactivate the HARQ mechanisms.
  - Performance assessment of NR in selected deployment scenarios (LEO based satellite access, GEO based satellite access) through link level (Radio link) and system level (cell) simulations [RAN1]

Standardization Activity: Rel-16

- Objectives of Layer 2 and above, and RAN architecture
  - Study the following aspects and identify related solutions if needed: Propagation delay: Identify timing requirements and solutions on layer 2 aspects, MAC, RLC, RRC, to support non-terrestrial network propagation delays considering FDD and TDD duplexing mode. This includes radio link management. [RAN2]
  - Handover: Study and identify mobility requirements and necessary measurements that may be needed for handovers between some non-terrestrial space-borne vehicles (such as Non Geo stationary satellites) that move at much higher speed but over predictable paths [RAN2, RAN1]
  - Dual connectivity [RAN3 aspects] involving
    - NTN-based NG-RAN (Transparent GEO or LEO satellites) and terrestrial based NG-RAN access: Xn terminated on the ground
    - or two NTN-based NG-RAN access (between Regenerative LEO satellites): Xn over ISL
  - Architecture: Identify needs for the 5G's Radio Access Network architecture to support non-terrestrial networks (e.g. handling of network identities) [RAN3]
    - Paging: procedure adaptations in case of moving satellite foot prints or cells

NTN Overview: Roles

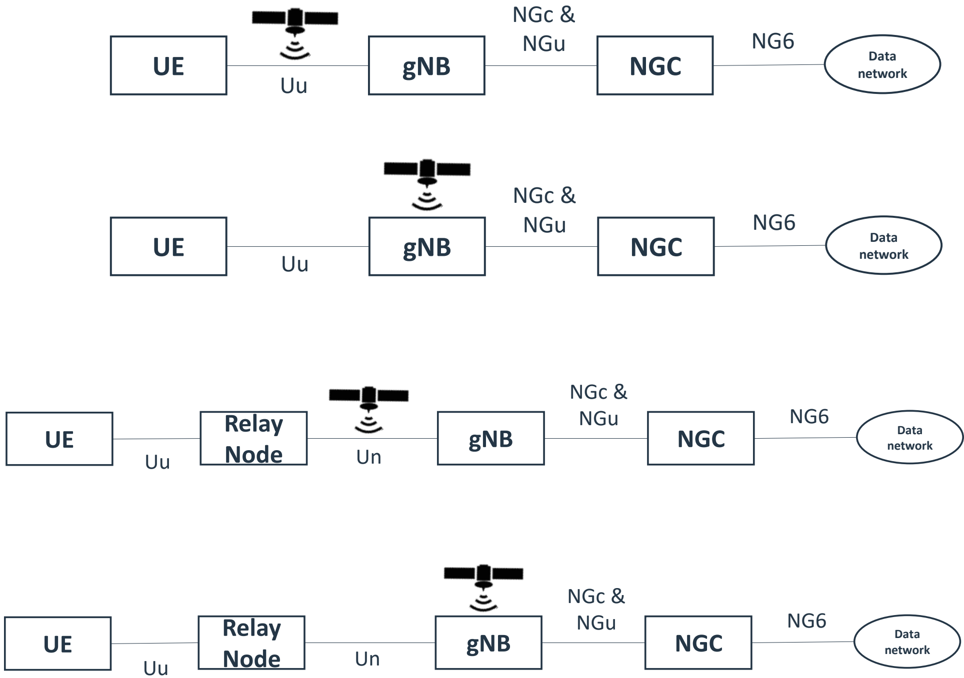
- Wide service coverage capabilities and reduced vulnerability of space/airborne vehicles
  - foster the roll out of 5G service in un-served areas that cannot be covered by terrestrial 5G network and underserved areas,
  - reinforce the 5G service reliability by providing service continuity,
  - enable 5G network scalability.
- Major impacts: coverage, user bandwidth, system capacity, service reliability or service availability, energy consumption, connection density.
- Non-Terrestrial Network components in the 5G system: Transport, Public Safety, Media and Entertainment, eHealth, Energy, Agriculture, Finance, Automotive.

NTN Overview: Use Cases

- eMBB:
  - Multi-connectivity: Users in underserved areas are connected to the 5G network,
  - Fixed cell connectivity: Users in isolated villages or industry premises,
  - Mobile cell connectivity: Passengers on board vessels or aircrafts,
  - Network resilience: Some critical network links requires high availability to prevent complete network connection outage.
  - Etc.
- mMTC:
  - Wide area IoT service: Global continuity of service for telematic applications based on a group of sensors/actuators scattered over or moving around a wide area,
  - Local area IoT service: Group of sensors that collect local information, connect to each other and report to a central point.
- Satellites provide broadband connectivity between the core network and the cells.

NTN Overview: Architectures

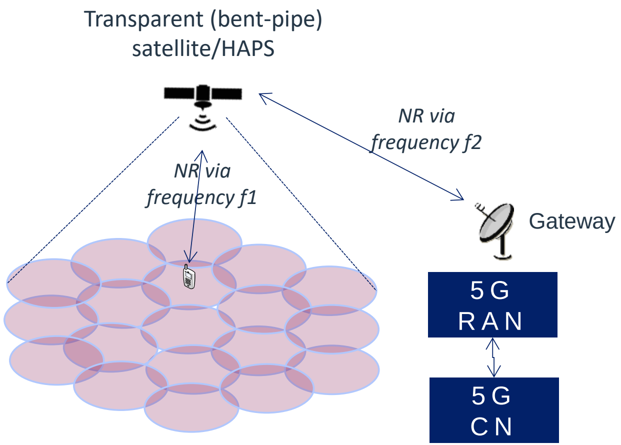
5G elements - NTN elements mapping			
NTN architecture options	NTN Terminal	Space or HAPS	NTN Gateway
A1: access network serving UEs via bentpipe satellite/aerial	UE	Remote Radio Head (Bent pipe relay of Uu radio interface signals)	gNB
A2: access network serving UEs with gNB on board satellite/aerial	UE	gNB or Relay Node functions	Router interfacing to Core network
A3: access network serving Relay Nodes via bent pipe satellite/aerial	Relay Node	Remote Radio Head (Bent pipe relay of Uu radio interface signals)	gNB
A4: access network serving Relay Nodes with gNB on board satellite/aerial	Relay Node	gNB or Relay Node functions	Router interfacing to Core network

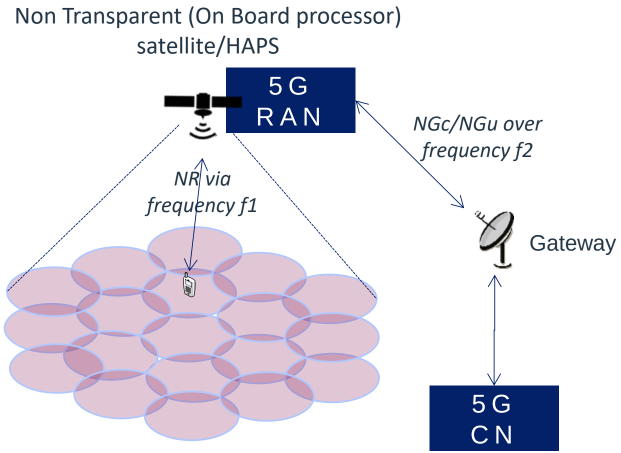


NTN Overview: Deployment Scenarios

- Coverage pattern
  - Multiple beams over a given area
  - Elliptic shape footprint.
  - Fixed and moving beam footprints.

Attributes	GEO	Non-GEO	Aerial
Beam foot print size in diameter	200 – 1000 km	100 – 500 km	5 - 200 km





NTN Overview: Deployment Scenarios

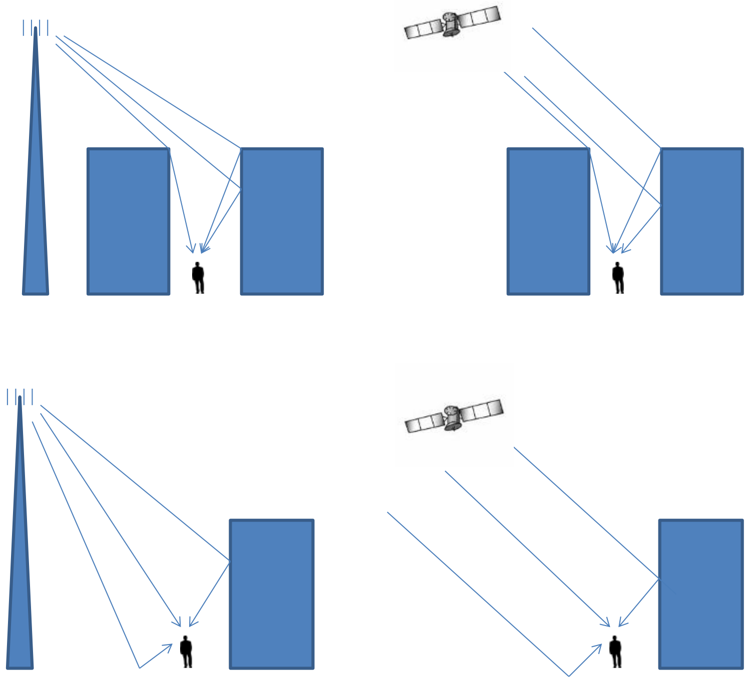
Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
Platform orbit and altitude	GEO at 35 786 km	GEO at 35 786 km	Non-GEO down to 600 km	Non-GEO down to 600 km	UAS between 8 km and 50 km including HAPS
Carrier Frequency on the link between Air / space-borne platform and UE	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Around 2 GHz for both DL and UL (S band)	Around 2 GHz for both DL and UL (S band)	Around 20 GHz for DL Around 30 GHz for UL (Ka band)	Below and above 6 GHz
Beam pattern	Earth fixed beams	Earth fixed beams	Moving beams	Earth fixed beams	Earth fixed beams
Duplexing	FDD	FDD	FDD	FDD	FDD
Channel Bandwidth (DL + UL)	Up to 2 * 800 MHz	Up to 2 * 20 MHz	Up to 2 * 20MHz	Up to 2 * 800 MHz	Up to 2 * 80 MHz in mobile use and 2 * 1800 MHz in fixed use
NTN architecture options (See clause 4)	A3	A1	A2	A4	A2

NTN Overview: Deployment Scenarios

Main attributes	Deployment-D1	Deployment-D2	Deployment-D3	Deployment-D4	Deployment-D5
NTN Terminal type	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a relay node	Up to 3GPP class 3 UE [2]	Up to 3GPP class 3 UE [2]	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a Relay node	Up to 3GPP class 3 UE Also Very Small Aperture Terminal
NTN terminal Distribution	100% Outdoors	100% Outdoors	100% Outdoors	100% Outdoors	Indoor and Outdoor
NTN terminal Speed	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 1000 km/h (e.g. aircraft)	up to 500 km/h (e.g. high speed trains)
Main rationales	GEO based indirect access via relay node	GEO based direct access	Non-GEO based direct access	Non-GEO based indirect access via relay node	Support of low latency services for 3GPP mobile UEs, both indoors and outdoors
Supported Uses cases, see clause 4	1/ eMBB: multi-connectivity, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, edge network delivery, Mobile cell hybrid connectivity, Direct To Node multicast/ broadcast	1/eMBB: Regional area public safety, Wide area public safety, Direct to mobile broadcast, Wide area IoT service	1/eMBB: Regional area public safety, Wide area public safety, Wide area IoT service	1/ eMBB: multi-homing, fixed cell connectivity, mobile cell connectivity, network resilience, Trunking, Mobile cell hybrid connectivity	1/ eMBB: Hot spot on demand
NTN Terminal type	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a relay node	Up to 3GPP class 3 UE [2]	Up to 3GPP class 3 UE [2]	Very Small Aperture Terminal (fixed or mounted on Moving Platforms) implementing a Relay node	Up to 3GPP class 3 UE Also Very Small Aperture Terminal

NTN Channel Model

- Modeling objectives
  - Support frequency range from 0.5GHz up to 100GHz.
    - below 6GHz and Ka bands.
  - Accommodate UE mobility.
    - For satellite channel models, mobility speed up to 1000km/h
    - For HAPS channel models, mobility speed up to around 500 km/h
- Differences between satellite/HAPS and cellular channel modelling
  - The terrestrial propagation is quite similar.
  - The angular spread from satellite is almost zero.
  - Depends on elevation angle
  - Coordinate system: Earth Centred Earth fixed



NTN Channel Model

- Antenna model
  - Satellite: based on Bessel function
  - HAPS: Bessel function and 3GPP antenna pattern
- Large scale
  - LOS probability: depending on elevation angle
  - Pathloss
    - Atmospheric gasses: absorption depends mainly on frequency, elevation angle, altitude above sea level and water vapour density (absolute humidity)
    - Scintillation: rapid fluctuations of the received signal amplitude and phase. Depending on the frequency band, ionospheric and/or tropospheric scintillation
- Fast fading
  - Frequency selective
  - Flat fading ITU two-state model: the signal level is statistically described with a good state and a bad state.
- Additional components
  - Time varying Doppler: depends on the time evolution of the channel.
  - Faraday rotation: rotation of the polarization due to the interaction of the electromagnetic wave with the ionized medium in the earth's magnetic field along the path.

Major Technical Challenges for NTN

- Propagation delay
  - In NTN networks, due to the extremely large distance between the gNB and the UE, the propagation delay can be up to a few hundreds ms for GEO satellites, especially for bent pipe scenario.
- Doppler effect
  - Due to the fast relative movement between a spaceborn vehicles, e.g., LEO satellite, and the UE
  - More than 7km per second and more than 20 ppm Doppler shift for 2 GHz carrier frequency.
- The current NR specifications are mainly designed for cellular system and not supposed to handle such propagation delay and Doppler Effect.

NTN scenarios	A	B	C1	C2	D1	D2
	GEO transparent payload	GEO regenerative payload	LEO transparent payload		LEO regenerative payload	
Satellite altitude	35 786 km		600 km			
Relative speed of Satellite wrt earth	negligible		7.56 km per second			
Min elevation for both feeder and service links	10° for service link and 10° for feeder link					
Typical Min / Max NTN beam foot print diameter (note 1)	100 km / 1000 km		50 km / 500 km			
Maximum Round Trip Delay on the radio interface between the gNB and the UE	541.46 ms (Worst case)	270.73 ms	25.77 ms		12.89 ms	
Minimum Round Trip Delay on the radio interface between the gNB and the UE	477.48 ms	238.74 ms	8 ms		4 ms	
Maximum Delay variation as seen by the UE	Negligible		Up to +/- 40 µs/sec (Worst case)		Up to +/- 20 µs/sec	
Maximum delay difference within a NTN beam as seen by the UE	16 ms (Worst case)		4.44 ms			

Potential Solutions: PHY Layer Control Procedure

- Power control
  - OLPC and CLPC
  - Distance based ULPC
  - Extension of ULPC parameter ranges
- AMC/CSI feedback
  - Prediction-based link adaptation with prediction confidence level
  - AMC with CQI reflecting only long-term fading
  - Additional BLER targets for CQI reporting to limit number of retransmissions and latency
  - CQI offset applied by gNB
  - Finer granularity of CQI
- Beam switching
  - Rel-15 BM as starting point
  - BWP switching
- Uplink Transmission timing
  - Configurable offset value is agreed
  - Implicit derivation v.s. UE specific configuration
  - Signalling details

Potential Solutions: Timing Issues

- DL synchronization
  - With pre-compensation as baseline
  - Without pre-compensation
- UL synchronization
  - Frequency offset
    - OL: pre-compensation with location information
    - CL: UE specifically configured by the network
  - Timing adjustment
    - OL: location information available
    - CL: extension of TA range, multiple reference points
- New PRACH format
  - Extended longer preamble used in FR2
  - Extension of FR2 preamble formats
- RACH Procedure
  - RAR window for msg3
  - Etc.
- HARQ
  - Semi-static and dynamic enabling / disabling
  - Number of HARQ procedures

RAN2/3 Issues

- Radio protocol issues
  - UP enhancements
    - MAC: RA, DRX, scheduling request
    - RLC: HARQ
    - PDCP
    - SDAP
  - CP enhancements
    - Idle mode mobility enhancements
    - Connected mode mobility enhancements
    - Paging issues
    - RLM
- NG-RAN architecture and interface protocols
  - TA management: fixed and moving cells
  - Registration update and paging: availability of UE location
  - Connected mode mobility
  - Transport aspects
  - Network identity handling
  - Feeder link
  - O&M

Future Standardization of NTN

- Timeline for NTN
  - Rel-15
    - Channel models
    - Use cases and deployment scenarios
    - Potential NR impacts
  - Rel-16 (ongoing)
    - Performance evaluation
    - Layer 1
      - Physical layer control procedures (e.g. CSI feedback, power control)
      - Uplink Timing advance/RACH procedure including PRACH sequence/format/message
      - Retransmission mechanisms

- Timeline for NTN
  - Rel-16 (ongoing)
    - Upper layers
      - Layer 2 aspects, MAC, RLC, RRC, to support non-terrestrial network propagation delays considering FDD and TDD duplexing mode.
      - Handover
      - Dual connectivity
      - Architecture
  - Rel-17 (expected)
    - NR and 5G support for NTN

Thank you for your attention

Questions?