APPLICATION NOTE

Advanced 5G Non-Terrestrial Network Mobility

Ensure mobility in satellite networks

KEYSIGHT

5G NTN: Signal from Space to Your Smartphone

By democratizing wireless communications through space, internet providers aim to provide access to 50% of the Earth's population currently disconnected from terrestrial networks (TN). The incorporation of non-terrestrial networks (NTN) in the latest 3rd Generation Partnership Project (3GPP) Rel-17 poses significant technical and business challenges. This integration mandate pressures the communications industry to transform the envisioned goal into a tangible reality.

Besides offering connectivity to subscribers in the current unserved and underserved locales and enabling applications such as the Internet of Things (IoT), this not-so-futuristic vision of wireless connectivity plans to leverage airborne stations and high-altitude platforms (HAPs) such as uncrewed aerial vehicles (UAVs), balloons, or dirigibles, shown in Figure 1. developers intend to use this infrastructure to complement existing terrestrial networks and enable seamless connectivity worldwide.

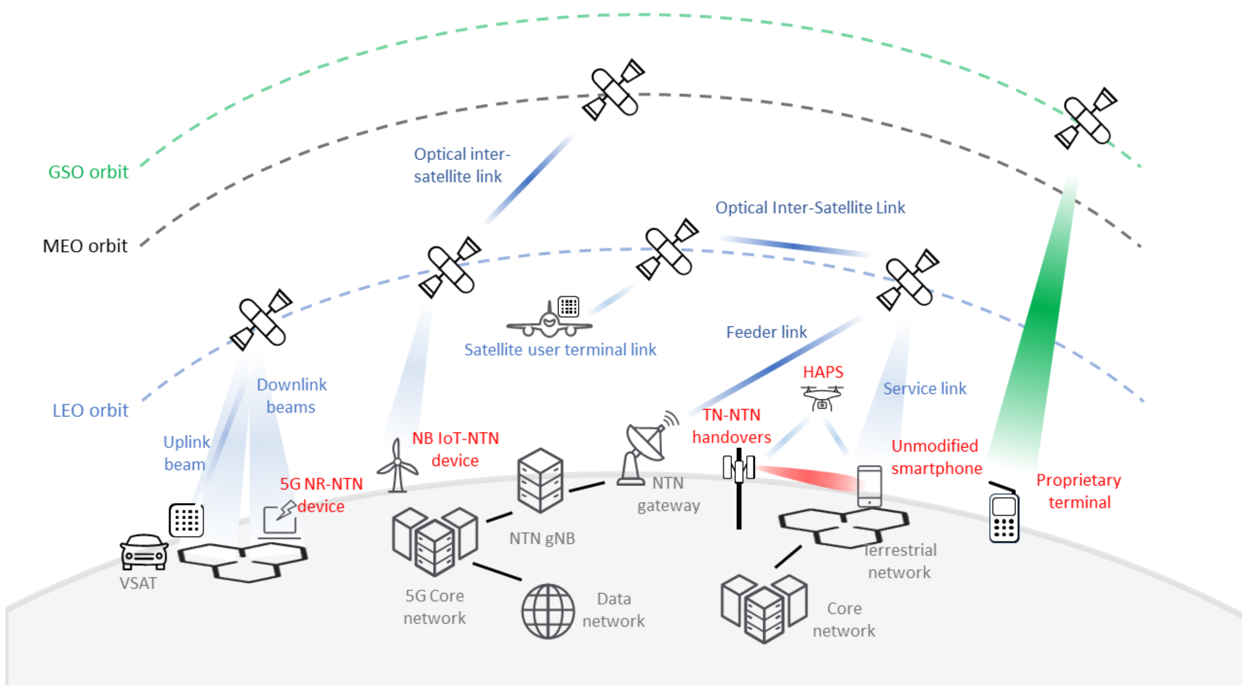


Figure 1. Integration of terrestrial and non-terrestrial networks

5G NTNs leverage many features from 5G terrestrial networks because they face similar challenges. Because of this, there are heightened reliability expectations for 5G NTN services compared to earlier SATCOM networks. Handheld or vehicle-based user equipment (UE) demands high volumes of data for video and mapping services. Alternatively, sensor applications connect multiple user equipment with lower data rates. Delivering the required volumes of data means leveraging 5G signaling fundamentals for 5G NTN. The Federal Communications Commission (FCC) has already designated 5G spectrum exclusively for terrestrial networks. The deployment of tens of thousands of satellites for 5G NTNs introduces even more spectrum crowding.

The Importance of Mobility in Satellite Networks

Three types of satellite orbits support 5G NTN:

- geostationary orbit (GSO)
- medium Earth orbit (MEO)
- low Earth orbit (LEO)

Geosynchronous equatorial orbit (GEO) satellites orbit at an altitude of 35,786 km and travel at the same velocity as the Earth on a path parallel to the Earth's rotation. Consequently, GEO satellites appear stationary in the sky due to the considerable distance to Earth. Theoretically, complete communications coverage requires only three GEO satellites.

Satellite properties	LEO	MEO	GSO
Altitude (km)	~ 1,000	~ 20,000	~ 35,786
Orbit period (hour)	~ 2	~ 12	~ 24
Speed (km / s)	~ 7.5	~ 4	~ 3
RTT (ms)	~ 14	~ 100	~ 500
Max Doppler (kHz)*	~ 50	~ 3	< 1
Beam footprint (km)	100 – 50	100 – 500	200 – 1000
Satellites required	100s	10s	Few

*These are illustrative values for orbit comparison and calculated for a frequency of around 2 GHz.

In contrast, LEO satellites orbit closest to the ground, providing lower latency and path losses compared to GSO, enabling the deployment of wideband connectivity access in remote locations.

However, the high speed of LEO satellites causes high-velocity delay variations and significant Doppler shifts, as shown in Figure 2. Low Earth orbit satellites provide limited coverage at a given location on Earth for only a few minutes, which makes satellite-to-satellite handovers a critical factor affecting service quality. Considering 5G NTN handovers as a topic of importance, 3GPP Rel-18 and beyond are addressing this matter.

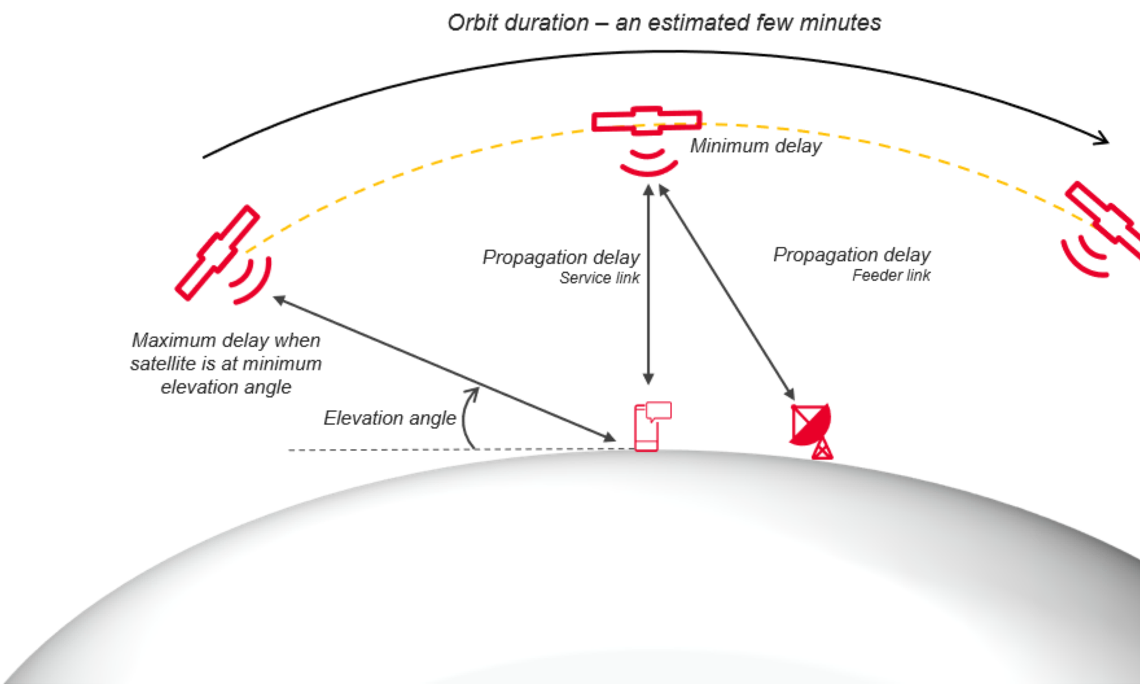


Figure 2. Diagram of a LEO satellite orbit flyby

Satellite-to-satellite handovers

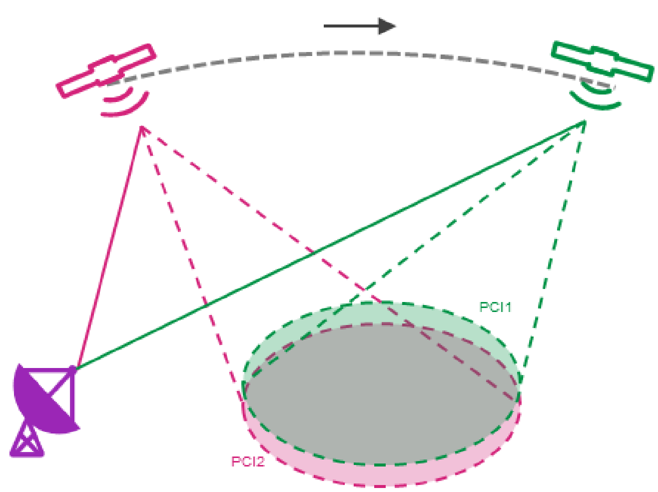


Figure 3. Frequent handovers caused by multiple satellite orbital movement

The support of 5G NTN impacts existing procedures related to mobility. NTN developers critically need to address the mobility challenges related to LEO satellites, given their fast movement with respect to the UE.

That means even static or stationary user equipment on the ground requires handovers to other satellites to maintain effective connectivity, as shown in Figure 3. Furthermore, frequent handovers impact the quality of real-time services by necessitating a handover procedure triggered every few minutes. The substantial number of measurements and protocol activities needed leads to faster UE battery drain.

For a smooth handover process between source and target satellites, it is crucial to consider whether they belong to the same orbital plane. The target broadcasts the neighbor's cell ephemeris to the information block type 19 (SIB19) within the source cell to ensure a seamless transition with no packet loss. The information in Figure 4 enables the UE to estimate the trajectory of the target satellite, facilitating the estimation and compensation of delay and Doppler shift. Accurate synchronization between the ephemeris information conveyed in the broadcast and the actual satellite position is crucial.

Figure 4. Data results using Keysight WaveJudge analyzer RF protocol sniffer for SIB19 satellite assistance information that includes a neighboring satellite

Figure 5 illustrates the combination of the satellite's orbital movement with the ground movement of the UE, which can lead to increased complexity in these scenarios. In this scenario, the UE can experience handovers or signal reacquisitions to different beams (cells) within the same satellite or even changing satellites.

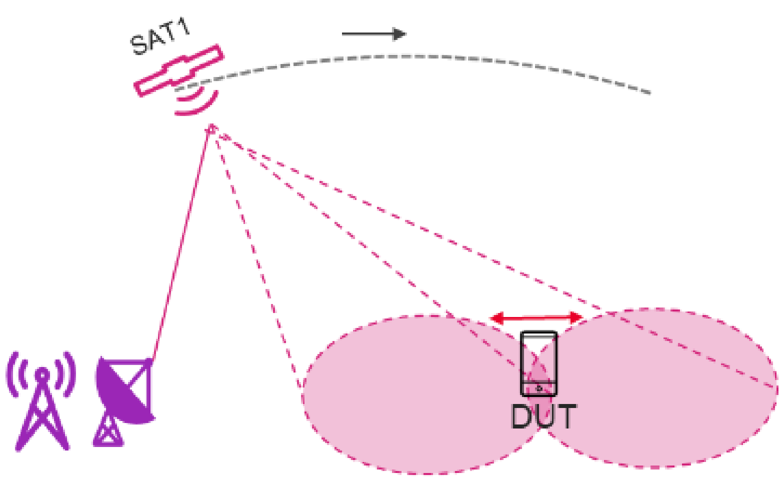


Figure 5. Satellite beam switch due to moving user equipment

However, relying solely on received power (RSRP) for handovers may not be optimal. This outcome is due to the minimal RSRP variations caused by the significant distance to the satellite, unlike terrestrial scenarios where RSRP changes quickly with the base station's distance.

For this reason, NTN has expanded Rel-16 conditional handovers with additional Rel-17 conditions. These new conditions include time-based (condEventT1-r17) and location-based (condEventD1-r17) triggers to assist the UE in determining the initiation of RSRP measurements based on time or location, as outlined in Figure 6. This optimization improves the timing of handovers while minimizing power consumption by avoiding unnecessary neighbor measurements during the process.

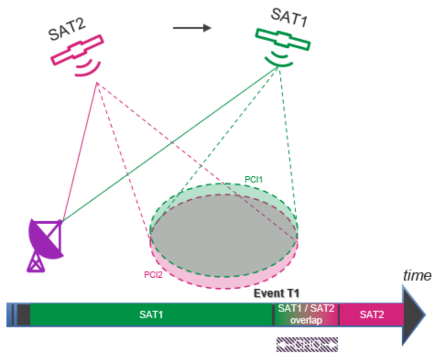
Rel-17

Additional conditions for quasi-Earth-fixed:

A. Time-based trigger condition (condEventT1-r17)
B. Location-based trigger condition (condEventD1-17)

Besides RRM measurement (RSRP) UE may wait to evaluate HO until:

A. UTC time corresponding to satellites overlap
B. Distance to reference center of cell



Rel-18 / 19 and beyond

- Extend event T1/D1 to Earth-moving beam satellites
- Broadcast *servingCellConfigCommon* to reduce signaling overheads
- Group based handovers for quasi-Earth-fixed
- Un-changed PCI switch for zero gap quasi-Earth-fixed

Figure 6. Rel-17 conditional handovers in NTN scenarios

Before the handover, the network can configure a conditional handover by considering the satellites' known orbit trajectory, timing, and position. This process involves indicating the future time in Universal Time Coordinated (UTC) units. Figure 7 shows the data that specifies when the UE should begin assessing the conditions using the network emulation configuration of the Keysight C8700200A test application.

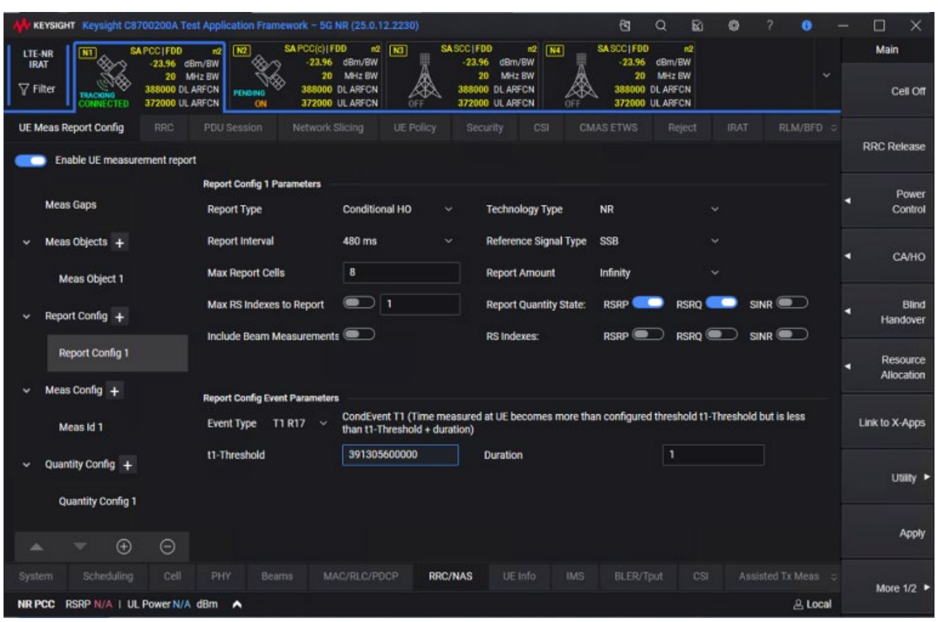


Figure 7. Rel-17 measurement report configuration using the C8700200A test application

Integrating Terrestrial and Non-Terrestrial Networks

The primary focus of an NTN is to offer coverage in underserved areas. An essential aspect that sets 5G NTN apart from previous technologies is its seamless integration with existing terrestrial network (TN) infrastructure. This integration unlocks the following new opportunities and use cases:

- Public safety for critical communications provides a backup in the absence of cellular coverage due to terrestrial network shutdowns, natural disasters, and emergencies.
- 3D coverage supports reliable communications when using aerial moving objects like balloons or UAVs, increasing the provision of multidimensional coverage and seamless transition.
- Massive IoT enables global coverage, alleviates cross-country border challenges, and optimizes power consumption and network resources when moving between TN and NTN as needed.

Illustrated in Figure 8 are various scenarios that are now enabled, facilitating a smoother convergence and optimization of TN and NTN networks. These scenarios address specific use cases outlined in the Rel-18 NTN specifications.

Figure 8. Keysight Test Application enabling mobility testing between TN and NTN

Sky-to-Lab Emulation

The complexity of mobility scenarios, encompassing multiple satellites and base stations, sophisticated link channel models spanning multiple orbital planes, and the new 5G NTN signaling for handovers and measurements, underscores the importance of replicating these conditions in a lab setting. Doing so under realistic, controlled, and repeatable conditions can significantly decrease test cycles, enhance product and service quality, and eliminate the reliance on satellite availability in space.

The Keysight sky-to-lab test solution for end-to-end NTN emulation recreates various non-terrestrial and terrestrial network scenarios. Figure 9 illustrates how it covers multiple satellites and diverse orbital and channel models and evaluates application-level performance metrics like energy consumption, protocol, RF, throughput, and latency. Comprehensive testing in the lab assesses the robustness of your mobility management strategies.

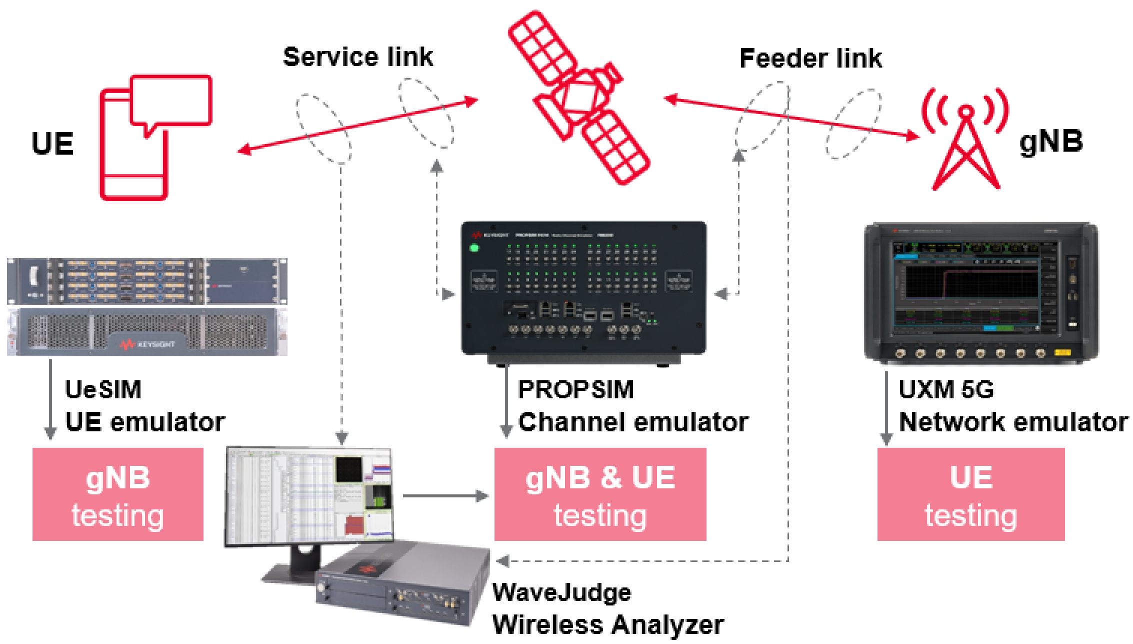


Figure 9. Sky-to-lab test solution for end-to-end NTN emulation

Depending on the use case and device under test, the components of this solution are tightly integrated and operate in conjunction or separately.

Solution	Description
UXM 5G network wireless test platform 	Keysight UXM 5G wireless test platform can emulate multiple terrestrial networks and NTN cells across a wide range of NTN frequencies to support various cellular technologies. The UXM 5G network wireless test solution enables the recreation of realistic scenarios by mimicking the behavior of real base stations with a wide range of protocol parameters. The solution enables performance measurements such as RF transmitter and receiver, block error rate (BLER), and throughput.
PROPSIM channel emulator 	Keysight PROPSIM channel emulator recreates the propagation conditions of one or more satellites. Link channel emulation offers geometric orbital paths such as delay, Doppler shift, and power profiles. The solution encompasses channel impairments like multipath fading and atmospheric effects.
UeSIM UE emulation for radio access network testing 	Keysight UeSIM emulation for radio access network test enables infrastructure vendors, chipset providers, and mobile operators to validate end-to-end radio access network performance by emulating real network traffic over radio and O-RAN fronthaul interfaces.
WaveJudge wireless analyzer toolset 	Keysight SJ001A WaveJudge wireless analyzer toolset combines powerful over-the-air communications analysis and real-time protocol decoding with physical layer (PHY) analysis. This tool troubleshoots wireless network performance issues, including cellular and O-RAN networks between devices and base stations in development and deployment.

Figure 10 is an example of the results of embedded software utilities. These utilities provide a seamless integration within the solution components. These utilities enable scenario replication and automate RF measurements using the Keysight S8702A RF automation toolset. The platform enhances functional and performance measurements by including battery drain and mobility assessments through the Keysight S8703A functional KPI toolset.

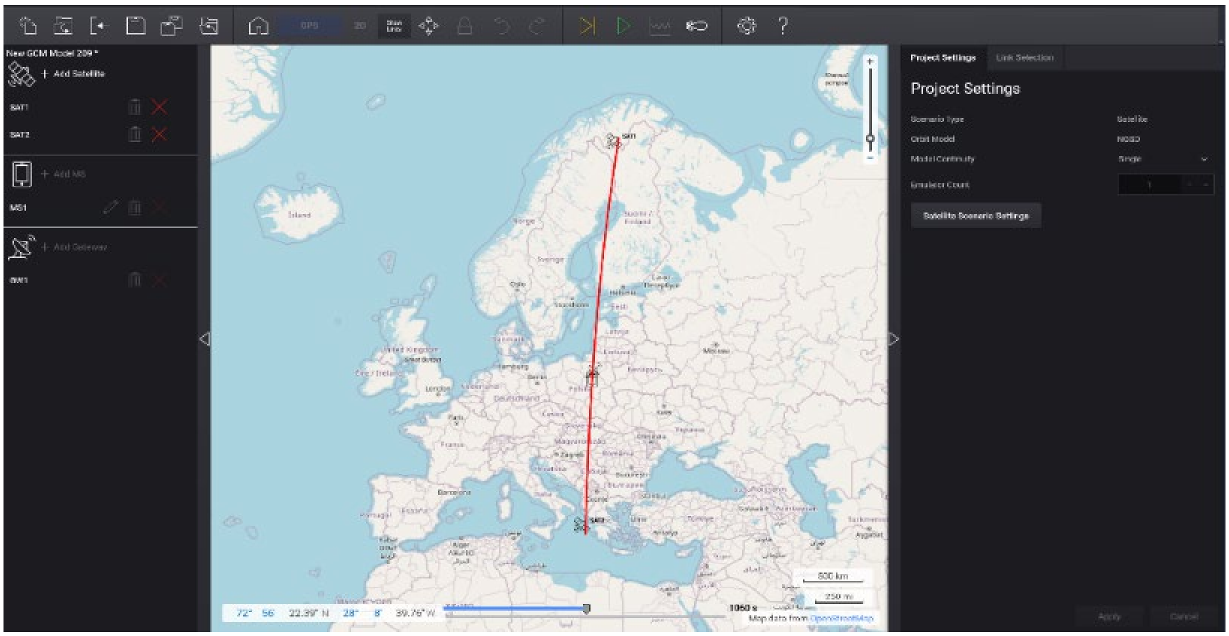


Figure 10. The Keysight F9860000A Channel Studio GCM modeling tool NTN-NTN handover scenario
The sky-to-lab test solution enables engineers to rapidly test NTN features, including functionality, performance, RF front, and device robustness.

With the addition of supporting multiple satellites, antenna effects like polarization and diversity, as well as a combination of NTN and TN in the same test bed, Keysight reaffirms its leading position at the forefront of this technology-enabling innovation.

Learn more

Discover how to accelerate 5G NTN innovation across the device workflow:

Enable Next-Generation Non-Terrestrial Networks