The Definitive Guide to Non-Terrestrial Networks

Understand satellite fundamentals, standards, trade-offs, and innovations shaping the non-terrestrial network landscape

eBook

KEYSIGHT

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NTN Basics

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NTN Basics

The introduction of non-terrestrial networks (NTNs) in 3GPP standards will revolutionize wireless communications by integrating terrestrial cellular networks with satellite communications. Mobile network operators (MNOs) want to expand their fifth-generation (5G) and eventually sixth-generation (6G) cellular networks and infrastructure while delivering more bandwidth. Government and military agencies want advancements like enhanced imaging and improved security from the new generation of satellite technologies.

For commercial and defense organizations, space provides a path to enhancing connectivity and transforming current capabilities. The space and satellite industry is experiencing rapid evolution driven by new companies, research efforts, and investment. The resulting advances face complex challenges, prompting the development of use cases to optimize and assure performance throughout space and satellite missions — from initial design and development through orbit.

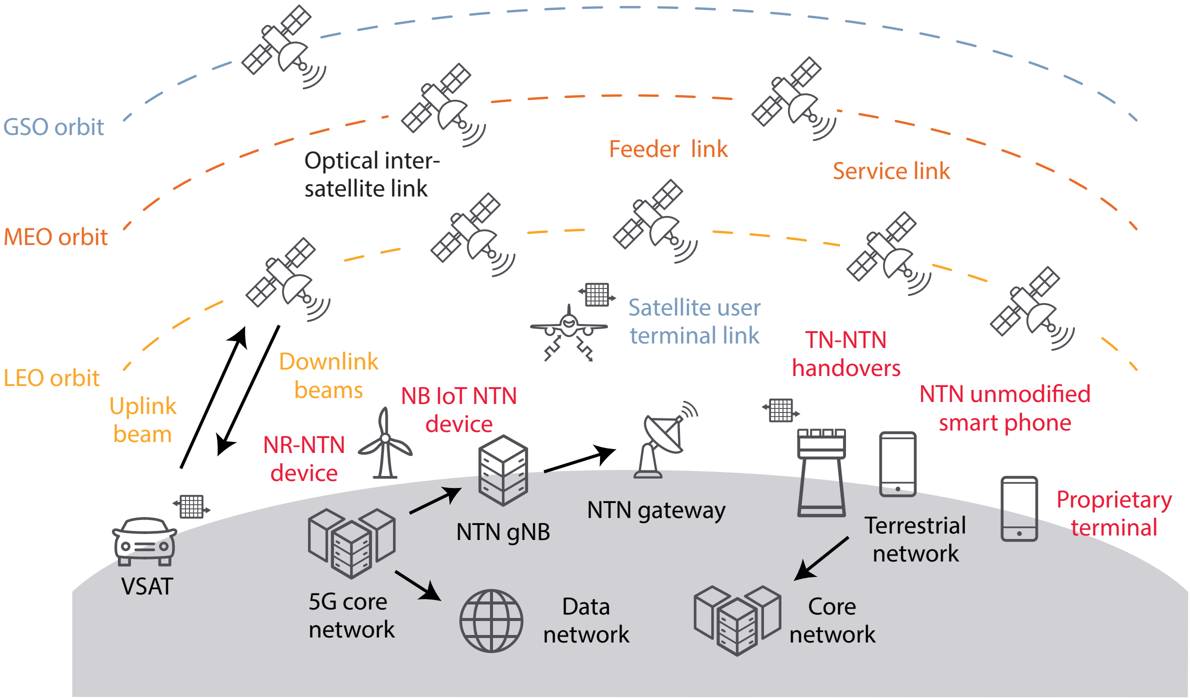


Figure 1. This graphic depicts the NTN ecosystem from ground to space

An NTN is a network that includes nodes not physically located on Earth. Although we think primarily of satellites in NTNs, other components can consist of low-altitude platforms / drones (LAP), high-altitude pseudo satellites / drones / balloons (HAPS), satellites across the various orbits, and combinations of these.

Figure 1 illustrates NTN space-borne and aerial communication networks operating across the geostationary or geosynchronous equatorial orbit (GEO), medium Earth orbit (MEO), and low Earth orbit (LEO). 5G NTN's primary applications are in GEO and LEO. The current explosive growth in LEO satellites provides the foundation for most other NTN use cases across the commercial, government, and military industries.

Each orbit creates different challenges in communication networks. With LEO, the satellite operates at a nearer distance but moves more quickly. Due to the proximity, you can have low-latency communications from satellite to ground. In contrast, traditional GEOs provide long duration fixed connections with much longer delay in the signal path between satellites in that orbit and ground stations. This process exponentially increases latency depending on the number of times the signal must travel between points. For example, if the satellite must travel around the globe, noticeable latency will occur.

Latency also arises in store and forward scenarios. Here, a satellite receives a signal, then transmits that signal later when it gains visibility to the target ground station. This occurrence is often called "discontinuous transmission."

An obvious example of latency occurs when a remote news crew experiences delays in their communication with the team in the physical newsroom. In this scenario, the signal travels to a GEO satellite, down to a ground station, up to another GEO satellite, then down again. Viewers can easily notice the delay in this process as correspondents attempt to exchange information.

Because GEO is geosynchronous, it offers several advantages due to its fixed point in the sky. As a result, you simply point large parabolic antennas in one direction, and they serve as large data pipes. In contrast, LEO satellites typically travel above your head and past you, requiring beam steering. You have two options if your application does not demand constant communication. You can either use a parabolic dish that tracks the satellite or wait for the satellite to come over. For example, data upload for the Internet of Things does not need to be continuous.

NTN architecture

Every NTN has several points of presence where the satellite network connects to the terrestrial internet. Fiber-optic links connect land stations together, while laser-optical links are used between satellites. From satellite gateways on the ground, wideband links connect cellular networks to satellite constellations with massive 20-plus gigabits per-second connections, referred to as feeder links. These points of presence connect to one or more gateways. Figure 2 illustrates these links between the gateways and the satellites as the wideband backhaul links for terrestrial cell towers.

The satellites may link in a mesh with their nearest neighbors in the constellation via high-bandwidth optical inter-satellite links, where the data transfer speeds are more than 1,000 megabits per second (Mbps).

Low-cost phased array antennas form the basis of user terminals. These antennas may have a fixed location, like a house, or are attached to vehicles like airplanes. These satellite-to-user terminal links have speeds of more than 100 Mbps. Mesh networks typically use optical links to connect the satellites.

Proven connections with less than 50 milliseconds (ms) latency to the point of presence (POP) and greater than 100 Mbps throughput already exist. Fixed or mobile terminals can, in turn, deliver network access to handsets and other devices over a local wireless network.

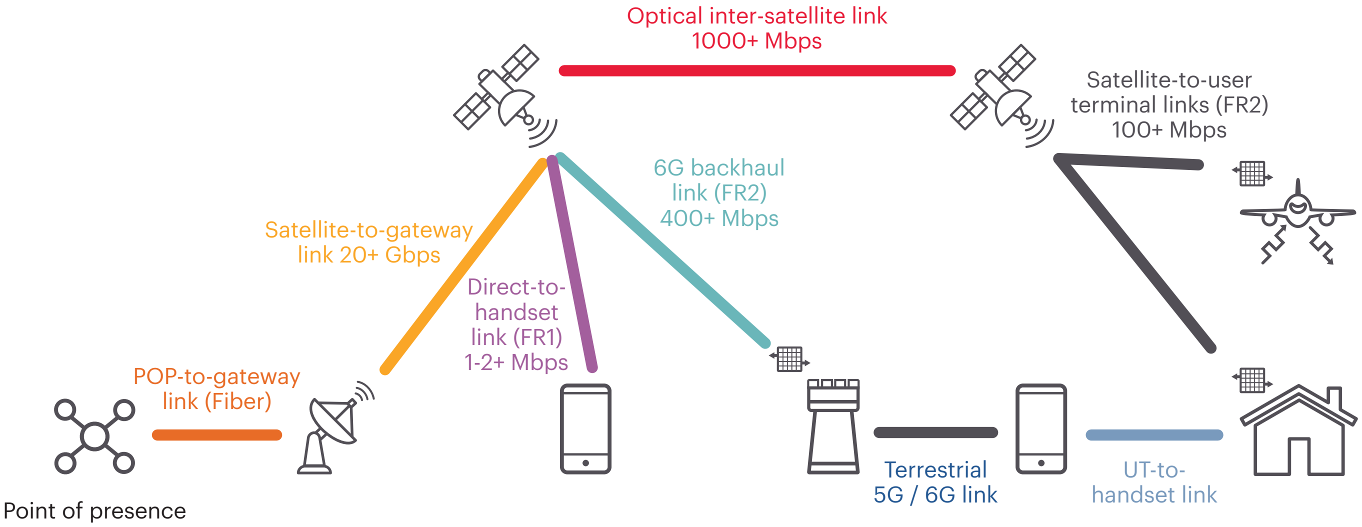


Figure 2. An array of satellite links connects the satellite and terrestrial networks. *(Source: Todd Humphreys, University of Texas Austin)*

Direct-to-cell phone capability

Much of the hype around NTNs currently centers on direct-to-device capability. This capability allows cellular phones to connect to satellites when they are out of range of terrestrial base stations. For example, future 3GPP releases will include very short aperture terminals (VSATs), which consist of high-gain antennas, such as dish or array panels, and higher power modems in fixed installations.

The industry must innovate to provide this constant connection to orbiting satellites. The primary use cases for direct-to-cell phone access include the following:

- Proprietary satellite systems, such as Iridium satellite communications, and government use cases that require direct-to-call phone access and connected vehicles.
- All unmodified cell phones that use 4G and 5G to connect with satellites.
- Both narrowband Internet of Things (NB-IoT) over NTN and 5G New Radio (NR) over NTN that relate to Release 17 for the 3GPP.

CHAPTER 2

Brief History of NTNs

Brief History of NTNs

Scientists and visionaries have long envisioned creating networks of low-Earth orbit satellites that could connect everyone on Earth. Current NTN commercialization efforts can trace their roots back to the 1990s, when two companies, Globalstar and Iridium Communications, formed and launched major satellite networks that aimed to realize that goal.

Globalstar and Iridium deployed satellites specifically built to support low-bandwidth satellite communication directly to specialized handsets. While both satellite networks are still in operation, neither company has achieved mass commercial success. The key reason was that mobile network operators launched terrestrial networks much faster than anyone had expected, reducing the demand for direct-to-handset NTN services. Additionally, neither venture provided service that lived up to consumer expectations — the signals could not penetrate dwellings enough for indoor use and were highly compressed, resulting in poor voice quality.

It is important to note that the cost of launching a satellite has decreased dramatically since the formation of Globalstar and Iridium. When Iridium began launching its constellation of 66 satellites in 1997, each launch was a massive undertaking. But thanks to improving rocket technology and declining costs, launching a LEO satellite is much less costly today. According to a study by Thomas G. Roberts in Aerospace Security, the price of heavy launches for LEO satellites has fallen as much as 85 percent since the 1990s, from around $10,200 per kilogram to as low as $1,500 per kilogram today. However, while launch costs have fallen precipitously, the increase in number of satellite launches has created a severe shortage of launch capacity.

Handsets also have significantly benefited from technological advances and declining costs since the 1990s. Iridium's initial handsets released in 1999 weighed more than a pound, nearly twice the weight of the average cell phone at the time, and cost about $3,000.

In recent years, several firms have undertaken new initiatives to promote direct-to-device NTN communications. These newer ventures, notably Starlink, Amazon, and others, have shown great promise and early success. These ventures rely mainly on proprietary, non-standard technologies, requiring proprietary algorithms and circuits within the satellite to handle the complexity of various communications.

CHAPTER 3

Advantages of NTNs

Advantages of NTNs

A key feature of NTNs is the ability to bring mobile communications to remote and under-served regions. This aspect helps to bridge the digital divide by providing connectivity to areas lacking terrestrial infrastructure. NTNs also play a crucial role in disaster response and emergency communications in remote regions, enabling communication restoration in times of crisis.

For example, the US Space Force looks at multiple and varied NTNs to provide global coverage for communications, intelligence, and early warning systems. In addition, NTNs can supply emergency support via a combined NB-IoT LTE / 5G GEO solution and internet coverage in remote areas using a 5G NTN LEO or proprietary solution.

Non-terrestrial networks largely increase global sensing capabilities through NB-IoT over NTN, enabling various industries to leverage the resulting data. For example, using distributed sensors will increase efficiency and yields in agriculture. Incorporating non-terrestrial networks expands communication capabilities and maximizes the potential of data observation from space. This approach includes connecting sensors on the ground with IoT and using hyperspectral imaging to monitor crop water needs and harvest readiness. NTNs also would enhance employing drones for pest control and fertilization, self-driving tractors with GPS, and much more. These advancements can lead to improved agricultural practices.

Enabling technologies

Several developments, including the deployment of multifunctioning satellites, are crucial to ensure the success of NTNs. These satellites can combine data gathering and transfer technology within a mesh network. The approach planned by the US Space Development Agency (SDA) organizes the deployment of these networks in layers or tranches, where communications serve as the backbone. According to the SDA, Tranche 0 will prove the feasibility of the following technologies:

- Low-latency data connectivity
- Beyond line-of-sight targeting capabilities
- Missile tracking and warning
- On-orbit fusion
- Multi-phenomenology ground-based sensor fusion

The first operational generation of the Proliferated Warfighter Space Architecture by the SDA, known as Tranche 1, includes 126 transport layer satellites, 35 tracking satellites, and 12 tactical demonstration satellites referred to as T1DES. The Space Development Agency's space centers, which rely heavily on commercial space operations models, will operate Tranche 1.

With this approach, any additional functionality can capitalize on the network for data transfer. New satellites also will boast onboard processing power to host base station functionalities (full or partial). In doing so, they enable higher power, lower latency, and wideband connections. Deployments of new LEO and ultra-low orbits will incorporate these capabilities onboard as part of 3GPP releases in 2025 and beyond.

Providing high capacity requires many satellites, sometimes referred to as massive LEO constellations. Commercial advancements have driven the development of massive LEO constellations, such as the SpaceX Starlink network. Taking an alternate route to provide NTN coverage, these early but market-dominating developments are shaping the marketplace before NTNs become fully integrated into 5G and 6G networks. Proprietary approaches will likely remain part of the NTN landscape, although their relevance may change.

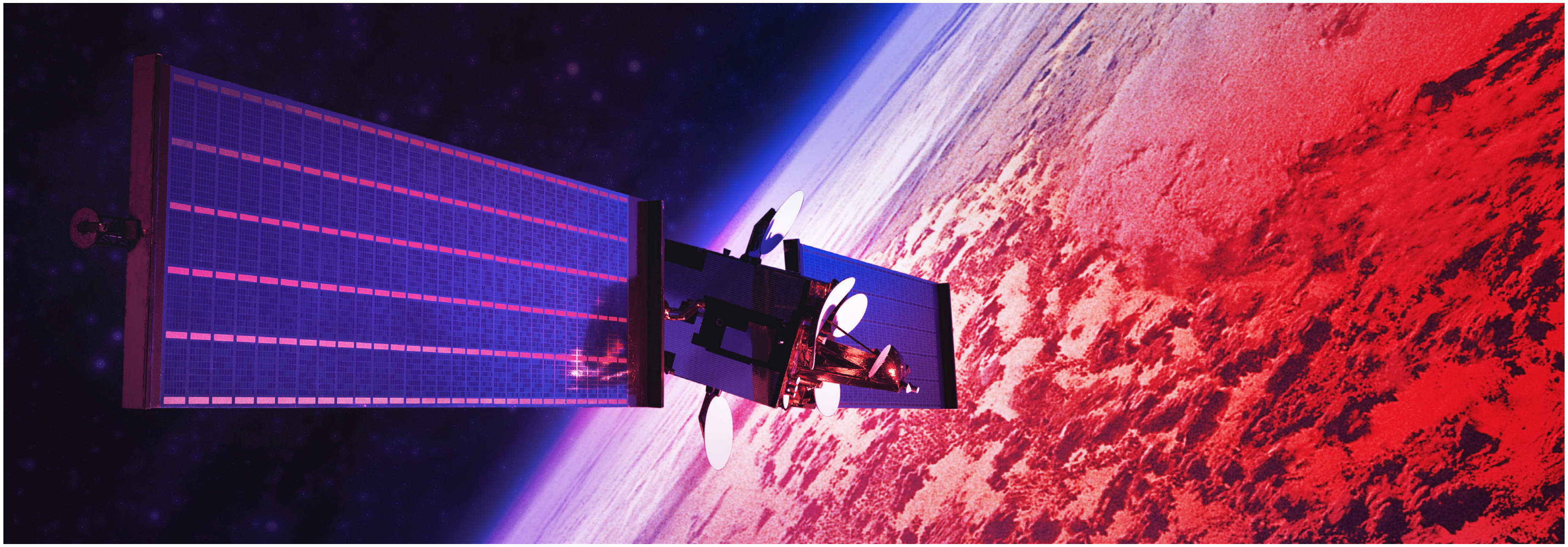
CHAPTER 4

Primary Challenges

Primary Challenges

While the future of NTNs shows great promise, their deployment comes with challenges. The most obvious is the harsh operating environment of space and the need to launch systems into orbit successfully. Building mesh networks in space exacerbates these complexities by multiplying the chances for problems.

For NTNs to satisfy the increased demand for data, they must transmit and receive more information through their satellites for communications and data transfer. The advantage of a distributed LEO satellite constellation is that it spreads risks and costs across hundreds or thousands of satellites. For military and government applications, however, this approach invites additional security risks for the hardware as it passes over unfriendly territories. National security needs exert demands for cyber protections and novel operations to protect infrastructure deployed in space.



Optical communications

Optical communications links provide advantages that help to overcome NTN challenges. As a critical enabler of mesh networks, optical communications use light to transmit information, providing several benefits over traditional radio frequency (RF) communications. The benefits of this technology include increased bandwidth, higher frequencies, improved security, and the capability to transmit data without signal degradation.

The deployment of optical links connects satellites and establishes a more resilient and secure network for flexible data transfer over longer distances. With its focused laser approach, optical communications eliminate the bandwidth and latency issues associated with traditional satellite systems. The localized laser source and A-to-B communication associated with optical photonics also help organizations encode over wider bandwidths and achieve higher data rates.

New Earth observation technologies like synthetic aperture radar rely on optical communication as a critical component. This technology enables organizations to send raw data to terrestrial applications in a highly secure manner.

Synthetic aperture radar is an example of one use case that underscores the importance of security, helping to drive the rise of optical communications. The technology's tight, precise laser beam is much narrower than RF, meaning that the point-to-point communication of data is highly secure. The laser beam protects optical links more effectively from eavesdropping, is more resistant to jamming and spoofing, and is better suited for confidential and military communication.

LEO performance

In addition to providing increased security, LEO satellites must maintain performance despite weather, the environment, and even motion. These satellites move at around 17,000 mph as they orbit Earth. Though such constellations often have many advantages for low latency communications, failure to correctly consider the communication link's dynamic nature can lead to Doppler shift and fading issues.

Unlike GEO satellites, LEO satellites have a very limited field of view. Due to the lower orbit and speed of motion, more LEO satellites are needed to provide equivalent coverage of a given area. Communication with a LEO constellation requires ground terminals to switch between multiple satellites and beams to maintain uninterrupted communication, for example. Such coordination between terminals and individual LEO satellites occurs automatically. Communication with a LEO satellite occurs by tracking one satellite, then tracking another as the first satellite starts to go out of view. A successful connection must seamlessly connect between the two satellites.

Phased array antennas perform this task well, tracking multiple LEO satellites and enabling backups to ensure continuous connectivity. A phased array comprises many antenna elements arranged in a matrix to provide desired characteristics or features not available in a single antenna. Each radiating element can be phase-shifted so that the radiated waves add constructively, maximizing gain in the desired direction.

Spectrum congestion

Spectrum crowding presents another challenge for LEO satellites. Limited availability in reserved satellite bands and requirements for wider bandwidth communications through satellite links have increasingly pushed deployment into higher frequencies, even for aerospace and defense applications.

The ever-increasing bandwidth driving satellites to higher and higher frequencies demands new design requirements and methods to ensure satellite performance. However, wider bandwidth and higher-order modulation schemes introduce challenges that can affect link quality at millimeter-wave frequencies. For example, higher frequencies encounter stronger fading due to the water vapor within atmospheric conditions.

Once deployed, networks must operate in a very congested spectrum environment. With other systems operating in very close frequency bands, and some of them critical, NTNs must build in the ability to step down if needed. They defer to the priority of those critical networks so they remain operational at all times. Non-terrestrial networks must also incorporate resilience to attacks from criminals and governments looking to hijack the network, spy on traffic, or diminish capabilities. Such threats create challenges ranging from delays and loss of service to threats to military missions and national security.

Creating links with satellites and handsets also presents technical challenges. The Doppler effect is one of the main technical challenges in mobile satellite communications. It involves the change in a wave's frequency in relation to an observer moving relative to the wave source. Compensation for the Doppler effect is necessary for links with satellites.

The delay in sending the signal between the satellite and the handset also creates challenges. The delay in a GEO satellite is much different from that in a LEO satellite due to the greater distance to the GEO satellite. However, the delay and Doppler from the orbit physics limit NTN system capabilities. Additional system-level challenges arise in the handling of the complexity of handovers between terrestrial networks and satellites, as well as simultaneous handovers between the user terminal and satellite. Adding satellite-to-satellite handovers further complicates these issues. Solutions are evolving to overcome these protocol-related challenges, but their complexity continues to increase.

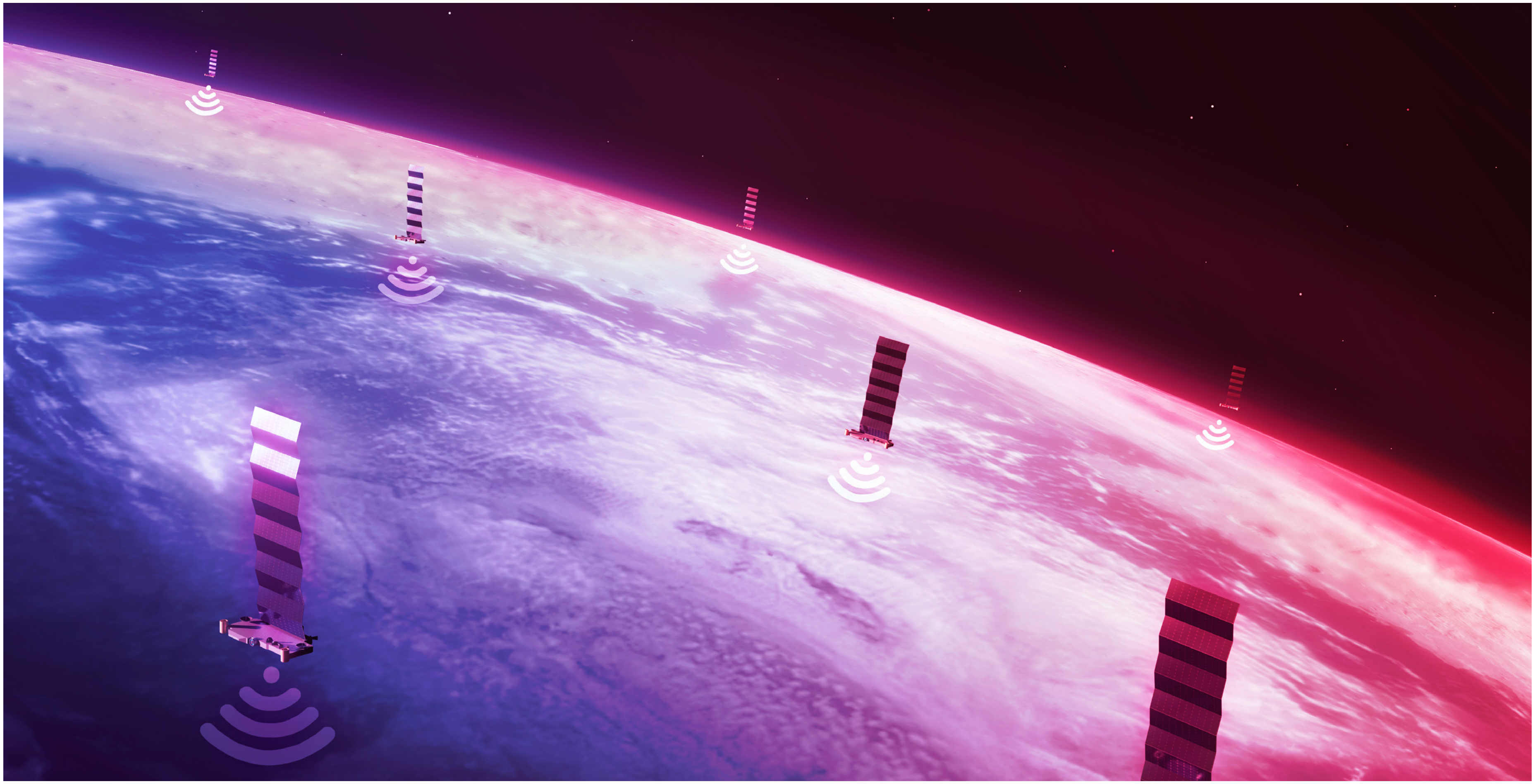
Signal power levels pose an added risk, as they need to maintain a certain level to maintain the expected quality of service (QoS). If limited, the capacity of satellite networks also will impact QoS.

Additional issues to remember include regulatory and policy considerations, which must be addressed to ensure the equitable distribution of network resources and the protection of frequencies for terrestrial and non-terrestrial networks. Environmental sustainability is another crucial aspect to consider, as the proliferation of satellites raises concerns about the negative impact of space debris.

Trade-offs to consider

Engineers need to make trade-offs in several areas to optimize NTN performance. Latency is the clear tradeoff in communication over great distances. However, the mesh network may offer lower latency over fiber optic communications across longer distances because the speed of light in a vacuum is greater than the speed of light in glass.

The additional delay significantly reduces the link's capacity. Designers must also consider design decisions that affect capacity, signal power, and robustness, such as seamless connections and uninterrupted links.



CHAPTER 5

Use Cases

Use Cases

Non-terrestrial network technology has many potential applications that vary widely in scope. One promising use case for broadband LEO communications is providing backhaul to cell towers in remote locations where fiber or terrestrial microwave connections are impractical. These towers can then service handsets or devices over standard cellular links.

Other applications include using NTNs to augment service to sensors, actuators, and IoT devices. The most ambitious NTN proposals call for direct-to-device links with global coverage, low latency, and rates beyond 2 Mbps. 3GPP initially defined several primary NTN use cases as part of its efforts, including:

Multi-connectivity: The user equipment (UE) simultaneously attaches to terrestrial and satellite links for multi-connectivity. This setup allows routing time-sensitive low-latency traffic through the terrestrial links, while satellite links manage less mission-critical traffic.

Fixed cell connectivity: This use case enables users in remote geographical areas and other places like ships at sea or offshore oil platforms to access 5G services.

Mobile cell connectivity: The UE accesses available terrestrial networks and automatically switches to satellite links in remote areas, providing seamless 5G coverage to aircraft and high-speed rail.

The mobile communications industry has also outlined three other use cases for NTNs, including:

- Increasing network resiliency by providing a backup in case of network outages and bolstering network availability by aggregating multiple network connections in parallel to prevent complete network connection outages.
- Enabling mobile network operators to stitch together unconnected areas of 5G network coverage.
- Delivering satellite-based television or multimedia services using 3GPP's 5G multicast-broadcast services (MBS) specification.

CHAPTER 6

The Role of Standardization

The Role of Standardization

More recently, 3GPP set the standards and targets for NTNs within 5G and future 6G networks for direct-to-handset communications and IoT devices. The 3GPP published Release 17 in 2022, making it the first release to account for ground-based terrestrial networks and non-terrestrial network platforms in the 5G specifications or any previous 3GPP cellular specifications. As defined in Release 17, these NTN platforms include multiple types of satellites, high-altitude platform stations (HAPS), and crewless aerial vehicles.

Release 17 introduced support for two types of non-terrestrial networks — 5G NR and narrowband-IoT (NB-IoT). 5G NR NTN supports satellite network access to handsets in the Frequency Range 1 (FR1) band for use cases such as voice and data transmission in geographic areas not served by terrestrial networks. NB-IoT NTN supports access to IoT devices directly from satellites for agriculture, transportation, and other applications.

Release 17 enhancements address the technical hurdles inherent in communication between handsets, IoT devices, and satellites to enable NTN support. These challenges include propagation delay, Doppler shift, and the difficulties associated with communication between moving terminals (user equipment) and base station platforms such as satellites, HAPS, and crewless aerial vehicles.

Release 17 makes several NTN-related enhancements to the 5G protocols to accommodate the longer distance between the user equipment and the satellites. These enhancements include changes to hybrid automatic repeat request (HARQ) and random channel access (RACH) procedures to allow for increases in signal propagation delay.

The inclusion of system information broadcast (SIB) messages having information on the location and movement of the satellites, also known as ephemeris data, enables the UEs to estimate when satellites might become available.

Release 18

Release 18, due for completion in 2024, includes promising new NTN capabilities, coverage enhancements, performance enhancements, and support for new frequency bands. Figure 3 illustrates the timeline for this release. Some Release 18 enhancements focus on extending LTE support of NTN, while others primarily focus on enhancing 5G NR NTN capabilities for IoT. Some of the upcoming enhancements are mobility management and power-saving enhancements for discontinuous coverage.

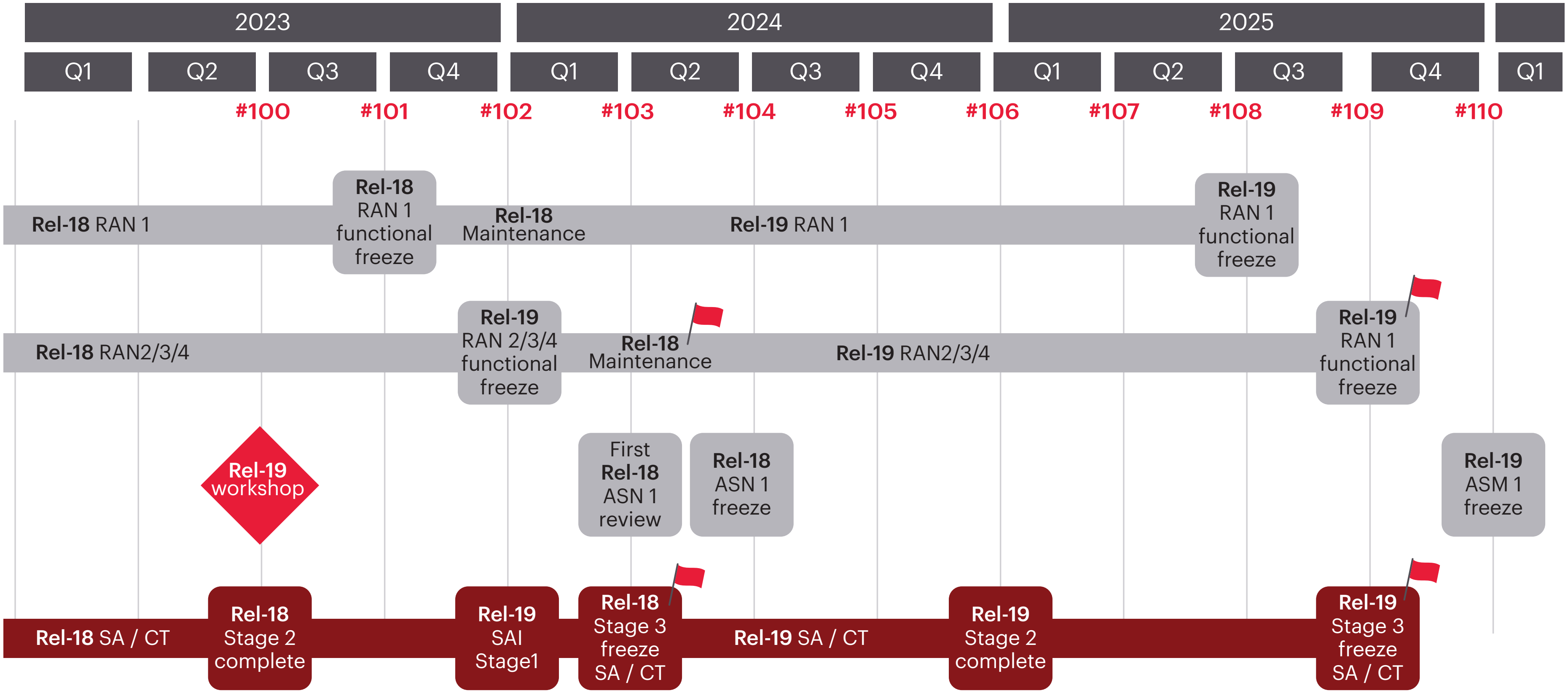


Figure 3. The proposed development timeline for 3GPP Release 18 and 19

Specific Release 18 enhancements focus on:

- Improving NTN mobility by modifying support for neighbor cell measurements before the UE loses coverage due to radio link failure — and adding support for signaling neighbor cell ephemeris data for enhanced Machine Type Communication (eMTC) and NB-IoT.
- Advancing overall NTN throughput performance — including disabling HARQ feedback to mitigate the impact of HARQ stalling on UE data rates and identifying global navigation satellite system (GNSS) operation improvements to reduce UE power consumption and create a new position fix for UE pre-compensation during long connection times.
- Optimizing of GNSS for power efficiency for long-term connections.
- Supporting new scenarios covering deployments in frequency bands above 10 GHz, such as the introduction of extended L-band and frequency division duplexing (FDD) LTE band operation for IoT NTN.

Release 19

The 3GPP is currently defining Release 19, and finalization will occur in late 2025. Although 3GPP plans to limit the scope of the overall enhancements in Release 19, it will include some additional NTN enhancements. Several proposals are under consideration for Release 19, including a specification for a regenerative architecture for NTNs that includes distributed unit processing on board the satellite supporting inter-satellite links.

The following are recommendations from the 3GPP:

- Enable indoor NTN access with uplink and downlink coverage enhancements.
- Support increased capacity for uplink access with uplink capacity and throughput enhancements.
- Support for 5G reduced capability (RedCap) devices, including NTN assistance for 5G multicast broadcast services (MBS).
- Reduce NTN's dependence on Global Navigation Satellite System (GNSS) with enhanced GNSS operation that includes UE pre-compensation for uplink time and frequency synchronization in case of GNSS availability decline.
- Support for NTN discontinuous coverage for IoT NTN.

Beyond 3GPP Standards

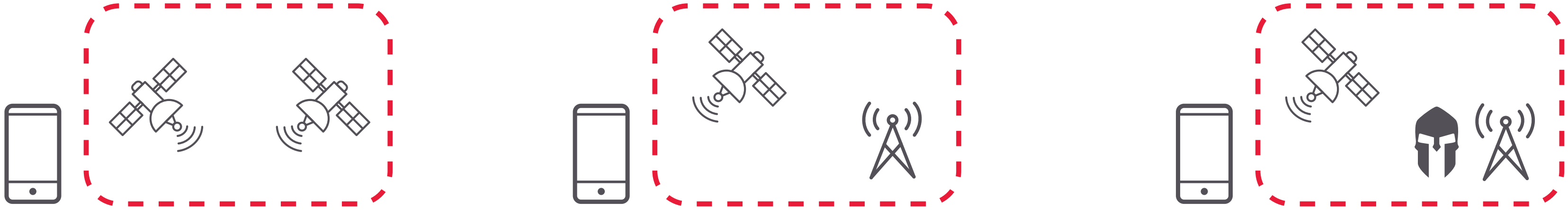
Not all NTN solutions and services will operate within the 3GPP standards. Many vendors outside 3GPP already rely on proprietary waveforms, with more in development. DVB-S2X is the Digital Video Broadcasting Project Second Generation Satellite Extension, offering alternatives to wideband data transfer via NTNs.

CHAPTER 7

NTN Testing Challenges and Solutions

NTN Testing Challenges and Solutions

One of the primary advantages of NTN inclusion in 3GPP standards is the ability to access satellite networks with existing, unmodified 5G and LTE devices. 3GPP enhancements and releases ensure that the origin of the cell from a space-borne platform does not affect communications.



Stress and performance	
Timing / Delay	Tolerance to varying delay, excess of Timing Advance
Doppler	Performance for high and varying at cell edges
Link budget	Absence of HARQ in a large and varying path loss
Random access	PRACH retransmissions and RAR delays

TN-NTN, NTN-NTN handoff	
Mobility	Reselection, handover, intra-satellite beam change
Inter-RAT	TN to and NTN between 5G – 4G
Interference	Co-existence with terrestrial bands
Cell monitoring	RLM and beam failure dectection, with/out DRX
Measurement procedure	Asynchronous, intra and inter frequency

E2E real-world test	
Throughput	TCP back-off when high packet data error rate; low data rates experience
Latency	Congestion, capacity
Security	Find vulnerablities in device (privacy, functionality)

Figure 4. Test challenges and use cases associated with unmodified and direct-to-cell NTNs

Accessing NTNs with unmodified cell phones

Non-terrestrial networks provide access to unmodified cell phones by employing distortion in transmission to mitigate the impact of satellite Doppler on the signals. NTNs also use techniques to compensate for the high-velocity LEO satellites, which travel at approximately 17,000 mph.

Network planning for NTNs requires adding both cellular networks and satellite cells. In unmodified 5G cell phones, networks and base stations compensate for timing and frequency errors, as shown in Figure 4. The goal is to create conditions for satellite cells that are similar to those of terrestrial cells. Directive antennas and beamforming split the service area of a satellite into small cells, making the network manageable. As a result, cell edges have more issues with frequency and timing errors than the middle of the cell.

As shown in Figure 5, Keysight's NTN solutions portfolio includes end-to-end emulation technology. A network emulator simulates base stations while a channel emulator reproduces satellite links with real-world conditions.

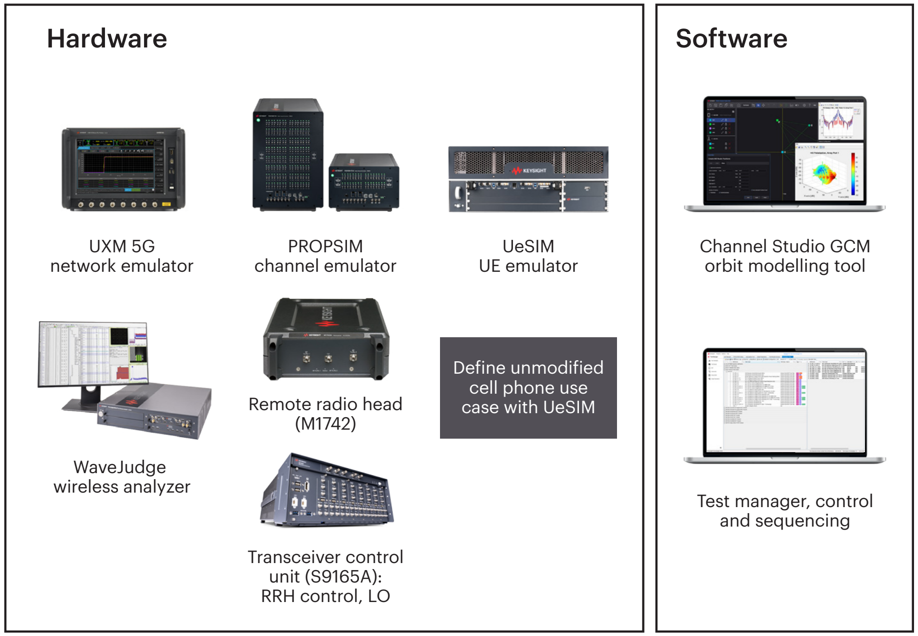


Figure 5. Keysight's test solution for unmodified cell phone NTN access leans heavily on Keysight's emulation portfolio and other components

Integrating cellular networks and NTN devices

To realize the mobile communications industry's vision of integrating cellular networks with NTNs over the next several years, device makers and mobile network operators must test NTN wireless links with actual base stations and real devices.

Significant challenges include simulating life-like conditions for satellite end-to-end links and the ability to connect NTN nodes and terminals before system deployment, as shown in Figure 6. NTN development projects need the ability to test and connect network entities and terminals in the prototyping phase and before and during deployments to avoid costly delays.

The Keysight Satellite and Aerospace Channel Emulation Toolset, based on the PROPSIM channel emulator, enables satellite, aerospace, and airborne radio system performance validation under coherent real-world complex 3D propagation conditions.

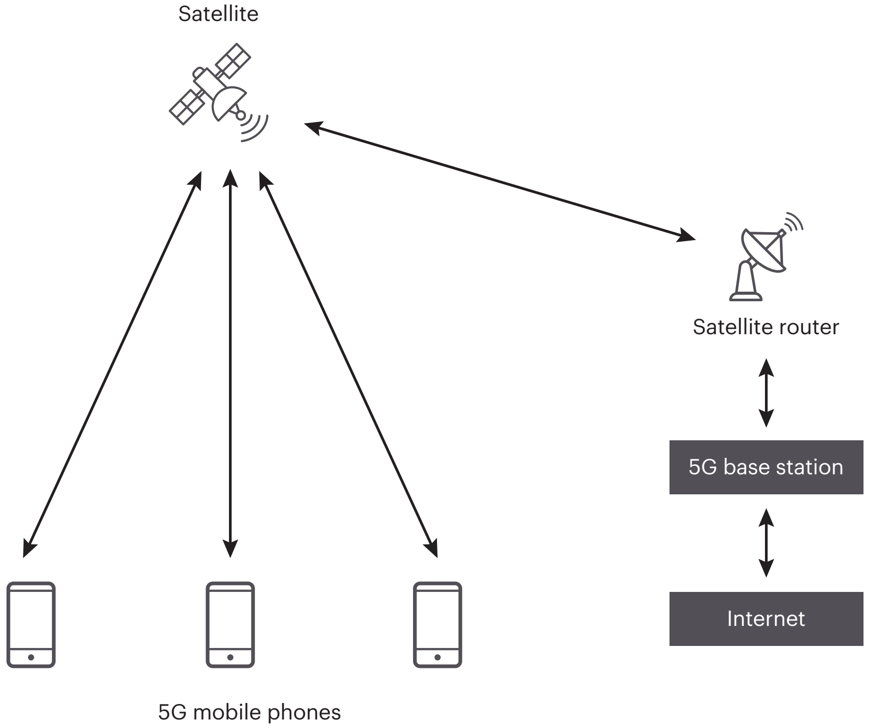


Figure 6. NTN network showing incorporation of direct-to-device capable NTN devices

As shown in Figure 7, using the Satellite and Aerospace Channel Emulation Toolset enables testing real-world NTN scenarios in a laboratory environment. It allows network and device vendors to verify system performance under real-life operating conditions before launching devices and networks. They can also use PathWave to create the payload signal waveforms, which can then be used in testing system performance. The WaveJudge wireless analyzer is used either during runtime or using recorded data. It reveals what is happening in the system level and validates functionality against system requirements.

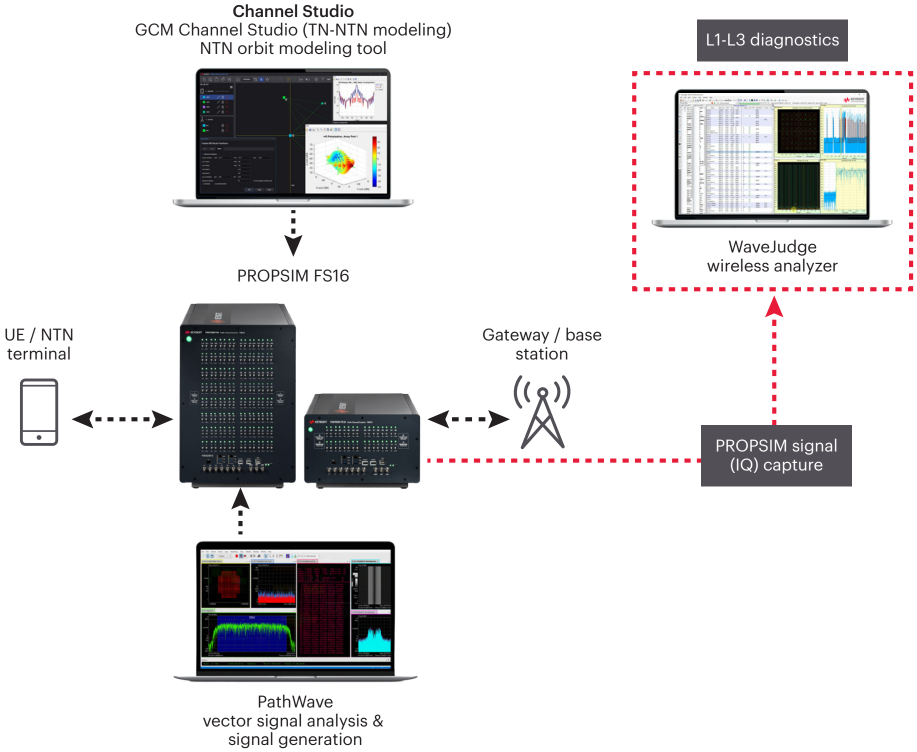


Figure 7. NTN test setup using the Satellite and Aerospace Channel Emulation Toolset

CHAPTER 8

Looking Ahead

CHAPTER 8

Looking Ahead

NTNs have transformed mobile communications over the last 30 years. As 5G and future 6G networks incorporate NTNs into their design, pushing past the boundaries of terrestrial-based infrastructure, the impact of NTNs will become even more significant. Because of their ability to connect the unconnected (theoretically anywhere in the world), NTNs continue to play an increasingly prominent role in wireless communications, enabling ubiquitous connectivity and supporting emerging technologies like autonomous vehicles and IoT.

NTNs also have the potential to overcome infrastructure challenges in developing regions, empowering communities with access to education, healthcare, and economic opportunities. By supplying reliable connectivity, these networks foster social and economic development on a global scale.

Learn More

- Enable Next Generation Non-Terrestrial Networks
- Space and Satellite Solutions
- Wireless Solutions
- **White Paper:** Accelerate Deployment of Space Missions Through Digitalization
- **White Paper:** RF System Measurement Science Launches 5G NTNs
- **Brochure:** Satellite Mission Assurance
- **White Paper:** Satellites Bolster 5G Through Non-Terrestrial Networks

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