# ATU-R REPORT

*relating to*

## DEVELOPMENTS IN SATELLITE COMMUNICATIONS

*numbered*

**ATU-R Report 006-0**

**JUNE 2025**

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## SCOPE OF THE REPORT

The satellite communications industry is experiencing unprecedented innovation and growth enabled by new emerging and evolving technologies such as advancements in multi-orbit architectures, direct-to-device connectivity, and the integration of artificial intelligence.

This report provides a comprehensive overview and accessible resource that captures these developments. It provides an up-to-date overview of the latest satellite technology innovations and information on technological advancements, ensuring that ATU Member countries remain at the forefront of industry knowledge. This is crucial in a rapidly changing environment where staying informed can mean the difference between leading and lagging.

Further, the report highlights the potential impact of these technologies to transform global connectivity. As satellite communications play an increasingly vital role in bridging the digital divide and enabling connectivity in all areas, including remote and underserved areas, understanding the full potential of emerging technologies becomes essential for strategic planning and decision-making.

As African countries consider future investments, research directions, and product development initiatives, having a clear picture of emerging trends and their potential impact will be crucial. This report serves as a critical resource to equip policy makers, regulators and industry stakeholders with the knowledge needed to navigate the future of satellite technologies coupled with its integration to terrestrial solutions, and guiding ATU members' strategic planning and decision-making processes.

Further, the report explores the technical, operational, and economic implications of these technologies, highlighting their role in expanding broadband access, enabling IoT scalability, and supporting wireless broadband backhaul including 5G/IMT-2020 in remote areas. Additionally, the report addresses regulatory and standardization challenges, offering insights to guide ATU Member States in formulating policies to harness satellite technologies for sustainable development and inclusive digital growth.

**EXECUTIVE SUMMARY**

The satellite communications industry is undergoing a paradigm shift, driven by innovative solutions. The development of multi-orbit systems combines the broad coverage of GEO satellites with the low-latency benefits of LEO and MEO constellations, enabling service delivery across diverse applications.

Direct-to-device (D2D) connectivity, standardized through 3GPP's NTN frameworks, enables devices to communicate directly with satellites, extending coverage to unserved and underserved areas.

In addition, advancements in ground segments such as flat-panel antennas and interoperable protocols are reducing costs and improving performance, making satellite solutions more accessible. Artificial intelligence and inter-satellite links further optimize satellite network efficiency, while in-orbit servicing extends satellite lifespans, reducing operational costs.

This report highlights how these new satellite technologies enhance global connectivity, improve capacity, and meet the growing needs of various users, including enterprises, governments, and individuals. The document serves as a guide to understanding how these innovations are making satellite communications more versatile, cost-effective, and integral part of the future of global connectivity.

For ATU Member States, these technologies present transformative opportunities: satellite backhaul can accelerate wireless technologies including 5G deployment in rural areas, satellite IoT networks can enable a wide range of use cases including environmental monitoring, smart agriculture and other economic activities, and hybrid orbital systems can bolster disaster resilience.

To fully realize this potential, it is recommended that ATU Member States proactively develop and harmonise policies and regulations, that among others, facilitate investment in next-generation satellite infrastructure. This report underscores the need for ATU Members States and other stakeholders, to embrace these technologies to ensure no community is left behind in the digital era.

## 1. BACKGROUND

Satellite communication refers to the use of orbiting satellites to transmit signals and data between different points on Earth. These satellites are primarily categorized by their orbital characteristics and altitude. Geostationary Orbit (GEO) satellites, positioned approximately 36,000 km above the equator, remain fixed relative to the Earth's surface, making them ideal for broadcasting and fixed communication services. Medium Earth Orbit (MEO) satellites, operate between 2,000 km and 36,000 km, and are commonly used for navigation systems like GPS and Galileo. Low Earth Orbit (LEO) satellites, operate at altitudes of 300 km to 2,000 km and offer low-latency connectivity and are increasingly deployed to provide broadband services, earth observation, and emerging Direct-to-Device (D2D) services. Highly Elliptical Orbit (HEO) satellites provide specialized coverage for high-latitude regions where GEO satellites are less effective.

Satellite services are also grouped according to functionality, Fixed Satellite Services (FSS), facilitate communication between fixed ground stations (e.g., VSAT networks and backbone connectivity), Broadcasting Satellite Services (BSS), dedicated to television and radio transmissions for fixed or mobile users and Mobile Satellite Service (MSS) which enables communication with mobile users on land, sea, or in the air, supporting services such as satellite phones and maritime/aviation safety applications.

Satellite communications have long been at the forefront of global connectivity, providing critical Internet, broadcast television and communication services to users at home, in the office and on the move. Satellites support weather forecasting (providing real-time information about weather patterns and storm systems), remote sensing (collecting data and monitoring events on the Earth's surface, such as oceanic and coastal phenomena and wildfires), defence and security, and PNT (Positioning, Navigation and Timing). Satellites provide lifelines for remote regions, disaster-stricken areas, and maritime and aviation industries.

In recent years, new satellite technologies are bringing increased choice for connectivity and more competition in the telecommunications industry offering greater capabilities to users. Those technologies are characterized by significant advancements that are reshaping the landscape of satellite communications and global connectivity. These innovations focus on enhancing capabilities, reducing costs, and increasing accessibility across various sectors and enable scalable, cost-effective and reliable connectivity solutions that can respond to a plurality of needs.

## 2. NON-TERRESTRIAL NETWORKS

Non-Terrestrial Networks (NTNs) are defined by the 3rd Generation Partnership Project (3GPP) as networks or segments of networks that use either Uncrewed Aircraft Systems (UAS) such as HAPS known as air-based NTN or satellites known as satellite based NTN to support seamless service continuity across different environments, addressing connectivity needs in regions where traditional Terrestrial Networks (TNs) are unavailable or unreliable. This section will focus on satellite-based NTN and throughout the document the acronym NTN will mean satellite-based NTN.

At the initial phase within 3GPP, 5G standardization (Release-15 and Release-16) focused mainly on the development of the terrestrial 5G component. From Release-17, NTNs component began to be integrated in the 5G system. 3GPP members (representatives of industry verticals, equipment/network vendors, mobile and satellite operators) recognized the benefits of 5G NTNs as it enables service provisioning beyond the coverage of 5G Terrestrial Network component.

NTNs encompass 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 and technology. Thanks to this technology commonality, economies of scale can be achieved for Direct-to-Device (D2D), Internet of Things (IoT), broadband, mobile VSAT, voice and emergency services, for example, at the terminal level.

### 1.1 Direct-to-Device

Historically, satellite to device connectivity was provided by legacy satellite networks, primarily using geostationary satellites (GSO). These services were limited to basic voice telephony and text messaging, typically offered through dedicated devices distinct from standard mobile phones. Due to high latency and limited bandwidth, such systems were unsuitable for real-time or data-intensive applications, and their use remained confined to niche scenarios such as emergency communications.

However, recent advancements in satellite technology in both GSO and NGSO, particularly the deployment of the new generation of Low Earth Orbit (LEO) satellite constellations have transformed D2D into a practical and scalable solution. Modern NTN systems now support direct connectivity with unmodified smartphones, delivering lower latency, higher data throughput, and improved signal reliability. This evolution enables services such as text, voice, and even broadband data to be delivered directly from space, extending mobile coverage to rural, remote, and disaster-affected areas without relying on traditional terrestrial infrastructure.

A noteworthy aspect of Modern NTNs is Direct-to-Device (D2D) connectivity, which allows satellites to connect directly to devices like smartphones, facilitating seamless communication without the need for traditional terrestrial infrastructure. D2D connectivity leverages existing satellite technologies to enhance mobile communication capabilities, especially in areas where terrestrial networks are sparse or non-existent.

There are two different approaches for Modern D2D connectivity:
The first utilizes spectrum already allocated to the Mobile Satellite Service (MSS) and generally leverages 3GPP NTN standard specifications enabling features to be implemented in both the satellite Radio Access Network (RAN) and User Equipment (UE), ensuring compatibility and multi-vendor interoperability, and possible integration across terrestrial and non-terrestrial radio interfaces in the future. It utilises existing allocations and standardized protocols and frameworks, capitalizing on 3GPP NTN specifications for seamless terrestrial and satellite connectivity networks across various applications, with no additional changes to ITU Radio

Regulations. This approach necessitates increased collaboration with mobile chipset vendors to develop and support relevant MSS frequencies in their user equipment.

The second approach aims at addressing already commercialised mobile handsets (i.e., UE pre 3GPP Release–17 specifications) by utilizing spectrum allocated to the Mobile Service (MS). This approach requires careful considerations to ensure that the D2D service is compatible with the terrestrial mobile service. It provides a solution to complement mobile coverage, addressing gaps in connectivity where traditional networks fall short, potentially using off-the-shelf mobile handsets. However, the technical requirements and regulatory frameworks of these approaches are under development

Overall, the evolution of D2D paves the way for a more interconnected world, enhancing access to reliable communication services across diverse environments. By integrating satellite and mobile ecosystems, D2D connectivity promises to bridge significant coverage gaps, (approximately 2.6 Bn people globally remain offline[1]), improve user experiences and expand market opportunities in telecommunications.

### 1.2 Internet of Things (IoT)

The Internet of Things (IoT) is significantly enhanced by the capabilities provided by Non-Terrestrial Networks (NTNs), which encompass satellite communications integrated with Terrestrial Networks. As the number of connected devices is projected to skyrocket, with estimates reaching over 20 billion[2], NTNs are critical for addressing the limitations of Terrestrial Networks, particularly in remote or underserved areas.

Terrestrial and satellite IoT networks are so complementary to each other that standardization bodies have been working on creating a fully integrated IoT ecosystem. The advantages of high data rates provided by Terrestrial Networks and the global coverage by satellite networks are combined to maximise the potential of IoT deployments.

One of the key advantages of NTNs is their ability to provide seamless and reliable connectivity to IoT devices, regardless of their location. This is particularly valuable for vertical industries like agriculture, livestock, transportation and logistics, energy and utilities, environmental and disaster management, where operational efficiency relies on real-time data. The integration of satellite-based IoT solutions facilitates applications such as precision agriculture, which requires constant monitoring of crop conditions and resource usage, thereby enabling farmers to make informed decisions that increase yield. Moreover, logistics and transportation sectors are transforming through real-time tracking of assets and vehicles, enhancing supply chain management and operational efficiencies.
Integration of NTN and Terrestrial Networks in 3GPP Rel. 17 allows cost-effective deployments worldwide.

[1] https://www.itu.int/en/ITU-D/Statistics/pages/stat/default.aspx
[2] https://www.itu.int/en/mediacentre/backgrounders/Pages/5G-fifth-generation-of-mobile-technologies.aspx

Satellite NB-IoT (Narrowband IoT) solutions employ small, low power and low-cost IoT modules designed for efficient operation with satellite networks, making applications more affordable and sustainable.

Additionally, CEPT has introduced satellite IoT usage in the Short-Range Devices (SRD) bands (also referred to as license-exempt or class license bands, depending on national regulations), specifically the 862-870 MHz band, to enable communication with terrestrial SRDs. This innovative approach, considered as IoT-NTN in SRD bands, ensures interoperability with terrestrial networks and supports new use cases through seamless and robust satellite network coverage. The solution facilitates efficient operation of satellite systems using low-power, low-cost IoT modules while enhancing spectrum efficiency by complementing terrestrial spectrum usage. It is based on existing terrestrial standards and technologies, employing the same technical conditions as terrestrial SRDs in the uplink direction, along with in-band and out-of-band power-flux density limits in the downlink direction to prevent any unacceptable interference with existing applications and services.

Other satellite IoT solutions use non-3GPP protocols and operate in SRD bands (e.g., LoRa) or the MSS 400 MHz band. These solutions for low-data-rate applications via satellite have been increasingly deployed and recently made available on a global commercial basis.

### 1.3 Mobile VSAT

The growing demand for seamless connectivity is leading to a significant increase in the number of connected vehicles, vessels and aircrafts in the mobility market. This expansion presents huge opportunities however to date the satellite industry has relied on proprietary technologies for its connectivity solution, with the growing interest and success of 5G-NR and NTN Technologies and the 3GPP Open Standards, the natural trend is to migrate services to a more a cost effective and a more widely accessible industry[2].

Currently, mobile VSATs (also known as Earth Stations in Motion (ESIMs)) are being introduced in the 3GPP for Release 19 to understand the large assortment of performances, antenna form-factors, and radiation patterns. The large variations of mobile VSATs builds makes the standardisation process difficult due to large number of antenna characteristics.

To provide a baseline model of the mobile VSAT terminals, and to streamline the standardisation activities, 3GPP is evaluating four antennas models that reflect the performance and characteristics of combined Land, Maritime, Aeronautical and Vehicular mobile VSATs.
The first two i.e. 60cm x 60cm and 40cm x 40cm antenna models are based on empirical values gathered from a variety of Mobile VSAT terminals already deployed in the Ku Band. Furthermore, the antenna models presented for the 20cm x 20cm reflect a new conceptual approach which is being considered within 3GPP Release 19 specification.

[2] Market analysts, forecasts that the total number of FPAs shipped worldwide will increase eight-fold between 2023 and 2033.

Mobile VSATs constitute to a large category of terminals which are the workhorse of the satellite communication industry and provide connectivity to GEO and to NGSO Satellite constellations. 3GPP Release 19 is taking major steps toward standardizing mobile VSATs, particularly focusing on Ku-band operations allocated to satellite services. These efforts aim to support high-throughput, mobile 5G connectivity over satellite, enabling dynamic backhaul and access use cases across air, sea, and land domains.

These Mobile VSATs are in three (3) main categories:

### *1.1.1. Land-based Portable and Mobile VSATs/Land ESIMs*

Portable VSAT systems are designed for quick deployment in remote or temporary locations, offering flexibility and ease of transport. They are ideal for situations where quick, reliable communication is needed but not necessarily while on the move.

Land-based Mobile VSAT (ESIMs) systems, on the other hand, are designed for vehicles or mobile units that require continuous satellite communication while on the move. They are equipped with auto-tracking antennas and are built for dynamic environments like commercial fleets, military convoys, or emergency response vehicles.

Both systems offer satellite communication where traditional terrestrial networks are unavailable but serve different operational needs based on whether the setup is stationary or mobile.

### *1.1.2. Maritime Mobile VSATs*

Maritime Mobile VSATs play a critical role in providing reliable satellite communication for vessels at sea. These systems offer global connectivity, support high-speed data services, and enable voice and video communication, making them indispensable for modern maritime operations. Whether for commercial shipping, leisure yachts, military vessels, or fishing fleets, maritime VSAT ensures that vessels stay connected, informed, and safe, regardless of their location on the world's oceans.

### *1.1.3. Aeronautical Mobile VSATs*

Aeronautical Mobile VSATs provide essential satellite-based communication capabilities for aircraft, enabling high-speed internet, secure voice and data communication, and real-time operational support. These systems are crucial for both commercial and private aviation, military and government aircraft as they offer numerous benefits such as global connectivity, enhanced passenger experience, and safety (excluding safety of life operations). The continued development of satellite technologies is offering more reliable and affordable solutions for aviation communication.

These advanced VSAT terminals will consist of Electronically Steered Flat Panel Antennas (FPAs) that provide connectivity to stationary GEO and Non-Stationary Satellites such as MEOs and LEOs. Furthermore, multiple connectivity guarantees that customers and partners aren't confined to a single satellite technology. This flexibility allows for the customization of services to fit a wide range of market segments, use cases and applications.

### 1.4 Satellite as Backhaul for 5G Networks

Satellite systems provide 5G backhaul in areas where terrestrial network infrastructure (e.g., fiber or microwave links) is not feasible or commercially viable. Satellites may enable 5G service providers to extend broadband coverage to remote and hard-to-reach areas. Satellites thus serve as a critical component for extending 5G coverage, especially in remote locations.

Recent developments within 3GPP have formally recognized and standardized the use of satellite systems as a viable backhaul solution for 5G networks. In Release 18, the “Study on 5G System with Satellite Backhaul” (TR 23.700-27) investigates architectures leveraging GEO satellites for backhaul connectivity, including scenarios where the User Plane Function (UPF) is deployed on-board the satellite to enable localized traffic routing. Complementing this, TS 23.501 (Release 18) explicitly states in Clause 5.43 that satellite links may be used in the backhaul between the RAN and the 5G Core Network. Earlier, foundational requirements for satellite integration were already outlined in TS 22.261 (Release 14), which emphasized the role of non-terrestrial networks (NTN) in supporting enhanced coverage and reliability for mission-critical applications. Across Releases 16 to 18, 3GPP has continued to enhance NR support for satellite links, including adaptations in timing, mobility, and waveforms further underscoring the growing importance of satellite backhaul within the 5G ecosystem.

While satellite-based 5G backhaul faces challenges such as latency, bandwidth limitations, and mobility management, the satellite industry is actively developing solutions. These solutions include LEO constellations, high-throughput satellites, 5G NTN standardization, on-board processing, and smart terminal technology to close these gaps. These innovations are making satellite increasingly viable not just for remote coverage, but also for agile, resilient, and high-capacity 5G deployments.

### 1.5 NGSO Data Collection Systems (DCS)

NGSO Data Collection Systems (DCS) rely on non-geostationary satellite to transmit small data packets from distributed ground sensors directly to the satellites. NGSO DCS are used for environmental monitoring, wildlife tracking, or early warning systems.

The long-established DCS, operational under international cooperations, has recently been modernized with dedicated new nanosatellite technologies, enhancing global coverage, data capacity, and power efficiency, reflecting ongoing evolution towards Low Data Rate applications and supporting scientific and environmental activities in the EESS 401 MHz band.

### 1.6 Software Defined Satellite

Software-Defined Satellites (SDS) are a revolutionary advancement in satellite technology that introduces flexibility and programmability into traditional telecom networks. This innovation significantly simplifies management, enhances the efficiency of resource utilization, and reduces operational costs. By moving towards a global network ecosystem that incorporates software-defined satellites, modems, antennas, and the necessary interoperability, the satellite industry is poised to realize the full potential of future applications and connectivity demands.

These software-based satellites have notable features, such as superior connectivity where beam shapes and power allocation can be dynamically adapted to optimize coverage and link performance. They also offer flexible capacity availability with dynamic bandwidth allocation that adjusts based on demand, allowing satellites to modify their capacity to align with user traffic needs. Furthermore, SDS enable seamless end-to-end networking through dynamic software-based interactions with user terminals and central networks, which facilitates comprehensive service orchestration.

The development of a unified network that employs a multi-orbit, multi-layer, and multi-band system, supported by smart ground terminals, unlocks significant capabilities for satellite communications. By combining geostationary and non-geostationary satellites, the industry aims to optimize routing of traffic over multi-orbit networks. This approach effectively exploits unique characteristics of different satellite orbits in terms of coverage, throughput, and operational ease, enriching the service quality and meeting specific user needs in more effective ways. Thus, software-defined satellites are setting the stage for a new era of scalable, cost-effective, and reliable satellite communication systems that promise to enhance global connectivity.

## 3. MULTI-ORBIT SATELLITES

Multi-orbit solutions in satellite communications refer to the integration of satellites operating in different orbital configurations, such as Geostationary Orbit (GSO) and Non-Geostationary Orbit (NGSO). This approach leverages the unique characteristics and advantages associated with each type of orbit to optimize satellite coverage, throughput, and latency, ultimately enhancing the quality of communication services offered to users. The goal of multi-orbit solutions is to meet various service level requirements set by customers across a diverse range of applications and geographic locations.

By employing a multi-orbit strategy, satellite operators can effectively route traffic based on real-time conditions and user demands. The combination of these orbits allows for more flexible and efficient data transmission, enabling seamless connectivity across different environments—be it urban, rural, or isolated locations. This capability is particularly beneficial for enterprises, governments, and individual users who require reliable and high-capacity communication services in real-time.

Moreover, multi-orbit networks facilitate advanced applications such as earth observation and remote sensing. By connecting satellites across different altitudes and orbits, operators can relay large volumes of data more efficiently, thereby providing timely information critical for various sectors including agriculture, disaster response, and environmental monitoring. This integration not only enhances connectivity but also plays a pivotal role in addressing the rising demands for improved data services and global inclusivity in the digital landscape. Overall, multi-orbit solutions are reshaping the satellite communication industry, ensuring that diverse communication needs are met while advancing the sustainability and efficiency of satellite networks.

To summarise, Multi-Orbit Connectivity enables:

1) Seamlessly switching or blending between GEO, MEO and LEO networks based on the capacity needs of individual applications.
2) GEO: Broad coverage, bandwidth capacity, stability, security, and precise location capabilities of GEO networks.
3) NGSO (LEO/MEO): low-latency connectivity and overflow capacity from NGSO networks for applications that require to deliver high quality QoE even during peak demand.
4) More accessible, affordable, and versatile satellite communication.

## 4. INNOVATION IN THE GROUND SEGMENT

The satellite system ground segment is evolving with the changing nature of both GSO and NGSO satellite constellations. With the proliferation of NGSO constellations and satellites in inclined orbits, the need for antennas that track the satellites has become essential. This can be served by traditional parabolic antennas, often operating in pairs to ensure a "make before Image by Hughesbreak" connection, or by Flat Panel Antennas (FPA). Another industry trend is towards an agnostic ground ecosystem where interoperability is key. The Digital Intermediate Frequency Interoperability [DIFI] initiative utilizes an existing ANSI standard as a means to achieve this by presenting the signal for onward processing in a generic form. This is being used in hub architectures and there are moves to have it more widely implemented in terminals.

Satellite user terminals have been reduced in size, weight, power consumption and cost, and provide a wide array of solutions for the end user. For instance, significant improvements in small form factor antennas have created terminals that are more portable, while providing a better performance than earlier generation models. These improvements are facilitating the wider deployment of user terminals that facilitate greater connectivity to the global network.

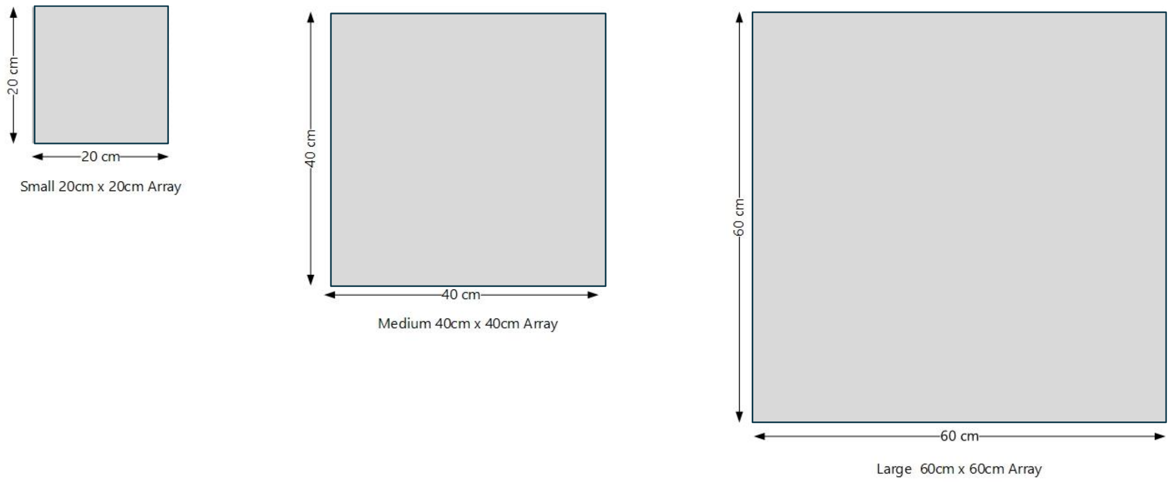


*Figure 1: These figures illustrate notional FPAs used in the SatCom Industry*

## 5. INTER-SATELLITE LINKS

Inter-Satellite Links (ISL)are an innovative technology that enable direct communication between satellites in orbit. These links facilitate the real-time transfer of data, which is particularly valuable for LEO satellite constellations. Traditionally, LEO satellites could only communicate with ground stations within a limited view of the Earth. However, with the implementation of ISLs, data can be relayed between satellites, allowing for enhanced connectivity and a more efficient communication network.

This capability is also crucial for applications such as Earth observation, where satellites can transmit high-quality images and data back to the ground in real time through satellite in other orbits, even when they are not in direct line of sight to a ground station.

The advancement of optical communication technology plays a significant role in transforming ISLs by providing high-speed connections that enhance the efficiency and security of data transmissions. Optical Inter-Satellite Links offer greater resiliency compared to traditional radio frequency communications, resulting in less interference and improved data integrity. As these optical technologies become more widely adopted and their costs continue to decrease, they are expected to drive further innovations in satellite communications, expanding the number of potential applications and increasing overall capacity.

The capabilities provided by ISLs are critical for the growing demands of various sectors, ranging from telecommunications to disaster response and emergency services. They enable a broader array of services, such as real-time bandwidth allocation for IoT traffic and improved weather forecasting data transmission. Overall, inter-satellite links represent a significant leap forward in satellite communication technologies, allowing for more interconnected and resilient networks that can meet the increasing global demand for high-capacity communications.

## 6. IN-ORBIT SERVICING AND LIFE EXTENSION

In-Orbit Life Extension and Servicing are vital components of modern satellite operations, aimed at enhancing the longevity and functionality of satellites beyond their originally intended lifespan. Life extension services allow satellite operators to reuse existing assets rather than replacing them, which is particularly important given the high costs associated with deploying new satellites. By focusing on in-orbit servicing—repairing, upgrading, or refueling satellites—operators can maximize their investments and ensure continued service delivery without incurring the significant costs of replacement.

The benefits of in-orbit servicing extend beyond mere cost savings. These services can enhance satellite reliability, ensuring that satellites continue to function even after they exhaust their fuel or experience subsystem failures. For example, through life extension initiatives, satellites can remain operational longer, with projections suggesting that in-orbit servicing could generate over US$4 billion in revenues by 2028[3]. GEO satellites often cost well over $200 million to deploy, underscoring the value of servicing, repairing or upgrading such satellites rather than just replacing them.

[3] Astroscale U.S. Enters the GEO Satellite Life Extension Market - Astroscale

This capacity to maintain and extend operational life spans helps prevent potential service disruptions in critical sectors such as telecommunications, defense, and disaster response. Furthermore, as the satellite industry continues to evolve, various new in-orbit services are being developed, from refurbishment to debris removal, indicating a shift towards ensuring safer and more sustainable use of the orbital environment. This proactive approach to satellite management aims to keep orbital highways safe and secure for economic development, ultimately supporting a robust and resilient satellite ecosystem.

## 7. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Artificial Intelligence and Machine Learning play a transformative role in the field of satellite communications, significantly enhancing the efficiency, reliability, and security of satellite operations. By optimizing various operational aspects, AI can improve network performance and enable predictive maintenance, which is crucial for preventing system failures. For example, employing AI algorithms for data analysis allows operators to identify patterns and anomalies in performance data, facilitating timely interventions before potential issues escalate.

Moreover, AI's capabilities extend to dynamic resource allocation, particularly concerning radio spectrum management. Through ML techniques, satellite systems can better detect and mitigate interference, ensuring clearer communication channels. This not only enhances user experience but also maximizes the bandwidth utilization across satellite networks. As the demand for higher capacity and more reliable communication services grows, integrating AI and ML into satellite operations is becoming essential for maintaining competitive advantages in the evolving telecommunications landscape.

The advent of AI and ML technologies also paves the way for innovative applications in satellite-based services, such as intelligent routing for data transmission and enhanced security measures to protect against cyber threats These advancements are particularly vital as satellites become increasingly integral in supporting emerging technologies, including the Internet of Things (IoT) and the next generation of mobile networks like 5G and 6G.
The convergence of AI and satellite technology is poised to not only optimize current operations but also to define new paradigms in global connectivity and communication capabilities.

## 8. CONCLUSION

The dynamic evolution of satellite communications is transforming global connectivity. The ongoing development detailed in this report including multi-orbit satellite networks, inter-satellite links, and the integration of non-terrestrial networks exemplify the industry's commitment to expanding and enhancing connectivity solutions. These advancements are pivotal to meet the increasing demand for reliable, secure and high-capacity communication services. The deployment of these cutting-edge technologies is driving a new era of satellite communications that is bridging the digital divide and fostering global inclusivity.

The convergence of these innovative technologies positions the satellite communications industry to play a crucial role in the future of global connectivity, ensuring an inclusive digital future for all. This ongoing transformation highlights the industry's commitment to creating a more connected and secure world.

The implications of these developments for ATU Member States are profound. These transformative technologies provide opportunity for ATU Member States to achieve universal broadband coverage complementing terrestrial networks.

Further, the integration of multi-orbit systems, operating in different orbital configurations, with terrestrial networks, enables redundancy in national infrastructure deployment enhancing network resilience.

As the satellite industry continues to evolve, it is important for ATU Member states to proactively leverage these emerging technologies, update and harmonise policy frameworks to enable the use of these innovative solutions. These technological advancements can be harnessed for sustainable development, economic empowerment, and the creation of an inclusive digital economy that ensures no community is left behind.

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## 10. ABBREVIATIONS

3GPP - 3rd Generation Partnership Project
AI - Artificial Intelligence
ANSI - American National Standards Institute
ATU - African Telecommunications Union
BSS - Broadcasting Satellite Services
CEPT - European Conference of Postal and Telecommunications Administrations
D2D - Direct-to-Device
DCS - Data Collection Systems
DIFI - Digital Intermediate Frequency Interoperability
EESS - Earth Exploration Satellite Service
ESIM - Earth Stations in Motion
FPA - Flat Panel Antennas
FSS - Fixed Satellite Services
GEO - Geostationary Earth Orbit
GSO - Geostationary Orbit
GSOA - Global Satellite Operators Association
HEO - Highly Elliptical Orbit
HAPS - High Altitude Platform Station
IoT - Internet of Things
ISL - Inter-Satellite Links
ITU - International Telecommunication Union
LEO - Low Earth Orbit
MEO - Medium Earth Orbit
ML - Machine Learning
MNO - Mobile Network Operator
MS - Mobile Service
MSS - Mobile Satellite Services
NB-IoT - Narrowband Internet of Things
NGSO - Non-Geostationary Orbit
NOAA - National Oceanic and Atmospheric Administration
NTN - Non-Terrestrial Network
O-RAN - Open Radio Access Network
PNT - Positioning, Navigation, and Timing
QKD - Quantum Key Distribution
QoE - Quality of Experience
RAN - Radio Access Network
RIC - Radio Access Network Intelligent Controller
SCADA - Supervisory Control and Data Acquisition
SDS - Software-Defined Satellites
SRD - Short Range Device
TN - Terrestrial Network
UAS - Uncrewed Aircraft Systems
UE - User Equipment
UPF - User Plane Function
VSAT - Very Small Aperture Terminal

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