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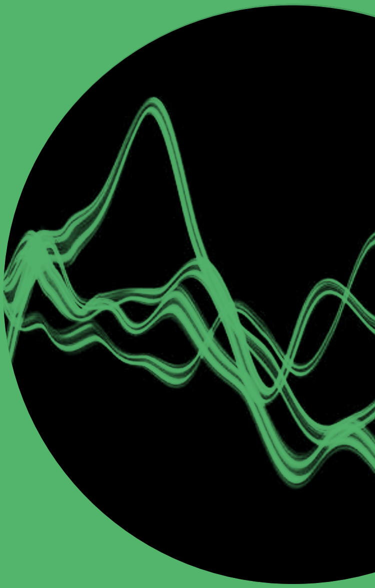
Review

ERICSSON TECHNOLOGY



3GPP TECHNOLOGY FOR SATELLITE COMMUNICATION

ERICSSON

Using 3GPP technology for satellite communication

Most satellite communication today is based on proprietary solutions, but that may soon change. Non-terrestrial networks became part of the 3rd Generation Partnership Project standard in Release 17, establishing a strong foundation for direct communication between satellites, smartphones and other types of mass-market user equipment.

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As the rate of adoption of mobile communication technology around the world continues to rise, the goal of using it to provide seamless global coverage to anyone, anywhere, at any time has become increasingly important. This has led to major advances in both terrestrial and non-terrestrial satellite networking technology.

■ Smooth interworking and integration of terrestrial network (TN) and non-terrestrial network (NTN) components is the next logical step on the coverage journey to provide enhanced mobile broadband (eMBB) to consumer smartphones (direct-to-smartphone) and Internet of Things (IoT) use cases.

Integration with satellite networking technologies that can provide coverage in areas that TNs cannot reach would help to deliver resilient services to people and businesses currently unserved in both developed and undeveloped parts of the world, bringing significant social and economic benefits [1].

Beyond the benefits NTNs will deliver to smartphones, they will also have the capability to support both industrial and governmental IoT devices for verticals such as automotive, health care, agriculture/forestry, utilities, maritime transport, railways, aeronautic/drone sector, national security and public safety.

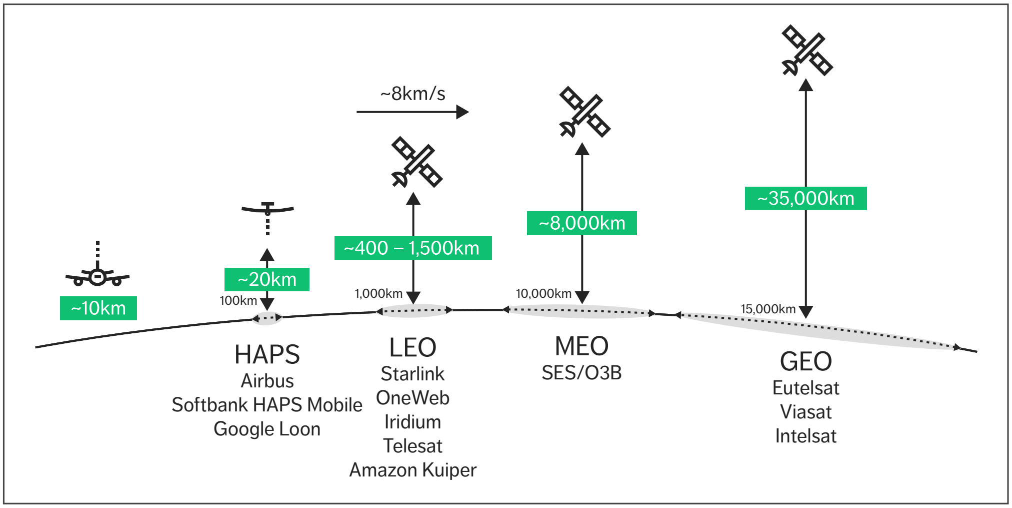

Figure 1 Overview of existing satellite systems

Overview of satellite systems

Different satellite systems have been used for years to provide services such as TV broadcasting, navigation, communications, surveillance, weather forecasting and emergency systems [2]. *Figure 1* illustrates the orbits of the three main satellite types – geostationary (GEO), medium-Earth orbit (MEO) and low-Earth orbit (LEO) – in comparison to a commercial aircraft and high-altitude platform system (HAPS) providing local service coverage.

GEO satellite systems are operated at a high altitude of approximately 36,000km, which introduces long latencies (>500ms) and limited data rates due to the large path loss. GEOs appear stationary to the device and provide a large field of view, which makes them well suited for satellite

Terms and abbreviations

3GPP – 3rd Generation Partnership Project | **5GC** – 5G Core | **CHO** – Conditional Handover | **CSP** – Communication Service Provider | **CT** – Core Network & Terminals | **DL** – Downlink | **FDD** – Frequency Division Duplex | **FSS** – Fixed Satellite Services | **GEO** – Geostationary Orbit | **gNB** – gNodeB | **GNSS** – Global Navigation Satellite System | **HAPS** – High-Altitude Platform System | **HARQ** – Hybrid Automatic Repeat Request | **HRC** – High Reliability Communications | **IoT** – Internet of Things | **LEO** – Low-Earth Orbit | **LTE** – Long-Term Evolution | **LTE-M** – LTE for Machine-Type Communications | **MBB** – Mobile Broadband | **MEO** – Medium-Earth Orbit | **mMTC** – Massive Machine-Type Communications | **MSS** – Mobile Satellite Services | **NB-IoT** – Narrowband IoT | **NG** – Interface between the gNB and the core network | **NMS** – Network Management System | **NR** – New Radio | **NTN** – Non-Terrestrial Network | **ppm** – Parts Per Million | **RF** – Radio Frequency | **RTT** – Round-Trip Time | **SA** – Service & System Aspects | **SI** – Study Item | **SNO** – Satellite Network Operator | **TN** – Terrestrial Network | **UE** – User Equipment | **Uu** – Interface between the gNB and the UE | **UL** – Uplink | **WI** – Work Item

> MOBILE SATELLITE SERVICES ARE BEST POSITIONED AS A COMPLEMENT TO TERRESTRIAL MBB SERVICES, CREATING A WIN-WIN-WIN SITUATION

television, business-to-business data services (such as trunking/backhauling and enterprise networking) and governmental services (such as military satellite communication systems).

MEO satellite systems such as Galileo, GPS (Global Positioning System) and GLONASS are mainly used for navigation and are typically deployed at an altitude of approximately 20,000km in a semi-synchronous orbit that is predictable and reliable with an orbital period of 12 hours. There are constellations in MEO that are also used for communications services deployed at a height of about 8,000km. This leads to a latency that is five times lower compared with GEO, providing higher data rates.

LEO satellite systems are used for services such as Starlink, OneWeb, Iridium and Globalstar. These satellites operate at altitudes of approximately 400-2,000km, where a higher speed (about 8km/s, full orbit time of 90-120 minutes) is required to stay in orbit. LEO satellites provide the lowest latency and tens of megabits per second of capacity, making them suitable for MBB and IoT applications. As the footprint is notably smaller compared with MEO and GEO, larger constellations are needed.

Satellite communication use cases and business rationale

The first commercial rocket launches by SpaceX in the mid-2010s coincided with an ongoing paradigm shift in the space industry that soon resulted in a significant drop in the cost of launches as well as an increase in capacity [3]. The "New Space Era" that has emerged since then has been defined by a dramatic increase in annual private venture capital investments in large LEO constellations focusing on fixed broadband internet services for residential and business users in existing and planned satellite constellations such as Starlink, OneWeb and Amazon Kuiper. The next step in the development of mobile satellite services (MSS) focuses on the ability to communicate with standard smartphones. Three development tracks have emerged: legacy MSS, legacy Long-Term Evolution (LTE) and 5G NTN.

The legacy-MSS track aims to integrate legacy MSS technologies into new smartphones using MSS spectrum. Examples of this approach include Apple iPhone 14 and Globalstar, Huawei Mate 50 and BeiDou, and the addition of Iridium to the Qualcomm Snapdragon Satellite. Meanwhile, the legacy-LTE track is focused on creating a modified network using terrestrial LTE spectrum to reach unmodified LTE phones from LEO satellites. This work is running parallel to the 5G-NTN track, which is based on the 3rd Generation Partnership Project (3GPP) standardized solution specified in Release 17 (Rel-17) that was completed in 2022. Like the legacy-MSS track, the 5G-NTN track uses MSS spectrum.

The assumption is that the legacy-LTE and 5G NTN technologies will be used in cooperation with communication service providers (CSPs), as direct-to-smartphone services cannot compete in terms of price and performance with terrestrial services, where they are available. MSS are therefore best positioned as a complement to terrestrial MBB services, creating a win-win-win situation. This is because, firstly, CSPs run no commercial risk in allowing their subscribers to roam into the satellite network, and doing so enables the CSP to collect roaming fees based on a revenue-sharing model. Secondly, satellite operators gain exposure to a much larger potential market than they are able to reach today with expensive proprietary devices. And finally, the device industry is interested in building devices that are guaranteed to work with satellite systems because they know that this additional functionality will increase the value of the devices.

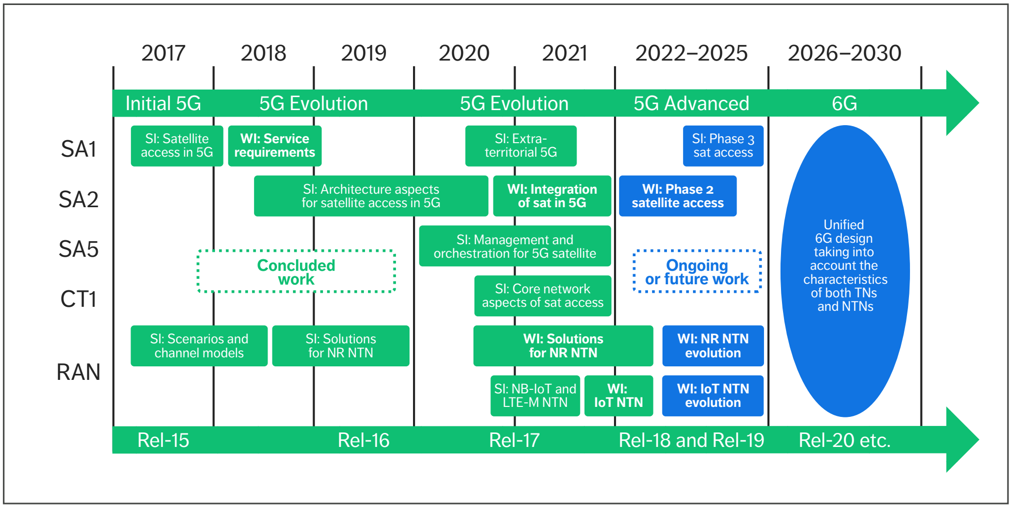

Figure 2 3GPP NTN standardization timeline in the SA, CT and RAN working groups

The 3GPP initiative on non-terrestrial networks

In line with the growing interest in satellite communication in recent years, 3GPP has made efforts to adapt 5G New Radio (NR) as well as narrowband IoT (NB-IoT) and LTE for machine-type communications (LTE-M) to provide satellite-based connectivity. *Figure 2* provides an overview of these efforts. Work started with study items (SIs) in Rel-15 and Rel-16, but Rel-17 was the first to include normative work. The focus of the 3GPP NTN efforts so far is on providing communication services to consumers via satellite; other use cases such as backhaul via satellite are out of scope. The work encompasses support for different satellite constellations, in particular LEO above an altitude of 600km and GEO satellites [4].

Figure 3 presents the two different architectures that can be used to realize satellite communication systems based on 3GPP NTN architecture. In general, the satellite radio payload is connected to the core network through a satellite ground station or gateway using what is referred to as the feeder link. The satellite provides communication services to user equipment (UE) via the service link. Although 3GPP Rel-17 specifies the transparent NTN architecture shown on the left side of Figure 3, the algorithms and enhancements are flexible enough to also support the regenerative architecture shown on the right side.

In the transparent architecture, the base station (gNodeB or gNB) is located on the ground behind the gateway, and the satellite's main purpose is to act as a repeater. The only processing that can be performed on the satellite is radio frequency (RF) processing such as frequency conversion, amplification and beam management.

In the regenerative architecture, the satellite carries either an entire gNB or parts of it, such as the radio unit which makes it possible to decode and process packets on the satellite. The feeder link in this case is akin to terrestrial fronthaul/backhaul and it is not necessarily implemented using NR. The regenerative architecture provides more flexibility, better performance and global coverage due to the ability to support inter-satellite links.

Rel-17 NR non-terrestrial networks

Modern satellites typically divide their service areas into several hundred sub-areas, which they serve with individual beams ("spot beams"). In general,

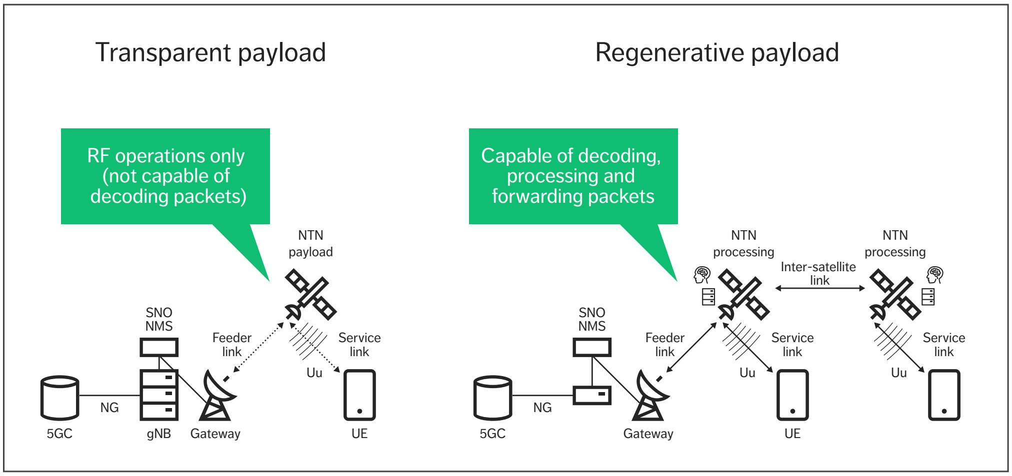

Figure 3 Two different NTN architectures

each of these areas corresponds to one cell, and can have a diameter of tens or even hundreds of kilometers.

While GEO satellites are (almost) stationary with respect to a point on the Earth's surface, LEO satellites move at approximately 8km/s (~30,000km/h) in their orbits. If the beams are fixed with respect to the satellite, the beams will sweep the surface of the Earth, leading to frequent mobility events, such as handover between cells, even for stationary UEs (typically every few seconds).

Alternatively, a beam steering mechanism can be implemented on the satellite to steer the beams toward a fixed area on the Earth for as long as possible. This concept, known as "Earth-fixed beams," allows a device to remain in the same beam and cell for several minutes. While both alternatives are supported in Rel-17, a particular benefit of the Earth-fixed beam concept is that it avoids frequent handover between cells.

The fundamental challenge for any satellite communication system is how to overcome the large round-trip delays and frequency shifts due to the movement of the satellite relative to Earth, also known as Doppler shifts. For GEO satellites, the round-trip delay can be longer than 500ms, and even for LEO satellites it can amount to tens of milliseconds. The differential delay within a cell is also large, extending to as much as 10ms depending on cell size. The fast movement of LEO satellites creates large Doppler shifts of up to 25ppm (50kHz at 2GHz carrier frequency).

The 3GPP solution to this challenge is to require the UEs to compensate delay and service link Doppler shift before accessing the network. To this end, the satellite broadcasts its ephemeris corresponding to its position and velocity. The UE is required to be equipped with a Global Navigation Satellite System (GNSS) module, which it uses to determine its own position before accessing the network.

From its own position and the satellite ephemeris, the UE calculates the distance to and relative velocity of the satellite, and it determines the required pre-compensation values and applies a large frequency shift and timing advance. This enables the gNB to operate at its nominal frequency and with uplink (UL) and downlink (DL) timing aligned, as in a TN.

The long propagation delays necessitate further changes. Scheduling timing relationships, which are designed to cater for round-trip times (RTTs) below

1ms in a TN, have been redesigned to cope with the longer delays as well.

Hybrid automatic repeat request (HARQ) operation, which guarantees reliable data transmission, is also affected. HARQ is a "stop-and-wait" protocol, meaning that a HARQ process ID can be reused only after the corresponding feedback has been received. In legacy NR, there are 16 HARQ process IDs, which in NTNs would lead to a situation where no new data can be transmitted simply because there are no free HARQ process IDs available.

To avoid this effect, known as "HARQ stalling," the number of HARQ processes has been increased to 32. For GEO scenarios with their extremely long round-trip delays of several hundreds of milliseconds, an unfeasible number of HARQ process IDs would be needed. The option to disable HARQ feedback (per HARQ process ID) was therefore also added. In this case, retransmissions are handled by the slower feedback loop that is supported by the Radio Link Control layer.

Mobility is another area in which NTNs differ significantly from TNs, most obviously in LEO constellations, where even stationary UEs will experience frequent handovers because of the orbital movement of the satellites. In TNs, UEs experience a clear difference in measured signal strength depending on the distance between the UE and the base station, whereas in NTNs all UEs have approximately the same distance to the satellite, with only a small difference in signal strength between cell center and cell edge.

This difference is utilized in legacy mobility procedures such as cell selection, which is based on received DL signal strength. In NTNs, the primary solution for connected mode mobility is expected to be conditional handover (CHO). To support NTN, CHO has been upgraded to include a time-based trigger condition and a UE-location-based trigger condition. The former allows the UE to execute the handover during a certain time period, while the latter takes the device location relative to the target and source cells into consideration for the handover decision.

> “MOBILITY IS ANOTHER AREA IN WHICH NON-TERRESTRIAL NETWORKS DIFFER SIGNIFICANTLY FROM TERRESTRIAL NETWORKS”

Other enhancements include support for DL transmission polarization signaling, extension or offset start of various timers, enhancements for cell selection/reselection, reporting of the applied timing advance during random access, and UE location reporting to facilitate procedures like selection of a core network in the correct country and lawful intercept.

Rel-17 IoT non-terrestrial networks

Rel-17 also includes adaptations to NB-IoT and LTE-M that will enable them to support NTNs. This 3GPP track is known as IoT NTN. The work item (WI) was started very late in Rel-17 with minimal scope, focusing on essential functionalities. The general approach in IoT NTN is to follow the NR NTN work as closely as possible and adapt its solutions. For example, the basic solution for pre-compensation of delay and Doppler shift is the same, requiring IoT NTN UEs to have GNSS support. The NR NTN enhancements to scheduling timing relationships have also been adopted for IoT NTN. No mobility enhancements (such as CHO) have been considered, however.

Discontinuous coverage is a topic that is specific to IoT NTN. In contrast to NR NTN, the UEs in many IoT NTN use cases may not need continuous coverage. For example, it may be sufficient if they can transmit their data once every few hours. These types of use cases could make it feasible for some satellite operators to deploy sparse constellations with fewer satellites. To support such operation, information – such as the satellite ephemeris of neighboring cells along with coverage info of the cells – will be signaled to enable the UEs to predict the times when they will have coverage.

> THE ITU-R VISION FOR mMTC INCLUDES SUPPORT FOR UP TO 500 DEVICES PER SQUARE KILOMETER

Rel-18

Both the NR NTN and the IoT NTN work continues in Rel-18. For NR NTN, the new objectives focus on coverage enhancements, further improvements to the mobility procedures and methods for the network to independently verify the reported UE location. For IoT NTN, the scope includes a method to disable HARQ feedback similar to NR NTN, mobility enhancements such as CHO for LTE-M and further enhancements for discontinuous coverage.

Spectrum for 3GPP non-terrestrial networks

Spectrum for satellite communications is divided into spectrum for providing MSS and fixed satellite services (FSS). The S- and L-bands are examples that belong to the MSS domain, while the Ka- and Ku-bands provide FSS.

Rel-17 specified support for the L- and S-bands as band n255 (1,626.5MHz-1,660.5MHz and 1,525MHz-1,559MHz for UL and DL, respectively) and n256 (1,980MHz-2,010MHz and 2,170MHz-2,200MHz for UL and DL, respectively). Each of these frequency division duplex (FDD) bands offers approximately 30MHz of spectrum in each link direction.

In Rel-18, another MSS FDD band will be added with the UL in L-band (1,610-1,626.5MHz) and the DL in S-band (2,483.5-2,500 MHz). This addition makes about 80MHz of DL and 80MHz of UL spectrum that is suitable for providing operation from a satellite direct to a handheld device available to 5G NR NTNs [6].

In Rel-18, 3GPP will also specify at least three example bands (n510-n512) in the Ka frequency range 17.7-20.2GHz (DL) and 27.5-30GHz (UL). While the L/S-band targets handheld devices, in the Ka-band, devices with higher-gain antennas are required, such as very small aperture terminals, which are typically mounted on buildings or vehicles.

5G non-terrestrial network system performance

Similar to terrestrial 5G, NTN aims to provide services beyond MBB. The ITU-R (International Telecommunication Union – Radiocommunication Sector) outlines performance requirements intended to facilitate ubiquitous and resilient coverage for MBB, massive machine-type communications (mMTC) and high reliability communications (HRC) [7]. The report elaborates on the key performance requirements for each use case in the context of a LEO 600km constellation operating over a 30MHz carrier.

Notable requirements are peak data rates of 70Mbps (DL) and 2Mbps (UL), corresponding to spectral efficiencies of 3bps/Hz (DL) and 1.5bps/Hz (UL). This can be translated to DL and UL area traffic capacity of 8kbps/km2 and 1.5kbps/km2 for this particular constellation. The ITU-R vision for mMTC includes support for up to 500 devices per square kilometer, while the HRC use case is associated with a reliability of 99.9 percent.

Providing direct-to-handheld connectivity from a satellite constellation presents a considerable challenge due to the propagation loss between the satellite and the handheld device on the ground. The available link budget depends on many factors such as orbit height, system architecture, antenna design, area to be served by the constellation and the elevation angle between the satellite and the UE.

The link budget in turn determines many performance figures, such as the achievable throughput. As an example, a user can expect the highest throughput when the satellite is directly overhead, at an elevation angle of 90 degrees. The path loss increases when the satellite is at lower elevation angles, and at elevation angles around 30 degrees, the achievable throughput might be reduced by a factor of 2.

A second effect of the distance between the terminal and the satellite radio is the increase in latency. The overall latency that the user experiences will vary depending on the satellite's position in relation to the user and the ground station. Taking a terrestrial system as reference with a maximum RTT of approximately 1ms, the round-trip latency for a LEO constellation at an altitude of 600km will be between 8ms and approximately 20ms when using the transparent architecture, assuming a minimum elevation angle of about 30 degrees.

Key benefits of a 3GPP-based non-terrestrial network solution

Regardless of the architecture, the main benefit of a 3GPP-compliant NTN solution will be immediate compatibility with mass-market smartphones. In comparison with the bulky and expensive terminals used in non-3GPP-based legacy-MSS systems, a 3GPP solution will bring global data-and-voice connectivity to regular-sized smartphones. Terrestrial operators can boost their geographical coverage and close the gap of connectivity in sparsely populated areas, including rural settings, while reaching new use cases such as maritime coverage.

A system based on 3GPP NTN accounts for the Doppler shifts and delays that are inherent to satellite systems without relying on proprietary workarounds. It is a future-proof solution with an evolution that follows the 3GPP releases and is both backward-compatible with 4G LTE IoT NTNs and forward-compatible with 6G NTNs. It is also very flexible, with the ability to provide connectivity for LEO, MEO and GEO during the full life cycle of a constellation.

A 3GPP-compliant NTN solution makes it possible to deliver a single network that comprises both terrestrial and non-terrestrial components, incorporating the world's largest ICT ecosystem. This evolution will enable satellite operators to provide affordable satellite communication and inherently better performance due to specified enhancements including the improved HARQ mechanism. And as the services that a 3GPP-compliant NTN solution will deliver will be deployed through NTN-specific spectrum, there is minimal risk of interference.

Conclusion

Satellite connectivity based on open 3rd Generation Partnership Project (3GPP) specifications offers the best opportunity to create a large non-terrestrial network (NTN) ecosystem, enabling connectivity between terrestrial systems and satellite systems on the same mobile platform. As satellite systems will not have the same capacity as terrestrial systems, they should be viewed as complementary rather than competing systems. We expect to see more cooperation between satellite operators and terrestrial communication service providers (CSPs) in the years ahead to achieve mutual benefits in this area.

One of the main challenges that must be overcome in the work to create NTNs is the issue of the interference that can arise if the same spectrum is used for both terrestrial and satellite systems. In many regions, there are already regulatory requirements that could prevent the use of CSPs' terrestrial spectrum for satellite operations. To overcome the challenge of potential interference, Ericsson's position is that it is preferable for satellite-based services to use specific satellite spectrum.

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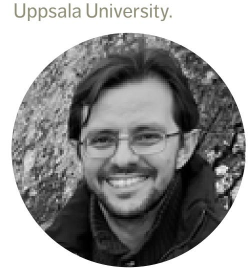

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Further reading

» **Ericsson press release, Ericsson, Qualcomm and Thales to take 5G into space, available at:** *https://www.ericsson.com/en/press-releases/2022/7/ericsson-qualcomm-and-thales-to-take-5g-into-space*

» **Ericsson Technology Review, 5G evolution toward 5G advanced: An overview of 3GPP releases 17 and 18, available at:** *https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/5g-evolution-toward-5g-advanced*

» **IEEE, Non-Terrestrial Networks in 5G & Beyond: A Survey, available at:** *https://ieeexplore.ieee.org/document/9193893*

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