UNOFFICIAL MACHINE TRANSLATION

Financováno Evropskou unií
NextGenerationEU

The Use of Satellite Communications for 5G – Coexistence and Cooperation between Terrestrial and Satellite Networks

Prepared for the Ministry of Industry and Trade

[June 2025]

Grant Thornton

Contents

Grant Thornton

List of abbreviations and explanatory notes

BEREC	The Body of European Regulators for Electronic Communications – Association of European regulatory authorities in the field of electronic communications
CEPT	European Conference of Postal and Telecommunications Administrations – European Conference of Postal and Telecommunications Administrations
CGC	Complementary ground component – Complementary ground component
CHO	Conditional handover
CRTC	Canadian Radio-television and Telecommunications Commission – Canadian Radio-television and Telecommunications Commission
DSA	Direct Satellite Access – Direct access to satellite services
ECS	Environmental Control System – Environmental Control System
eMBB	Enhanced Mobile Broadband – Enhanced mobile broadband and high-speed mobile communications
e / mMTC	Enhanced / Massive Machine-Type Communications – Enhanced / Massive machine-type communications
ESA	European Space Agency – European Space Agency
ETSI	European Telecommunications Standards Institute – European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplex – Frequency-division duplex
GEO	Geostationary Earth Orbit – Geostationary Earth Orbit
GES	Gateway Earth Station – Earth station
GNSS	Global Navigation Satellite System – Global Navigation Satellite System
GPS	Global Positioning System – Global Positioning System
GSO	Geosynchronous/Geostationary Orbit – Geosynchronous/Geostationary orbit
HAPs	High Altitude Platforms – High-altitude platforms (systems located at high altitudes)
HARQ	Hybrid Automatic Repeat reQuest – Hybrid Automatic Repeat Request
HFT	High-Frequency Trading
HRC	High Reliability Communication
HTS	High Throughput Satellites
IMT	International Mobile Telecommunications – Mobile Satellite Service (IMT-MSS) – Existing mobile satellite service
IRIS2	Infrastructure for Resilience, Interconnectivity and Security by Satellite – Infrastructure for resilience, interconnectivity and security via satellites
ISED	Innovation, Science and Economic Development Canada – Canadian Institute for Innovation, Science and Economic Development
ISL	Inter-Satellite Link – Inter-satellite link
ITU	International Telecommunication Union

MANO	Management, automation and network orchestration – Management, automation and network orchestration

MEO	Medium Earth Orbit – Medium Earth Orbit
MIoT	Mobile Internet of Things – Mobile Internet of Things
mMTC	Massive Machine-Type Communications – Massive machine-type communications
MSS	Mobile Satellite Service
M2M	Machine-to-Machine – Machine-to-Machine
NB-IoT	Narrowband Internet of Things – Narrowband Internet of Things
NIDD	Non-IP Data Delivery – Delivery of non-IP data
NFV	Network Functions Virtualisation – Virtualisation of network functions
NFVI	Network Functions Virtualisation Infrastructure – Virtualised network functions infrastructure
NGSO	Non-Geostationary Orbit – Non-geostationary orbit
NTN	Non-Terrestrial Network
LEO	Low Earth Orbit
PPDR	Public Protection & Disaster Relief – Public protection and disaster relief
PRACH	Physical Random Access Channel
QoS	Quality of Service
SSO	Semi-synchronous Orbit – Semi-synchronous orbit
TDD	Time Division Duplex – Time Division Duplex
TN	Terrestrial Network – Terrestrial network
UAM	Urban Air Mobility – Urban air mobility
UAS	Uncrewed Aircraft Systems – Unmanned Aerial Systems
UE	User Equipment – User equipment
URLLC	Ultra-Reliable Low Latency Communications – Ultra-reliable low-latency communications
vLEO	Very Low Earth Orbit
VLoS	Visual Line of Sight – Visual line of sight
VNFs	Virtualised Network Functions
WRC	World Radiocommunication Conference – World Radiocommunication Conference

Executive Summary

The combination of satellite (NTN) and terrestrial (TN) networks is currently emerging as a strategic solution for extending high-quality internet coverage. Satellite networks provide a stable connection and can be combined and integrated with terrestrial networks in various ways. Thanks to low-Earth orbit satellite constellations, high-quality connectivity can be achieved even in remote areas where terrestrial infrastructure is not available.

The study focuses on the technological and legislative aspects of integrating NTN with 5G, describes the technical integration models known to date, identifies key barriers and provides recommendations for overcoming them. Key points highlighted include ensuring harmonised spectrum access, economic feasibility and compliance with European regulatory frameworks, all whilst taking into account local conditions and the applicability of the solution in the Czech Republic.

The coexistence of satellite and terrestrial 5G networks requires the optimisation of suitable spectrum usage and the development of hybrid network architectures. The use of satellite technology in 5G networks is currently largely, if not entirely, dependent on further technological progress and international technical standardisation activities led primarily by the 3GPP, ETSI and ITU-R, which have already made significant progress in this regard.

Future technical capabilities will, in practice, determine the most effective ways for terrestrial 5/6G networks to cooperate with NTNs, and will also define the prevailing technical and commercial models for integrating NTNs to address specific areas requiring, alternatively, high-capacity (eMBB), high-capacity but dispersed (eMTC), or reliable (HRC) data coverage, with different usage scenarios requiring distinct approaches. In practical terms, this primarily involves solutions for coverage in white spots, on moving platforms (aircraft, ships, trains), for emergency, security and defence applications, and the expansion of IoT and M2M communication platforms.

The costs of deploying satellite 5G communications are offset by its ability to provide connectivity in otherwise uncovered areas and to serve dispersed, mobile or fully autonomous devices that would otherwise require physical maintenance or the use of more expensive proprietary connectivity.

From a national perspective, emerging technical standards and rules for the use of NTN will need to be incorporated into the national regulatory framework. This will primarily involve new dedicated frequency bands for NTN communications and the transposition of rules on fair access to them, which are being developed by the RSPG (currently, in particular, the decision on the future use of the MSS band following the expiry of the current licences in 2027). From this perspective, it appears crucial not only to elaborate and transpose the access rules themselves at national level (ČTÚ/MPO), but also, in particular, to carry out an impact assessment and determine the procedure for the subsequent allocation of the recommended bands for individual types of 5G-NTN communication (CTU), as recommended by the ITU-R in Resolutions 253 and 254 (from WRC-23) and which are to be subsequently codified at the forthcoming WRC-27.

Although it might seem that, in the Czech Republic, data transmissions via NTN will not play a significant role, it is worth bearing in mind scenarios involving the complementary use of TN-NTN, which will undoubtedly be both necessary and practical: communication between emergency services in the event of disruption to terrestrial infrastructure, one-off capacity boosts for terrestrial networks, air traffic control and navigation, and the opening up of airspace to autonomous drones (e.g. for the inspection of linear structures). Another area for development is the identification of further sectors, such as agriculture, forestry and water management, where there is a prospect of a need for rapid data communication between dispersed and mobile devices in areas with uneven TN coverage.

It is necessary to take into account the current technical limitations, which are only just being overcome through development and standardisation – higher latency in NTN networks, the integration of NTN into 5/6G network platforms, including resolving issues relating to traffic routing, traffic prioritisation, TN–NTN handovers, and parallel terrestrial and NTN connections. This also places demands on new functionalities in end-user devices, the sufficient penetration of which will only enable the solution to make economic sense. These steps therefore determine the timeframe for the roll-out of joint 5/6G-NTN technologies, which could be compared to the gradual roll-out of current 4.5G and 5G networks; in other words, this is a medium-term horizon of approximately five years.

Management summary

The combination of satellite (NTN) and terrestrial networks (TN) is currently emerging as a strategic solution for expanding the coverage of high-quality internet connectivity. Satellite networks provide stable connections and can be integrated with terrestrial networks in various ways. Thanks to low Earth orbit (LEO) satellite constellations, it is possible to achieve high-quality connectivity even in remote areas where terrestrial infrastructure is unavailable.

This study focuses on the technological and legislative aspects of integrating NTN with 5G, describes currently known technical integration models, identifies key barriers, and provides recommendations for overcoming them. Emphasis is placed on ensuring harmonised spectrum access, economic feasibility, and compliance with European regulatory frameworks, whilst taking into account local conditions and the applicability of the solution in the Czech Republic.

The coexistence of satellite and terrestrial 5G networks requires optimising spectrum usage and developing hybrid network architectures. The integration of satellite technology into 5G networks remains largely, if not entirely, dependent on further technological advancements and international standardisation efforts led primarily by organisations such as 3GPP, ETSI and ITU-R, which have already made significant progress in this area.

Future technical capabilities will determine the most effective ways for terrestrial 5G/6G networks and NTN to cooperate, as well as the prevailing technical and commercial models for NTN deployment in specific areas. These areas may require different types of data coverage: high-speed broadband (eMBB), capacity-intensive but dispersed connectivity (eMTC), or highly reliable communication (HRC), whilst each of these use cases may require different approaches. In practical terms, this primarily involves solutions for covering ‘white spots’, roaming platforms (aircraft, ships, trains), emergency, security and defence applications, as well as the expansion of IoT and M2M communication platforms.

The costs associated with implementing satellite 5G communication are offset by its ability to provide connectivity in areas that would otherwise be uncovered and to serve dispersed, mobile, or fully autonomous devices that would otherwise require physical servicing or expensive proprietary connectivity solutions.

From a national perspective, it will be necessary to incorporate emerging technical standards and rules for the use of NTN into the national regulatory framework. This will primarily concern the allocation of new frequency bands dedicated to NTN communications and the transposition of fair access rules for these bands, which are currently being developed by the RSPG (notably, the decision regarding the continued use of the MSS band following the expiry of existing licences in 2027). In this context, both the detailed elaboration and transposition of the access rules at national level (by ČTÚ and MPO) and, in particular, the preparation of an impact analysis and the subsequent allocation process for the recommended bands for various types of 5G-NTN communication (by ČTÚ) appear to be crucial. This should be in accordance with the recommendations of ITU-R as set out in Resolutions 253 and 254 (from WRC-23), which are to be codified at the forthcoming WRC-27.

Although data transmission via NTN may not appear to play a major role under the conditions in the Czech Republic, it is important to consider complementary TN-NTN use cases that will undoubtedly be both necessary and practical: communication for emergency services in situations where terrestrial infrastructure is disrupted, temporary capacity boosts for terrestrial networks, air traffic management and navigation, and enabling autonomous drones to access airspace (e.g., for the inspection of linear infrastructure). Another important area of development is the identification of additional sectors such as agriculture, forestry and water management, where there is a growing need for fast data communication between dispersed and roaming devices in areas with patchy terrestrial network coverage.

It is necessary to take into account existing technical limitations, which are still being addressed through development and standardisation – such as higher latency in NTN networks, the integration of NTN into 5G/6G network platforms, including challenges relating to traffic routing, traffic prioritisation, handovers and parallel TN-NTN connectivity. These challenges also place demands on new functionalities of end-user devices, the sufficient market penetration of which is a prerequisite for making these solutions economically viable. These factors dictate the timeline for the adoption of joint 5G/6G-NTN technologies, which can be compared to the gradual deployment of current 4.5G and 5G networks, indicating a medium-term horizon of approximately five years.

1 Introduction

The use of satellite technologies to extend 5G coverage has become an increasingly significant option in recent years for improving access to high-quality internet connectivity across countries and regions. For such applications within the 5G ecosystem, the satellite network must provide a sufficiently stable connection whilst maintaining very low latency. The growing deployment of satellite systems by various companies, organised into interconnected constellations – particularly in low Earth orbit – now offers the possibility of affordable internet connectivity via both fixed and non-fixed satellite stations. A major advantage of satellite network solutions is, in particular, the ability to provide coverage in hard-to-reach areas (white spots) where terrestrial connectivity is unavailable for various technical, legislative, economic or other reasons. The combination of satellite and terrestrial networks is therefore a highly flexible and practical solution for streamlining the roll-out of 5G internet coverage to all locations, whilst also bringing us closer to meeting the EU's legislative targets for gigabit connectivity.

1.1 Objectives of the study

This study focuses in detail on the parameters of the coexistence of 5G and satellite networks and identifies the technical and legislative barriers to the roll-out of these technologies in the Czech Republic, taking into account both technical and economic feasibility. The main output of this study is an overview of the situation in the field of satellite communications, along with a set of recommendations aimed at ensuring that satellite communications meet the requirements of communities and customers, with a key focus on maintaining and expanding access to harmonised spectrum resources (eMBB). The outputs also include a cost estimate and an assessment of the economic impact of these recommendations. Previous 5G technical standards – in particular the 3GPP specifications, ITU-R recommendations (IMT-2020) and ETSI standards – therefore did not initially address the integration of satellite communications. However, with growing interest in using satellites to extend 5G coverage and capacity, it has become apparent that these standards have fundamental shortcomings with regard to satellite networks. The original 5G specifications simply did not account for the technical peculiarities of satellite links, such as very long signal delays, significant Doppler shift or the atypical architecture involving moving base stations in orbit. This has led to the need to update and expand the existing standards so that satellite 5G technologies can operate effectively and be integrated with terrestrial networks.

The study focuses in particular on the following topics:

- A description of the technology and architecture of satellite-based 5G technologies and the technical possibilities for interconnection with terrestrial networks.
- Classification of individual types of satellites and high-altitude platforms (HAPs), including their advantages and disadvantages for use in 5G networks.
- An overview of the frequency bands allocated for satellite communications and their current use and limitations in the Czech Republic.
- Developments in satellite 5G technologies and related studies by 3GPP, ITU-R and ETSI.
- Opportunities for the practical use of satellite services in expanding 5G network coverage.
- A comparison of measures and actions taken by regulatory authorities in various countries with regard to the roll-out of satellite technologies for 5G applications.
- An overview of the options and providers of 5G satellite technologies, and an assessment of the feasibility and availability of implementing these solutions in the Czech Republic.
- Implications for the development of satellite communications in the Czech Republic

1.2 Regulatory positions

The integration of satellite telecommunications services into 5G networks presents challenges not only from a technological perspective, but also in terms of regulatory issues at international and European level. The main institutions dealing with this issue are the International Telecommunication Union (ITU) and the Body of European Regulators for Electronic Communications (BEREC).

The ITU establishes global rules for the harmonised use of spectrum and satellite orbits, ensuring minimal interference between different services and operators. At European level, BEREC is currently focusing on coordinating regulatory approaches and promoting fair competition alongside the efficient use of spectrum in line with the requirements of 5G networks.

1.2.1 ITU

In order to meet the ever-growing needs of the satellite sector (and all other sectors using radio frequencies), the ITU oversees the regular updating of the Radio Regulations, the international treaty governing the use of radio frequencies worldwide, including in outer space.

The ITU Radio Regulations and the ITU Constitution (No. 197, Article 45) stipulate that

'all stations, whatever their purpose, must be established and operated in such a way as not to cause harmful interference to the radio services or communications of other Members, recognised operating agencies or other authorised operating agencies providing a radio service and operating in accordance with the *Radio* Regulations'[1].

The ITU administers a cooperative system for the international coordination of radio frequencies used by satellites, the aim of which is to prevent mutual interference between these systems or with other radio systems. It oversees the satellite frequency registration process, under which an ITU Member State submits a description of the radio frequencies that its satellite operators plan to use as part of a project. In the event of a conflict between member states' plans (to use the same frequency bands), these issues are resolved bilaterally through the ITU with the aim of finding an ideal solution for all parties.

The ITU Radiocommunication Bureau examines the compliance of these descriptions with the Radio Regulations and publishes the descriptions and the results of the ITU's examination to all other ITU Member States.

1.2.2 BEREC

Partly due to the increase in the number of satellite constellations, space in general, and GSO slots in particular, is becoming increasingly congested. There is therefore a greater potential for radio interference between services. According to BEREC, the use of satellite communications services for standard commercial services must meet certain conditions[2]:

- The need for and availability of authorisation to use frequencies within the relevant jurisdiction. Authorisation may be granted in various forms:
    - Satellite network authorisation (individual authorisation – e.g. fixed satellite earth station, portable earth station, equipment with more than one transmitting antenna); where user terminals are under the control of the network, they are usually exempt from the obligation to obtain individual authorisation;
    - General authorisation (licence-exempt authorisation);
    - Authorisations based on the relevant reference to the frequency usage plan issued by the ITU and subsequently adopted within Europe by the CEPT;

- The efficient and interference-free use of satellite networks, which may require further, and in particular greater, use of NGSO constellations and may increase the need for coordination between nearby earth stations. Availability of technical

[1] Regulation of satellite systems

[2] Final Report on Satellite Connectivity for Universal Service, BoR (22) 169

studies in the CEPT/ECC field is considered useful in this regard, as is the use of highly directional antennas;

- Use in accordance with national telecommunications laws and regulations on universal service. This may include provisions requiring lawful interception capabilities in accordance with national legislation. Some national regulatory authorities may also require their end-users to be routed via gateways within their jurisdiction or, at the very least, within the EU;
- In some countries, legal issues need to be resolved in cases where, for example, the network authorisation process requires public consultation or other scrutiny with regard to the possibility of law enforcement in the case of non-European satellite network operators;
- Compliance of satellite equipment, including end-user terminals, placed on the European market with all relevant regulations, such as the Radio Equipment Directive 2014/53/EU;
- Administrative requirements imposed by the competent authorities to ensure that coordination with existing satellite and terrestrial networks is completed before authorisation is granted to the relevant satellite network;
- Certain aspects of satellite licensing are supranational, in particular the licensing of space-based components. Rights to operate a satellite network on specific frequencies and within a specific geographical area are, in principle, granted through the ITU on a ‘first come, first served’ basis;

BEREC therefore notes that each of these regulatory areas has a significant national dimension, which supports a case-by-case approach to satellite communications solutions for universal service.

In a survey conducted amongst EU countries, the majority of respondents stated that, within their countries, no changes to national regulations are required in the event of the use of new satellite technologies.

2 5G satellite communication architecture and technology

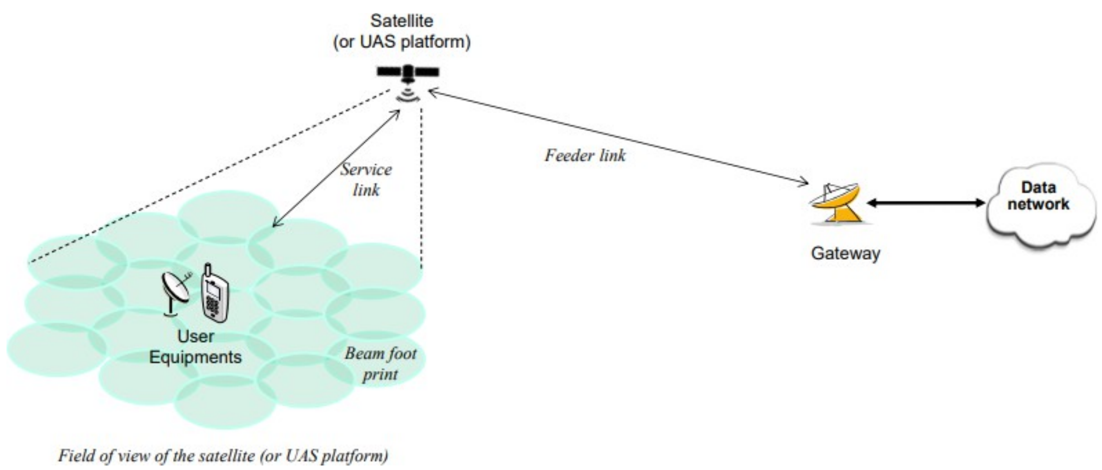
2.1 Methods of integrating satellite links into 5GS (RAN), overview of proposed architectures for the 5GS satellite segment

The integration of satellite links into the architecture of fifth-generation mobile networks (5GS) represents a key step towards ensuring global connectivity, extending coverage to remote areas and ensuring greater resilience of mobile networks. Satellite services can fulfil various roles within 5GS – ranging from providing direct access to end-users to interconnecting base stations as part of hybrid terrestrial-satellite solutions. The integration of NTN into the 5GS architecture also presents a number of technological challenges, particularly due to satellite movement, higher latency and specific atmospheric effects. This chapter focuses on an overview of NTN architectures and describes the key factors affecting their operation, such as latency, cell size and signal propagation in the atmosphere.

2.1.1 Non-Terrestrial Network (NTN)

Non-Terrestrial Networks (NTNs) are wireless communication networks that utilise non-terrestrial platforms, such as satellites, located in various orbits (LEO, MEO, GEO), or unmanned aerial systems (UAS) situated at altitudes of 8–50 km above the Earth's surface (including high-altitude platforms (HAPs) situated at altitudes of 20–50 km). These platforms are used to provide telecommunications services in areas where traditional terrestrial networks do not provide coverage. NTNs are a key component of modern 5G and future 6G technologies, as they enable global connectivity in remote areas, over oceans or in emergency situations[3].

Figure 1: Basic diagram of an NTN



Source: 3GPP

[3] 3GPP NTN Overview

Payload architecture

A concept used primarily in the field of satellite and telecommunications systems to describe the structure and organisation of a device's main functional elements. The payload is the part of a satellite that serves its primary purpose – such as transmitting signals, imaging the Earth or conducting scientific measurements – and sends these signals or measurements back to Earth.

- **Transparent**

In this case, it refers to a space/aerial platform without the capability for independent processing, which changes the carrier frequency of the received RF signal on the uplink, filters it and amplifies it before transmitting it on the downlink; in other words, the platform functions as an analogue RF repeater, with signal processing taking place at the ground station.

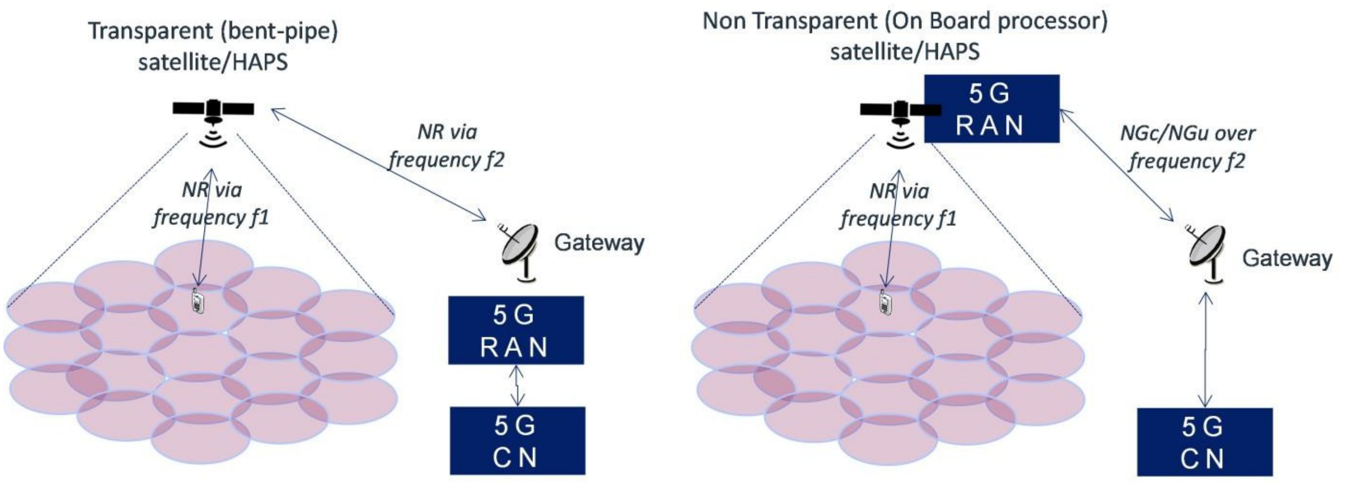
- **Regenerative**

A space/aerospace platform which, in addition to RF filtering, frequency conversion and amplification, also has its own processing capabilities (demodulation, decoding, switching, routing), meaning that this platform incorporates base station functions and thus offers much more flexible services. This architecture is particularly suitable for inter-satellite links, as it eliminates the need for frequent switching between ground stations when relaying signals.

- **Hybrid**

A combination of the two previous methods. Some, mostly simpler, operations are carried out directly on the satellite, whilst more complex operations take place at the base station. In this way, greater efficiency and flexibility of the entire system can be achieved.

Figure 2: Transparent and Regenerative Models



Source: 3GPP

Compared to terrestrial networks, non-terrestrial networks have a number of characteristics that require appropriate adaptations:

- **Movement of space/aerial platforms**

  In this respect, GEO satellites behave similarly to terrestrial network equipment, given their stable position relative to the Earth's surface. LEO and MEO satellites, by contrast, move at high speeds. Due to this rapid movement, the coverage area (cell) is constantly shifting, signals experience varying delays, and there is a greater change in frequency (known as the Doppler effect). To cope with this, the network uses advanced methods to track the position of satellites and predict which beam will best cover users on the ground.

- **Altitude**

  Compared to ground-based stations, satellites operate at much greater distances from the UE, which increases connection latency due to the longer signal propagation delay. Ground-based transmitters are capable of achieving latencies of less than 1 ms, whilst GEO satellites achieve values of several hundred ms.

- **Cell size**

  NTN networks have much larger cell sizes than terrestrial stations, which in turn can lead to greater variation in signal propagation delay and the near-far effect, whereby a signal further away from the receiver (NTN) is overwhelmed by a signal closer to the receiver (terrestrial).

- **Effect of the troposphere**

  Relevant in the lower parts of the atmosphere below 12 km. For frequencies above 6 GHz in these regions, signal absorption and interference may occur, caused by various atmospheric effects.

- **Effect of the ionosphere**

  Relevant in the upper parts of the atmosphere above 80 km. For frequencies below 6 GHz in these regions, signal absorption or reflection may occur, caused by various atmospheric effects.

2.1.2 Network Function Virtualisation (NFV) and Slicing

Network Function Virtualisation (NFV) and Slicing are functionalities whose integration into terrestrial networks will play a key role in interoperability with NTN and in expanding the applicability of combined 5G-NTN networks.

Network Function Virtualisation is the process of moving functions that were previously hardware-only (e.g. data encryption, routing) into a fully virtual environment. This process significantly helps to reduce operating costs and optimise the provision of these network services. The use of NFV thus creates a network of functions that is highly scalable and adaptable compared to a hardware-based solution. With the advent of 5G wireless technologies, there are opportunities to utilise NFV in an ever-increasing number of areas, the main ones including, for example, autonomous vehicles, smart grids and industrial robotics. Some technology companies (e.g. Allot[4]) operating in the telecommunications sector have already launched their own NFV interfaces designed to streamline the deployment, operation and management of network services and operational processes.

The NFV architecture defines the key elements and interfaces for the operation and management of virtualised network functions. The European Telecommunications Standards Institute's (ETSI) Network Functions Virtualisation Industry Specification Group has established an initial open-source NFV framework. Other organisations have also contributed to the development of NFV, but the basic architecture remains the same and consists of three main layers[5]:

4 Allot NFV

5 What Is Network Functions Virtualisation (NFV)? | IBM

- **Virtualised Network Functions (VNFs)**

VNFs are services that previously ran on physical hardware. Routing, firewalls, IP configuration and intrusion detection systems, SD-WAN systems and file-sharing programmes are common types of virtualised network functions.

Through virtualisation, these services can be interconnected in a process known as ‘service chaining’. Service chaining helps network operators automate the provisioning of resources for each service on the network. A centralised overview of all functions gives operators greater control over the network and enables them to route traffic and workloads to available servers, thereby reducing the risk of service outages.

- **Network Functions Virtualisation Infrastructure (NFVI)**

NFV infrastructure consists of servers, storage, switches and the computing resources required to create an NFV environment. To abstract network functions from the physical hardware, network operators create a virtualisation layer using software known as a hypervisor. A hypervisor, or virtual machine monitor (VMM), creates a software layer capable of partitioning a single physical machine into multiple virtual machines. These virtual machines can run simultaneously alongside one another on their own operating systems. NFVI provides the connectivity to create a unified network comprising multiple physical and virtual machines.

- **Management, Automation and Network Organisation (MANO)**

NFV MANO is the fundamental framework for managing the deployment, provisioning, monitoring and performance of virtualised network functions. NFV MANO also provides an interface for the NFVI to communicate and interact with existing Operations Support Systems (OSS) and Business Support Systems (BSS).

Slicing

In 5G, NFV enables network slicing – an aspect of virtual network architecture that allows multiple virtual networks to be created on a shared physical infrastructure. These virtual networks can then be tailored to the needs of applications, services, devices, customers or operators. In 5G, NFV also enables a distributed cloud, which helps to create flexible and programmable networks to meet the needs of modern technologies.

NFV enables the virtualisation of 5G, so that the physical network can be divided into multiple virtual networks, which can support different radio access networks or different types of services for specific customer segments. Parts of the network will be isolated from one another at the control and user planes, so that the user experience will be the same as if it were a physically separate network.

2.1.3 Direct Satellite Access

The next step in integrating satellite services into 5G technology is the ability to connect satellites in low Earth orbit (LEO) directly to end-user devices on the Earth’s surface.

As part of testing 5G NTN connectivity, the European Space Agency (ESA), in collaboration with Telesat and Amarisoft, successfully established this connection in the Ka-band (27–40 GHz). In the past, this was only possible in combination with a GEO satellite. A key innovation of this experiment was the use of open standards developed by the international organisation 3GPP, rather than proprietary waveform technology. The successful connection with a LEO satellite marks a significant step forward in the development of 5G technologies and paves the way for further progress, whereby in the future anyone could be able to connect to these satellites using, for example, their mobile phone (a scenario known as ‘direct-to-device), which could reduce the cost and complexity of terrestrial infrastructure and increase interconnectivity between different providers. In theory, this technology enables seamless switching between terrestrial networks and satellites, ensuring uninterrupted coverage regardless of whether you are in a city centre or a remote and inaccessible area.[6]

The outlook for the coming years suggests that prices for Direct Satellite Access (DSA) devices will continue to fall as production volumes increase and competition intensifies. The involvement of major manufacturers and the standardisation of the technology are key

---

[6] ESA – World’s first direct 5G connection to a low Earth orbit satellite heralds a new era for mobile coverage

factors that are already pushing this once-exotic functionality towards the mainstream. Analysts point to "the emergence of satellite-enabled mobile devices from major manufacturers such as Apple, Qualcomm, Motorola, MediaTek, Huawei and ZTE, signalling the penetration of satellite services into the mainstream consumer market"[7]. It is precisely competition and standardisation that will lead to cost reductions. Chip manufacturers are working on the 3GPP NTN (Non-Terrestrial Networks) standard, which will enable phones to communicate with various satellite networks using standard modems. It is expected that new generations of chipsets will integrate NTN support directly, without the need for proprietary solutions. Experts emphasise that "the openness of standards is what will enable the mass adoption of direct satellite services for devices"

A parallel can be drawn with the advent of 5G to illustrate the potential for the expansion and penetration of this technology. The fifth generation of mobile networks also initially suffered from high device costs and limited availability. The first 5G phones (in 2019) cost over a thousand dollars and appealed only to a narrow circle of enthusiasts. The turning point came in 2020, when Apple launched the 5G-enabled iPhone 12 – which, on its own, rapidly increased the share of 5G phones from 2 per cent (2019) to nearly 20 per cent during 2020. Premium models led the initial wave (in 2020–21, growth was driven by more expensive phones). However, truly mass adoption of 5G only came once prices fell and the technology reached the mid-range market. According to Canalys[8] analysis, by the end of 2021, a third of all 5G phones shipped cost less than $300. Since then, 5G has become the standard: in the first half of 2024, two out of every three new smartphones sold globally were 5G. The average price of 5G phones has fallen by more than 30 per cent since 2019, and 5G models can now be purchased for under 5,000 thousand crowns. This affordability, combined with sufficient market penetration, has then motivated operators to provide widespread 5G coverage, thereby firmly establishing the technology.

We can expect a similar development for direct satellite access. First, a certain percentage of users needs to have compatible devices – penetration of around 10–20 per cent is likely to be sufficient for DSA services to be viable on a wider scale. This point could be reached by the end of this decade, provided the pace of integrating satellite modules into phones continues.

2.2 Types of satellites by orbital altitude and their key parameters for integration into 5GS

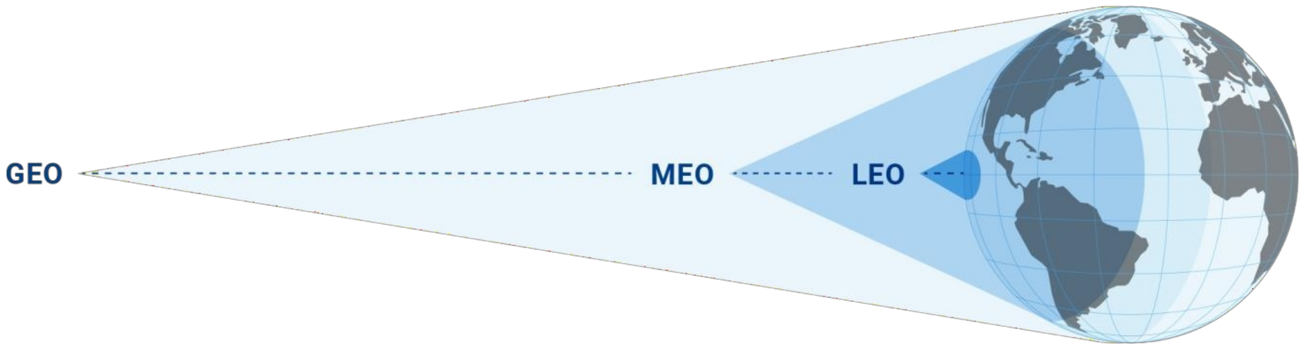
Satellites are primarily classified as GSO (GEO) and NGSO (MEO and LEO) based on their orbital motion relative to the Earth's rotation and, respectively, to receiving antennas on the Earth's surface. GSO satellites are positioned at an altitude and move at a speed such that they track the Earth's rotation and are therefore always in the same position relative to the antenna pointed at them. In contrast, NGSO satellites are located at different altitudes and their speeds also vary; consequently, the time it takes them to complete a full orbit differs. For MEO satellites in medium Earth orbit, the orbital period is between 2 and 12 hours; for LEO satellites in low Earth orbit, this period is approximately 90–120 minutes[9].

[7] Satellite-enabled mobile devices – Apple, Qualcomm, Motorola, MediaTek, Huawei and ZTE

[8] Global smartphone market 2021 forecast

[9] GEO, MEO, and LEO – Via Satellite

Figure 3: Diagram of satellite orbital altitudes and their coverage range



Source: EuroSkyPark

- **GEO satellites**

GEO satellites adjust their movement to match the Earth's rotation, so that they remain constantly above the same point on the Earth's surface. There are currently hundreds of GEO satellites in orbit, which traditionally provide services such as weather data, television broadcasting and some low-speed data communications. In recent years, the GEO constellation has been significantly expanded to include high-throughput satellites (HTS), which are specifically designed for data transmission. Satellite traffic in this orbit is not particularly dense; thanks to their sufficient distance from Earth—which is around 36,000 km—these satellites are able to cover approximately one-third of the Earth's surface, thus offering a much wider coverage area than MEO and LEO satellites; however, due to their distance from Earth, the two-way connection latency is around 500–700 ms – many times higher than for other types of satellites – which is a significant drawback for modern technologies and services that rely on very fast internet connections.

- **MEO satellites**

Medium Earth Orbit (MEO) encompasses a large number of individual orbits; this category covers distances ranging from 2,000 to 36,000 km from Earth. In the past, MEO satellites were used primarily for GPS and other navigation applications. More recently, HTS MEO constellations have been deployed to provide low-latency, high-bandwidth data connections to service providers, government agencies and commercial enterprises. Compared with GEO and LEO satellites, MEO offers a compromise between latency and coverage area, with two-way latency ranging from 30 to 120 ms. Given the wide range of different orbits and their corresponding distances from Earth, the coverage area of individual satellites also varies significantly; most satellites (particularly those used for GPS systems) are located at an altitude of 20,350 km in a so-called semi-synchronous orbit (SSO), in which they orbit the Earth in exactly 12 hours.

MEO satellites provide fibre-optic-like performance to remote areas where laying fibre-optic cables is impractical, for example in the case of commercial maritime and air transport, offshore platforms, network redundancy and stability in difficult terrain, and humanitarian operations.

- **LEO satellites**

Compared with previous types of satellites (particularly GEO), these are much smaller satellites orbiting at lower altitudes, ranging from 500 to 1,200 km. Thousands of LEO satellites are currently in operation, primarily for scientific purposes, imaging and low-bandwidth telecommunications. The new generation of HTS LEO satellites is intended to serve communications markets, such as broadband internet for mass consumption and businesses. Thanks to their position in low Earth orbit, these satellites provide internet connectivity with very low two-way latency of 20–50 ms, which is more than 10 times lower than that of GEO satellites. Such extremely low latency is particularly important for applications requiring real-time communication, such as voice and video conferencing, certain financial transactions and modern technologies utilising, for example, the IoT.

Over the last few years, major technology companies such as SpaceX, OneWeb and Amazon have been investing increasing amounts of resources into LEO satellites and their further development to make various services and technologies accessible, such as broadband connectivity, high-speed internet access, remote sensing and satellite communications. In addition to these major players, there are many smaller companies that often specialise in specific technologies or applications and can offer more targeted or specialised services.

When deploying LEO and MEO satellites as part of a stable 5G network, the satellites in a given orbit need to be combined into large constellations that are interconnected and, together, provide coverage of the entire Earth's surface. In this respect, GEO satellites offer the advantage of being able to cover a much larger area using a small number of satellites; however, this advantage is currently overshadowed by other disadvantages of these satellites, particularly high connection latency.

2.3 Overview of the frequency bands used by 5G satellite technology and their potential interference with terrestrial communication bands, with a specific focus on spectrum allocation in the Czech Republic

With the advent of 5G satellite technologies comes the question of which frequency bands are best suited for this application. Based on the 3GPP release, these bands have been divided into two main groups:

- **FR1 (low-frequency bands)**, covering frequencies up to 7 GHz in the range 410–7,125 MHz

Thanks to their lower frequencies, this group offers better coverage and signal penetration through various obstacles (atmospheric, as well as building walls, etc.). This capability enables them to cover large areas with a very stable signal; they are therefore well-suited for covering densely populated areas, as well as remote and hard-to-reach areas. As some frequency bands in this category are currently used in GPS systems and mobile networks, the FR1 band offers better integration with existing terrestrial networks, thereby reducing the costs of integrating terrestrial 5G RAN with satellite NTN technologies. Conversely, these frequencies achieve much lower capacity and data transfer rates compared to FR2, which may be problematic, particularly in densely populated areas where there will be a large number of simultaneously connected devices. Furthermore, the bands in the FR1 group are more frequently used by other technologies; it is therefore necessary to take adequate measures to ensure proper spectrum sharing with other terrestrial services in these bands and to prevent mutual interference.

Of particular importance in this group is the MSS band (1980–2010 MHz / 2170–2200 MHz; 2×30 MHz), currently used for satellite connectivity to provide ECS services on board aircraft. In addition, the band may also be used by terrestrial stations that boost the satellite downlink signal via stations located on Earth (CGC). The current licences for MSS operators (Inmarsat, now Viasat, and EchoStar) are due to expire in May 2027. The RSPG, as an advisory body to the European Commission, has therefore drawn up recommendations on MSS for the Commission in the form of an RSPG Opinion, which was subject to public consultation[10]. The document strikes a balance between, on the one hand, protecting the investments of existing users of the band (licence holders) and, on the other hand, responding to new (both European and global) needs for hybrid terrestrial and satellite communications. It is evident from the public consultations and other discussions within the EU, CEPT and ITU-R[11] (we refer here to WRC-27 items 1.12, 1.13 and 1.14) that the potential for new satellite networks in medium (MEO) or low (LEO) Earth orbits is relatively high. The aforementioned RSPG Opinion responds to these needs and presents several scenarios for the possible allocation of frequencies, without, however, prejudging the procedural steps to be taken by the Commission (extension of licences, possibly with a change in conditions, or a tender procedure for the entire band). One of the scenarios indirectly takes into account the delay in the network roll-out of one of the licence holders and considers narrowing

[10] RSPG Opinion on the assessment of different possible scenarios for the use of the 1980–2010 MHz and 2170–2200 MHz frequency bands by Mobile Satellite Services beyond 2027

[11] ITU-R Preparatory Studies for WRC-27

of the existing spectrum for licence holders with the aim of freeing up frequencies for new spectrum users (e.g. 2×5 MHz). To prepare for the tender process, the Commission has established an MSS committee within COCOM, which is discussing proposals for further procedural steps in this matter.

- **FR2 (millimetre waves)**, covering frequencies in the 24.2–52.6 GHz range.

The FR2 band offers, in particular, high-speed data transmission and relatively low latency. This capacity is made possible by the available spectrum width and range of bands, as well as the relatively lower congestion of these bands by various other mobile technologies. The high frequencies in this band allow for the use of advanced technologies such as massive MIMO, frequency division multiplexing and beamforming, which enable adaptive bandwidth allocation according to user needs and thus further improve the efficiency of these frequency bands. The main disadvantage, however, is the very limited range of these services, due to the shorter wavelengths, which are also highly sensitive to weather conditions during transmission. Satellite services therefore require much greater investment in a denser network of satellites and transmitters to ensure stable transmission.

The optimal solution for satellite 5G networks is to utilise the strengths of both frequency bands – FR1 for wide-area coverage and FR2 for high-speed and high-capacity requirements.

Table 1: NR NTN satellite bands defined according to 3GPP

Edition 3GPP	NR band	Uplink (UL) / Downlink (DL)	Current allocation in the Czech Republic	Note
Rel-17	n256 (S-band, FR1, FDD)	1980–2010 MHz / 2170–2200 MHz	Mobile Satellite Service (MSS), 2 × 30 MHz, secondary use by radar systems	In close proximity to the terrestrial band n1 (2100 MHz), primarily for HAPs (at lower altitudes).
Rel-17	n255 (L-band, FR1, FDD)	1626.5–1660.5 MHz / 1525–1559 MHz	Mobile satellite service, secondary use by various services including non-civilian services; in the downlink, priority is given to maritime distress communications (GDMSS).	
Rel-18	n254 (LS band, FR1, FDD)	1610–1626.5 MHz / 2483.5–2500 MHz	Band used primarily for aeronautical navigation, shared with other services; downlink primarily for industrial, scientific and medical applications.	The downlink is in close proximity to the terrestrial band n7 (2600 MHz).
Rel-18	n512* (Ka-band, FR2, FDD)	27.5–30 GHz / 17.3–20.2 GHz	A band used for both fixed and mobile satellite services.	
Rel-18	n511* (Ka-band, FR2, FDD)	28.35–30 GHz / 17.3–20.2 GHz	A band used for both fixed and mobile satellite services.	
Rel-18	n510* (Ka-band, FR2, FDD)	27.5–28.35 GHz / 17.3–20.2 GHz	A band used for both fixed and mobile satellite services.	

**still under discussion*

Source: Compiled by the author based on data from the Czech Telecommunications Office (ČTÚ)

2.4 Other RAN technologies, combined with satellite transmission – conditions and benefits

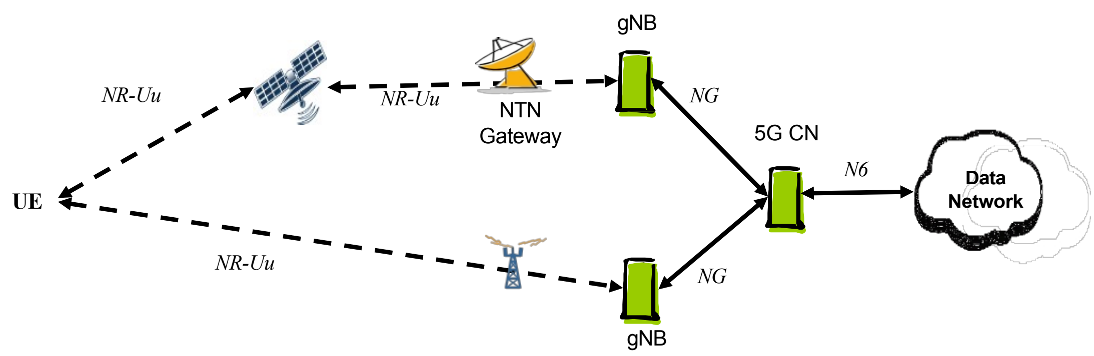
2.4.1 Multi-connectivity incorporating NG-RAN technologies based on NTN

In underserved areas, the bandwidth provided by terrestrial access (e.g. LTE) at the cell edge may be limited. Adding an NTN-based NG-RAN network will enable the target data transmission speed to be achieved. In a number of service scenarios (e.g. users in residential buildings, in vehicles, on high-speed trains or on board aircraft), utilising an appropriate combination of terrestrial and non-terrestrial access would achieve the target service performance in terms of data transmission speed and reliability.

Each device could thus be connected simultaneously to at least:

- **One NTN-based NG-RAN access and one terrestrial access**

Figure 4: Multi-connectivity via a combination of NTN and terrestrial access

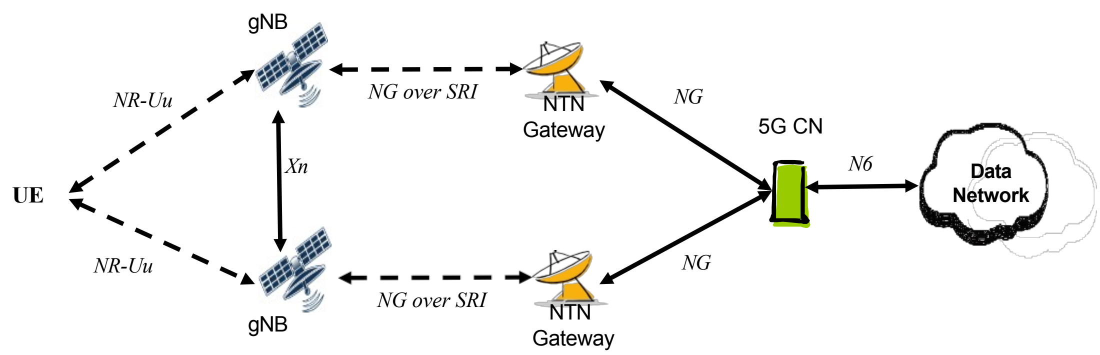


Source: 3GPP

- **Two unique NG-RAN approaches based on NTN**

LEO-based NTN NG-RAN, with its relatively low latency, can be used to support delay-sensitive traffic, whilst a GEO-based NTN NG-RAN network would provide additional bandwidth to meet target throughput requirements. In the transparent model, satellites are used solely for data transmission; in the regenerative model, satellites are capable of processing and modifying the signal, as well as communicating with other satellites within large constellations.

Figure 5: Multi-connectivity via a combination of two NTNs



Source: 3GPP

2.4.2 Multi-orbital approach

One of the key factors for reliable data transmission when using 5G technologies is latency. Among satellite technologies, LEO satellites are considered the best option; however, their disadvantages include, for example, limited coverage area. One possible solution to these problems in the future could be to link satellites in different orbits, providing a combination of the high-speed transmission of LEO satellites and the transmission capacity, as well as the wider coverage area, offered by MEO and GEO satellites.

An experiment to test the feasibility of this concept was carried out under the auspices of the ESA, involving several research centres across Europe. The aim of the experiment was to conduct a video call using a combination of terrestrial and satellite (LEO and GEO) connections. During the experiment, the call connection passed through four different satellite networks and three different terrestrial networks, whilst maintaining a stable, high-quality connection throughout. The success of this experiment holds potential for further research and innovation in the field of technologies combining terrestrial and satellite communication networks.[12]

[12] ESA – Multi-orbit connectivity tests

3 Technological developments in satellite 5G

3.1 Overview of activities (studies) on satellite communications within 3GPP (Rel 15–17–19), ETSI and ITU-R, and the EU's position

Satellite communications have become a key component in the development of 5G and future 6G networks. Given that satellite networks enable the extension of coverage to remote areas, ensure connectivity during disasters and support new applications, they are receiving significant attention within standardisation organisations. The main players in this field include 3GPP, ETSI and ITU-R, which focus on various aspects of the integration of satellite and terrestrial mobile networks.

This chapter summarises key activities and studies within 3GPP, ETSI and ITU-R in the field of satellite communications, focusing on individual 3GPP Releases and related standards. The conclusion of the chapter also includes the EU's position in relation to the regulatory activities mentioned.

3.1.1 3GPP activities in the field of satellite communications

The 3rd Generation Partnership Project (3GPP) plays a key role in the standardisation of non-terrestrial networks (NTNs) by integrating satellite and high-speed platforms into the architecture of mobile networks. Through its technical working groups, 3GPP develops specifications for NTNs with the aim of ensuring their seamless interoperability with terrestrial mobile networks. Key areas of standardisation include mobility management, frequency synchronisation, regenerative satellite relays and direct satellite connectivity for end-user devices. These activities enable global broadband coverage, IoT connectivity and a resilient communications infrastructure for remote and underserved areas.

3.1.1.1 Release 15

Release 15 was the first 5G standardisation release to focus primarily on terrestrial networks, whilst support for non-terrestrial networks (NTN) was not fully included at this stage. Nevertheless, as part of the 'Study on NR Support for Non-Terrestrial Networks' (FS_NR_nonterr_nw – TR 38.811), the potential use of NTNs was analysed, the 3GPP channel model was adapted, and possible deployment scenarios were defined, including GEO and LEO satellite networks and HAP platforms in various frequency bands. NTN was identified as a key element for extending broadband connectivity (eMBB) to remote areas, ensuring connectivity for mobile platforms (aircraft, ships, trains), providing network resilience (e.g. during disasters) and enabling multicast/broadcast services. For mMTC, NTN was considered as a solution for the global interconnection of IoT devices, including the direct connection of sensors to the satellite network or via base stations. The study identified four main deployment scenarios, involving GEO and LEO satellites in the S and Ka bands, whilst considering both transparent and regenerative data transmission options. These concepts laid the foundation for the further development of NTN within Release 16 and subsequent versions.

3.1.1.2 Release 16

Release 16 laid the foundations for the integration of non-terrestrial networks (NTNs) into 5G by identifying 12 key use cases:

- Roaming between terrestrial and satellite networks
- Broadcasting and multicast with satellite overlay
- Internet of Things with a satellite network

- Temporary use of satellite components
- Optimal routing or control via satellite
- Cross-border continuity of satellite services
- Global satellite coverage
- Indirect connectivity via a 5G satellite access network
- Fixed 5G backhaul between NR and the 5G core
- 5G Moving Platform Backhaul
- 5G to Premises
- Satellite connection between a remote service centre and an offshore wind farm

The study focused on transparent and regenerative satellite architectures in GEO and LEO scenarios, where satellites either merely relay the signal (transparent mode) or function as an active component of the radio access network (regenerative mode). Furthermore, multi-connectivity scenarios were analysed, where a single device can be simultaneously connected to both a satellite and a terrestrial network, or to two satellites at the same time. Key NTN challenges at this stage included high signal latency, uplink synchronisation, management of handover between satellite and terrestrial networks, and beam-to-beam interference management.

The study resulted in recommendations for improving time synchronisation, managing handover between cells, and optimising access methods such as PRACH and HARQ for NTN scenarios. Improvements to the MAC, RLC and PDCP protocols were also proposed, including strategies for cell selection and reducing service interruptions during handover between satellites. The RAN3 Working Group recommended focusing standardisation work on transparent GEO satellite access and LEO satellites with both transparent and regenerative links, thereby laying the foundations for the further development of NTN in Releases 17 and 18.

3.1.1.3 Release 17

Release 17 introduced the first normative requirements for non-terrestrial networks (NTN) within the 3GPP specifications and significantly expanded support for satellite access in 5G. Key requirements in TS 22.[26113] include service continuity between satellite and terrestrial networks, roaming between these access modes, and optimised network selection based on operator policies. Furthermore, the user location tracking system was extended to enable positioning via satellites for the purposes of traffic routing or emergency calls. Release 17 also introduced support for low-power IoT devices (MIoT) in satellite networks and enabled the use of inter-satellite links, thereby improving overall coverage and connectivity. As part of mobility management, conditional handover (CHO) between satellites and terrestrial networks has been implemented, enabling more efficient transitions between cells at different orbital altitudes.

At the architectural level, SA2 defined 10 key challenges in the integration of NTN into 5G:

- Mobility management with extensive satellite coverage areas
- Mobility management with moving satellite coverage areas
- Satellite latency
- QoS with satellite access
- QoS with satellite backhaul
- RAN mobility with regenerative satellite access based on NGSO
- Multi-connectivity with satellite access
- Multi-connectivity with hybrid satellite/terrestrial transmission
- The role of satellite links in content distribution towards the network edge
- Regulatory services with a transnational satellite ground station

Two new frequency bands (n255 in the L-band and n256 in the S-band) have been introduced, and band n1 has been designated for HAPs operations. Synchronisation and Doppler control have been improved using network ephemerides and correction mechanisms in both the uplink and downlink. Rules for switching services and feeder links between satellites have been defined, enabling more efficient use of orbital networks. Release 17 thus laid the foundations for a fully integrated NTN in 5G, paving the way for future improvements in Releases 18 and 19.

[13] ETSI: Service requirements for the 5G system (3GPP TS 22.261 Release 16)

3.1.1.4 Release 18

3GPP Release 18 focuses on the further development of non-terrestrial networks (NTN) within the 5G standards. A key component is the NTN self-assessment for IMT-2020, which includes support for 5G connectivity via satellite using NR and LTE (NB-IoT/eMTC). In collaboration with ITU-R, two variants of the specifications have been proposed:

- NR NTN (NR satellite access)
- IoT NTN (NB-IoT/eMTC satellite access)

The study analyses scenarios for eMBBs, HRCs and mMTCs in rural areas, and the results are recorded in document TR 37.911. The RAN4 working group has specified support for a 30 MHz channel bandwidth in the L/S bands for satellite access, reflecting ITU-R requirements. Furthermore, within the RAN2 working group, support for user equipment (UE) location verification in NTN has been extended, which is important for meeting regulatory requirements in various countries, for example for warning systems or emergency calls (PPDR systems).

Other significant changes in Release 18 relate to mobility management, the optimisation of paging mechanisms, and energy savings in situations of intermittent coverage, which occur in satellite networks, particularly in NGSO (non-geostationary) constellations. Working Group SA3 addressed security aspects, in particular the trustworthiness of satellite data sources for mobile network cores (5GC/EPC). Other key amendments include support for the new FDD NTN band (n254) and the extension of NR NTN to the Ka band (20–30 GHz). Working Group SA2 examined satellite backhaul and its potential for edge computing, including data transmission between users without the need for ground-based infrastructure. Release 18 also includes studies focusing on the pricing of NTN services, including charges for access to the satellite network and inter-operator payments for data transmission via satellites.

3.1.1.5 Release 19

Release 19 focuses on the further development of non-terrestrial networks for the Internet of Things and the expansion of satellite communications within 5G systems. The main objectives include improving downlink and uplink coverage and capacity in FR1-NTN and supporting regenerative payload modes (see 2.1.1)[14], which will enable 5G system functions directly on board satellites. In addition, the capability for device-to-satellite communication (UE-Satellite-UE) will be introduced, eliminating the need for a connection to a terrestrial network and reducing latency and the load on transmission resources. To ensure better positioning accuracy and communication without GNSS receivers, the positioning method and support for GNSS-independent operation will be improved. At the network management level, improvements are planned for mobility coordination and ensuring service continuity between satellite and terrestrial networks, including support for mission-critical services and new deployment models. Documentation of these studies and results will be included in a series of technical reports (e.g. TR 23.700-29 and TR 28.874).

3.1.2 ETSI activities in the field of satellite communications

The European Telecommunications Standards Institute (ETSI) is a key player in the development of standards for non-terrestrial networks (NTN), which are essential for future wireless communications. With the growing focus on 6G networks (IMT-2030), ETSI is concentrating on ensuring the seamless integration of satellite and high-altitude platform (HAP) communication technologies into terrestrial mobile networks. The ETSI conference on non-terrestrial networks, held in April 2024, confirmed the importance of NTNs for the future of global connectivity. In collaboration with key industry partners, ETSI has identified several key market segments where NTNs play a vital role, including the consumer market, where NTNs extend mobile coverage to remote areas and enable seamless satellite connectivity for smartphones, wearable devices and other mobile systems. NTNs also have significant applications in the enterprise sector, where they provide reliable connections for businesses operating in rural and poorly covered areas, and in specialised sectors such as aviation, maritime transport, defence and emergency services, which benefit from the global reach and resilience of NTNs. NTNs also play a key role in expanding broadband connectivity, particularly in remote and underserved areas, and are essential for the Internet of Things (IoT) and machine-to-machine (M2M) communication, enabling the global interconnection of sensors and automated systems.

---

[14] A satellite modulation technique featuring enhanced on-board processing capabilities (for demodulation/decoding, switching and/or routing, encoding/modulation), such that the space platform (satellite) incorporates base station functions on board.

To support the 6G vision of a fully connected world, ETSI emphasises the development of NTNs to ensure service continuity and network resilience, enabling a seamless transition between terrestrial and satellite networks. ETSI is working to make NTNs a native part of 6G, thereby reducing energy consumption, improving network reliability and supporting new technologies. To achieve this goal, ETSI is working closely with 3GPP and the ITU to define the technical framework for NTNs in 6G. The forthcoming 3GPP Releases 20 and 21 will lay the foundations for the integration of satellite systems into terrestrial networks, with standardisation efforts focusing on interoperability, spectrum coordination and adaptive radio access. Through its collaboration with the ITU, ETSI is seeking to establish NTN as a key component of IMT-2030, which will shape regulatory and spectrum policies.

3.1.3 ITU-R activities in the field of satellite communications

Proper technical and regulatory conditions are essential, given that WRC-27 (e.g. agenda items 1.[1315] and 1.[1416], based on Resolutions 253 and 254) will identify potential new frequency allocations for mobile satellite services; it is therefore necessary to ensure equitable access to spectrum that will support the development of a range of radio networks accessing the same frequency bands.

Resolutions 253 and 254 (from WRC-23) focus on studies of new frequency allocations for the mobile satellite service (MSS) with the aim of enabling direct connection of IMT equipment to satellite networks and expanding capacity for NTN within IMT systems. ITU-R is analysing the spectrum requirements and regulatory aspects for MSS, with an emphasis on compatibility with existing fixed and mobile networks and the potential for spectrum sharing with terrestrial services. The studies cover the 694 MHz – 2.7 GHz bands and, specifically, 2 010–2 025 MHz (Earth-to-space), 2 160–2 170 MHz (space-to-Earth) in Regions 1 and 3 (the Czech Republic belongs to Region 1) and 2 120–2 160 MHz (space-to-Earth) in all regions. ITU-R is investigating ways to minimise interference and the technical aspects of integrating MSS into IMT networks, with the results to be presented at WRC-27, where a decision will be made on the allocation of new spectrum. The main objective is to support NTN as part of global IMT networks, primarily to ensure connectivity in remote areas and during emergencies.

3.1.4 Progress within the EU

There are currently proposals regarding the conditions for DSA services in IMT bands (4G, 5G), which are being discussed both from a technical perspective (CEPT and ITU-R, WRC-27 items AI 1.13; and, in bands outside the IMT bands, also items 1.12 and 1.14), and within the EU from the perspective of opportunities and competition law issues. New opportunities are therefore being considered in Europe, for example to provide coverage in certain areas without a mobile signal, whilst ensuring the protection of existing mobile networks and other radiocommunication services (e.g. the protection of scientific services, including radio astronomy). At present, there is no unified view amongst European countries on the short-term opportunities for utilising DSA in the IMT bands, and discussions are ongoing.

For any proposals common to the EU, it is essential to create the conditions for competition and cross-border coordination in situations where the operational areas of services extend beyond national borders. It is anticipated that the European Commission's decision on the 2 [GHz] MSS [band17] will provide the first insights in this area. However, this does not preclude, for example, testing of DSA services at national level or learning from the experience of other countries (an example being the collaboration between the UK's Vodafone and [AST18]).

---

[15] WRC-23 – Resolution 253

[16] WRC-23 – Resolution 254

[17] RSPG Opinion on the assessment of different possible scenarios for the use of the 1980–2010 MHz and 2170–2200 MHz frequency bands by Mobile Satellite Services beyond 2027

[18] Vodafone and AST SpaceMobile to set up a European satellite service business

4 Satellite 5G services and applications

4.1 Communication modes for which satellite communication offers advantageous characteristics

ITU-R Recommendation M.2514-0[19] defines three main usage scenarios within IMT-2020: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC) and ultra-reliable low-latency communication (URLLC). The satellite component of IMT-2020 supports satellite variants of the eMBB and mMTC scenarios, adapted to the specific parameters of satellite networks. Instead of URLLC, satellite communications are intended to provide High Reliability Communications (HRC), which is designed to meet specific requirements for availability and reliability.

According to the Recommendation, the satellite component of IMT-2020 may be used in the following applications:

- Network resilience through high availability combined with high reliability for HRCs
- Connectivity for transport
- Content distribution via broadcast or multicast to end devices
- Machine-to-machine communication.

4.1.1 Enhanced Mobile Broadband (eMBB)

The eMBB recommendation states: *"The use case for Enhanced Mobile Broadband (eMBB) in the context of the satellite component of IMT-2020 should support high-speed applications in rural and remote areas, in aviation and maritime environments, and in some cases also in suburban areas. Mobile terminals capable of maintaining communication whilst moving at high speeds should be supported in order to meet transport requirements and the needs of associated users. Specifically, the following use cases have been identified:"*

- **Continuity of coverage:** Moving pedestrians (smartphone users) should be able to maintain access to a wide range of communication services and applications even whilst moving into remote areas, for example whilst working remotely or engaging in leisure activities.
- **Connecting populations in areas with insufficient or no coverage**.
- **Connectivity for transport:** Buses, trains, vessels (recreational or cruise ships) and aircraft.
- **Public safety:** Provision of communication services (e.g. messaging, voice calls, video) for emergency services (e.g. firefighters, medical staff).

4.1.2 Massive Machine-Type Communications (mMTC)

'Massive Machine-Type Communications (mMTC) provided via IMT-2020 satellite components should be capable of serving a large number of dispersed, connected fixed or mobile devices across vast areas. These devices may be low-cost and have long battery life. Some typical use cases for mMTC scenarios in a satellite context are listed below:

[19] ITU-R Report M.2514-0

- **Automotive**: This may include traffic flow optimisation, vehicle diagnostics and safety status reporting.
- **Public services**: E.g. monitoring of oil/gas, energy/water supply infrastructure and wind farms.
- **Transport** (road, rail, maritime, aviation): Fleet management, asset tracking, digital information boards, remote road warnings.

4.1.3 High-Reliability Communications via Satellite (HRCs)

The scenario for high-reliability communications (HRCs) has specific requirements regarding availability and reliability. This means that this technology should primarily be used for transport safety and applications in critical sectors.

The document also sets out minimum operational requirements, which are subsequently tested in ETSI document TR 137 911[20].

4.2 Examples of NTN usage in 5G networks

Examples of the use of satellite communications in 5G networks were presented by 3GPP in its document TR 22.822. The main premise of this document is to support the continuity of 5G access via satellite access, which is also reflected in the use cases described below. **It is important to note that satellite networks are not primarily intended to function as a standalone component, but rather as a complementary service to terrestrial networks.** The characteristics of satellite networks allow these use cases to be divided into three main categories:

- **Service continuity:** The roll-out of terrestrial networks often focuses on covering the population rather than the entire territory, which creates areas where 5G services may not be continuously available, particularly for users on moving platforms such as cars, trains, aeroplanes or ships. The scenarios under consideration focus on ensuring seamless access to 5G services through a combination of terrestrial and satellite networks, including for entire fleets of such vehicles.

- **Service availability:** Terrestrial networks may not be available either for economic reasons (expected revenues do not reach the minimum break-even point) or due to emergency situations (e.g. earthquakes, floods) that cause temporary outages or the complete destruction of infrastructure. Some users in these ‘uncovered’ or ‘under-covered’ areas would like to use 5G services, which is only possible thanks to 5G satellite networks; examples of use cases include the Internet of Things for agriculture and critical infrastructure, public safety and home connectivity.

- **Service scalability:** Compared with terrestrial networks, satellite networks offer very wide coverage, which is effective for broadcasting or multicasting the same content across large areas, or directly to users’ devices. Satellite networks can also relieve the burden on terrestrial networks during peak periods by transmitting data during off-peak hours, for example when distributing rich TV content in formats such as 3D or Ultra High Definition.

4.2.1 Broadcast and multicast transmission with satellite coverage

Release 14 specified 3GPP enhancements enabling mobile networks to deliver television and multimedia services more efficiently using extended eMBMS broadcasting, including free-to-air and enhanced digital video transmissions. This approach can also be extended to satellite networks, which, thanks to their extensive coverage, enable the distribution not only of video content but of any digital content to multiple users, either in receive-only mode or in two-way mode. In a situation where a mobile network operator (MNO) provides television services in urban and suburban areas and growing demand is saturating its network, it utilises a satellite network operator (SNO) for extended coverage; users then receive content either

[20] ETSI – Technical Report 137 911

via the MNO, the SNO, or a combination of both. This enables the MNO to maintain the quality of its services even under increasing load, whilst system requirements include the optimisation of content delivery via the satellite network and the ability for user devices to utilise both satellite and terrestrial access simultaneously.

4.2.2 IoT utilising satellite networks

A 5G satellite network may consist of one or more low Earth orbit (LEO) satellites, which enable the connection of devices with limited radio and power capabilities, thereby providing global and continuous coverage. An Internet of Things (IoT) service provider that ensures connectivity across various mobile networks uses the satellite network as an extension of coverage to ensure geographical availability. An example is a situation where a fleet of vehicles transporting VIPs requires continuous monitoring of its location, but terrestrial 5G networks in the planned area are unable to provide such coverage. Thanks to the availability of a satellite network in the area without coverage, the vehicles' positions can still be tracked and reported to a security officer. To ensure stable quality of service, the 5G system must define the conditions for a seamless handover between the satellite and terrestrial networks.

4.2.3 Temporary use of satellite networks

In the event of a crisis, elements of the terrestrial 5G infrastructure may be partially or completely destroyed, thereby preventing access to the services normally provided by these networks. In such a scenario, a 5G satellite network covering the same geographical area can be utilised to enable basic communications (voice, messaging, email) for users with the necessary equipment. The satellite network will provide different users with separate network slices (network slicing), ensuring a guaranteed share of transmission capacity according to their role, whether routine or emergency. During the transitional period, until the terrestrial network is restored, the 5G satellite network provides the necessary connectivity for both civilian and emergency services, whilst the system must be capable of routing certain types of traffic via satellite access depending on the severity of the situation and the type of service.

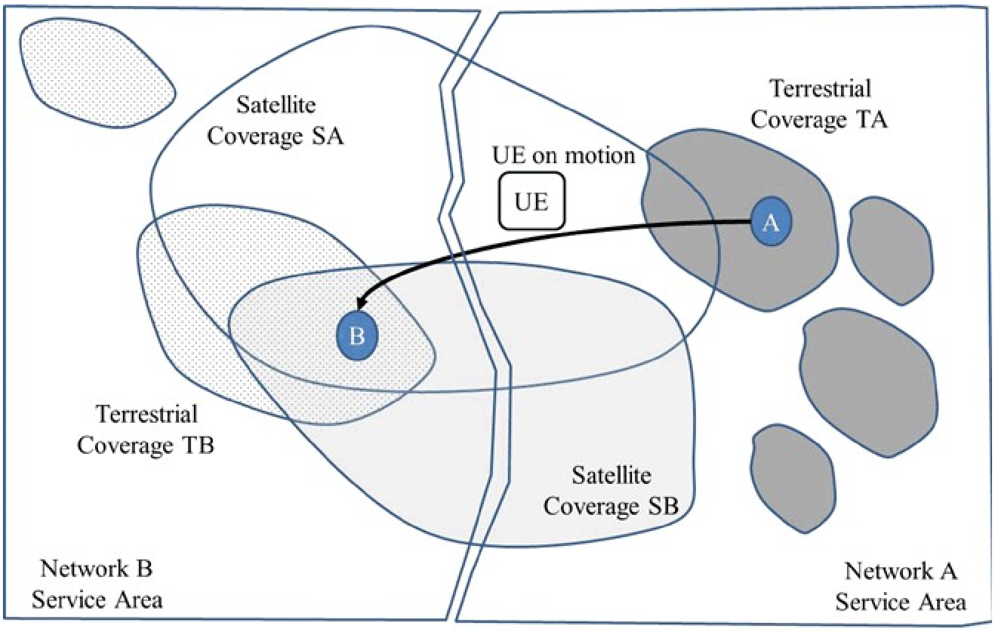
4.2.4 Optimal routing or control via satellite

Let us imagine the owner of two factories producing mechanical components using Additive Layer Manufacturing processes, one of which is located on the edge of the terrestrial 5G network's coverage area and the other in an area with no terrestrial connection at all. Both factories are almost fully automated and work with large and complex electronic files, the transmission of which places a strain on available communication capacity. Thanks to 5G coverage via the satellite network, the owner in question can optimise data transmission, thereby routing less time-sensitive transfers (e.g. uploading production files) via satellite, whilst low-latency services (e.g. video surveillance and machine control) utilise the terrestrial network where it is available. This approach enables the efficient use of available networks according to quality of service (QoS) requirements, whilst the system must be capable of intelligently combining terrestrial and satellite connections according to specific needs.

4.2.5 Continuity of cross-border satellite services

Hypothetical Operator TA in Country A and Operator TB in Country B operate their 5G terrestrial networks within individual areas in accordance with their deployment plans. Their coverage partially overlaps with that of satellites SA and SB, which also provide access to the TA and TB networks. The satellite component can function either as an extension of the terrestrial network, as access to the TA or TB core network, or as a standalone 5G network with roaming agreements. A user is travelling by train from the capital of Country A to the capital of Country B and wishes to remain connected to the internet throughout the journey. Their device first connects to the terrestrial TA network, but automatically switches to the SA satellite when coverage is lost. As soon as the train crosses the border and moves out of range of the TA network, the device remains connected via SA, or switches between SA and SB depending on availability. Upon returning to an area with terrestrial coverage, the device reconnects to the preferred network. This ensures that the user has seamless connectivity throughout their journey and can therefore remain connected to the internet without interruption. A 5G system supporting satellite access must be capable of managing user mobility, taking into account transitions between terrestrial and satellite networks. This entire scenario is illustrated in the figure below.

Figure 6: Cross-border continuity of satellite services



Source: 3GPP

4.2.6 Global satellite coverage

Due to physical limitations (e.g. the speed of light), significant latency can occur when transmitting data over long distances, which is a particular problem for applications demanding high speed and reliability, including high-frequency trading (HFT). As an alternative to optical networks, a global network of low-Earth orbit (LEO) satellites, equipped with base stations and interconnected via inter-satellite links, can be utilised to create an overlay network with low latency and high security. This network is suitable for organisations with globally distributed branches, such as stock exchanges in Paris, Tokyo and New York, which need to share trading data and place orders with minimal delay. For each connection, the optimal route is selected based on current latency and network load. This may be via a terrestrial or satellite path. This ensures the best possible quality of service for global connectivity, enabling the satellite overlay network to significantly improve performance where conventional networks fall short.

4.2.7 Indirect connectivity via a 5G satellite access network

In cases where users are outside the range of a terrestrial 5G network (e.g. on board aircraft or ships, in remote areas or during emergency operations), the 5G satellite network can provide connectivity via so-called relay devices (similar to Wi-Fi hotspots), i.e. user devices supporting satellite connectivity, which act as intermediaries for other, standard devices without direct satellite access. This indirect connection enables the provision of basic services such as data, messaging, voice and low-bandwidth video, even whilst on the move, when crossing national borders or in areas without a signal. Examples include a user utilising the connection during a flight, or an emergency services worker who, thanks to a device with satellite connectivity, is able to assist a missing person in real time in winter conditions. These scenarios require the management of roaming, security, load management of relay devices and the definition of the minimum services that can be provided in this way. The aim is to ensure that users with standard devices have access to services comparable to those they would have on a standard terrestrial 5G network.

4.2.8 Fixed 5G Backhaul between NR and the 5G Core

The model scenario involves two users living in two different small villages (Village A and Village B), which are approximately 5 km apart and are situated in a sparsely populated area where there is poor or no connectivity to modern communication services. Mobile operators have decided to erect a shared transmitter between the two villages, but due to the distance from the network core in the nearest town, C, they have opted for a satellite backhaul via the network of operator S, which has excellent coverage in the area. This allows the new tower to be brought into service quickly without the need for extensive construction work. The interfaces between the 5G radio access network (NR) and the network core are transmitted via the satellite link, enabling the provision of full-featured mobile services even in these rural areas. Both of these users can therefore enjoy high-quality mobile connectivity at home, just as they would in a city, and the successful trial deployment of mMTC at a nearby farm confirms the potential of this solution. The main advantage of satellite backhaul is the ability to rapidly provide coverage to hard-to-reach areas, although it is necessary to address higher transmission delays (latency), which may affect service quality and require certain adjustments to the network architecture.

4.2.9 Mobile 5G Backhaul Platform

The train operator (TO) is introducing a new 1,000 km high-speed line across the country and wishes to offer passengers entertainment services requiring high downlink capacity and minimal uplink capacity, as well as internet access for paying customers and the transmission of operational data for internal purposes. Although the TO has good agreements with mobile operators and most of the route is well covered, there is no mobile coverage along approximately 200 km in the centre of the country. The TO has therefore partnered with a satellite operator (SO) that provides high-quality nationwide coverage and high downlink capacity, and which also cooperates with mobile operators. As part of the solution, 5G base stations will be installed on trains. Content (e.g. entertainment services) can be provided to passengers via both terrestrial and satellite networks, and in areas without a terrestrial signal, connectivity will be provided exclusively by satellite. Frequently used content is stored locally to minimise latency. Passengers thus have access to services regardless of their location, and the entire system effectively combines different networks as required. To ensure quality, the 5G system must support satellite links between the radio access network and the network core and be able to handle the delays caused by satellite transmission.

4.2.10 5G to Premises

A high-altitude village, built in the 1970s in the foothills of the Krkonoše Mountains as a holiday resort near a ski lift, has, due to climate change, been transformed into a permanent settlement comprising around 80 houses. However, the infrastructure in the area has remained outdated; that is, the DSL connection is weak due to the distance from the exchange, and the mobile signal is inconsistent because of the hilly terrain. There is no cable connection here, but many households use satellite TV reception. A new satellite operator, S, has begun operating in the area and, in collaboration with mobile operator T, is offering improved services via a new home gateway that combines signals from both the satellite and terrestrial networks to provide high-quality Wi-Fi inside homes. The satellite component is used for broadcast/multicast content, whilst frequently accessed content is stored locally. Unicast communication is handled via the mobile network, and where the service does not require low latency, the satellite link may also be used. Operator T is also considering the possibility of having gateways located in favourable positions to cover neighbouring households in less favourable locations. The result is a significant improvement in service quality for residents, whilst the 5G system must support the delivery of broadcast/multicast services via the satellite component.

4.2.11 Less relevant use cases in the context of the Czech Republic

The document also mentions two further use cases which are less relevant to the Czech Republic. Specifically, these are (1) providing connectivity for maritime carriers on transoceanic voyages, where a combination of terrestrial and satellite services is used, along with other relay equipment where necessary (e.g. when tracking the location of a specific container), and (2) the use of satellite connectivity between the communication networks of offshore wind farms and an inland service centre, which enables remote monitoring and non-critical control of the wind farm’s operations via data-intensive real-time transmissions.

4.2.12 Examples of NTN applications in 6G networks

There are currently working groups focusing on the use of NTN in 6G networks, i.e. where current 5G technologies are reaching their limits. From a European perspective, this involves the 6G-NTN project, which is part of Horizon

Europe programme, which identifies and describes relevant use cases for satellite communications across various sectors and consumer segments with future 6G networks, whilst highlighting the limitations of current 5G NTN solutions. Specifically, these include the automotive, maritime transport, energy, drone, PPDR and direct end-user connectivity sectors. The reference document for this section is ‘Vision on Non-Terrestrial Networks in 6G systems (or IMT-2030)’, which sets out a vision for the integration of NTNs as a native component of 6G systems (IMT-2030).

According to the report, the main challenge for 6G-NTN is to ensure a seamless, high-performance 3D multi-layer network, with different use cases requiring distinct approaches. All use cases emphasise the need for optimal interconnectivity between all network components, taking into account cost and performance requirements. The use of NTN and the complementarity of TN-NTN is, to a certain extent, similar to that in 5G networks; however, it is anticipated that the distinctive features of the 6G standard will be utilised, in particular:

Table 2: Comparison of 5G and 6G within the NTN framework

Parameter	5G	6G
Maximum data rate	10 Gbps	1 Tbps
Maximum frequency range	W-band (<110 GHz)	<10 THz
End-to-end latency	10 ms	1 ms
Connection density	10^5 devices/km²	10^7 devices/km²
Maximum spectral efficiency	30 bps/Hz	100 bps/Hz
Mobility support	> 500 km/h	> 1,000 km/h
Satellite integration	Partial	Full
Artificial intelligence integration	Partial	Full
Support for autonomous vehicles	Partial	Full
AR/VR/MR support	Partial	Full
Haptic communication/control	Partial	Full
Key technologies/aspects	mmWave, small cells, mMIMO, beamforming, antenna arrays, use of non-terrestrial networks	THz spectrum, visible light communication (VLC), smart surfaces, data-driven automated processes

Source: Own compilation

Examples of applications where 6G is (currently) expected to contribute to efficiency and the further development/innovation of services fall primarily into the following areas, in which research and development based on current 5G technologies is already underway:

- Autonomous inspection of power lines using drones
- Urban air transport
- PPDR and temporary events with a sharp increase in traffic
- Connecting user devices and positioning in remote areas
- Continuous two-way data flow under high mobility
- Direct connection of end users
- Coverage of maritime areas for coastguard search and rescue operations

4.2.13 Autonomous inspection of power lines using drones

In recent years, drones have become an essential tool for infrastructure inspection, monitoring industrial sites and creating 3D models; however, current network services do not provide reliable connectivity in remote areas, which is hindering market development. This problem is illustrated by the example of power line inspection, which is also applicable to other sectors (e.g. inspection of oil and gas pipelines, or rail and road infrastructure). Drones enable more frequent inspections, rapid detection of faults (bird nests, corrosion, damaged bolts) and monitoring of damage caused by natural disasters, compared to inspections carried out using helicopters and technicians.

However, current drone services mostly operate under visual line-of-sight (VLOS) conditions, where the pilot must remain in close proximity to the drone throughout the flight. This limits the possibilities for remote control and real-time data transmission, as large amounts of data must be stored on the drone and subsequently transferred and processed manually, which hampers the operational efficiency of inspections. In this scenario, routine checks using UAVs are envisaged, with manual inspections carried out should any anomalies be detected.

As mentioned above, drones monitoring high-voltage power lines often operate in remote areas where terrestrial networks are unavailable, which limits the ability to connect to servers and necessitates offline data processing. Advanced on-board processing increases the drones' energy consumption and costs. The solution lies in seamless switching between terrestrial and non-terrestrial networks (NTN) during flight, utilising both public and private networks in the vicinity of electrical installations. For this scenario, both reliable positioning using 6G-NTN technologies – which could complement satellite navigation systems (GNSS) and improve their accuracy – and the automated use of network services and edge computing services could be beneficial.

4.2.14 Urban Air Mobility

Urban Air Mobility (UAM) represents a safe and sustainable air transport system for the movement of passengers and cargo in urban and suburban areas. This concept encompasses parcel delivery, urgent medical supplies, emergency transport for emergency services, and, in the future, automated passenger transport, thereby complementing existing transport infrastructure and reducing traffic congestion.

For UAM to function effectively, airspace management and resilient communication networks are essential. Current 5G networks provide only limited support, whilst a fully integrated 6G-NTN architecture will enable the opening of airspace to drones, ensure reliable communication, and integrate both piloted and autonomous aircraft into a unified air traffic management system. To achieve these objectives, new technical requirements must be defined, aligned with U-Space services that support the digitalisation and automation of air traffic management. Work is underway on several main system variants: (1) the creation of on-demand air corridors for last-mile delivery, (2) an anti-collision and autonomous deconfliction system, and (3) emergency management. NTN networks should therefore assist both in the pre-flight phase and during flight.

Drones should be able to transition seamlessly between ground-based and non-ground-based networks, whilst maintaining connectivity and service continuity (identification, tracking, etc.) via U-Space. Reliable positioning using 6G-NTN would complement traditional GNSS technologies and enhance the resilience of drone navigation. Computing capacities should dynamically track the movement of drones (this applies in particular to anti-collision and autonomous deconfliction systems) so that they remain as close as possible to their current position. A critical aspect of ensuring unified management of UAV operations is high interoperability between the various layers of the 3D architecture (ground networks, vLEO, LEO, MEO, GEO) and the U-Space system.

4.2.15 PPDR and temporary events with a sharp increase in traffic

6G NTN offers the opportunity to redefine the way in which organisations in the public safety sector and other verticals provide network connectivity, enabling reliable and efficient communication anytime, anywhere. This is particularly crucial when responding to incidents involving PPDR systems or during temporary planned events, where a sharp increase in user traffic is expected at a given moment, which may exceed the capacity of conventional terrestrial infrastructure.

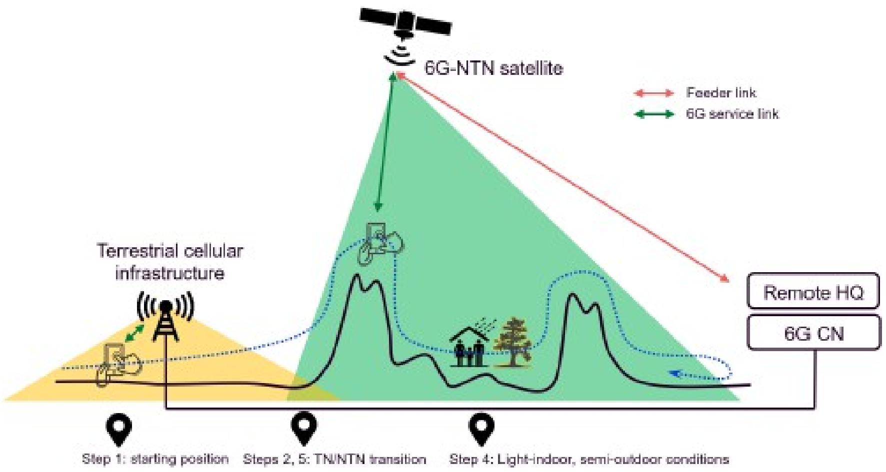
This chapter focuses in particular on scenarios where an effective combination of TN and NTN is required, especially in situations where TN is being gradually restored, such as when supporting emergency services, and in cases of increased demands on network capacity (events with a high concentration of visitors). The increased performance of 6G networks will thus enable faster deployment of communication services, including near-instantaneous connectivity for emergency services, which can be further scaled up as required. As part of the 6G-NTN project, an advanced PPDR deployment scenario is already being developed, based on an integrated 6G NTN architecture alongside supporting technologies that will enable the 6G NTN architecture to effectively meet the requirements associated with PPDR operations. Automated service deployment will enable rapid support for PPDR communications, the collection and analysis of sensor data, and its transmission to command centres or operational teams. The proximity of network elements to the scene of an incident will reduce latency, thereby improving service quality, particularly for interpersonal communication between response teams. Furthermore, NTN will ensure connectivity even where terrestrial networks fail or lack sufficient capacity, thereby increasing service availability[21].

4.2.16 User user devices and location the position in remote areas

Direct communication between satellites and standard mobile devices (UE) enables smartphones to connect to the NTN infrastructure without the need for modifications to their hardware or antennas. However, this approach faces challenges such as weak signals from ground-based equipment, low transmission capacity and limited functionality indoors. Integrating NTN into global networks in such a way that transitions between terrestrial and non-terrestrial segments are seamless for users remains a challenging task, particularly within the context of 5G NTN Rel-17.

The aim of 6G-NTN is to improve the quality of the user experience by enabling seamless switching between TN and NTN without interrupting the connection and by supporting higher transmission speeds. At the same time, it focuses on expanding the availability of NTN not only in outdoor environments but also in constrained indoor conditions.

Figure 7: Use of satellite connectivity in remote areas



[21] 6G-NTN – The Role of 6G NTN in Emergency and Crisis Management

Source: 6G-NTN.eu

The 6G-NTN architecture offers several key advantages in this regard. Current solutions have limited bandwidth, which allows only text-based communication, whilst voice calls and data services remain unavailable, even though they are already being actively tested. The same applies to handover between terrestrial and non-terrestrial networks, which is currently imperfect and slow, and often relies on roaming with long handover times. Last but not least, today's NTN solutions only work outdoors, as the signal is not strong enough to cover indoor areas. The development of 6G networks should address all the limitations described above, whether this involves increasing transmission speeds, seamless handover between segments, or improving signal coverage indoors.

4.2.17 Uninterrupted two-way data flow in high-mobility scenarios

For mobile solutions (e.g. in vehicles), 6G NTN offers alternative connectivity in the event of a terrestrial network outage. Interconnection between TN and NTN is crucial for maintaining connectivity for services requiring uninterrupted data flow, such as media streaming or video conferencing. The aim of this scenario is to prevent service interruptions in mobile data transmission by ensuring that TN and NTN networks complement each other, either when using NTN networks alone, when switching between NTN and TN networks, or between two NTN networks.

Thanks to 6G networks, NTN networks should improve the stability and continuity of services in areas with limited or intermittent TN coverage, particularly in rural areas. Thanks to higher transmission speeds and suitable vehicle-mounted antennas, they will ensure a seamless connection even in challenging conditions. Shorter transmission delays will enable low-latency services (e.g. gaming or VR). Commercial agreements and regulatory adjustments will be required to achieve seamless switching between networks.

4.2.18 Direct connection for end users

This scenario focuses on direct communication between two or more user equipment (UE) devices via satellites, without the need for a connection to a ground station. This method is suitable for HAPs, drones and other NTN infrastructure, with the main technical challenges relating to the satellite segment. In areas without terrestrial coverage or in the event of a network outage (e.g. during natural disasters), satellite links enable communication to be maintained, for example for public safety purposes.

Thanks to the extensive coverage provided by satellites, the probability of a connection between two UEs is higher than with terrestrial networks. Inter-satellite links (ISL) can extend this coverage even further. Sidelink communication is an alternative, but due to the large distance between devices, it is less efficient and is subject to signal interference. Direct communication via satellites eliminates this problem, as all receivers receive the signal from a single satellite, ensuring better conditions and higher efficiency than sidelink technology. This approach is demonstrated in a scenario involving emergency services, but can also be extended to other areas. This solution would be beneficial for IoT applications, autonomous vehicles and modern transport services.

Current NTN solutions up to 3GPP Rel-18 require a feeder link to connect the satellite to the ground network, but this may not always be available. During the initial roll-out of 6G NTN, a dense network of ground stations cannot be assumed, which may lead to temporary connection outages, particularly in the event of natural disasters.

6G NTN is intended to provide nationwide coverage; it is therefore crucial to support direct communication via satellite without a feeder link. This will enable the provision of critical services even in the event of a failure of the terrestrial infrastructure. The new 6G NTN architecture will require regenerative satellite systems for QoS management, mobility and routing. The use of inter-satellite links will further improve coverage, support for mobility and service continuity in an NTN environment.

4.2.19 Coverage of maritime areas for coastguard search and rescue operations

For many years, there have been ongoing efforts to improve the capabilities of search and rescue (SAR) services so that they can respond as quickly as possible in an emergency. The main objective of SAR technology is the timely detection and localisation of people or property in distress, enabling rescuers to focus on the rescue operation itself. Reliable communication between the SAR team and those in distress is crucial for speeding up the response and increasing the effectiveness of the operation.

This use case focuses on maritime emergencies, where coordination is required between various agencies, such as the coastguard, the armed forces and civil defence. This can be achieved by combining the communication capabilities of terrestrial networks (TN) and non-terrestrial networks (NTN). However, a similar model could also be applied in other situations where conventional terrestrial networks are not available.

The document identifies four possible usage scenarios in the event of a coastguard intervention (as mentioned above, the scenarios deal with situations where a vessel needs to be located) using: (1) terrestrial coverage, (2) non-terrestrial coverage alone, (3) support for multiple links to ensure reliable roaming, and (4) a seamless handover process to various transmission links for connection to the NTN network.

6G technology is expected to bring many improvements over current technologies. One of these is more accurate positioning using sidelink positioning technology, which is set to be enhanced in 6G networks to account for challenging maritime conditions. Reliable, uninterrupted communication with low latency is essential for critical maritime missions; however, traditional terrestrial networks have a limited range (20–25 km from the coast), as current NTN solutions (up to 3GPP Rel-18) require a feeder link, which results in high costs, latency and limited bandwidth, thereby preventing mobile devices from accessing satellites directly. 6G NTN is intended to provide comprehensive coverage and enable direct communication with satellites even without a feeder link, with LEO satellite constellations playing a key role in meeting low-latency requirements. To achieve this, it is necessary to overcome the Doppler effect and introduce a new dynamic network model that supports multi-connectivity and interconnects terrestrial, UAV and satellite networks for seamless connectivity between users at sea and on land. Privacy and security are important aspects of SAR missions; therefore, 6G networks must support 3GPP public safety services, including mission-critical communications (push-to-talk, data, video), in order to meet all critical requirements.

4.3 Examples of B2C applications

4.3.1 Practical applications of non-terrestrial 5G networks

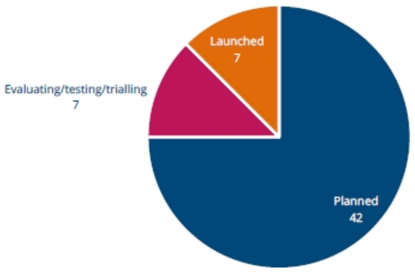
Although the current use of satellites in 5G networks remains limited, partly due to higher investment costs, we are seeing the beginnings of collaboration between mobile operators and satellite service providers. The GSA[22] report identified 101 publicly announced partnerships across 53 countries and territories. By the end of July 2024, 62 operators were planning to use satellite services, 17 were conducting trials, and 12 had launched commercial services. The report also examines in more detail broadband connectivity for rural areas and businesses, Satellite-to-Cellphone, and the IoT and M2M sectors.

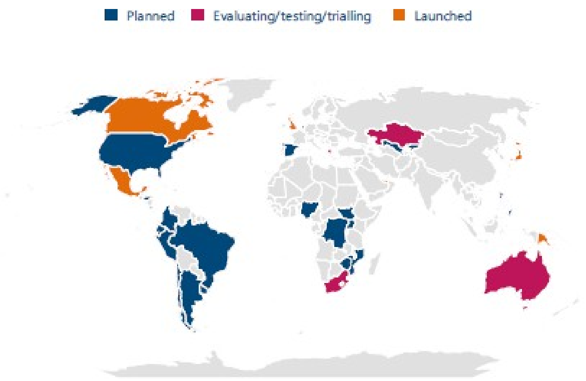
4.3.1.1 Broadband connectivity for rural areas and businesses

Satellite internet provides high-speed connectivity by transmitting signals between a ground station and satellites. It is particularly useful in remote areas, at sea or in mobile scenarios where traditional infrastructure is not available. This technology is currently the most common use of satellite services in 5G networks, accounting for 55 per cent of all partnerships. It should be noted that commercial use (7 partnerships) is only evident in a handful of countries, including Canada, Japan and the United Kingdom.

[22] GSA – 5G Satellite Connectivity September 2024

Figures 8 & 9: Level of penetration of high-speed satellite connectivity



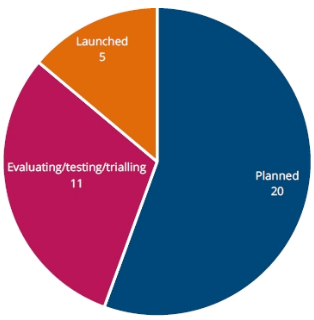


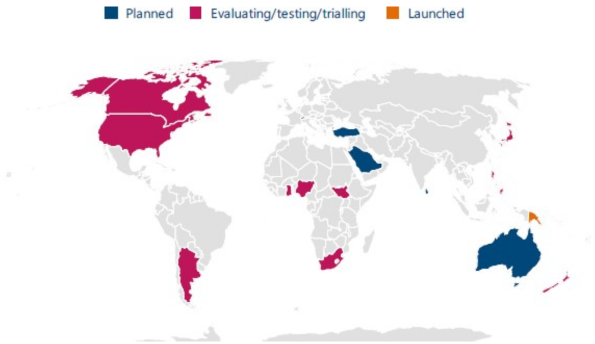
Source: GSA

4.3.1.2 Direct Satellite Access (Satellite-to-Mobile Phone)

As mentioned in section 2.1.3, this involves a mobile phone connecting directly to LEO satellites using existing spectrum. At present, it is used for emergency messaging and basic communication, but with the development of LEO networks, it could also offer broadband services, thereby ensuring coverage in remote areas. The leading companies in this category are SpaceX, AST SpaceMobile and Lynk, which collaborate with operators and use their terrestrial frequency spectrum instead of traditional satellite frequencies. The breakdown by stage of development/implementation can be seen in the figures below. Commercial use is currently available in five island nations (Palau, the Cook Islands, Papua New Guinea, the Solomon Islands and Vanuatu).

Figures 10 & 11: Level of penetration of satellite-to-mobile phone connectivity





Source: GSA

4.3.1.3 IoT and M2M

This solution accounts for only a small proportion of total satellite applications. Eight projects are in the planning phase and only one is in the commercial launch phase (in the USA). These figures can be explained by operators' focus on more profitable projects and the growing market size of the previous two categories.

4.3.1.4 Frequency bands used

The table below shows the number of satellite service providers by frequency band. This naturally depends on the region and provider in question, but generally speaking, the L-band is intended for voice and data services, whilst the S-band and Ka-band are intended for broadband connectivity.

Table 3: Overview of the number of providers by frequency band

Frequency band	Number of providers
L-band (1.5–1.6 GHz)	3
S-band (2–4 GHz)	2
C-band (3.7–4.2 GHz)	3
Ku-band (12–18 GHz)	7
Ka band (27–40 GHz)	15
Q-band (36–46 GHz)	2
V-band (40–75 GHz)	2
E-band (60–90 GHz)	1
W-band (75–110 GHz)	1

Source: Compiled by the author based on GSA data

4.3.2 Pilot projects and test programmes for satellite communications and their results

4.3.2.1 Study

A group of researchers from Simon Fraser University investigated the potential[23] of LEO satellite networks for connectivity in remote areas through the practical deployment of Starlink connectivity at salmon monitoring stations in northern British Columbia. The study demonstrates the potential of LEO satellites to provide connectivity in geographically isolated regions, but also identifies the technological, environmental and regulatory challenges associated with this technology.

When deploying satellite connectivity for monitoring salmon populations, Starlink was used as the main network backbone for transmitting data from underwater cameras and microprocessors located in isolated environments that were previously completely without connectivity. The results showed that whilst the technology provides sufficient connectivity for remote monitoring, its performance is significantly reduced when affected by various factors (most notably heavy cloud cover or solar storms).

One of the main findings is that lower-orbit satellite networks provide faster connectivity and lower latency than traditional GEO satellites, but still do not match the quality of terrestrial networks. The measured latency was 10 per cent higher than that of terrestrial networks. Transmission asymmetry is also a significant issue – download speeds reached 66–108 Mb/s, whilst upload speeds were limited to 6–7 Mb/s; in both cases, these figures are significantly lower than those of terrestrial networks.

[23] LEO Satellite Network Access in the Wild: Potentials, Experiences and Challenges

4.3.2.2 Commercial solutions

In the US, the commercial use of satellite communications in mobile devices has already been launched through a partnership between SpaceX and T-Mobile on Apple devices. At present, this is limited to text messaging, with the potential for voice and data services to be added in the future. This service was already utilised during Hurricane Helene in North Carolina at the end of 2024 and during the wildfires in Los Angeles at the start of 2025.

In January 2025, Vodafone, in collaboration with satellite service provider AST SpaceMobile, tested a direct-to-smartphone service using a video call on a standard smartphone without specialised hardware. According to the company, this is believed to be the first instance of its kind in the world. A commercial launch in Europe is planned for the end of 2025.

AST SpaceMobile provides its services via five BlueBird satellites in low Earth orbit (LEO), which the company has launched to date. The signal is routed via a space-to-land gateway, which connects the satellites to Vodafone's terrestrial network. Vodafone regards satellite services as a complementary technology that can fill in the gaps in its existing mobile network and cover remote areas, including mountains and the sea, as early as 2026, with speeds of up to 120 Mbit/s.[24]

4.3.3 IoT in non-terrestrial networks

Non-terrestrial networks have the potential to open up new possibilities for the Internet of Things. As already mentioned, these networks provide coverage in places where terrestrial networks have so far failed; we are talking, for example, about remote areas, areas with varied terrain, or during emergencies when terrestrial networks fail. Non-terrestrial networks are therefore intended to serve as a complementary technology to terrestrial networks and must thus enable seamless switching between these networks.

With new IoT standardisations from 3GPP, energy efficiency and reliability are also increasing, and, most importantly, the costs of new IoT solutions are falling. This should encourage the development of new products. Indeed, a study by Juniper Research[25] estimates that total revenue from satellite-based IoT will double between 2024 and 2027, rising from USD 2.9 billion to USD 5.8 billion.

4.3.3.1 Practical applications of NTN IoT[26]

In December 2024, Mavenir and Terrestar Solutions Inc. (TSI) reached a significant milestone by successfully conducting the first live Narrowband IoT (NB-IoT) data sessions via TSI's Echostar T1 satellite, which is located in geostationary orbit (GEO) and forms part of a non-terrestrial network. These sessions were conducted under real-world conditions, demonstrating the robustness of this technology.

The testing took place at Allan Park in Ontario and validated key functions such as network connectivity, paging, ping, data sessions and non-IP data delivery (NIDD), all whilst the connection was continuously monitored for 24 hours. Successful data sessions were achieved using commercial IoT modules, demonstrating the technology's readiness for commercial deployment using 3GPP-standardised products from various suppliers.

Mavenir has developed its own Radio Access Network (RAN) interface for seamless integration with TSI's satellite ground equipment, which is consistent with TSI's infrastructure for delivering satellite NB-IoT services. This milestone paves the way for future enhancements, as Mavenir and TSI are actively developing advanced features, including voice services and 5G NR, with plans to expand testing to additional locations across Canada and ultimately provide ubiquitous satellite coverage, including the most remote regions.

In addition, Mavenir and Terrestar have announced the launch of a laboratory in Montreal, Canada, designed for advanced NB-IoT testing and to facilitate seamless integration with TSI's partners. The laboratory is equipped with state-of-the-art

---

[24] Vodafone – 'World's first' satellite-to-phone video call

[25] Juniper Research – Satellite IoT 2024–2027 forecast

[26] Mavenir and Terrestar – NB-IoT NTN milestone – Live Data Sessions

Mavenir's RAN and Core solutions operate on Amazon Web Services (AWS) Public Cloud and support NTN on NB-IoT. This initiative represents a step towards accelerating the development and deployment of satellite-connected services, reinforcing the commitment to innovation and collaboration in this space.

Pardeep Kohli, President and Chief Executive Officer of Mavenir, highlighted the challenge of providing universal coverage, particularly in regions where it is not economically viable, and stated that non-terrestrial networks offer an ideal solution to this challenge by providing cost-effective coverage across vast areas. Further developments in the fields of IoT and NTN can therefore be expected in the future.

4.4 Regulatory approaches in technologically advanced countries

4.4.1 Ofcom

Investment in satellite technologies is one of the main priorities of the UK telecoms regulator, Ofcom. The main focus of investment and development will be on the deployment and expansion of satellites, the total number of which orbiting the Earth has increased over the last few years from 1,784 in 2017 to 12,383 in 2025–27 (the majority of which are NGSO satellites in LEO).

As the number of NGSO satellites increases, pressure on spectrum usage will grow, and coordination to prevent interference between systems will become increasingly complex. Ofcom has introduced a new approach to NGSO authorisation, which should help to manage this complexity, and is also investing in its own system monitoring capabilities. The new approach should help to streamline the allocation of spectrum amongst users. Key points of discussion regarding the roll-out of these networks include consultations on proposals for the authorisation of ground earth stations (GES), particularly in the Q (36–46 GHz) and V (40–75 GHz) frequency bands, and potentially also in the E band (60–90 GHz). For uncoordinated user GSO and NGSO terminals, access to the 14.25–14.5 GHz band will be extended, which will double the available spectrum in this band and support the roll-out of both fixed (homes, businesses) and roaming (aircraft, ships, other vehicles) stations. Access for these Earth-station equipment (ESIM) will be further extended to include frequencies in the 27.5–30 GHz band, whilst, as part of the decisions of the World Radiocommunication Conference (WRC-23), the security of existing services in the 12.75–13.25 GHz band will be examined28.

The main objectives of Ofcom's satellite strategy are:

- To ensure access to spectrum that will enable the space sector to deliver greater benefits to people, businesses and the public sector in the United Kingdom;
- To ensure that the space sector uses spectrum efficiently and does not impose undue constraints on the growth of other spectrum users;
    - This point will focus in particular on improving data analysis models to optimise spectrum sharing between individual users and minimise potential interference;
- Enabling as many NGSO satellite systems as possible to provide services in the UK, whilst promoting their efficient use and sharing of spectrum (in line with the previous objective);

NGSO projects present many investment opportunities for the UK, but they also pose a number of challenges, including potential competition in the NGSO sector or interference issues, which must be properly addressed to ensure the effective roll-out of these technologies.

4.4.2 FCC

The US Federal Communications Commission (FCC) actively supports the gradual transition to modern 5G technologies through a range of measures, including the release and reallocation of spectrum bands allocated to older technologies,

[27] Orbiting now – Active satellite database

[28] Statement: Space spectrum strategy – Ofcom

support for investment in technology development and efforts to achieve nationwide coverage. In the context of satellite-based 5G services, the FCC has focused on several key action points:

- **Making the C-band available**

Following a decision in 2020, the 3.7–4.2 GHz band was released for future use in 5G services. Existing services in this band were moved to the upper parts of the band, making the 280 MHz section that was freed up available for flexible use across the US in 5G applications, including advanced satellite applications[29].

- **Integration of satellite and terrestrial networks**

In November 2024, the FCC approved the granting of a licence to T-Mobile and SpaceX (Starlink) to launch a joint project to expand telecoms coverage. This project aims to eliminate 'white spots' or 'dead zones' where internet connectivity is not available via terrestrial means. This is the first time the FCC has approved collaboration between a terrestrial internet service provider and a provider of supplementary satellite connectivity. Based on the FCC's statements and active support, it is expected that similar projects and collaborations will continue to increase in the US; the FCC already has a number of applications for similar projects from other companies pending[30].

The Starlink satellites, together with the terrestrial network, are expected to cover an area of over 1.3 million km^2 in the US, which has hitherto been inaccessible due to the complexity of the terrain, land-use restrictions and other factors[31].

- **Support for innovation**

One of the most significant innovations in satellite 5G services in the US is SpaceX's direct-to-cell technology, which will enable mobile devices to connect directly to the satellite network. As part of testing SpaceX's direct-to-cell technology, SpaceX and T-Mobile have already launched the first few satellites capable of operating this technology; however, the nationwide roll-out of this service will require the deployment of full constellations. According to SpaceX, during this testing phase the company will be able to provide basic text messaging; support for voice and video calls is not expected until 2025 at the earliest.

The FCC sees this innovation as the way forward for mobile connectivity, although certain specific issues are still under discussion, in particular increasing the radio transmission power of Starlink satellites, which would enable real-time voice and video calls. AT&T and Verizon have previously expressed concerns that this increase could adversely affect the services they currently provide[32].

4.4.3 CRTC

The Canadian Radio-television and Telecommunications Commission (CRTC), in collaboration with the Canadian Institute for Innovation, Science and Economic Development (ISED), expects that the now relatively widespread availability of satellite services across North America will continue to grow. ISED forecasts an annual growth rate of around 8.5 per cent until 2029. In particular, an increase in the use of NGSO and GSO satellites within Canada is anticipated to ensure adequate internet connectivity for rural and otherwise inaccessible areas beyond the reach of terrestrial networks.

One of the main reasons for the increased interest in these services is the Internet of Things (IoT). For example, satellite services will be key in the future to making next-generation agriculture more efficient through the IoT and precision farming methods. The Internet of Things is also expected to be a driving force behind operational improvements, including enhancements in health and safety and in the mining, oil and gas industries. Given that these sectors are often located in remote areas, satellite solutions will help meet the demand for the Internet of Things.

29 FCC Report – Expanding Flexible Use of the 3.0 to 4.2 GHz Band

30 Reuters – FCC – Approval of licences for T-Mobile and SpaceX

31 T-Mobile and SpaceX coverage cooperation

32 Starlink's 'Direct-to-cell' satellite service – FCC approval

The main bands for satellite services in Canada are the C-band, Ku-band and Ka-band. ISED has examined the demand for each of these bands in order to better determine their future use[33].

- **C-band (3.5–7 GHz)**

Satellite networks in this band are used in Canada for voice and video services as a complement to terrestrial networks in areas without coverage, or during various outages or emergencies. Most of this band in Canada is covered by three Telesat satellites. The C-band offers a relatively stable and robust signal. However, this band requires larger and more expensive antennas and is less suitable for bandwidth-intensive applications, such as higher-capacity internet services or high-definition video streaming.

ISED has therefore decided to keep the C-band available for fixed and mobile 5G services, whilst reserving satellite services for remote and inaccessible areas.

- **Ku-band (10–18 GHz)**

The Ku-band is primarily used for broadcasting video content or corporate data services, such as network connections for oil and mining companies, and point-of-sale terminals for petrol stations and post offices. Compared with the C-band, the Ku-band allows for the use of smaller antennas, which are suitable for consumer use. The spectrum in the Ku-band is allocated exclusively for fixed and broadcast satellite services and can therefore support bandwidth-intensive applications such as broadband internet and high-definition video.

The Ku band continues to be actively used for satellite services, and continued interest is expected in the future in further utilising parts of the band for user terminals of NGSO satellites as well as for mobile earth stations.

- **Ka-band (18–30 GHz)**

The main uses of the Ka-band include providing broadband internet access to households and businesses. The Ka-band also requires smaller antennas than those used for consumer satellite services in lower bands, which makes installation easier and cheaper. Although this band is more susceptible to weather-related outages than the C and Ku bands, it currently offers much higher capacity and is the preferred band for many LEO satellite constellations.

In June 2020, ISED issued a decision regarding the Ka band, granting co-primary service status to GSO and NGSO fixed satellite services in parts of the Ka band, in order to provide both types of satellites with an equal opportunity to utilise this spectrum and to facilitate new and innovative services in rural and remote areas.

Due to the ever-increasing demand for satellite services, consideration is being given to extending these services to other bands; in particular, the Q band (33–50 GHz) and the V band (40–75 GHz) are being discussed as suitable candidates.

4.4.4 MIC

The Japanese Ministry of Internal Affairs and Communications (MIC) is actively involved in the integration of satellite services into 5G networks. It is devoting considerable attention and resources to developments in the field of NTN, in collaboration with academic institutions as well as Japanese technology companies. In 2021, the MIC carried out 26 development demonstrations for the implementation of 5G services with the aim of addressing local issues. It placed particular emphasis on harmonising regulatory frameworks, as well as on making these technologies accessible and ensuring their widespread adoption[34].

MIC is currently focusing on the HAPs project, under which it aims to launch solar-powered unmanned aerial vehicles equipped with 5G mobile network base stations by 2025. These stations will fly in the stratosphere and provide wider network coverage than traditional ground-based stations. The commercial roll-out of these devices has been made possible by the recent adoption of Japan’s proposal, put forward at WRC-23, for the 1.7 GHz, 2 GHz and 2.6 GHz frequencies to be made available globally

33 ISED – Spectrum Outlook 2023 to 2027

34 MIC – Announcement of FY2021 Results of Development Demonstrations

designated as standard HAP frequencies. In addition to these newly approved frequency bands, the 700–900 MHz band is also in use. The approval of these frequency bands was an important step towards the further expansion of these devices in Japan and globally. The MIC plans a large-scale roll-out during 2025, with the main priority being their use in conjunction with ground stations in remote, hard-to-reach locations (in the case of Japan, this includes a number of very small and remote islands).

Another important step in expanding the HAPs project is to reduce the lack of internet access in poor regions and areas. Following a test by SoftBank, which involved a 5G call between Japan and Rwanda, efforts are continuing to expand these technological solutions into economically disadvantaged regions in the future. With this ambitious plan, Japan aims to take a leading position in the global telecommunications market[35].

4.4.5 MSIT

The South Korean telecommunications regulator, part of the Ministry of Science and ICT (MSIT), has outlined several key steps in its Spectrum Plan 2024–2027 that it intends to take to optimise the use of its telecommunications services and establish medium- to long-term strategies for the spectrum. Key objectives include the reallocation of frequency bands whose licences are due to expire shortly, as well as opening up these bands for use in new sectors.

With regard to satellite technologies, the MSIT proposed in its plan support for the expansion of these services, in particular by allocating the 10.7–11.7 GHz frequency band. Through this measure, it aims to support the growth of digital sectors and simplify the integration of satellite services into 5G networks[36].

The MSIT also strongly supports developments in the field of NTN; in 2024, an attempt was made in South Korea to link a terrestrial 5G network with a GEO satellite operated by KT SAT. This trial was carried out in collaboration with Rohde & Schwarz Korea and Viavi Solutions Korea. KT SAT announced the successful interconnection of these two technologies and the overcoming of technical complications associated with the great distance of the GEO satellite by reducing signal latency, which opens up new possibilities for extending coverage to inaccessible areas or objects in airspace[37].

In 2024, the European Space Agency (ESA) signed a cooperation agreement on the development of 5G/6G telecommunications services with the South Korean Satcom Forum, a group of 41 technology companies including LG, KT SAT and Intellian. This collaboration is intended to support the further development and integration of 5G/6G services, whilst facilitating the sharing of best practices and know-how. South Korea, a pioneer in the field of 6G, is an important partner for Europe in the field of terrestrial and other telecommunications, and through this collaboration it aims to achieve a leading position in the field of modern satellite communication technologies and to establish an international shared network of 6G LEO satellites[38].

[35] Japan's Flying 5G Base Stations – 2025

[36] MSIT Spectrum Plan for 2024–2027

[37] KT SAT, Rohde & Schwarz Korea and Viavi Solutions Korea – 5G NTN via GEO satellite

[38] ESA's ongoing 5G/6G NTN cooperation with South Korea

5 Availability and economic parameters of satellite 5G in the Czech Republic

5.1 Overview of satellite communications providers, their service specialisations and availability in the Czech Republic

Services providing high-speed internet connectivity via satellite transmission are already appearing on the market. Probably the best-known provider at present is SpaceX, which operates its own constellation of satellites in low Earth orbit (LEO) at an altitude of around 550 km. These satellites are equipped with three space lasers in the form of inter-satellite links (ISLs) and operate in the Ku, Ka and E bands with a latency of approximately 25 ms[39].

INTV, spol. s r.o. also offers a satellite internet service using Tooway technology.[40] This service provides internet connectivity via the KA-SAT satellite and a system of ground gateways connected to the internet via major European hubs. According to the operator, internet coverage should extend across the whole of the Czech Republic, and both download and upload speeds vary depending on the type of service selected, ranging from 10 to 50 Mbit/s and 6 to 10 Mbit/s respectively. These speeds may be further reduced once the monthly priority data allowance has been used up. Compared to Starlink, this service has up to forty times higher latency. Prices vary depending on the service chosen, ranging from 490 to 2,490 Kč (excluding hardware).

Another option is the service from IT Eron X[41], which offers two variants at different price points (a slower variant for 1,000 CZK/month + 15,000 CZK/installation and a faster one for 1,900 CZK/month + 18,000 CZK/installation) with download speeds of up to 200 Mbit/s, upload speeds of up to 50 Mbit/s and latency of 50–150 ms.

As part of the IRIS2 (Infrastructure for Resilience, Interconnectivity and Security by Satellite) project, the European Union plans to build a multi-orbital satellite internet constellation comprising a total of 290 satellites in medium and low Earth orbit. According to the EU, the aim is to provide broadband connectivity to government bodies, private companies and citizens themselves across all Member States. The system will support a wide range of applications, from crisis management and the protection of critical infrastructure to transport, energy, healthcare and rural connectivity. The EU plans to implement the project in stages, with the first government services set to be launched in 2025 via GOVSATCOM and full capacity to be achieved by 2030. The private sector will play a significant role, participating through a concession agreement, thereby optimising costs and fostering innovation within the 'New Space' ecosystem. The European Commission will oversee the project in collaboration with the ESA (European Space Agency) and the EUSPA (European Union Agency for the Space Programme) to ensure the effective development and deployment of the service[42].

[39] Starlink – Overview of satellite technology

[40] INTV – Overview of services provided

[41] EronX – Overview of internet services offered

[42] European Commission – IRIS^2 – New EU Secure Satellite Constellation

5.2 Applications of satellite transmission to address the situation in the Czech Republic

High-speed internet solutions using satellite transmission are already available in the Czech Republic (e.g. via Starlink). This chapter examines the provision of satellite transmission services to the remaining households (approximately 2.5 million) and compares their costs with those of fibre-optic connections.

SpaceX's Starlink product was selected as a case study, as it currently offers its services throughout the Czech Republic. It was chosen primarily due to the availability and price of the services offered compared with competitors in the market. The 'Residential' tariff, intended for households, was selected as the input parameter, along with the purchase of the 'Standard' hardware required for the service to function[43]. According to the website, these services achieve download speeds of between 121 and 274 Mbit/s and upload speeds of between 17 and 31 Mbit/s, consistently across the whole of the Czech Republic. The table below shows a comparison of speeds and latency between the Czech Republic and other countries in Central Europe.

Table 4: Quality of Starlink coverage in Central Europe

Coverage area	Download speed	Upload speed	Latency
Czech Republic	121–274 Mbit/s	17–31 Mbit/s	26–34 ms
Slovakia	141–267 Mbit/s	19–33 Mbit/s	26–37 ms
Germany	95–237 Mbit/s	15–28 Mbit/s	26–34 ms
Poland	145–292 Mbit/s	20–35 Mbit/s	24–32 ms
Austria	117–258 Mbit/s	16–29 Mbit/s	29–36 ms

Source: Compiled by the author based on Starlink.com

The difference in connection latency across these countries is due to several factors. These include, for example, variations in the capacity of ground stations to provide adequate coverage; where infrastructure is insufficient, the number of inter-satellite links required for the connection increases, thereby reducing service quality. It also includes variations in signal availability from orbit due to different atmospheric and geographical influences.

Download and upload speeds also vary across countries, showing fluctuations over time, either as existing capacity is utilised (a decrease) or, conversely, in connection with the expansion of the satellite constellation over a particular area (an increase). In this regard, it is interesting to note that in 2024, the median download speed of the Starlink service in five European countries (the Czech Republic, Austria, Greece, Croatia and Italy) was higher than that of broadband connections (again, based on the median in each specific country)[44]. This is a situation where the satellite service may appear more attractive in a given country, thanks to both its speed and the relatively high stability of the internet connection. However, it is important to bear in mind the limitations of such a broad comparison – fixed broadband services encompass a range of technologies with varying capacities, and another factor is the mix of tariffs being compared, which do not always represent the technically achievable maximum speeds. In practice, therefore, customer preference will be based on the range and price of services available under specific local conditions at the level of a municipality or individual address.

Generally speaking, the option of using Starlink services is more attractive in countries with a lower level of fibre-optic network coverage (as demonstrated by the previous example). Given the heavy investment in fixed broadband and, in particular, fibre-optic connections across the EU, the significance of satellite internet solutions as a competitor to fixed internet is diminishing; instead, they are emerging as a complementary service to address the shortcomings of fixed networks across different countries.

---

[43] Starlink – For households, the monthly subscription fee is 1,250 CZK, and the cost of the hardware is 6,740 CZK including delivery; prices valid as at 7 February 2025.

[44] Ookla – Starlink – Constellation investments boosting performance

To compare the cost-effectiveness of fixed-line connections with satellite connections in the Czech Republic, data was taken from the study 'Definition of the investment gap in VHCN network deployment in relation to 5G network development'[45]. For the price of a 'standard' tariff using a fibre-optic connection, we assume an amount of 350 Kč per month with a twenty-year lifespan for the optical fibre.

Table 4 below shows the ranges of households not yet connected, sorted by the cost of fibre-optic connection. The row also shows the lowest, highest and average costs for fibre-optic connection within each range. The final column indicates what the theoretical monthly tariff would be if the stated cost of fibre-optic connection were spread over a period of 20 years. The theoretical price, taking into account the actual costs of fibre-optic connection, was not calculated for the most investment-intensive range (99.95–100%), as the costs of connecting these households would raise the price above 16,500 CZK. The table also shows that, at the current price for satellite transmission of 1,250 CZK (+ the cost of equipment), this type of connection is already more cost-effective for 5,455 households.

It can be concluded that, in the Czech Republic, the use of satellite services for standard provision to unconnected households is merely a marginal issue, and the main purpose of implementing satellite coverage will lie in other usage models described in this study.

Table 5: Costs of connecting unconnected households via FTTx and the break-even point for satellite communications

Interval of unconnected	Minimum connection costs	Maximum cost of	Remaining number of unconnected households	Average price per fibre-optic connection	Theoretical tariff price, after taking into account
99.95 – 100%	396,000 CZK	CZK 7,437,830	1,268	CZK 3,916,915	Not calculated
99.90–99.95%	CZK 283,323	396,000 CZK	2,536	339,661 CZK	1,765 CZK
99.85–99.90%	CZK 250,909	283,323 CZK	3,804	CZK 267,116	1,463 CZK
99.80–99.85%	CZK 229,412	250,909 CZK	5,072	CZK 240,160	1,351 CZK
99.78% [46]			**5,455**	**222,740 CZK**	**1,278 CZK**
99.75–99.80%	CZK 212,738	229,412 CZK	6,340	CZK 221,075	1,271 CZK
99.50–99.75%	175,784 CZK	212,738 CZK	12,679	194,261 CZK	1,159 CZK
99.25–99.50%	155,013 CZK	175,784 CZK	19,019	165,398 CZK	1,039 CZK
99.00 – 99.25%	142,537 CZK	155,013 CZK	25,358	148,775 CZK	970 CZK
98.00%	108,538 CZK	142,537 CZK	50,716	125,538 CZK	873 CZK
97.00%	74,144 CZK	108,538 CZK	76,075	91,341 CZK	731 CZK
96.00%	60,000 CZK	74,144 CZK	101,433	67,072 CZK	629 CZK

Source: Own calculations

[45] Ministry of Industry and Trade – Definition of the investment gap in the roll-out of VHCN networks in relation to the development of 5G networks

[46] The threshold at which it is more cost-effective for households to use satellite connections rather than FTTx connections

6 Conclusion and recommendations

Although technological developments to date offer promising prospects for the use of TN – NTN technologies on a relatively large scale, from the Czech Republic's perspective it is advisable to consider primarily those usage scenarios that are compatible with local conditions – a landlocked country, a relatively small area, good 5G coverage and widespread availability of terrestrial optical networks, but also the as yet unstarted modernisation of the communications infrastructure for emergency /rescue services (PPDR networks) has not yet begun.

Given these conditions (few white spots, no remote areas, and no maritime applications), the use of NTN in the Czech Republic is likely to be primarily in a complementary role to terrestrial networks.

For these reasons, the following can be recommended:

a) To explore the potential benefits of TN–NTN cooperation in sectors where scenarios suitable for local conditions have been identified for the use of NTN, namely:
   - secure communications for emergency services,
   - secure emergency communications for government bodies,
   - air traffic control and navigation,
   - monitoring of transport and energy infrastructure,

b) Supporting development in other sectors as well, such as agriculture, forestry and water management, i.e. those where there is a prospect of a need for rapid data communication between dispersed and mobile devices in areas with uneven TN coverage.

c) Focus attention on the most pressing issue, which appears to be the allocation of the MSS frequency band (2 GHz) following the expiry of current licences in 2027, by participating in the assessment of individual usage scenarios and conditions for the allocation of this band (for potential new applicants) in accordance with the RSPG's alternative proposals as part of the preparation of the EC's proposed procedural steps – in particular, the preparation of elements of the selection procedure within the relevant COCOM committee established to discuss further steps in relation to MSS.