SOLUTION BRIEF

5G NTN Testing Using S8825A Satellite & Aerospace Channel Emulation Toolset

Accelerate non-terrestrial network (NTN) development with realistic satellite radio channel emulation

KEYSIGHT

Table of Contents

5G NTN – Satellite Service for the Masses

Traditionally, satellite communications networks require special user terminals, with large cell phone antennas and a satellite subscription plan.

But 5G Non-Terrestrial Networks (NTNs), introduced as part of the Third Generation Partnership Project (3GPP)'s Release 17, are revolutionizing satellite phone availability and delivery. Satellite service will soon be available to billions of mobile phone subscribers worldwide.

5G NTN differs from the traditional satellite networks via network-assisted operations, where the base station helps establish and handle the cell phone connection to the satellite. In 5G NTN, the network adjusts the timing of the radio frames to match the user location and pre-compensates part of the link frequency error caused by the satellite movement, making it easier for the user terminal to tolerate the satellite link characteristics.

Network broadcast system information blocks (SIBs), which store information about satellite locations and velocities, enable the cell phone to estimate link conditions, the delay of the satellite link, and Doppler error in transmission frequency.

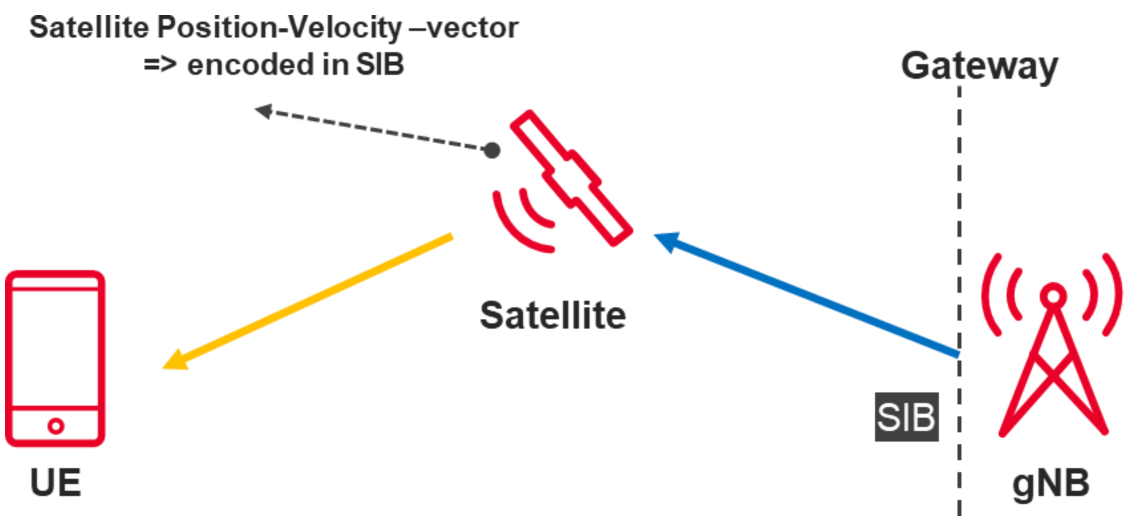

Figure 1. 5G NTN transparent link, where satellite position/velocity is sent to cell phone in SIB

NTN Technology Overview

Base stations and network access points are critical network components to provide a smooth and seamless service to 5G NTN users. This is particularly true in the case of cell phones that have not been specially modified for NTN, which see the satellite cell the same way as any other network cell.

Using unmodified cell phones is possible within a limited cell radius, where the satellite cell conditions are almost identical throughout the cell for multiple users. Within this radius, the cell phones see the satellite in the sky at the same angle, and the delay and Doppler of neighboring users are close to each other. In practice, using unmodified cell phones requires splitting the network into relatively small cells with the users being within a few miles from each other. This is a simplified special use case of the larger scale 5G NTN, where the phone is also responsible for the tolerance of the satellite connections, its delay, and Doppler error.

The key techniques and methods involved in 5G NTN communications include:

1. Minimizing the frequency error by estimating the link conditions and making counteractions in the radio link's network and cell phone ends.
2. Adjusting the timing to make the gateway-to-satellite-link (feeder link) invisible to the end user terminal in the downlink (network-to-user direction).
3. Handling the link from the satellite to the service subscriber (service link) from the NTN-capable cell phone, including minimizing the frequency error in the phone-to-satellite uplink (user-to-network direction).

Main challenges in deploying 5G NTN

Deploying 5G NTN services opens satellite services to subscribers of cellular networks. In principle, this means integrating both terrestrial and satellite networks so that a single network operator can offer both.

In practice, different operators deploy satellite networks and ground / terrestrial networks. Also, the equipment used in satellite and mobile networks typically come from different vendors that specialize in either satellite or mobile network nodes.

Figure 2. Decreasing costs of launch services enable the deployment of more satellites

Deploying cellular networks can cost hundreds of millions of dollars. Traditionally, satellite network deployment carries an even higher price tag. Ten to 20 years ago, delivering a payload into orbit using space shuttles cost around $50,000 per kilogram. SpaceX's StarShip is expected to bring down the price per kilogram to no more than $20 – a massive cost reduction of 2,500X!

In 2019, the cost for launching satellites with Falcon rockets was around 7,500 per kilogram ($6.8 million per ton). The industry continues to focus on reducing costs for the deployment of satellite constellations hosting thousands of satellites flying in low earth orbits (orbital altitudes less than 2,000 kilometers).

Implementing satellite services is challenging for the user terminals, especially for smartphones. The satellite receivers usually need to use larger, higher gain antennas because distant satellites result in low signal levels. Also, 5G NTN supports direct satellite-to-phone service only outdoors because the signal from the satellite is not strong enough for indoor applications. Modulations better suited for lower signal levels, such as quadrature phase shift keying (QPSK), deliver more robust transmission for use cases in which low bit rate is not an issue.

In addition to low received power, satellite movements pose challenges by introducing Doppler error in the frequency domain. Algorithms that use predistortion on the signal before transmission in accordance with link estimation can help mitigate the frequency errors. The satellite distance causes additional delay in the link from the network to the end users, which requires adjusting the protocol timing and a more efficient way of handling the frame retransmissions. The movement of the satellites also cause big changes in the delay and Doppler of the wireless link, which the phone and network must tolerate to provide seamless service.

Figure 3. NTN devices include Bluetooth dongles and smartphones.

For cellular networks, adding satellite users generates new requirements for handling the customer connections and interactions between the satellite and cellular networks. 3GPP defines different scenarios for 5G NTN where the user terminal directly connects to the network via the satellite. In the future, a ground relay node could retransmit traffic from the satellite network to surrounding cell phones.

3GPP has introduced modifications to the 5G protocol stack for satellite link use, including retransmission procedure, doubling the number of hybrid automatic repeat request (HARQ) retransmission processes from 16 to 32 to increase tolerance for delays in receiving satellite signals. Also, new interfaces enable sharing ephemeris data between entities. Traditional cellular networks require new network entities to complete the service, such as an NTN control center for containing and sharing the satellite location and velocity information, and satellite gateways to enable the base stations and other network elements to access the satellite constellation.

5G NTN Channel Modeling Tools

Testing NTN system performance before deploying the satellite network and updating the cellular network requires simulating and testing the operational environment. You can use channel emulation with channel models for testing with hardware.

Keysight's Channel Studio GCM tool is a complete channel model creation environment which contains ready-made standard models and user defined models for both cellular and satellite networks. The output of the ephemeris data file used for defining the satellite link channel models is available for the UXM 5G network emulator or the real base station in the test setup.

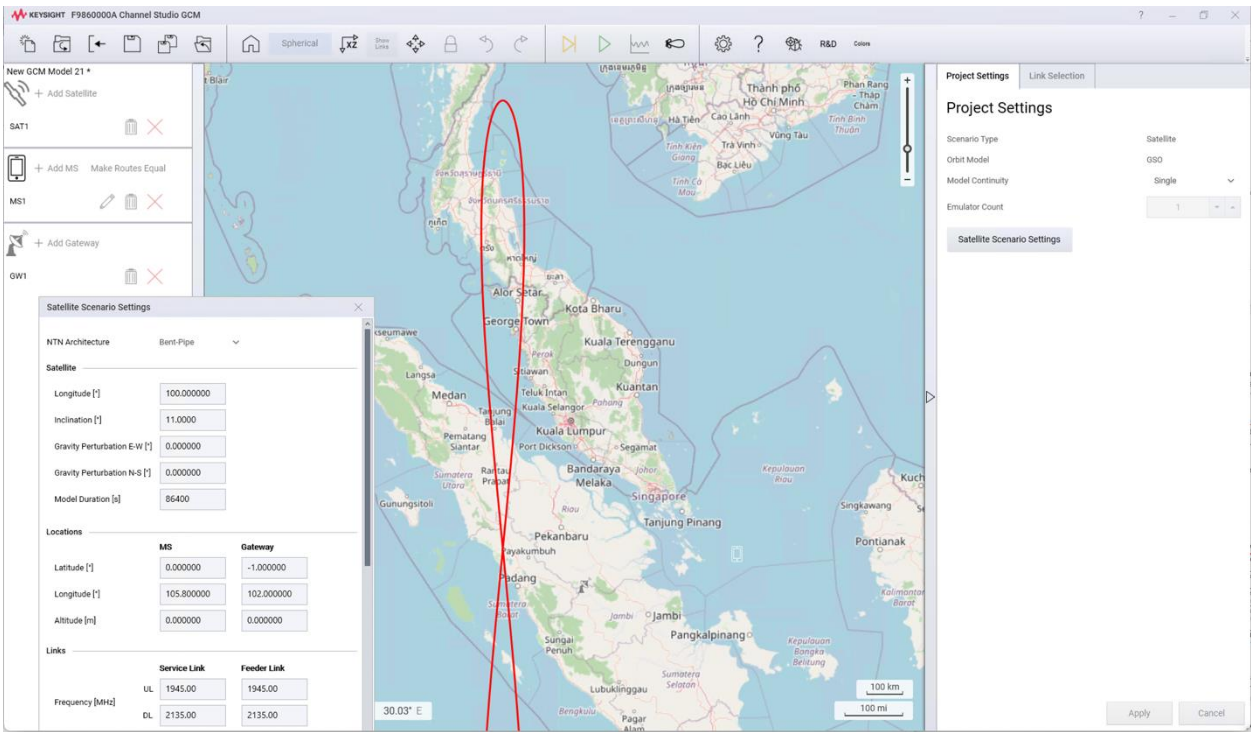

Figure 6. Keysight's Channel Studio -tool generating orbit models and test scenarios for NTN testing.

Scenario type - satellite

"Satellite" is the latest addition to the scenario types supported in the Channel Studio GCM tool. This mode enables the creation of NTN models. Channel Studio GCM uses "Satellite Scenario Settings" that guide you through a set of parameters to create satellite trajectories and test scenario data files for NTN.

The NTN scenario is stored in a set of emulation files ready-made to upload into the PROPSIM channel emulator.

At the beginning of NTN development, narrowing down the possible causes of problems that relate to new functionality of the system under test is critical. Increased delay between the network and user terminals is the main new characteristic the channel model to mimic and test at the system level when adding satellite links in a cellular network.

Consider starting with fixed delay testing to check the estimated satellite delay between the gNB and the cell phone and the tolerance for the delay without other satellite link characteristics. Fixed delay testing reveals the retransmission performance of the satellite links, as well as the timing and timing adjustments with the addition of NTN support.

With GEO orbits almost equal to static delay lines, fixed delay testing is helpful to understand the behavior of these satellites.

Table 3. Overview of 5G NTN Test Cases

5G NTN – test cases

Test Case	Description	GEO/GSO (NB-IoT)	LEO (NR-NTN)	Comments
1	Fixed delay with no Doppler	Delay: 120 ms Doppler: 0 Hz	Delay: 6 ms Doppler: 0	Fixed satellite position for gNB
2	Fixed delay and static Doppler	Delay: 120 ms Doppler: 200 Hz	Delay: 6 ms Doppler: 45 kHz	Fixed satellite position for gNB
3	Variable delay and Doppler as per 3GPP model	Differential delay: 120-130 ms Max Doppler: 400 Hz	Differential delay: 1-7 ms Max Doppler: 50-100 kHz	3GPP model aligned ephemeris data for gNB
4	Variable delay and Doppler as per imported satellite orbit model and different UE locations	Same as above	Same as above	Orbit model aligned ephemeris data for gNB
5	Variable delay and Doppler of steps 3 and/or 4 with fixed conformance TDL models (TS 38.101-5)	Differential delay: 120-130 ms Max Doppler: 400 Hz	Differential delay: 5 ms Max Doppler: 50-100 kHz	Model aligned ephemeris data for gNB

Apart from delay, frequency error caused by satellite movements is the key difference between satellite connections and cellular networks. LEO satellites with orbital altitudes between 500 and 2,000 km and velocities between 7 and8 km/s (which typically have a lot of Doppler error in the link) are particularly prone to frequency errors.

Doppler error can vary from some tens of kilohertz up to the megahertz range depending on the elevation angle toward the ground receiver and the frequency. Large frequency errors result in challenges to the test arrangement. The ability of the PROPSIM platform to adjust Doppler up to 1.5 MHz per link is helpful to overcome this challenge.

The Channel Studio GCM tool can adjust the fixed delay and fixed Doppler error or use satellite-trajectory based dynamic parameters. In addition to fixed or dynamically changing parameters, the satellite links typically handle the links for uplink and downlink using separate frequencies. Currently, the N255 and N256 bands with frequencies of 1.6 and 2.1 GHz are the most prominent frequencies allocated for direct-to-cell phone 5G NTN use cases.

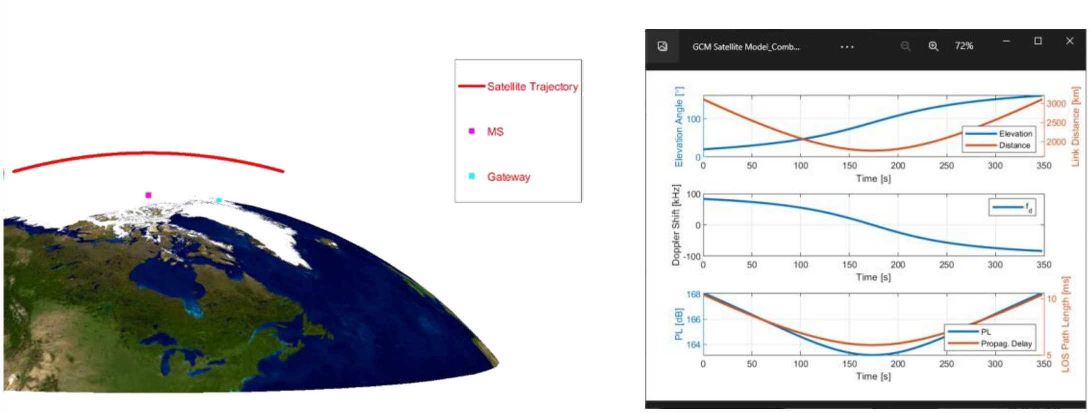

Figure 5. Keysight Channel Studio software shows the satellite trajectory and resulting channel model parameters.

Creating Test Cases with Channel Studio

The workflow for creating NTN test cases with Keysight's Channel Studio software begins with defining the satellite orbit parameters. Selecting constant or dynamic parameters helps keep up with the gradually increasing complexity for testing. The dynamic parameters follow the defined satellite orbit parameters including velocity, altitude, and elevation angle range, and the frequencies of the serving and feeder links in the uplink and downlink.

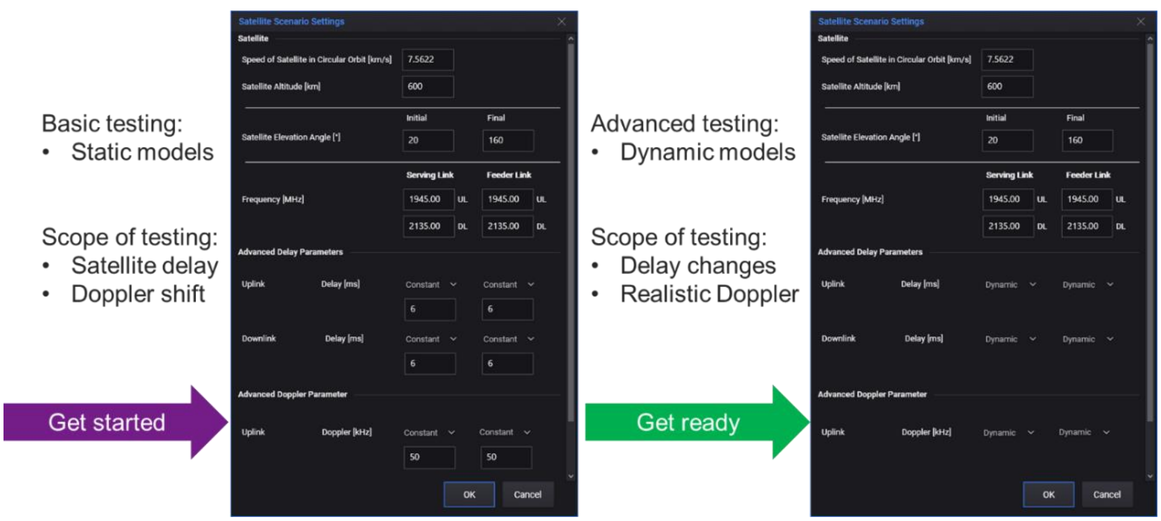

Figure 7. 5G NTN test case creation with Keysight's Channel Studio software

PROPSIM channel emulation scenarios

Channel Studio software creates ready-to-run scenarios for the PROPSIM channel emulation platform. The scenarios contain files for both PROPSIM and the UXM 5G wireless test platform for simulated networks use cases.

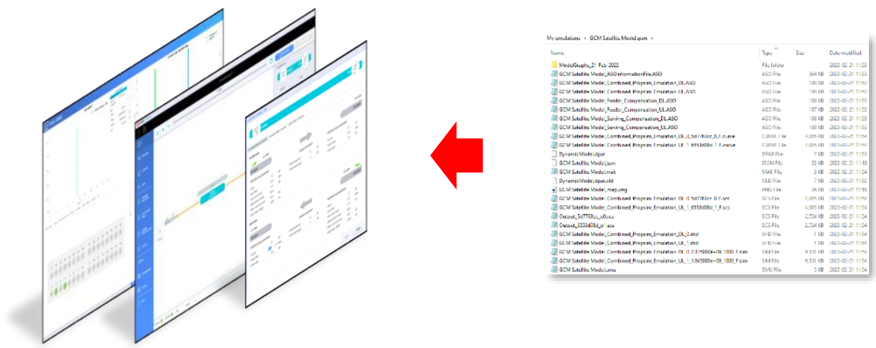

Figure 8. File based emulation with ready-to-run test scenarios ensures consistent results over test runs

Dedicated, test scenario-specific files ensure consistent test results over different test runs. Version control and variations in test material can be easily integrated into modern test management systems.

Importing orbital data

All satellites orbiting Earth are monitored, and their position and velocity at any given time are tracked. The position and velocity of satellites is known as “PV data,” also referred to as “ephemeris data.” This data is publicly available for commercial satellites. Satellite ephemeris data enables recreating orbits can for testing purposes.

Modeling the satellite orbit can serve as the baseline for defining the channel model for the radio link between the satellite transponder and ground terminal. Playing back the model simulates the link conditions in the lab for the PROPSIM channel emulation platform.

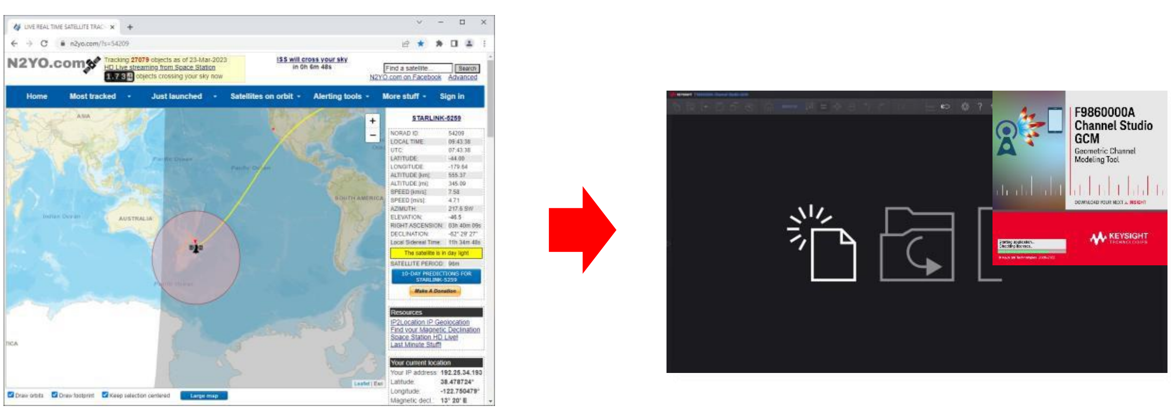

Figure 9. Keysight’s Channel Studio software uses publicly available ephemeris data to recreate satellite channel conditions.

5G NTN Wireless Test Solutions

Test planning starts with defining the content of the system under test (SUT) and the boundaries and interfaces of the device under test (DUT). Surrounding the SUT/DUT with suitable tools and test equipment the test environment can terminate all interfaces. You can measure the performance of the DUTs using digital twins of the radio channels, the channel models, just as if the devices were connected over the air in real operating conditions. The test setup needs to ensure antenna-to-antenna connectivity and leverage radio channel models to interlink all devices.

Keysight's portfolio of 5G NTN test solutions covers various testing needs. Select the appropriate test and measurement equipment depending on the use case. The main NTN use cases from a testing point of view are:

- testing the ground devices and user terminals / cell phones
- testing the network access points / base stations
- integrating network and user terminals in an end-to-end connection

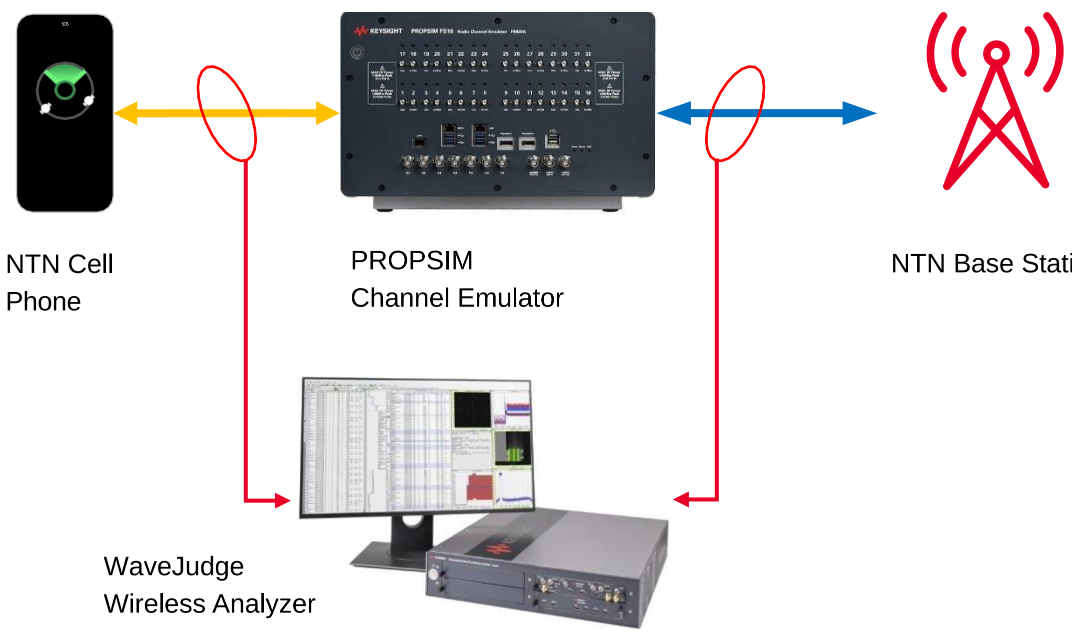

Figure 4. Keysight wireless solution for testing NTN cell phones

The test environment must simulate the network connection and link to the satellite when testing ground devices and user terminals such as cell phones. You can use real or simulated network access points and generic test equipment for testing the service from the DUT point of view. The cell phone sees the service like a real-world satellite cell, regardless of whether the network portion is real or simulated.

Testing the satellite links requires mimicking the target service's intended use case and operational environment. For example, geostationary equatorial orbit (GEO) satellites provide a long delay and quite static link conditions. Low earth orbit (LEO) satellites provide a shorter delay, but link conditions change rapidly as the satellites move across the sky. Keysight's PROPSIM channel emulation solutions create satellite orbit-related radio channel models. The models make the signal look like it is propagating through the atmosphere from the ground to the satellite and back. The test solution simulates satellite movements by dynamically adjusting the link delay / Doppler / attenuation, mimicking the way the signal behaves when using real satellites.

Testing with a real base station

Connectivity is the main challenge for the test environment when the system under test contains real cell phones and real network entities.

Traditionally, this testing requires a cable between the phone and access point or adding test antennas to both end for establishing a link over the air. Adjustable or programmable attenuators typically control link power. However, testing delay, changes in the delay, frequency errors, and dynamic Doppler can be difficult or impossible when using cables and attenuators.

Channel emulators enable delay and Doppler variations over time to represent link conditions that approximate those in the field. Environment model and changes are stored in a channel model. The model contains the rules defining link behavior during testing. The main channel model parameters are dynamic signal attenuation, delay, and Doppler, which, taken together, recreate the radio channel identical to the real world.

The PROPSIM channel emulator is the main component of the test environment for connecting a real base station and a real cell phone. You can select different hardware options, features, and tools according to the parameters of the target system, such as the frequency band, signal bandwidth, and number of channels. The number of channels and other channel emulator capabilities depend on the needed number of nodes and connected antenna lines in test scenarios.

You can also extend the frequency range of the PROPSIM channel emulator by using remote radio heads (RRHs). RRHs convert the DUT radio frequency signals to the internal frequency range of the channel emulator. Radio propagation modeling considers the frequency conversion so that the Doppler calculations match the real-world radio propagation channel.

Testing with an Emulated Base Station

Using the UXM 5G changes the solution domain to a complete mobile phone testing solution – e.g. for the conformance testing of system requirements namely the S8705A RF/RRM DVT and Conformance Toolset.

Keysight's UXM 5G wireless test platform can simulate the functionality of a full cellular base station – called a gNodeB (gNB) in 5G networks. The UXM network emulator represents the 5G service to a device. The latest version of the UXM supports the 5G satellite use case. As with a real base station, the UXM 5G needs the satellite trajectory information and the ephemeris data encoded into the SIB broadcasted to the cell phone.

The ephemeris data and satellite channel model in PROPSIM must match the satellite trajectory. Satellite channel model and UXM payload data synchronization is essential to ensure that the cell phone receiver matches the test scenario.

Keysight's Channel Studio software can create the channel model and the ephemeris data file, matching the simulated satellite trajectory encoded in the PROPSIM channel model and ephemeris information broadcast by the UXM 5G as encoded in the SIB.

For more information on the solution components

Visit Keysight's S8825A solution webpage has a solution specific webpage for more details about the solution components can be found, including brochures, data sheets with technical system requirements, and links to other related material.

S8825A NTN Test Solution

The main purpose of the S8825A solution is to define the suitable PROPSIM configuration for 5G NTN uses cases.

The configuration using the 16-channel FS16 PROPSIM as the main unit covering the sub-6 GHz frequency range and 100 MHz signal bandwidth is well suited for all NTN testing. It features four local oscillators, enabling the use of four carrier frequencies from the unit frequency range, as the center of link bandwidth. This test setup can create two independent bent-pipe links, with feeder and service link frequencies defined separately.

This configuration includes standard software tools that are mandatory and the Channel Studio GCM tool as an option. The software tools include all the capabilities needed to construct and test NTN standard and non-standard use cases and link models.

Table 1. Solution Components for S8825A Satellite and Aerospace Channel Emulation Toolset for Real Networks

Model	Function	Description
F8820A FS16 	Full 5G NTN compatible multi-channel emulator, which requires the listed options for satellite link / 5G NTN testing	Select: -Frequency range -Bandwidth -GCM Channel Studio NTN
Ku-K-Ka -band extension 	M1742A Remote Radiohead -transceivers in between DUT and the test environment S9165A Transceiver Control Unit	NTN band support for R18 and beyond Test bed and control interfaces
WJ5900A WaveJudge 	Modular and scalable test platform that captures and decodes LTE, 5G, and Wi-Fi signals as a part of the SJ001A WaveJudge Wireless Analyzer Toolset	3GPP NR Rel 15-17 (NR NTN, RedCap, V2X) BW up to 800 MHz RF ports scalable, 2, 4, 6, or 8 SSD storage for long IQ captures

F8820A FS16

-3…6000MHz, K-band

-Up to 1200MHz IBW

-1.5MHz real-Doppler

-1500ms propagation delay

Figure 10. PROPSIM FS16 channel emulator unit, suitable for satellite link emulation with the S8825A solution

Summary

Focused on re-creating the satellite radio links between different network entities using channel emulation solutions, the S8825A solution toolset is essential to verify the functionality and resulting performance of satellite access.

Power efficiency, subsystem circuitry design, regulatory aspects, as well as the actual deployment of the networks are other factors that need to be taken into consideration when creating a satellite network. Keysight's test and measurement portfolio contains suitable and powerful solutions to speed up the design, optimize the use, and maintain the operation of satellite networks.

Satellite Networks Are Here to Stay

Satellite networks are evolving from closed proprietary systems to widely available cellular networks. These networks need to scale to host more subscribers and meet their expectations for high-quality connections. Validating network functionality and performance from the early launch of these services is critical to drive consumer adoption. Successfully integrating terrestrial and non-terrestrial networks depends on robust test plans to check connections thoroughly before operational systems are in orbit.

Currently, the industry is adding satellite access onto 5G networks running off of established cellular networks, but in 6G, non-terrestrial satellite parts in networks will likely be available from the start to ensure seamless connectivity and enable unprecedented use cases.

The time of two-dimensional networks is coming to an end. The industry is entering the era of multi-dimensional networks with access points all around (and above) users.

More Information on Keysight Solutions

Keysight's website contains information on all our solutions for wireless communications, the satellite industry, NTN, and 5G NTN use cases, as well as traditional test and measurement needs.

Check out the following links and material to start on your next NTN innovation today.

For more information on NTN

Find insights on how to accelerate NTN innovation in the following documents:

- White paper: Bolster 5G Through Non-Terrestrial Networks
- Blog: Non-Terrestrial Networks for 5G and Global Connectivity
- News release: Keysight Delivers New Channel Emulation Capabilities to Speed Deployment of 5G Non-Terrestrial Networks (NTN)