

NR Non-Terrestrial Networks (NTN) Technology and Testing

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AGENDA

NTN Market Overview

3GPP NTN Technology Overview

Keysight NTN Test Solutions

Video Demonstration



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5G Non-Terrestrial Networks (비지상 네트워크)

Ubiquitous Coverage (Mountains, Rugged Terrain, Oceans, Planes...)



Northern Sky Research (NSR) indicates that close to 10 million active revenue sources will help provide **\$32.5 billion** of extra revenue by 2029

“Why is Everybody Suddenly Interested in Satellites?”

Market Opportunity

1. Global coverage of **High-Speed Internet** is very expensive

2. Terrestrial Infrastructure is too sensitive to **natural disasters**

3. Dead zones, emergencies, text messaging, voice, etc in handsets are now **differentiators**



1. **Satellite launch cost** has extremely reduced in past few years (Space-X)

2. Constellation with **+10,000 satellites** are now an achievable and affordable project

3. Use of **low earth orbits (LEO)** enables low latency and higher data rates

SPACEX



AST
SpaceMobile

omnispace



Globalstar



Recent Announcements in This Space

Satellite to Smartphones

Apple iPhone 14 / GlobalStar

- Emergency SOS service for free available in 2022 – likely using approved GlobalStar spectrum

Qualcomm / Iridium / Android

- SMS texting planned for end of 2023; exclusive to phones using Snapdragon SOC using Iridium's radio interface

Huawei Mate 50

- China's global BeiDou satellite network for text messaging, allowing for messages in areas without cellular coverage

1. PROPRIETARY

SpaceX / T-Mobile US

- Text messages and voice calls in “un-modified phones” using TMO PCS spectrum (likely 4G/5G) using new Starlink Satellites V2 to be launch along 2023 (no FCC approval yet)

AST / AT&T / Vodafone

- Support for “unmodified 5G smartphones” with higher data rates (dealing with technical and regulation challenges)

2. Unmodified Phone

Skylo / Bullitt

- Adoption of NB-IoT NTN and offering two-way messaging using GEO/GSO

Omnispace

- Adoption of 5G NTN and offering 5G and IoT services using LEO/MEO in US and EU

3. 3GPP R17 NTN

Activities from Device Manufacturer

Satellite to Smartphones

Satellite constellation	Service	Altitude (km)	Number (satellite)	Radio Tech.	Frequency
Globalstar	SOS message	1440	22	CDMA	S-band n53: 2483.5 – 2495, BW5 or 10
Iridium	Test message	689	92	FDMA/TDMA	L-band 1~2GHz: 1,618.85 to 1,626.5 MHz
Starlink (SpaceX)	V2X	530~570 335~335	thousands	N/A	Ka-band Satellite-to-Terminal: 10.7 – 12.7 GHz Terminal to Satellite: 14.0 – 14.5 GHz
Beidou	Text message	21150	25	CDMA	B1C: 1575.42 MHz, BW 32.736 MHz B2a: 1176.45 MHz, BW 20.46 MHz B3I: 1268.52 MHz, BW 20.46 MHz
Skylo	Text message	35786	A few	NB-IoT NTN	Band: 23 / 255 / 256



Key Aspects For Success in Handsets

Satellite to Smartphones

1. Continuous investments on **new Satellite Constellations** ready to support broadband communications
2. Development of **Low-cost terminals** would enable mass market ambitions
 - Use of LEO help improve the link margin, reduce the size of the device
 - Use of standardized radio access avoids technology fragmentation
3. **Adoption of 3GPP NTN** to enable massive number of devices and enable new services
 - Needed 5G enhancements to compete against new proprietary services
4. **Regulatory approvals** and global agreements is a risk that needs to be resolved

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3GPP Technology Timeline



5G Advanced – 3GPP Release 18 Started



1st Launch May'18



NR NSA Freeze
NR NSA ASN.1
NR SA Freeze
NR SA ASN.1
R15 Late Drop Freeze
R15 Late Drop ASN.1

R15 Focus Area

- 5G NR NSA & SA
- eMMB in FR1, FR2



R16 Focus Area

- C-V2X
- Private Network / IIoT & URLLC
- Industrial IoT
- Positioning
- Power efficiency
-

Package Approval
RAN 1 Freeze
R16 R16 Freeze ASN.1
R16 RAN4 Completion



R17 Key Focus Areas

- NR RedCap
- eMMB evolution
- IIoT & URLLC enhancements
- NR positioning enhancements
- NR for non-terrestrial networks
- Integrated access & backhaul
- More power savings
- Up to 71 GHz
-

Package Approval
RAN1 Freeze
Stage-3 Freeze
ASN.1 Freeze
RAN4 Completion



Package Approval
RAN1 Freeze
Stage-3 Freeze
ASN.1 Freeze
RAN4 Completion



Package Approval



Package Approval



Types of Orbits

Impact to Communications

Satellite Properties	NGSO		GSO 지구동기궤도
	LEO	MEO	GEO
Altitude (km)	~ 1,000	~ 20,000	~ 35,786
Orbit period (hrs)	~ 2	~ 12	~ 24
Speed (km/s)	~ 7.5	~ 4	~ 3
RTT (ms)	~ 13	~ 100	~ 500
Max Doppler (kHz)	~ 50	~ 3	< 1
Beam footprint (km)	100 – 50	100 – 500	200 – 1000
Satellites Required	1,000s	10s	Few

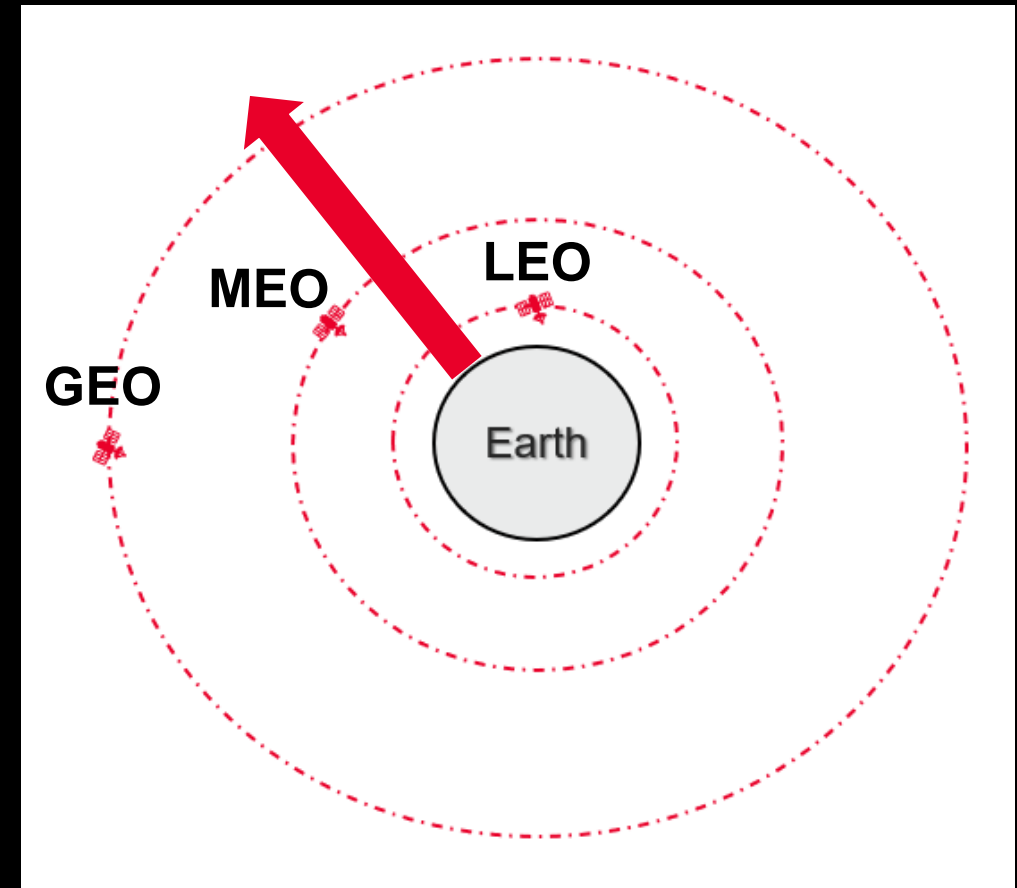
Note: These are just illustrative values for orbit comparison around 2GHz

Low Earth Orbit constellations are of high interest for handsets given:

- Lower path loss
- Lower Latency

although:

- Higher Doppler due to satellite speed
- Large number of satellites required to achieve service continuity



- * LEO (Low Earth Orbit)
- * MEO (Medium Earth Orbit)
- * GEO (Geostationary Earth Orbit)

Satellite Communications

Challenges

1. Link budget due to **high path loss**

- Large distance leads to longer transmissions
- Device size need to be considered

2. Propagation **delay and time drift** due to moving distance

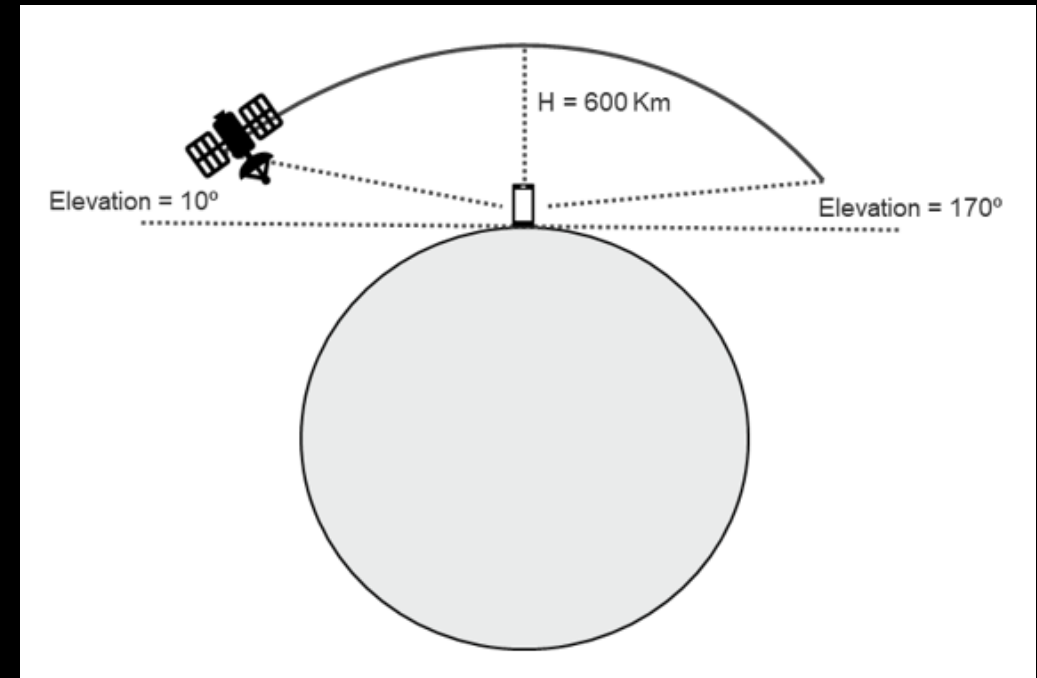
- High and variable delay
- Varying delay of around 1-2 samples per slot

3. **Doppler** caused by moving Satellite

- Changes over time in LEO given moving satellite
- Doppler offset in the range of tens ~ kHz

4. **UE pre-compensation**

- UE needs to compensate Doppler, Delay and Time drift
- UE needs Satellite ephemeris (broadcasted by NW)
- UE's Location (GNSS)



Challenges of Longer and Varying Delay

Max RTT and Varying Delay

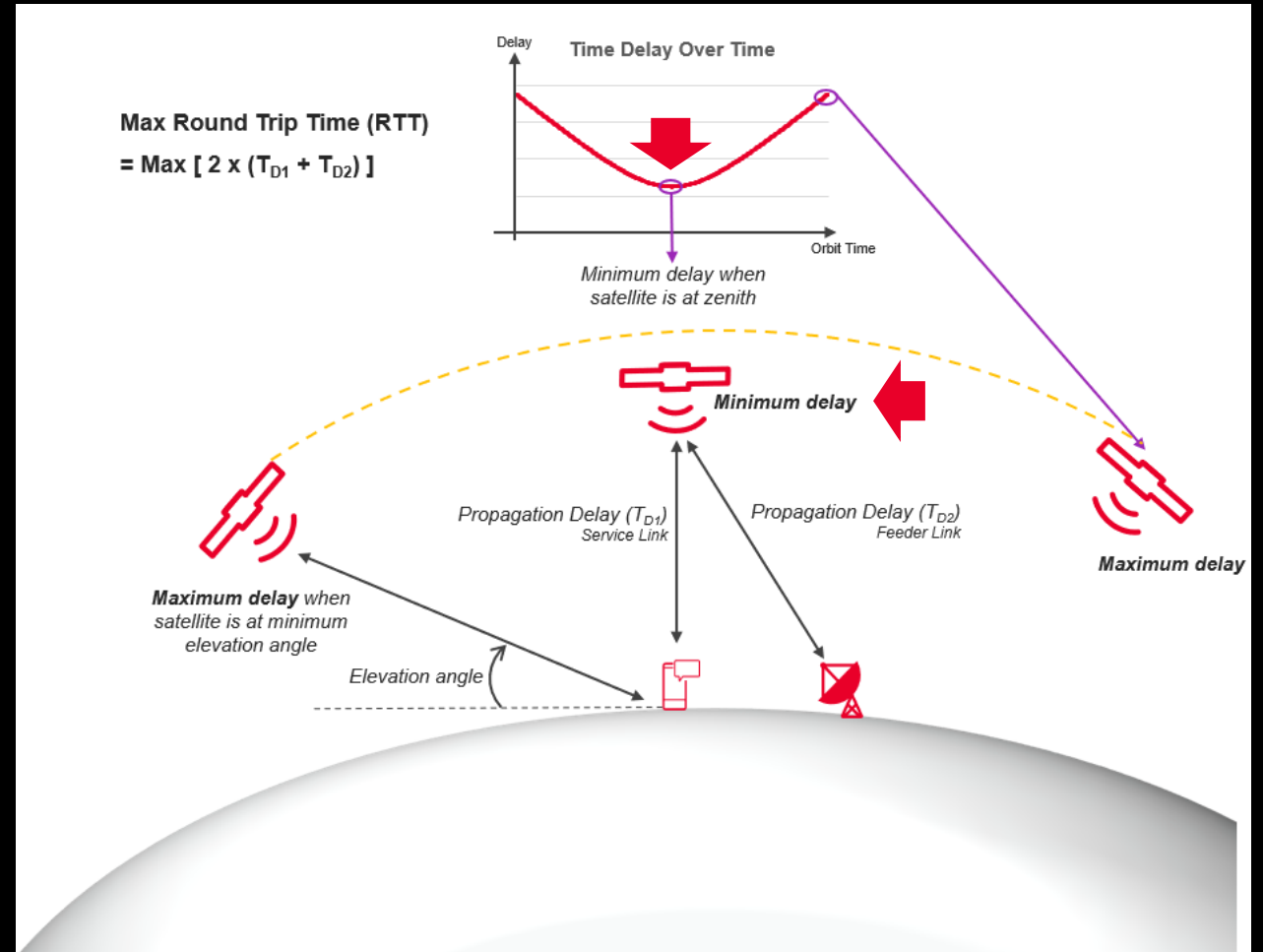
Larger propagation delay due to large distance to satellite

Round Trip Time (RTT) is the propagation time a packet would take since this is sent from the GW to the terminal and back

RTT is calculated as **2 times the one-way** trip time

The propagation **delay** between satellite and the UE **varies over time** depending on satellite's orbit

RTT reaches its maximum value at the minimum visible elevation angle



Challenges of Larger Doppler Variation With Time

Max and Varying Doppler

Doppler shift is caused by the relative velocity difference between Transmitter and Receiver → carrier shift and Code Doppler effect

Satellite orbital velocity depends on satellite altitude

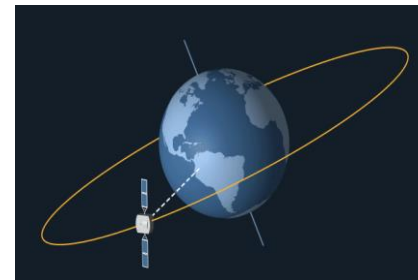
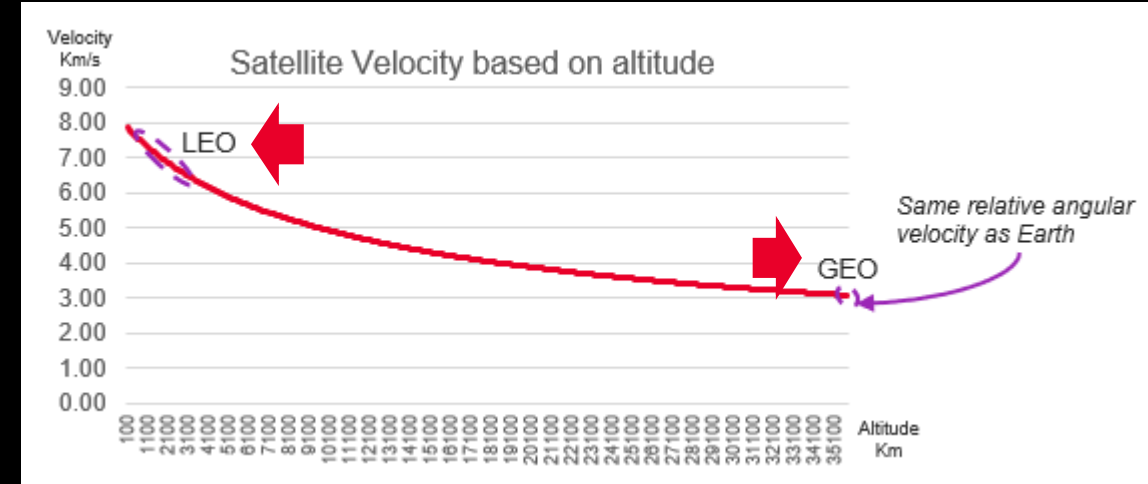
- Faster velocity is required at low altitudes in order to compensate the attraction gravity force of Earth

For **GEO** satellites, altitude is calculated so that the Satellite and Earth rotation angular velocity matches → ~ **Zero Doppler**

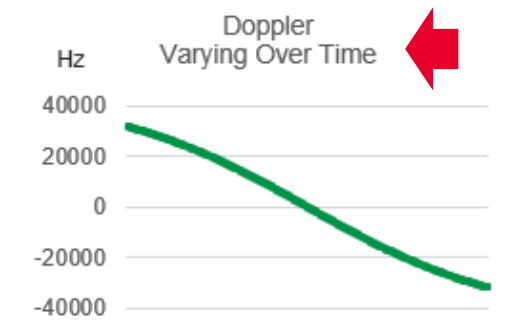
- Special case is GEO with inclination, in which Doppler can go up to kHz

For **LEO** satellites, relative velocity difference changes over time:

- Maximum, at minimum Elevation angle
- Minimum (0 Hz), at Zenith



GEO satellite with zero Doppler



LEO satellite with +/- 40 kHz Doppler

3GPP NR NTN Technology Architecture

High Level 3GPP Definition for Rel-17 NR NTN

Focused on already authorized bands

- Rel-17 is focused on 1.5GHz and 2.1GHz bands (S and L bands)
- Ka / Ku bands being investigated in later 3GPP releases (>10 GHz)

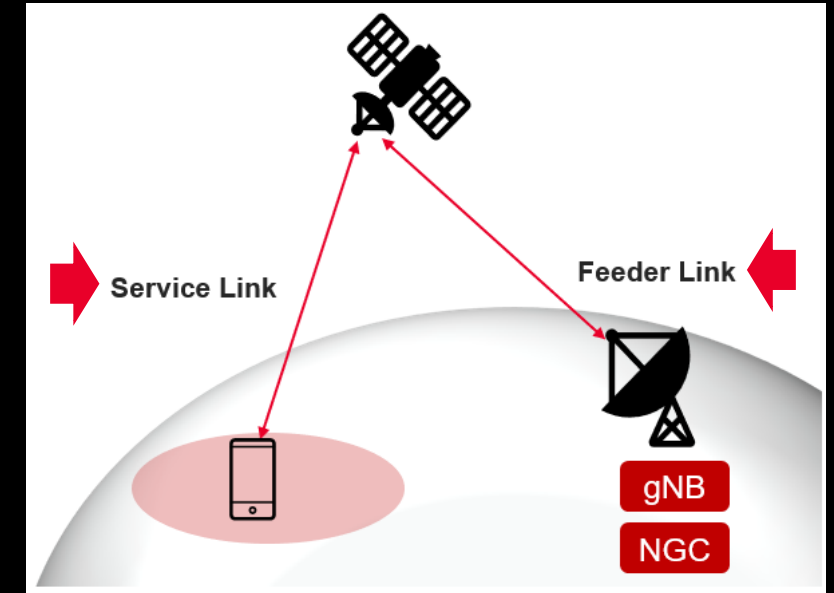
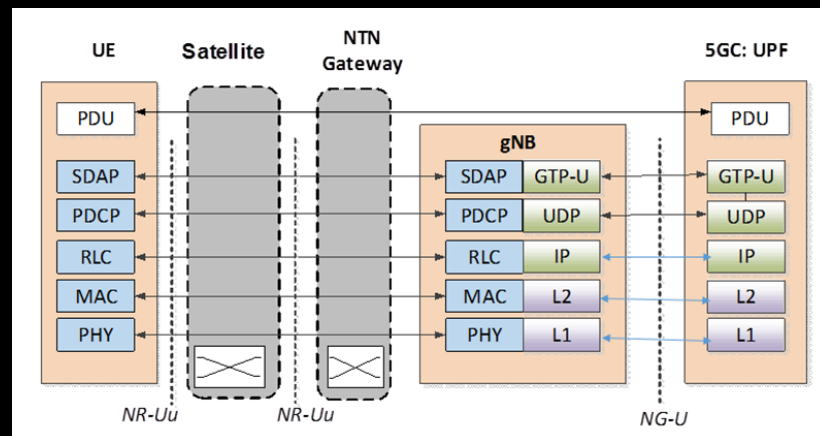
Transparent payload (Bent-Pipe Architecture)

Satellite equivalent to a RF Remote Unit

GEO and **LEO** scenarios

User Equipment(UE) with GNSS capability are assumed

No inter-satellite links



Transparent payload

- Standardized in Rel-17
- gNB is on the ground; no major NG-RAN changes required
- Uu interface is used in both Feeder and Service Links
- **Satellite performs RF filtering, Freq conversion (if needed) and amplification**
- Potential noise amplification

Differences Between Transparent and Non-Transparent

Transparent

Standardized in Rel-17

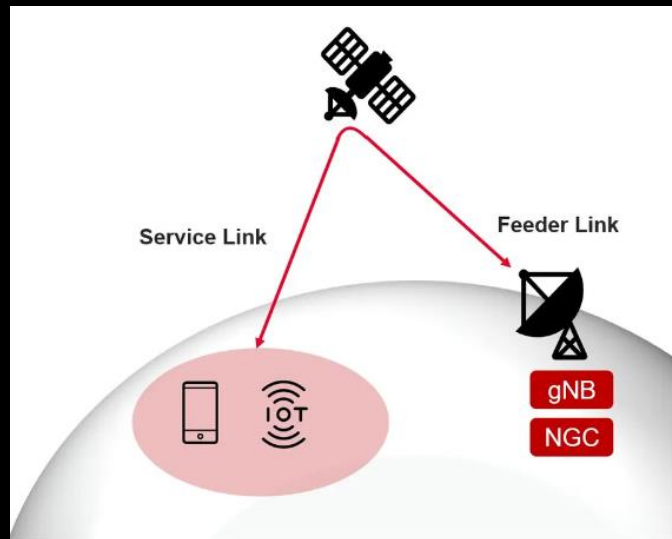
gNB is on the ground; no major NG-RAN changes required

Uu interface is used in both Feeder and Service Links

Satellite performs RF filtering, frequency conversion (if needed) and amplification

Potential noise amplification

Higher radio access latency



Non-Transparent

Not yet standardized by 3GPP

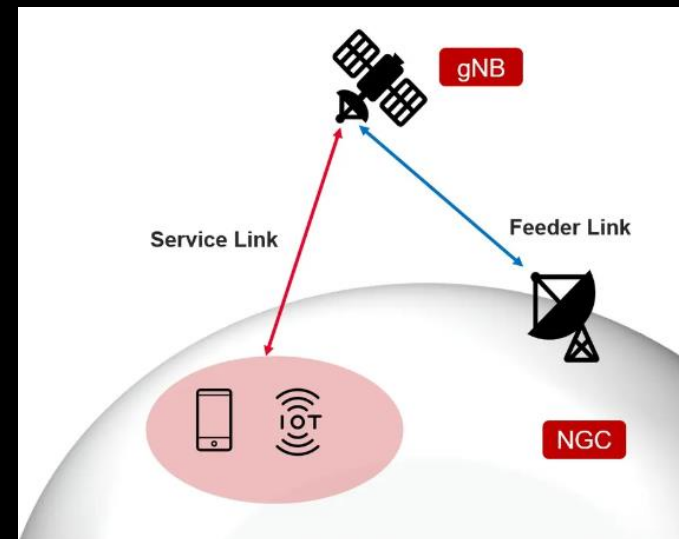
Equivalent to having (parts of) the gNB on board

Responsible for RF, (de)modulation, coding, scheduling, etc...

Heavier payload to be put in space

Lower latency in Radio Access

It allows to have different interfaces for Feeder and Service links (e.g. mmW)



Timing Relationship

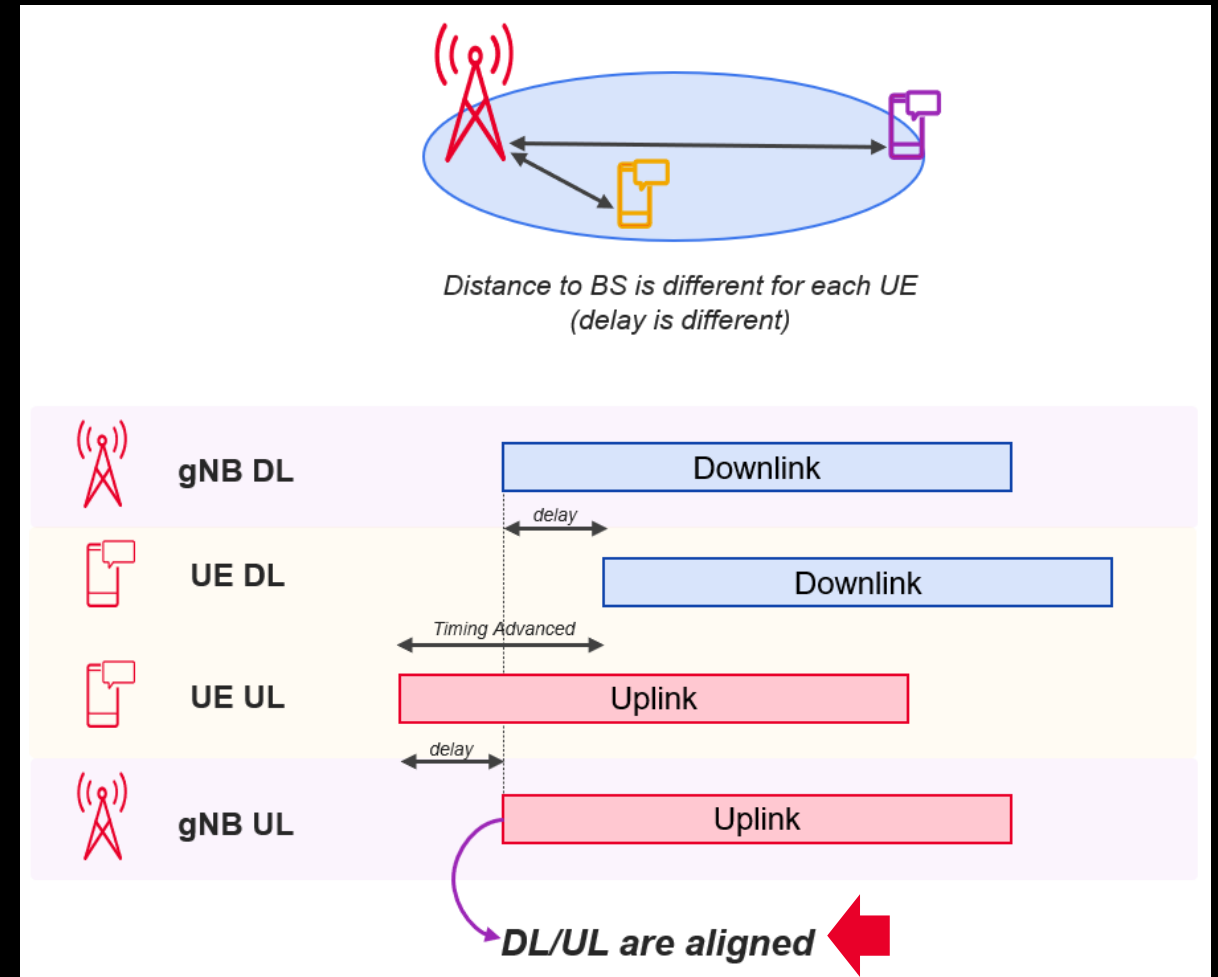
UL Timing Advance

The propagation delay

- Terrestrial Network: less than 1ms
- NTN: up to about 500ms

Solution

- UE applies a large TA, and gNB's **DL and UL frame timing** are aligned at gNB side just like terrestrial network
- A UE may need to apply a large TA value that leads to a large offset in its DL and UL frame timing



New Concept for DL/UL Frame Timing in Rel-17 NTN

NTN Koffset

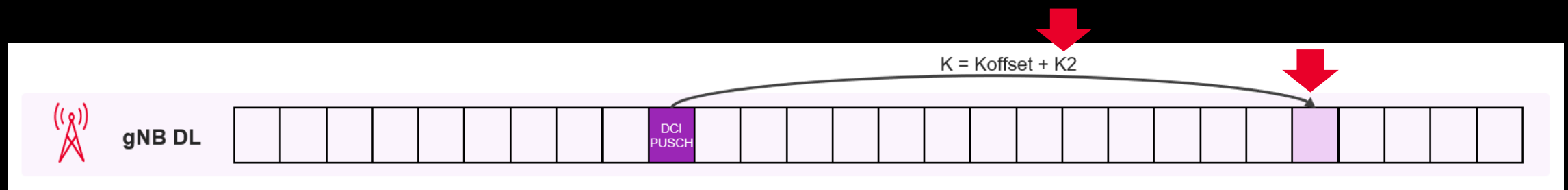
Koffset is a Scheduling offset used for the timing relationships that are modified for NTN

- That is, it is used to compensate for the large Timing Advance in UL transmissions

Koffset is given in number of slots and is added to **K2**

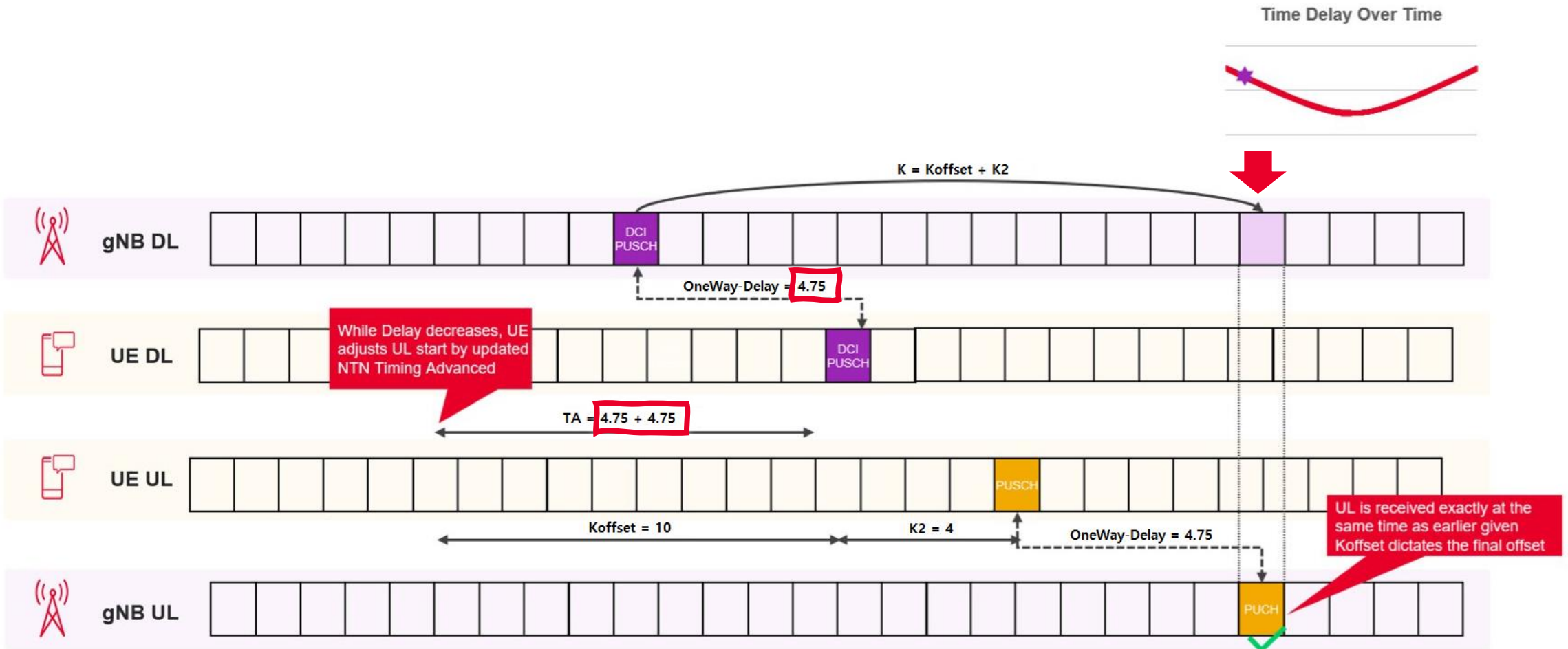
Koffset value \geq Round-Trip Time(RTT) or $2 * (\text{Feeder Link Delay} + \text{Service Link Delay})$

Koffset is applicable to UL messages including MSG3, PUSCH, HARQ on PUCCH, aperiodic SRS



Example with Koffset=10 and NTN Timing Advanced

OneWay-Delay = 4.75, K2 = 4



Time and Frequency Synchronization

High Level Summary

An NTN UE is required to:

- Support UE-specific **TA (Timing Advance)** calculation based on its GNSS-acquired position and the serving satellite ephemeris (SIB*)
- Use its acquired GNSS position and satellite ephemeris (SIB*) to calculate **frequency pre-compensation** to counter shift the Doppler experienced on the service link

The UE assumes that it has lost uplink synchronization if new or additional assistance information through SIB* is not available within the associated validity duration

NTN SIB*
- NR: SIB19
- NB-IOT: SIB31

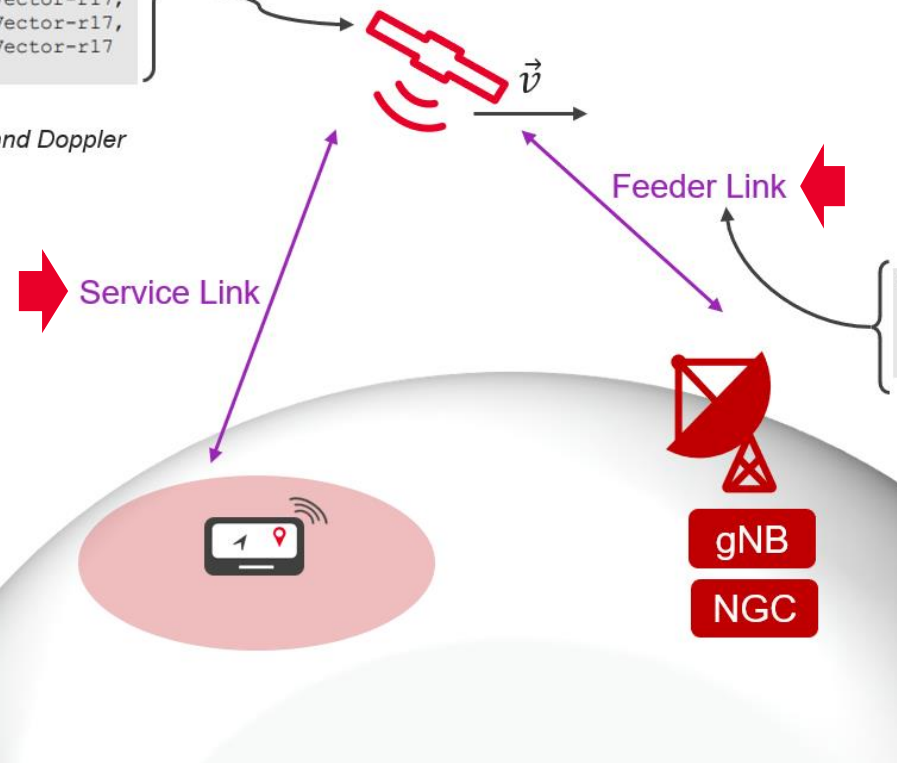
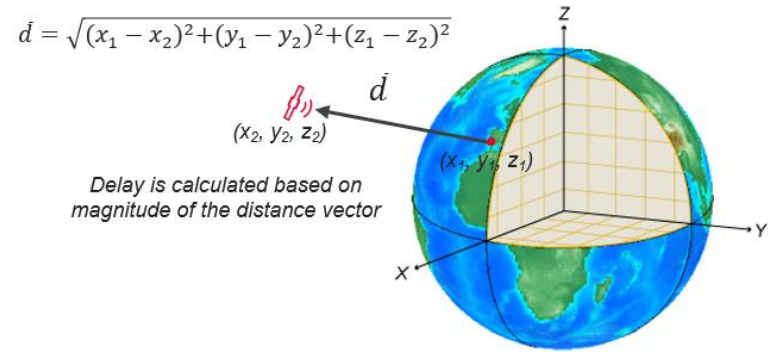
Pre-Compensation of Delay and Doppler

How Does Rel-17 NTN Address These Challenges?

```

EphemerisStateVectors-r17 ::= SEQUENCE {
  positionX-r17      PositionStateVector-r17,
  positionY-r17      PositionStateVector-r17,
  positionZ-r17      PositionStateVector-r17,
  velocityVX-r17     VelocityStateVector-r17,
  velocityVY-r17     VelocityStateVector-r17,
  velocityVZ-r17     VelocityStateVector-r17
}
    
```

Information about the Satellite position and velocity
 This is used by the UE to estimate Service Link Delay and Doppler



```

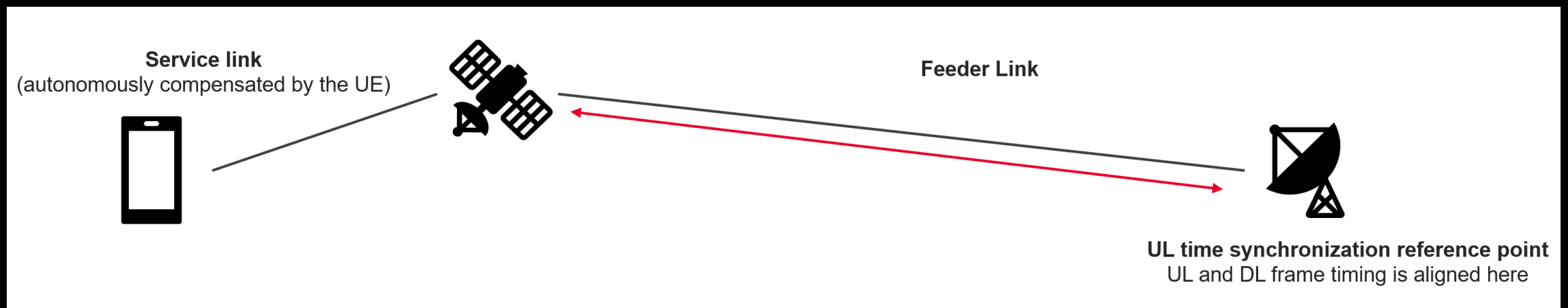
nta-CommonParameters-r17 SEQUENCE {
  nta-Common-r17          INTEGER (0..8316827)
  nta-CommonDrift-r17     INTEGER (-261935..261935)
  nta-CommonDriftVariation-r17 INTEGER (0..29479)
}
    
```

Information about the Feeder link delay and how it changes over time

Pre-Compensation Responsibilities

Doppler and Delay compensation in UXM and UE

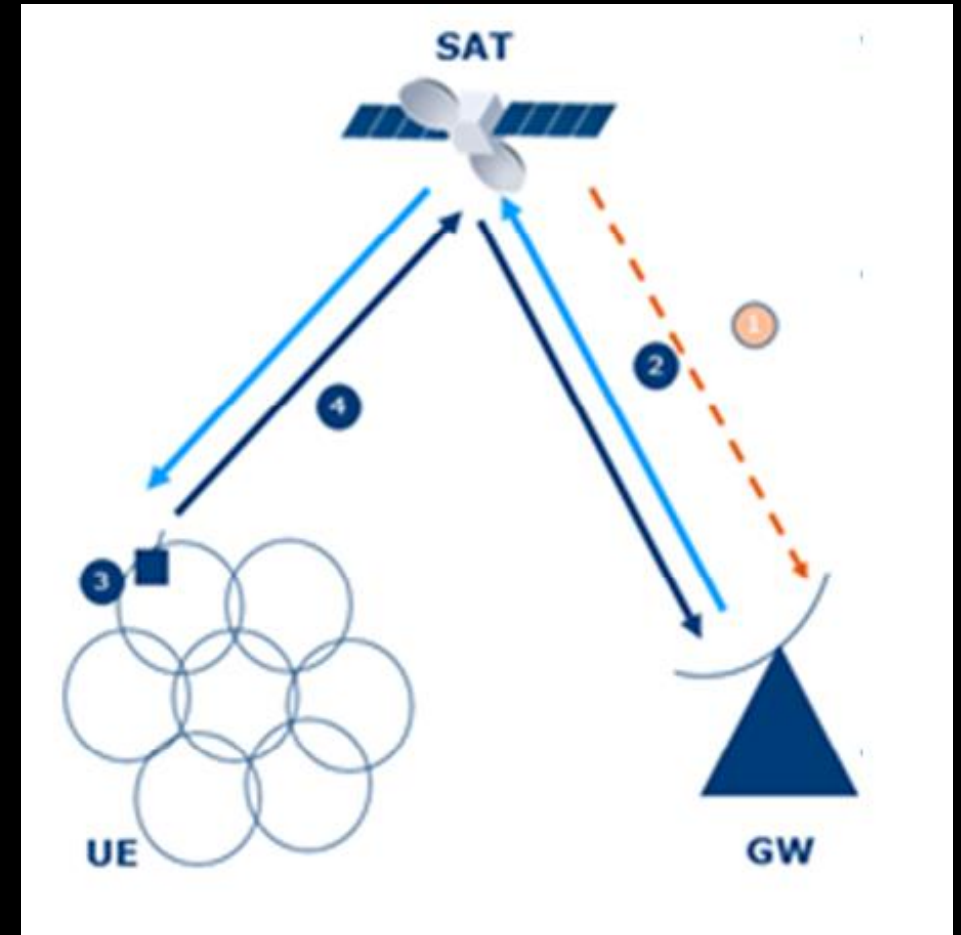
		UXM / GW	UE	How UE compensates
Doppler	DL	Feeder Link	Service Link	Ephemeris based
	UL	Feeder Link	Service Link	Ephemeris based
Delay	DL	Time-drift in Feeder Link	Time-drift of Service Link	Ephemeris based
	UL	--	Delay + time-drift for Feeder and Service Links	TA related parameters in NTN SIB



Pre-Compensation Procedure

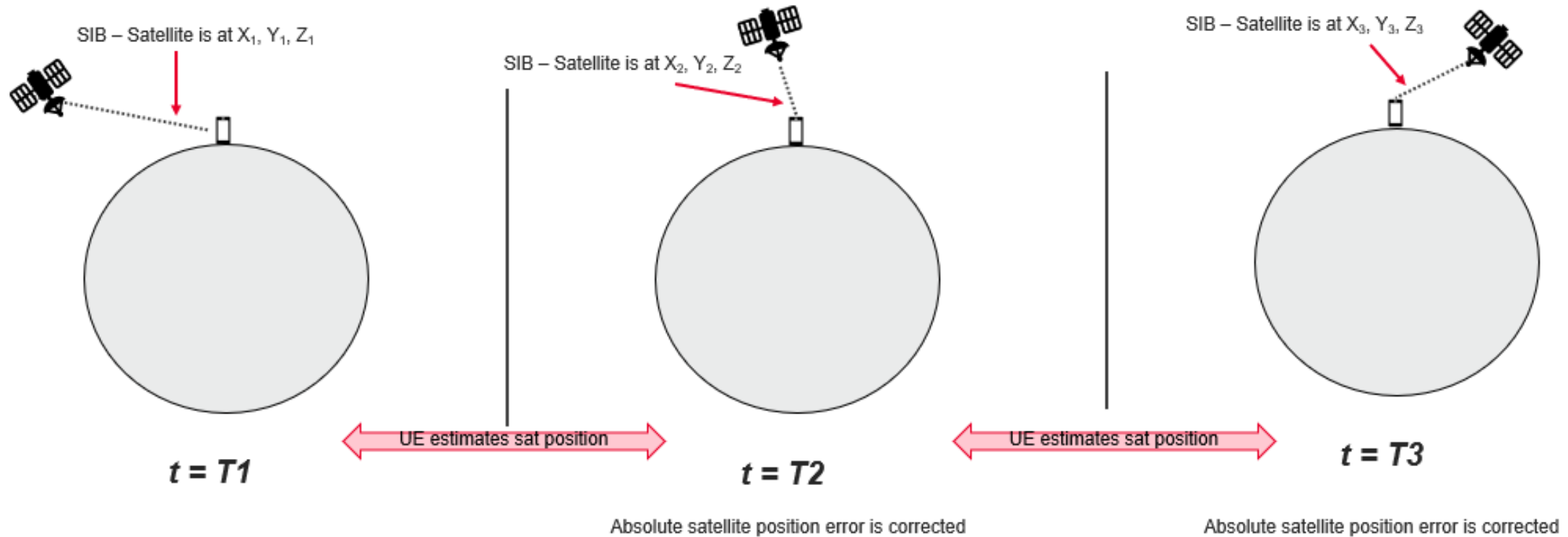
Delay and Doppler

- The **Gateway** gets from a telemetry link the position and velocity of the satellite typically using on-board GNSS, processes it and determines the satellite position and speed
- The **Gateway** propagates the satellite position and velocity determined from the telemetry link to the end of the frame containing the **SIB** used to broadcast the current satellite position and velocity
- The **UE** reads the current satellite position and velocity on the **SIB** and uses its GNSS-acquired position to determine the satellite delay and satellite Doppler shift
- The **UE** **pre-compensates** the link delay and Doppler before transmitting on the **UL**



SIB Information Is Refreshed Over Time

Satellite Position Error Corrected



T430 is new RRC timer - maximum amount of time the **SIB19** is not acquired

- In RRC_CONNECTED state, if T430 expires, UE informs the lower layers that it lost UL sync, then tries to re-acquire SIB19

NTN Assistance Information Over New SIB

SIB19 for NR NTN

SIB19 contains the NTN-Config IE with:

- Ephemeris data: Satellite position and velocity
- Timing Advance Common: Feeder link delay
- UlsyncValidityDuration: Used to set new RRC timer T430
- Koffset: To help cope with high RTT
- Epoch time: When Ephemeris and TAcommon starts being applicable

Additional information

- Though the information in the **SIB19** is continually changing, a change in SIB19 doesn't trigger a SI change indication
- Thus, it is up to the **UE implementation** on how often it acquires SIB19

```

-- SIB19
SIB19 contains satellite assistance information for NTN access.

SIB19 information element

-- ASN1START
-- TAG-SIB19-START
SIB19-r17 ::= SEQUENCE {
  ntn-Config-r17          NTN-Config-r17          OPTIONAL, -- Need R
  t-Service-r17          INTEGER (0..549755813887)  OPTIONAL, -- Need R
  referenceLocation-r17  ReferenceLocation-r17     OPTIONAL, -- Need R
  distanceThresh-r17    INTEGER(0..65525)          OPTIONAL, -- Need R
  ntn-NeighCellConfigList-r17  NTN-NeighCellConfigList-r17  OPTIONAL, -- Need R
  lateNonCriticalExtension OCTET STRING          OPTIONAL,
  ...
  [
    ntn-NeighCellConfigListExt-v1720  NTN-NeighCellConfigList-r17  OPTIONAL -- Need R
  ]
}

```

```

-- NTN-Config
The IE NTN-Config provides parameters needed for the UE to access NR via NTN access.

NTN-Config information element

-- ASN1START
-- TAG-NTN-CONFIG-START
NTN-Config-r17 ::= SEQUENCE {
  epochTime-r17          EpochTime-r17
  ntn-UlsyncValidityDuration-r17  ENUMERATED{ s5, s10, s15, s20, s25, s30, s35,
                                             s40, s45, s50, s55, s60, s120, s180, s240, s900}
  cellSpecificKoffset-r17  INTEGER(1..1023)
  kmac-r17                INTEGER(1..512)
  ta-Info-r17             TA-Info-r17
  ntn-PolarizationDL-r17  ENUMERATED {rhcp, lhcp, linear}
  ntn-PolarizationUL-r17  ENUMERATED {rhcp, lhcp, linear}
  ephemerisInfo-r17      EphemerisInfo-r17
  ta-Report-r17          ENUMERATED {enabled}
  ...
}

```

HARQ Enhancement

Solution to Long Delay

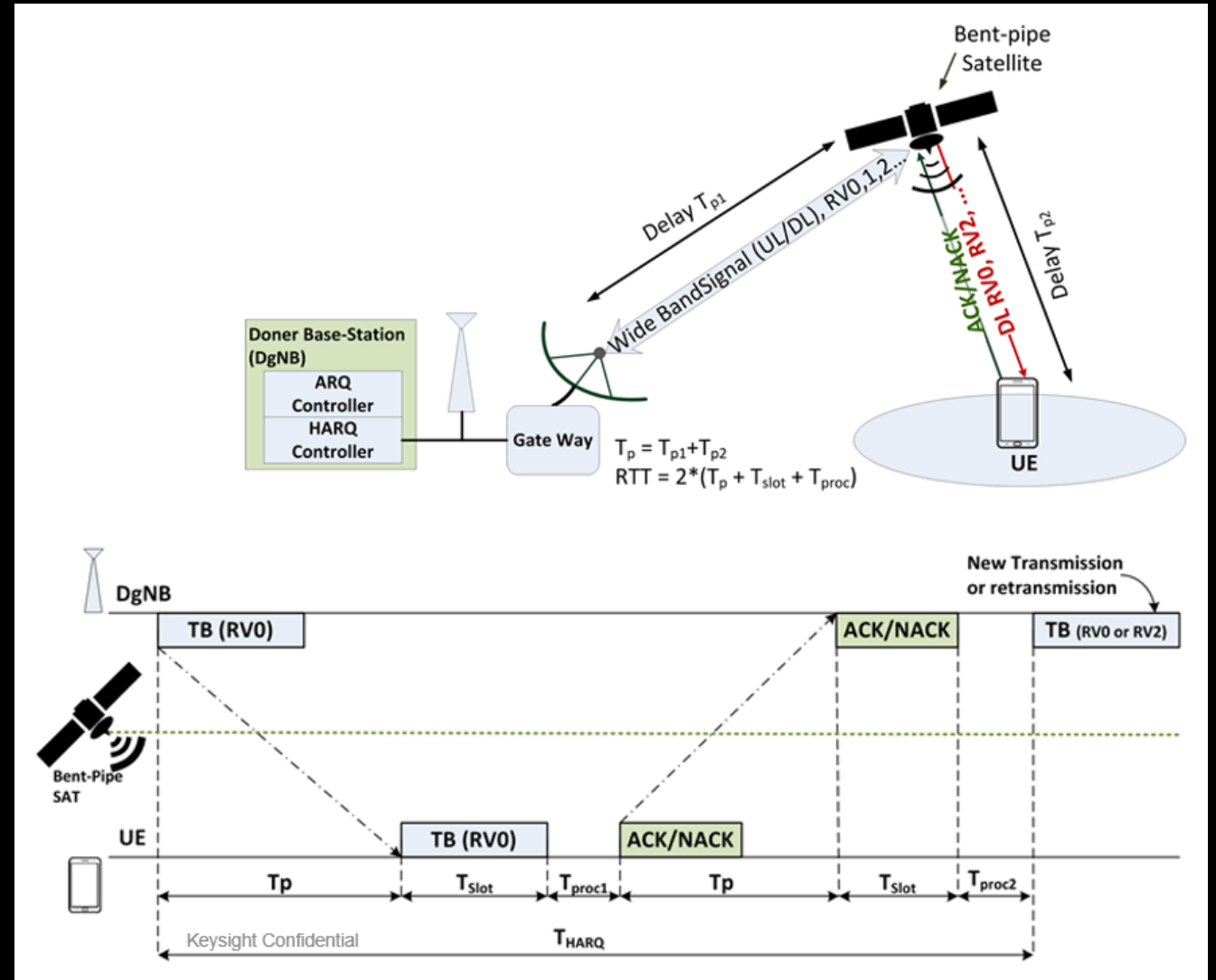
HARQ (Hybrid-ARQ) process:
very time-critical mechanism
(even more critical at extremely long RTT)

Problem

- The maximum number of HARQ processes can be very large due to the high delays
- **Cost:** UE soft-buffer needs to be increased enormously
- **Control channel reliability:** HARQ feedback field bit-size increases enormously

Solution alternatives

- **32 HARQ** processes while maintaining buffer size under control
- **Disabling HARQ at L1**



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Keysight 3GPP NTN Test Solutions- UE Testing

Propagation conditions



- LEO, GEO, HAPS, 3GPP, import
- Fading, Shadowing, Atmospheric
- Satellite modeling, Multi-satellite

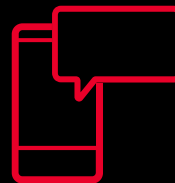


➔ **PROPSIM Channel Emulator**

3GPP Rel-17 Compliance



- NR, NB-IoT UE Test
- Rel-17 Koffset, 32x HARQ, NTN SIB
- End-to-end emulation in the Lab



UE (DUT)

Performance Characterization



- Throughput, Latency, Sensitivity
- Signal quality, Doppler Compensation
- Conformance Testing



➔ **UXM 5G Network Emulator**

Keysight 3GPP NTN Test Solutions-Network Testing

Propagation conditions

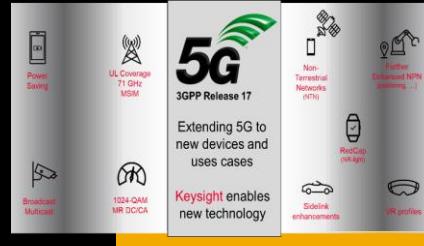


- LEO, GEO, HAPS, 3GPP, import
- Fading, Shadowing, Atmospheric
- Satellite modeling, Multi-satellite



➔ **PROPSIM Channel Emulator**

3GPP Rel-17 Compliance



- NR, NB-IoT gNB Test
- Rel-17 Koffset, 32x HARQ, NTN SIB
- End-to-end emulation in the Lab



➔ **UeSIM UE Emulator**

Performance Characterization



- Throughput, Latency, Sensitivity
- Signal quality, Doppler Compensation

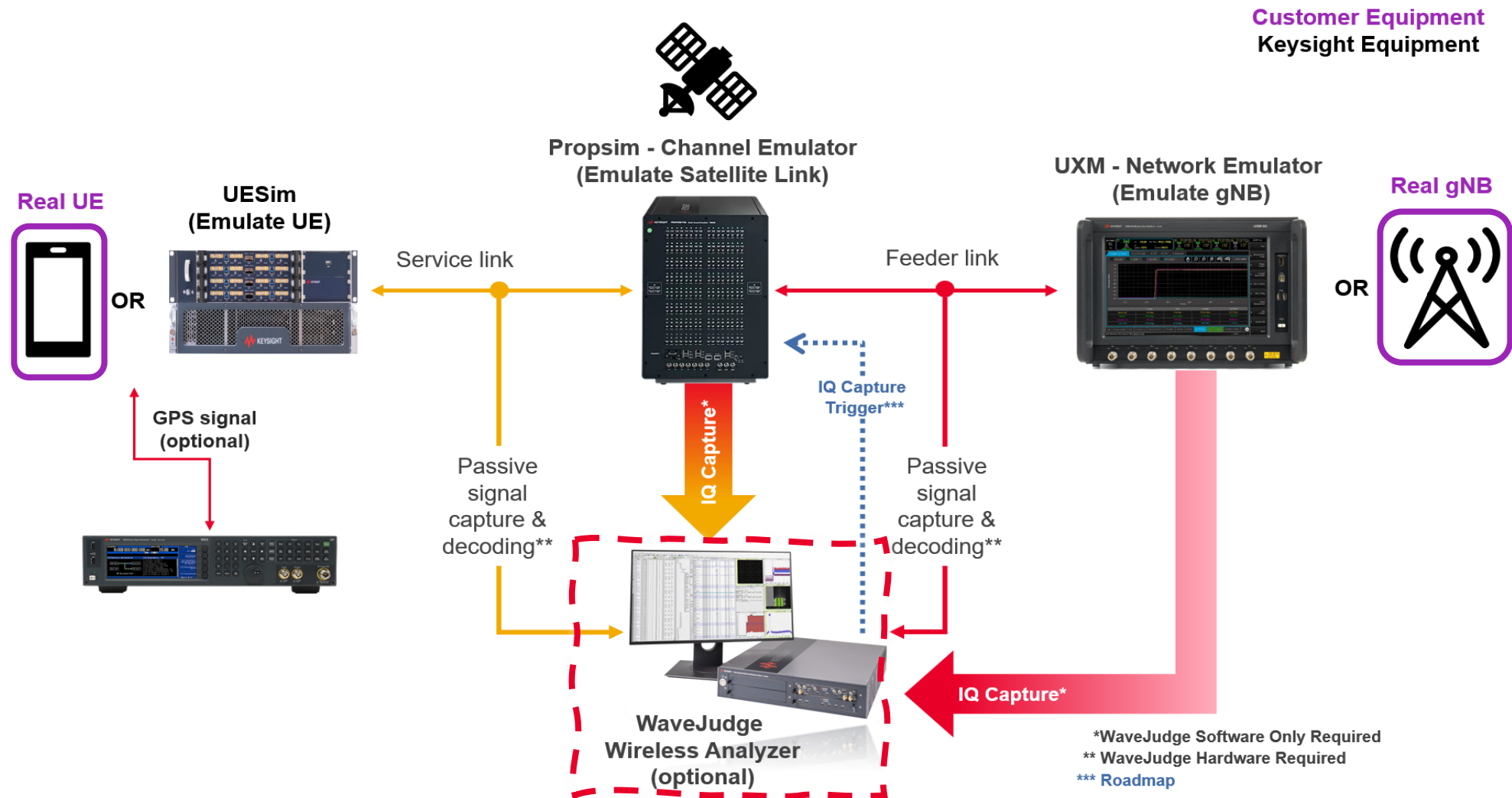
EPC/NGC

eNB/gNB



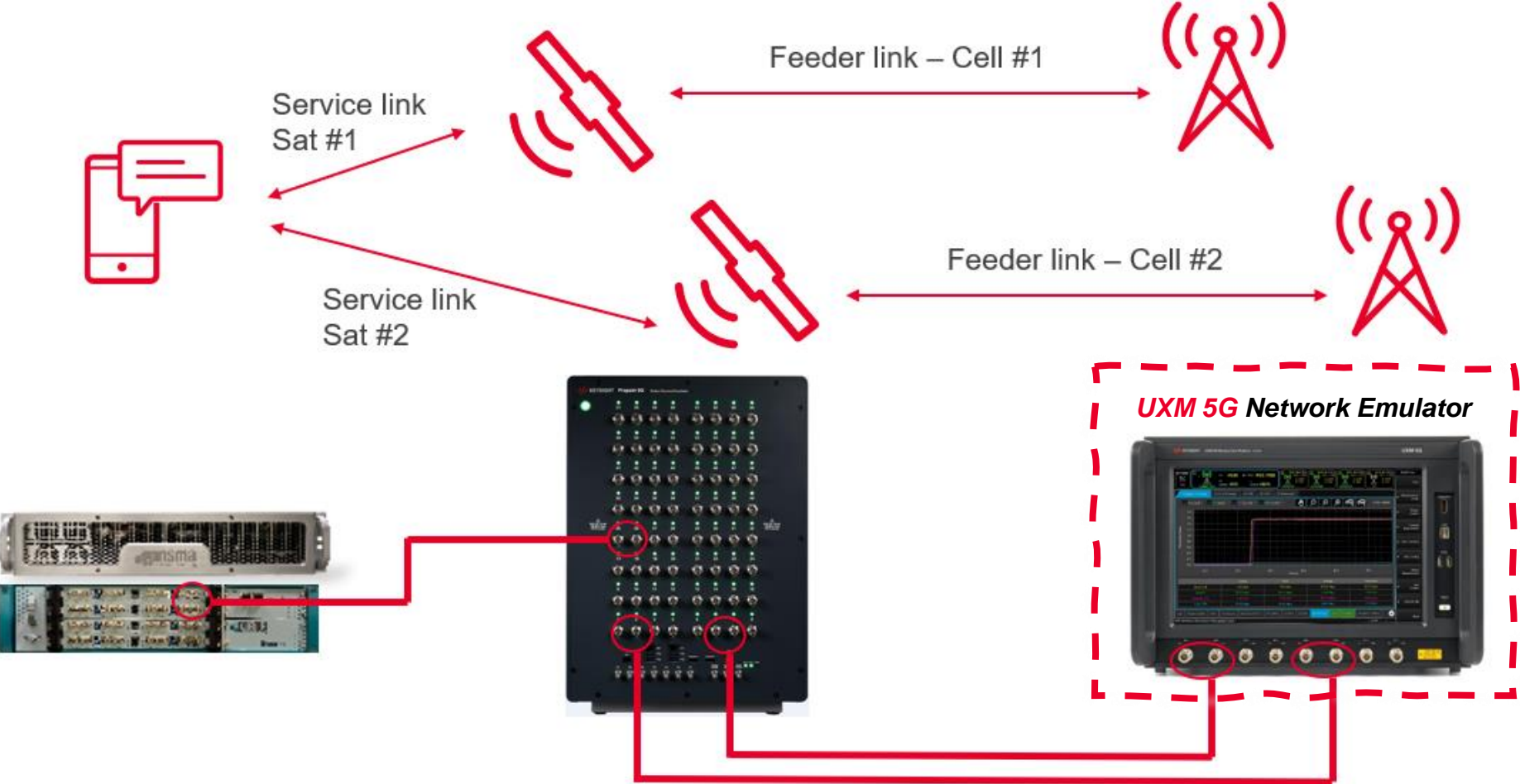
NR NTN Test Bed Example

UE/gNB as DUT



NTN Test Bed – Handover Concept

Mobility Management



RF monitoring at launch

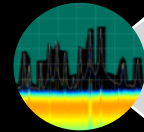
N9042B UXA

Real-time spectrum analysis allows gap-free capture of signals

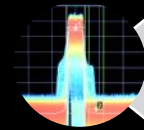
- Capture telemetry interference and analyze complex signals



Widest BW and Dynamic Range Scan 2 GHz Real Time BW and up to -65 dBc Spurious Free Dynamic Range



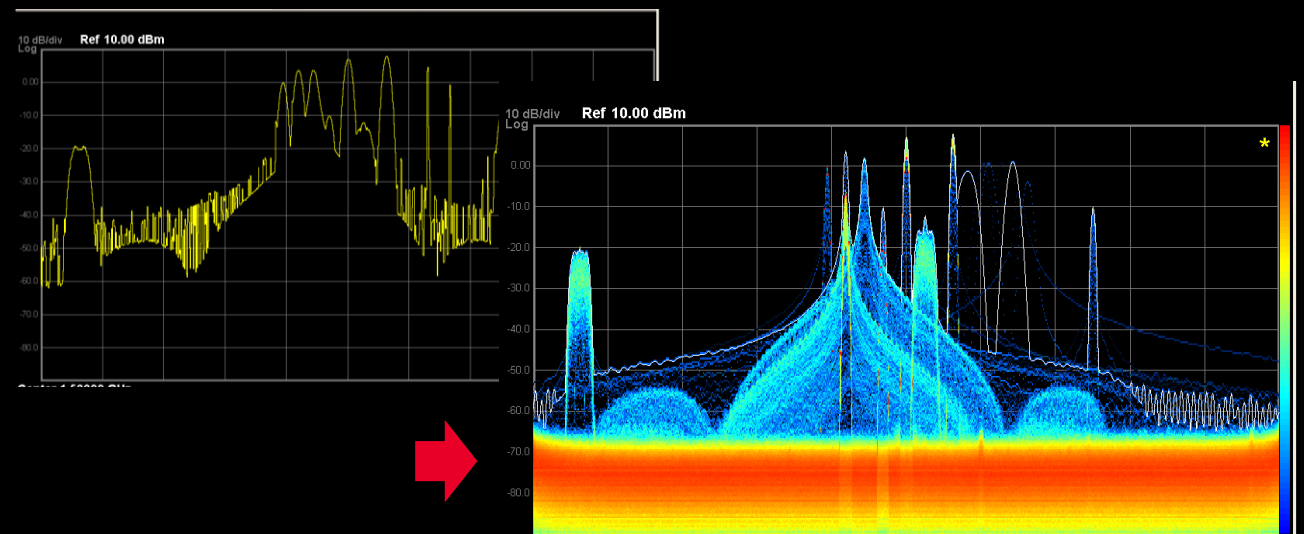
Frequency Mask Trigger Combine FMT and low noise floor to detect signals as short as 227 ns with 100% POI



Analysis of Complex signals Seamless integration with X-Series Measurement and Vector Signal Analysis software



Retain Full Swept-Tuned Performance Eliminate the need for dedicated instrument and upgrade existing N9042B/N9032B



Press Release: Keysight – Qualcomm 5G NTN Collaboration

Enabling and Accelerating 5G NTN

Collaboration used satellite channel and 5G base station emulation platforms (UXM and PROPSIM) to establish a 5G NTN connection with a Qualcomm Technologies 5G mobile test platform

NTN using satellite-to-ground communication brings complete global 5G coverage

Successful NTN connection enables faster development of 3GPP Release 17 compliant designs

MWC 2024: Qualcomm demonstrated video call through the satellite with NR-NTN

5G NR Terrestrial Network (TN) to Non-Terrestrial Network (NTN) handover (NR to NR-NTN)

News Releases

Keysight, **Qualcomm** Accelerate 5G Non-Terrestrial Network Communication to Support Broadband in Remote Areas

- Collaboration used satellite channel and 5G base station emulation platforms to establish a 5G NTN connection with a Qualcomm Technologies 5G mobile test platform
- NTN using satellite-to-ground communication brings complete global 5G coverage
- Successful NTN connection enables faster development of 3GPP Release 17 compliant designs

SANTA ROSA, Calif. January 4, 2023

[Keysight, Qualcomm Accelerate 5G Non-Terrestrial Networks for Rural Broadband](#)



Keysight – SAMSUNG SLSI 5G NTN Engagement

5G NTN Engagement Milestones Summary

Key Milestones Achieved:

- **First NR NTN call** under real LEO orbit in Dec'22
- Successful end-to-end demo at MWC:
 - Unique NR-NTN demo using LEO orbit
 - Two-way messaging and video streaming
 - 100s of customer meetings and visits
- Joint press release

Engagement Highlights:

- Technical thought leadership
- Bi-directional direct access to R&D teams
- Quick turnaround to challenges
- Possibility to customizations
- Daily on-site local support

Keysight and **Samsung** to Demonstrate 5G Non-Terrestrial Networks Data Connection at Mobile World Congress 2023

- Demonstration of SMS two-way texting over a live 5G NTN connection with a Samsung Electronics System LSI mobile modem platform
- Enabling 3GPP Rel-17 NTN in commercial smartphones allows satellite communications to scale to meet ubiquitous coverage challenges
- End-to-end NTN emulation enables the design and validation of user equipment prior to network deployments

SANTA ROSA, Calif. February 23, 2023

[Keysight and Samsung to Demonstrate 5G NTN Data Connection at MWC 2023 | Keysight](#)

Tech Blog

[MWC 2023] System LSI Unveils Advanced Mobile Technologies to Power Future Devices



[MWC 2023: System LSI Unveils Advanced Mobile Technologies to Power Future Devices | Samsung Semiconductor EMEA](#)



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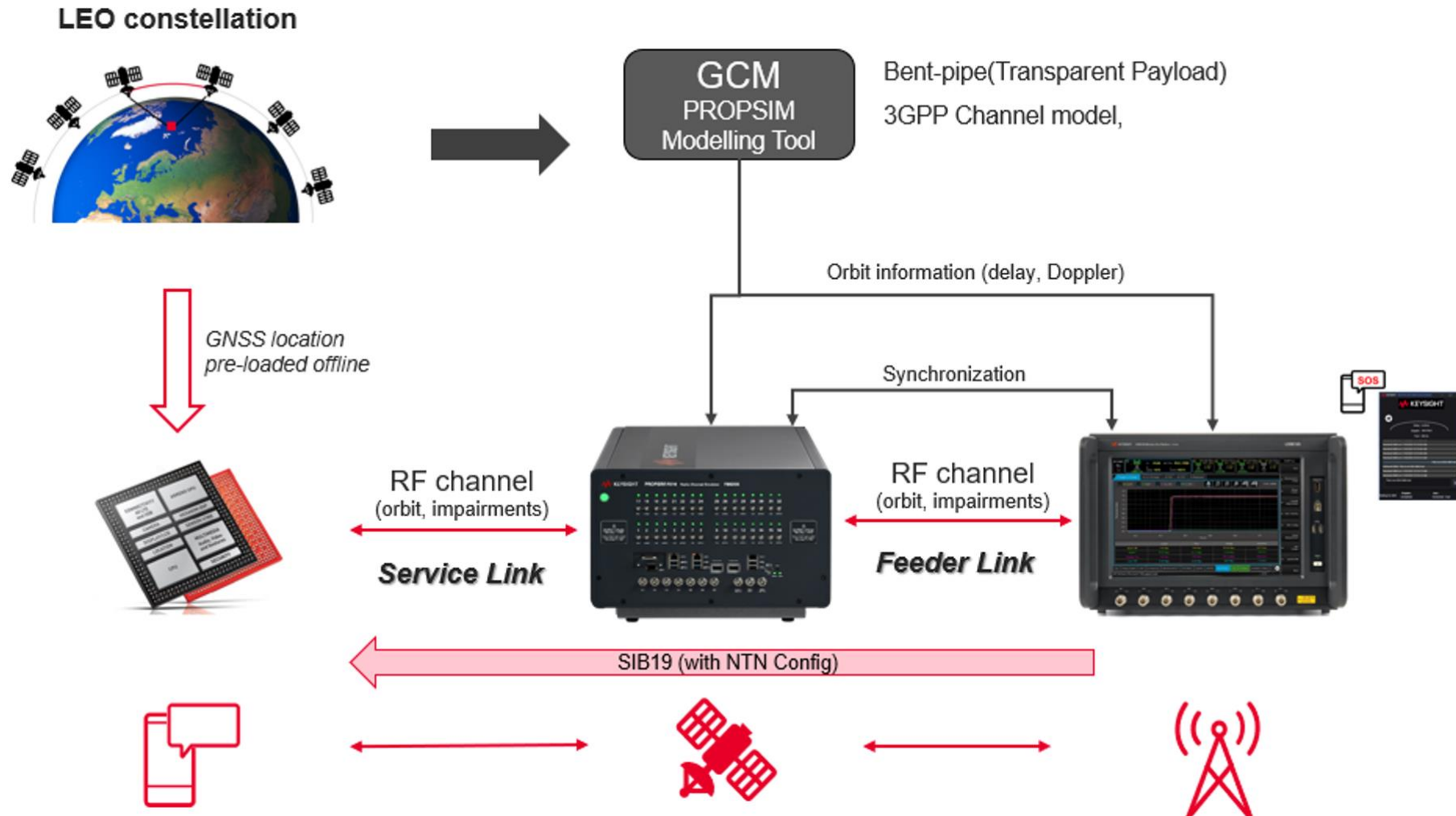
Video Demonstration



5G NR NTN Signaling Demo



Block Diagram





Thank you

