

A satellite is shown in the upper left quadrant, with its solar panels and various instruments visible. The background features a bright light source, possibly the sun, creating a lens flare effect. The overall scene is set against a dark blue and black space background with a grid-like pattern of lines.

• Whitepaper

5G Non-Terrestrial Networks and Satellites

Considerations for Programmable Silicon Platforms

Land based mobile networks are going into space. For several years, the satellite industry has been participating in the 3GPP standards process with the goal of integrating their networks into the 5G ecosystem. The result is the arrival of 5G Non Terrestrial Networks (NTNs), both as a technology and an emerging market.

Consumers and businesses have had access to satellite based TV, phones, internet service, and GPS for decades. What's new is the attempt to integrate satellite based signal transmission with a global standard and an extensive terrestrial mobile platform.¹ The 5G NTN initiative also extends beyond humans, as the designated endpoints are not only 5G enabled smartphones, but also the mobile subset of the even larger population of IoT devices, empowered by standards such as Narrowband (NB) IoT and LTE massive machine type communication (mMTC).

The 5G NTN market is young, and manufacturers are still sorting out chip level requirements. This paper is for anyone in that situation. It first reviews drivers and use cases and identifies key deployment challenges. Next, it points to several options and tradeoffs. Finally, it recaps three considerations for moving forward, includes an overview of one system on a chip (SoC) relevant to some NTN use cases, and spotlights several IoT related deployment issues.

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¹ This paper focuses on satellites, but the NTN family also includes high altitude platform systems (balloons), air to ground networks (airplanes), gliders, and unmanned aerial vehicles (UAVs).

5G NTN Drivers & Use Cases

The market for services that leverage 5G NTN integration is only just emerging. Limited emergency texting is available on some smartphones via low earth orbit (LEO) satellites, but consumer demand remains a projection. Broader demand, encompassing business to business applications, is also nascent. The 3GPP contributors to 5G NTN technical reports have nonetheless grounded their multi-year effort in several compelling use cases.

A 3GPP Working Group initially named three categories of NTN use cases: service continuity, service ubiquity, and service scalability. The ETSI 3GPP Technical Report for Release 17 indicated that their efforts will support NTN use cases in the following categories:

- Coverage extension – enabling services for commercial activities in industries (e.g., agriculture, mining, forestry) that occur outside inhabited areas
- Internet of Things – addressing requirements for low power IoT applications related to monitoring of assets, infrastructure, or the environment
- Disaster communication – making satellite communication available as a fallback when existing cellular infrastructure is damaged through natural disaster
- Global roaming – supplementing the tracking of containers in a harbor or on a truck with coverage in areas where only satellite communication is possible
- Broadcasting – making the same application content (e.g., mobile gaming) available over a very wide area or at many different edge locations

The market also reflects two broader categories:

- 1) New Radio (NR) NTN communications; and,
- 2) IoT NTN, or more precisely, LTE-M/NB-IoT.

Time will tell which one gains the most or earliest currency. It is nonetheless auspicious that 5G NTN is tied to a diversity of use cases in several industries.

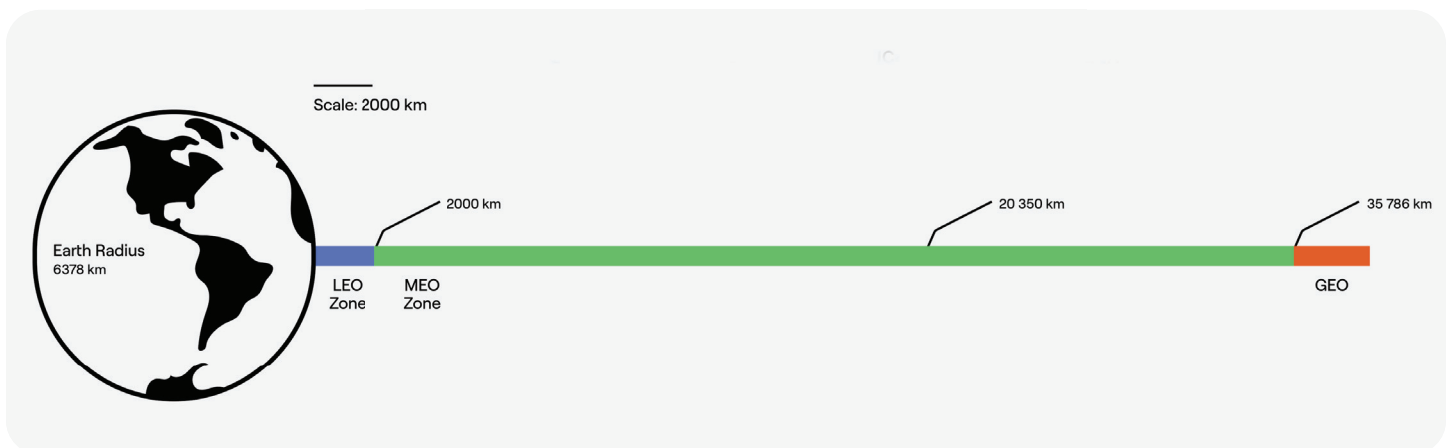


Diagram 1: Satellite classification by orbital distance from Earth.

Key Deployment Challenges

Integrating satellites within 3GPP based networks is a nontrivial exercise. The first challenge is posed by the sheer distance of satellites from NTN gateways and end devices. Long propagation times pose the most obstinate issues. The second relates to the type of satellites; in particular, the difficulties posed by those in non geostationary satellite orbit (NGSO). The third is 3GPP itself, which like all standards efforts has its advantages and drawbacks. Finally, there are several hardware related considerations, including power consumption.

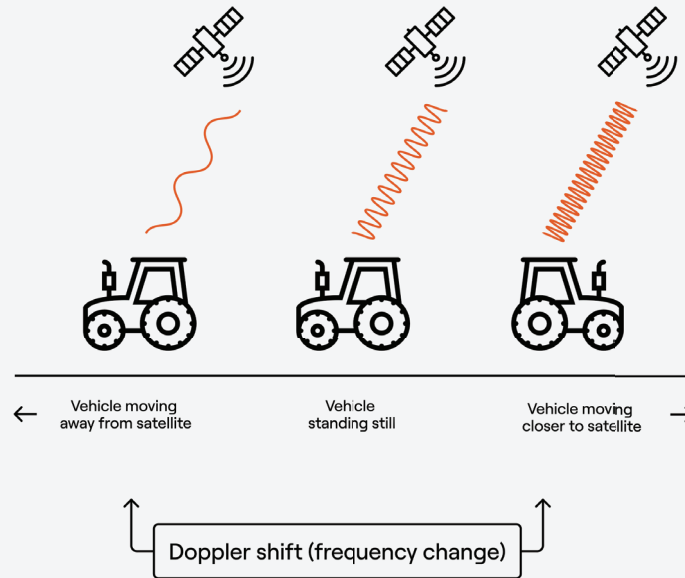


Diagram 2: How the Doppler effect can impact satellite frequencies.

1. Long Propagation Delays

Distance is the biggest issue. On land, where a mobile device and base station may be 1 to 10 km apart, a one way message can take a millisecond. In a LEO enabled NTN, with typical distances between 600 and 1400 km, that signal may take 30 milliseconds. (That is still a fraction of the time it takes to access geostationary satellites, at 35,000 km above the earth.) With a longer round trip time, more variables arise in the channel conditions, which can impact quality of service.

2. Doppler Shift, Moving Coverage Areas

Non-geosynchronous satellites, like those in the LEO and MEO classes, move in relation to the ground, causing a phenomenon called Doppler shift. This shift alters the frequency of the signal transmitted by the satellite, resulting in a mismatch with the frequency received on the ground. To avoid incorrect signal sampling, compensation for this effect is necessary. Failure to do so can lead to a high error rate, which can have a cascading effect. Additionally, LEO satellites use steerable beams to cover a specific area, but these beams are only quasi-fixed. Eventually, the satellite must hand over its coverage to the next satellite in the constellation, making managing these handovers a challenge.

3. Evolving Standards

The primary advantage of the 3GPP standard is its link to an immense base of mobile user equipment (UE). Beginning with 4G, 3GPP also incorporated NB-IoT and LTE M. Yet standards evolve slowly, where every new iteration attempts to reduce limitations and address a broader range of applications. The initial work on 5G NTN, for instance, has been limited to the transparent mode, in which the satellite acts as a relay point. Some applications, however, are better suited to the regenerative mode, which provides more architectural flexibility and improved performance.

4. Form Factors, Power, Radiation

LEO satellites are smaller than their GEO counterparts, but the paradigm has further shifted with mini, micro, nano, and pico satellites. Satellites that conform to the CubeSat specification weigh less than 2 kg. Small form factor and low power consumption are desirable characteristics in these smaller classes, which are often associated with LTE-M and NB-IoT use cases. Of course, whatever size the payload, satellite components need to be protected from radiation in outer space.

Options & Tradeoffs



Physical Layer Techniques

Channel State Information (CSI)

A mobile device reads reference signals sent from a terrestrial base station and responds with information about channel state (quality, signal level, etc.) The base station considers that feedback to determine what frequency, time resources, power level, and modulation scheme to use when transmitting to the mobile. In a 5G NTN network, however, by the time the mobile reads satellite delivered signals and responds, the channel may have changed. Options include ignoring CSI, taking the average from CSI reports over a span of milliseconds, or creating a prediction based link adaptation.

Random Access Channel (RACH)

The channel used to initiate the random access procedure carries preambles, important and complex signature like signals that are difficult to decode, especially when the UE is far away, as in a 5G NTN deployment. Other challenges arise when numerous mobile devices are trying to set up calls at the same time and when a device may have inaccurately estimated the distance to the network. To improve the detection of this initiating signal, the sequence detection algorithm may be modified to take into account the large latency.

Pre-compensation for Doppler

Smartphones already receive one way signals from GPS satellites. The combination of those signals with ephemeris data on satellite orbits allows them to know their position. Global Navigation Satellite System (GNSS) functionality also enables a mobile device to calculate the relative speed between itself and any GPS satellite and then determine the correct pre compensation for the Doppler shift. Doppler compensation techniques must also be applied directly to LEO radio satellites as well. How to optimize these adjustments is a matter of ongoing research on both the UE and transmitter side.

Of these challenges, the most relevant from a silicon point of view are propagation delays. Doppler shift, moving coverage, and bandwidth are also germane. We will first look at several tools and options that can meet these challenges at the Physical Layer (L1) and then turn to several counterparts higher up on the Open Systems Interconnection (OSI) stack (L2/L3).

Timing Relationships

Long transmission delays impact the timing relationships that are critical to network access. One solution is to have the base station set a reference point, ask the UE to provide a measurement and then use that to converge on a common timing advance (TA). You can also shift the time references of the uplink (UL) and downlink (DL) chains at the transmitter and the receiver. On land, UL and DL are closely aligned. With much longer roundtrip times in the satellite domain, you may need to offset a frame and delay the clock so that messages sent on one block are received in the correct, corresponding block.

Modulation and Coding

Channels that are noisy or fading or experience interference transmit lesser amounts of data; but the UE still needs to receive and decode the message. With adaptive modulation and coding (AMC) you can dynamically compensate for changes in link conditions. To meet the tighter parameters of 5G NTN, you could try a more granular reporting of AMC, or opt to live with a higher bit error rate (BER) at the possible cost of lower bandwidth. You can also fine tune block error rate (BLER), converging on conservative modulation and coding schemes (MCSs) and trading off spectral efficiency for reliability.

Retransmission

Error correction mechanisms reside at different layers on the base station and the UE. Algorithms at the Physical Layer allow for retransmitting bits. Or you can avoid doing so. If bits are lost or corrupted beyond a certain amount, which is likelier given longer propagation times, packets also get corrupted. Retransmission of packets can occur at higher layers via Automatic Repeat Request (ARQ), or Hybrid (H)ARQ. (See diagram 4 on page 5.)

Beam Management and BWP Operation

Managing coverage handoffs from one non geosynchronous satellite to another takes a system level approach. One 5G feature that provides additional control is Bandwidth Part (BWP) operation. By giving an operator the ability to split bandwidth into different cells, it enables flexible and efficient radio resource planning. It also allows a UE to save power by listening to a fraction of the total spectrum that a base station might have available. Several different solutions for beam management and BWP for NTN with frequency reuse have been proposed.



Higher Layer Techniques

Modifications at the Physical Layer are rarely standalone. They often have a corresponding impact at higher layers. A few examples that draw from the preceding discussion include network timers, random access preambles and retransmission mechanisms.

In addition to the common TA mentioned earlier, timing functions impacted by satellite-induced round trip delays include Discontinuous Reception (DRX) timers, which put devices into sleep mode when there is no DL/UL traffic. Other Layer 2/3 timers that may need to be modified address questions such as how long to wait for a message response; how much time is required for broadcasting certain messages; and how long to wait for Physical Layer signaling before declaring a channel failed.

Preamble detection is another candidate for enhancement. The normal RACH process involves four steps: The UE initiates com-

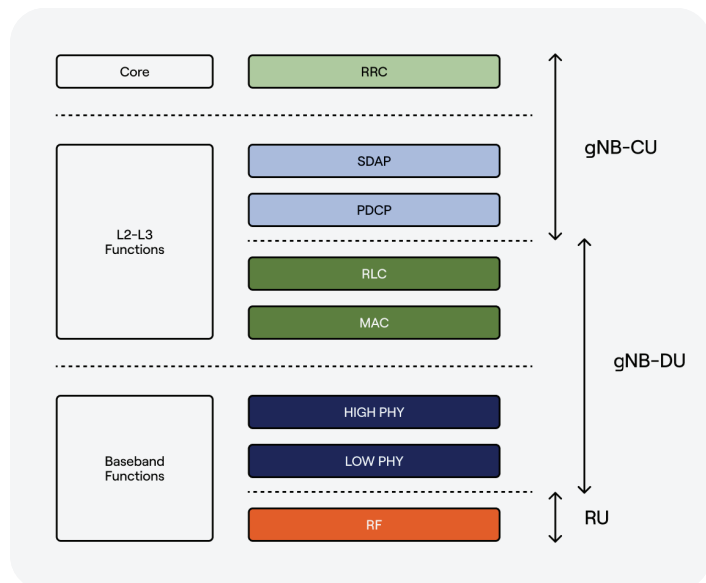


Diagram 3: Modifying Layer(s) 2/3 to address timing functions.

munication with a message that includes the preamble; then the base station receives it, responds, and gets an acknowledgment from the UE. In the 5G NTN framework, more speed is desirable. Accordingly, 3GPP has defined a two step RACH process that could be adapted for a faster attach of the mobile.

As for a partial or full retransmission, that falls within the scope of HARQ, a closed loop, fast response signaling feature that includes Forward Error Correction (FEC). In an NTN scenario, the HARQ feedback Round Trip Time (RTT) is significantly higher than for terrestrial networks. Delayed HARQ feedback can lead to HARQ stalling and corresponding throughput degradation. To mitigate HARQ stalling, 3GPP NTN specifications support an increased number of HARQ processes and options to disable HARQ feedback for DL transmissions.

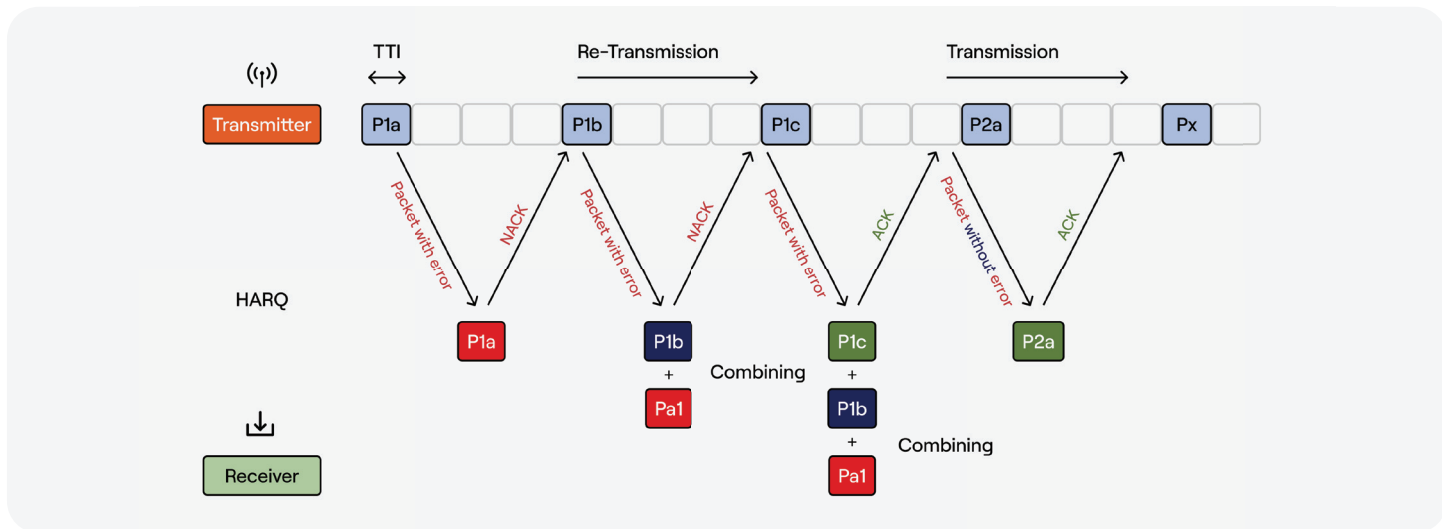


Diagram 4: How 3GPP NTN specifications help mitigate HARQ—a closed loop, fast response signaling feature—from stalling.

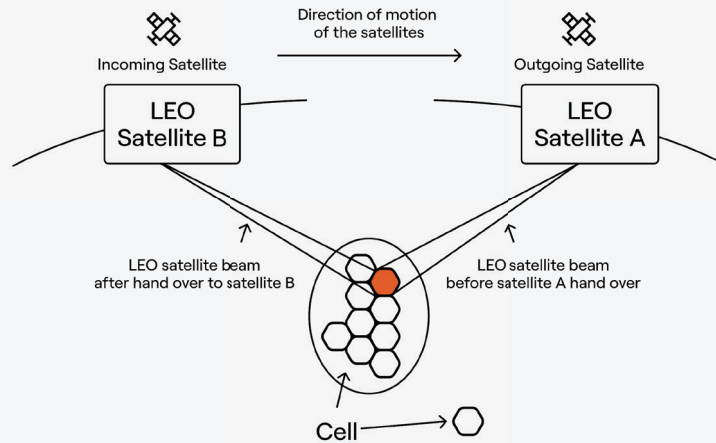


Diagram 4: LEO beam steering and hand over.

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Considerations for Programmable Silicon

The preceding discussion provides a good sampling of the kinds of enhancements to 5G that can facilitate integration with a satellite based NTN. In this section, we will recapitulate those programmable options and add several points regarding chipsets and system level solutions.

Enhanced 5G Software

In the realm of wireless technology, relying solely on lab-tested software is inadequate. Real-world factors, including interference, reflections, and other hard-to-simulate variables, may require you to adjust your algorithms and the entire system architecture.

Even if your code is 3GPP-compliant and battle-tested, running 5G software ‘as is’ over a satellite network is not possible. Instead, timing relationships must be modified, timers adjusted, optimize CSI use for delays, trade-off higher modulation for error tolerance, shorten preamble sequences, turn off or modify retransmission mechanisms such as HARQ, and fine-tune code for improved beam and spectrum management.

When the software implementation and architecture are optimized for the digital signal processor (DSP), modifications to the base station and UE can be optimized. DSPs are designed to handle intensive signal processing tasks efficiently, with specialized instruction sets and hardware accelerators that improve performance. When the software is optimized for a DSP, it can take advantage of these capabilities, resulting in faster and more efficient signal processing.

Optimized Chipsets

Overall system performance improves when hardware and software are developed in tandem. When deployed over programmable DSPs designed for wireless applications, the instruction set, accelerators, and software combinations typically outperform software ported onto standard chips from third parties by a wide margin.

A system on a chip (SoC) used in a 5G NTN network also should draw sufficiently low power to work in any form factor, whether a handheld or satellite. Chipsets also should be tunable to very low power consumption requirements, whether supporting IoT NTN or NR NTN. They should align with form factor requirements, including those of smaller class satellites. And to minimize the charges generated by high energy particles in space, which can impact memory and transistor logic state, any silicon deployed on satellite payloads needs adequate protection from high radiation. (For one SoC example, see sidebar on the Oct3032.)

OCT3032-based NTN Payload

- 28nm Fully Depleted Silicon on Insulator (FDSOI) radiation tolerant process
- Tuneable power consumption (0.5 W to 8W)
- Complete 5G gNB reference solution stack:
 - Including L2/L3 Stack and Core Networks via partners
 - Available in source code license with training and support
 - Can be deployed for any frequency band
- Fast prototyping: Availability of frequency agile dual channel SDR platform (OCTNode2)
- UE solution roadmap
- Ease of programming: Opus Studio IDE with full set of development tools and real time libraries (DSP/Math, 5G/4G Comms)
- Full set of development tools including Opus Studio IDE and real time libraries
- Core Integrated Hardware Accelerator (CIHA) to efficiently accelerate custom algorithms (e.g., in gNB receiver)
- Adopted by leading Tier1 organizations across multiple industries (Tactical Comms, 5G Private Networks, Industrial IoT and Public Safety)
- Strategic partnerships with system integrators for application specific customizations and reference deployments



OCT3032W 5G SoC DSP Device



OctNode2 SDR Platform

System level Modes

Some of the challenges already discussed, such as beam management, call for system level considerations. Standard interfaces are certainly important for partnering with other components, particularly the analog radio front end. But in terms of architecture, the key question for silicon is where a chip sits in the software stack. In that context, the choice between transparent vs. regenerative mode is highly relevant.

The 3GPP process has initially focused on the transparent mode, in which the satellite acts as a simple relay. The regenerative mode, however, which involves deploying some or all gNodeB (gNB) functionality in the satellite payload, has advantages. (5G NR Open RAN enables centralized or distributed architectures.) The regenerative mode allows you to partition a solution into aspects that are more sensitive to delays and latency vs. those that are not. As always, there are trade offs: you need more processing power and components on the gNB but benefit from lower latency and better user experience.

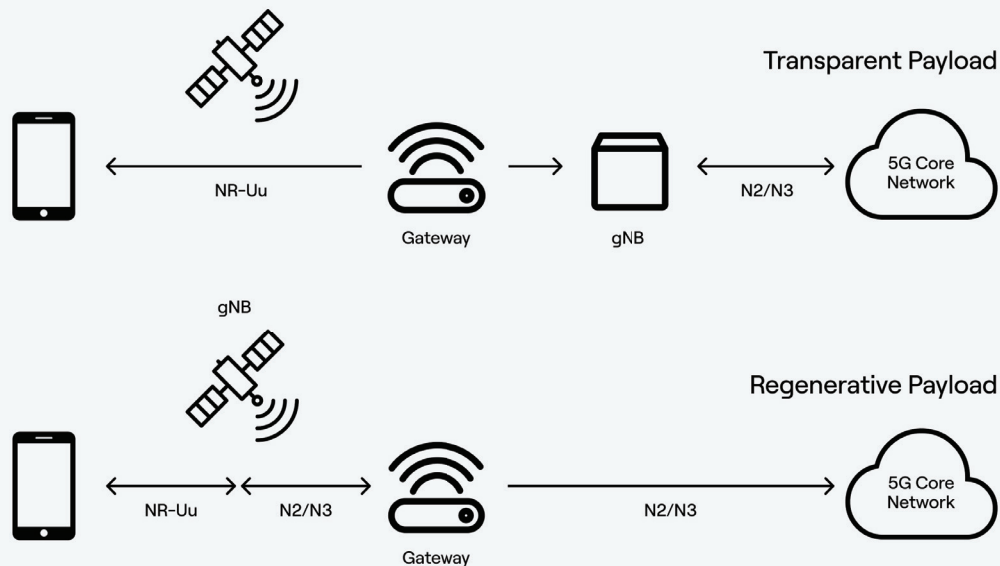


Diagram 5: Corresponding gNB placement considerations regarding Transparent and Regenerative payloads.

Five

Deployment Scenario: NB-IoT, LTE M

Leaving aside mobile broadband for now, we'll briefly address the less familiar, IoT class of 5G NTN deployments. A LEO satellite constellation can connect with several million objects with very low transmission rates across numerous industries, including agriculture, construction, fleet management, health care, marine telematics, mining, oil rigs, and utilities. These connections can take place over two standards: NB-IoT and LTE-M.

Both are low cost technologies that draw minimal power for non latency sensitive devices. Response times for LTE-M are slightly lower than for NB-IoT. Both types of end devices are assumed to have GNSS capability, like other 5G NTN mobile devices, to pre compensate for timing and to offset frequencies. Whereas LTE-M focuses on mobile applications, NB-IoT is a good fit for indoor coverage.

In either case, what is desirable is a chipset that can provide the massive amounts of IoT connections needed for NTN deployments at relatively low power consumption levels.



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Summary Remarks

Reusable delivery vehicles have lowered the barriers to sending satellites into orbit. The smaller form factor of LEO satellites, which have performance characteristics highly favorable to integration with land-based communications, have also reduced cost structures. The use cases for 5G NTN are compelling, and many satellite operators are eager to launch.

What also deserves attention are the software and hardware requirements for the SoCs that will power the 5G NTN service. Whether the service uses private or public networks, or involves NR NTN or IoT NTN traffic, manufacturers should be looking for optimized and programmable chipsets capable of running the gamut of 5G NTN enhancements and deploying in the mode best suited to their customers' business models.

About Octasic

Octasic enables government and commercial clients to accelerate their go-to-market strategies with complex custom 5G wireless designs deployed for both terrestrial and non-terrestrial networks. The Octasic portfolio of programmable SoC DSP devices and sub-systems form the integral technologies in many of the world's SWaP-constrained software-defined radios, base stations, and UE solutions. Octasic architects 100% of its own integrated 5G stack and software development platform for applications that require any custom, proprietary, or enhanced 3GPP waveforms.

To find out more about how your business can gain a head start with its 5G NTN payload designs, please visit the Octasic Contact page to make a request for more information or to speak with one of our wireless specialists.