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5G from Space:

A Flight Path to Non-Terrestrial Networks

A Heavy Reading white paper produced for Qualcomm Technologies

Qualcomm

AUTHOR: GABRIEL BROWN, SENIOR PRINCIPAL ANALYST, HEAVY READING

SATELLITE COMMUNICATIONS AND 5G

The satellite communications sector is booming. Supported by lower launch costs, rapid advances in satellite technology, and strong end-user demand for connectivity everywhere, the sector is attracting record investment and generating record deployment activity.

Driven by mutual interest, there is now unprecedented collaboration between the satellite communication and 5G mobile ecosystems. There are three compelling reasons for this:

- Satellite access allows terrestrial mobile operators to radically expand coverage to remote locations and to connect devices worldwide.
- For satellite operators, terrestrial mobile operators can bring billions of new customers and devices to their systems.
- The scale of the 3GPP technology ecosystem can deliver lower cost, standardized technology—especially user devices—to improve satellite economics.

This white paper investigates activity in the satellite communications ecosystem to scale space-to-handset and space-to-Internet of Things (IoT) services as a precursor to the integration of non-terrestrial network (NTN) technology with 5G terrestrial networks (TNs). Heavy Reading argues that today's space-to-X services based on proprietary satellite technology offer strong customer value and create a "flight path" for the satellite sector to adopt standardized 3GPP technologies.

The opportunity is for the terrestrial 5G operators to integrate NTN to offer near ubiquitous outdoor connectivity directly to smartphones and IoT devices, with a target of service continuity between TNs and NTNs. This paper discusses the 5G NTN technology roadmap and how it sets a foundation for developing NTN-native 6G systems.

Note that the paper does not argue that NTN will subsume or dominate the satellite communications ecosystem. There are many reasons for satellite systems and technologies to expand and prosper outside of NTN. Heavy Reading recognizes these are historically distinct ecosystems and that TN and NTN operators will continue to compete for spectrum.

In the satellite industry, the terms "direct-to-device" and "D2D" have become commonplace to describe a connection to a handset or IoT module direct from space. However, mobile devices already connect "direct-to-device" from the cell tower. Furthermore, in 3GPP standards, the acronym "D2D" stands for device-to-device (where devices connect directly to each other without the need for infrastructure). To avoid confusion, therefore, Heavy Reading uses the terms "space-to-handset" and "space-to-IoT."

SATELLITE SECTOR IS BOOMING

The satellite communications sector is booming. Existing systems are being expanded and many new constellations are being planned or deployed. The expansion of the satellite market is enabled by technology but driven fundamentally by demand for connectivity. According to satellite operator Iridium, only 20% of the globe's surface and around 40% of the landmass is covered by TNs. In modern society and industry, there is a clear need to extend network connectivity to unserved, remote areas.

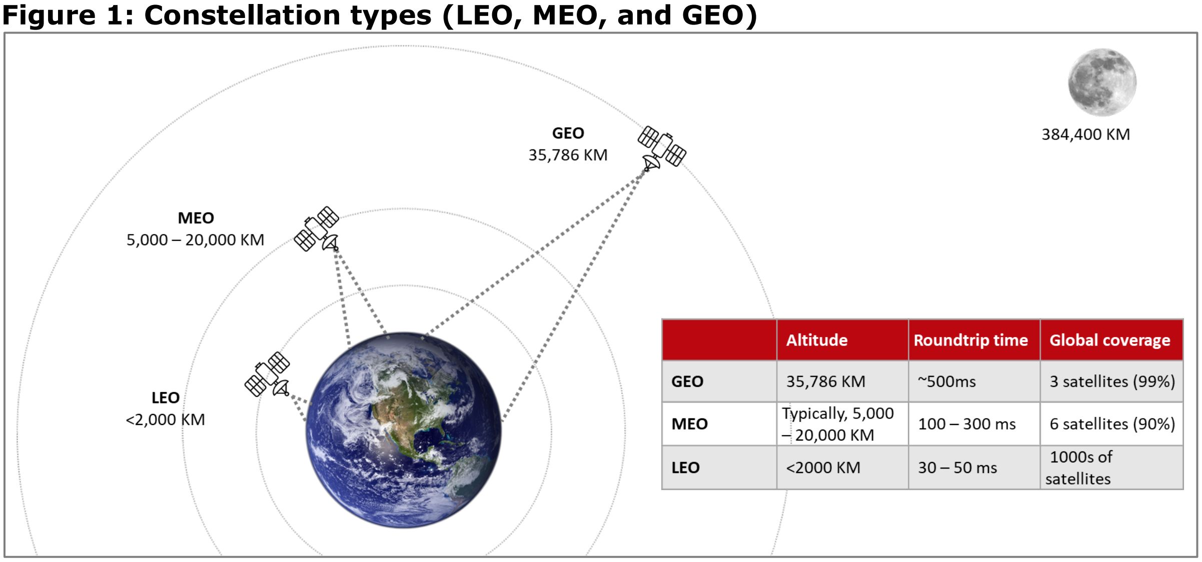
Satellite constellations

Figure 1 shows the relative altitude, latency, and cell sizes for low Earth orbit (LEO), medium Earth orbit (MEO), and geostationary equatorial orbit (GEO) constellations. Many space-to-X services, and later NTN services, will be delivered by LEO systems because these offer lower latency, lower path loss, and greater area capacity density. One downside is that LEO satellite cell sizes are smaller, which drives the need for more satellites. Another is that because they move rapidly relative to the Earth's surface (7.8 kilometers per second), channel conditions are highly variable and devices must support the frequent reselection of "Earth-moving cells." Relative to GEO systems, LEO satellites are roughly half the cost per kilogram to launch. However, the lifespan is shorter, as low Earth orbits degrade faster.

GEO systems, where the satellite position is fixed relative to the Earth, offer always available "Earth-fixed cells." This drives simpler requirements on terminals (e.g., fewer requirements to offset Doppler shift or for cell reselection) but longer round-trip times and higher path loss. Generally, GEO systems offer lower aggregate capacity. GEO characteristics suit some services, in particular, critical services or low data rate IoT.

Typically used for global navigation satellite systems (GNSS), MEO systems should not be underestimated for communication services. MEO systems, such as the second-generation O3B constellation (operated by SES), offer fixed satellite services (e.g., for enterprise or cell backhaul applications).

Figure 1: Constellation types (LEO, MEO, and GEO)



	Altitude	Roundtrip time	Global coverage
GEO	35,786 KM	~500ms	3 satellites (99%)
MEO	Typically, 5,000 – 20,000 KM	100 – 300 ms	6 satellites (90%)
LEO	<2000 KM	30 – 50 ms	1000s of satellites

Source: Heavy Reading

Fixed and mobile satellite services

Satellite is an essential part of the global telecommunication market. Spectrum, orbital positions, and so on are regulated by the International Telecommunications Union (ITU). GNSS—typically, GPS—are widely used to provide a time signal to radio base stations (time sync is essential to radio performance) and user devices (e.g., maps and navigation).

Fixed satellite service (FSS) is used for broadband access as a redundant backup service to critical locations and for on-demand connectivity. This is a well-established sector that is set to grow rapidly in the coming years. In mobile networks, cell site backhaul can play a particularly important role in extending coverage to remote areas and in disaster recovery and redundancy. FSS is also used to backhaul private mobile networks deployed at remote locations (e.g., in the mining sector).

Mobile satellite services (MSS) are widely used, notably in the military, public safety, marine, and aerospace sectors. Relative to FSS, mobile services to handheld devices typically achieve lower data rates due to antenna size, processing capabilities, and spectrum. Handheld satellite services target the government, commercial, and consumer sectors and are generally used for connectivity as the last resort.

MSS use proprietary air interfaces (with both ends of the link under the control of the operator) to enable the system to meet the demands of satellite links (e.g., long round-trip times and high propagation loss). MSS handheld services over proprietary air interfaces are the basis of the current generation of mass-market space-to-device services being launched by the mobile industry. However, a new breed of space-to-device services is emerging that uses an adapted LTE (and in the future, 5G New Radio [NR]) air interface to connect to unmodified mass-market handsets.

Space-to-device mobile satellite services

Space-to-IoT satellite services will initially offer downlink data rates of a few hundreds of kilobits per second, which is sufficient for two-way messaging and location sharing. In the medium term, this could increase to 1–2Mbps and then perhaps toward 10Mbps in the longer term. (Uplink speeds are substantially lower.) By contrast, specialist very small aperture terminal (VSAT) and Earth station in motion (ESIM) devices with more advanced antennas can support much higher broadband data rates. In all cases, devices should be outdoors with a clear view of the sky.

There are now several announced, and one commercial, space-to-device satellite services available for off-the-shelf commercial smartphones. The pace was set by Apple, which launched emergency messaging for iPhone 14 in partnership with Globalstar. This is commercially available in multiple markets. Even though Apple offers only emergency messaging on the latest generation of handsets, it is the pioneer service in this category.

As shown in **Figure 2**, several other examples of satellite and mobile industry partnerships are now targeting space-to-device services. Iridium, for example, is using its large, already-deployed constellation, which has proven to work reliably with proprietary handheld devices. Qualcomm is working with Android device makers to integrate Iridium connectivity into commercial smartphones, with the device maker and/or mobile operator responsible for the commercial service offer.

Figure 2: Space-to-device partnerships

Partnership	Summary	Spectrum	Launch progress	Offer
Globalstar / Apple	LEO satellites; 2nd gen system; transparent architecture	L- and S-band spectrum	First commercial launch in the category	Emergency messaging for iPhone 14
Iridium/ Qualcomm	LEO satellites; 2nd gen system	L-band spectrum	First services to launch in 2H23**	Two-way messaging focused on Android smartphone ecosystem
Starlink/T-Mobile US	Starlink LEO system (modified?)	Terrestrial PCS spectrum to unmodified handsets*	Testing to begin in 2023; commercial services from 2024	Global MNO wholesale offer
Lynk/Spark	LEO; limited constellation so far (seeking funding)	Terrestrial spectrum to unmodified handsets*	Trial of direct-to-handset service in New Zealand	Global MNO wholesale offer
AST/Vodafone, AT&T, Rakuten	LEO system; limited constellation so far; transparent architecture; phased-array satellites	Terrestrial spectrum to unmodified handsets*	Funded for phase 1 launch; first call 2Q23	Agreements with 40 mobile operators
Inmarsat/ MediaTek/Bullitt	GEO system	L-band	First services to launch in 2H23	Two-way messaging to handsets using NB-IoT module

*Subject to regulations ** Subject to handset manufacturer interest
Source: Heavy Reading

The next major target in space-to-device services will be to launch satellite constellations that use spectrum licensed for terrestrial mobile services to connect unmodified LTE smartphones (and, in time, to 5G devices). It has been proven to be technically possible to "close a link" between a standard smartphone and satellite in low Earth orbit, and the race is on to scale the required infrastructure to support commercial service. Diverse regulatory responses to the use of licensed terrestrial spectrum for satellite services can be expected, ranging from relatively permissive to more restrictive.

Starlink has an established constellation with proven performance for fixed services and a new mobile VSAT service. Details about the space-to-device partnership it announced with T-Mobile US are scarce. Starlink plans to use terrestrial spectrum and to scale globally using a wholesale roaming model. It is not clear if this service will require new satellites.

AST's unique play is that its satellites use large, phased-array antenna to extend coverage, capacity, and uplink performance. The company has demonstrated the system works with test calls in the US using its first BlueWalker 3 satellite. By virtue of the antenna array (but dependent on spectrum), AST is aiming to offer downlink data services in the low megabits per second range direct to unmodified handsets. This is sufficient for browsing, app scrolling, and small downloads. In the medium term, AST aims to deliver an experience close enough to a regular smartphone experience for users that cannot access a terrestrial 5G network. AST is partly funded by telecom operators (notably, AT&T, Rakuten, and Vodafone) and has many agreements in place with mobile operators. It is working with Orange, for example, in an unnamed African country to trial 3GPP terrestrial spectrum for satellite access.

Lynk is also using terrestrial spectrum and has proven its system works in partnership with New Zealand operator Spark. New Zealand has large, remote rural areas to which satellite is well suited. Spark will start a customer-friendly trial for two-way messaging by the end of 2023 and aims to move to commercial service in 2024. Because Lynk has only one satellite operational, this service will initially offer intermittent connectivity when the satellite is overhead. Lynk says it has more than 30 mobile operator service agreements covering more than 50 countries. It is seeking funding to deploy a larger constellation.

There are many other communication satellite constellations in the deployment and expansion phases (e.g., focused on FSS or on space-to-IoT). One big question is how to fund these new constellations and scale operations over the long term. Great potential and promise are driving a mix of strategic and speculative investment into the sector. However, there are economic, regulatory, and technical challenges to overcome. Many of the newer systems have only a few satellites airborne and still need to prove the commercial model to access further investment.

The 3GPP NTN ecosystem can help the economics and scalability of satellite communications through standardized technology, open interfaces, high product volume, and low cost terminal devices.

TOWARD 5G NTN

The NTN concept, which includes satellites, high altitude platforms (HAPS), and other air-to-ground communications, has been part of the 5G work plan for several years. The basic calculus is that the 5G system and NR radio interface are designed to be highly flexible and can be readily extended to NTN scenarios.

5G mobile services over satellite

The first NTN specifications were delivered in 3GPP Release 17 in 2022. There are two major components: 5G NR for NTN (NR-NTN) and IoT for NTN (IoT-NTN), as shown in **Figure 3**.

NR-NTN is focused on data services to fixed, nomadic, and mobile customer equipment. Services to mobile handsets will be offered in sub-7GHz spectra. In spectra above 7GHz, VSAT devices will be required. IoT-NTN is focused initially on the narrowband IoT (NB-IoT) air interface in sub-7GHz.

Both types of space-to-device NTN service will be offered initially in the L-band (n255) and S-band (n256) frequency bands already approved by the ITU for mobile satellite use and already specified by 3GPP for NTN. In Release 17, mobile devices are specified to include GNSS to help synchronize with satellite orbits. For fixed devices, location can be hard-coded, which is particularly useful for low complexity IoT-NTN.

Figure 3: 5G satellite services

	IoT-NTN	NR-NTN	
	Direct connectivity (<7GHz)		**Indirect connectivity (<7GHz)**
Device type	IoT modules, devices, and gateways	Smartphones, cars, other embedded devices	VSAT and ESIM devices
Performance	Narrowband (10s of kbps)	1–10Mbps	Broadband (50Mbps+)
Radio interface	NB-IoT and eMTC	5G NR	5G NR
Example use cases	Utilities, agriculture, mining, oil & gas, logistics, environmental monitoring	Direct-to-handset: consumer smartphones, public safety, defense, agriculture, utilities, transportation	Cell backhaul, enterprise access, on-demand connectivity, transportation, public safety, defense, etc.
Spectrum	L- and S-bands (n255 and n256)	L- and S-bands (n255 and n256)	Likely in Ka-band (Ku-bands in early stages)

Source: Heavy Reading, Thales Alenia Space

NTN for IoT services

Low data rate IoT services are likely to be the first commercial NTN application. The NB-IoT interface and protocol stack is already highly optimized (requires only a 200kHz channel and typically -23dbm antenna gain) and can be adapted to NTN quite readily. IoT-NTN devices need to be outdoors, with a view of the sky, and should tolerate intermittent connectivity. This fits well with use cases that may only need to send small amounts of data infrequently (e.g., daily or every few days), such as in the agricultural, utilities, environmental monitoring, and transportation sectors.

A fixed IoT device communicating with an Earth-fixed cell may be the simplest and fastest way to start IoT-NTN. GEO constellations with fixed-position devices simplify the antenna design and minimize signal processing on the device, reducing cost and complexity.

There are several providers working on IoT-NTN satellites, modules, and services. Sateliot and OQ Technologies, for example, are LEO operators that aim to start commercial services with just a few satellites providing intermittent connectivity to a service area. The idea is to prove the technology and business model and then scale coverage and resiliency with more satellite launches. In the meantime, existing operators such as Inmarsat and Viasat plan to offer NB-IoT services on their existing constellations of GEO satellites.

There are also IoT service providers and IoT module vendors integrating IoT-NTN into their existing offers. Often, these companies already use satellite to backhaul IoT (including NB-IoT) with gateway devices, and they may also partner with satellite operators for proprietary satellite IoT solutions. Through these types of providers, 3GPP NTN will become part of a wider IoT solution that incorporates land-mobile and space-based access to deliver the coverage and resiliency a customer requires.

As IoT-NTN modems become available over the next year, vendors will create direct-to-IoT satellite devices. This is expected to include hub designs that also incorporate terrestrial connectivity and simple connectivity modules that can be attached to customer equipment, such as sensors, outdoor machinery, and shipping containers. IoT-NTN chipsets are also being added to smartphones to provide two-way messaging and location sharing (e.g., by Bullitt Group in a range of hardened devices).

NR-NTN for space-to-handset services

NR-NTN delivers the 5G radio interface over satellite to offer services direct to handsets and to VSAT devices. The aim is to deliver data services that are close to a broadband terrestrial experience and to support satellite-optimized applications. A broad categorization for NR-NTN by frequency range is as follows:

- FR1 (sub-7GHz) for narrowband space-to-handset services (up to 1–2Mbps initially)
- FR2 (above 7GHz) for broadband VSAT services (50Mbps+) for aircraft, ships, and fixed access

NR-NTN for handsets is challenging in the same way as proprietary MSS systems: the user devices will not be in a fixed position, will not have consistent channel conditions, and will have only small antennas. Nevertheless, as NR-NTN satellite capacity is deployed, it should be possible to support services with sufficient data rates to enable navigation, web browsing, app scrolling, and real-time communication. Industrial and enterprise mobile devices may also use NR-NTN in the FR1 range.

Initially, NR-NTN space-to-handset may be integrated into smartphones using standalone chipsets. This allows for faster introduction at the expense of space, power, and cost optimization. Over time, while separate RF frontends for select satellite bands will likely be retained, it is expected NTN will be integrated into standard modems.

A challenge for NR-NTN is building sufficient capacity into a constellation. It is not clear that existing LEO constellations—which are adding capacity quickly—will be able to be updated via software to NR-NTN. This means NR-NTN capacity will grow in line with new satellite launches, driven by refreshes and expansion programs. At the time of this writing, Heavy Reading is not aware of a satellite operator that has publicly committed to deploying an NR-NTN constellation.

As noted, NR-NTN for fixed and mobile VSAT applications is of great interest. By virtue of larger, more powerful antennas, and wider FR2 spectrum bands, performance and consistency will be stronger than those for space-to-handset services. There are many applications for this mode of operation, including, for example, acting as a relay or aggregator of local IoT devices, providing connectivity to a local private network, or backhaul to terrestrial mobile networks.

NTN STANDARDS AND TECHNOLOGY

To make NTN part of the 3GPP standards in Release 17 required extensive prior work. As far back as Release 15 (the first 5G release), a study on deployment scenarios and channel models identified that, considering path loss, frequencies, elevation angles, atmospheric conditions, and so on, the NR interface could be adapted to support a satellite link. This set the foundation for ongoing specification work.

There are three primary areas of attention the 3GPP will address through the release cycles:

- **Link-level issues:** This includes the channel model, adapting for high path loss, propagation delays, handling retransmission, and coping with high and variable Doppler shifts. This is a well-studied domain, and there is high confidence that space-to-handset and space-to-IoT NTN links can be robust and reliable.
- **System-level considerations:** This includes architecture choices (transparent and regenerative), managing handover between satellites (for LEO), core network integration issues (e.g., access control, tracking areas, policy, and charging), and service continuity between TN and NTN.
- **Spectrum:** 3GPP specifies bands for 5G systems. For satellite access, currently only L- and S-band are specified. These are relatively narrow bands with limited capacity. Clearly, 3GPP will need to add further bands. Spectrum access is, however, highly dependent on regulation and international agreements (see below).

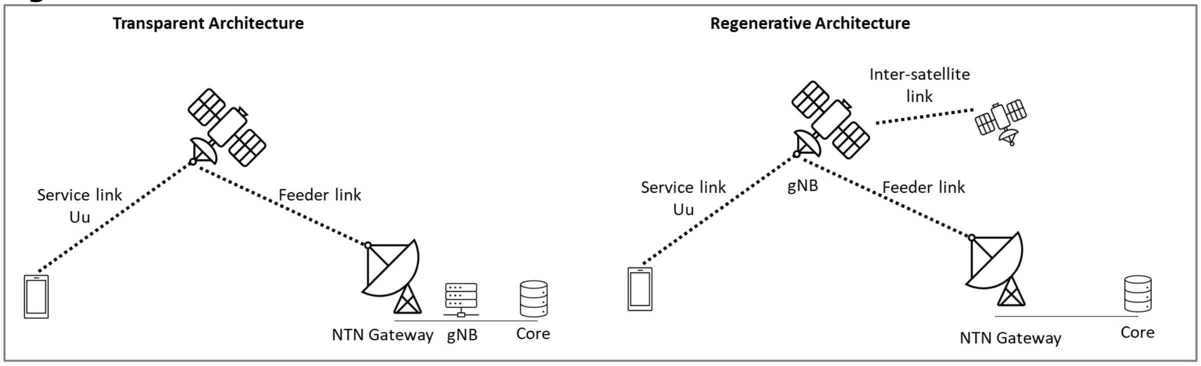
Transparent and regenerative architectures

Two options for the high level NTN architecture are shown in **Figure 4**. To the left is the transparent architecture—also known as the "bent pipe" architecture—in which the satellite payload handles the RF filtering, conversion, and amplification. However, the terrestrial signal is unchanged and processed in the base station (gNB) located at the NTN gateway at the ground station. The advantage of this architecture is that it simplifies the satellite payload and allows greater flexibility to reconfigure or update the terrestrial baseband. There are still many opportunities to improve or optimize radio performance on the satellite itself (e.g., by deploying an active antenna array). The transparent architecture is the initial NTN specification by 3GPP.

In the regenerative architecture shown on the right, the full gNB is part of the satellite payload. This, in principle, allows for a more optimized service link (again over the standard Uu interface) because the baseband can adapt faster to channel conditions. It also allows for inter-satellite links, which can be useful if the satellite operator, for example, has a limited number of high capacity ground stations and needs to backhaul traffic to a home country (e.g., for regulatory or security reasons, an operator may want to limit ground stations to particular countries). Currently, it is expected that regenerative architecture will be specified from Release 19.

Both architectures can support a multi-operator core network deployment, allowing the satellite RAN to connect to different terrestrial core networks. This will be useful for global wholesale models, where one satellite RAN serves many terrestrial operators.

Figure 4: NTN architectures



Source: Heavy Reading

NTN standards roadmap

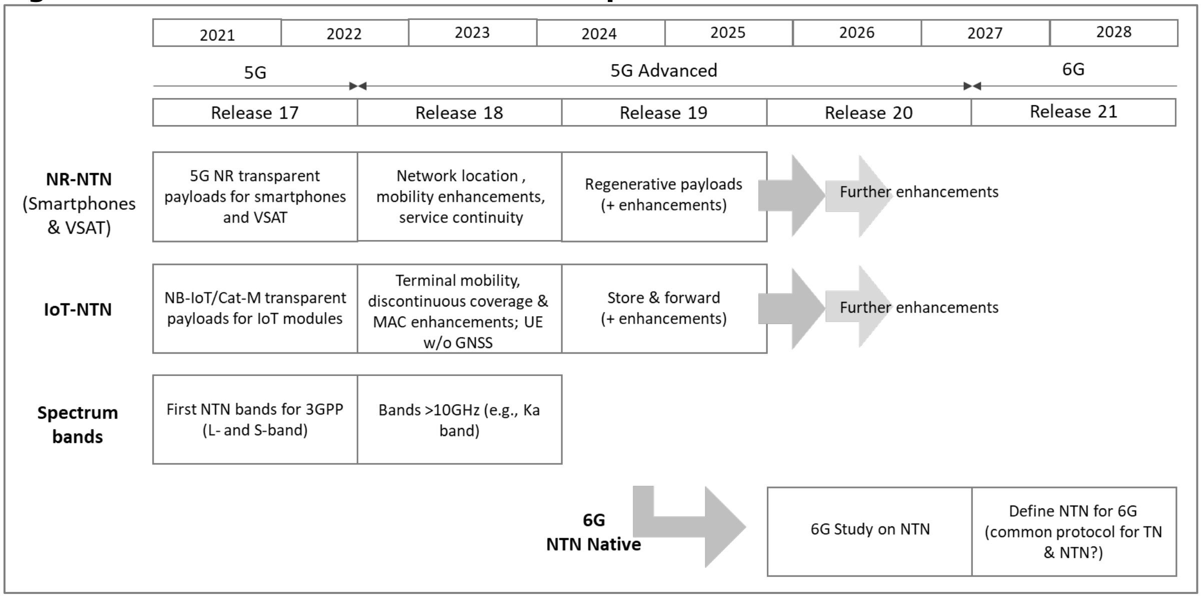
Release 17 is a first step to integrating satellite with the 3GPP mobile ecosystem. As shown in **Figure 5**, ongoing specification work is planned for future releases through the 5G Advanced cycle (Releases 18, 19, and 20).

Release 18 for NR-NTN (smartphones and VSAT devices) will include network location enhancements to enable regulated services (such as lawful intercept) and mobility enhancements for service continuity. For VSAT, it is anticipated that 3GPP will identify bands in spectrum above 10GHz (probably in Ka-bands; Ku-bands will potentially be identified in R19). For IoT-NTN, a major enhancement will be to support discontinuous coverage and to enable terminals without GNSS capabilities.

Release 19 will add regenerative payloads. For IoT-NTN, store and forward capabilities for satellites that cannot immediately connect to an NTN gateway on Earth will be added. There are likely to be ongoing “further enhancements” to NR-NTN and IoT-NTN in Release 20 and beyond.

Release 20 will also be the start of 6G NTN work, with a Study Item planned ahead of formal specification work in Release 21. As expected, there will be informal research and collaboration on 6G NTN prior to the 3GPP study.

Figure 5: Overview of standards roadmap for NTN

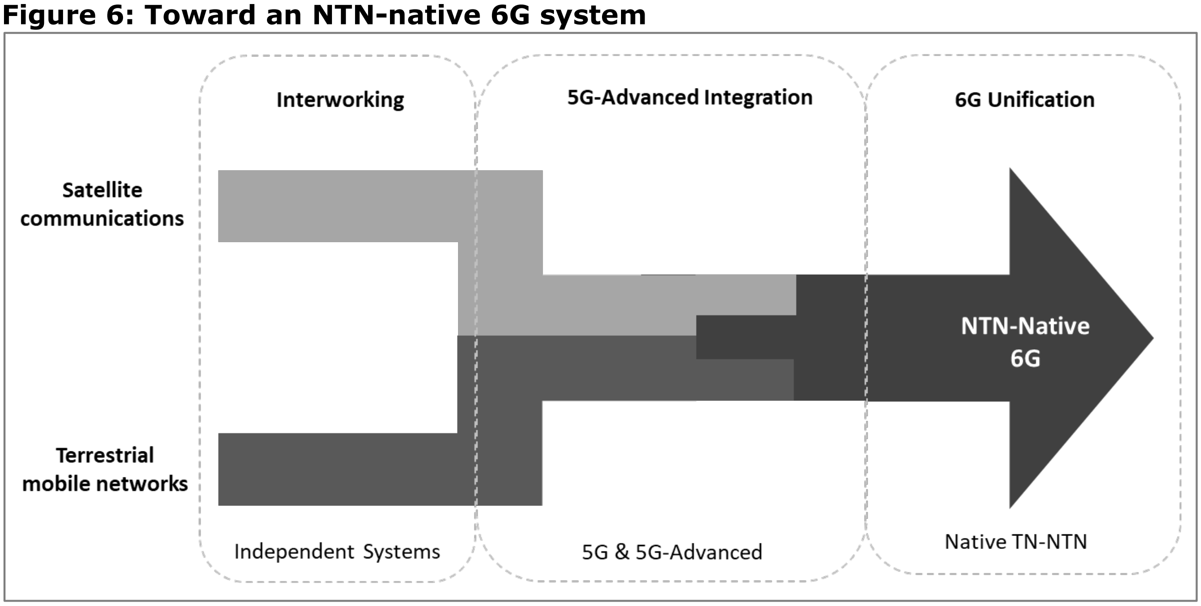


Source: Heavy Reading

NTN-native 6G

Initial work on NTN in 5G is focused on bringing two separate ecosystems together. Ongoing 5G Advanced specification work (Release 18 onward) will further integrate the two ecosystems to create a satellite system capable of supporting 5G NR and IoT services at a commercial scale for deployment over the next decade. The next step, shown in **Figure 6**, will be to go from an integrated system to an "NTN-native" 3GPP system in 6G.

Figure 6: Toward an NTN-native 6G system



Source: Heavy Reading

The development of 6G is in the early stages. Industry, government bodies, and academia are scoping the technologies and use cases that will define 6G through the ITU's International Mobile Telecommunications 2030 process. Over the next year or two (from Release 20 onward; i.e., from 2025), the work will transition from a search for new ideas to a selection of leading contenders for inclusion in the formal specification work. At the time of this writing, it is expected that NTN will be included.

The proposal is to make 6G "NTN-native" from the design phase to create a unified system that will support mobility and service continuity between terrestrial and non-terrestrial access. This has implications for waveform, numerology, protocols, architecture, and more. It will also leverage advances in satellite technology and impact the design of satellite constellations themselves (e.g., by setting standards for inter-satellite and feeder links). Just as in 5G Advanced, NTN in 6G will likely incorporate a wide range of aerial technologies, including HAPS, drones, and aircraft.

REGULATION AND SPECTRUM

International space treaties are beyond the scope of this paper. For communication services, the ITU has oversight of both satellite and terrestrial networks. In practice, however, each ecosystem is subject to a largely different regulatory regime at international and national levels. National regulators, moreover, also have a degree of autonomy from each other in how satellite services are regulated within their territories.

For space-to-handset and space-to-IoT satellite services, there are two major regulatory issues to consider: regulation of the service and spectrum allocations.

Regulation of the service includes factors such as the legal jurisdiction where the service is sold and provided, as well as legal intercept and roaming. Satellite raises several challenges in this regard that (though well-known to existing satellite operators) may present problems at the scale of mass-market mobile services provided by integrated TN-NTN operators. For example, the wide coverage area (potentially multi-country) of a satellite system may require changes to the core network in order that the mobile operator can verify the user is located in a country where it is permitted to offer service.

Spectrum is a critical topic in space-to-handset services. For the purposes of this paper, there are two key issues:

- Mobile satellite spectrum approved by the ITU
- Proposals to use terrestrial spectrum for satellite access

Frequency bands approved for satellite use by the ITU, and subsequent specification of the bands by the 3GPP, represent the formal route to offering NTN services. The L-band and S-band have already been ITU-approved for mobile services for some years and have been specified by the 3GPP in Release 17 as bands n255 and n256, respectively.

Potentially, more spectrum bands will be identified by the ITU for mobile satellite use in the future, but it could take a decade—or more—to identify and approve a new allocation. In the meantime, the already approved fixed access satellite spectrum can be put to use and will likely be specified by 3GPP for fixed NR-NTN services in Release 18. If this spectrum access model, based on well-established ITU and 3GPP processes, was all there is to think about, this would be a slow-moving market and relatively simple to analyze.

Proposals to use terrestrial spectrum for mobile satellite access change how the industry should think about space-to-handset services. This mode of operation is highly contentious in international regulatory circles, and the general view is that without the identification of a band at the World Radio Congress and subsequent ITU approval, terrestrial spectrum should not be used for satellite access. In the meantime, in the commercial world, numerous trials in terrestrial spectrum are underway (see **Figure 2**), and national regulators will be forced into making decisions about what is allowable within their territory.

The US Federal Communications Commission (FCC) is taking the lead. In March 2023, the agency proposed a new regulatory framework that would allow mobile satellite service in certain flexible-use terrestrial bands if certain prerequisites are met. "A satellite operator could then serve a wireless provider's customers should they need connectivity in remote areas, for example, in the middle of the Chihuahuan Desert, Lake Michigan, the 100-Mile Wilderness, or the Uinta Mountains," says the FCC. The emphasis is on very remote locations where potential interference with terrestrial systems would be limited.

At the time of this writing, 3GPP NTN work does not address the use of terrestrial spectrum for satellite access to unmodified handsets.

CONCLUSION: A LAUNCH PAD TO NTN

Satellite connectivity direct to mass-market commercial handsets is an idea whose time has almost come. The use cases are compelling—connectivity everywhere—and proof-of-concept trials show the technology works. With the first specifications now available, a launch pad is in place for the creation of a vibrant NTN ecosystem. The challenge is to scale the infrastructure and operations and to identify sustainable business models.

The high level of ecosystem activity and investment in satellite communication is exciting and inspiring. However, the industry should keep in mind that space-to-handset services are currently limited to low data rate narrowband services to outdoor users (with the potential to go to higher speeds over the longer term). For customers in unserved locations, this is highly valuable; for most mobile operator customers, this is an add-on service that is likely to be used only sparingly as a last resort. Service providers will therefore need to target sectors such as public safety, utilities, agriculture, extraction industries, and consumer adventure to fully capitalize on the space-to-IoT opportunity.

The first commercial NTN services will be based on NB-IoT over GEO stationary satellite constellations. There are myriad applications for IoT-NTN in diverse industries delivered as part of a wider service integrated with terrestrial connectivity. IoT-NTN can also provide a step to direct-to-handset services where modules are integrated into handsets to enable two-way messaging and location sharing.

Spectrum is a key factor in the development of NTN. The emergence of space-to-handset services in terrestrial spectrum is potentially game-changing for the satellite communications industry. However, there are many regulatory uncertainties in this model, and it is likely to proceed via a series of country- and operator-specific steps and be limited, initially, to the most remote areas.

The communications industry is only at the start of a long journey for space-to-handset and space-to-IoT satellite services using standardized 3GPP interfaces. 5G NTN specifications, evolving through 5G Advanced, and later 6G, are a compelling way to introduce standards and scale to the satellite communications sector.