A 5G Americas Briefing Paper

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UPDATE ON 5G NON-TERRESTRIAL NETWORKS

Purpose

The purpose of this briefing paper is to provide an update on 5G Americas' February 2022 white paper, *5G and Non-Terrestrial Networks*, and familiarize the reader with the status of the 5G Non-terrestrial Networks (NTN) telecom segment by exploring a snapshot of the current developments. The paper will explore some of the key features, implications, benefits, challenges, and roadmaps of 5G NTN technology, with a focus on existing and impending satellite constellations offering services in three areas: broadband and internet, Internet of Things connectivity, and Direct-to-Cell.

Background

As of the first half of 2023, Non-terrestrial Networks (NTN) is becoming a highly dynamic market with a few different technical and commercial approaches. At the same time, the emergence of 5G technology has opened new possibilities for connecting people and devices across the world with unprecedented speed and reliability. A 5G NTN is designed to provide high speed wireless connectivity to remote and underserved locations, by leveraging a 'space segment' in the access side of the mobile network to deliver mobile services to users on the ground from satellites.

Today broadband connections are already offered by several NTN operators with proprietary technology, using VSAT/dish antennas at the user equipment for reception of broadband speeds on Ka or Ku frequencies. Most of the focus in NTN deployments is on the use of GEO and LEO satellites, with the most common approach for GEO satellites (around 36,000 km altitude) to be used for fixed broadband and IoT (i.e., for non-delay-critical services), whereas LEO-s (less than 1,000km altitude) are more attractive for their low delay and better link budget due to the much lower distance.

The use of NTN technology has numerous potential use-cases for IoT applications, which can be served from both Low Earth Orbit (LEO) or Geostationary (GEO) satellites, particularly in remote and hard-to-reach areas. For example, precision agriculture systems can leverage real-time data from sensors placed on unmanned aerial vehicles to optimize crop yields and reduce resource waste. Similarly, remote monitoring and control of critical infrastructure such as oil rigs, wind turbines, and mining sites can be made more efficient and secure with the help of NTN-enabled sensors and actuators.

Direct-to-cellular device services are also emerging, offering emergency and messaging services with the promise to evolve to higher speeds over LEO networks. With a 3GPP-based NTN solution in Release-17 using the sub-2Ghz band spectrum, it is possible to achieve tens of megabits per second speed in the downlink (although this peak speed will be shared among all users in a given cell), as well as a round trip delay in the range of a few tens of milliseconds. With 3GPP Rel- 18 additional spectrum in Ka band will offer much higher speed – to the order of hundreds of Mbps - to non-handheld devices using small dish antennas, similar to that offered by SpaceX's Starlink service. Practical speed will vary depending on device capability, spectrum utilized, load and antenna sizes. Furthermore, NTN can be used for disaster response and recovery operations by providing reliable and resilient communication links in areas affected by natural disasters. In any of these scenarios the remarkable outcome of satellite D2C is the expansion of coverage for current and future consumer cellphones in hard-to-reach and remote or rural areas, to an extent a terrestrial network cannot achieve.

More information on the central concepts of non-terrestrial networks can be found in *5G and Non-Terrestrial Networks.*

Current Status

Broadband main satellite providers are summarized below (not exhaustive). These providers offer communication services to fixed user devices, but devices can be moved from one location to another.

Some operators listed in Table 1 use geostationary orbit (GEO) satellites, which allow for a larger coverage area—meaning less satellites are needed to cover a certain part of Earth. The advantage of GEO satellites is that they do not move relative to Earth, whereas LEO satellites move at high speeds and require tracking and handovers. However, LEO's lower latency allows for more services (including voice), and their comparatively shorter distance to Earth (600 km vs 36000 km) leads to larger throughputs. Additionally, a LEO beam's smaller size/coverage translates to better scalability from a capacity point of view, however a larger number of satellites will be needed for coverage and performance – so it is fair to mention there will be a direct correlation between number of satellites in a constellation and the capability/performance of the services it can offer.

Table 1: Broadband and satellite providers 2023

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
Space X (Starlink)	12000+ (3580)	Ku-band	Proprietary	Yes	Broadband
OneWeb	648 (542)	Ku-band	Proprietary	TBD	Broadband
Kuiper	3236 (0)	Ka band	Proprietary	Estimated 2024	Broadband
Galaxy Space	1000 (7)	Q/V spetrum	Proprietary	TBD	Broadband
Boeing	147 NGSO (1)	V band	Proprietary	TBD	TBD
Inmarsat	14 GEO (14)	TBD	Proprietary	TBD	Broadband to IoT
Telesat	188 (2)	C, Ku, Ka bands	Proprietary	TBD	Broadband
Echostar	10 GEO (10)	Ku, Ka, S bands	Proprietary	Yes	Broadband
HughesNet	3 GEO (2)	Ka band	Proprietary	Yes	Broadband
Viasat	4 GEO (4)	Ka band	Proprietary	Yes	Broadband

These systems use proprietary technology and typically operate in the higher (Ku/Ka) frequency bands. Additional details from the largest LEO constellations (Starlink, Oneweb, and Kuiper) are explored below:

STARLINK

- Biggest operator in this domain with 3,580 deployed LEO satellites
- Primarily provides fixed broadband service targeting rural areas
- Average throughputs of 50-100 Mbps DL and around 10 Mbps in UL in North America[1] through a 23'' diameter dish antenna
- Offers premium service with larger throughput using a different dish antenna
- The dish can be moved, which allows for roaming, and service for remote access (ships and planes)
- Currently provides service in the United States, Canada, Australia, New Zealand, most of Europe, large parts of South America, and some countries in Africa and Asia

ONEWEB

- Plans for a constellation of 648 LEO satellites, of which 542 are operational (January 2023)
- Will provide broadband services primary targeting businesses and governments rather than the residential market

KUIPER

- Subsidiary of Amazon with plans to deploy a LEO satellite system with 3,236 satellites at around 600 km altitude
- Recently disclosed customer terminal designs include:
  - A standard customer terminal measuring 11-inches square and 1 inch thick and promising to deliver speeds up to 400 Mbps.
  - An ultra compact, more affordable 7-inch square model promising speeds up to 100 Mbps that will serve residential customers, and government and enterprise customers in need of ground mobility and IoT.
  - A high-bandwidth design measuring 19 by 30 inches, and delivering speeds of 1 Gbps for enterprise, government, and telecom applications.[2]

The main providers for IoT and Direct-to-Cell as of first half of 2023 are listed in Table 2. Dedicated providers (owners of satellite constellations) are grouped separately from partnerships, but most partnerships rely on at least one dedicated provider. Some of the newer constellation owners (e.g., Starlink, AST SpaceMobile) have not secured their own North American spectrum yet, but plan to initially offer their services through partnerships with Mobile Network Operators.

Emergent dedicated providers seek high numbers of LEO satellites to offer latencies and speeds comparable to those of ground networks. Satellite's ability to reach nearly any point on the planet will allow dedicated providers to exploit the market for global NB-IoT, and simultaneously offer limited capabilities to smartphones. Roaming agreements with MNOs can help realize this vision for global connectivity while remaining cost-efficient—thanks to the reduced cost of launching into orbit.

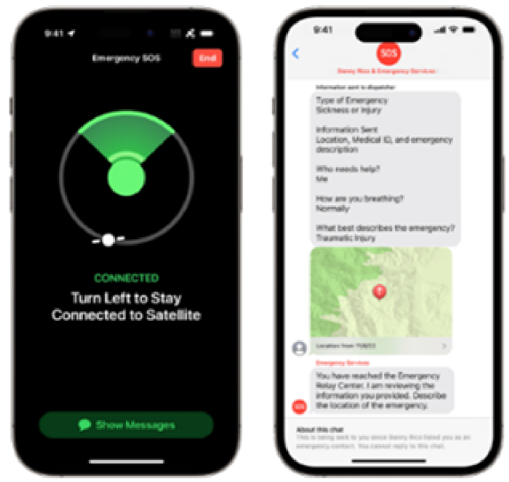
Table 2: IoT/D2C service providers 2023

Operator	Satellite system (deployed)	Spectrum	Technology	Operational	Services
Dedicated providers					
Space X	2016 LEO (0)	MNO spectrum/ 2GHz MSS	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
AST SpaceMobile	243 LEO (1)	MNO spectrum	Pre Rel-17 3GPP	2024	Messaging, speech, broadband
Lynk	5000 LEO (3)	MNO spectrum	Pre Rel-17 3GPP	2Q2023	Messaging, LDR (low-data rate)
Sateliot	250 LEO (1)	2.0GHz MSS	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Iridium	66 LEO	L-band	Proprietary	Yes	LDR/Messaging
Orbcomm	31 LEO	137-150 MHz	Proprietary	Yes	Assets tracking
GlobalStar	24 LEO	L/S-band	Proprietary	Yes	Assets tracking
Ligado	1 GEO	L-band	Rel-17 NB-IoT (NB-NTN)	TBD	NB-IoT
Partnerships					
T-Mobile/SpaceX	2016 LEO (0)	MNO spectrum	3GPP-Rel 12	2024	Messaging, Data, Voice, Video
AT&T/AST	243 LEO (0)	MNO spectrum	3GPP-Rel 12	2024	Messagign, Data, Voice, Video
Verizon/Kuiper	3236 (0)	Ka band	Proprietary	TBD	Ground sites backhaul - LTE and 5G
Apple/Globalstar	24 LEO	L-band, S-band	Proprietary	4Q2022	Emergency Messaging
Qualcomm/ Iridium	66 LEO	L-band	Proprietary	4H2023	Messaging
Mediatek/ Skylo/Bullitt	6 GEO (Inmarsat)	L-band	3GPP-NTN	1Q2023	Messaging
Skylo/ Ligado/Viasat	1 GEO (Ligado)	L-band	3GPP-NTN	2H2023	NB-IoT, Messaging, LDR

APPLE/GLOBALSTAR

This partnership was announced on September 7, 2022, and service launched on November 15, 2022. It offers emergency messaging and support only for "Find My" device via pre-scripted prompts (rather than freeform messaging). It is only supported on iPhone 14 and the first two years of service are free. Apple's partnership allows access to Globalstar's existing 24 LEO satellite constellation, which uses a proprietary communication protocol. Apple also agrees to cover 95% of the cost associated with launching new satellites (17 more estimated in 2025) to expand and replace the end-of-life ones. Globalstar owns global spectrum rights in L-Band 1610-1618.7 MHz (UL) and S-Band 2483.5-2500 MHz (DL) and can achieve downlink data rates of 9.6 to 256 kbps with their current devices. Apple has not shared any plans to add more services at the time of this paper's publication, although Globalstar stated they will allocate 85% of their capacity to Apple while using the rest for their own NB-IoT services.

Figure 1: Apple emergency messaging application screenshots



QUALCOMM/IRIDIUM

On January 5, 2023, Qualcomm entered into an agreement with Iridium to include satellite connectivity on "next generation premium Android smartphones". It will offer global service for two-way emergency messaging, SMS texting, and other messaging applications using Iridium's fully operational LEO satellite constellation with sixty-six satellites. Emergency messaging is expected to debut in the second half of 2023 in newly launched premium Android phones (not limited to a single manufacturer). Iridium's NEXT (2nd generation) satellite constellation was completed in January 2019 while the 1st generation constellation (completed in 2002) was decommissioned as satellites reached end-of-life. Iridium's existing proprietary solution will be used for communication protocol (currently in use today by Iridium satellite phones, IoT modules, Garmin devices, and similar products). The spectrum assets are 1616-1626.5 MHz (L-Band), with exclusive rights to 7.775 MHz and the rest shared.

MEDIATEK/BULLITT/SKYLO

Announced in February 2023, the Mediatek MT6825 is a standalone chipset that supports 3GPP Release 17 NTN standard while only adding less than $10 to the cost of the device or smartphone. It can be added to any 4G/5G device and can connect to GEO satellite constellations (Inmarsat and EchoStar). In partnership with smartphone maker Bullitt, two new smartphones (Motorola Defy 2 and CAT S75) will be launched as well as a dongle Bluetooth accessory (Motorola defy satellite link) that can allow any smartphone to connect to the Bullitt Satellite Platform. Mediatek's partnership with Skylo (an NTN service operator)—using Inmarsat's 6-satellite GEO network with L-Band spectrum—also provides smartphone and IoT manufacturers with solutions for new connectivity experience on phones and wearables, but no further launches of new services or products have been announced at the time of this paper's publication.

NORTH AMERICAN CELLULAR OPERATOR PARTNERSHIPS (T-Mobile/SpaceX, AT&T/AST SpaceMobile, Verizon/Kuiper)

Verizon discussed working with Amazon's Project Kuiper on connectivity solutions in October of 2021, but only about plans to provide backhaul for remote Verizon sites that would not be realized until the end of 2024—so technically, Verizon/Kuiper are not planning to become a D2C (direct-to-consumer) provider yet.

The first official D2C MNO-Satellite partnership announcement was in August 2022, with T-Mobile and SpaceX announcing plans to provide satellite direct to cellphone services. AT&T and AST SpaceMobile announced similar plans in December of 2022 and in both cases, the satellite operator would make use of the terrestrial operator spectrum. The initial goal would be delivering emergency calls/messages, and eventually expanding to data, voice, and video services for existing handheld devices while also expanding terrestrial coverage in those hard-to-reach and remote rural areas – within the limits of a satellite beam capacity. Following T-Mobile approach, Rogers Communications, parent company of Rogers Wireless announced in April 2023 a similar partnership with SpaceX, for providing coast to coast connectivity initially for SMS and eventually for voice and data.

As of May 2023, AT&T and AST SpaceMobile have announced the successful completion of a voice call using the second AST satellite prototype (BlueWalker3) demonstrating the capability of a LEO satellite communicating directly to a regular of-the-shelf cell phone (Samsung Galaxy S22 smartphone).

Key Information

NTN operates on two distinct architectural paradigms: regenerative and non-regenerative (also known as transparent mode) that play a crucial role in the overall performance and capabilities of the system. Regenerative architecture involves processing and amplifying signals at the satellite, whereas non-regenerative architecture repeats signal with satellite amplification to extend the range of signals. In non-regenerative Low Earth Orbit (LEO) constellations, each satellite acts as a reflector, bouncing signals from one satellite to another until they reach the ground. In regenerative LEO constellations, signals from the ground are processed and amplified before relayed to the next satellite in the constellation, or back to the ground. This process includes demodulation, decoding, encapsulation, routing, and forwarding. Regenerative constellations have increased flexibility and control by leveraging geospatial-software-defined-networking approaches.

Although the 5G NTN design in 3GPP considers different scenarios (e.g., including satellites at different orbits, unmanned aerial vehicle, drones, and balloons), NTN communication over satellites has the most distinctive characteristics, so satellites as NTN platforms will be the primary focus.

5G and Non-Terrestrial Networks provides an overview of the 5G NTN standardization in 3GPP on different design aspects (system architecture, radio access network [RAN], and core network) primarily based on Release 16, but only provides high-level objectives of Release 17, which is the first 3GPP Release that specifies 5G NTN.

New radio (NR) to support NTN in Release 17

Some of the critical design aspects of Release 17 cover the following topics (with the main design assumptions being FDD, GNSS-capable UEs and transparent payload):

TIME AND FREQUENCY SYNCHRONIZATION

- UE behavior will compensate for propagation delay by estimating satellite position (using NTN specific SIB information) and using the UE's GNSS position to determine an accurate timing advance (TA) for UL transmission.
- The Doppler shift of frequency on feeder link (due to high speed of LEOs) will be compensated at the gateway and/or the NTN payload. However, the UE will also have to calculate and compensate for the shift of its service link using its own position as well as satellite velocity information (for counter-shifting its UL transmission frequency).
- Use of larger offsets (a new was introduced) between a received DL slot and the UL slot indicated/scheduled by the received DL, due to the larger Timing Advance (TA) in NTN.

ENHANCEMENTS FOR HARQ AND RACH:

- HARQ process needs to also account for larger propagation delays (e.g., with an increased number of HARQ processes at the UE).
- Another Rel-17 solution allows the network to continuously reuse an HARQ process for scheduling the UE by disabling its HARQ feedback.
- Postpones the starts of the RA response window and the contention resolution timer at the UE by the UE's real-time UE-to-gNB RTT.

MOBILITY SUPPORT:

- Reuse and improve the legacy Handover and Conditional Handover mechanisms by leveraging predictability of satellite movements as well as NTN specific characteristics.
- Allow multiple TACs to be broadcasted per cell, and not require Registration update if one of the cell's broadcasted TAC is included in the UE's configured Timing Advance list.

NEW NTN BANDS:

- Two NTN frequency bands operating in FDD mode are specified, (n255 and n256[3]), which are under 6 GHz.

NTN SPECIFIC SIBS:

A new NTN specific SIB (SIB19) was introduced to carry NTN specific configurations, such as:

- Cell's ephemeris information as well as the associated epoch time to assist the UE for determining the satellite's real-time position.
- Common Timing Advance parameters, polarization info, slot offsets, neighbor cell information, etc.

Internet of Things (IoT) support for NTN in Release 17

Many solutions inherited from NR-NTN to IoT NTN can support eMTC and NB-IoT devices over NTN, such as the ones for time and frequency synchronization. Additional enhancements have been introduced to handle the IoT-specific requirements. For instance, network may broadcast the mean values of the satellites' orbital parameters, which helps the IoT UE to predict the NTN coverage discontinuity and determine when it can disable its access stratum layer functions for power-saving.

Ongoing NTN enhancements in 3GPP Release 18

Rel-18 will enhance the 5G NTN design, with a target completion date by the end of 2023. For NR-NTN[4], additional enhancements will be specified, such as improving UL coverage, deploying NR-NTN in spectrum ranges above the 10 GHz band, supporting network to verify a UE's location, and enhancing NTN-TN and NTN-NTN mobility and service continuity.

Rel-18 will also enhance IoT NTN[5] by disabling HARQ feedback, improving the UE's GNSS operations for a new position fix during its long connection, and enhancing the support for mobility as well as discontinuous coverage.

Three new NTN bands above 10 GHz are specified (bands n510, n511 and n512[6]).

Potential for new services with 3GPP NTN Solution

By using the 3GPP-based NTN solution in conjunction with the sub-2Ghz band spectrum in Rel-17, it is possible to achieve tens of Mbps speed in the downlink (peak speed shared among all users in a given cell), and round trip delay in the range of a few tens of milliseconds using LEO satellite network. This will enable services beyond IoT, text or emergency calls, such as video call to handheld devices as seen in Ericsson's video call demo over an NTN network during Mobile World Congress 2023.

Practical speed will vary depending on device capability, spectrum utilized, load and antenna sizes. NTN can offer much higher speed with the additional Ka band spectrum from Rel-18 (100s Mbps to non-handheld devices such as small dish antenna, similar to what Starlink offers), which will create opportunities for new services beyond broadband—similar to what 5G will enable on terrestrial networks.

Federal Communications Commission activities related to NTN

In April 2023, the US Federal Communications Commission launched the Space Bureau, which together with the Office of International Affairs (OIA), will replace the previous International Bureau. The Space Bureau will focus on policy and licenses for promoting satellite and space-based communications, while OIA will lead the commission's work with foreign regulatory authorities.

As of the end of April 2023, the Space Bureau has approved new rules on spectrum sharing and coordination between space-based operators, ultimately enabling access to newcomers while still protecting incumbents. The bureau acknowledges the increased interest in new satellite system launches (especially LEOs) and aims to promote US leadership in the emerging space industry by modernizing and adapting regulations.

Recommendations

The satellite broadband segment shows a clear trend in massive LEO constellation deployment that can address performance and capacity growth, despite limiting factors such as spectrum availability, possible orbital-overcrowding with the risk of space debris and the challenge LEOs have to astronomy (the astronomical community is working with the satellite industry collaboratively to minimize the impact). Consumers and businesses will greatly benefit from this expansion of access to internet.

Affordable, global connectivity that extends to IoT devices will see continued growth by addressing existing phones, and making use of the future NTN-capable chipsets that can benefit from 5G NTN enhancements. Handsets equipped with this chipset are not yet commercially available yet, but an NTN-capable dongle device may provide an intermediary solution with its ability to connect with older phone models via Bluetooth.

The path toward further developing satellite communication involves active support from FCC on spectrum regulation, while additions to 5G NTN standards in 3GPP Rel-17 and 18 will help manage the complexity and performance of LEO satellites. Ultimately, the services launched by these emerging ecosystems will change the way we communicate on Earth by connecting the unconnected, protecting lives in unpredictable places and situations, and optimizing global supply-chain systems.

Conclusion

Technology advancements of the last few decades—complemented by the growth of private space companies—have reduced orbital launch costs significantly. This, combined with miniaturization and cost reduction of satellite hardware, has ignited a flurry of industry activity with increasingly sophisticated plans for ‘mega-constellations’ consisting of tens of thousands of satellites. The lower latency and active-regenerative capabilities of these systems offer competitive broadband performance in hard-to-reach areas and are even able to directly communicate with current smartphones. The list of broadband providers and partnerships offering IoT and D2C services only continues to grow.

5G Americas continues its work to support the development NTN connectivity and technologies for wireless cellular networks throughout the Americas.

Acronyms

DL: Downlink	NGSO: Non-Geostationary
eMTC: Enhanced Machine-Type Communication	NTN: Non-terrestrial network
FDD: Frequency division duplex	OIA: Office of International Affairs
GEO: Geostationary Earth Orbit	RA: Random Access
GNSS: Global navigation satellite system	RTT: Round Trip Time
HARQ: Hybrid Automatic Repeat Request	SIB: System Information Broadcast
IoT: Internet of Things	TAC: Tracking Area Code
LEO: Low Earth Orbit	UE: User Equipment
MNO: Mobile Network Operators	UL: Uplink
NR/gNB: New Radio 5G	VSAT: Very small aperture terminal

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