



# Non-terrestrial networks - opportunities and challenges

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# 1

# Executive Summary

According to GSMA Mobile Economy Report 2024<sup>1</sup>, there were 8.6 billion mobile subscriptions by the end of 2023, surpassing the world's population of 8.1 billion people. The number of unique mobile subscribers is 5.6 billion of which 4.6 billion<sup>2</sup> are mobile internet users, representing 58% of the world's population. GSMA State of mobile Internet Connectivity Report 2024<sup>3</sup> and the ITU Mobile Network Coverage<sup>4</sup> conclude that more than 95% of the world's population is today covered by mobile broadband networks (3G, 4G or newer technologies), while 37% of the population live within coverage but do not use internet connectivity. Analysis of global population distribution reveals that is concentrated within just 20% of the Earth's landmass, even if mobile networks coverage extend beyond that still ample areas are not covered by terrestrial networks.

The emerging 5G NTN ecosystem combines the capabilities of satellites, uncrewed aircraft system (UAS) and high-altitude platforms (HAPS) with terrestrial networks and mobile devices. Various NTN solutions can support a variety of use-cases including backhaul solutions, broadband, IoT applications, direct-to-device (D2D) satellite connectivity, and mobility applications, such as vehicle communications, and advanced maritime and aviation connectivity.

The key sectors that are expected to benefit from NTN include telecommunications, smart-mobility applications (land, aviation, maritime), agriculture, defence and emergency services. As the technology matures, the potential for NTN to transform satellite connectivity and empower a multitude of use cases will continue to grow, paving the way for advanced and more connected environments worldwide. In particular, for the emerging direct-to-device services, there are three competing tracks. Commercial deployments of such services have already launched, excluding those based on NR-NTN technologies:

1. **3GPP NTN:** 3GPP has defined the following 5G radio access technologies for NTN:
  - **NR-NTN** - part of the 5G NR radio interface family
  - **IoT-NTN** - an extension of the 4G NB-IoT and eMTC radio interface family

This track, which employs established MSS spectrum (S- and L-band), is already supported by some new handsets. 3GPP 5G NR NTN will also include FSS spectrum for broadband access use cases.

Early NTN direct-to-device implementation on proprietary services:

2. **Proprietary D2D services** that use non-3GPP radio access technologies and established MSS spectrum in the S- and L-bands.
3. **Proprietary D2D services** to unmodified 3GPP phones, that recognize the satellite as a terrestrial tower, using terrestrial mobile spectrum. Some satellite operators are deploying or plan to deploy LEO (low earth orbit) satellites to support these services to unmodified devices. This track necessitates cooperation between the satellite operator and a mobile operator for access to the terrestrial mobile spectrum. End-users authenticate themselves using a terrestrial SIM card provisioned by the mobile operator.

## Satellites technical constraints

While non-terrestrial networks (NTNs) face inherent technical challenges due to the significantly greater distances involved compared to terrestrial networks, these challenges also create opportunities for innovation. Key areas of focus include optimising the air interface and network layers to manage issues

1/ <https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-economy/wp-content/uploads/2024/02/260224-The-Mobile-Economy-2024.pdf>

2/ <https://www.gsma.com/r/somic/>

3/ The State of Mobile Internet Connectivity Report 2024

4/ <https://www.itu.int/itu-d/reports/statistics/2023/10/10/ff23-mobile-network-coverage/>

such as latency, doppler shifts from fast-moving LEO satellites, signal attenuation, and the complexity of seamless handovers between terrestrial and satellite links. Overall performance still lags behind terrestrial systems.

Also, many satellite operators operate with a mix of legacy systems, third-party applications and diverse technology stacks, which can create compatibility issues.

The device ecosystem for the new 5G NR NTN needs to be developed.

The full potential of NTN applications and the value that NTN can bring to various industries is still unfolding. While careful evaluation is needed, the momentum is growing. Close partnerships between Satellite Network Operators (SNOs) and Mobile Network Operators (MNOs) are key in accelerating and unlocking new opportunities.

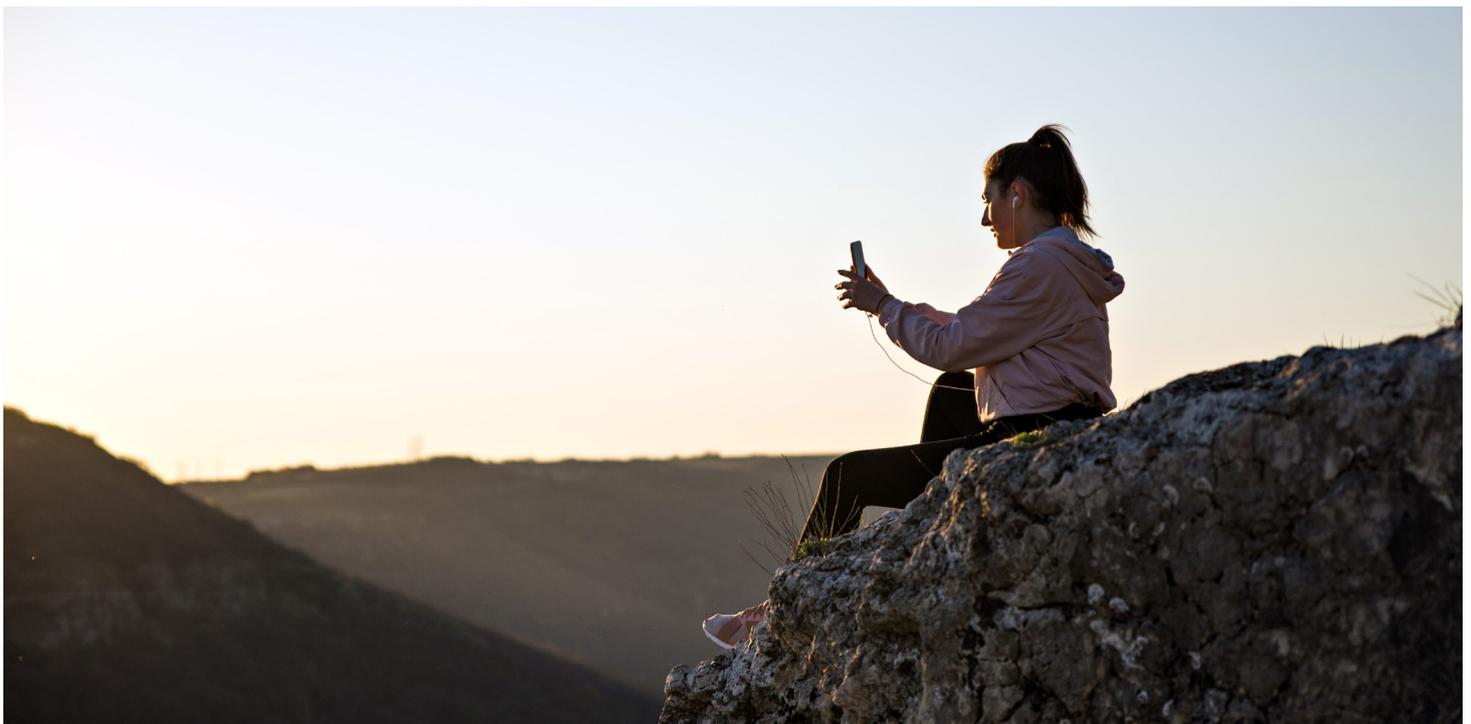
### Spectrum considerations

For D2D services that use the MSS spectrum as specified in 3GPP, a satellite operator will typically arrange for licenses in the countries throughout its service area. Device ecosystem should be developed supporting the relevant frequencies. Furthermore, as MSS operators use different bands to terrestrial IMT systems, they can operate complimentary to IMT terrestrial networks in areas with limited or no terrestrial coverage. However, as some MSS bands overlap with IMT systems for example, in the S-band there may be coexistence issues, which need to be considered on a case-by-case basis at national/regional level.

D2D services intending to use the terrestrial mobile spectrum will require careful consideration of the compatibility with the terrestrial mobile service. The regulatory environment for D2D using terrestrial mobile spectrum is still being developed by countries around the world. In this case, satellite networks utilise bands licensed to MNOs and an agreement with the MNOs holding the terrestrial spectrum license to use their spectrum is required along with the requisite regulatory approval. But the coexistence with networks in the adjacent channel, as well as interference to terrestrial mobile networks in neighbouring countries, should be considered. Spectrum is a scarce resource, and its overall efficiency needs to be guaranteed encompassing both coverage need in remote areas (where satellite can play an important role), guarantee quality of service and high-capacity requirements for terrestrial networks in non-remote areas. Satellite deployments need to avoid interference with terrestrial networks. The partnership between Mobile Network Operators (MNOs) and Satellite Network Operators (SNOs) is the key to bridge the technological challenges allowing interworking of terrestrial and satellites technologies.

Similarly, satellites employing the FSS spectrum must operate in a manner that avoids interference with other users of the frequencies.

Moreover, satellite operations whether D2D or FSS, must also operate in manner that ensures it restricts the provision of related services to territorial areas of countries which have authorised the operation of such services.



## How NTN will evolve from here

For 3GPP NTN in Releases 17 and 18, 3GPP essentially considered a transparent payload architecture (also known as bent-pipe architecture). However, Release 19 have considered more advanced 5G NR NTN integration with 5G by standardising regenerative payload (or packet-processing payload) in which a base station is integrated into the satellite. This will increase resilience, reduce latency and enable support for more capabilities. Release 19 will also support the Ku band. NTN end-users should benefit from higher data rates, better power management, whilst maintaining backwards-compatibility with the already deployed NTN services such as broadcasting via satellite, and IoT with satellite networks could become accessible to a larger population.

Release 19 will further optimise voice and video in NTN communication services.

Future NTN will be integrated with terrestrial 5G/6G networks, enabling service continuity when the terminal moves between terrestrial and satellite coverage areas.

NTN end-users should benefit from higher data rates, better power management, whilst maintaining backwards-compatibility with the already deployed NTN services such as broadcasting via satellite, and IoT with satellite networks could become accessible to a larger population.

# 2 Introduction

## 2.1 Overview

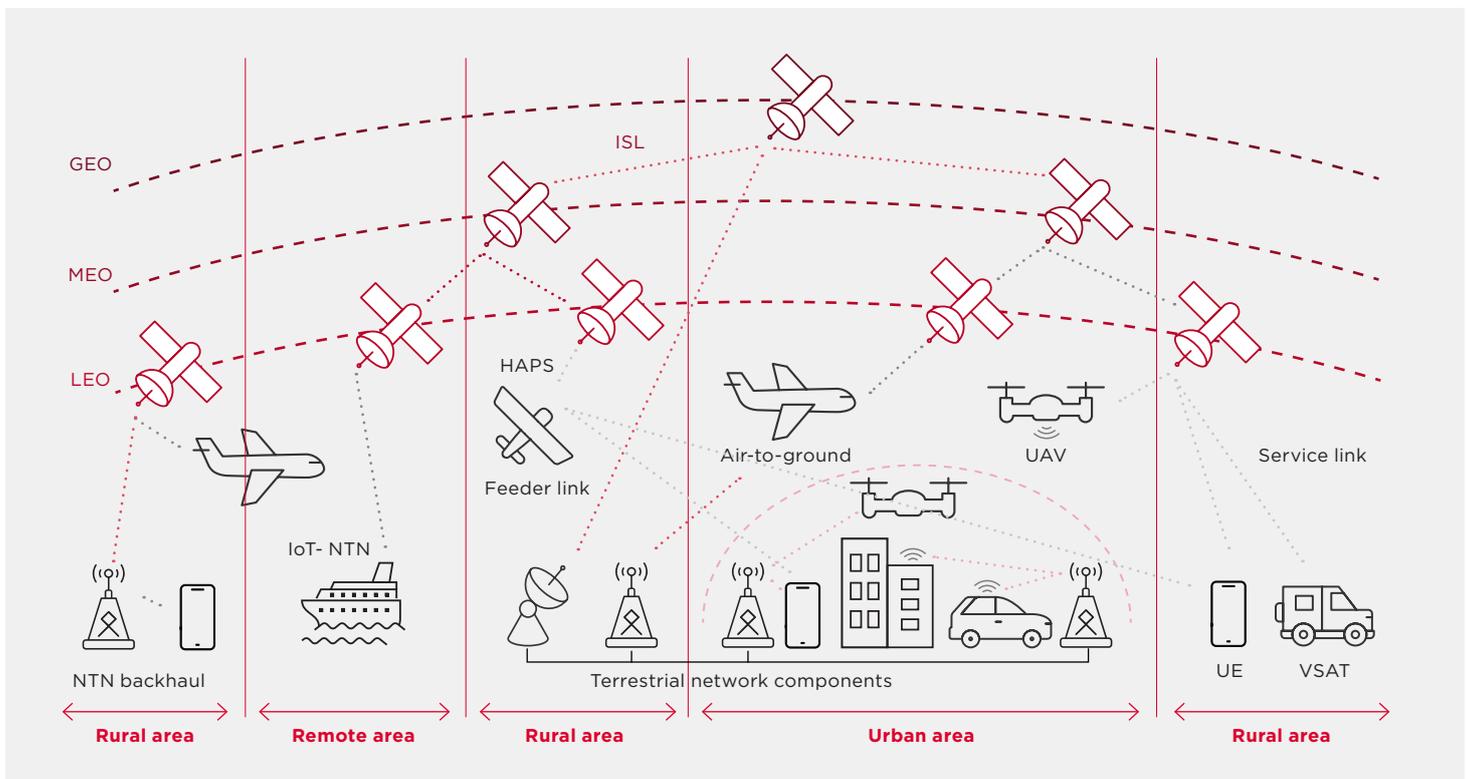
Non-terrestrial networks (NTN) could become a key component of the next generation of wireless communication technology. This document explains the role of the NTN ecosystem in extending the reach of terrestrial services, especially as NTN converge with the 5G standards. The 5G NTN ecosystem is about to combining satellites', high altitude platforms' (HAPS) and terrestrial networks' capabilities with mobile devices, enabling new complementary coverage to terrestrial cellular networks, particularly in remote locations.

## 2.2 Scope and target audience

This document provides a comprehensive overview of the NTN ecosystem, focusing on the interworking of satellite and terrestrial networks. It describes the state of the art of satellite connectivity from various perspectives, including NTN use cases and technical challenges.

As shown in Figure 1, NTN<sup>5</sup> includes networks operating above the earth's surface, involving satellites in low earth orbit (LEO), medium earth orbit (MEO) and geostationary earth orbit (GEO) constellations, and also high-altitude platforms (HAPS) and unmanned aerial systems (UAS).

**Figure 1**  
**Overview of the infrastructure employed by different NTN**



They provide connectivity in areas where terrestrial networks (TN) are unavailable or difficult to deploy, regardless of geographical location or terrain.

Please note that UAS and HAPs will not be addressed in this paper. For more information about HAPs, please refer to the GSMA whitepaper High Altitude Platform Systems: Towers in the Skies<sup>6</sup>.

NTN can support a variety of commercial wireless use-cases, including backhaul solutions, broadband, IoT applications<sup>7</sup>, narrowband internet of things (NB-IoT)<sup>8</sup>, fixed wireless access (FWA), direct-to-device (D2D) satellite connectivity and smart- mobility applications, such as vehicle communications and advanced maritime and aviation connectivity.

The first official introduction of the term NTN comes from the 3GPP Rel-17 specification, which introduced the initial work for IoT-NTN (Internet of Things) and NR-NTN (New Radio)<sup>9</sup> based on the 5G standards. The evolution in 3GPP is detailed in Chapter 4.

To promote TN-NTN interoperability, this document outlines market trends and services, while considering various challenges to NTN adoption and deployment. These challenges include global spectrum allocations, interference with terrestrial networks, user equipment (UE) mobility and power saving management, paging enhancements and incorporating features on mobile devices that can be optimised for NTN communications. Additionally, it explores how NTN services can expand both satellite and terrestrial connectivity to deliver complementary coverage to users, enhancing the partnership between MNOs, handset, terminal chipset manufacturers, and satellite providers to evolve NTN services and benefit the entire ecosystem.

To promote TN-NTN interoperability, this document outlines market trends and services, while considering various challenges to NTN adoption and deployment.

6/ <https://www.gsma.com/solutions-and-impact/technologies/networks/wp-content/uploads/2022/02/HAPS-Towers-in-the-skies-draft-v-2.1-clean.pdf>

7/ Employing Non-Terrestrial Networks for IoT Connectivity, <https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/wp-content/uploads/2024/08/Employing-Non-Terrestrial-Network-for-IoT-Connectivity.pdf>

8/ 3GPP TR 38.821, Technical Specification Group Radio Access Network; Solutions for NR to support non-terrestrial networks (NTN)

9/ 3GPP, TR 21.917, Release 17, IoT and 5G access via Satellite/Non-Terrestrial (NTN) link

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## 2.3

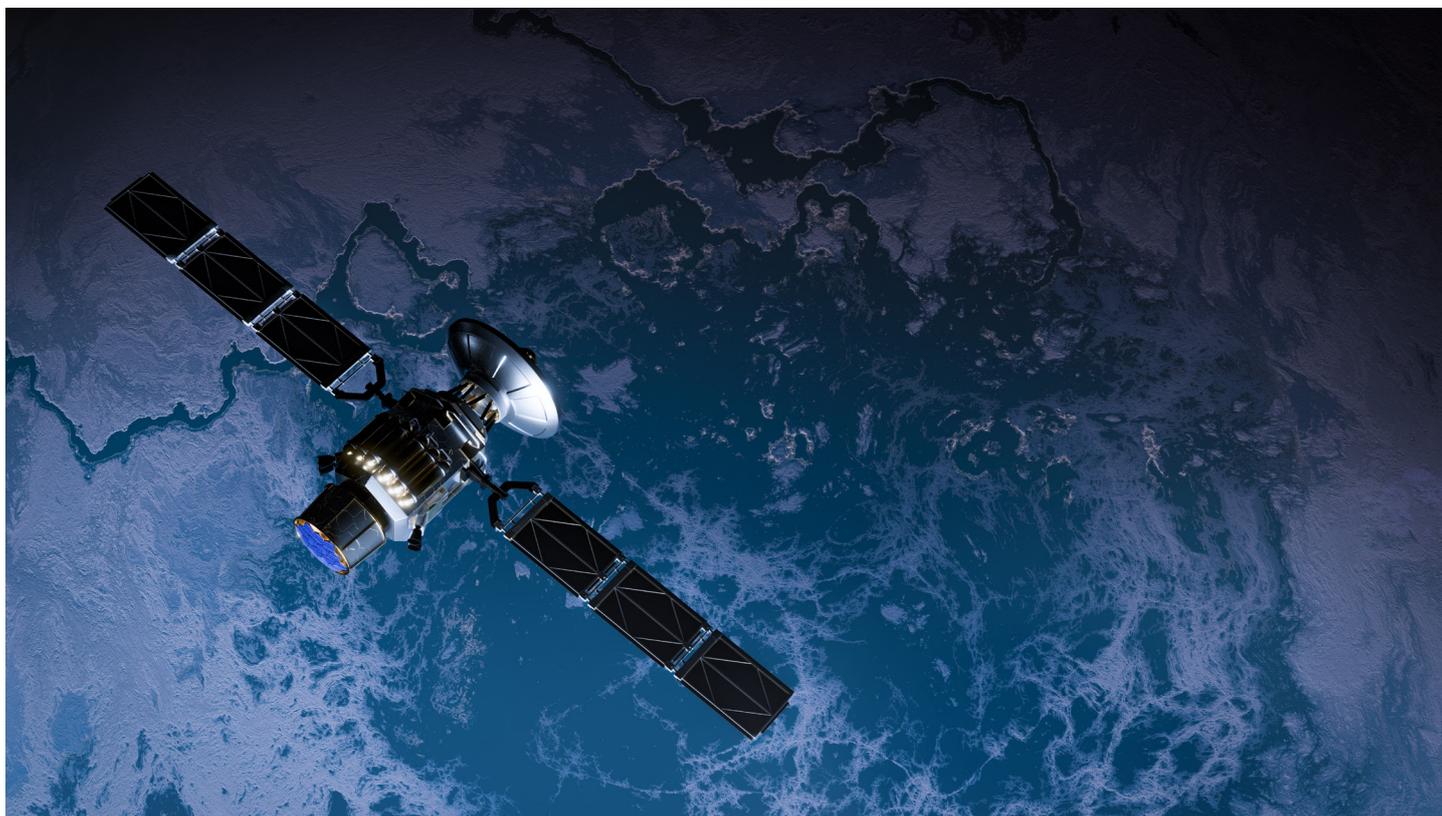
### Acknowledgments

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## 2.4

### Definitions

Term	Description
NTN	NTN combines the capabilities of satellites, uncrewed aircraft system (UAS) and high-altitude platforms (HAPS), enabling new solutions for businesses and consumers. 3GPP NTN covers IoT, broadband to handheld devices (smartphones) and non-handheld devices (VSAT).
GEO <sup>10</sup>	Geostationary earth orbit satellites operate at an altitude of approximately 35,786 km directly above the equator
LEO	Low earth orbit satellites operate at an altitude ranging from 200 km to 2,000 km
MEO	Medium earth orbit satellites operate at an altitude between 2,000 to 35,786 km and are used for commercial as well as navigation systems
HAPS <sup>10</sup>	High altitude platforms (HAPs) are aircraft or airships situated in the stratosphere (from 17 to 22 km above the ground)
UAS <sup>10</sup>	Unmanned aerial systems or unmanned aerial vehicles (UAVs) are guided autonomously and/or by remote control and carry sensors. They typically operate at an altitude of between 8 to 50 km
FWA	A fixed wireless access service uses the cellular network to deliver ultra-fast broadband
IoT	The IoT (Internet of Things) is a generic term for a network of physical objects that contain embedded technology to communicate and sense or interact with the external environment. IoT offers functions and services that go beyond the scope of traditional M2M (machine-to-machine) services
NB-IoT	NB-IoT (Narrowband-Internet of Things) is a standards-based low power wide area (LPWA) technology developed to enable a wide range of new IoT devices and services
Roaming	Roaming is defined as the ability for wireless customers to automatically make and receive voice calls, send and receive data, or access other services when travelling outside the geographical coverage area of their own home network, by means of using a visited network

<sup>10</sup>/ <https://www.3gpp.org/technologies/ntn-overview>

## 2.5

### Abbreviations

Term	Description
<b>3GPP</b>	3rd Generation Partnership Project
<b>CPE</b>	Customer premise equipment
<b>D2D</b>	Direct-to-device
<b>eMBB</b>	Enhanced mobile broadband
<b>eMTC</b>	Enhanced machine type communication
<b>FWA</b>	Fixed wireless access
<b>FSS</b>	Fixed satellite services
<b>GEO</b>	Geostationary earth orbit
<b>GSMA</b>	GSM Association
<b>GSOA</b>	Global Satellite Operator's Association
<b>HAPS</b>	High altitude platforms
<b>IoT</b>	Internet of Things
<b>ISL</b>	Inter-satellite link
<b>ITU</b>	International Telecommunications Union
<b>IMT</b>	International mobile telecommunications
<b>LEO</b>	Low earth orbit
<b>LTE-M</b>	Long-Term Evolution machine type communications
<b>MEO</b>	Medium earth orbit
<b>MNO</b>	Mobile network operator
<b>MS</b>	Mobile service
<b>MSS</b>	Mobile satellite services
<b>NB-IoT</b>	Narrowband-Internet of Things
<b>NGSO</b>	Non-geostationary satellite orbit
<b>NR</b>	New Radio
<b>NTN</b>	Non-terrestrial networks
<b>RAN</b>	Radio access network

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## 2.5

### Abbreviations

Term	Description
<b>SNO</b>	Satellite network operator
<b>TN</b>	Terrestrial network
<b>UAS</b>	Unmanned aerial systems
<b>UE</b>	User equipment
<b>VSAT</b>	Very-small-aperture terminal



# 3 Non-terrestrial Networks

## 3.1 Introduction

Non-terrestrial network (NTN) refers to a 3GPP-defined concept involving the integration of satellite and terrestrial networks for the support of seamless service continuity in diverse environments. NTN encompasses satellite-based networks operating in frequency bands allocated to mobile satellite services (MSS) or fixed satellite services (FSS). They leverage the 3GPP-defined mobile system, technology and waveforms. Thanks to this technology commonality, economies of scale can be achieved for IoT, broadband, voice and emergency services, for example, at the terminal level.

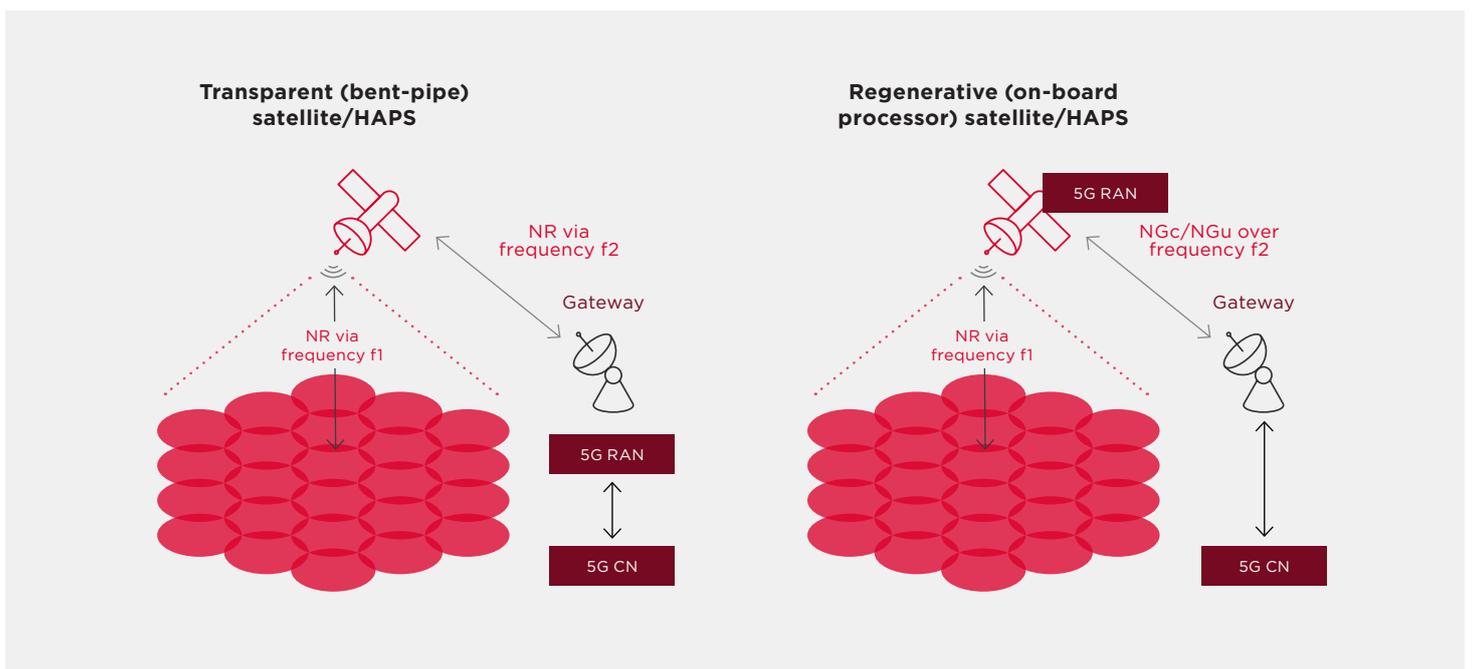
## 3.2 Technical implementation options

### Technical implementation - architecture

#### RAN architecture

For 3GPP Releases 17 and 18, only a transparent payload architecture (also known as bent-pipe architecture) was considered. However, Release 19 is considering more advanced NTN integration with 5G by standardising regenerative payload (or packet-processing payload) where the satellite can host 5G gNB functions on board and become a full base station. While both architectures have their respective advantages and limitations, the choice of deployment strategy will ultimately depend on the specific needs and priorities of satellite operators.

**Figure 2**  
The differences between a transparent and regenerative payload architecture, reference: 3GPP TS 38.811



TRANSPARENT PAYLOAD		REGENERATIVE PAYLOAD
<b>Advantages</b>	<ul style="list-style-type: none"> <li>- Lower complexity as the satellites act as repeaters amplifying and forwarding signals</li> <li>- Enables early deployment</li> <li>- Upgradability (RAN on the ground)</li> <li>- Use of ISL link possible without 3GPP adaptation</li> </ul>	<ul style="list-style-type: none"> <li>- More flexible and future-proof</li> <li>- Better performance due to support of more advanced functions, such as resource coordination and routing</li> <li>- Adaptation of 3GPP interface to support inter-satellite links</li> <li>- More resilient</li> <li>- Lower latency (termination of radio bearer in satellite)</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>- Signal degradation in case of interference or noise presence on uplink</li> <li>- Lower spectrum efficiency of backhaul link</li> </ul>	<ul style="list-style-type: none"> <li>- Higher on-board processing requirement complexity</li> <li>- Higher cost</li> <li>- Higher power consumption</li> <li>- Limited upgradability of payload</li> </ul>

### 3.3 TN-NTN interworking

There are several approaches to realise interworking between non 3GPP satellite-based network/ NTN and TN services:

1. Interworking between fully proprietary, (non 3GPP) based satellite network and 3GPP TN
2. Interworking between NTN at least partially compliant with 3GPP and 3GPP TN
3. Interworking between fully 3GPP-compliant NTN and 3GPP TN

In the first case the non-3GPP satellite and the 3GPP terrestrial networks are operating fully independently from each other. Some level of interworking can be provided based on proprietary implementation either at application level on the device (i.e. Apple/Globalstar) or at network level (i.e. Tiantong-1 solution interworking with China telecom CN).

For the second case of interworking between TN and satellite services at least partially compliant with 3GPP (i.e., some of the D2D existing services), a first level of service interworking can be realised at core network level, leveraging the well-established roaming framework.

This mode of operations can already be supported by current 3GPP specifications, though it may require some updates of the roaming model in GSMA. The interworking approach is most suitable for locations where TN and NTN serve different areas or when NTN provides different types of services.

In the third case, TN and NTN are interfaced, through the core network (CN) or even the radio access network (RAN). This interworking can occur at different levels, thus enabling different services making use of 3GPP-based mechanisms, for example inter-PLMN handovers (RAN + CN interconnections), handovers (RAN interconnection, with one Core for both TN and NTN), slicing scenarios, etc., which have been firstly defined for TN and are under study for NTN adaptation.

The main benefits of interworking between TN and fully 3GPP compliant NTN compared to the simpler interworking include the following aspects:

- Unified identification, authorisation and authentication of users to access communication services. For example, some satellite operators have already moved to SIM cards for their devices and PLMN ID for their networks, even if based on proprietary radio technologies and protocols.
- Idle mode mobility: a device not engaged in active communication (idle mode) may switch between TN and NTN networks without the need of user intervention. For a better user experience, it is desired that both networks support the same service capabilities.
- Uninterrupted user experience of a service that is using an active communication when a UE undergoes an access change without, as far as possible, the user noticing the change. In 3GPP Release 18, TN/NTN architecture aims to provide service continuity for some services.
- Multi-connectivity to take advantage of overlapping terrestrial and non-terrestrial access. Multi-connectivity can deliver optimised resource allocation through AI-powered traffic prediction and load balancing. This is currently an active area of research.

## 3.4

### D2D deployments

#### 3.4.1 3GPP Compliant D2D Deployments

3GPP compliant solutions based on IoT-NTN, using MSS spectrum (S- and L-band) for IoT and D2D services.

#### 3GPP compliant D2D communication using satellite spectrum

Existing & planned NTN deployments	Partner	Devices	Spectrum band	Use-cases	NTN Solution
Iridium (LEO)	Multiple MNO partners for NTN	Pre 3GPP Rel.19 IoT-NTN (in progress)	MSS S-band	IoT & D2D	3GPP IoT-NTN
Skylo (virtual operator GEO)	Multiple MNO/MVNO partners for NTN fallback	3GPP Rel. 17 IoT-NTN compliant devices	MSS L/S Band	IoT, D2D, eSOS, SMS	3GPP NB-IoT
EchoStar (GEO)	MNO/MVNO	3GPP Rel. 17 IoT-NTN compliant devices	MSS S-Band	IoT, D2D, SMS	3GPP IoT-NTN (NB-IoT)
EchoStar (LEO)	MNO/MVNO	3GPP NTN Rel-17, 18 (NTN compliant devices) & pre 3GPP Rel.19 (in progress)	MSS S-Band	IoT, D2D, SMS	3GPP NTN-NR and NTN-IoT (NB-IoT)
Viasat (GEO)		3GPP Rel. 17 IoT-NTN compliant devices	MSS L-band	IoT, D2D, SMS	3GPP IoT-NTN (NB-IoT)
Sateliot (LEO)	Comfone (enabling 480 MNOs and MVNOs)	3GPP Rel. 17 IoT-NTN compliant devices	MSS S-band	IoT & D2D	3GPP IoT-NTN (NB-IoT)
OQ Technology	Deutsche Telekom, O2 Telefónica	3GPP Rel. 17 IoT-NTN compliant devices	MSS S-band	IoT, D2D, SMS, Image	3GPP IoT-NTN (NB-IoT)

### 3.4.2 Proprietary D2D Deployments

1. Proprietary D2D services that use unmodified 3GPP phones, by guiding them to recognize the satellite as a terrestrial tower, and terrestrial mobile spectrum. Some satellite operators are deploying or plan to deploy LEO (low earth orbit) satellites to support these services to “unmodified” devices.
2. Proprietary D2D services that use non-3GPP radio access technologies and established MSS spectrum in the S- and L-bands have already been commercially deployed.

#### Category 1: D2D communication using terrestrial mobile spectrum bands

Existing & planned NTN deployments	Partner	Devices	Spectrum band	Use-cases	NTN Solution
Starlink	T-Mobile (US)	Unmodified LTE	1900 MHz in US	SMS, voice and data	LTE based proprietary
AST	AT&T, Verizon (US), Vodafone	Unmodified LTE	Sub 1 GHz and Sub 1-GHz	Messaging, voice and data	GSM, LTE and beyond
Lynk Global	More than 40 MNOs globally	Unmodified 2G, LTE	Sub 1-GHz	Messaging, voice and data	GSM, LTE (Radio Access)

#### Category 2: D2D communication using satellite spectrum

Existing & planned NTN deployments	Partner	Devices	Spectrum band	Use-cases	NTN Solution
Globalstar	Apple	iPhone 14 or later	MSS L-band	Emergency SOS and SMS	Proprietary
BeiDou-3 Satellite System (GEO)	China Mobile	Huawei	MSS L/S-band	SMS, Image	Proprietary
Tiantong-1 Satellite System (GEO)	China Telecom	Huawei, ZTE, Xiaomi, Oppo, Honor, Vivo, Samsung, China Telecom	MSS S-band	SMS, Voice, light data	Proprietary
Space42 (GEO)	Etisalat	Thuraya	L-band	Emergency SOS, SMS, Voice, light data	Proprietary

# Standardisation landscape

## 4.1

### Introduction

The rapid advancement of NTN is driven by a comprehensive standardisation framework that ensures interoperability, quality and widespread adoption on a global scale. NTN standards are mostly based on technical specifications produced by 3GPP, an organisation with a successful track record of integrating technologies from multiple industries and developing standards that have formed the basis for the global mobile systems of the past 25 years.

Once standards are established, it is possible to develop a complete testing regime for terminals and network components as well as certification programmes, ensuring that products placed on the market conform to strict specifications.

This chapter identifies the industry associations and regional bodies that have driven the standardisation of NTN and are already defining the future direction of NTN standards.

## 4.2

### NTN Standards

#### 4.2.1 3GPP

Starting with its Release 17, 3GPP introduced several new functionalities and features into the mobile system specifications, both in radio access network and core network to support the NTN component of 5G.

Two 3GPP-defined radio access technologies have been enhanced with NTN capabilities:

- NR-NTN is part of the 5G NR radio interface family
- IoT-NTN is an extension of the 4G NB-IoT and eMTC radio interface family

Both NR-NTN and IoT NTN meet the requirements to become a satellite component of IMT-2020 (5G) as per criteria defined in<sup>11</sup>, and have been included in the Recommendation ITU-R M. [IMT-2020-SAT. SPECS]<sup>12</sup>.

11/ "Vision, requirements and evaluation guidelines for satellite radio interface(s) of IMT 2020": <https://www.itu.int/pub/R-REP-M.2514-2022>

12/ ITU-R M. [IMT 2020-SAT.SPECS] <https://www.itu.int/md/R23-WP4B-C-0072>

## Minimum requirements of satellite components of IMT-2020

Parameter	Explanation	Satellite Requirement
Downlink peak data rate	Maximum achievable channel data rate under ideal conditions (channel bandwidth up to 30MHz)	70 Mbit/s
Uplink peak data rate		2 Mbit/s
Downlink user experienced data rate	Data Rate maintained for 9% of the time	1 Mbit/s
Uplink user experienced data rate		100 kbit/s
Area traffic capacity	Overall traffic in a coverage area	8 kbit/s/km <sup>2</sup> (DL) 1.5 kbit/s/km <sup>2</sup> (UL)

The minimum technical performance requirements of the IMT-2020 radio interface technologies are included in the Report ITU-R M.2410-0<sup>13</sup>.

## Minimum requirements of terrestrial components of IMT-2020

Parameter	Explanation	Satellite Requirement
Downlink peak data rate	Maximum achievable channel data rate under ideal conditions (in the eMBB usage scenario) bandwidth at least 100 MHz	20 Gbit/s
Uplink peak data rate		10 Gbit/s
Downlink user experienced data rate	User throughput (during active time) is defined as the number of correctly received bits (in the dense urban - eMBB test environment)	100 Mbit/s
Uplink user experienced data rate		50 Mbit/s
Area traffic capacity	Total traffic throughput served per geographic area (in the indoor hotspot - eMBB test environment)	10 Mbit/s/m <sup>2</sup> (DL)

13/ <https://www.itu.int/pub/R-REP-M.2410>

## NR-NTN key features by 3GPP

RELEASE 17	RELEASE 18	RELEASE 19
(JUN 2022)	(JUN 2024)	(DEC 2025)
<ul style="list-style-type: none"> <li>- Support of GEO, MEO and LEO constellations with GNSS-capable user equipment</li> <li>- Transparent payload</li> <li>- L-band (n256) and S-band (n255) support</li> </ul>	<ul style="list-style-type: none"> <li>- NTN coverage enhancements</li> <li>- NTN deployment above 10 GHz (Ka-band)</li> <li>- Mobility and service continuity between NTN-TN and NTN-NTN</li> <li>- Network-verified user equipment location</li> <li>- Fixed VSAT for GSO/NGSO / Mobile VSAT for GSO</li> <li>- L, S Band (n254)</li> </ul>	<ul style="list-style-type: none"> <li>- Regenerative payload</li> <li>- Downlink coverage enhancements</li> <li>- Uplink capacity/throughput enhancement</li> <li>- Notification of the service area of a broadcast service</li> <li>- LTE to NR NTN mobility</li> <li>- Mobile VSAT for NGSO</li> <li>- Support of higher Tx power UE in FR1 bands</li> <li>- Extended L Band (n253) + (n252) S band</li> <li>- Ku band support</li> </ul>

## IoT-NTN key features by 3GPP Releases

RELEASE 17	RELEASE 18	RELEASE 19
(JUN 2022)	(JUN 2024)	(DEC 2025)
<ul style="list-style-type: none"> <li>- FR1 spectrum only (b256) and (b255)</li> <li>- Support of GEO and LEO constellations with GNSS capable UEs</li> <li>- Transparent payload</li> </ul>	<ul style="list-style-type: none"> <li>- Mobility procedures</li> <li>- Disabling of HARQ feedback</li> <li>- Discontinuous coverage</li> <li>- L,S Band (b254)</li> <li>- Extended L (b253)</li> </ul>	<ul style="list-style-type: none"> <li>- Store &amp; forward operation on regenerative payload</li> <li>- Uplink capacity enhancements</li> <li>- Support of PWS</li> <li>- Support of higher Tx power UE in selected FR1 bands</li> <li>- New combinations around L/S bands</li> <li>- S Band (b252)</li> </ul>

In addition, 3GPP SA1 has already started work on service requirements for satellite access for the Release 20 NTN 5G-Advanced.

## 4.2.2 Other Key Organisations

Besides 3GPP, several other organisations have contributed to the growth of NTN by working on specific aspects close to their main domain or outlining performance requirements and guidelines. Some of the most prominent organisations are described in the table below.

### Standards-defining organisations active in NTN

ADDITIONAL ORGANISATIONS THAT HAVE CONTRIBUTED TO NTN STANDARDISATION:	
ITU	<p>The International Telecommunication Union (ITU) plays a critical role in allocating global radio spectrum and satellite orbits, developing the technical standards that ensure networks and technologies connect seamlessly, and working to improve access to digital technologies in underserved communities worldwide. Through its ITU-R sector, the ITU allocates and harmonises spectrum for satellite communications, ensuring efficient and interference-free operation of NTN. Additionally, ITU-T develops foundational recommendations that outline performance requirements and technical guidelines for integrating NTN with terrestrial networks.</p> <p>In this context, in November 2022 ITU-R started the process to define a new Recommendation on the satellite component of the radio interface(s) for IMT-2020 (see 4/LCCE/134). The procedure asked organisations to submit proposal candidate radio interface technologies fulfilling the minimum requirements defined by ITU-R in the Report M.2514, "Vision, requirements and evaluation guidelines for satellite radio interface(s) of IMT-2020."</p>
ETSI	<p>The European Telecommunications Standards Institute (ETSI) develops harmonised standards to support European regulations and comply with the Radio Equipment Directive (RED).</p> <p>These harmonised standards are European Standards (ENs) applicable to all EU/EFTA member states. The ETSI Technical Committee Technical Committee (TC) on Satellite Earth Stations and Systems (SES), along with its Working Groups TC-SES SCN and TC-SES HARM, are currently developing two new work items to ensure that, as much as possible, harmonised standards (ENs) are available to meet market needs and timelines for placing NTN-capable user equipment on the market and putting NTN D2D user equipment into service within the European Union.</p>

## 4.3

### Shaping the future of NTN standardisation

While NTN standards are being developed by 3GPP and other organisations, work is already ongoing in the industry to define the commercial and technical requirements of future NTN systems. Some prominent organisations working in this area are presented in the table below.

#### Organisations working on defining NTN commercial and technical requirements

ORGANISATION	OVERVIEW
GSMA	The GSMA is a global organisation unifying the mobile ecosystem. It supports the technology and interoperability for commercially deployed solutions. For NTN, the GSMA's primary activities are related to developing complementary conformance and field tests for user equipment, to ensure that NTN deployments meet the expected performance levels in real-world environments.
GSOA	As the representative body for the satellite industry by regional, national and international bodies, GSOA (Global Satellite Operator's Association) provides thought-leadership. GSOA provides technical contributions to pre-standardisation discussions, particularly in areas where satellite networks must align with standard and terrestrial communication standards converge.
NGMN	NGMN (Next Generation Mobile Networks) contributes to the evolution of next-generation mobile networks, with a focus on harmonising NTN and terrestrial network standards. The alliance collaborates with global stakeholders to ensure NTN can deliver robust communication solutions by overcoming challenges, such as signal propagation delays and mobility management. NGMN's focus is to provide an optimal user experience across terrestrial and non-terrestrial networks by developing future-proof mobile standards that incorporate satellite technologies.
ESA NTN Forum	ESA NTN Forum aims to bring together diverse stakeholders to foster collaboration on standardisation, consolidating requirements and addressing key areas, such as NTN experimentation and demonstration. By focusing on overcoming barriers and challenges, the initiative seeks to advocate, cooperate and promote the adoption of NTN. The Forum also supports efforts toward interoperability and certification to ensure service integration and performance across various systems and networks
TCCA	Established for 30 years, TCCA (the Critical Communications Association) is the 3GPP Market Representation Partner (MRP) for critical communications verticals comprising public safety, critical infrastructure, transport and resource industries and many other critical user groups. TCCA drives the development of standardised critical communications technology globally. For NTN, TCCA gathers and presents the use case requirements, contributes to standardisation and co-operates with the Global Certification Forum (GCF) to enable 3GPP conformance and interoperability certification for mission-critical services (MCX) including terrestrial, off-network and NTN connectivity.
MSSA	MSSA (Mobile Satellite Services Association) works to establish common standards that facilitate the integration of NTN into the global communication ecosystem, helping to drive long-term interoperability and support for advanced satellite applications

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## 4.4

### Testing and conformance

The global organisations that perform either conformance testing or define test cases and test specifications are listed in the table below. The testing is conducted by specialised organisations and by individual network operators to ensure that the terminal or network component is functioning correctly with their network setup.

#### Organisations defining test specifications for NTN

ORGANISATION	OVERVIEW
3GPP RAN5	3GPP RAN5 is responsible for creating conformance test specifications at the radio interface, including NTN NR and NTN IoT based on 3GPP core specifications. RAN5 conformance test specifications can help to identify potential bottlenecks in integrating satellite systems with terrestrial networks.
TTCN	TTCN (Testing and Test Control Notation) provides a formal language for specifying test cases for telecommunications systems, including NTN. It is used to create detailed, reproducible test specifications that can be used by manufacturers, operators, and standardisation bodies to ensure that NTN equipment complies with global standards. TTCN's role is crucial for the automated testing of complex systems, such as NTN, where multiple scenarios must be validated to ensure performance, reliability and security.
GSMA TSG	GSMA TSG supports the development of complementary conformance and field tests for 3GPP RAN5, providing additional layers of validation for NTN components in live networks. TSG's focus is on ensuring that NTN deployments meet the expected performance levels in real-world environments. Most of the test cases defined in TSG form part of the GCF and PTCRB certification criteria (see next table), as well as being used by MNOs for their own device approval processes.

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## 4.5

### Certification

#### Organisations certifying NTN devices

ORGANISATION	OVERVIEW
GCF	The GCF (Global Certification Forum) ensures that NTN terminals comply with global standards by developing certification programs. This helps facilitate global interoperability and ensures that devices and networks conform to recognised global benchmarks.
PTCRB	Focused on North America, PTCRB provides certification processes to ensure that NTN devices meet regional regulatory and technical standards. This ensures compatibility and reliable performance within the North American market.
WPC	The national radio regulatory nodal agency of the Government of India, the Wireless Planning & Coordination (WPC) Wing of the Ministry of Communications, is responsible for planning, engineering, regulating, managing and monitoring spectrum and satellite orbits, including those in GSO and non-GSO orbits.

# 5 Ecosystem

Non-terrestrial networks (NTN) are being integrated with terrestrial networks creating a new ecosystem, which will include NTN capabilities in TN devices ecosystem.

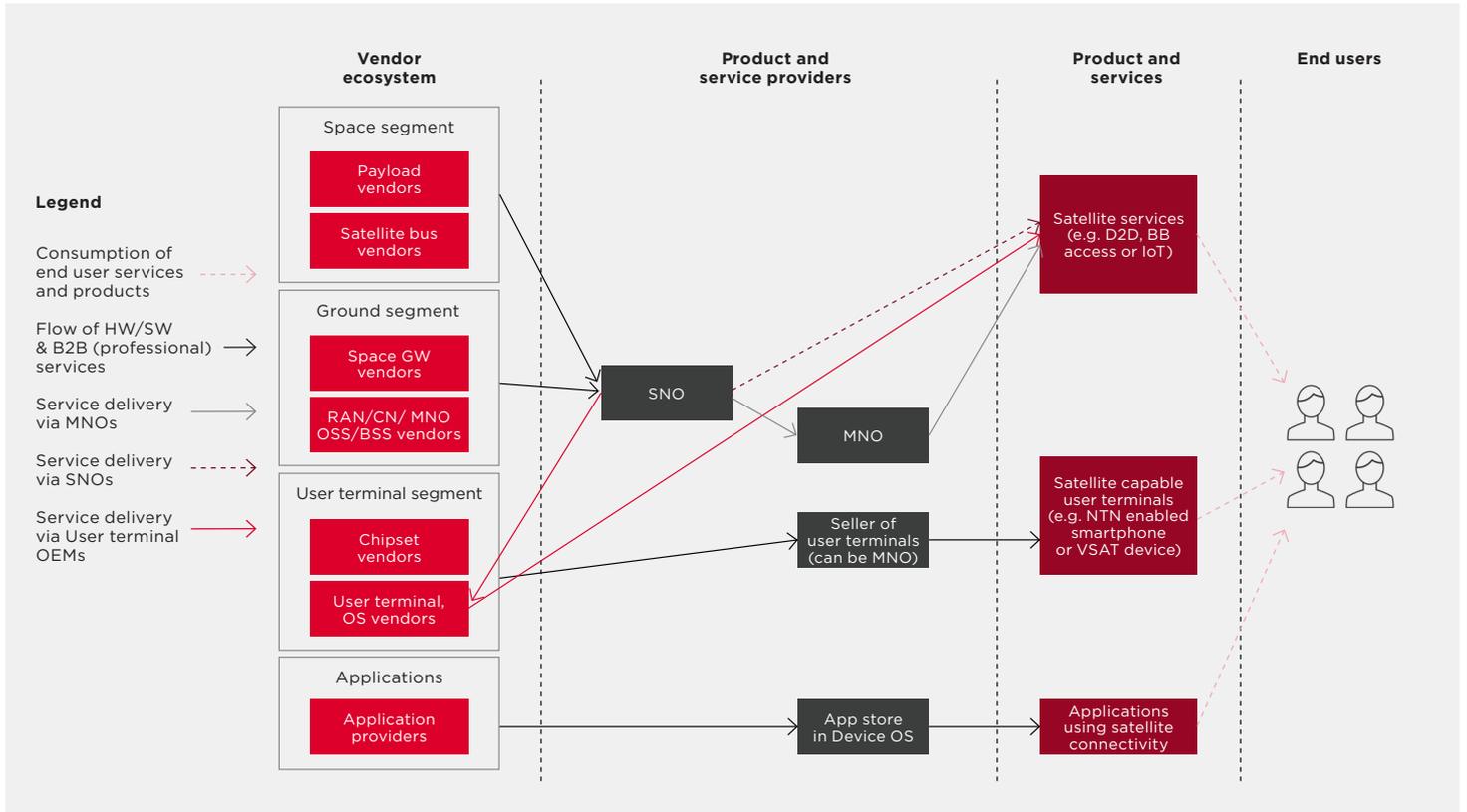
This chapter elaborates on the ecosystem players and how they interact.

Figure 3 shows the ecosystem for NTN services. It consists of:

- End users, which are typically consumers, enterprises or governmental agencies. Individuals in remote or underserved areas rely on NTN services for connectivity. Enterprises operating in remote locations, such as mining sites, at sea or in the air, use NTN services for reliable communication and data transfer. Government entities utilise NTN services for public safety, disaster recovery and national security.
- Mobile network operators (MNOs) and satellite network operators (SNOs) are the main service providers in this ecosystem. They are responsible for ensuring the quality of service and providing technical support to end users. In many cases, MNOs are also distributors of devices to end users. MNOs cooperate with SNOs to support NTN roaming services.
- The vendor ecosystem consists of a space segment in which vendors are providing the satellite bus and the satellite payload, a ground segment where vendors are providing equipment in the satellite gateway sites and the satellite operation centres (SOC). With NTN, telecom vendors provide radio access networks (RAN), core networks (CN) and equipment for network operation centres (such as operations and business support systems or OSS/BSS) enabling the deployment of 5G services.
- The user terminal ecosystem consists of chipset vendors, operating system (OS) vendors and terminal manufacturers. Chipset vendors provide the essential hardware components that enable devices to connect to NTN networks. OS vendors develop and maintain software platforms that run on these devices. Device OEMs, such as smartphone, tablet and IoT device manufacturers, produce end-user devices that access NTN services. Application providers are part of the device ecosystem, but they typically reach the end users via app stores rather than distributing their software with the sold device.

Figure 3

The NTN ecosystem and examples of service delivery flows.



For NTN to succeed, devices must be interoperable across different satellite constellations. The provision of products and services to the end user requires efficient collaboration between the telecom (RAN/CN) vendors, the chipset/device vendors and the satellite network operators to realise the necessary features and agree, implement and test satellite services.

Telecom equipment (RAN/CN) vendors and space infrastructure vendors, such as payload vendors and satellite gateway vendors, need to collaborate to create a scalable system architecture with well-defined interfaces between the different network segments. While implementations can differ between the different constellations, reuse of developed solutions results in a better aggregate business case for all involved.

There are also calls for the development of open and multi-tenanted satellite infrastructure that can sustainably scale to support the capacity demand of the industry, as well as allow governments to leverage those systems for sovereign capabilities.

Different types of satellite connections often exhibit diverse characteristics, such as differing latency, bandwidth and signal strength, which can impact the performance and user experience of applications. Application providers, device vendors and service providers (SNOs/MNOs) will benefit from working together to identify solutions to improve the user experience while making the best use of satellite connections. Users benefit from smoother, more reliable performance. This is particularly important for applications that require real-time data transmission, such as video conferencing, online gaming and remote monitoring. Optimised applications make better use of available bandwidth and reduce the strain on satellite networks. This can lead to more efficient data transmission, lower latency and better overall network performance.

## Challenges

A key challenge in the adoption of NTN technologies is the need for a broader understanding among stakeholders about how these technologies can be applied to address specific business needs. There remains some uncertainty around practical NTN applications and the value that NTN can bring to various industries. This can lead to cautious adoption. With more focused information and real-world examples, stakeholders can gain a clearer perspective on the benefits and potential return on investment (ROI) that NTN technologies offer. With greater clarity and confidence, broader and faster adoption can naturally follow.

Integrating NTN technologies into existing business ecosystems is another significant challenge. Many organisations operate with a mix of legacy systems, third-party applications and diverse technology stacks, which can create compatibility issues. Ensuring service continuity and interoperability between NTN solutions and these existing systems is crucial to avoiding disruptions in business operations. The complexity of ecosystem integration can slow adoption, particularly for organisations relying on stable, well-established technology infrastructures.

Ensuring service continuity and interoperability between NTN solutions and these existing systems is crucial to avoiding disruptions in business operations

# 6 Global Outlook

Mobile and fixed broadband access via terrestrial networks have become indispensable for consumers across the globe, transforming how we access information, connect with others, and consume entertainment. As a result, the broadband market has experienced significant growth both in terms of subscriptions sold and data usage.

However, deployment of fixed and mobile terrestrial network infrastructures could be challenging in remote areas with low population density. This opens up opportunities for complementary broadband solutions, such as satellite services that can reach challenging geographies where they can provide service in underserved areas, as well as for industries and user groups with specific requirements that terrestrial networks cannot fulfil.

According to GSMA Mobile Economy Report 2024<sup>14</sup>, there were 8.6 billion mobile subscriptions by the end of 2023, surpassing the world's population of 8.1 billion people. However, the number of unique mobile subscribers is 5.6 billion of which 4.6 billion<sup>15</sup> are mobile internet users representing 57% of the world's population.

The majority (78%) of mobile subscriptions are smartphone subscriptions. There were also 130 million FWA connections and 1.5 billion fixed

broadband connections in 2023. The number of licensed cellular IoT connections is set to reach 5.8 billion globally by 2030, up from 3.5 billion in 2023 (8% CAGR)<sup>16</sup>. Considering the high penetration of mobile communications in developed countries, the growth of mobile subscriptions tends to mirror global population growth, which is ~1% per year. More and more people are replacing feature phones with smartphones contributing to the growth rate for mobile broadband connections of approximately 3% per year<sup>17</sup>.

According to the GSMA and the ITU<sup>18</sup>, more than 95% of the world's population is today covered by mobile broadband networks (3G, 4G or newer technologies). Analysis of global population distribution reveals that is concentrated within just 20% of the Earth's landmass<sup>19</sup>.

Additionally, seas covering ~70% of the earth's area, there are large areas on Earth not covered by cellular networks. Thus, the next frontier is to explore how to reach highly mobile users (adventure travellers, commuters, boats and vehicles, among others) wherever they are on Earth and 100% of the time. Since NTN offers ubiquitous coverage regardless of topography and environmental conditions, they are a top technological candidate to bridge the coverage gaps.

14/ The Mobile Economy 2024

15/ <https://www.gsma.com/r/somic/>

16/ <https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-economy/wp-content/uploads/2024/02/260224-The-Mobile-Economy-2024.pdf>

17/ Statista Mobile internet usage worldwide - statistics & facts

18/ <https://www.itu.int/itu-d/reports/statistics/2023/10/10/ff23-mobile-network-coverage/>

19/ [https://gsoasatellite.com/reports\\_and\\_studies/satellite-solutions-for-universal-service-bridging-the-digital-divide/](https://gsoasatellite.com/reports_and_studies/satellite-solutions-for-universal-service-bridging-the-digital-divide/)

At the same time, complementary technologies such as device-to-device (D2D) communication are gaining traction, especially for supporting connectivity in dynamic and infrastructure-sparse scenarios. Together, these approaches represent a growing ecosystem of services and opportunities aimed at ensuring service connectivity for highly mobile users.

New satellite services are in development which will permit satellites to communicate directly with end user phones. This large opportunity has led to three competing tracks for direct-to-device services that differ in technology and spectrum usage and have different pros and cons:

**5G NTN** as defined by 3GPP Release 17 and subsequent. 3GPP NTN comes in two access technologies: IoT-NTN based on the NB-IoT and eMTC protocols and NR NTN based on the 5G NR protocols. NB-IoT NTN was put into commercial operation in 2023 by Skylo using GEO satellites from Viasat, TerreStar, EchoStar and Ligado. Early compatible devices include the Ulefone and Google Pixel 9 as well as the Samsung Galaxy S25 family of phones. NB-IoT NTN using LEO is launched by Sateliot. NR NTN is set to arrive as a later addition following the deployment of future LEO satellite constellations. Today, both solutions use traditional MSS spectrum (S- and L-band) for D2D services.

**Proprietary D2D services** are not using 3GPP standards. This track was introduced by Apple with the iPhone 14 using Globalstar's LEO constellation. In China, Huawei introduced messaging services over the BeiDou system with the Mate 50 phone. Now all major Chinese manufacturers (e.g. Huawei, ZTE, Xiaomi, Oppo) offer voice and messaging services using the Tiantong satellite system (GEO satellite system). These services all use established MSS spectrum in the S- and L-bands. The "proprietary D2D services" not using 3GPP standards track is primarily driven by the reuse of existing space segments/satellites, enabling a short time to market, where the need for new devices (smartphones) with proprietary (dual) chipset implementations is necessary.

**Proprietary D2D services** from reaching to unmodified 3GPP-compliant smartphones and 3GPP-compliant (terminals are 3GPP compliant and the satellite system is proprietary) by guiding them to recognize the satellite is a terrestrial tower. Thus, this solution uses a 3GPP-compliant radio interface (e.g., GSM, LTE) and terrestrial IMT spectrum bands to be able to connect to the phones. SpaceX, AST and Lynk are deploying LEO satellites with the ambition to support services to

"unmodified devices". The "proprietary D2D services to unmodified 3GPP devices" track use standard chipset implementations by reusing the 3GPP air interface without modifications, enabling a wide range of available devices. The ability of devices to access NTN services depends on how an NTN system has been designed.

There is an interest, especially in the chipset ecosystem, to drive 5G NTN as a standardised solution for the next generation. This approach ensures well tested devices, but then also requires new devices and RF chipsets to be developed. In the case of NB-IoT NTN, there is an ambition to shorten time-to-market and lower costs by reusing the existing GEO S- and L-band satellites. However, the MSS spectrum in S- and L-bands are scarce resources in the global arena.

3GPP NR NTN can also be used in the FSS spectrum (Ka band and Ku bands) for fixed broadband access use cases (then using VSAT type of devices and 5G user terminal). The EU and the IRIS2 project are likely to be early movers in implementing 5G NTN for fixed broadband access.

Satellite IoT is also set to experience strong growth in coming years, benefiting from the movement towards 3GPP technologies in the chipsets and thus also in the satellite IoT devices. Key markets for satellite IoT are set to be agriculture, energy/utilities, aquaculture and environmental monitoring.

There is also the question of technology readiness: A likely commercial model for direct-to-device partnerships is that the SNOs are providing roaming services. Although NB-IoT NTN can be more easily supported by existing networks, the narrowband nature of the technology is best aligned with use case that prioritise coverage for wide range of IoT applications over high throughput.

Satellite IoT is also set to experience strong growth in coming years, benefiting from the movement towards 3GPP technologies in the chipsets and thus also in the satellite IoT devices

# 7 Use Cases

## 7.1 Introduction

When NTN are combined with terrestrial networks, they can enhance mobile connectivity for various applications and support a wide range of innovative use cases across multiple industries.

Key sectors benefiting from NTN include telecommunications, transportation, aviation, maritime, agriculture, defence and emergency services. NTN enables broadband access in locations where conventional infrastructure is lacking, enhances the operational capabilities of various platforms, and facilitates new applications for the IoT<sup>20</sup>, the Industrial IoT, and autonomous systems and broadband on the move. As the technology matures, the potential for NTN to transform connectivity and empower a multitude of use cases will continue to grow, paving the way for smarter, more connected environments worldwide.

For simplicity, this chapter groups NTN use cases into three categories consumer, business and societal.

As the technology matures, the potential for NTN to transform connectivity and empower a multitude of use cases will continue to grow, paving the way for smarter, more connected environments worldwide.

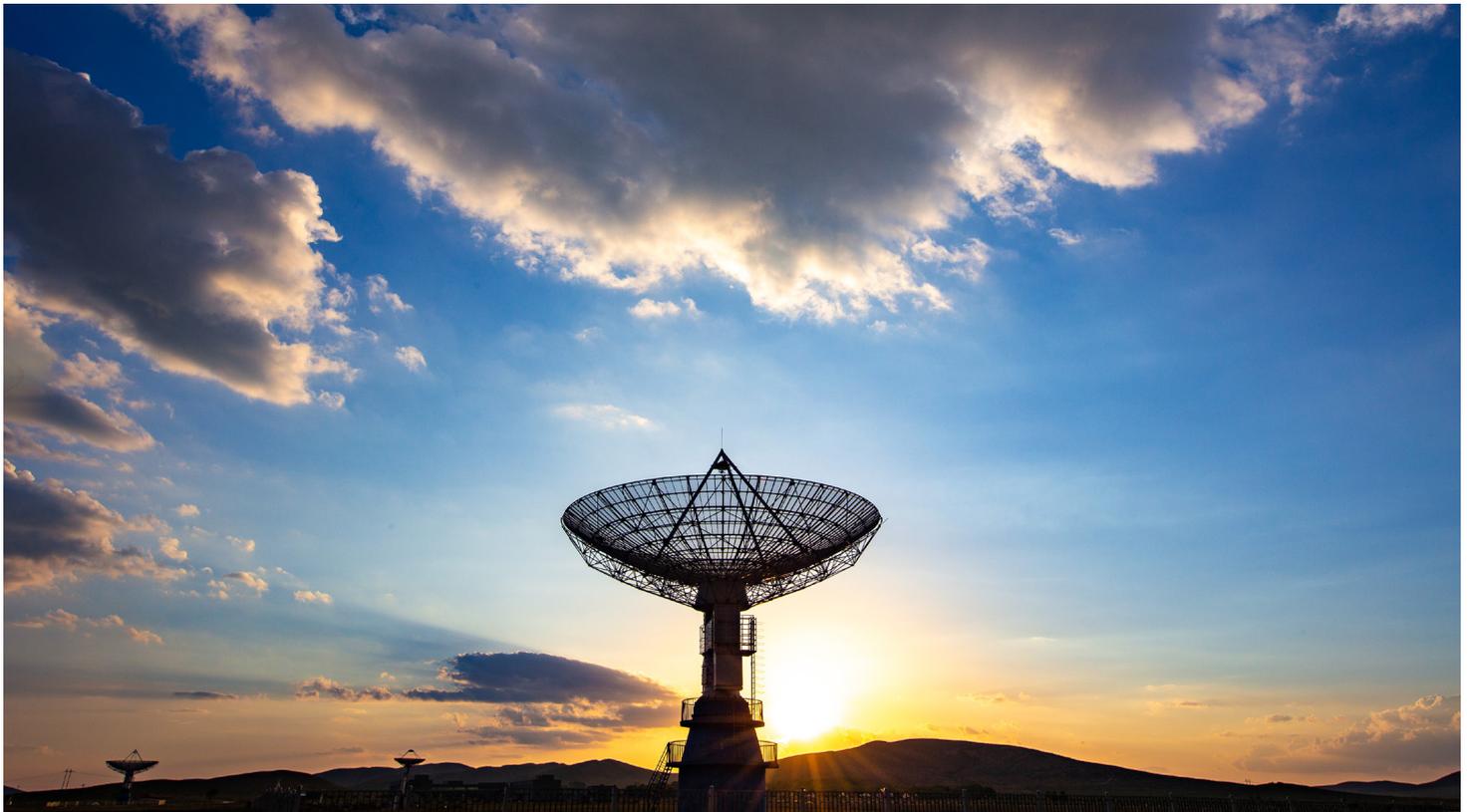
20/ <https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/wp-content/uploads/2024/08/Employing-Non-Terrestrial-Network-for-IoT-Connectivity.pdf>

## 7.2

### Consumer use cases

Satellite connectivity will be primarily utilised in locations not served adequately by the terrestrial networks or not served at all. Examples of locations where NTN access will be the primary or only means to access communication services include national parks, remote, scarcely populated locations and offshore locations.

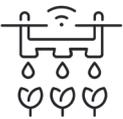
	NTN consumer use cases	Description
	Consumer broadband access	Satellites can deliver broadband internet connectivity in rural and remote areas lacking sufficient terrestrial infrastructure enabling access to online digital services
	Mobile connectivity “Direct to device”	NTN allows mobile users to enjoy services, such as voice and messaging via satellite connectivity in locations not reached by a terrestrial network



## 7.3

### Business use cases

Different industries will benefit from NTN complementing terrestrial systems through enhanced coverage and greater capacity and resilience. Below is a high-level overview of the key business use cases, demonstrating the tangible benefits of NTN technologies.

NTN business use cases	Description
	<p><b>B2B Broadband access for under-served areas</b></p> <p>NTN can connect businesses in under-served regions and hard to reach location on ground and oceans (e.g. Offshore rigs) enabling businesses critical communication to be maintained. NTN can also facilitate broadband access to healthcare infrastructure (specialists and medical services) and online learning platforms (digital educational resources) in regions with limited connectivity.</p>
	<p><b>Maritime and aviation communication</b></p> <p>For industries that operate beyond terrestrial network coverage, such as shipping and aviation, NTN can maintain communication. This can help businesses optimise operations and ensure continuous monitoring of assets across global routes. They can also provide connectivity for passengers, enhancing general broadband access to infotainment services.</p>
	<p><b>Automotive communication</b></p> <p>NTN can provide coverage when vehicle leaves terrestrial coverage, seamlessly supporting enhanced vehicle-to-everything (V2X) communication, and advanced telematics services, providing infotainment to passengers wherever they are.</p>
	<p><b>Utilities</b></p> <p>NTN extend the use of smart meters (electricity, water and gas) in areas with limited or no cellular coverage, as well enabling critical infrastructure monitoring (e.g. energy pipeline, powerline).</p>
	<p><b>Global supply chain and logistics</b></p> <p>NTN can enhance supply chain and asset management with real-time tracking and monitoring of shipments with reliable global connectivity.</p>
	<p><b>Smart agriculture</b></p> <p>NTN can provide farmers with reliable connectivity in areas with limited or no cellular coverage, enabling the use of precision farming tools that rely on IoT devices and sensors.</p>
	<p><b>Mobile networks backhaul</b></p> <p>NTN can serve as a backhaul solution for mobile networks using NTN NR. This can help MNOs to extend network reach, in remote or difficult-to-reach areas where other means of backhaul are not feasible.</p>
	<p><b>Industrial IoT</b></p> <p>NTN technologies enable widespread deployment of industrial IoT devices, in locations where traditional networks are not viable. This is particularly valuable for industries, where remote monitoring, automation and data collection are critical for optimising operations and reducing costs (e.g. open-pit mining)</p>

## 7.4

### Societal use cases

As NTN technologies advance, there is a growing recognition of their potential to address critical societal challenges, from bridging the digital divide to enhancing public safety and enabling smart cities in underserved regions.

	NTN business use cases	Description
	Disaster response and recovery and emergency communication	NTN provide resilience and extended coverage for emergency services. During natural disasters or emergencies, Satellites can quickly re-establish communication links in affected areas.
	Environment monitoring	IoT sensors, connected through NTN, can monitor environmental conditions such as air and water quality, deforestation, illegal poaching, and changes in biodiversity.



# 8 Spectrum

## 8.1 Introduction

### Background

NTN spectrum includes bands allocated to the Mobile Satellite Service (MSS), Fixed Satellite Service (FSS) and, in one specific case, terrestrial mobile service (MS) frequency bands identified for IMT, which is used for direct connectivity between satellite and user equipment.

Further spectrum for satellite services, including D2D, is being considered both by national regulators and internationally by the International Telecommunication Union (ITU) in preparation of WRC-27.

### Overview of the ITU's role

The ITU has a key and long-standing role in providing the international framework for the operation of various radiocommunication services. The ITU has responsibility for:

- ❑ Satellite-satellite and satellite-terrestrial coordination
- ❑ The definition of technical and regulatory provisions to enable sharing the same or adjacent bands

## 8.2 MSS spectrum

The 3GPP specifications envision using MSS spectrum for NTN applications. The full NTN connectivity specification was published in 2022 with Release 17 in L-band (n255: 1525-1559/1626.5-1660.5 MHz) and S-band (n256: 1980-2010/2170-2200 MHz). Release 18 encompasses the L-band (n254:1610-1626.5) and S-band (n254: 2483.5-2500 MHz) and Release 19 the L-band (n253: 1668-1675/1518-1525 MHz)<sup>21</sup> and S-band (n252: 2000-2020/2180-2200 MHz). Implementing D2D in MSS bands entails mobile chipset vendors supporting relevant MSS frequencies in smartphones, wearables and IoT devices. Although there are few available of these devices on the market at this stage, the numbers are expected to grow.

As MSS operators use different bands to terrestrial IMT systems, they can operate complementary to IMT terrestrial networks in areas with limited or no terrestrial coverage.

However, as some MSS bands overlap with IMT systems in the S-band there may be coexistence issues, which need to be considered on a case-by-case basis at national/regional level.

The upcoming World Radiocommunication Conference in 2027 (WRC-27) will discuss additional spectrum allocations for MSS – for narrow-band and standard MSS services in agenda items 1.12 and 1.14, respectively.

21/ Release 19 still in progress at the time of publication (expected in September 2025)

## Challenges

Employing MSS spectrum necessitates increased collaboration with mobile chipset vendors to support the relevant frequencies in their user equipment. It's also important to ensure coexistence between NTN and IMT networks in both L- and S-bands and in possible new spectrum.

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## 8.3

### MS Spectrum - IMT

D2D services may use terrestrial IMT bands to connect directly to standard user equipment, including both D2D and D2D IoT. This could serve as a supplemental solution to terrestrial mobile coverage in areas where such coverage is unavailable. In this case, satellite networks utilise bands licensed to MNOs, so an agreement with the MNOs holding the terrestrial spectrum license to use their spectrum is required. Using IMT spectrum would leverage standard mobile handsets. However, as these bands are not allocated to satellite services, such operation would be on a no interference, no protection basis (RR 4.4).

The IMT spectrum used by MNOs can be found in Recommendation ITU-R M.1036<sup>22</sup>. Broadly, the new work on D2D may consider the following bands: 700 MHz, 800 MHz, 850 MHz, 900 MHz, 1500 MHz, AWS (1700 MHz paired with 2100 MHz), 1800 MHz, PCS (1850 MHz paired with 1900 MHz), 2100 MHz, 2300 MHz, and 2500 MHz.

The regulatory environment for D2D using terrestrial mobile spectrum (MS) is still being developed by countries around the world. One early example of regulation comes from the United States. The US Supplemental Coverage from Space or SCS regulation<sup>23</sup> proposes the use of certain MS-IMT bands below 2 GHz for potential use with a satellite element. SCS requires that satellite operators and MNOs establish partnerships and enter into a lease arrangement or agreement for access to licensed MNO spectrum in the MNO's licensed area.

WRC-27 agenda item 1.13 considers studies on possible new allocations to MSS for direct connectivity with user equipment to complement terrestrial IMT network coverage between 694/698 MHz and 2.7 GHz, taking into account IMT frequency arrangements addressed in the most recent version of Recommendation ITU-R M.1036, and ensuring that the stations in the MSS do not cause harmful interference to, or claim protection from, stations operating in the mobile service.

22/ [https://www.itu.int/dms\\_pubrec/itu-r/rec/m/R-REC-M.1036-7-202312-!!!PDF-E.pdf](https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1036-7-202312-!!!PDF-E.pdf)

23/ <https://www.federalregister.gov/documents/2024/04/30/2024-06669/single-network-future-supplemental-coveragefrom-space-space-innovation>

## Challenges

Employing IMT spectrum requires careful considerations to ensure that the D2D service is compatible with the terrestrial mobile service and other incumbent services. The coexistence with networks in the adjacent channel, as well as interference to terrestrial mobile networks in neighbouring countries, should be considered. Spectrum is a scarce resource, and its overall efficiency needs to be guaranteed encompassing both coverage need in remote areas (where satellite can play an important role), guarantee quality of service and high-capacity requirements for terrestrial networks in non-remote areas. The regulatory environment for D2D using terrestrial mobile spectrum (MS) is still developing and a number of regulatory issues need addressing. These include:

- ❑ Definition of roles and responsibilities of satellite and mobile operators
- ❑ Definition of measures resolving interference
- ❑ Coexistence in adjacent areas, including bilateral cross-border agreements
- ❑ Coexistence of in-band and adjacent bands

The partnership between Mobile Network Operators (MNOs) and Satellite Network Operators (SNOs) is the key to bridge the technological challenges allowing interworking of terrestrial and satellites technologies.

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## 8.4 FSS Spectrum

FSS spectrum for NTN applications typically caters for fixed and mobility applications, such as homes, businesses, earth stations-in-motion, broadcasting and private data networks.

The number of FSS bands, including Ku- and Ka-bands, designated by 3GPP for NTN is increasing, with the most recent development being the approval of the workplan to support the Ku band. Overall, while the current industry and regulatory focus remains on using MSS and terrestrial spectrum for NTN, efforts to leverage FSS satellite frequencies in the Ka- and Ku bands for 5G services are gradually advancing.

3GPP Release 18 focused on the development and evolution of cellular technologies, such as 5G, and addressed the interworking of NTN with terrestrial 5G infrastructure. One of the NTN bands included was the FSS Ka-band (17.3-20.2 GHz/27.5 GHz to 30 GHz). It provides a link in the end-to-end communication chain from mobile devices to the core network, ensuring service connectivity across terrestrial and satellite infrastructure

Other sub-bands in the Ka-band are used for specific purposes, such as feeder links and inter-satellite communication.

Furthermore, 3GPP<sup>24</sup> is also undertaking work to harness the Ku-band frequencies. While in ITU Regions 1 and 3, this work focuses on 10.70-12.75 GHz/12.75-13.25 and 13.75-14.50 GHz, in ITU Region 2 there is a slight difference of 50 MHz, covering 10.70-12.70 GHz/12.70-13.25 GHz and 13.75-14.50 GHz.

Systems operating in the Ku-band today provide all types of services, including broadband use cases around the world, from internet access to regional cellular connectivity to consistent connectivity for planes, ships and ground vehicles.

## Challenges

Satellites in the FSS spectrum must operate in a manner that avoids interference with other users of the radio spectrum. This includes coordination between GSO and NGSO satellites, as well as terrestrial networks. Satellite systems in the FSS spectrum are subject to international agreements, and their deployment must ensure coordination between countries to avoid interference.

**Systems operating in the Ku-band today provide all types of services, including broadband use cases around the world, from internet access to regional cellular connectivity to consistent connectivity for planes, ships and ground vehicles.**

24/ Ku Band WID approved at the 3GPP RAN#104 in Shanghai in June 20th 2024

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## 9.1

### Non-terrestrial terminals

Different types of NTN terminals are being developed to serve different use cases: small low-power IoT devices based on NB-IoT; compact user terminals for individual and residential broadband connectivity, high capacity and high reliability terminals for use in enterprise and industrial applications, as well as terminals to connect moving platforms, such as airplanes or vehicles. Being specifically designed to support connectivity via NTN access, these devices will address as far as possible design constraints, and user experience requirements adopting technical solutions specified by 3GPP.

The success and adoption of services that use satellite communications will depend in large part on the availability of terminals that meet the needs of the operators and users. Terminal design, both in terms of hardware and software, needs to ensure that developers can offer services and products that utilise NTN access.

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## 9.2

### Historical Satellite Terminals

In the context of satellite telecommunications, the most common type of terminal for satellite broadband access until recently was the VSAT (very small aperture terminal). A VSAT is typically equipped with a small parabolic dish (60cm to 90cm in diameter) that uses geostationary satellites to establish a bidirectional connection to data servers. More recently VSATs have also been equipped with mechanical steerable antennas, as well as phased array antennas, which do not contain any mechanical moving parts and are more suitable for use on mobile platforms, such as vehicles, planes and ships. Today, VSATs can achieve data rates ranging from tens to hundreds of Mbps and typically operate in the Ku and Ka bands.

From the second half of the 2010s, several companies started to deploy satellites in NGSO orbit instead of only GSO while transitioning towards terminals with electronically steered array (ESA) antennas which are compatible with both geostationary (GSO) and low-earth orbit (LEO) constellations.

## 9.3

### NTN Terminals Design Requirements

As discussed in chapter 7 different satellite communication services employ different types of terminals which fulfil different performance requirements. At a high level, there are two classes of terminals - one serving the personal communication needs of cellular customers, and one serving the needs of vertical industries. Satellite communication services for cellular customers, can be further distinguished into four traffic scenarios: phone direct-to-satellite, vehicle direct-to-satellite, aeronautical and maritime and fixed wireless access via satellite. For each of these scenarios, there are several key performance indicators.

- **Phone direct-to-satellite.** To meet users' requirements to be "never lost and always online", smartphones need to directly connect to satellite. Due to the existing appearance of smartphones and user habits, phone-direct-to-satellite terminals need to include built-in antennas and exhibit reasonable battery consumption when using NTN.
- **Vehicle direct-to-satellite.** Vehicles can support satellite communication via vehicle-mounted satellite communication modules. Although the antenna design needs to integrate with the shape of vehicles, the design constraints are much more relaxed compared to phone-direct-to-satellite, allowing for higher data rates and a large portfolio of communication services. Satellite communication modules in vehicles also have less stringent power-saving requirements than those for mobile phones, which simplifies the design and increases performance. On the other hand, the automotive industry has its own stringent requirements in terms of accommodation, aesthetics, certification and safety. More information on the integration of satellite communications into vehicles can be found in the 5GAA report Maximising the Benefit of Future Satellite Communications for Automotive<sup>25</sup>.

- **Aeronautical and maritime.** This type of terminal generally employs low profile flat panel antennas which are mounted on the top of aircrafts and vessels. They use electronically steered beams to provide connectivity. The design isn't constrained by either aesthetics or battery consumption.
- **FWA via satellite.** As a FWA device is generally connected to mains power and has no particular requirements with respect to its appearance, there are few limitations on the design of these terminals.

Terminals employed in vertical industries will have different design goals depending on the specific application. These goals generally do not present major aesthetics challenges, though the position and size of the antenna and power consumption are both factors that need to be taken into account.

Three factors need to be considered in the design of a terminal in order to optimise the user experience: availability of the access, latency and throughput.

The different services that can be provided via satellite access would have different user experience requirements. For voice services, for example, the latency should remain below 400 ms and the data rate should be above 1 kbps (for reference the common data rate of a voice call in terrestrial networks ranges from 5.2 kbps in extremely poor radio conditions to 48 kbps). For many data services, latency is not critical. However, quite a high throughput may be required to ensure a good user experience. For reference, the typical data service provided to a pedestrian requires a downlink data rate of 1 Mbps and an uplink data rate of 100 kbps. A video surveillance data service on the other hand requires a downlink data rate of 500 Kbps and an uplink data rate of 3 Mbps.

25/ "Maximising the benefit of future satellite communications for automotive", 5GAA, <https://5gaa.org/content/uploads/2024/09/5gaa-ntn-ras-technical-report.pdf>

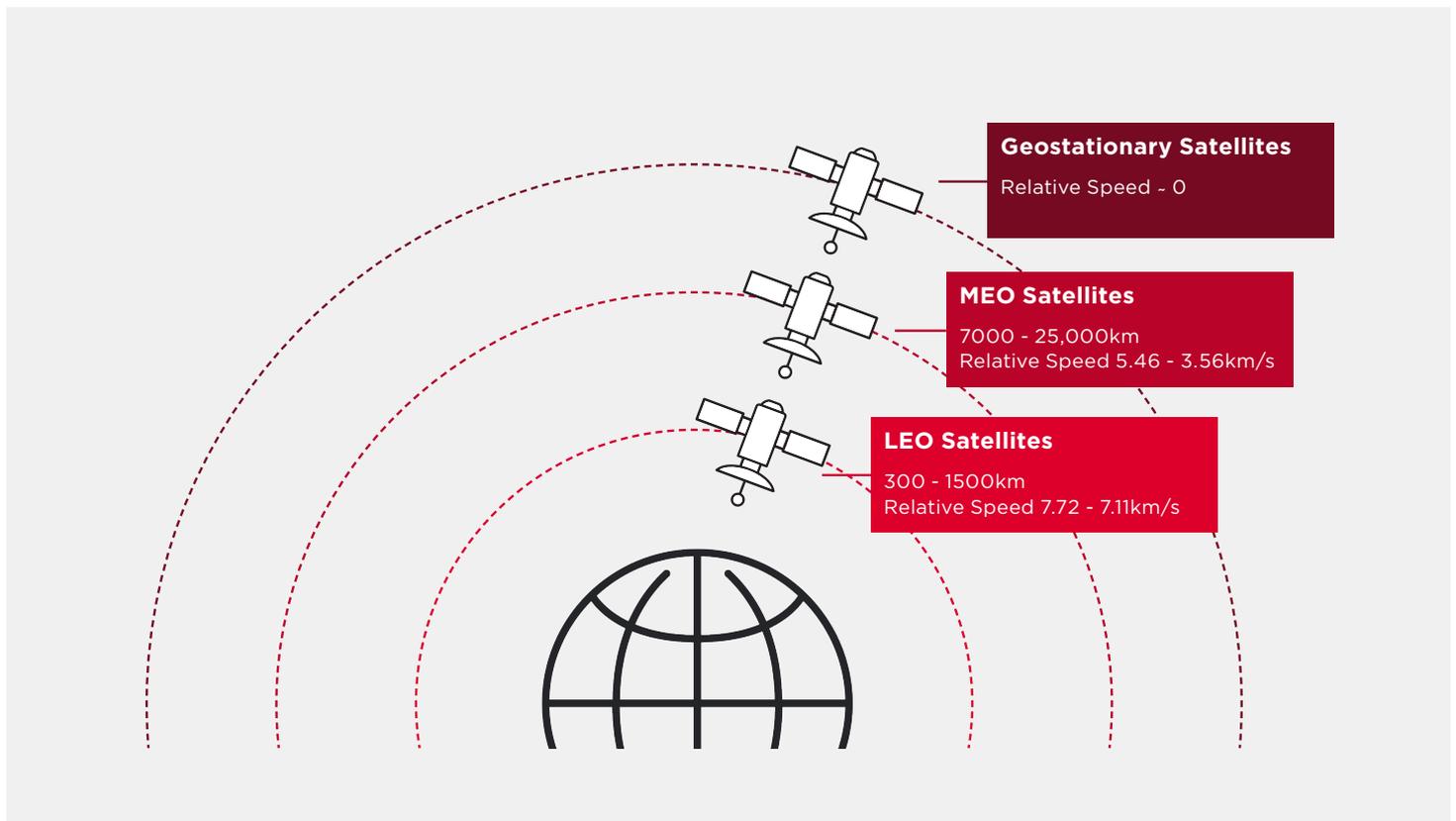
## 9.4

### NTN Terminals Design challenge

Satellite position and movement: Unlike terrestrial networks, where the base station is in most cases stationary and relatively close to the device, the relative speed of the satellite compared to an observer on the ground can be quite high, especially when considering LEO orbits, and so is the distance. This challenge is visually represented in Figure 4.

Figure 4

The operating height of an artificial satellite and relative speed from a ground observer



The relative speed results in Doppler shift and rapid changes in the angle of arrival. If not taken into consideration, the effects of the high relative speed can greatly reduce the quality of the connection, therefore specific modifications to the receiver and transmitter will need to be factored in when designing a terminal that is capable of satellite access.

**Propagation loss:** The greater distance between transmitter and receiver, the higher the propagation loss - only a small fraction of the transmit power

arrives at the receiver. In a terminal dedicated to satellite communications (e.g. VSAT), the transmission loss can be compensated by the high-gain antennas and increased transmit power, but this option is not available for handheld and IoT terminals due to power consumption and design constraints.

Focusing on TN-NTN integrated terminals (e.g. smartphones) the design constraints result in the following challenges.

- **Integrated miniaturised antenna.** Support of satellite communications capabilities with integrated antennas requires advanced technologies to improve the terminal antenna gain, including micro-antennas, high performance built-in antennas and strategies to optimise mobile phone MIMO antenna arrays. In the context of 3GPP NTN, many of these challenges have been addressed, particularly to mitigate propagation loss — uplink enhancements completed in Release 18, while downlink enhancements are being tackled in Release 19. Furthermore, the introduction of High-Power User Equipment (HPUE) in Release 19 provides an additional boost in performance, especially at the beam edge.
- **Multi-mode and multi-frequency integration.** Support of both terrestrial cellular communications and satellite communications results in the particularly challenging situation of having to cater for a very large number of frequency bands and access types. An extremely advanced set of components, including baseband chip, radio frequency chip and radio frequency front-end, are needed to ensure user experience expectations are met.
- **Improving link budget.** The link budget calculate how much of the transmitted power actually reaches the receiver. The parameters determining the path loss include distance, transmit power, frequency band used, antenna performance of both transmitter and receiver, and thermal noise. In this respect, the following design challenges need to be considered:
  - **High gain/wide angle antenna in terminal.** The antenna on the terminal should strike the optimal balance between high gain (to amplify the received signal) and wide reception angle (to reduce sensitivity to movement). Unfortunately, these two targets cannot be met concurrently since the wider the angle of the antenna the lower is the gain.
  - **Receiver noise power reduction.** Using high performance and expensive low-noise amplifiers, higher performance filters and computationally expensive noise reduction algorithms, it is possible to reduce the noise and improve the link budget.

- **Better tracking and alignment in terminals.** By providing means in the terminal to keep a good alignment with satellite (that could be fast moving), the path loss could be significantly reduced. However, as this problem does not affect terrestrial networks, further research is needed.

To improve the uplink link budget, the following challenges should be addressed:

- **Higher transmit power.** Higher terminal transmit power would directly improve the uplink. However, for handheld terminals, in particular, there are very stringent limits to the maximum power that can be transmitted.
- **Computational power** to operate coding schemes such as LDPC, or convolutional codes with a rate that improves robustness against errors and provides a significant amount of error correction.
- **High efficiency power amplifier.** The power amplifier is a core component of the radio frequency transmitter of wireless communication equipment and has a major impact on its performance and power consumption. As for the antenna, balancing high power good linearity, high efficiency against power consumption and heat generation is a difficult task. Heat generation is particularly problematic as terminals can reach temperatures that are not acceptable for handheld use cases, as well as increasing the noise. Furthermore, linearity of the power amplifier allows the use of higher order modulation schemes which can improve the overall throughput.
- **Power saving mechanism.** As smartphones and IoT terminals already face the challenge of limited battery life, efforts must be made to improve this metric. This can be achieved with more efficient and larger batteries (within design constraints); by improving the integration of components for TN and NTN in the device and through software that implements advanced power saving mechanisms (both 3GPP defined and vendor-specific).

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## 9.5

# Current trends and future evolution of terminals

### 9.5.1 Technology trajectory

3GPP NTN technology has now reached its third iteration with Release 19 scheduled to be functionally completed by September of 2025. Future 3GPP releases are likely to add more functionality in the terminals, based on market demand and technical feasibility. Some of these key enhancements that are set to be part of 5G Advanced include:

- ❑ GNSS resilient/less operation that removes the need for the terminal to support GNSS onboard.
- ❑ Robust notification: due to the very limited power margin, NTN terminals usually require line of sight, however smartphones are often placed in pockets, backpacks and so on, compromising the signal reception. 3GPP is considering support for a highly reliable and efficient notification that can inform the user of incoming calls or messages, thereby improving user reachability from the satellite access system.
- ❑ Extension of support of IoT-NTN to 5G. Currently, 3GPP has specified some IoT services only for NB-IoT. The next step would be to take advantage of the capabilities and features of the 5G radio access technology.

The progress of the technology is expected to facilitate the partial mitigation of certain challenges outlined in the previous section.

### 9.5.2 Services trajectory

During 2025, terminals that are compliant with Release 17 and Release 18 are available on the market. In future, Release 19 will include more smart-mobility broadband applications utilising the Ku band. MediaTek showcased a 5G-Advanced NR-NTN satellite prototype chip achieving over 100Mbps data throughput under LEO satellite emulation for Ku-band broadband connections in automotive and broader types of terminals at MWC 2024 in Barcelona. With suitable terminals, services such as broadcasting via satellite, and Internet of things with satellite networks could be deployed.

Looking further out to the rest of the decade, more services that are being specified today will be added to the portfolio of NTN communication services that the terminal will be able to support. Most notably they will include:

- **Optimal media routing of voice and video traffic:** When two users are served by the same satellite constellation, a service may be routed directly from one terminal to another without crossing the ground network. This will result in greatly reduced latency and could enable more advanced mission critical communication services that can in theory operate without the need of a connection between the satellite and a ground station.
  
- **IMS voice over geostationary satellites:** When the smartphone is connecting to a GSO satellite, it can support short message service based on the current IoT-NTN. From a standards perspective, however, IMS-based telephony service is not supported. Support of a voice call via GSO will require defining a low bit rate codec which is more suitable for use over GSO, optimising the signalling and introducing efficient packet header compression. Without these changes, it would still be possible to establish an IMS voice call, but the service would suffer from very high call set-up delay and poor capacity - the number of concurrent voice calls via a satellite will be low. While the quality may not be at par with current VoLTE or voice via LEO, it would still be suitable to provide connectivity globally.



# 10 What's next?

As NTN gains momentum in the industry with several planned deployments, research should focus on areas, such as expanded capability, further performance improvements, integration between satellite and terrestrial networks, which will be the key to opening future communication systems. Also, enhanced NTN capabilities and use cases should be an integral component of the future NTN standards from the outset ensuring that they are a central part of the industry's roadmap.

Adoption of 3GPP Release 19 and subsequent releases will enable regenerative payload, Ku band support and other L/S bands downlink coverage enhancements, uplink capacity and throughput enhancements, support of higher Tx power for UE in FR1 bands, and more robust mobility management for NTN, whilst maintaining backwards-compatibility with the already deployed NTN. Future NTN will be integrated with terrestrial networks, enabling, service continuity when the terminal moves between terrestrial and satellite coverage areas.

More and more devices will be capable to connect to both terrestrial and satellite networks, owing to the advancements in chipset technology, allowing users to access both networks. Satellite-based handheld devices integration of precise positioning, navigation, and timing (PNT) services over NTN for autonomous systems and critical infrastructure are some of the key areas that will evolve in the next few years.

Multi-orbit constellations, and inter-satellite links (ISLs) will enable direct satellite-to-satellite communication for dependency on ground earth stations. As constellations grow, robust policies for debris mitigation and collision avoidance will be critical.

More and more devices will be capable to connect to both terrestrial and satellite networks, owing to the advancements in chipset technology, allowing users to access both networks.

An important consideration for the broader adoption of NTN technologies is the complexity of the regulatory landscape. Businesses seeking to implement NTN must navigate a range of regulations and industry standards, which can differ significantly across regions. Ensuring compliance with these evolving regulations, particularly for organisations operating across multiple jurisdictions, can present challenges.

Looking ahead, NTN is not only contributing to shape the trajectory of 5G but is also poised to become a foundational pillar in the evolution toward 6G—where seamless, global connectivity is expected to be one of defining features of the next-generation network landscape.



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