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Towards Ubiquitous Broadband Access: Policy Imperatives for Developing Next-Generation Non-Terrestrial Networks

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**Towards Ubiquitous Broadband Access:
Policy Imperatives for Developing Next-Generation Non-Terrestrial Networks**

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Non-technical Highlights:

- Technological advancements in non-terrestrial networks (NTNs), such as Low Earth orbit (LEO) satellites, offer a promising solution to broadband connectivity in areas where financial costs and geographic obstacles impede the deployment of terrestrial networks.
- Policymakers have the opportunity to unlock the connectivity potential of emerging NTN innovations by crafting a robust, flexible and future-oriented policy framework.
- Specifically, spectrum and interference policies must evolve alongside technological advancements to ensure competition and fair utilization of spectrum resources.
- Forging alliances with international partners and working with legally-binding authorities is vital to a collaborative and secure approach to space operations across jurisdictions. Topics to consider include enhanced cybersecurity, improved space traffic, debris management and reduction of light pollution.
- In countries with expansive geography and sparsely-populated regions provide an unparalleled opportunity for NTNs to deliver connectivity to underserved communities; however, as NTN technology matures and investment costs reduce, more and more countries are expected to deploy NTN solutions to enhance resilience in telecommunications and bolster IoT applications.

Introduction

Broadband internet is a crucial part of modern society, underpinning economic growth, educational advancement, and access to essential services. Despite its critical role, many remote and underserved areas lack reliable broadband connectivity, exacerbating the digital divide and limiting opportunities for these communities. Extending terrestrial networks to these regions is often insurmountable due to financial constraints and geographic obstacles, necessitating the exploration of alternative technologies.

Deploying terrestrial networks in remote and sparsely populated regions presents significant challenges. The high infrastructure development and maintenance costs, coupled with difficult terrain, make traditional network expansion unfeasible in many cases. This situation highlights the need for innovative solutions, such as non-terrestrial networks (NTNs), to bridge the connectivity gap. Although geostationary satellites have provided some connectivity, they are limited by high latency and capacity constraints, making them less suitable for modern, high-demand applications.

Advancements in NTNs, particularly with the development of Low Earth Orbit (LEO) satellite constellations, present new opportunities to address these challenges. LEO satellites offer lower latency and higher bandwidth capabilities, making them a viable solution for extending broadband coverage to remote areas and supporting the burgeoning Internet of Things (IoT) ecosystem. As the technology matures, costs are expected to decrease, leading to broader adoption and enhanced resilience in telecommunications networks. The significant increase in satellite deployments, spearheaded by companies like SpaceX, underscores the growing role of NTNs in global connectivity strategies.

However, the rapid growth of NTNs has caught many policymakers off guard. Current regulations, often designed for traditional terrestrial and geostationary systems, are

outdated and ill-suited to the unique characteristics and needs of new-generation NTNs. This regulatory gap hampers the deployment and innovation of these technologies. Policymakers need to update and adapt regulatory frameworks to support the expansion of NTNs and unlock their full potential for providing universal broadband access.

In this paper, we conduct a comprehensive analysis of the policy landscape surrounding the expansion of LEO satellite technologies. Specifically, we examine the evolution of next-generation NTN technologies, identify key policy issues that are likely to arise as these technologies become more widely adopted, and explore how policymakers can navigate these challenges to leverage NTNs for enhancing broadband access in their regions.

Our methodology includes a systematic review of existing literature, analysis of case studies, and consultation with industry and policy experts to identify the key challenges and opportunities in the current regulatory environment for NTNs. This approach allows us to highlight the critical policy areas that require attention and propose solutions to foster the sustainable growth of NTNs.

Our research reveals several key insights, particularly regarding spectrum management, regulatory frameworks, and international coordination. Addressing these issues is crucial for ensuring that NTNs can effectively bridge the digital divide, support IoT deployment, and enhance the resilience of telecommunications networks. By focusing on these areas, policymakers can create an enabling environment that maximizes the benefits of NTNs.

The paper is structured as follows: First, we review the existing literature on broadband connectivity and identify key gaps. Next, we discuss the challenges of deploying traditional terrestrial networks in remote areas. We then examine the evolution of competing NTN

technologies, outlining their technological and economic advantages and disadvantages. Finally, we identify the key policy areas that require attention to enhance NTN deployment and draw lessons from early experiences in managing spectrum and competition. We conclude by suggesting policy recommendations to support the sustainable growth of NTNs and their integration into national and global connectivity strategies.

Literature Review

Broadband internet has become an essential component of modern human activity, with its importance underscored during the COVID-19 pandemic. The pandemic catalyzed a significant shift towards online platforms, accelerating trends such as remote work, digital education, telemedicine, and e-commerce. Despite the growing reliance on broadband, approximately three billion people globally lack access to reliable internet services. This digital divide threatens to exacerbate socio-economic disparities, placing communities without adequate access at a significant disadvantage.

Broadband internet has emerged as a critical infrastructure for economic growth, innovation, and human capital development. Studies have highlighted the positive impact of broadband penetration on GDP growth, with a 10% increase in broadband adoption associated with a 0.9-1.5 percentage point rise in GDP growth rates (World Bank, 2009). Broadband facilitates knowledge sharing, collaboration, and access to educational resources, thereby improving human capital (Holt & Jamison, 2009; Whitacre et al., 2014). It enables online learning, skill development, and access to global knowledge repositories, enhancing the quality of education and training. Additionally, studies have also explored the role of broadband in enhancing market efficiency by reducing information asymmetries and transaction costs (Greenstein & McDevitt, 2011). Broadband

enables e-commerce, digital marketing, and real-time access to market data, facilitating better decision-making and resource allocation. There is also a positive correlation between broadband speed and innovation (Chen & Wang, 2022), and research has linked digital infrastructure to nations' competitiveness, innovation, and economic growth, as businesses and industries increasingly rely on digital technologies and online platforms (Greenstein & Prince, 2007; Crandall et al., 2007).

Scholars have also explored adoption barriers, such as motivational, material, skill-related, and usage gaps, that hinder access and usage of broadband services (Van Dijk, 2000; Hargittai, 2002). Researchers have proposed that integrating broadband data access with other infrastructure indicators like libraries and building permits to create a "social sensor" that can detect marginalized communities lacking digital access, helping target policies to bridge the digital divide (Mossberger et al., 2012).

Thus, extant research highlights the crucial role of broadband as an enabler of economic growth, innovation, human capital development, market efficiency, and inclusive development. Investing in high-speed broadband infrastructure and promoting digital literacy can unlock significant socio-economic benefits (see also Koutroumpis, 2009; Czernich et al., 2011), however, if barriers to broadband access remains the consequences could be severe and far-reaching.

In particular, failing to provide equitable access to broadband infrastructure and digital literacy can exacerbate existing socio-economic inequalities and marginalization (Mossberger et al., 2003; Norris, 2001). Communities and individuals lacking access to high-speed internet and digital skills risk being left behind in the digital economy, facing limited opportunities for education, employment, and economic mobility (Hargittai, 2002; van Dijk, 2006). This digital exclusion can perpetuate cycles of poverty, hinder social integration, and impede the

realization of human potential (Warschauer, 2004; DiMaggio & Hargittai, 2001). Addressing the digital divide is not merely a matter of technological access but also requires addressing socio-economic factors, digital literacy, and the development of relevant content and services that cater to diverse communities (Warschauer, 2003; Gurstein, 2003).

A major obstacle in digital access is the lack of adequate broadband infrastructure, especially in rural and remote areas where deploying networks is often economically unviable for service providers due to low population density and high costs (Prieger, 2003; Grubestic, 2003). Even where infrastructure exists, the cost of subscribing to broadband services can be prohibitively expensive for many households, particularly those with low incomes (Horrigan, 2009; Hauge & Prieger, 2010). Lack of digital skills and literacy is a significant barrier, especially among disadvantaged groups and older generations (van Dijk, 2006; Hargittai, 2002). Rural communities face compounded issues, including limited provider competition, leading to higher prices and fewer choices (Whitacre et al., 2014), while overreporting of broadband availability by ISPs has led to an underestimation of the rural digital divide (Kruger & Gilroy, 2013).

Addressing these barriers requires a multi-pronged approach involving infrastructure investments, affordability measures (subsidies or incentives), and digital literacy initiatives, particularly targeting underserved rural areas (Strover, 2001; LaRose et al., 2007). Governments and industry players around the world have been actively working to promote broadband connectivity, primarily through terrestrial solutions. Many countries have invested heavily in building broadband infrastructure, particularly fiber-optic networks and advanced mobile technologies like 4G/5G, aiming to expand coverage and improve speeds, especially in underserved rural and remote areas. For instance, the European Union has launched initiatives like the Connecting Europe Facility

and the WiFi4EU program, China has made significant investments in its "Broadband China" strategy, and India's BharatNet project aims to provide broadband connectivity to over 600,000 villages through a fiber-optic network.

Governments have also implemented regulatory reforms to encourage competition, attract private investments, and facilitate infrastructure sharing among service providers, including spectrum allocation, licensing frameworks, and policies to reduce deployment costs. The United States has taken steps to streamline the deployment of small cells and fiber networks, while also allocating new spectrum bands for 5G services, while the Nigerian Communications Commission has introduced initiatives like the National Broadband Plan and the Infracore Project. Many countries have adopted public-private partnership (PPP) models to leverage private sector expertise and resources in building and operating broadband networks, often involving revenue-sharing agreements or co-investment models, such as Australia's National Broadband Network (NBN) and the Philippines' Common Tower Policy.

While these efforts have primarily focused on terrestrial solutions, the recent rise of non-terrestrial networks (NTNs), such as low-earth orbit (LEO) satellite constellations, has introduced a new dimension to broadband connectivity (see figure 1). Companies like SpaceX (Starlink), Amazon (Project Kuiper), and OneWeb are deploying thousands of satellites to provide global broadband coverage, particularly in areas where terrestrial infrastructure is lacking or challenging to deploy. Several key factors drive the motivation for the increased use of satellite networks. Firstly, in remote and underserved areas, the development of terrestrial networks is often prohibitively expensive or nearly impossible due to challenging terrain and sparse populations. Secondly, the growing demand for Internet of Things (IoT) applications worldwide requires broader satellite coverage to ensure seamless

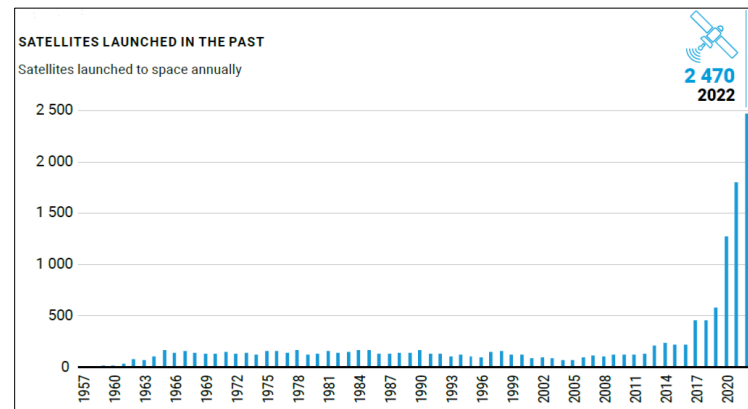
connectivity across diverse regions. Additionally, NTN are becoming integral to enhancing the resilience of telecommunications, particularly in the face of climate change-related disasters that disproportionately disrupt terrestrial networks. Finally, NTNs are experiencing a technological revolution, resulting in significant cost reductions and making them a more viable option for widespread adoption in the future.

Technological innovations in satellite communications, especially with the advent of Non-Geostationary Orbit (NGSO) systems, have opened new avenues for delivering broadband services. These NGSO systems, which include Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites, are pivotal due to their lower latency and higher bandwidth capabilities compared to traditional Geostationary Orbit (GEO) satellites.

The integration of these satellite systems with terrestrial networks poses considerable technical and regulatory challenges, as well as the need for updated regulations that keep pace with technological advancements to avoid stifling innovation. Some scholars have argued that outdated power limits and spectrum-sharing rules, initially designed for GEO systems, are inadequate for NGSO systems, restricting their potential coverage and efficiency (Furchtgott-Roth, 2023)¹. Moreover, the sustainable use of space is becoming increasingly critical as satellite deployments multiply, with a report by the Space Generation Advisory Council (SGAC) emphasizing the importance of proactive debris management to mitigate the risks associated with space congestion (Nasseri, S. A., & Emanuelli, M. (2015))

Figure 1 illustrates the number of satellites launched per year since 1957, the year Sputnik 1 was launched as the first satellite. The figure indicates a substantial rise in annual satellite launches began in 2017.

Figure 1: Satellites launched to space annually



Source: United Nations Office for Outer Space Affairs For All Humanity²

What remains underexplored in the current literature is a systematic examination of the policy outlook on the expanding space of low Earth orbit (LEO) satellite technologies. In particular, what has been the evolution of the next-generation NTN technologies? What are the key policy issues that are likely to arise as these technologies are more widely adopted? And should the policymakers navigate those issues and unlock the potential of NTN technology for broadband access in their regions? In this paper we aim to bridge these important gaps.

Network Deployment Challenges in Remote Areas

In regions with low population density, investment in telecommunications infrastructure is typically limited due to diminished expected return on investment (ROI). The primary barrier in enhancing connectivity in underserved areas is often middle-mile infrastructure. This infrastructure primarily employs terrestrial networks through infrastructure such as fibre optic cables and microwave transmission. Satellite links are also used, typically

geostationary satellites, but LEO satellites and HAPS have emerged as new alternatives.

The expansive distances between sparsely populated regions and metropolitan hubs housing the core network, compounded by rugged terrain, pose formidable investment challenges in many countries with vast landmasses. In Canada, for instance, laying down fiber-optic cables over such expansive, rugged terrain involves hefty installation expenses along with substantial ongoing costs for maintenance and repair, amplified by severe weather conditions and logistical complexities.

Similarly, in Australia, the vast Outback region covers a significant portion of the country's landmass, yet it is sparsely populated, with most of the population concentrated in coastal cities. The Australian Outback covers an area of over 2.5 million square miles but has a population density of less than one person per square mile,³ making it challenging and costly to deploy traditional terrestrial network infrastructure.

Brazil's Amazon rainforest, which covers a vast area of over 2 million square miles, presents significant challenges for traditional terrestrial network infrastructure deployment due to its remote location and dense vegetation.

Microwave transmission is often considered as a wireless solution to bridge large distances. However, this technology comes with its own set of challenges. Microwave transmission relies on a line-of-sight (LoS) connection between towers for signal transmission. The diverse and often challenging topography of the region, characterized by mountainous terrain, dense forests, and large bodies of water, can obstruct these LoS connections and impede consistent signal flow. Remote regions lacking commercial power and roads also present logistical and financial challenges to building and maintaining a tower network, exacerbated by a limited potential user base, leading to high per capita operational costs for radio sites.

The geographical factors that complicate the development of the middle-mile infrastructure also impact the last mile. Deploying last-mile connectivity in rural areas, whether through cell tower construction for wireless services or fibre-to-the-home installations for broadband, also faces high financial hurdles. For instance, cell towers, require a connection to fibre optics or microwave links to function effectively, but establishing these connections means overcoming terrain and distance barriers. These costs are again magnified by the low population density, with towers serving fewer customers, diminishing the potential ROI for telecom providers. The dispersed population and challenging terrain in many Indigenous, remote, rural communities make for a poor business case to invest in terrestrial networks.

Geostationary orbit (GEO)

Historically, telecom operators have tackled the middle-mile backhaul challenge by turning to satellites to connect the last mile to their core networks. However, the satellites used in the past have operated in geostationary orbit (GEO) which means they remain in the same position relative to the earth's surface (approximately 36,000 km). This distance results in prolonged signal travel times, significantly increasing latency (delays in network communications) compared to fibre optics and terrestrial microwave alternatives.

The most common implementation of GEO satellites is through a Direct-to-Home (D2H) model, predominantly serving users in low-density areas. (See Figure 3 for satellite-dependent communities in Canada as of March 2019.) Another widely-adopted model involves direct-to-community aggregators, who then facilitate distribution to closely-knit communities through fibre-optic last-mile connectivity.

GEO satellites once pivotal for communications in remote areas, are now less suited for modern applications requiring higher

bandwidth and lower latency. GEO latency can reach 600 milliseconds, far greater than terrestrial networks' 20 milliseconds. Although fractions of seconds might seem trivial, this high latency has a considerable impact on real-time applications: video conferencing and voice calls experience synchronization issues; real-time collaboration tools and telemedicine consultations face operational lags; and navigation and tracking systems might show outdated data. These latency effects compromise real-time response and the effectiveness of voice or data applications, adversely affecting user experience and hindering technology adoption. Despite the current use of GEO satellites, its latency and bandwidth limitations will not meet the demands of evolving use cases.

The ever-evolving landscape of technology is driving an insatiable demand for higher bandwidth and lower latencies that traditional GEO satellite systems struggle to meet. Emerging technologies such as the Internet of Things (IoT), autonomous vehicles, and advanced computing applications are pushing the boundaries of what current networks can deliver. This paradigm shift has paved the way for the rise of next-generation non-terrestrial networks (NTNs) operating at lower altitudes, promising to solve the connectivity challenges posed by these cutting-edge innovations. By leveraging constellations of satellites orbiting closer to Earth, these NTNs offer the tantalizing prospect of delivering the high-speed, low-latency connectivity required to meet the changing demands of users and industries alike, ushering in a new era of seamless global connectivity.

The Evolution of Next Generation Non-Terrestrial Networks

New NTN options are emerging as promising solutions for coverage in remote and

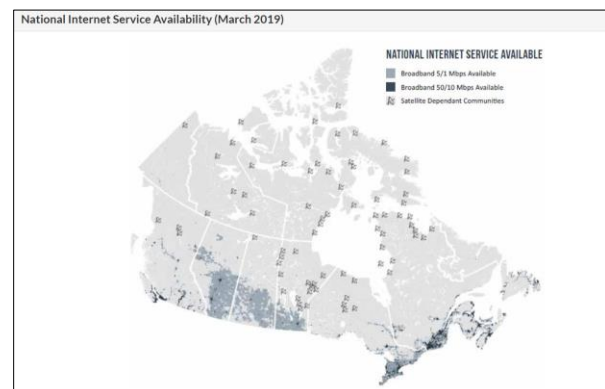
challenging areas, offering competitive alternatives. This section explores technologies enhancing connectivity in hard-to-reach locations, from traditional geostationary orbit to novel options like LEO and HAPS.

Low earth orbit (LEO)

A new generation of companies are addressing latency by launching satellites into low earth orbit (LEO), between 300 km to 2,000 km from earth, which cuts latency to approximately 30 milliseconds – a 20-fold improvement. The lower altitude of LEO satellites necessitates them to travel at higher speeds to maintain orbit but also limits their coverage area. This constraint demands the deployment of many satellites—a “constellation”—for global coverage. In contrast, GEO satellites, positioned at a much higher altitude and effectively stationary to earth (orbiting at a speed that matches earth’s rotation), can cover about one-third of the planet’s surface with a single satellite.

SpaceX leads this category, having launched over 5000 satellites into LEO as part of its Starlink constellation.⁴ Other active and planned players in the LEO space race include OneWeb, Telesat, Amazon’s Project Kuiper, Rivada and AST SpaceMobile.

Figure 3: Representation satellite dependent communities in Canada as of March 2019



LEO to Direct Homes

Currently, several LEO-based services, including that of Starlink, adopt a D2H business model, addressing the last mile and middle mile. They provide end-user customers with receiver dishes, roughly the size of a pizza box, to install in locations with an unobstructed view of the sky (e.g. rooftops, the ground) to establish a high-quality connection with the satellites, enabling Internet access.⁶

However, this solution is limited as connectivity is restricted to the receiver dish location (home, van, ship). Consequently, solutions enabling connectivity to mobile devices are also needed to grant users mobility while still enjoying broadband access.

LEO to Backbone Towers

LEO satellites could be used to provide reliable backhaul services to telecom operators, like GEO satellites but with near-terrestrial latencies. SpaceX, Telesat, and OneWeb are a few of the operators poised to offer LEO services tailored for middle-mile connectivity solutions.

The Canadian government has taken a proactive step by funding an initiative to support Telesat in launching a constellation of 198 LEO satellites, named the 'Lightspeed' project.⁷ Telesat, a Canadian engineering firm with more than half a century of experience in operating GEO satellites, has partnered with MDA, another Canadian engineering firm known for its satellite construction expertise, to oversee the engineering design and construction for Lightspeed. These satellites, which will orbit at about 1,000 km from Earth, are planned to be launched by SpaceX.⁸ Highlighting the significance of this development, Ontario's provincial government committed CAD 109.2 million to secure 40 gigabits of broadband

capacity on Telesat Lightspeed.⁹ This capacity will be available for local service providers to purchase at reduced rates, demonstrating the government's subsidization of middle mile infrastructure to supporting enhanced connectivity solutions.

Unlike a LEO D2H service, Lightspeed's middle-mile architecture will consist of a fibre link to a landing station, which then connects to the LEO satellite for backhaul to a cell tower. The last mile to users could be through wired connections like fibre or coaxial cable for remote locations with dense communities, or wirelessly through fixed wireless access from the cell tower to user devices including phones and Wi-Fi modems for more spread out populations.

LEO backhaul promises to provide a cost-effective alternative to laying extensive fibre cables or installing microwave links. For telecom operators, LEO backhaul could serve as either a primary backhaul link or as a reliable backup to existing fibre optics, enhancing network resilience by reducing downtime due to fibre cuts.

In South America, telecom providers facing terrain challenges similar to Canada are experimenting with replacing their GEO backhaul with Starlink.¹⁰ This involves mounting Starlink receiver dishes on cell towers to connect these remote towers to the core network. Initial demonstrations show improved performance metrics compared to traditional GEO solutions.¹¹ However, Starlink offers a "best-effort only" service without guaranteed minimum bandwidth, which can be problematic for network operators who require consistent, high-priority backhaul capacity. This scenario highlights the need for solutions that balance improved performance with the reliability demanded by network infrastructure.

Since networks based on satellite backhaul depend on ground-based infrastructure for providing last-mile connectivity, their coverage is limited to the extent of the terrestrial

network. Consequently, telecom providers still need to construct cell towers or lay fibre to premises to bridge the last-mile gap in order to bring mobile broadband access to those remote communities.

LEO to End-user Devices

Recently, connectivity is made possible between satellites and devices, including cell phones—direct-to-device (D2D). In early 2023, Qualcomm and MediaTek, the two leading mobile phone chipset manufacturers, announced the development of chips capable of facilitating two-way satellite communications directly to smartphones.^{12,13} This led to a series of announcements around D2D satellite usage, promising to provide seamless and omnipresent coverage.

Soon after, Apple introduced a satellite SOS feature for iPhone users, which enables users to send emergency messages when they are beyond the reach of cellular or Wi-Fi networks¹⁴. Enabled by a constellation of 24 LEO satellites operated by Globalstar, this service is currently limited to text-based communications.¹⁵

In April 2023, Rogers Communications introduce satellite-to-phone coverage in Canada by signing an agreement with SpaceX to¹⁶ through use of Starlink’s extensive LEO constellation paired with Rogers’ national wireless spectrum. Initially offering coverage for SMS text, services are expected to expand to voice and data by 2025. In scenarios where traditional cell towers might be compromised due to natural disasters like wildfires or hurricanes, this type of service could act as a vital redundancy, thereby adding digital infrastructure resilience.

SpaceX announced that new satellites would be equipped with an advanced eNodeB modem, acting as a space-based cell tower; the first batch of such direct-to-cell enabled satellites launched in January 2024.^{17,18} A lineup of global partnerships—T-Mobile in USA,

Optus in Australia, One NZ in New Zealand, KDDI in Japan, and Salt in Switzerland—highlights collaboration as a means of effective spectrum leverage.¹⁹

Bell Canada, through Bell Ventures, has invested in the LEO satellite sector, exemplified by its October 2022 investment in AST MobileSpace.²⁰ AST offers partnership with terrestrial network providers by utilizing their spectrum to offer D2D broadband services and middle-mile solutions, as demonstrated through AST’s successful tests of 5G calls with AT&T in Hawaii²¹.

In another noteworthy development, TELUS announced the successful completion of Canada’s first two-way communication test between smartphones and satellite.²² Although this test exploited a GEO satellite connection, it showcased the potential for D2D to eliminate coverage gaps. It was conducted in collaboration with TerreStar Solutions and Skylo.

HAPS: Balloon to End-user Devices

High Altitude Platform Stations (HAPS) are aerial systems, including high-altitude balloons, airships, or powered fixed-wing aircraft, that are positioned around 20 kilometers above the earth’s surface in the stratosphere. These systems are engineered for prolonged airborne duration, utilizing either solar power or an onboard energy source such as hydrogen for operation. While this innovative technology is in early maturity, various telecom companies are exploring HAPS as a frontier to deliver 4G and 5G signals directly from the stratosphere. Figure 5 shows networks that use LEO satellites or HAPs in the middle mile, which then directly connect to end-user devices, such as mobile phones or modems.

HAPS are a more responsive and efficient option than satellite-based services for telecommunications as they provide higher capacity and lower latency (10 milliseconds, compared to 30 milliseconds for LEO) due to

lower operating altitude and smaller service footprint.

One of the most promising and advanced HAPS projects is Airbus Zephyr. In the summer of 2022, Airbus introduced a HAPS connectivity service business, establishing it as a standalone entity and marking a significant stride towards redefining the future of connectivity.²³ Zephyr is designed to function as a “cell tower in the sky,” providing D2D low-latency 5G connectivity.²⁴

Canada’s harsh, northern climate poses a challenge for HAPS, which typically rely on solar power, a source that is less effective at higher latitudes due to limited sunlight and low sun ray angles. HAPS using alternative energy sources, like hydrogen-powered equipment, may be better suited to Canada’s environment.²⁵ However, perfecting hydrogen storage is crucial, due to complexities of deep cryogenic properties in its liquid state. This highlights the need for innovative solutions to address the specific energy requirements of HAPS in diverse environments.

These HAPS technology developments may also complement other NTN contributions in making promising strides towards 100% geographic coverage.

Pro and Con of NTN

Varying levels of availability and functionality illustrate the diverse landscape of satellite Internet services and the ongoing development of these technologies. D2H services such as Starlink are commercially available on a large scale, while middle-mile solutions like OneWeb are available but on a more limited scale and D2D options are also accessible, though limited mainly to text communication. SpaceX’s D2D data and voice service is expected by 2025²⁶ and Telesat’s Lightspeed, by 2027.²⁷ D2D and D2H will likely evolve to complement each other, with D2H for

the high data needs of homes and businesses, and D2D for mobile connectivity and as a backup during network outages.

LEO systems, facing challenges like radiation and atmospheric drag, have a shorter lifespan (circa 5 years) compared to GEO systems (circa 15 years). Consequently, regular satellite replacement is essential to keep the constellation functioning effectively over the long term.

The operations of LEO satellite constellations are expensive, with major players typically not revealing the costs associated with manufacturing these satellites. SpaceX, which accounts for nearly 80% of all satellite launches,²⁸ primarily utilizes the Falcon 9 rocket for these missions. SpaceX has disclosed that each launch costs USD 67 million,²⁹ with a rocket capable of carrying an average of 23 Starlink satellites,³⁰ suggesting a launch cost of approximately USD 2.9 million per satellite. LEO satellites also have relatively short useful lives, necessitating replacement approximately every five years. Ground stations, essential for providing Internet connectivity in this system, also require construction and operation investments. The financial commitment to LEO satellite operations appears substantial, underscoring the fact that engaging in LEO is a capital-intensive endeavor.

HAPS solutions have struggled with commercial viability. Google Loon was discontinued due to challenges in reducing costs sufficiently to build a sustainable long-term business.³¹ Similarly, Meta (formerly Facebook) ended its HAPS project, Aquila, in 2018, choosing instead to collaborate with companies such as Airbus.³² Additionally, LEO and HAPS networks face limitations in quality compared to terrestrial networks. A significant challenge is indoor coverage for D2D offerings; both LEO and HAPS require a clear line of sight to the sky, making reception difficult without additional equipment.

These technologies vary in maturity, with terrestrial networks and GEO satellites being the most mature and HAPS direct to cell still in the prototype stage. Emerging technologies like LEO D2H, LEO D2D and backhaul are promising but require further development and cost reduction.

Table 1 summarizes the advantages and disadvantages of these technologies, ranging from bandwidth capacity to infrastructure reliability and challenges in deployment and maintenance. This comparison provides insights into the diverse landscape of emerging communication technologies and their suitability for different applications and environments.

Table 1: Comparisons of Existing and New Network Solutions

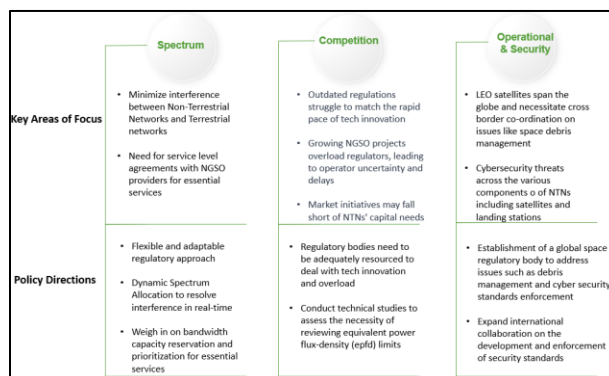
Solution	Pros	Cons	Maturity
Traditional Terrestrial Networks	<ul style="list-style-type: none"> • High bandwidth and data rate capacity. • Established, reliable infrastructure with widespread coverage in populated areas. • Lower latency within the network • Mobile coverage within cell tower coverage zones 	<ul style="list-style-type: none"> • Expensive and time-consuming to deploy in remote or rugged areas. • Susceptible to physical damage (e.g., natural disasters, vandalism). • Requires significant ongoing maintenance 	Mature
Traditional GEO Satellite	<ul style="list-style-type: none"> • Offers wide coverage area from a single satellite • Established technology with a long track record • Long operational lifespan, (approx. 15 years), due to stable orbital position 	<ul style="list-style-type: none"> • High latency due to distance of GEO satellites from Earth • Limited bandwidth and data rate capacity • Susceptible to signal delay and interference, especially in adverse weather conditions 	Mature
LEO Direct to Home (D2H)	<ul style="list-style-type: none"> • Provides broadband access to remote areas without ground infrastructure • Much lower latency compared to GEO satellites • Scalable as more satellites can be added 	<ul style="list-style-type: none"> • Requires end-user premises to have a receiver dish • Receiver dishes are relatively expensive • Mobility limited to location of receiver dish • Initial setup costs are high • Constellations require frequent replacements due to short operational lifespan (approx. 5 years) 	Emerging
LEO Backhaul	<ul style="list-style-type: none"> • Augments existing fibre networks, extending reach to remote areas • Reliable for areas where laying fibre is impractical • Can provide redundancy for ground networks' middle mile • Much lower latency compared to GEO satellites 	<ul style="list-style-type: none"> • Still dependent on some ground infrastructure, cell towers for last mile • Initial setup costs are high • Constellations require frequent replacements due to short operational lifespan (approx. 5 years) 	Emerging
LEO Direct to Device (D2D)	<ul style="list-style-type: none"> • Extends cellular coverage to areas without ground-based towers • Enables mobile operators to expand their network footprint • Can provide redundancy for ground networks' last mile • Much lower latency compared to GEO satellites 	<ul style="list-style-type: none"> • Limited bandwidth and data throughput compared to terrestrial networks • Not usable indoors, requires mobile device view of the sky • Initial setup costs are high • Constellations require frequent replacements due to short operational lifespan (approx. 5 years) 	Early-Stage
HAPS Direct to Cell	<ul style="list-style-type: none"> • Offers a stable communications platform • Can provide coverage in a targeted area with less infrastructure than satellites • Lower latency compared to other satellites 	<ul style="list-style-type: none"> • Limited by payload and power capacity • Solar energy source not suitable for Canada's latitude • Not usable indoors, requires mobile device view of the sky 	Proto-type

Policy Considerations for Canada and Beyond

In the development of NTN, it is vital to recognize Canada's unique position. Canada's vast geography, with sparsely populated rural and northern regions, presents an unparalleled opportunity for NTNs to connect underserved areas, addressing a critical national challenge. As NTN technologies mature and become more cost-effective, they hold the potential to bring ubiquitous national broadband access.

To unlock NTNs' potential, countries need to develop a robust, flexible, and forward-thinking regulatory framework that addresses key areas including spectrum, regulatory capacity, as-well-as operational and security considerations (Figure 6).

Figure 6: Key areas of focus for NTN policy



1. Spectrum Allocation, Interference and Competition

Governments around the world will face challenges in NTN spectrum management, highlighted by global disputes, necessitating

adaptive regulatory approaches. Among others, regulation must balance fair access and minimize interference between NTNs and terrestrial networks.

An illustrative spectrum case emerged in 2021 when Dish Network sought FCC approval to use the 12GHz band for 5G services.^{33,34} Dish's submission included a technical study advocating the coexistence of 5G and LEO internet services within this spectrum, espoused by the '5G for 12 GHz', a coalition of 35 companies pursuing the same goal.³⁵ However, SpaceX challenged the proposal, citing potential interference issues with a study indicating that terrestrial 5G operating alongside satellite services in the 12GHz band could lead to frequent Starlink outages, affecting service in 74% of cases.³⁶ Ultimately, the FCC sided with SpaceX, deciding not to authorize high-powered terrestrial mobile service in the 12.2-12.7 GHz band already used by Starlink customer terminals for downloads.³⁷

This dispute between Dish and SpaceX reveals the complexities of spectrum sharing between terrestrial and NTNs and illuminates the delicate balance regulators must strike between economic and public interests stemming from varied uses of the spectrum. It demonstrates the necessity for a regulatory framework that is not only informed and proactive but also flexible enough to navigate an evolving telecommunications landscape.

In addition to LEO and terrestrial networks disputes, interference regulations are at the centre of NTN tensions between LEO and geostationary satellite operators (GSO), and featured prominently in an Amazon Kuiper and Viasat dispute. LEO operators, like Starlink and Kuiper, face stringent equivalent power flux-density (epfd) limits, with these LEO satellite power limits designed to protect GSO networks from interference.³⁸ Established under ITU's Radio Regulations Article 22 since the late 1990s, these limits are now deemed outdated by some who argue that innovations such as

smaller, steerable spot beams, enhanced non-GSO (NGSO) constellation designs, and adaptive coding technologies have reduced GSO network interference risks.³⁹

Amazon leads the Alliance for Satellite Broadband, advocating for epfd rule revisions, arguing they enforce unnecessarily large exclusion zones,⁴⁰ which limits the customer base of a single satellite, effectively restricting broadband capacity, increasing satellite counts and operational costs, and reducing NGSO innovation due to lower potential ROI. An Amazon study claims that revising epfd limits could boost a generic NGSO network's capacity by 181% and reduce satellite count by 28%.⁴¹ A paper by former FCC chairman, Furchtgott-Roth, notes that reviewing epfd limits would lead to considerable consumer benefits, including reduced prices and a broader selection of LEO providers.⁴² However, GSO operators like Viasat and SES argue that interference is still a concern and argue that updating epfd limits is unnecessary for fostering NGSO competition.⁴³

Slated for review at the 2027 World Radiocommunication Conference (WRC-27), the issue of epfd limits emphasizes the delicate balance between fostering innovation in NGSO constellations and protecting the integrity of GSO services.⁴⁴ This ongoing debate underscores the complexities of regulating an increasingly crowded space environment, where regulatory frameworks are crucial to ensure a harmonious coexistence of satellite networks.

Innovation, Science and Economic Development Canada (ISED) recently updated national regulations for NGSO systems to address the emerging challenges and potential of commercial satellite constellations. These updates focus on efficient spectrum management, mandate 24/7 uninterrupted service coverage across 100% of Canadian territories (including remote and northern regions). They also require primary control facilities within Canada and mandate satellite

capacity reserved for Canadian capacity needs,⁴⁵ a condition that applies to Canadian-licensed NGSO systems, not to international systems such as Starlink.

Canada's regulatory framework for NGSO systems is designed for operational flexibility to foster innovation and adaptability in satellite communications. However, this approach, which currently does not stipulate a specific capacity reservation for Canadian use, may benefit from refinements to ensure that this flexibility doesn't compromise the availability of adequate service coverage.

Introducing minimum bandwidth requirements could ensure baseline service in remote areas, with prioritized bandwidth allocation for Indigenous communities and critical functions such as healthcare and emergency response to keep essential services operational. This approach may conflict with net neutrality principles which advocate for equal treatment of all data without prioritization. Bandwidth reservation also diverges from the common regulatory practice of auction-based spectrum allocation and historic reservations have resulted in unused spectrum and inefficiencies.

Implementation of monitoring and enforcement mechanisms is crucial to ensure compliance with service standards and to hold providers accountable for maintaining consistent service levels. Dynamic allocation strategies could optimize available spectrum use, allowing for adaptation to changing demands and usage patterns. However, such regulatory obligations come with trade-offs: they might deter global investments into the sector, which could then necessitate government incentives to attract international players and private investments.

These changes would require collaboration between regulatory bodies, service providers, and other stakeholders to balance innovation with reliable, high-quality service. It is then important to continuously evaluate and adapt the regulatory framework in the context of

emerging challenges to ensure optimal, ongoing connectivity.

2. Regulatory Capacity

To effectively navigate the evolving satellite communications landscape, governments should anticipate technological advancements and a surge in licensing demand.

The U.S. House Commerce Committee recently introduced the Satellite and Telecommunications (SAT) Streamlining Act and Secure Space Act to foster competition and spur innovation in the commercial satellite communications industry.⁴⁶ These bills aim to modernize Federal Communications Commission (FCC) satellite licensing rules and encourage investment and innovation. The impetus for this legislation stems from the complex and slow current licensing process, in which operators have faced significant delays and approval hurdles for satellite constellations. This is compounded by the FCC's struggle to keep pace with rapid technological innovation, hindered by outdated rules that no longer align with today's market realities.

The FCC, responsible for authorizing and regulating the radio spectrum for U.S. communication systems, including satellite services, oversees processes for licensing NGSO and GSO systems. The increase in proposed and operational NGSO constellations has strained FCC resources, creating a regulatory bottleneck and consequent uncertainty and delays for operators seeking to launch or modify satellite systems.

Addressing satellite licensing hurdles, the FCC introduced the Space Bureau in 2023 to lead policy and licensing for satellite and space-based activities, aiming to streamline regulations and ensure efficient use of spectrum and orbital resources.⁴⁷ This bureau is tasked with authorizing satellite and earth station systems and liaising with federal agencies on space

issues, which complements the legislative efforts with the SAT Streamlining Act. Furthermore, the FCC proposed licensing reforms in August 2023 aimed to modernize regulation to match the rapid evolution of the satellite industry through simplified licensing (including eliminating paper requirements) and innovation.⁴⁸ A new provision would also permit earth station operators to secure a provisional license, streamlining the launch of setup for satellite services.

Regulators around the world can expect similar challenges to the U.S. with the growing interest in LEO satellites. It becomes increasingly important for regulatory bodies to anticipate a surge in licensing requests by ensuring regulators are adequately resourced. This capacity preparation will enable regulatory bodies to handle the growing volume of applications, address complex technical and policy issues of emerging technologies, and in the process, effectively manage growth while avoiding the obstacles experienced by the FCC.

3. Operational Regulation

Telecommunications operational regulatory responsibilities are extensive, encompassing network resilience, data protection, consumer rights and privacy. Governments need clear cybersecurity regulations for NTN to manage massive data flow and safeguard against cyber threats. Moreover, cross-border regulatory coordination poses a significant challenge due to international 5G NTN services spanning multiple countries with disparate regulations. Key considerations include space debris regulations that facilitate the responsible lifecycle management of satellites; effective management of space traffic; and addressing issues related to radio astronomy and light pollution.

Several countries have introduced or updated cybersecurity legislation to address

emerging technologies like NTN and associated threats:

The United States is taking a proactive approach to address cybersecurity risks in non-terrestrial networks (NTNs), especially those supporting national security missions. The Committee on National Security Systems Policy No. 12 (CNSSP-12) mandates cybersecurity controls and the use of approved cryptography to protect satellite communications and data integrity.⁴⁹ This policy applies to both government and commercial satellites contracted for national security purposes.

CNSSP-12 facilitates information sharing between agencies and commercial providers to verify compliance with security requirements. It undergoes periodic updates to address evolving threats and align with changing practices. The latest update is expected to emphasize secure-by-design practices and incentivize industry to prioritize cybersecurity.⁵⁰

Additionally, the U.S. government is aligning its acquisition policies with CNSSP-12, evaluating proposed solutions' security posture before considering cost. The National Institute of Standards and Technology (NIST) has also published guidance to assist the commercial satellite industry in managing cybersecurity risks.⁵¹

The new Infrastructure Asset Pre-Approval (IA-Pre) program rolled out by the U.S. Space Force requires commercial satellite operators seeking to do business with the Department of Defense to undergo cybersecurity assessments and on-site verifications by third-party auditors. Those that pass are placed on a pre-approved list for contracts.⁵²

This makes it clear that any foreign commercial entity contracted to provide satellite services for U.S. national security purposes must comply with cybersecurity policies like CNSSP-12 and IA-Pre assessments mandated by the U.S. government.

Although Canada's *Critical Cyber Systems Protection Act* (CCSPA) proposed in Bill C-26 is based on terrestrial telecommunications, it has potential applicability to NTNs like satellite communications.⁵³ However, the absence of explicit mention of NTNs leaves room for ambiguity and potential overreach. Traditionally, legislation like the *Telecommunications Act* has adopted a technologically neutral approach in the industry. To effectively address the growing importance of these networks, future iterations of the legislation could benefit from explicit provisions and definitions covering NTNs, ensuring clarity and a proportionate approach to cybersecurity regulations in this rapidly evolving area.

China's Cybersecurity Law imposes stringent requirements on network operators, which could extend to NTN providers, and grants the government authority to conduct cybersecurity reviews of these networks. Australia's Security Legislation Amendment (Critical Infrastructure) Act 2022 establishes a risk management program for critical infrastructure assets, including telecommunications, which could encompass NTNs like satellite communications. The European Union's NIS2 Directive imposes cybersecurity measures for entities operating in critical sectors, explicitly including digital infrastructure and space, which covers NTNs.

While individual countries are taking steps to address cybersecurity risks in non-terrestrial networks through national policies and regulations, the inherently global nature of these networks necessitates increased international collaboration. Non-terrestrial networks like satellite constellations operate across multiple jurisdictions, making a harmonized approach to security frameworks crucial. International cooperation and coordination in areas such as threat intelligence sharing, incident response, and the development of common cybersecurity standards and best practices can enhance the overall security posture of these networks worldwide. Initiatives like the Cybersecurity

Tech Accord, which brings together global tech companies to collaborate on cybersecurity challenges, could be expanded to include non-terrestrial network operators and service providers. Additionally, forums like the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) can facilitate discussions and agreements on cybersecurity norms and responsible behavior in space.⁵⁴ By fostering international collaboration, countries can collectively address the unique cybersecurity challenges posed by non-terrestrial networks, promote interoperability, and ensure a secure and resilient global space ecosystem.

Regarding airspace regulation, civil aviation authorities typically govern airspace up to 60,000 feet (~18 Km),⁵⁵ while traditional air traffic control systems do not manage aircraft above this altitude, or to unmanned aircraft. In Europe, the U-Space system is proposed to manage Unmanned Aircraft Systems (drones), within controlled and uncontrolled airspace classes below 60,000 feet, but a unified approach is still in development.⁵⁶ There is an acknowledged need for space traffic management above 60,000 feet, but it remains undefined to date. Consequently, HAPS operations must be coordinated with local authorities in the absence of a regulatory structure. As HAPS activity and usage increases, the demand for regulatory framework for operations above 60,000 feet becomes more pronounced, but concrete strategies have not been solidified.

For LEO satellites, the International Telecommunication Union (ITU) and the WRC, held every four years, play a crucial role in global oversight. Companies planning to launch satellites must first obtain approval from their national licensing authority, followed by an ITU clearance request to use specific radio frequencies, as governed by the ITU's Radio Regulations.⁵⁷

With a growing number of satellites in LEO, the issue of space debris grows too,

stressing the need for a globally coordinated regulatory framework. Akin to the ITU's spectrum oversight, such a framework could offer a comprehensive and unified approach to regulating activities in space. A dedicated space regulatory entity would manage satellite trajectories and operational standards to mitigate the risk of collisions and minimize space debris. It would also develop and enforce international standards for satellite operation and decommissioning, paralleling the ITU's role in establishing technical standards for telecommunications. Furthermore, this entity would monitor compliance and facilitate global cooperation to address the challenges of space sustainability. This underscores the necessity for international collaboration, standard-setting, and regulatory oversight tailored to space activities.

Adopting the ITU's model for international coordination and regulation offers a robust blueprint for sustainable and safety of space activities, reflecting the critical need for a comprehensive approach to light pollution, radio astronomy, space traffic and debris management. The Inter-Agency Space Debris Coordination Committee, which issues guidelines (not legally-binding) on best practices for space debris, serves as a prime example of the type of alliances necessary in this field.⁵⁸

Conclusion

Bridging the global digital divide is a multifaceted and complex challenge, requiring a concerted effort across technological and regulatory fronts. The challenges in deploying traditional network infrastructure in remote and underserved areas worldwide underscore the need for innovative solutions such as Non-Terrestrial Networks (NTNs). These NTNs, including technologies such as Low Earth Orbit (LEO)-based satellite connectivity, offer a solution in regions where geographic and financial barriers have long impeded terrestrial connectivity. However, their deployment is not

without challenges. Spectrum allocation, international regulatory coordination, and considerations around data privacy and cybersecurity are critical components that must be carefully navigated across borders and jurisdictions.

Lessons can be learned from early test cases, such as the United States, which has already experienced a surge in licensing demands and spectrum disagreements between terrestrial and non-terrestrial networks. These early experiences underscore the importance of:

Balancing Technological Innovation and Regulation: Regulatory frameworks must be flexible and informed to accommodate rapid technological changes while ensuring fair spectrum access and minimal interference.

Efficient Licensing Processes: Streamlined and modernized licensing procedures are essential to support the deployment of NTN and address the growing demand for satellite services.

Collaboration Among Stakeholders: Effective regulation requires cooperation between nations, technology providers, and other stakeholders to develop standards that support innovation and protect existing services.

Collaboration on Cybersecurity Guidelines: Establishing clear and explicit cybersecurity regulations for NTN is critical to safeguard data and ensure network security, especially given the cross-border nature of these networks.

Proactive Resource Allocation: Adequately resourced regulatory bodies are necessary to manage the increasing number of applications and the complexities of emerging technologies.

International Regulatory Coordination: Harmonized regulations and international collaboration are vital for managing the global nature of NTN, including aspects like threat intelligence sharing, incident response, and space debris management.

As countries recognize the decreasing costs of deploying NTN and the increasing prevalence of the Internet of Things (IoT) as a part of resilient telecommunications infrastructure, the demand for NTN will only continue to rise. Vast countries like Russia, China, and Saudi Arabia, which face geographical impediments to economically deploying terrestrial networks, will likely turn to NTN as a solution to bridge the digital divide in their regions.

Even if the interests of different nations and stakeholders in the development and deployment of NTN do not fully align, international collaboration remains crucial, especially when it comes to addressing security concerns and promoting sustainable space use. The global nature of NTN and their potential impact on the space environment transcend national boundaries, necessitating a coordinated approach among all involved parties, regardless of their individual interests.

While the International Telecommunication Union (ITU) has played a commendable role in fostering collaboration on spectrum allocation and management issues related to NTN, efforts towards addressing security concerns and promoting sustainable space use have been lacking. The global nature of NTN and their potential impact on the space environment demand a coordinated approach among nations, technology providers, and stakeholders.

The ITU's governance mechanisms, such as the World Radiocommunication Conferences (WRCs) and the Radio Regulations, have facilitated the harmonization of spectrum allocations and the development of technical standards for space radiocommunication services. However, addressing cybersecurity risks, mitigating space debris, and ensuring the long-term sustainability of outer space activities require a broader international framework and concerted efforts from all space-faring nations.

While individual countries like the United States have implemented policies like the Committee on National Security Systems Policy No. 12 (CNSSP-12) to secure NTN supporting national security missions, a comprehensive global approach to NTN cybersecurity is still lacking. Similarly, initiatives like the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) and the Inter-Agency Space Debris Coordination Committee (IADC) have made progress in promoting sustainable space practices, but more robust international cooperation and binding agreements are needed to ensure the long-term viability of the space environment for NTN operations.

The ultimate goal is to bridge the digital divide globally, ensuring that every community has equitable access to the digital world regardless of location or socioeconomic status. This commitment not only addresses the digital divide but also fosters broader socio-economic development, improving the lives of people across the globe and promoting a more inclusive and connected world.

References

1 Furchtgott-Roth, Harold, The Economic Benefits of Updating Regulations that Unnecessarily Limit Non-Geostationary Satellite Orbit Systems (August 11, 2023).

2 Robert.wickramatunga. (n.d.). United Nations Office for Outer Space Affairs. Policy Brief 7: For all Humanity - the future of outer space governance.
<https://www.unoosa.org/oosa/en/documents/doc/policy-brief.html>

³ *Outback Communities Authority region*. profile.id. (n.d.).
<https://profile.id.com.au/outback-communities/about>

4 Starlink. (n.d.).
<https://www.Starlink.com/technology>

5 Sector, D. T. S. (2022, April 11). Government of Canada. Government of Canada, Innovation, Science and Economic Development Canada, Office of the Deputy Minister, Digital Transformation Service Sector. <https://ised-isde.canada.ca/site/high-speed-internet-canada/en/canadas-connectivity-strategy/high-speed-access-all-canadas-connectivity-strategy>

6 Starlink. (n.d.).
<https://www.Starlink.com/technology>

7 Telesat Lightspeed Leo Network.
<https://www.telesat.com/leo-satellites/>

8 <https://www.telesat.com/press/press-releases/telesat-and-spacex-announce-14-launch-agreement-for-advanced-telesat-lightspeed-leo-satellites/>

9 Ontario newsroom. (n.d.).
<https://news.ontario.ca/en/release/1000680/ontario-partners-with-world-class-satellite-operator-to-bring-high-speed-connectivity-across-province>

10 Backhaul LTE tests – Ass - Arqueiro Satellite Solution. Arqueiro Telecom. (2023a, July 25).
<https://www.arqueirotelecom.com/backhaul-lte-tests-Starlink/>

11 Backhaul LTE tests – Ass - Arqueiro Satellite Solution. Arqueiro Telecom. (2023a, July 25).
<https://www.arqueirotelecom.com/backhaul-lte-tests-Starlink/>

12 Qualcomm introduces Snapdragon Satellite, the world's first satellite-based solution capable of supporting two-way messaging for premium smartphones and beyond: Qualcomm. Wireless Technology & Innovation. (n.d.).
<https://www.qualcomm.com/news/release>

-
- s/2023/01/qualcomm-introduces-snapdragon-satellite--the-world-s-first-sate
- 13 Mediatek to showcase its groundbreaking satellite connectivity... MediaTek. (2023, November 25). <https://corp.mediatek.com/news-events/press-releases/mediatek-to-showcase-its-groundbreaking-satellite-connectivity-technology-at-mwc-2023>
- 14 Apple extends emergency SOS via satellite for an additional free year. Apple Newsroom (Canada). (2023, November 15). <https://www.apple.com/ca/newsroom/2023/11/apple-extends-emergency-sos-via-satellite-for-an-additional-free-year/>
- 15 <https://www.apple.com/ca/newsroom/2022/11/emergency-sos-via-satellite-made-possible-by-450m-apple-investment/>
- 16 Thiel, M. (2023, April 26). Rogers signs agreement with spacex to bring satellite-to-phone coverage to Canada. About Rogers. <https://about.rogers.com/news-ideas/rogers-signs-agreement-with-spacex-to-bring-satellite-to-phone-coverage-to-canada/>
- 17 Home - Starlink - direct to cell. Starlink. (2023b, November 6). <https://direct.Starlink.com/>
- 18 SpaceX launches first set of satellites with direct-to-cell ... (n.d.-a). <https://www.reuters.com/technology/spacex-launches-first-set-satellites-with-direct-to-cell-capabilities-2024-01-03/>
- 19 Home - Starlink - direct to cell. Starlink. (2023b, November 6). <https://direct.Starlink.com/>
- 20 AST spacemobile secures strategic investment from AT&T, Google and Vodafone. Business Wire. (2024, January 18). <https://www.businesswire.com/news/home/20240118463570/en/>
- 21 AST SpaceMobile. (2023, October 25). AST spacemobile achieves space-based 5G cellular broadband connectivity from everyday smartphones, another historic world first. <https://ast-science.com/2023/09/19/ast-spacemobile-achieves-space-based-5g-cellular-broadband-connectivity-from-everyday-smartphones-another-historic-world-first/>
- 22 TELUS, TerreStar and Skylo demonstrate Canada's first two-way communication between smartphones and satellites. TELUS. (n.d.). <https://www.telus.com/en/about/news-and-events/media-releases/telus-terrestar-and-skylo-demonstrate-canadas-first-two-way-communication-between-smartphones-and-satellites>
- 23 Airbus.com. (n.d.). <https://www.airbus.com/en/newsroom/press-releases/2022-07-airbus-to-deliver-connectivity-services-using-its-leading-zephyr>
- 24 Aalto Haps. HAPS. (n.d.). <https://www.aaltohaps.com/>
- 25 Leichtwerk AG stratoStreamer. Leichtwerk AG StratoStreamer. (n.d.). <https://haps-broadband.org/technology/>
- 26 Home - Starlink - direct to cell. Starlink. (2023a, October 11). <https://direct.Starlink.com/>
- 27 Telesat contracts MDA as PRIME satellite manufacturer for its Advanced Telesat Lightspeed low earth orbit constellation. Telesat. (2023, August 11). <https://www.telesat.com/press/press-releases/telesat-contracts-mda-as-prime-satellite-manufacturer-for-its-advanced-telesat-lightspeed-low-earth-orbit-constellation/>

28 Elon Musk's SpaceX now has a 'de facto' monopoly on rocket ... (n.d.-b).
<https://www.wsj.com/articles/elon-musk-spacex-now-has-a-de-facto-monopoly-on-rocket-launches-3c34f02e>

29 Capabilities and services - SpaceX. (n.d.-a).
<https://www.spacex.com/media/Capabilities&Services.pdf>

30 Lea, R. (2023, December 28). SpaceX Falcon 9 rocket launches 23 Starlink satellites into orbit in Final flight of 2023. Space.com.
<https://www.space.com/spacex-Starlink-6-36-satellites-launch-webcast>

31 Westgarth, A. (2021, August 17). Saying goodbye to Loon. Medium.
<https://blog.x.company/loon-draft-c3fceb11f3f>

32 Maguire, Y., & Maguire, Y. (2020, March 24). High altitude connectivity: The next chapter. Engineering at Meta.
<https://engineering.fb.com/2018/06/27/connectivity/high-altitude-connectivity-the-next-chapter/>

33 Allevin, M. (2023, August 9). 5G coalition presses FCC to allow FWA in lower 12 GHz band. Fierce Wireless.
<https://www.fiercewireless.com/5g/dish-led-5g-coalition-presses-fcc-allow-fwa-lower-12-ghz-band>

34 Dish Wireless: About Us. DISH Wireless Blog - 12 GHz. (n.d.).
https://www.dishwireless.com/blog_12ghz

35 5G for 12 GHz. 5G for 12 GHz. (2021, May 25). <https://5gfor12ghz.com/>

36 Starlink. (n.d.-a).
<https://www.Starlink.com/updates>

37 FCC fact sheet* expanding use of the 12.7-13.25 GHz band for mobile ... (n.d.-a).
<https://docs.fcc.gov/public/attachments/DOC-392970A1.pdf>

38 Article 22 Space Services I. (n.d.-a).
<https://life.itu.int/radioclub/rr/art22.pdf>

39 Furchtgott-Roth, Harold, The Economic Benefits of Updating Regulations that Unnecessarily Limit Non-Geostationary Satellite Orbit Systems (August 11, 2023). (Initial Report). Available at SSRN: <https://ssrn.com/abstract=4538619> or <http://dx.doi.org/10.2139/ssrn.4538619>

40 Alliance for Satellite Broadband. (2023, December 1).
<https://allianceforsatellitebroadband.org/>

41 Furchtgott-Roth, Harold, The Economic Benefits of Updating Regulations that Unnecessarily Limit Non-Geostationary Satellite Orbit Systems (August 11, 2023). (Initial Report). Available at SSRN: <https://ssrn.com/abstract=4538619> or <http://dx.doi.org/10.2139/ssrn.4538619>

42 Furchtgott-Roth, Harold, The Economic Benefits of Updating Regulations that Unnecessarily Limit Non-Geostationary Satellite Orbit Systems (August 11, 2023). (Initial Report). Available at SSRN: <https://ssrn.com/abstract=4538619> or <http://dx.doi.org/10.2139/ssrn.4538619>

43 Viasat warns Satellite Power Limit Review would hurt Geo Innovation. Viasat warns satellite power limit review would hurt GEO innovation. (n.d.).
<https://infowars.sfo3.digitaloceanspaces.com/newsarchive/viasat-warns-satellite-power-limit-review-would-hurt-geo-innovation.html#>

44 Rainbow, J. (2023, December 13). WRC-23 reaches tough compromise on Satellite Power Limit Review. SpaceNews.

-
- <https://spacenews.com/wrc-23-reaches-tough-compromise-on-satellite-power-limit-review/>
- 45 Sector, S. and T. (2017, June 5). Government of Canada. Government of Canada, Innovation, Science and Economic Development Canada, Office of the Deputy Minister, Spectrum and Telecommunications Sector. <https://ised-isde.canada.ca/site/spectrum-management-telecommunications/en/learn-more/key-documents/consultations/decisions-licensing-framework-non-geostationary-satellite-orbit-ngso-systems-and-clarification>
- 46 Text - H.R.2262 - 114th congress (2015-2016): U.S. commercial space ... (n.d.-c). <https://www.congress.gov/bill/114th-congress/house-bill/2262/text>
- 47 Space. Federal Communications Commission. (n.d.). <https://www.fcc.gov/space>
- 48 FCC Streamlines Satellite Application Processing. Federal Communications Commission. (2023, September 22). <https://www.fcc.gov/document/fcc-streamlines-satellite-application-processing>
- ⁴⁹ Administrator. (n.d.). Committee on National Security Systems. <https://www.cnss.gov/cnss/>
- ⁵⁰ Milsatmagazine. (n.d.). <http://www.milsatmagazine.com/story.php?number=1270370846>
- ⁵¹ Scholl, M., & Suloway, T. (2023, July 25). *Introduction to cybersecurity for Commercial Satellite Operations*. CSRC. <https://csrc.nist.gov/pubs/ir/8270/final>
- ⁵² USSF commercial satcom office announces development of new security program. United States Space Force. (n.d.). <https://www.spaceforce.mil/News/Article/2230831/ussf-commercial-satcom-office-announces-development-of-new-security-program/>
- 53 Government of Canada, D. of J. (2023, November 27). Charter statement Bill C-26: An act respecting cyber security, amending the Telecommunications Act and making consequential amendments to other acts. Government of Canada, Department of Justice, Electronic Communications. https://www.justice.gc.ca/eng/csjsjc/pl/charter-charte/c26_1.html
- ⁵⁴ Robert.wickramatunga. (n.d.). *United NationsOffice for Outer Space Affairs*. COPUOS. <https://www.unoosa.org/oosa/en/ourwork/copuos/index.html>
- 55 High altitude platform systems - GSMA. (n.d.-b). <https://www.gsma.com/futurenetworks/wp-content/uploads/2021/06/GSMA-HAPS-Towers-in-the-skies-Whitepaper-2021.pdf>
- 56 U-SPACE. Joinup. (n.d.). <https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/u-space>
- 57 Harper, N. (2023, November 16). Itu and space: Ensuring interference-free satellite orbits in leo and beyond. ITU Hub. <https://www.itu.int/hub/2022/02/itu->

space-interference-free-satellite-orbits-
leo/

58 Inter-agency Space Debris Coordination
Committee. IADC. (n.d.). [https://iadc-
home.org/what_iadc](https://iadc-home.org/what_iadc)