# NON-TERRESTRIAL NETWORKS

# TECHNOLOGY OUTLOOK

Reiner Stuhlfauth

Technology manager wireless

ROHDE&SCHWARZ

Make ideas real

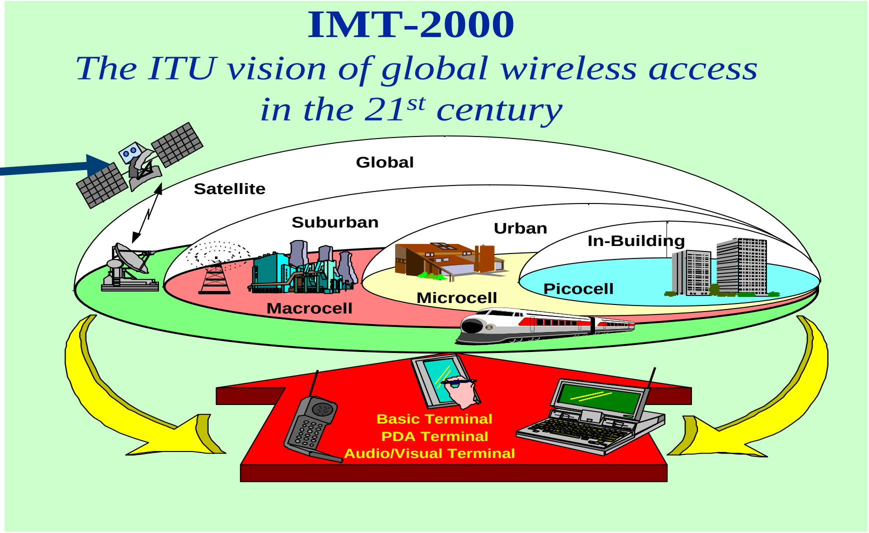
## Non-terrestrial networks (NTN)

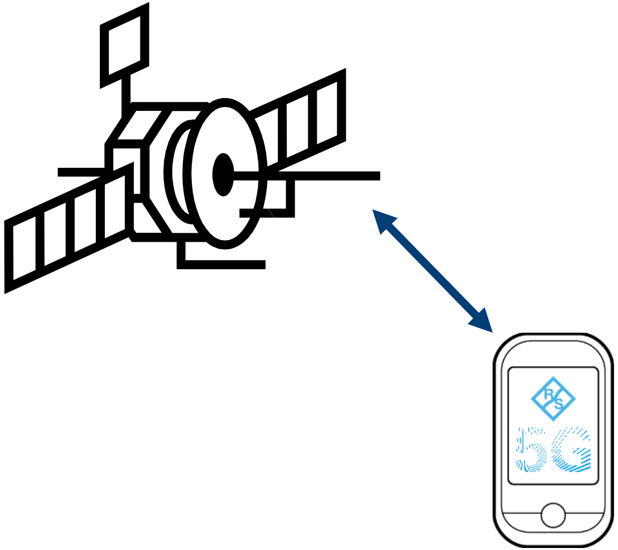
# MOTIVATION, STATUS + TIMELINE

# 5G NR OVER NON-TERRESTRIAL NETWORKS

Déjá vu???

IMT-2000 in the late 90s already defined the possibility of earth-to-satellite communcation. Never took off commercially



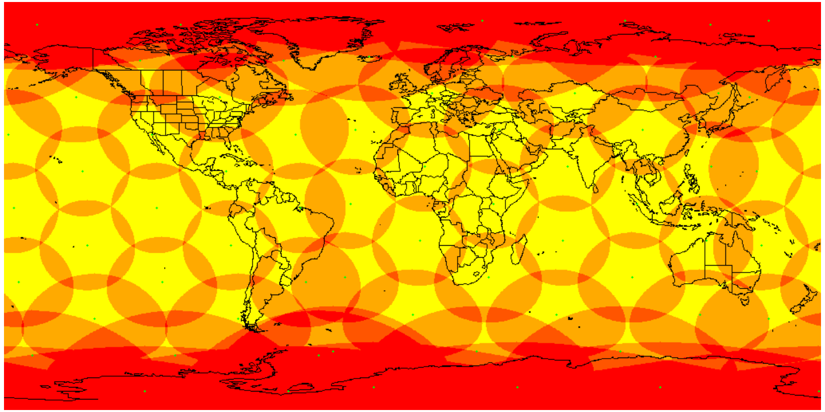

⇒ Now the situation has changed: Evolution in satellites has progressed, wireless is much more than „just voice“, etc. game restarts ☺

⇒ Rel. 16 work item for 5G NR over Non-terrestrial networks (NTN).

# NON-TERRESTRIAL NETWORKS - STATUS


Iridium satellite network, started as GSM add-on. Today, about 66 LEO satellites at ~780km altitude. Main application: Voice + data for civil but also military usage.

Satellite to UE uses L band: 1618.25 -1626.5 MHz



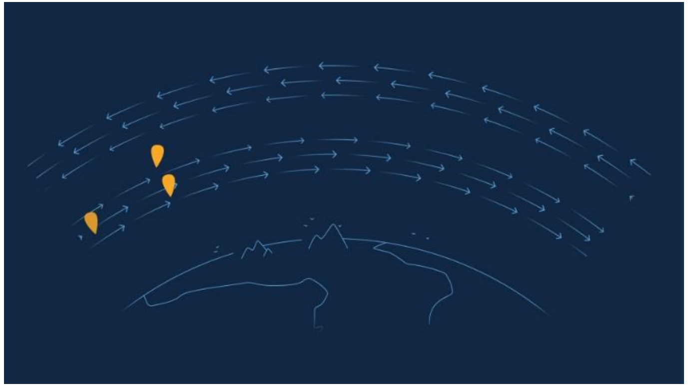

U.S. Army signs deal with SpaceX to assess Starlink broadband

by Sandra Erwin — May 26, 2020

The U.S. Army signed an agreement with SpaceX to test the use of Starlink broadband to connect units in the field. In this photo soldiers train at the National Training Center at Fort Irwin, Calif. Credit: Army

Source: spacenews.com

# NON-TERRESTRIAL NETWORKS - STATUS



HAPS use the winds at various altitudes to steer. Flight time of one ballon ~150 days. Cell radius ~40km

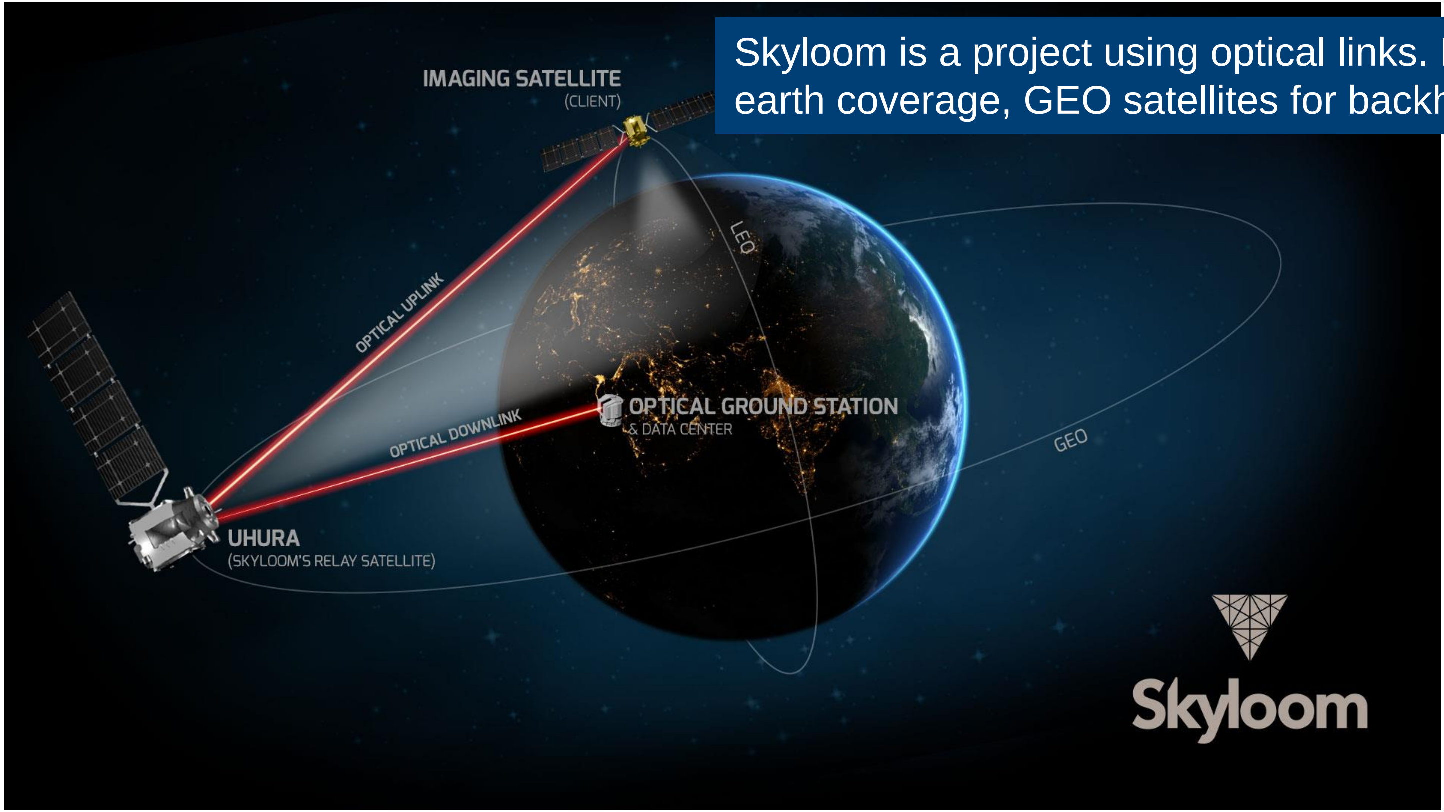

Loon is an LTE network, using balloon based base stations.
Cooperation with terrestrial networks to extend coverage.
Reuse of spectrum.
Advantages of 18-25km flight range for HAPS:
Low latency, very little wind (self-power with solar), optical links for inter-aerial and satellite communication possible due to low atmospheric conditions



Source: loon.com

# NON-TERRESTRIAL NETWORKS - OUTLOOK

Skyloom is a project using optical links. LEO satellites for earth coverage, GEO satellites for backhaul

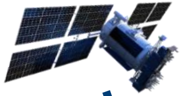


# NON TERRESTRIAL NETWORK APPLICATIONS

ETSI TR 103 612: Mobile/fixed communication network in the frequency range 6425-7125MHz

**3GPP: NR over NTN**
5G NR air interface adopted to NTN
GEO, LEO, HAPS -> air to ground
Fixed or moving terrestrial cells
UE support GNSS + NTN
Business case: „human“, eMBB

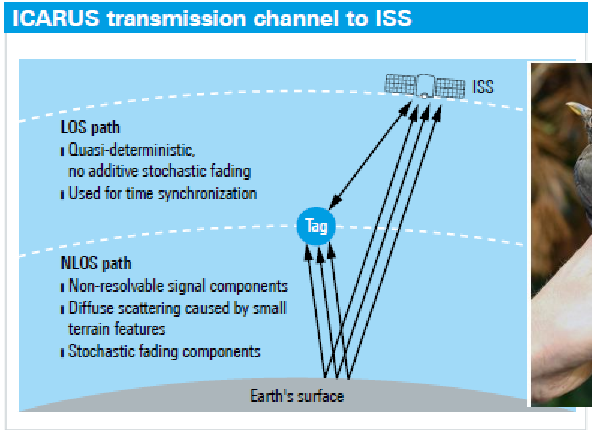
**3GPP: IoT over NTN**
NB-IoT & LTE-M adopted to NTN
GEO, LEO, HAPS -> air to ground
Business case: „IoT“
e.g. ICARUS: Internet of animals @400MHz



Remote areas

Public safety

Temporary hotspots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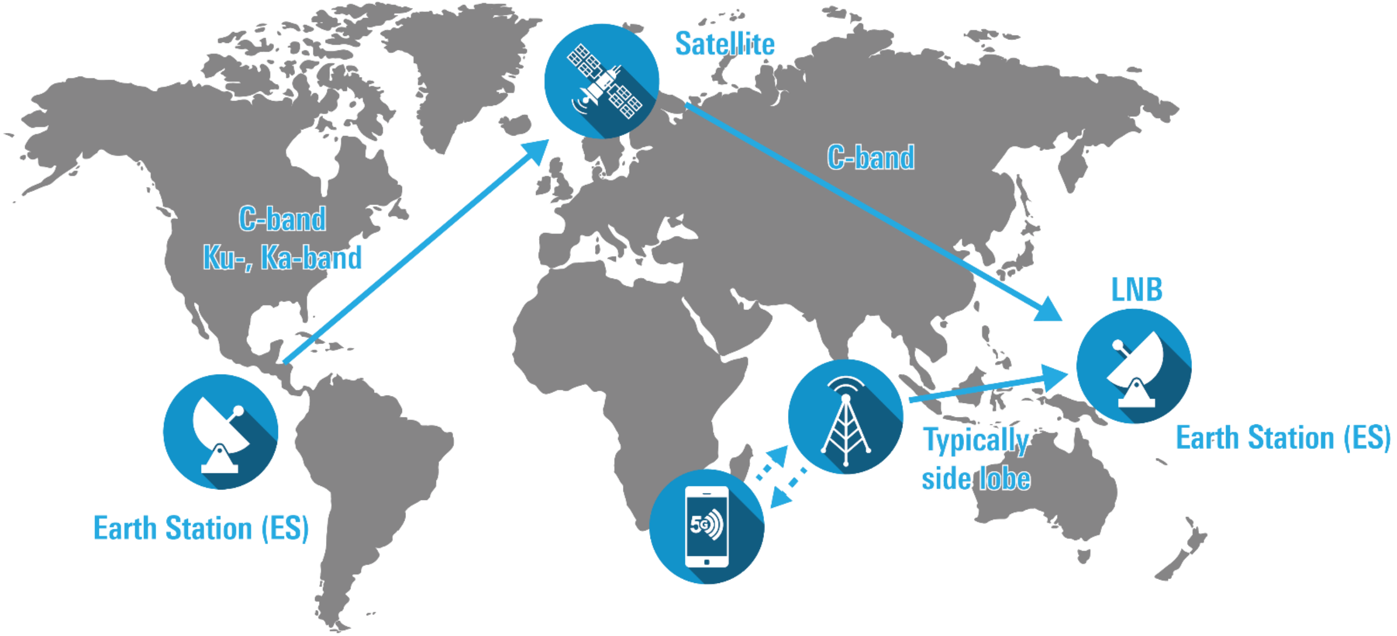
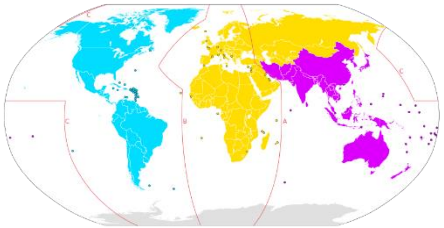
Non-terrestrial networks technology outlook

# NTN - MOTIVATION

Today wireless communication covers >60% of the population and <40% of the landmass
⇒ Coverage requirements of human and machines are different
⇒ Probably „coverage“ is an important requirement of „beyond 5G“?



# NTN – SPECTRUM DISCUSSIONS



RP 193234 proposes various frequency bands for HAPS, GEO, non-GEO NTN in FDD & TDD for the various ITU regions

**Ka-band: GEO**

| | Region 1 | Region 2 | Region 3 |
|---|---|---|---|
| Downlink (space to earth) | 17.3 – 20.2 GHz | 17.7 – 20.2 GHz | 17.7 – 20.2 GHz |
| Uplink (earth to space) | 27.5 – 30.0 GHz | 27.0 – 30.0 GHz | 27.0 – 30.0 GHz |

**Ka-band: non-GEO**

| | Region 1 | Region 2 | Region 3 |
|---|---|---|---|
| Downlink (space to earth) | 17.3 – 20.2 GHz | 17.7 – 20.2 GHz | 17.7 – 20.2 GHz |
| Uplink (earth to space) | 27.5 – 29.1 GHz & 29.5 – 30.0 GHz | 27.0 – 29.1 GHz & 29.5 – 30.0 GHz | 27.0 – 29.1 GHz & 29.5 – 30.0 GHz |

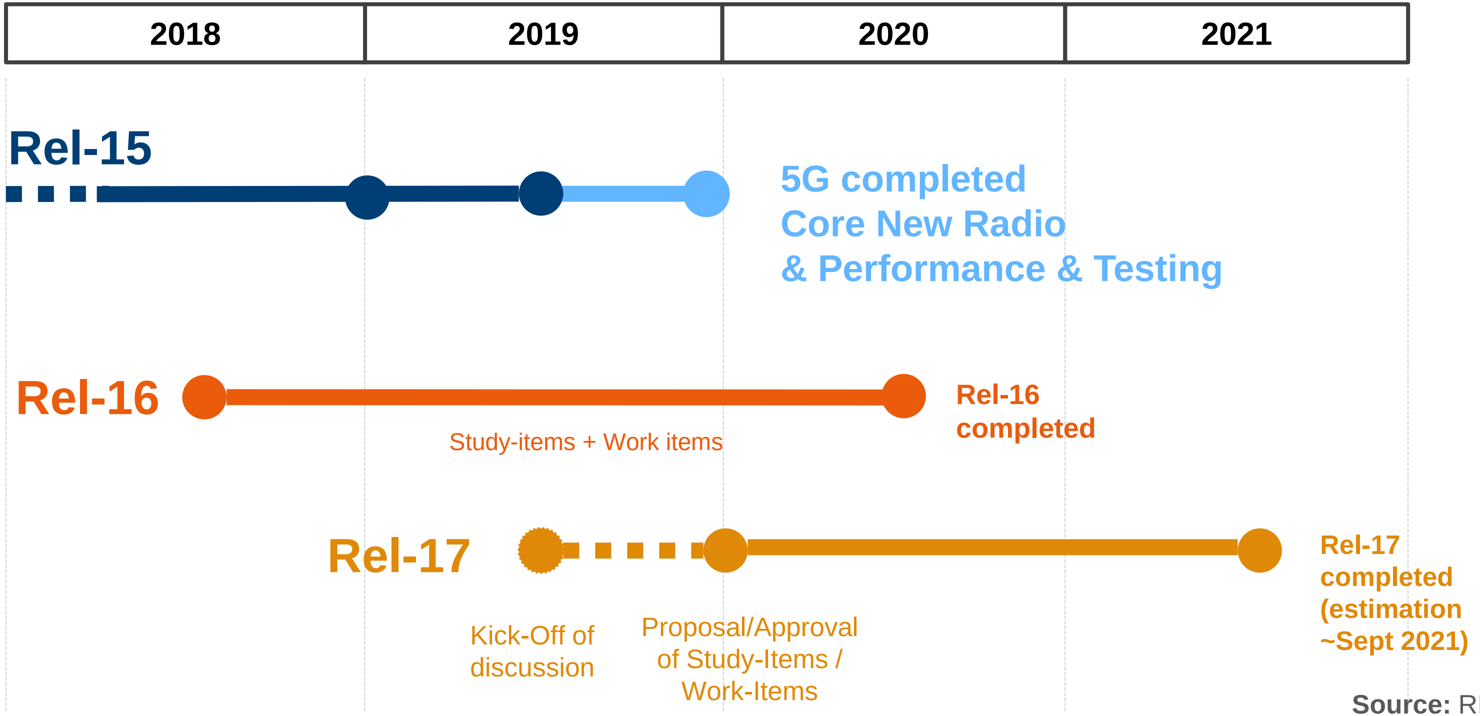
**S-band: GEO&non-GEO**

| | Region 1 | Region 2 | Region 3 |
|---|---|---|---|
| Downlink (space to earth) | 2170-2200 MHz | 2160-2200 MHz | 2170-2200 MHz |
| Uplink (earth to space) | 1980-2010 MHz | 1980-2025 MHz | 1980-2010 MHz |

**S-band: HAPS**

| | Region 1 | Region 2 | Region 3 |
|---|---|---|---|
| Downlink (aerial to earth) | 2110-2170 MHz | 2110-2160 MHz | 2110-2170 MHz |
| Uplink (earth to aerial) | 1885-1980 MHz & 2010-2025 MHz | 1885-1980 MHz | 1885-1980 MHz & 2010-2025 MHz |

# 3GPP STANDARDIZATION TIMELINE




**Source:** RP-190563

Non-terrestrial networks (NTN)

# OVERVIEW – SHORT SUMMARY OF TECHNOLOGY + CHALLENGES

# NON TERRESTRIAL NETWORK IN ONE SLIDE

Non-terrestrial networks refer to networks, or segments of networks, using an airborne or spaceborne vehicle for transmission (part of Rel. 17):

**Scenario:**

- Device :
    - Low Speed , pedestrian / ship, VSAT
    - Medium/High speed vehicle/train
    - Very High speed aerial
    - Unmanned aerial system UAS

- Base station
    - Spaceborne : Satellite systems like GEO, MEO or LEO
    - Airborne : aerial vehicles ( 8-50 km )
    - Air 2 Ground (A2G) system
    - High altitude platform station (HAPS)
    - Terrestrial

**Deployment:**

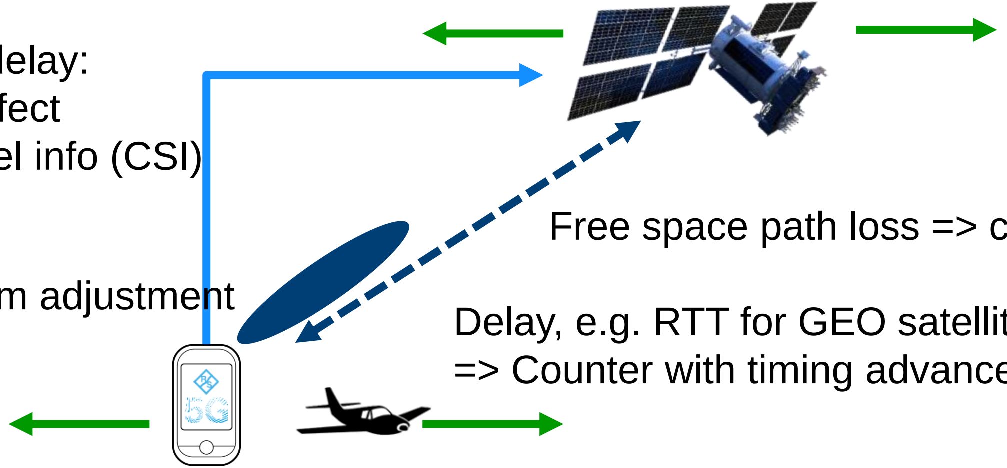
- Rural, suburban, isolated areas
- Internet access rural areas (MBB), MTC/IoT
- Cataclysm/disaster relief, public safety
- **Discussion to operate in S and Ka-band**

# NON TERRESTRIAL TECHNOLOGY CHALLENGES, SUMMARY

Doppler shift due to UE or gNB mobility => use location/orbit info to compensate Doppler

Long delay:
no perfect
channel info (CSI)

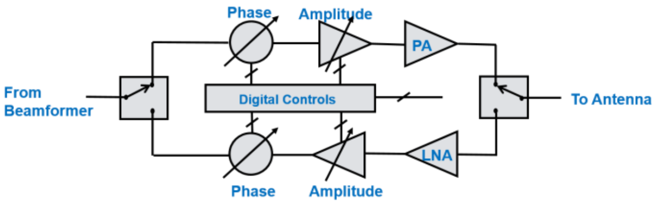
UL beam adjustment

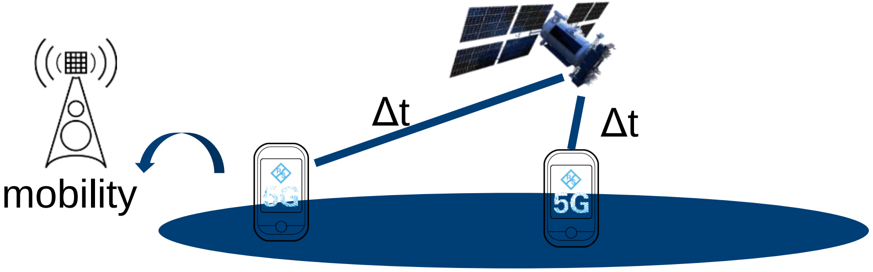


Free space path loss => compensation: beamforming + TX power

Delay, e.g. RTT for GEO satellites ~544ms (note: NR max RTT = 2ms)
=> Counter with timing advance strategies

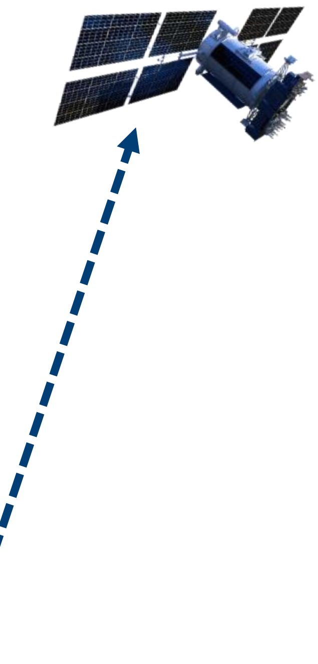
Carrier frequency offset

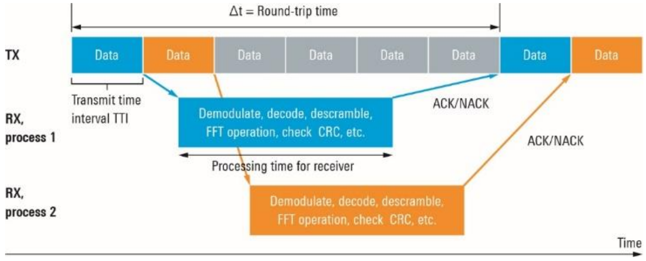


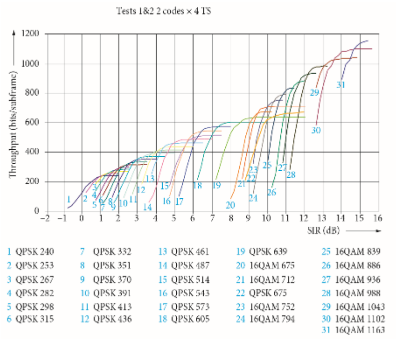

Large cell sizes: RTT delay spread

# NON TERRESTRIAL TECHNOLOGY CHALLENGES SUMMARY

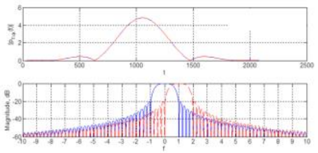





HARQ process (16 today) need to be increased (theoretical max ~545 at GEO) => Reduce system throughput to keep buffer size + automatic retransmissions




- Capability to turn off HARQ process and replace by automatic retransmission
- Slower MCS selection process

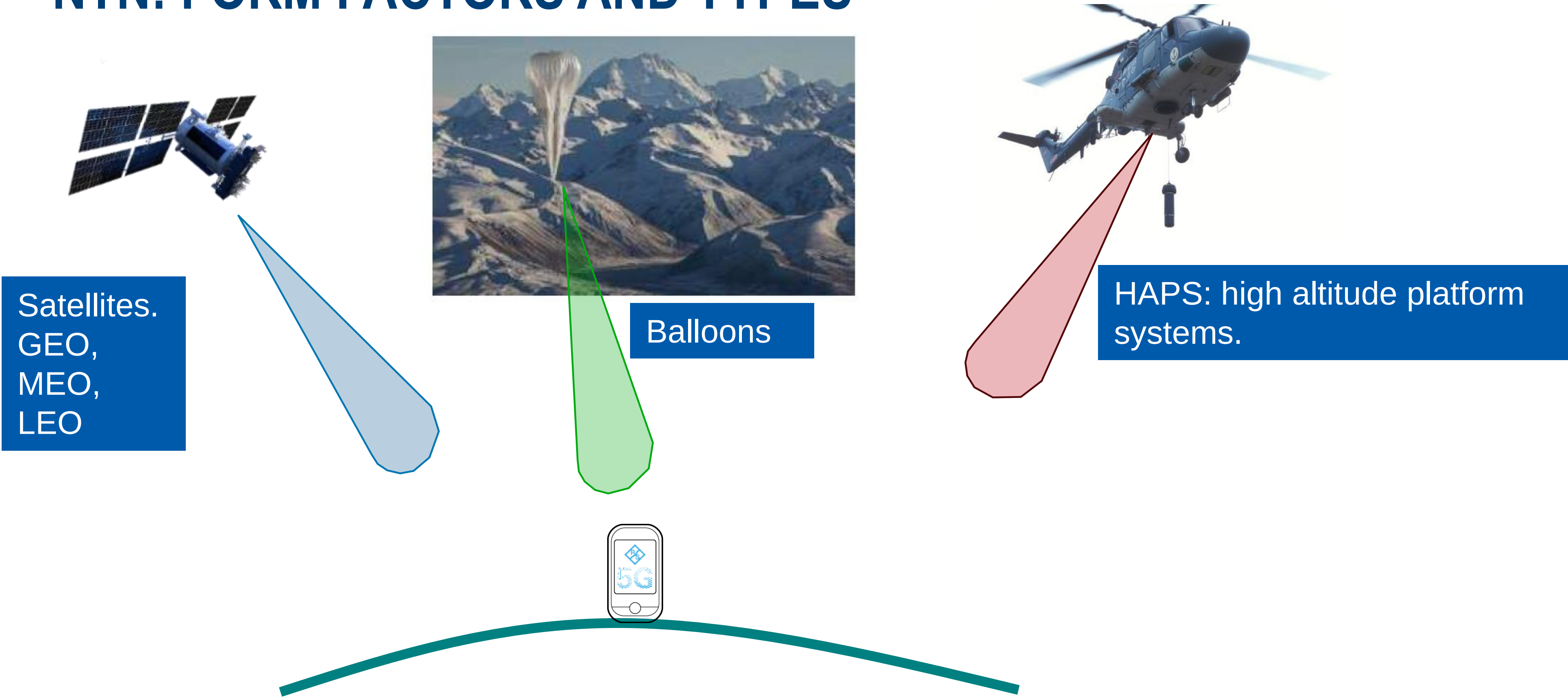


PRACH design based on FBMC: better PAPR + out of band emissions for lower missed detections

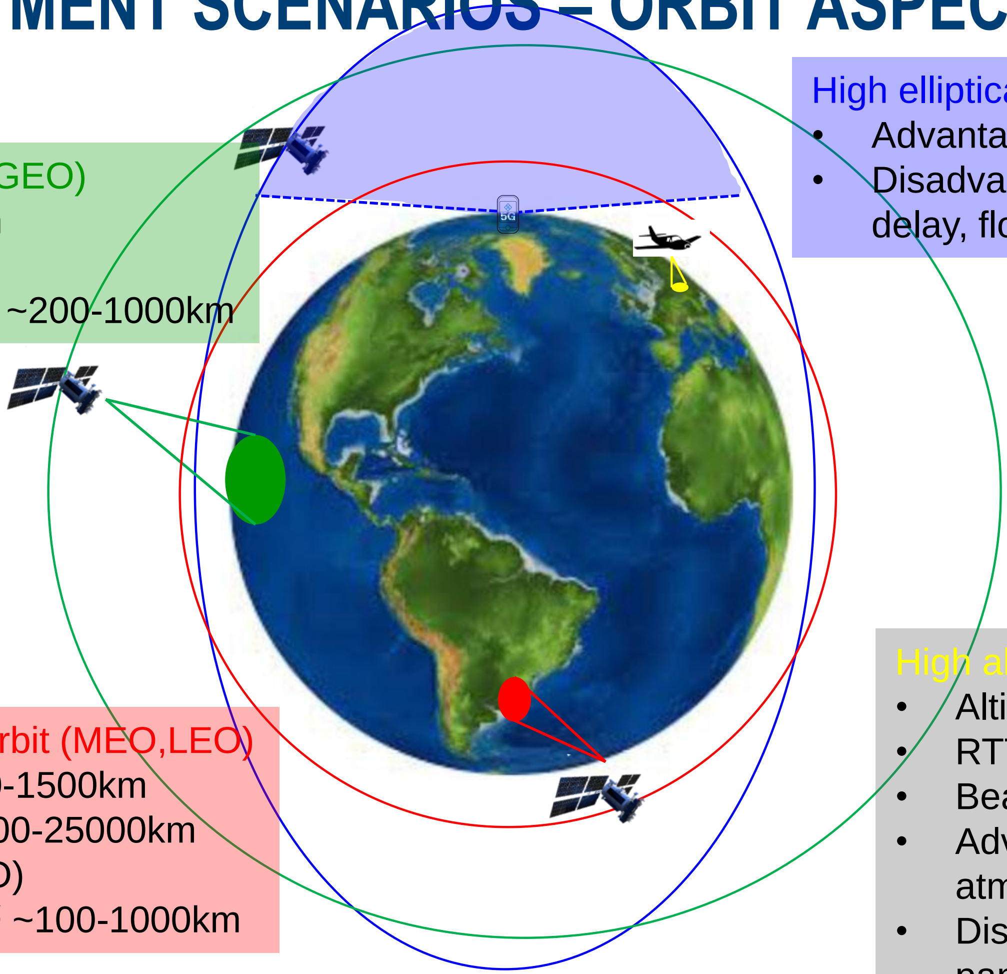
Non-terrestrial networks (NTN)

# DEPLOYMENT SCENARIOS & SPECTRUM

# NTN: FORM FACTORS AND TYPES



# NTN DEPLOYMENT SCENARIOS – ORBIT ASPECTS




**Geostationary orbit (GEO)**
- Altitude 36000km
- RTT ~544ms
- Beam footprint Ø ~200-1000km

**High elliptical orbit (HEO)**
- Advantage: longer visibility from earth
- Disadvantage: elliptical orbit, floating delay, floating coverage

**Medium/Low earth orbit (MEO,LEO)**
- Altitude LEO 300-1500km
  MEO 7000-25000km
- RTT ~30ms (LEO)
- Beam footprint Ø ~100-1000km

**High altitude platform (HAPS)**
- Altitude 8-15km
- RTT ~3ms
- Beam footprint Ø ~5-100km
- Advantage: low wind + low atmospheric influence
- Disadvantage: gravity (e.g. solar panel to feed engine)

# NON TERRESTRIAL NETWORK SATELLITE TYPES

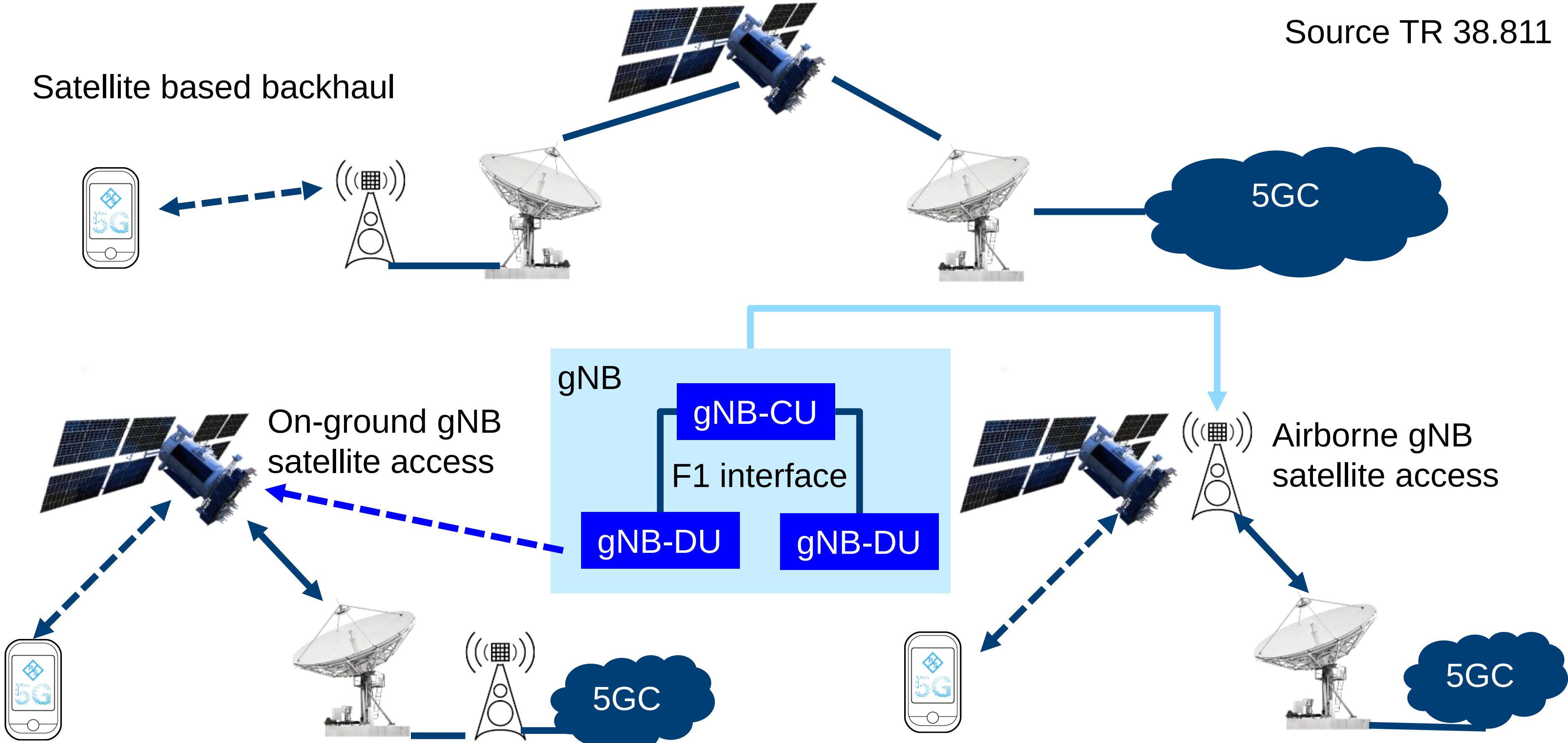
| Platforms | Altitude range | Orbit | Typical beam footprint size |
|---|---|---|---|
| **Low-Earth Orbit (LEO) satellite** | 300 – 1500 km | Circular around the earth | 100 – 1000 km |
| **Medium-Earth Orbit (MEO) satellite** | 7000 – 25000 km | | 100 – 1000 km |
| **Geostationary Earth Orbit (GEO) satellite** | 35 786 km | notional station keeping position fixed in terms of elevation/azimuth with respect to a given earth point | 200 – 3500 km |
| **UAS platform (including HAPS)** | 8 – 50 km (20 km for HAPS) | | 5 - 200 km |
| **High Elliptical Orbit (HEO) satellite** | 400 – 50000 km | Elliptical around the earth | 200 – 3500 km |

Note: HEO have lower priority in current release

Source TR 38.821

# NON TERRESTRIAL NETWORK SCENARIOS

Source TR 38.811



# NON TERRESTRIAL NETWORK SATELLITE TYPES

**Regenerative payload:**

- Radio Frequency filtering
- Frequency conversion and amplification
- Demodulation/decoding
- Switch and/or routing
- Coding/modulation

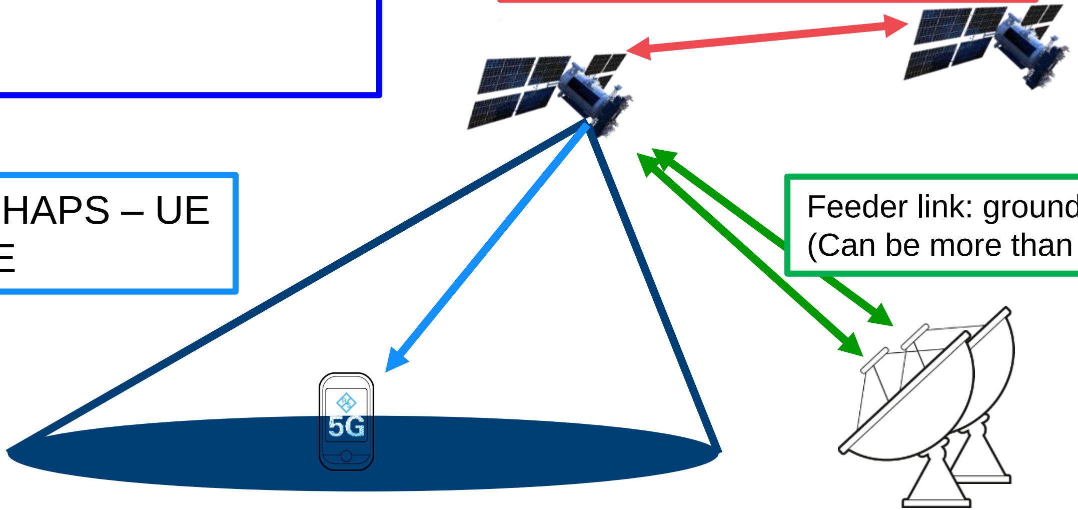
**Transparent payload:**

- Radio Frequency filtering
- Frequency conversion and amplification
- Waveform signal is unchanged

Feeder link: inter-satellite link (ILS)
(Can be more than 1)

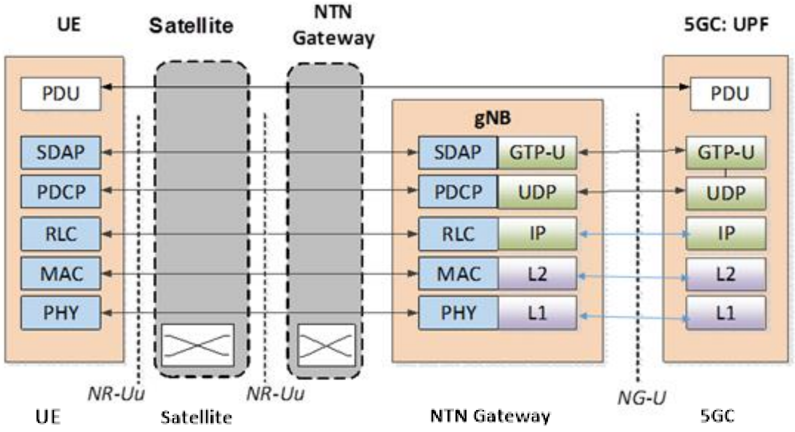
Service or radio link: HAPS – UE
Assumption: 1 per UE

Feeder link: ground station - HAPS
(Can be more than 1)

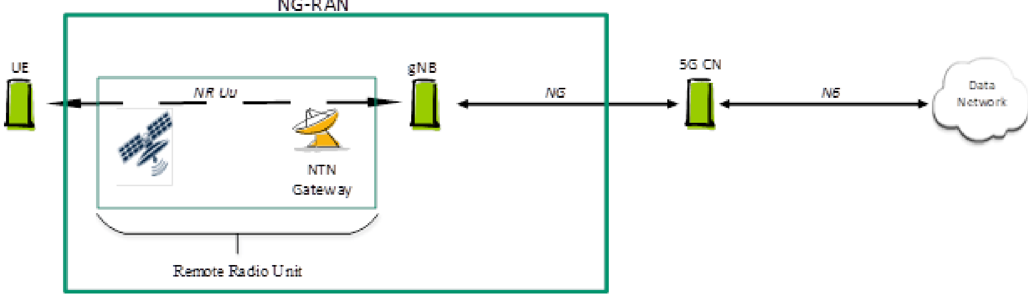



Elliptic shaped beam footprint

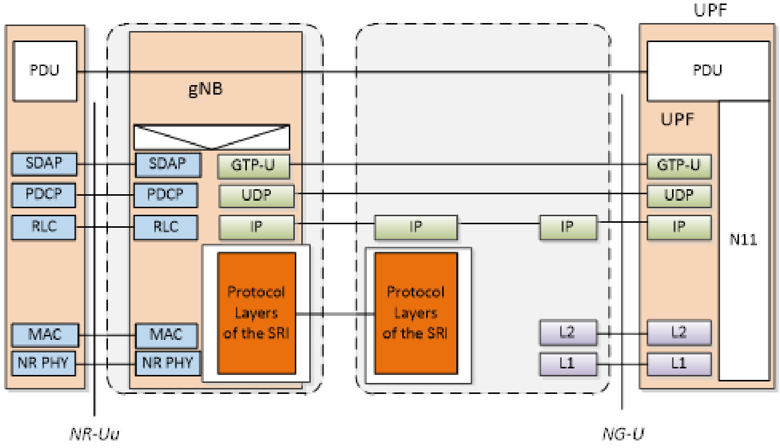
# NTN PROTOCOL STACK: TRANSPARENT & REGENERATIVE

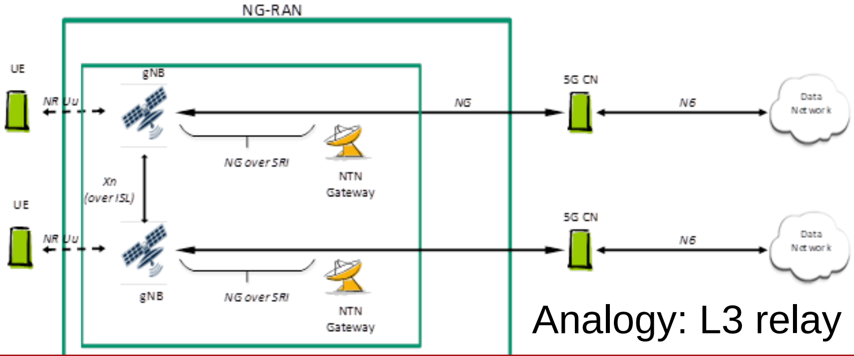



Analogy: RF repeater




Transparent NTN structure & U-plane protocol stack




Analogy: L3 relay

Regenerative NTN structure & U-plane protocol stack

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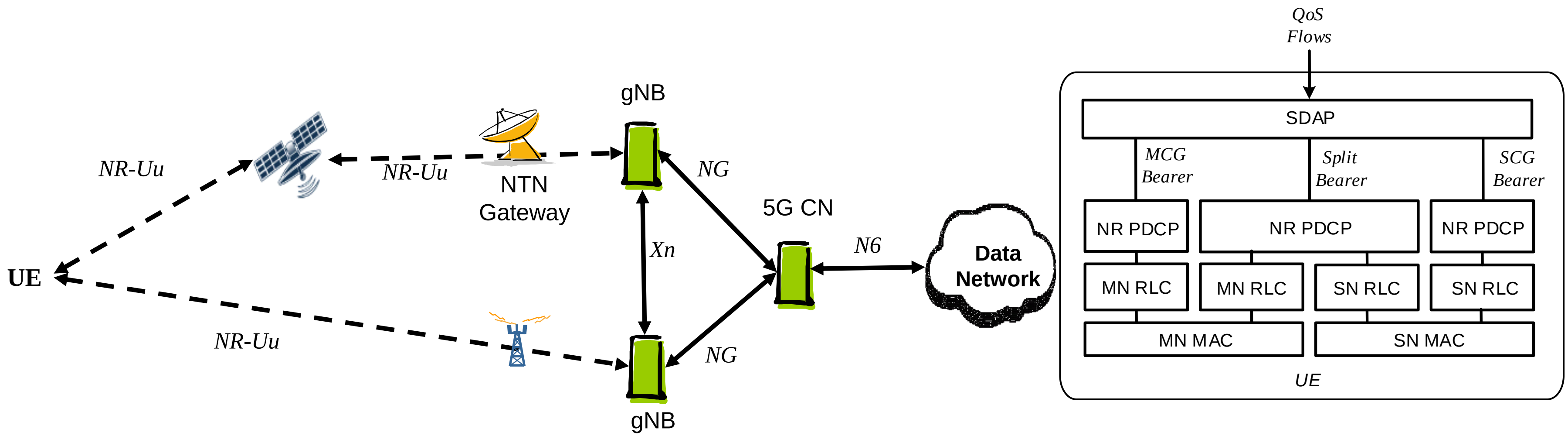
Non-terrestrial networks technology outlook

# NTN PROTOCOL STACK: TRANSPARENT & REGENERATIVE

NTN supports dual connectivity, two procedures possible: MR-DC with NTN & 5G NR terrestrial or MR-DC with 2 times NTN 5G possible



# NTN PARAMETERS – ALL 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 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 [2] 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) |

Source: TR 38.811

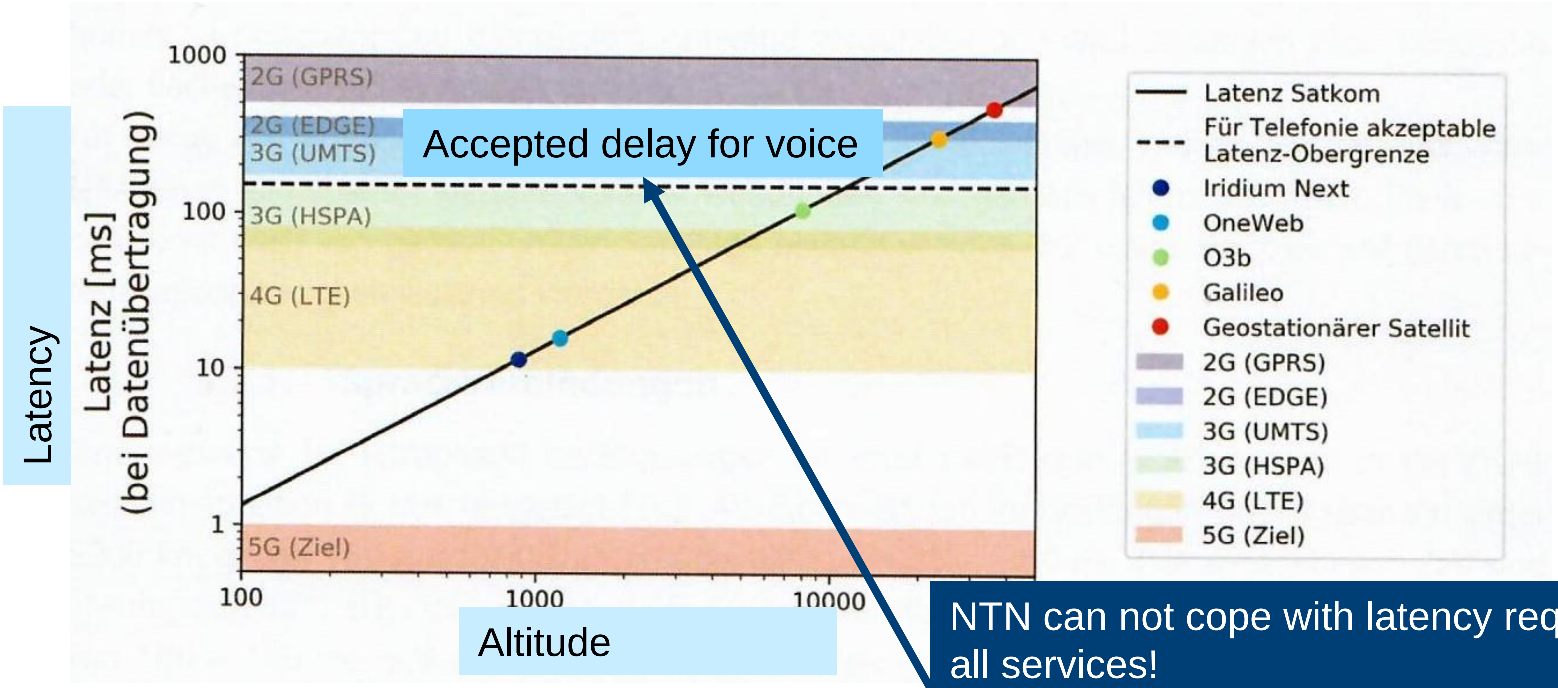
Non-terrestrial networks (NTN)

# TECHNOLOGY CHALLENGES - DETAILS

# NTN: LATENCY ASPECTS

Example: latency aspects of some satellite networks vs. Latency requirements of wireless communication services

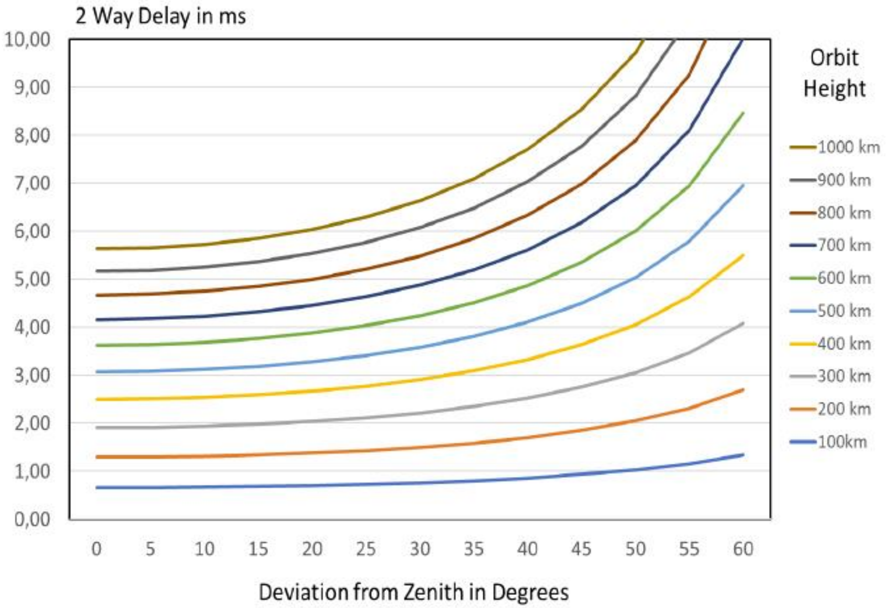
Source: Deutsches Zentrum für Satellitenkommunikation

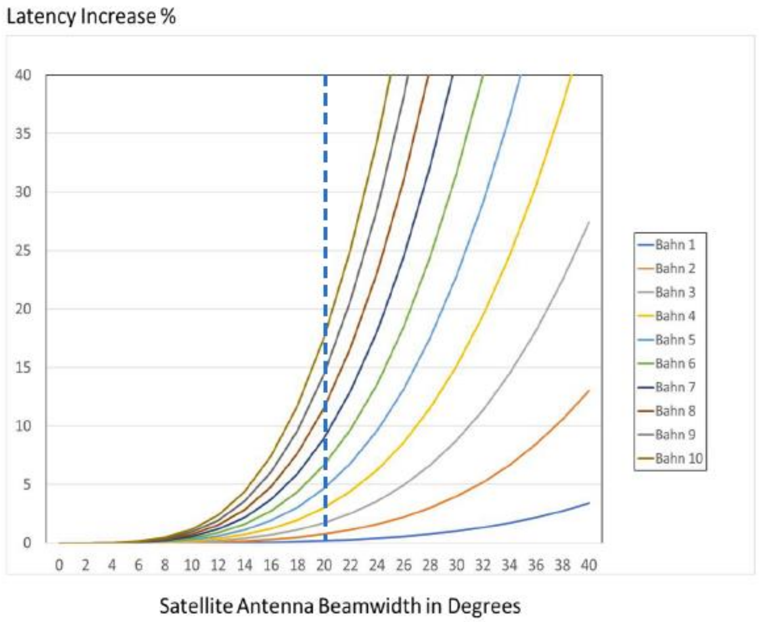



NTN can not cope with latency requirements of all services!
=> But for some delay tolerant services, NTN does fit!

# NTN: LATENCY ASPECTS

Example for LEO satellites: Assuming the beamwidth is small and orbit is short, latency can be kept <10ms. Will be different for MEO/GEO!

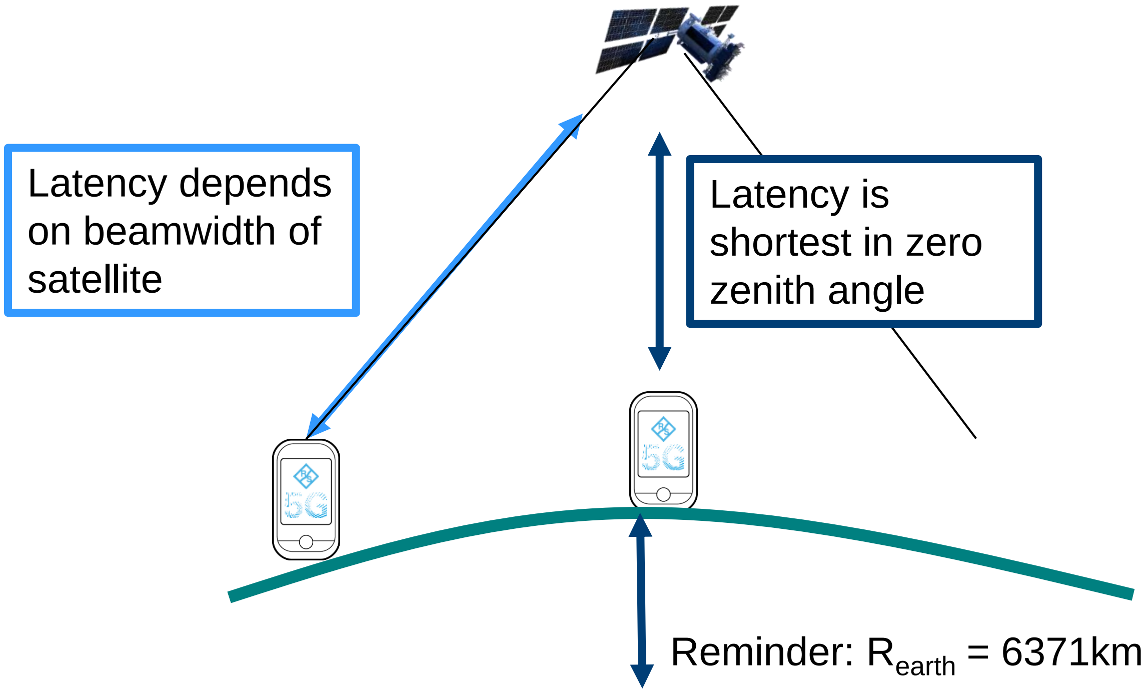



Source: Deutsches Zentrum für Satellitenkommunikation

# NTN: LATENCY ASPECTS – FLOATING RTT

Coverage expectation (here opening angle or beamwidth) and orbit height (distance info) will determine the number of satellites needed in LEO, MEO constellations



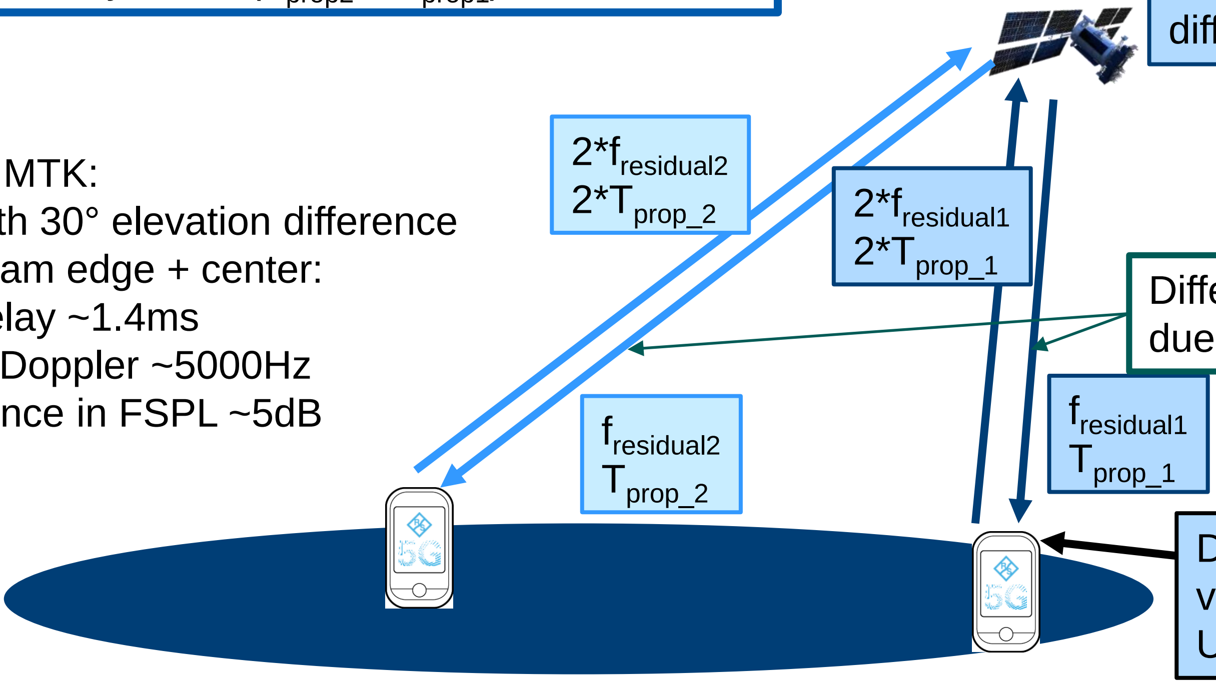

Can we neglect the influence of the earth radius?
=> Orbit distance

# NTN: LATENCY ASPECTS – FLOATING RTT

Residual Doppler = $\max(f_{residual1} - f_{residual2})$
Differential delay = $\max(T_{prop2} – T_{prop1})$

Satellite orbit, distance and elevation cause residual Doppler shift and differential delay

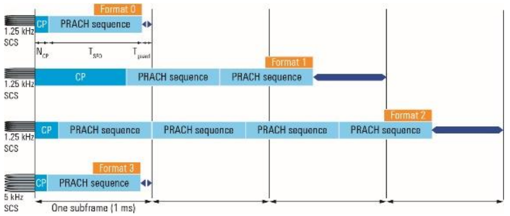
Quote from MTK:
@2GHz, with 30° elevation difference between beam edge + center:
Max diff. Delay ~1.4ms
Max. resid. Doppler ~5000Hz
Max. difference in FSPL ~5dB




Different pathloss (FSPL) due to elevation

Doppler shift and delay visible at RX entity (here UE)

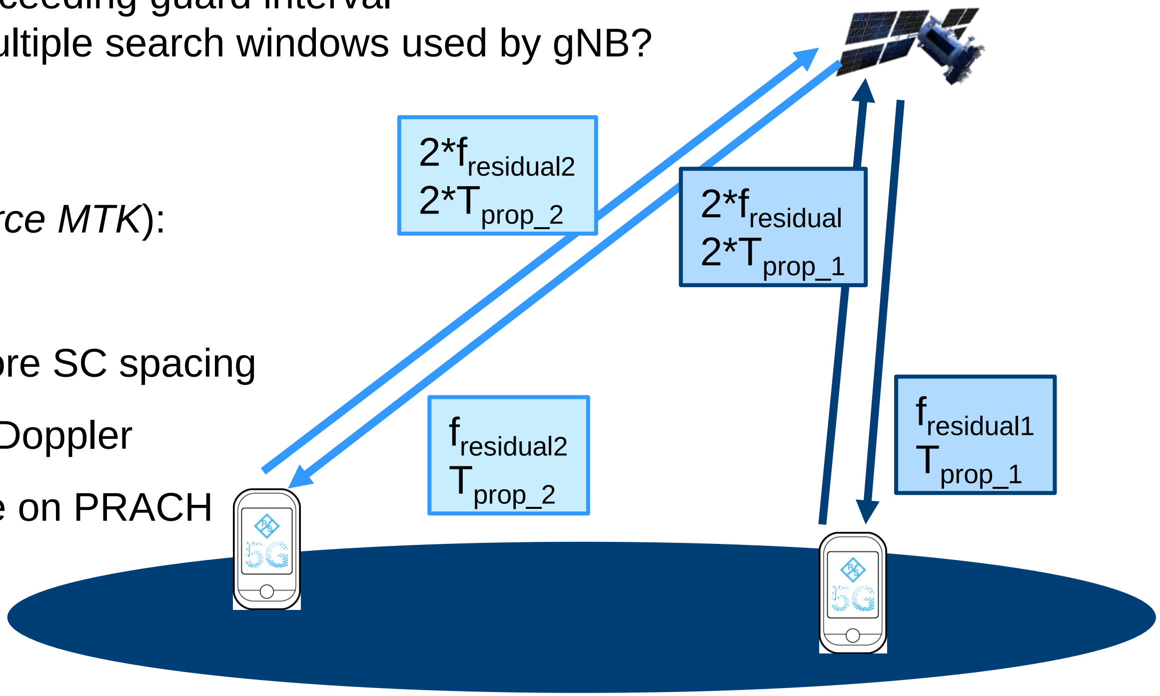
# NTN: LATENCY ASPECTS – FLOATING RTT




Propagation delay spread may cause misunderstanding of PRACH
=> exceeding guard interval
=> Multiple search windows used by gNB?

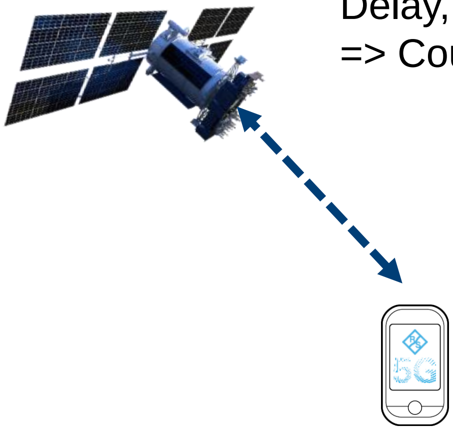
Proposals for RACH improvements (*source MTK*):

- Reduce beamwidth (cell size <50km)
- Restrict preamble formats to have more SC spacing
- GNSS capable UE: pre-compensate Doppler
- Fractional frequency hopping scheme on PRACH

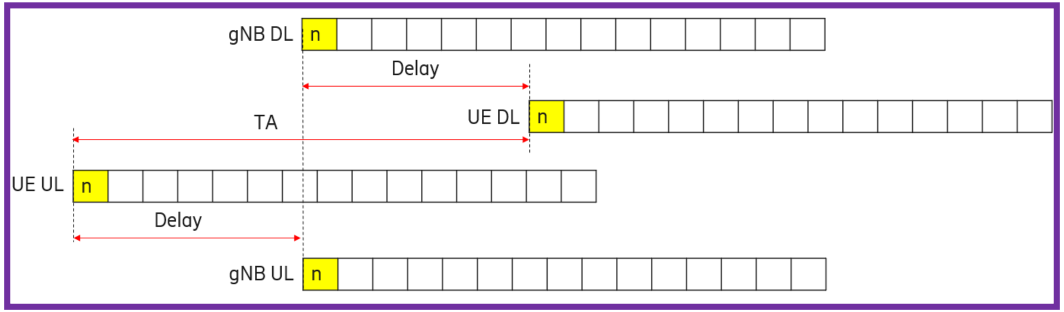


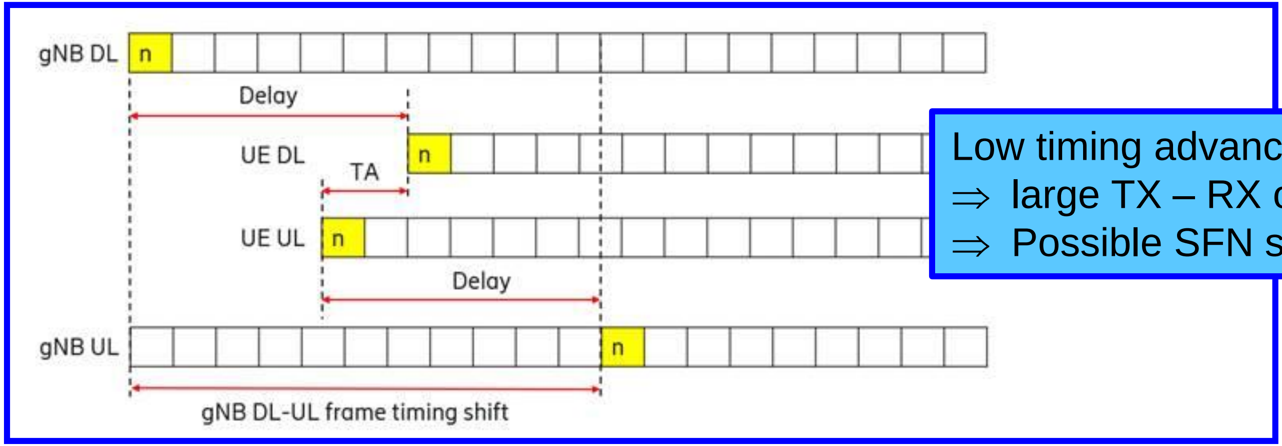
# NON TERRESTRIAL NETWORK CHALLENGES

Delay, e.g. RTT for GEO satellites ~544ms
=> Counter with timing advance strategies



Increased timing advance
=> large TX – RX offset in the UE




Low timing advance
⇒ large TX – RX offset in the gNB
⇒ Possible SFN shift in gNB for UL/DL

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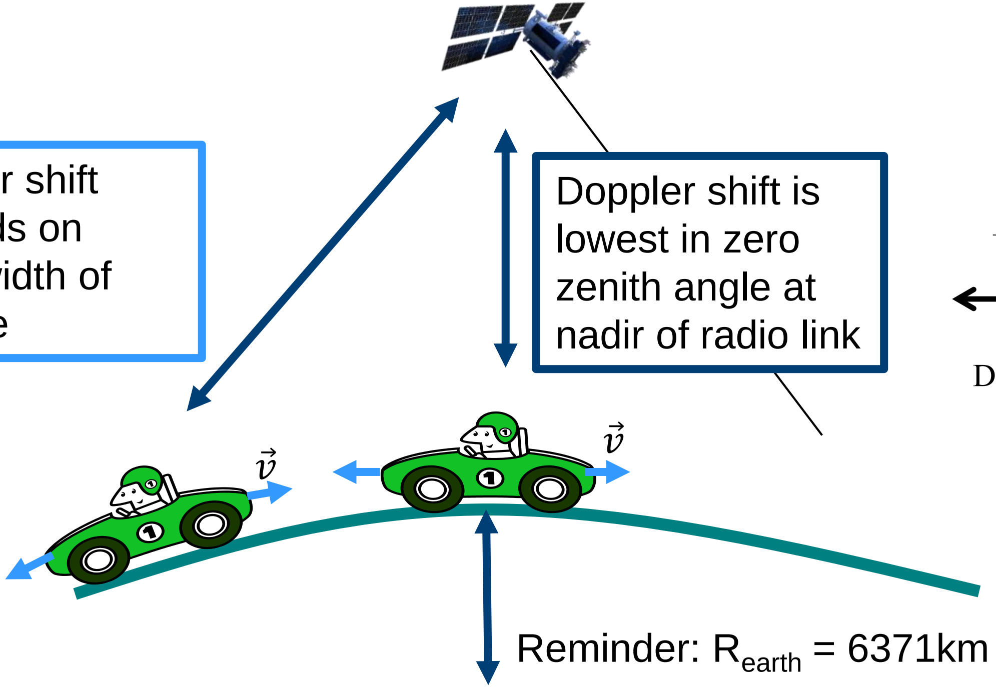
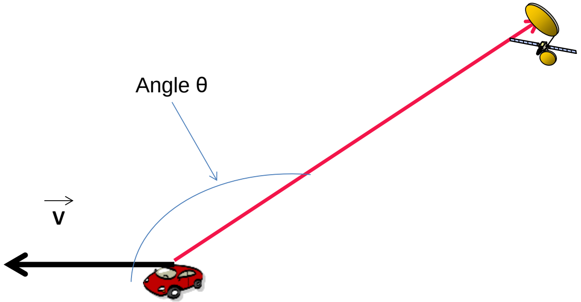
# NTN: IMPACT OF DOPPLER SHIFT

Doppler shift depends on the satellite viewing angle. Close to zero zenith, Doppler shift is low, at larger angles, Doppler shift becomes higher than in terrestrial networks
=> countermeasures: UE knows orbit and its own position. CFO adjustment at receiver to compensate Doppler (theory until now). Doppler pre-compensation at TX.




Doppler shift formula: $\Delta F = Fo*V*\cos(\theta)/c$

Fo: nominal carrier frequency

V = UE velocity

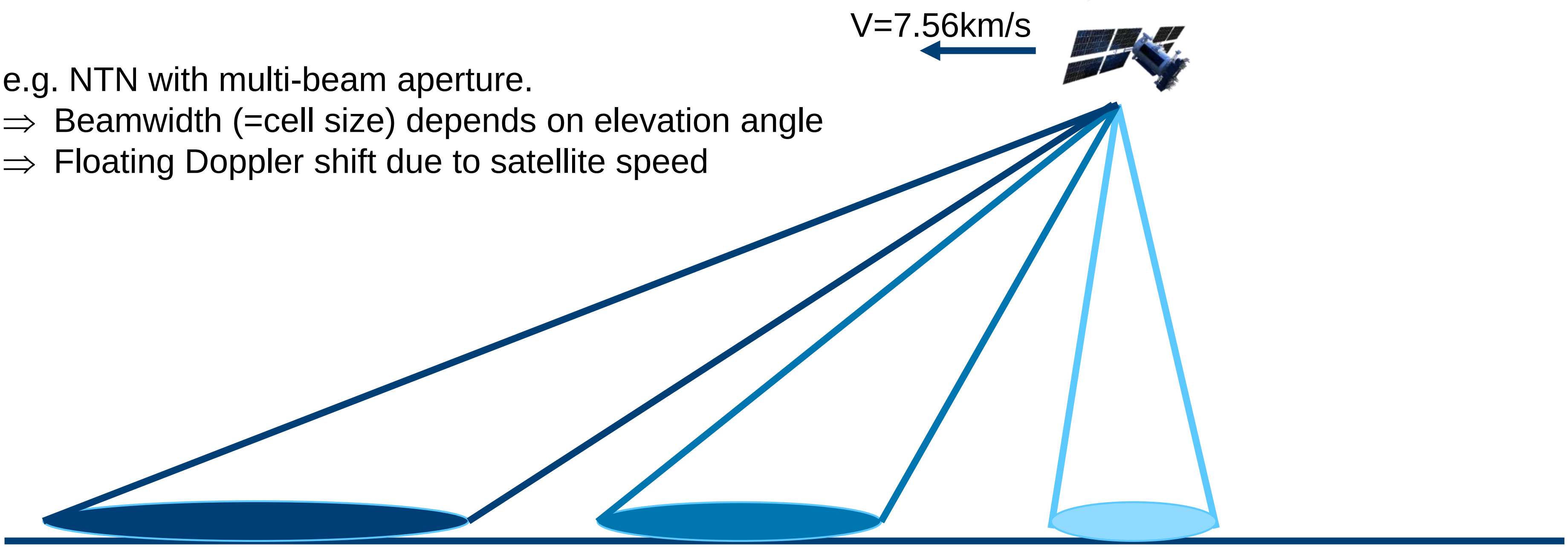
Θ is the angle between the velocity vector V of and the direction of propagation

# NTN: DOPPLER SHIFT COMPENSATION

e.g. NTN with multi-beam aperture.

⇒ Beamwidth (=cell size) depends on elevation angle

⇒ Floating Doppler shift due to satellite speed



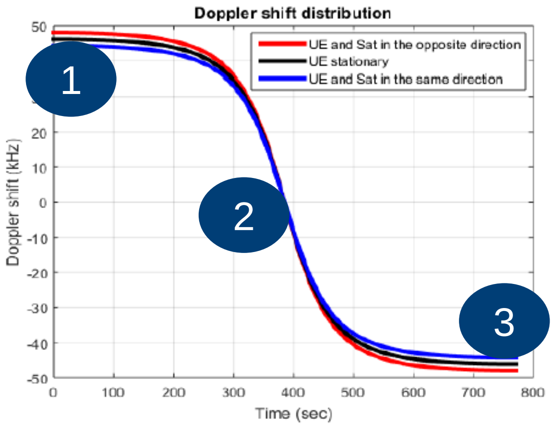

Source: MTK

# NTN: DOPPLER SHIFT COMPENSATION

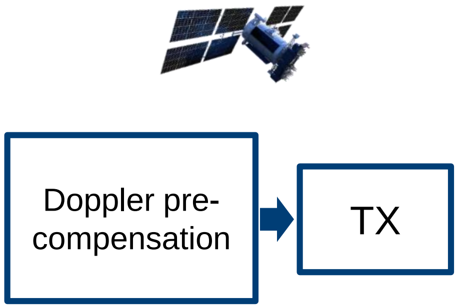

e.g. satellite speed causes Doppler shift of ~50kHz
=> After pre-compensation ~5kHz

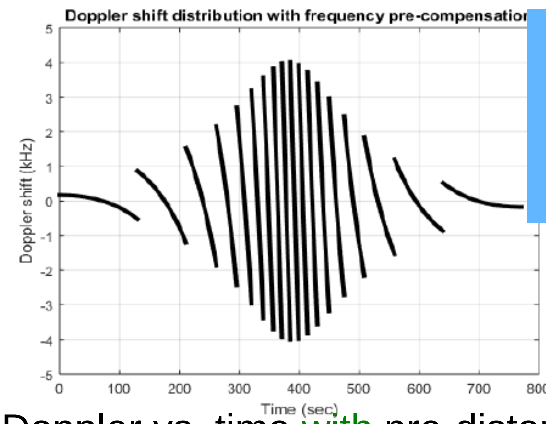
UE may spot the satellite with different angles => Doppler shift vs. time

Source: MTK




Doppler vs. time without pre-distortion



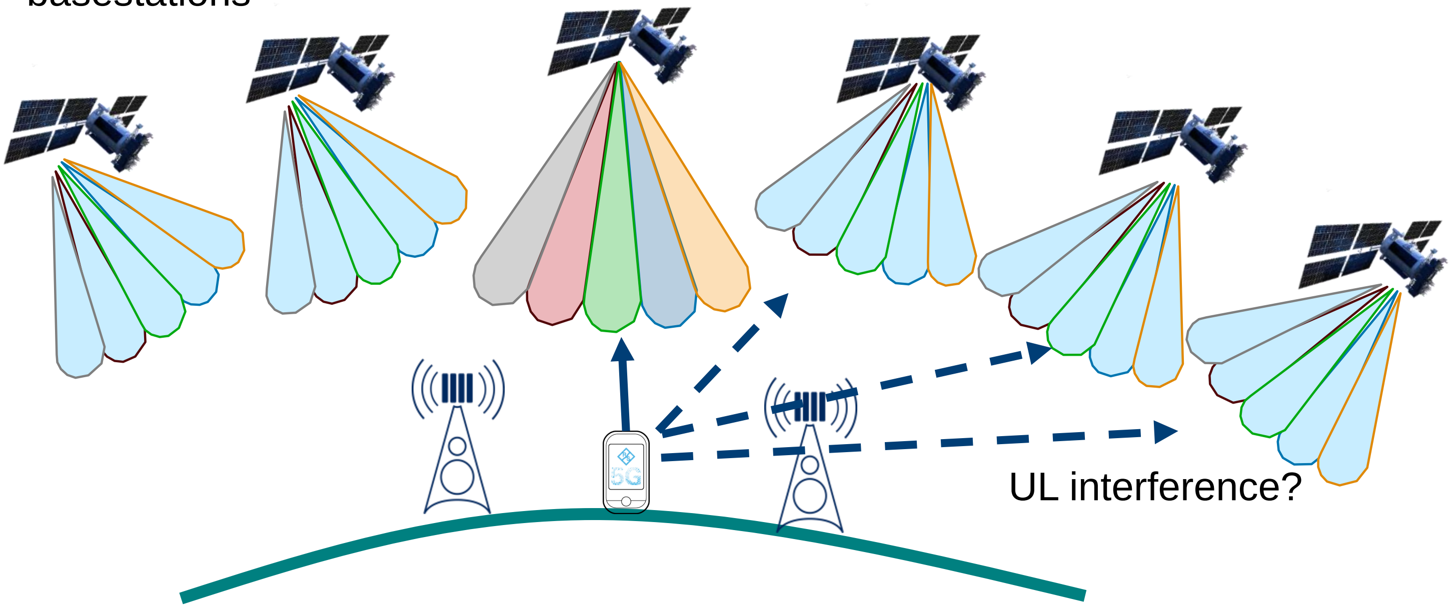

Residual Doppler shift due to beamwidth

Doppler vs. time with pre-distortion

# NTN: CAPACITY ASPECTS

Interference aspects:

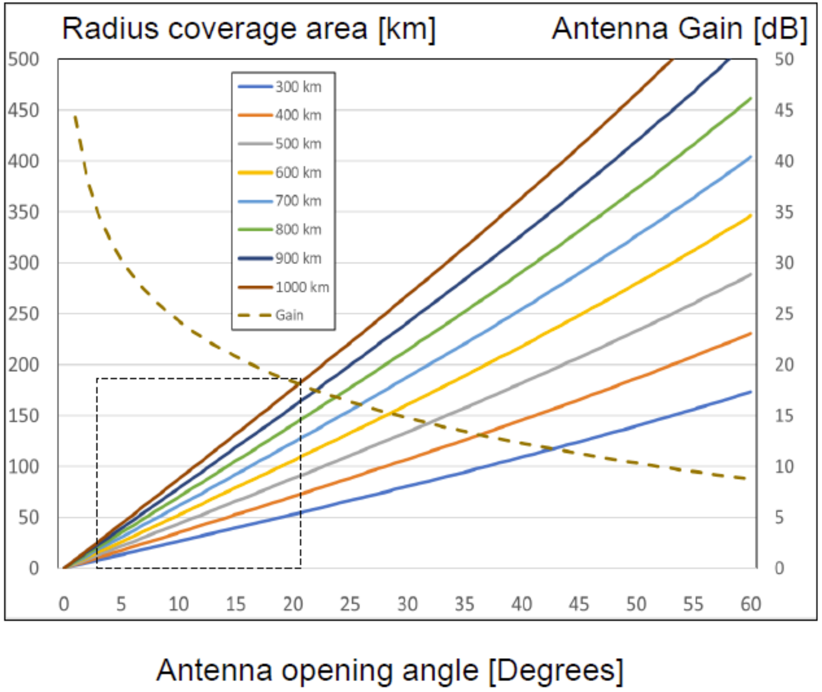
- overlapping situations of satellite beams?
- # of sattelites visible in UL direction?
- Moving “basestations“

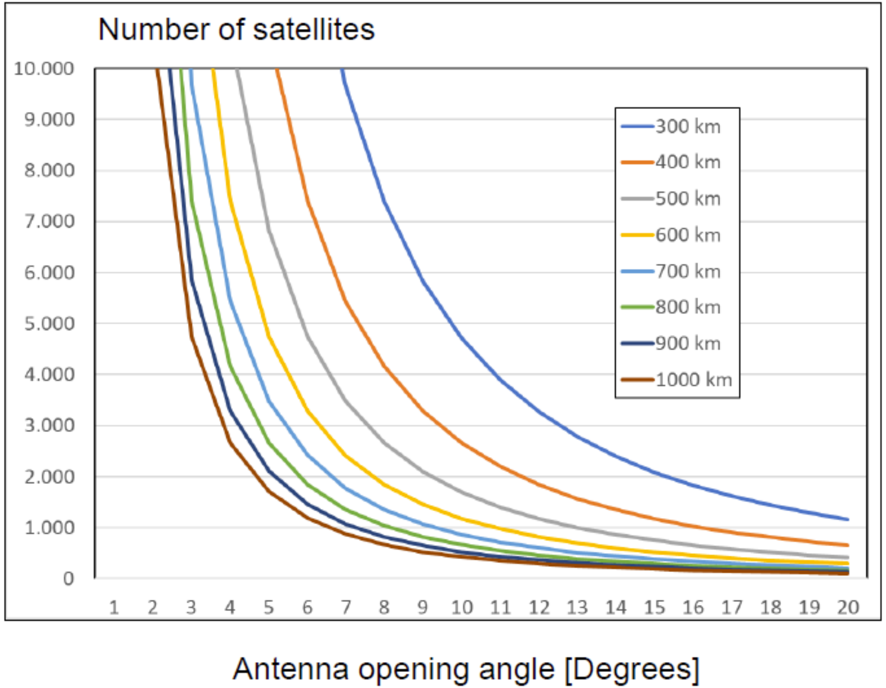



Terrestrial networks: mainly 2D-coverage, only few neighbor cells, interference aspects tackled by network planning

# NTN: #OF SATELLITES DEPENDS ON COVERAGE + ORBIT

As expected: coverage expectation (here opening angle), orbit height (distance info) will determine the number of satellites needed in LEO, MEO constellations

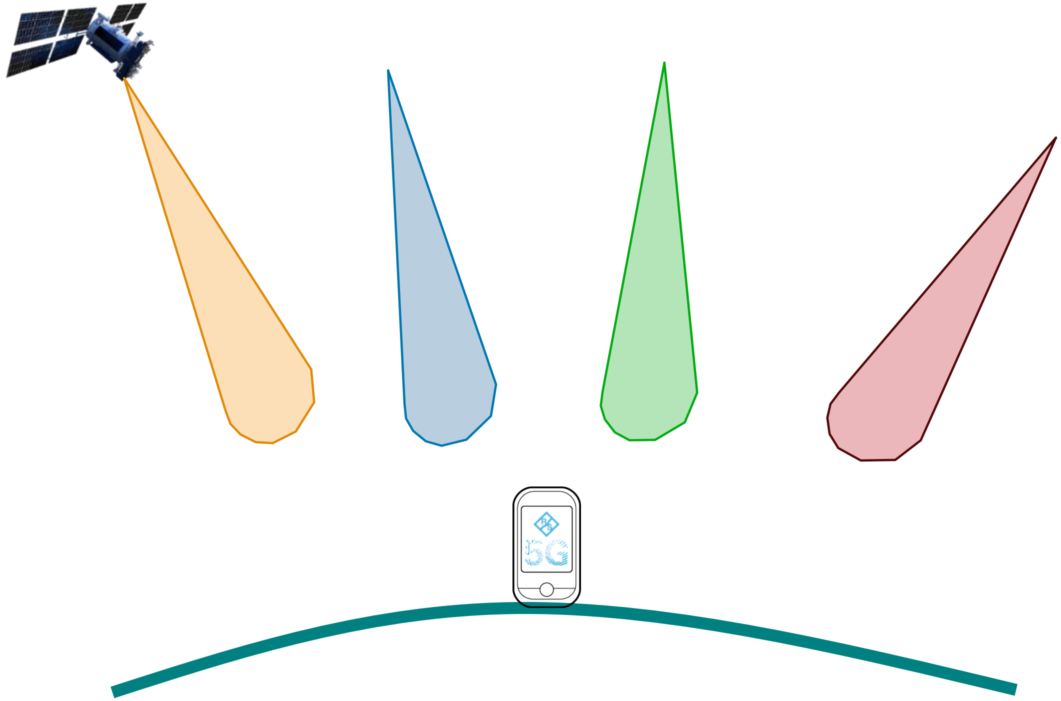



Source: Deutsches Zentrum für Satellitenkommunikation

# NTN: MOBILITY ASPECTS

Looks like we change from a mobile device to a mobile basestation ☺ Here satellite gNB without beamlock functionality

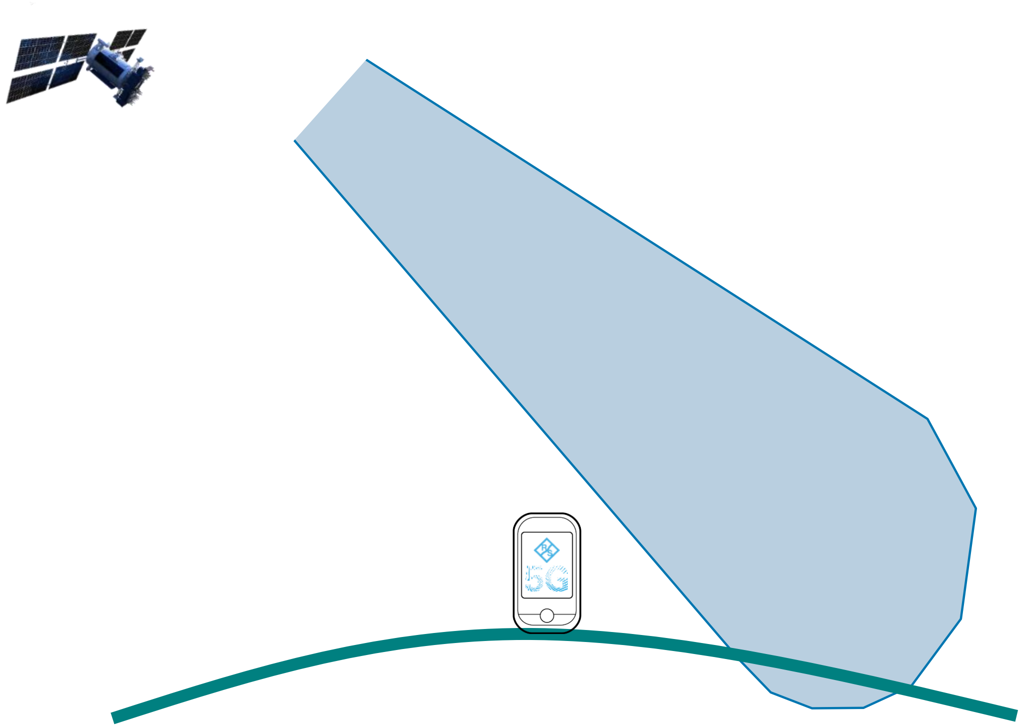



5G NR beam mobility cannot be ported:

- each satellite beam is a separate frequency channel
- Beam visibility only for short time

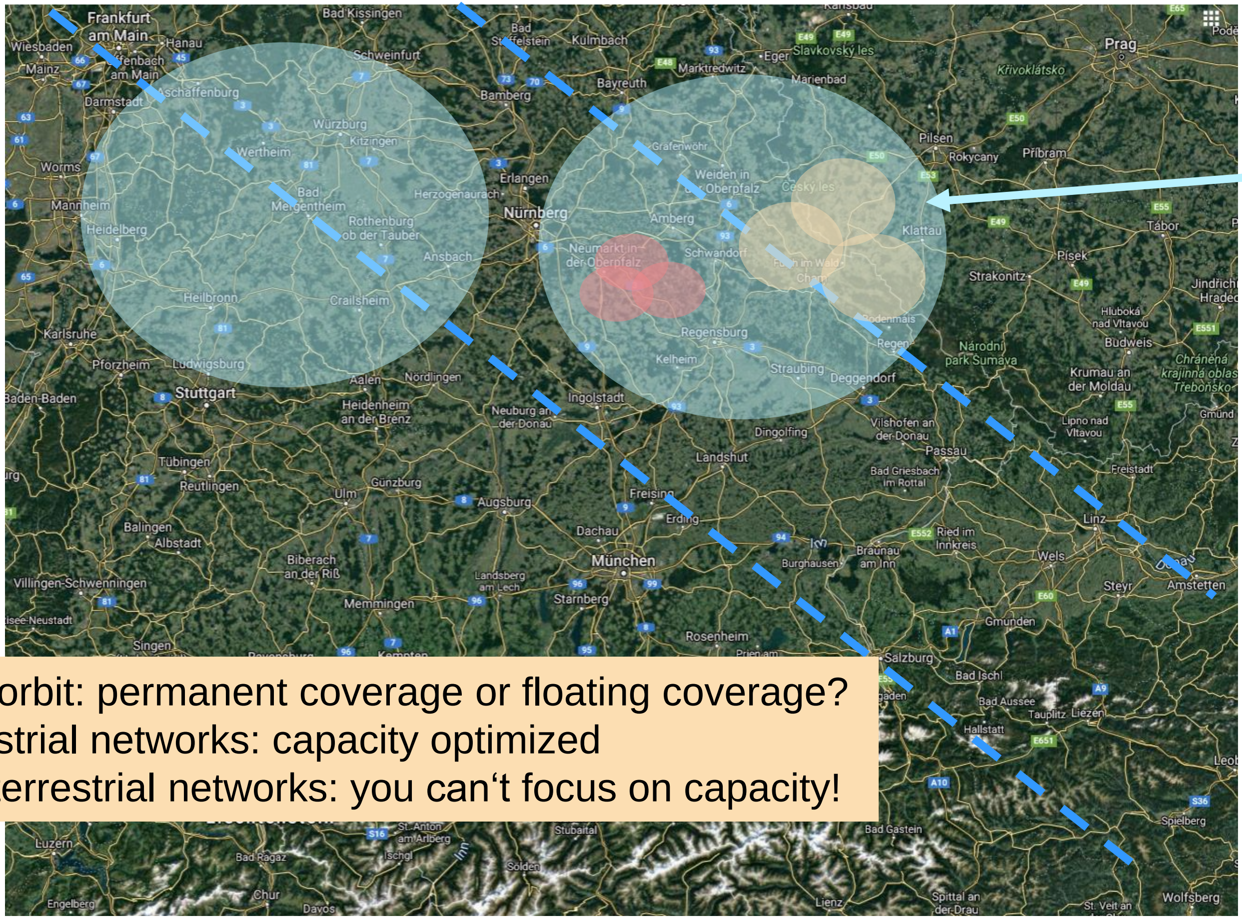
# NTN: MOBILITY ASPECTS

Satellite gNB with beamlock functionality, i.e. earth fixed beams => cell birth-death situations



5G NR beam lock will probably cause sudden cell birth and death situations. Beam visibility only for short time

# NTN: COVERAGE & CAPACITY ISSUES




Assumed satellite trajectory, here LEO (MEO)

Assumed S-band coverage (snapshot)

Assumed Ku-band coverage

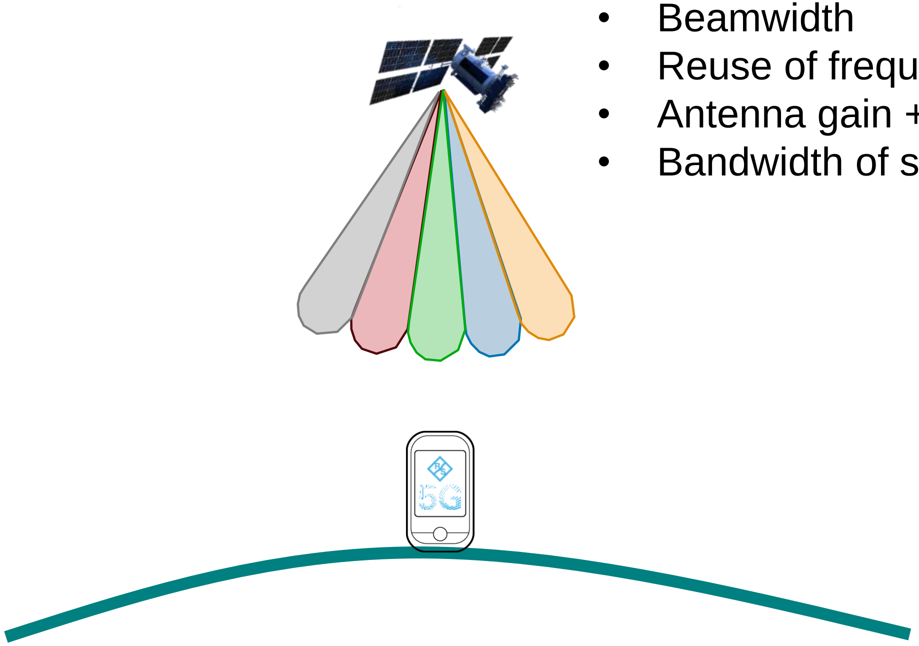
Assumed Ka-band coverage

Satellite orbit: permanent coverage or floating coverage?

⇒ Terrestrial networks: capacity optimized

⇒ Non-terrestrial networks: you can‘t focus on capacity!

# NTN: CAPACITY ASPECTS

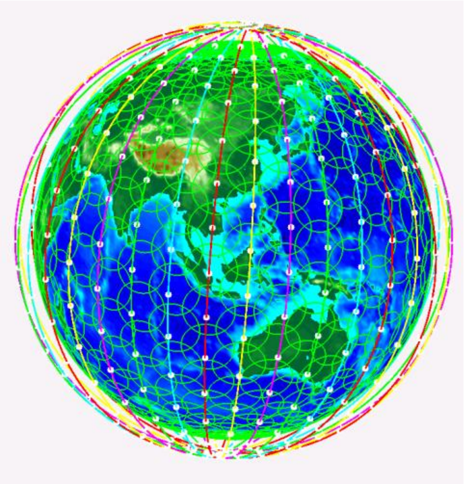



Satellite design aspects:

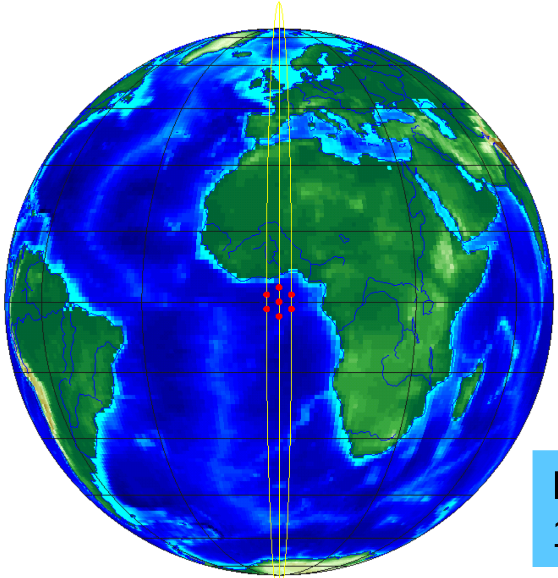
- #of beams
- Beamwidth
- Reuse of frequency? # of channels
- Antenna gain + EIRP
- Bandwidth of single channel

# NTN: COVERAGE ASPECTS

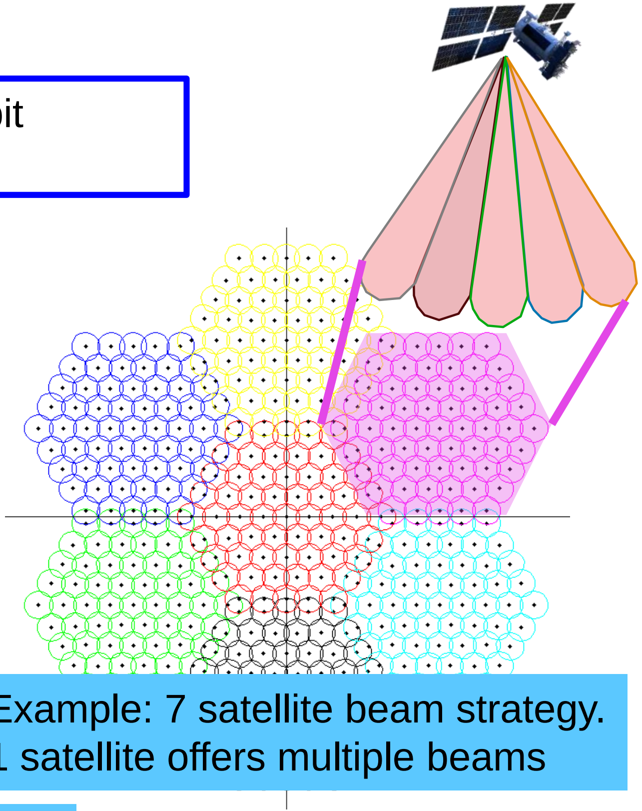
NTN coverage: large number of simulations playing with different orbit constellations & beamforming stragegies



Example: orbit constellation vs. earth coverage

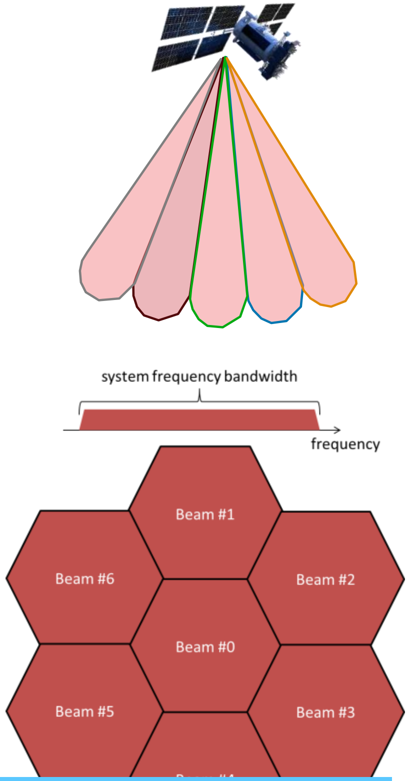


Example: satellite grouping, e.g. 7 satellites for one coverage area

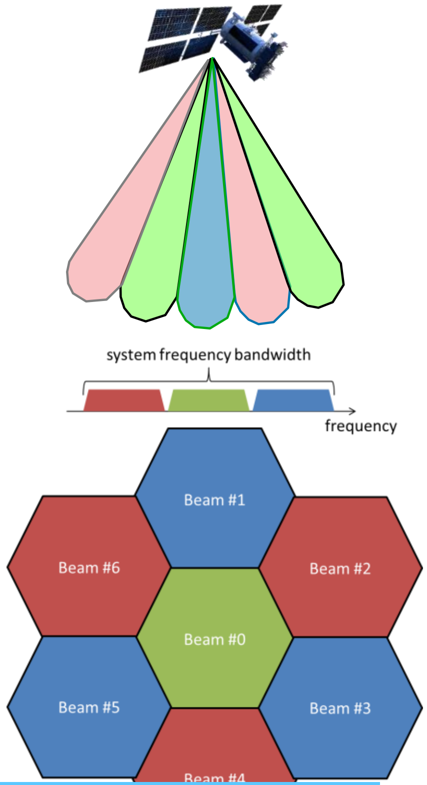


Example: 7 satellite beam strategy. 1 satellite offers multiple beams

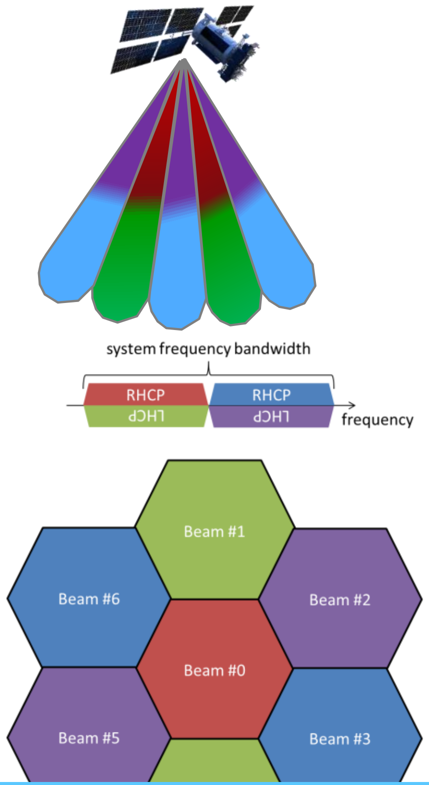
# NTN: BEAM DEPLOYMENT AND FREQUENCY REUSE




Full bandwidth,
Frequency reuse = 1




Divided bandwidth,
Frequency reuse = 3




Divided bandwidth + circular polarization
Frequency reuse = 2

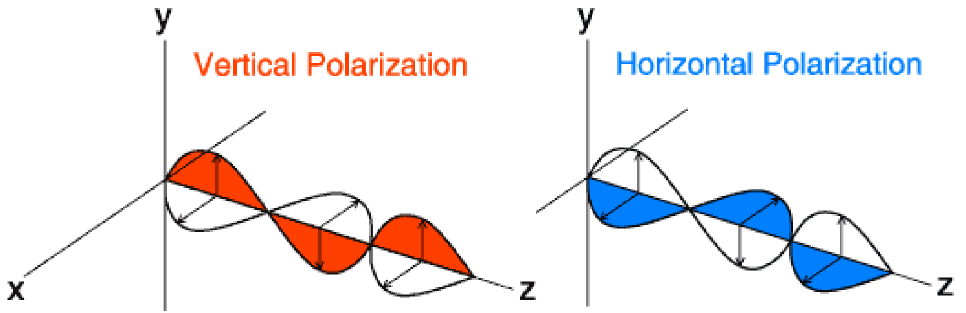
Rohde & Schwarz

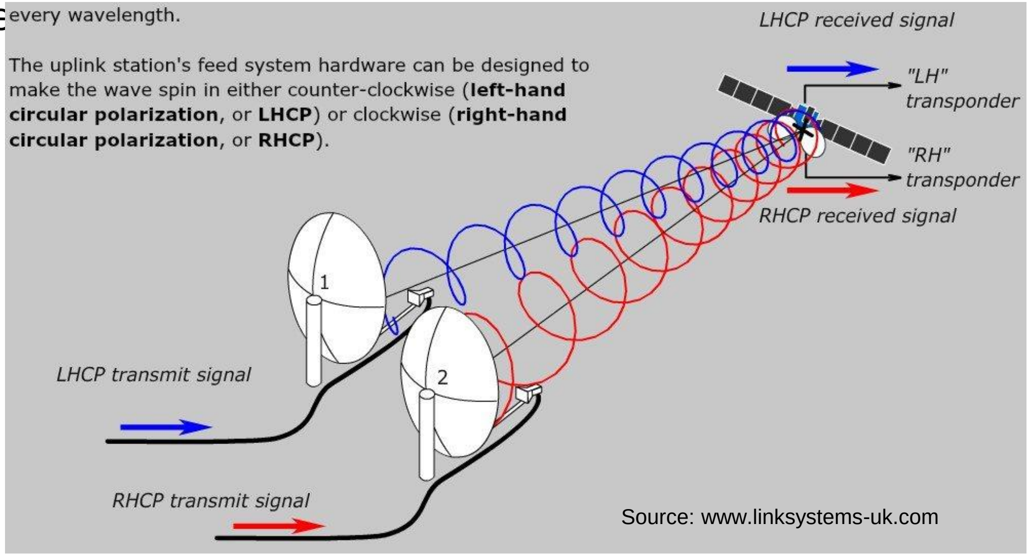
Non-terrestrial networks technology outlook

# REMINDER: ANTENNA POLARIZATION

Polarization is the orientation of the E-plane of a radio wave relative to the Earth’s surface.

The two most common types of linear antenna polarization are **vertical** polarization and **horizontal** polarization. **Circular** polarization is often found in space-based applications. The magnitude of the $\vec{E}$ field vector is constant, but the direction changes and rotates around the direction of propagation, either left-hand or right-hand.



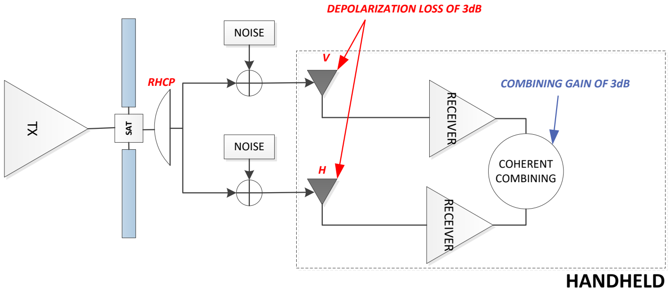

Antenna polarization

| E vector of incoming signal | ⇧ | ⇨ | ↷ | ↶ |
|---|---|---|---|---|
| V ⇧ | 0 dB | ∞ | 3 dB | 3 dB |
| H ⇨ | ∞ | 0 dB | 3 dB | 3 dB |
| RHC ↷ | 3 dB | 3 dB | 0 dB | ∞ |
| LHC ↶ | 3 dB | 3 dB | ∞ | 0 dB |

Rohde & Schwarz

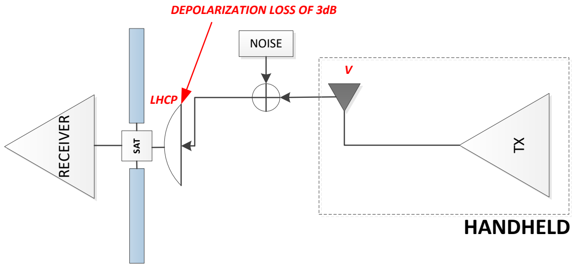
Challenge: polarization mismatch causes losses (example from WLAN 11ad)

# REMINDER: ANTENNA POLARIZATION




Scenarios described in TR 38.821

Downlink view: Assumption, UE with 2RX to prevent depolarization loss

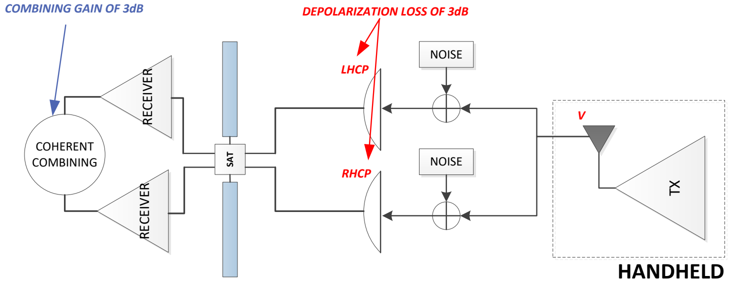



CONFIGURATION A

Uplink view: Assumption & scenarios:

- Circular polarization with polarization reuse => 3dB depolarization loss (configuration A)
- Dual polarization per beam => 0dB depolarization loss (configuration B)

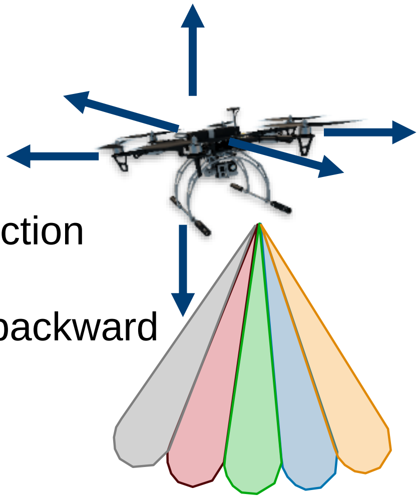
=> capacity aspects vs. Attenuation ☹



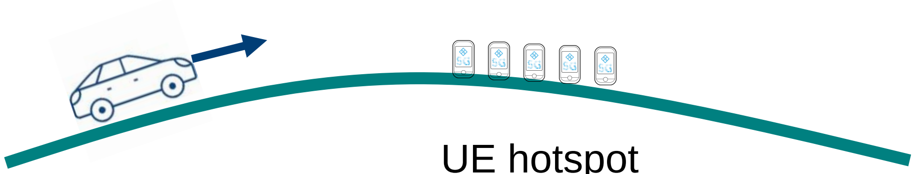

CONFIGURATION B

# NTN: CAPACITY ASPECTS, E.G. DRONES AS gNB

Drone control:
3D position + action
- Up & down
- Forward & backward
- Left&right



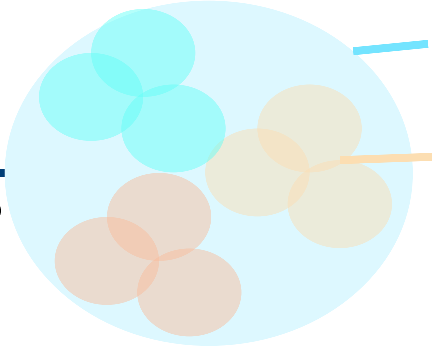
Positioning the drone gNB is a complex problem:
= max(∑users, ∑QoS, ∑ coverage)
= AI for positioning, i.e. Q-learning algorithm:
QoS metric
#user as metric
take action (new position s+1 => observe QoS + 1)
monitor QoS
-> undo or keep position s+1



# NTN: PAGING ASPECTS

AMF

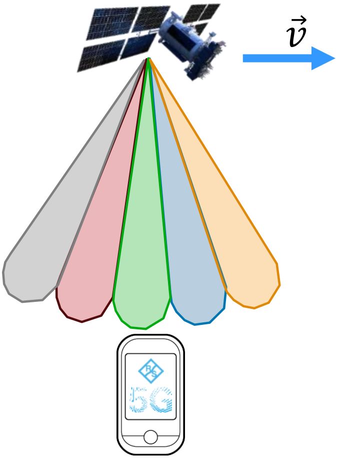
AMF has UE location info on registration area granularity for paging



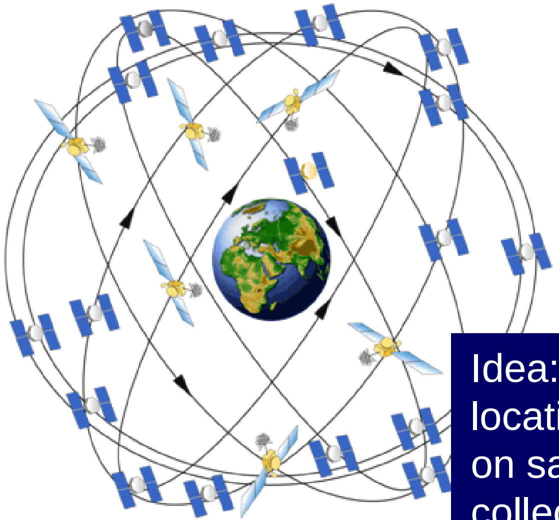
Registration area = collection of Tracking areas

Tracking area = collection of cells

=> But now we change our world: not the UE is mobile, but the "basestation"



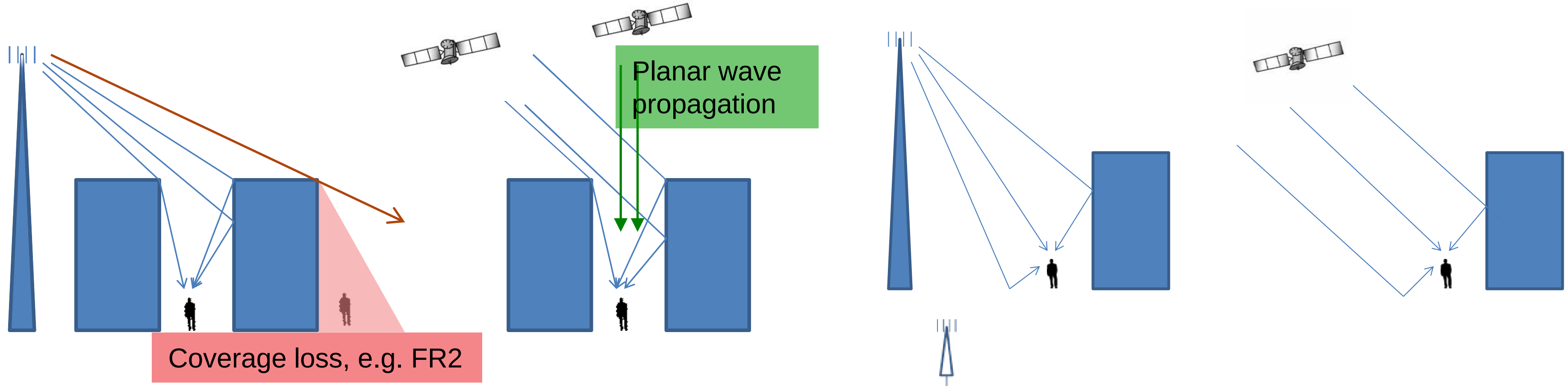

NTN challenge: satellite is moving, UE camps on beam
- ⇒ camping on different beams & different satellites
- ⇒ Traditional registration area concept will fail for paging purpose



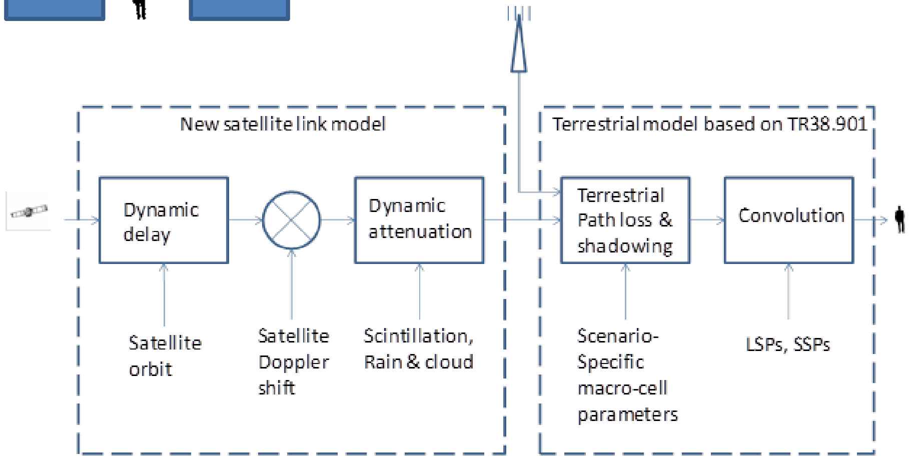
Idea: UE will report geo-location, ephemeris info on satellites is used to collect paging candidates

# NTN: IMPACT ON CHANNEL MODELS

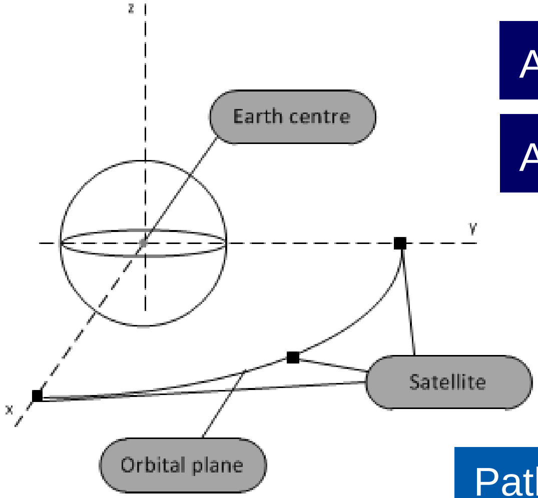
## Wave propagation differences NLOS/LOS between terrestrial and non-terrestrial




## Combine satellite & terrestrial channel models



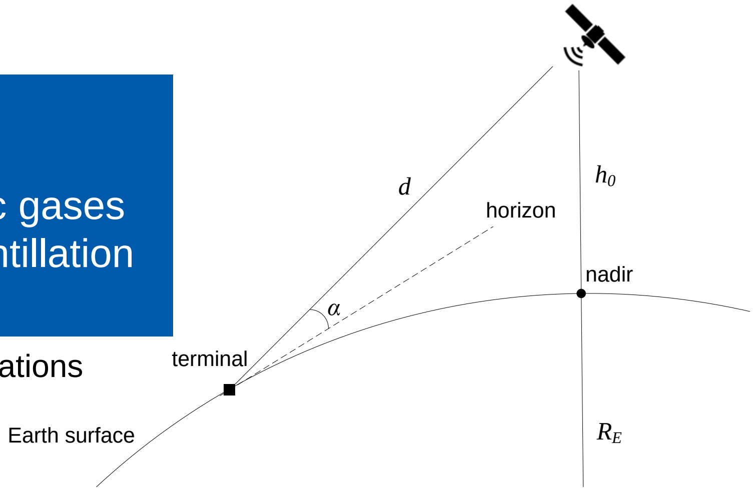
# NTN: IMPACT ON CHANNEL MODELS




Assumption: UE is on a spherical surface with $\sqrt{x^2 + y^2 + z^2} = 6371km$

Assumption: satellite is on a elliptical surface with $\sqrt{x^2 + y^2 + z^2} > 6371km$

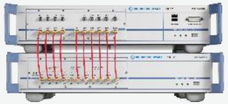
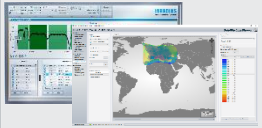
Pathloss $PL=PL_b+PL_g+PL_s+Pl_e$ with
$PL_b$= free space path loss
$PL_g$= attenuation due to atmospheric gases
$PL_s$= ionospheric + tropospheric scintillation
$Pl_e$ = building entry




Values for atmospheric attenuations or scintillation are given by ITU specifications

# R&S SATELLITE TESTING SOLUTIONS PORTFOLIO

| | |
|---|---|
|  | Signal Generators |
|  | Signal and Spectrum Analysis |
|  | IQ Acquisition and Replay |
|  | Network Analysis |
|  | OTA Chambers |
|  | Oscilloscopes |

| | |
|---|---|
|  | Power Sensors |
|  | TVAC |
|  | Switch Matrix |
|  | Satellite Load Generators |
|  | Ground Station Power Amplifiers |
|  | Monitoring and Planning Software |


"If you want to go fast, go alone.
If you want to go far, go together!"
African proverb

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