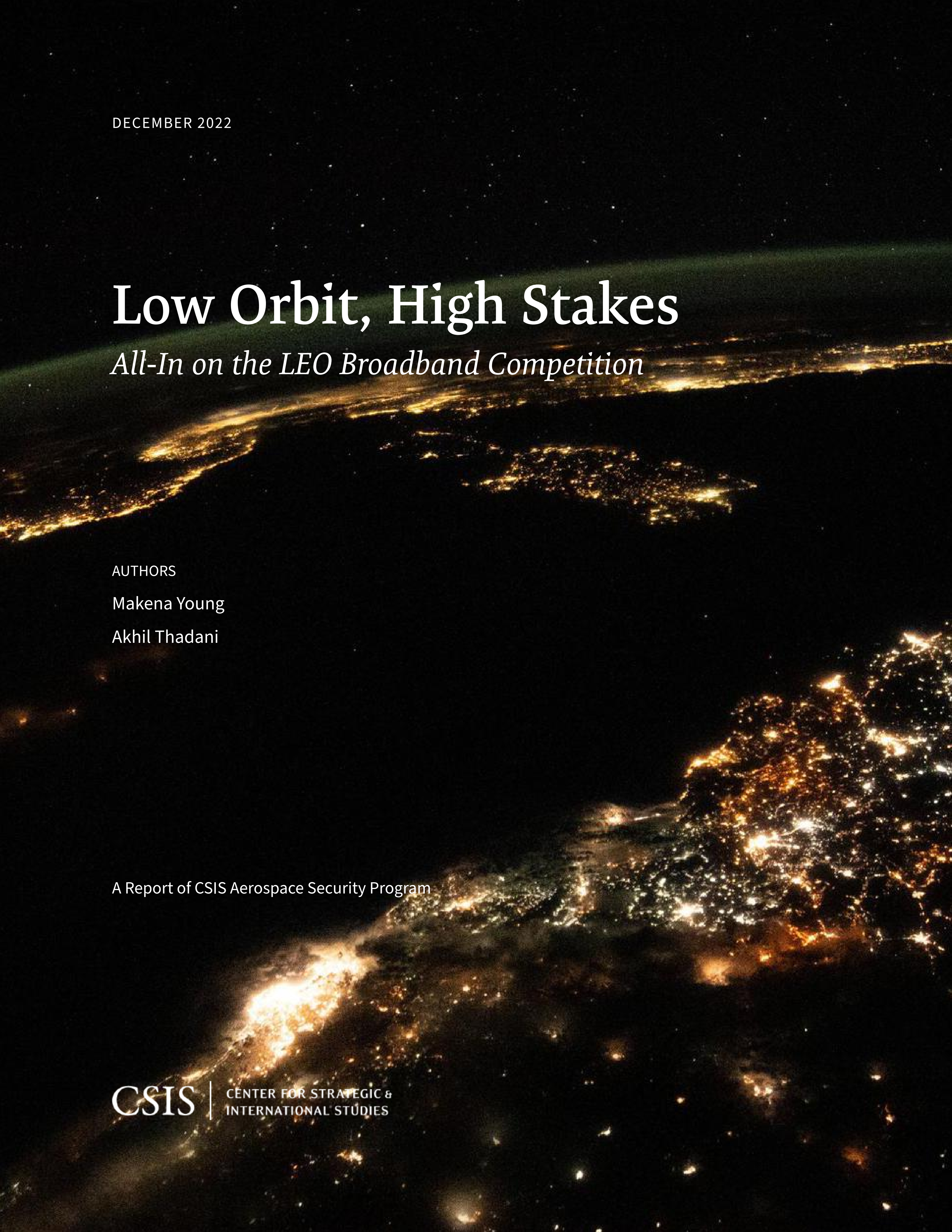

DECEMBER 2022

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All-In on the LEO Broadband Competition

AUTHORS

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A Report of CSIS Aerospace Security Program

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1

Introduction

As of November 2022, just over 63 percent of the 8 billion people in the world use the internet—leaving about 3 billion people (and potential customers) unconnected.[1] To bridge this digital divide, governments and private commercial companies are investing in initiatives to build space-based broadband internet. If successful, these efforts have the potential to quickly connect people around the globe, as well as change the space environment itself. Several countries are launching national initiatives to establish low Earth orbit (LEO) satellite constellations and capture large portions of a burgeoning market, unleashing extensive private- or state-backed resources to do so.

Competition to provide broadband services from satellites is not new. The 1990s saw a similar commercial broadband internet boom that resulted in little success. Companies such as Teledesic, Celestri, Globalstar, Odyssey, and Iridium all proposed large satellite-communications (SATCOM) constellations in LEO, but almost all ended in bankruptcy by the early 2000s.[2] As similar ambitions emerge 30 years later, will the new generation of LEO-based satellite broadband succeed? Today the barrier to entry to orbit has significantly decreased as technology, materials, and launch capabilities have become cheaper and more widely available. International competition to build, launch, and operate a low-cost and low-latency system that spans the globe is fierce, as the demand for fast, reliable, and affordable internet services continues to expand. As of 2022, only one operator, Starlink, is providing LEO-based service on the open market. High capital investment and extensive initial infrastructure requirements have slowed the commercialization of LEO broadband. However, this is set to change. Satellite broadband revenues have already increased by 1.1 percent in 2021, and global subscribers jumped by 11 percent—up to 3 million people—since the year prior.[3] The global SATCOM market is estimated to grow to $40 billion by 2030, largely driven by LEO-based ventures.[4]

Establishing a LEO constellation—a network of LEO-based satellites necessary for continuous global broadband delivery—involves substantial upfront investment, specialized technical know-how, and the ability to navigate a complex regulatory landscape. As international competition in LEO communications intensifies, it is imperative that the U.S. government creates an enabling (yet robust) regulatory environment for U.S.-based ventures to thrive at home and abroad. The government can also support U.S. companies, as well as the development of norms and standards, in key international coordinating bodies.

Today, the United States profits significantly—economically, militarily, and in global norms and standards setting—from its dominance in global networks, capturing 38 percent of industry revenue in 2021.[5] There have been significant investments in a U.S.-serviced space-based internet, to include U.S commercial endeavors and separate proposed Department of Defense (DOD) efforts. However, allies and competitors alike are launching their own ventures in an increasingly contentious market: Telesat LightSpeed is based in Canada, and the newly merged Eutelsat/OneWeb is supported by both private funders in India and the UK government. Perhaps the greatest U.S. competitor in the race to global connectivity through satellite broadband is China. It has proposed a 13,000-satellite constellation in LEO to serve residential and business needs in the Chinese market, as well as to underdeveloped internet markets across the globe.[6] Leveraging its state-owned enterprises (SOEs), public funding, and political and economic ties won through its Belt and Road Initiative (BRI), China poses a real threat to U.S. dominance in this market.

Policymakers in Washington and many allied nations now appreciate the risks that Chinese vendors pose in 5G networks, undersea cables, and other vital communications links. But they have yet to consider the economic and strategic implications of LEO satellite constellations, which promise to deliver quality and continuous coverage in underserved markets and bring more of the world online. In addition to reaping vast commercial rewards, nations with leading LEO broadband providers could enjoy increased economic benefits, resiliency, greater control over international communications networks, more accuracy in positioning services, enhanced early-warning capabilities, and potentially even greater intelligence access.

The following analysis examines the competition for satellite broadband, focusing on the interests of the United States and China. Beginning with a description of proposed satellite network constellations and their effects on the space environment, the paper will then examine U.S. interests in space, China's planned satellite broadband efforts (and the competitive environment that may build), and the risks of operating large constellations in low Earth orbit. Finally, the authors will conclude with recommendations for specific actors, with an emphasis on U.S. government agencies.

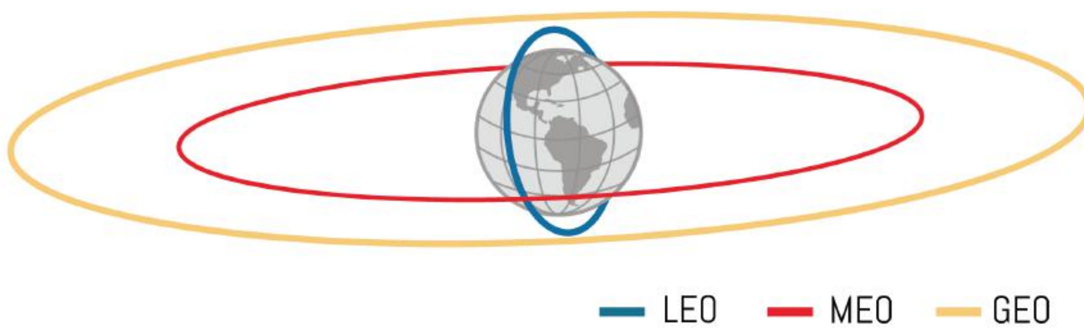
2

The State of Commercial LEO Broadband

Advantages of Low Earth Orbit

Satellites are typically launched into one of three popular orbits: LEO at 160 to 2,000 kilometers (99 to 1243 miles), medium Earth orbit (MEO) at 2,000 to 35,786 kilometers (1243 to 22,236 miles), or geosynchronous orbit (GEO) at up to 42,164 kilometers (26,199 miles). All three orbits have varying advantages and challenges for satellites operating within them. For example, a constellation in GEO can have global coverage with only three satellites because of its distance from the Earth's surface; GEO is popular for communications for this reason. However, because the satellites are so far away from Earth there is a longer period of latency—i.e., the time it takes for the signal to route to a satellite in GEO and back down to Earth.

Figure 1: Popular Earth Orbits



Source: Thomas G. Roberts, "Popular Orbits 101," CSIS, *Aerospace Security,* November 30, 2017, https://aerospace.csis.org/aerospace101/earth-orbit-101/.

The new generation of satellite internet suppliers are placing satellites in LEO instead of the traditional GEO for a multitude of reasons. Satellites launched into LEO are typically smaller and lighter than those in GEO, meaning that less fuel is required, and companies can place more satellites in orbit per launch for lower costs. Additionally, since LEO satellites are in relatively close proximity to Earth—between 160 and 2,000 kilometers (99 and 1243 miles) above the surface—user terminals can detect multiple satellites at once and connect with greater accuracy.[7] Because LEO satellites are in constant motion, each satellite can only service a relatively small area on Earth at any given moment, so a large constellation of satellites is necessary to provide continuous global coverage.

Communications from LEO also experience a lower latency than satellites in GEO because they are so much closer to the Earth's surface. LEO satellite operators tout that a web page can be opened around eight times faster when using LEO satellites than when using a traditional SATCOM system at GEO, something that has become more important to consumers who want to interact online in near-real time.[8] This means that satellite internet needs to be capable of supporting high-throughput applications such as streaming, video conferencing, and real-time gaming. At the time of publication, LEO broadband constellations are capable of download speeds up to 250 megabits per second (Mbps), upload speeds of 30 Mbps, and latency of 25 milliseconds.[9] This can be compared to cable internet, which in the United States can reach download speeds of up to 500 Mbps and upload speeds of 50 Mbps, with 100 milliseconds of latency.[10] As more satellites are added to each constellation, these numbers will continue to improve for each respective provider. For nonstationary customers, such as airline travelers or maritime shipping vessels, LEO's continuous coverage enables quicker and more reliable broadband than is currently provided through GEO- and MEO-based services.

3

Bridging the Digital Divide through LEO

Broadband has proven to be a critical enabler for global "trade, employment, learning, leisure, and communications."[11] Access to the rapidly growing digital economy, which comprises roughly 15.5 percent of global gross domestic product (GDP), can be transformational for previously unconnected and underdeveloped regions. The World Bank estimates that a 10 percent increase in broadband access can cause a 1.38 percent jump in GDP among low- and middle-income countries.[12] Particularly in remote, hard-to-reach areas where building dedicated ground infrastructure is too expensive or simply not possible, LEO systems can provide quality internet connectivity to populations that are unreliably served by legacy technology. In the case of outages or gaps in service, such as during conflict or natural disaster, LEO constellations can boost the resiliency of communications networks and help fill the gaps in global connectivity.

For rural households across the globe, 63 percent of which do not have access to the internet as of 2020, satellite internet may be the only option for connectivity.[13] Unlike other terrestrial forms of internet delivery, satellite terminals—receivers for space-based signals—require only a mostly unobstructed view of the sky and an electric connection. Current broadband services such as fiber optic cables, digital subscriber lines (DSL), or copper-based cable internet require extensive infrastructure (e.g., underground cable ducts or network tower construction) to become operational. The minimal and lower-cost ground-infrastructure requirements of satellite-based internet, coupled with LEO's ability to provide broadband of a superior quality than other forms of satellite broadband (i.e., higher data rates with lower latency) makes LEO an extremely compelling solution for bridging gaps in the digital divide. Yet while there is great potential for space-based broadband, companies will need to improve quality, reliability, and affordability in order to meaningfully expand coverage.

Though the barriers to entry and sustained operation are high, several operators throughout North America, Europe, and Asia are moving forward with LEO broadband plans. In the United States, SpaceX's Starlink, Amazon's Project Kuiper, and Boeing are expected to be top competitors in the market. In January 2015, Elon Musk, SpaceX's CEO, first announced a $10-billion space internet plan. This service, now known as Starlink, would reportedly come online after five years and would be a revenue stream for SpaceX to pursue founding a city on Mars.[14] As of November 2022, Starlink has launched over 3,500 satellites, all on SpaceX launch vehicles, and offers coverage in more than 50 markets across North America, South America, Europe, Japan, Australia, and New Zealand.[15]

Amazon's Project Kuiper constellation has been in progress since 2019 and is expected to launch its first prototype satellites in early 2023, with the full constellation being implemented over the following five-year period.[16] Named for the Kuiper Belt, a band of icy celestial bodies just beyond Neptune's orbit, Kuiper is meant to be available to residential customers as well as an anchor for Amazon Web Services (AWS) cloud computing. According to its operating license granted by the Federal Communications Commission (FCC), half of Kuiper's 1,618 satellite constellation must be launched by 2026, and the full constellation by 2029.[17] In April 2022, Amazon announced landmark launch agreements with Arianespace, Blue Origin, and United Launch Alliance (ULA) for a total of 83 launches of Kuiper satellites over a period of five years.[18]

Companies such as Verizon and T-Mobile are testing telecommunications integration with LEO satellites to create more robust fifth-generation (5G) wireless services.[19] This added competition from traditional terrestrial broadband providers will likely drive down prices in previously monopolized markets. In October 2021, Verizon and Project Kuiper announced a collaboration that would enable Project Kuiper satellites to "deliver backhaul solutions to extend Verizon's 4G/LTE and 5G data networks, connecting rural and remote communities in the U.S."[20] In August 2022, SpaceX and T-Mobile announced a similar agreement that would enable next-generation Starlink satellites (to be launched in 2023) to communicate with cell phones consumers already own, theoretically eliminating dead zones in the T-Mobile cellular network. Customers could then call, text, and possibly stream videos without connection to a cell tower.[21]

Boeing has been publicly discussing investing in satellite internet since 2015, hoping to substantially increase internet capability while driving down the cost of satellite networks.[22] After it failed to gain FCC approval for a 3,000-satellite LEO broadband constellation in 2017, an updated plan for a 147-satellite constellation was approved in 2021. This "V-band Constellation," as it is called in its FCC application, would provide internet and communication services to the United States and its territories before expanding globally. The 147 satellites are to be broken down into LEO and GEO segments, with 132 satellites orbiting at 1,056 kilometers (656 miles) and 15 additional satellites orbiting between 27,355 and 44,221 kilometers (16,998 and 27,478 miles).[23] According to its operating license granted by the FCC, half of the constellation must be launched by November 2027, and the rest by November 2030.[24]

Telesat, established by the Canadian parliament in 1969, has continued to operate domestic satellite communications networks in the years since, even after the company officially separated from the Canadian government in 2008. Telesat announced its Lightspeed LEO constellation in 2016, creating a network of 188 satellites orbiting at 1,000 kilometers (620 miles) above Earth. Lightspeed does not aim to be a consumer broadband company but will instead market to cruise ships, airlines, and rural municipalities.[25]

The largest publicly known plan for satellite broadband in Asia comes from China. Following the disintegration of two broadband constellation projects, China applied to the International Telecommunication Union (ITU) to operate a 12,992-satellite fleet in LEO in 2020. In early 2022, the local government of Shanghai entered into a strategic cooperation agreement with state-funded SatNet; in return for unknown support, SatNet will establish a space hub for the production of satellites and reusable launch vehicles in Shanghai.[26] Additional details about the constellation have not been made public, but SatNet is to be a critical part of China's political goal of being a leader in advanced technology across the globe.

Already, several would-be LEO operators have been forced to scale back their ambitions, declare bankruptcy, or seek drastic measures to keep afloat. UK-based LEO broadband start-up OneWeb filed for Chapter 11 bankruptcy in 2020, only eight years after it was founded.[27] Narrowly managing to escape default, the company received funding from the UK government and Bharti International, a large Indian conglomerate. Despite being one of the few firms close to bringing a product to market, having launched 66 percent (428 satellites) of its first constellation fleet and having received FCC permission to provide service in the United States, OneWeb struggled to attract the levels of investment it needed to stay afloat.[28] In July 2022, the company merged with Eutelsat, a GEO satellite operator backed by French and Chinese funders, to bridge its growing financial gap.[29]

A similar merger is expected to be finalized between U.S.-based GEO satellite operator ViaSat and UK-based satellite operator Inmarsat to deploy a constellation of 150 LEO satellites to join Inmarsat's already established GEO network. This constellation, named Orchestra, will provide increased cybersecurity to government customers, integrate with 5G services, and improve the network's latency, resiliency, and speed.[30]

LEO Economics

Today, the LEO satellite internet industry is heavily concentrated among a few private sector companies and government-backed or -owned ventures. The high capital expenditure requirements for launching, maintaining, and manufacturing LEO constellations, along with the competition over finite spectrum resources and near-Earth orbital space contribute to the market having only a few major players. LEO constellations are expensive in both resources and time. Establishing a satellite constellation capable of global coverage—necessary for continuous broadband service in any one location—is a long-term endeavor. Furthermore, licensing and regulatory requirements are extensive and highly variable across different countries, leading to greater uncertainty and high compliance costs. Investing in LEO broadband is a long-term venture with many uncertainties and risks.

However, the business case for LEO broadband is strong. Global demand for connectivity remains high—and so does the demand for low latency and quality service. Rural areas are a key potential consumer base for satellite-broadband operators, and the quality promised by LEO-based constellations make them a favored avenue to satisfy demand. In the United States alone, 28 percent of rural households (roughly 4.8 million Americans) remain unconnected[31]—but a MossAdams study reports that both subscribership and average revenue per user in U.S. rural areas are also on the rise.[32] Other key consumer bases for LEO-based services include business-to-business (B2B) applications, nonstationary customers such as airlines and shipping conglomerates, and developing economies. Some LEO providers, Telesat and OneWeb included, are focusing entirely on B2B applications.[33]

Another difficulty for the LEO broadband business case is that it requires substantial and costly infrastructure: hardware and software for satellites, ground stations, secure launch vehicles, and space situational awareness (SSA), just to name a few. Every segment needs to successfully work together and provide a high-quality product for the business to draw in customers and make a return on investment. Because of the growing desire for worldwide connectivity, experts assess that a strong and growing market will reach a 20 percent compound annual growth rate by 2030.[34]

Following the establishment of a LEO-based constellation, companies will be able to offer a range of services beyond simple connectivity, such as cloud computing, entertainment streaming, remote internet of things (IoT) applications, and government and military uses.[35] Once high initial barriers to connectivity are satisfied, extending service offerings involves relatively low marginal costs. Indeed, operators are already exploring LEO-constellation applications beyond direct broadband delivery.[36]

Private sector investment in space companies exceeded $10 billion in 2021, 60 to 70 percent of which is now directed into LEO-related ventures.[37] Venture capitalists, encouraged by decreasing launch costs and the development of commercially viable applications, have also turned their attention toward space firms operating in LEO.[38] While investment is increasing, current levels may not be enough to sustain a crowded industry due to the long-term nature of the LEO broadband enterprise.

Building and operating large LEO constellations are incredibly complex and expensive, and today the industry is primarily driven by large companies with vast monetary reserves or by SOEs, a paradigm reinforced by structural and policy challenges. McKinsey estimates a $5 to $10 billion price tag for deploying an operational LEO satellite constellation.[39] On top of that, recurring operating and maintenance costs are predicted to run companies $1 to $2 billion per year. In October 2022, Elon Musk said that the cost of the Starlink operation in Ukraine—including providing terminals and maintaining satellites and ground stations, among other expenditures—would reach $100 million by the end of the year.[40] Though extenuating circumstances are driving this estimate up to much higher-than-average national operating costs, it is an example of the large funding necessary to maintain a successful and operational network in a time of crisis. High barriers to entry have resulted in the need for continuous and substantial investment financing for the industry.

LEO constellations have the potential to reshape global networks, both those in orbit and on the ground. While reliant on the placement of numerous ground stations to extend service, the development of optical intersatellite links—communication channels that allow satellites within the same constellation to transfer data seamlessly between one another—will (when operational) further reduce the need for expensive ground infrastructure. Despite these advancements, one of the largest barriers to wide commercial adoption of LEO broadband services remains affordability. While end-user terminals allow communities to bypass the large infrastructure needs of traditional broadband delivery, production costs range anywhere from $1,000 for a home-use terminal to $10,000 for an airborne terminal (another potential market), making them prohibitively expensive for most customers in developing economies.[41] Industry experts estimate the price of home terminals will be cut in half by the 2030s, with Amazon's Project Kuiper already reporting terminal production costs will be under $500 per unit.[42] Still, LEO satellite terminals are estimated to be approximately three times more expensive than GEO satellite terminals and seven times more expensive than traditional internet routers.[43] Companies are likely to highly subsidize current and future terminals to incentivize adoption.

The high capital expenditures of manufacturing, launching, and maintaining a satellite constellation and its constituent parts require providers to charge high prices to recuperate these substantial early-stage investments. However, the average revenue per user in most developing markets is not currently high enough for companies to sustain operations. Instead, it is likely that select households will adopt and pay for these services, potentially driving the price down for expansion to underserved populations. Lack of access to broadband is heavily correlated with poverty, and the companies that can quickly decrease costs and meaningfully expand access to underserved populations could capture significant portions of the market share.[44]

4

China's Space Broadband Vision

China's space sector has historically been dominated by the China Aerospace Science and Technology Corporation (CASC). As an SOE, CASC, along with its many subsidiaries, is tasked with the "research, design, manufacture, test and launch of" all space-based activities.[45] Only over the past 10 years has there been a slow emergence of space firms not solely government-owned or -operated. Document 60, a policy directive issued by the National Development and Reform Commission (NDRC) in 2014, unlocked a small portion of the space sector to private financing and created the first Chinese commercial space companies.[46] A 2016 white paper called for increased "cooperation with private investors" on space, signaling a more relaxed approach to the restricted sector.[47] It wasn't until 2019 that an NDRC directive opened the majority of China's nascent space economy to private investors at home and abroad. With broader permissions than allowed by Document 60, this directive prompted a significant shift in China's space and satellite communications sector. That year, the country surpassed all but the United States in the number of space start-ups receiving funding, as well as in the amount of funding received, drawing 16 percent of total global investment in these ventures.[48]

The resulting flood of capital led to a boom in Chinese space start-ups. As the sector matures, so will China's capacity to grow and operationalize its space-based assets. According to an unclassified U.S. Defense Intelligence Agency report, China doubled the number of satellites it has in orbit from 250 to 499 between 2019 and 2021.[49] Accelerated by strong and well-communicated political will, that number is expected to grow quickly moving forward. Chinese auto manufacturer Geely, for example, is employing its deep manufacturing expertise to build a factory capable of producing 500 satellites per year by 2025.[50] According to Euroconsult, more than $1.9 billion was invested into China's commercial space companies between 2014 and 2020, half of which came from private capital.[51]

China's space sector and commercial capabilities have seen dramatic changes over the past 10 years. Bolstered by state resources and China's extensive Digital Silk Road (DSR) initiative, Chinese LEO operators are well placed to provide service to a global market and pose a significant competitive threat to U.S. strategic and economic interests. Beijing start-up GalaxySpace launched several operational satellites in March 2022 that will eventually form a larger, multiconstellation, interconnected Chinese "National Network" of LEO communications, Earth observation, and navigation satellites.[52] GalaxySpace intends to develop an integrated satellite/terrestrial 5G network via a 1,000-satellite constellation.[53] ITU spectrum applications in 2020 show plans for an additional Chinese constellation consisting of 12,992 satellites, indicative of aims to develop a national network.[54] Public ITU documents suggest this constellation, referred to as GuoWang or StarNet, will consist of two subconstellations capable of global broadband delivery.

China's attempt to deploy a national LEO broadband constellation enjoys significant support from the Chinese Communist Party (CCP). In 2020, China's NDRC added satellite internet to its list of priority "new infrastructures," signaling increased investment and support for the burgeoning commercial sector.[55] Adopted in 2021, China's 14th Five-Year Plan explicitly outlined the goal of establishing "a space infrastructure system for communication, navigation and remote sensing with global coverage and efficient operation."[56]

By allocating and directing resources toward competing enterprises, some of which are government-backed, China is developing a space sector capable of producing the infrastructure and expertise to support its vision for a national space-based internet. Shepherded by major CCP policy announcements and signals, the country's LEO communications market has trended toward consolidation over the past two years. Investment, flowing hotly since the sector opened in 2019, is beginning to cool and concentrate on fewer firms.[57] In April 2021, China's State-owned Assets Supervision and Administration Commission (SASAC), the body responsible for oversight of China's biggest SOEs, created China SatNet to manage the GuoWang constellation, blurring the lines between it being a government- or commercial-led service.[58] SASAC's direct creation and administration of SatNet places the company on the same level as China's three national telecommunication companies, as well as the China Aerospace Science and Industry Corporation (CASIC) and CASC. Elevating SatNet to the level of the country's most important SOEs likely grants the organization significant autonomy and expanded state support.[59]

CASIC and CASC have each launched experimental satellites for their own LEO constellations—Hongyun and Hongyan, respectively—that aim to provide connectivity to China's remote regions and to select maritime and air-travel customers. There is a significant chance that plans for both constellations will be absorbed by SatNet's GuoWang.[60]

China's Competitive Advantage

By leveraging the country's SOEs and its existing efforts under the DSR initiative, China could become an extremely robust competitor. China SatNet, along with CASIC's and CASC's LEO communications ventures, enjoys nearly unrestricted funding, municipal government support, and significant regulatory leeway.

Figure 2: Timeline of Select Chinese Policies on LEO Broadband

NOVEMBER 2014: Release of Document 60: Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment

- Opened select Chinese space sectors (not LEO/SatCom) to private capital investment for the first time.

DECEMBER 2016: Release of PRC State Plan for Informationization in the period of the 13th Five-Year Plan

- Called for "Coordinating the construction of ground-based infrastructure and the development of military-civil fusion, in order to obtain global service capabilities as fast as possible."
- Stated China will accelerate the deployment of broadband satellites in high earth orbits as well as in LEO.

NOVEMBER 2019: Update of National Development and Reform Commission (NDRC)'s industrial catalogue

- Opened and promoted the majority of the commercial space industry to foreign investors; impacted satellite communications systems, unlike 2014's Document 60.
- Led to a space start-up funding boom in 2019—surpassed all countries but the United States in the number of space start-ups receiving financing.

MARCH 2020: Announcement of plans to create a state-owned version of a LEO broadband constellation made up of more than 13,000 satellites

APRIL 2020: NDRC's declaration to advance satellite networks as a key element of national infrastructure

MARCH 2021: Passing of the 14th Five-Year Plan

- Called for building an integrated network of communications, Earth observation, and navigation satellites; completed the most space launches of any country in 2021.
- Increased state funding; noted lag in commercial funding and the beginnings of a consolidation of the Chinese space sector.

JANUARY 2022: Release of space white paper

- Published once every five years; announced a priority focus on "near-earth orbit" satellite systems.

Source: Authors' research and analysis. For a complete list of references used, please see endnote section

Following directives from the central government, municipal actors are heavily incentivized to invest in designated "strategic" sectors. For example, the city of Wuhan has committed to developing a local 100 billion yuan ($15.7 billion) space industry by 2025.[61] In a bid to host the Chinese "valley of satellites," Wuhan is offering millions in concessional financing to space companies. The city's pledges, however, pale in comparison to those of China's richer coastal regions. Taking advantage of this sentiment, SatNet executives have traveled to multiple cities in China attempting to court local leaders, receive regulatory concessions, and link SatNet with existing domestic industrial bases.[62] The same day that Shanghai announced a flurry of new initiatives to grow the city's space sector, local leaders signed a cooperation agreement with SatNet.[63] Chongqing, host to the majority of CASC's LEO Hongyan operations, has also signed a codevelopment agreement with SatNet for a new satellite industrial base.[64]

Economic concessions at home are bolstered by China's foreign engagement through the DSR and the Belt and Road Space Information Corridor, part of the broader BRI. China's 2021 white paper on space referenced the Belt and Road Space Information Corridor as a key avenue through which to "strengthen cooperation on the application of . . . communication satellites."[65] Since 2016, China has signed over 117 space cooperation agreements and 19 memorandums of understanding with at least 37 foreign governments to share space-related infrastructure and build ground stations.[66]

Given China's successful strategy of exporting terrestrial infrastructure through the DSR—up to 70 percent of 4G network infrastructure across Africa was built by Huawei—these agreements and engagements may significantly help the country achieve its aspiration of hosting a globally adopted LEO broadband service.[67] With its heavy economic presence in many BRI countries, China is positioned to negotiate regulatory concessions for its national LEO system while discouraging the adoption of U.S. commercial services. A combination of diplomatic maneuvering, the bundling of hard infrastructure and digital services, and attractive pricing will likely make it difficult to compete with Chinese companies for market share in BRI countries.

Dominance in foreign markets comes with benefits beyond economic gains. China's heavy information and communication technology (ICT) presence in BRI countries creates path dependencies, spreads techno-authoritarian norms and standards, grows China's voice in international governance and standards bodies, and strengthens China's power over global networks.[68] The successful proliferation of Chinese LEO broadband service could similarly boost China's presence in foreign terrestrial networks, providing Beijing with greater control over international data flows and granting it extensive intelligence and coercive powers.[69] China's open push for civil-military integration suggests built-in dual-use capabilities in overseas BRI infrastructure. A planning document published by the State Council in 2016 reiterated China's ambitions to establish satellite communications systems, linking them to the "development of military-civil fusion, in order to obtain global service capabilities as fast as possible."[70]

Because of the role that LEO constellations will potentially play in communications networks, countries that permit Chinese ground stations and grant the country landing rights may find it less costly to continue adopting Chinese ICT technology. This digital dependency is fostered through exorbitant replacement costs and a reliance on a small set of vendors, often SOEs, that rate low on interoperability.[71] High levels of dependency on Chinese-built and -operated digital infrastructure may lead to the default adoption of Chinese-crafted norms, standards, and data governance practices. Tanzania, a close BRI partner country, has modeled a subset of its data and cybersecurity laws after Beijing's example leading to more restrictions on country's social media landscape and information flows.[72] Such adoption and regulatory alignment in turn reduces regulatory compliance costs for purchasing other Chinese-origin ICT technology. For countries such as Pakistan and Egypt, whose entire suite of digital infrastructure heavily features Chinese assets—from submarine cables and terrestrial fiber optic lines to 5G networks and satellite ground stations—the choice to integrate Chinese LEO broadband into existing network stacks will be a relatively easy one.[73]

5

Security Implications for the United States

Today, the United States holds an advantage in the competition over LEO broadband, as just under 50 percent of new companies seeking to operate in LEO originate in the country.[74] But as China continues to further its ambitions for its own LEO broadband network, which may fall somewhere in the gray zone between commercial and governmental, the United States could lose its competitive edge. Furthermore, agreements through the DSR and the BRI could help China make inroads as the LEO broadband provider of choice in countries in Asia, South America, and Africa that do not currently have widespread internet infrastructure but do have good relationships with China. This could make burgeoning broadband markets reliant on Chinese services, leaving less room for U.S. manufacturers to provide service.

China has also been known to block certain websites for citizens using domestic internet sources; Western applications such as Google Maps are not available on Chinese-built phones and networks, and often domestic apps can only be accessed by divulging privacy information or verifying one's identity. If SatNet's GuoWang constellation becomes the dominant broadband supplier , users could be blocked from accessing entire sections of the internet or expose personal and identifying data to network operators.[75] This could further exacerbate the suppression or censorship of information in countries where there is already a widespread information vacuum or civil unrest. An infamous case of Chinese intelligence using BRI-built networks involves the African Union. Although officials have denied the allegations, for five years the African Union headquarters—paid, built, and wired by China—would send daily transmissions of confidential data to Beijing.[76] Conversely, open connectivity can support citizens who need accessible information and communication channels, particularly in times of civil unrest when citizens need access to unrestricted, reliable services.

Establishing efficient and affordable broadband services based in LEO is not only a priority for privately funded industry but also for the U.S. military. From relaying massive amounts of intelligence, surveillance, and reconnaissance data to detecting and tracking missiles to providing command, control, and communications for units in austere locations across the globe, the U.S. military's demand for SATCOM continues to grow.[77] The DOD has been working to build its own satellite broadband networks, the most public of which is the National Defense Space Architecture (NDSA) being designed by the Space Development Agency.[78] The NDSA will consist of several layers of military constellations in LEO, each focusing on different aspects to enhance military connectivity, sensing, and communication.[79]

In addition to developing domestic military capability, the U.S. Space Force has shown interest in leveraging commercial services to increase the resiliency of military broadband networks and communications. The Space Force is currently working on a design to build a "space data backbone," a service that will be able to integrate military, commercial, civil, and possibly allied networks. This access would follow a "fee for service" model wherein the Space Force would pay a fixed price to use a particular bandwidth over a fixed amount of time.[80]

Not only will the U.S. military depend on advanced LEO broadband constellations for its own network operations, but LEO broadband is already being used—and targeted—on the battlefield in Ukraine. The Starlink terminals SpaceX sent have been used by the Ukrainian military and people alike, connecting a country whose other operating forms of communication were hacked and jammed in the initial days of the conflict—though SpaceX has had to devote additional funding and resources to protect the signals from attack.[81]

LEO Broadband Licensing

Over the past two years alone, the FCC has received applications for over 64,000 new satellites. For perspective, there are only 6,800 functioning satellites in orbit as of November 2022.[82] Regulatory agencies with jurisdiction over space and space-related activities are struggling to keep pace with private sector growth in managing these constellations, a task that is correspondingly growing in difficulty. The rise of commercial space-based operations more broadly has forced new paradigms on a sector previously dominated by government and defense ventures, highlighting the need for updated regulation and an increase in capacity for the regulatory review process.[83]

Licensing requirements include allocating limited spectrum among a host of global actors, granting launch permissions, coordinating with international bodies, and managing orbital capacity and debris. In the United States, no single agency is responsible for overseeing these requirements; regulatory authority and review are unevenly split among the FCC, the DOD, the Federal Aviation Administration, the Department of Commerce, the Department of State, and the National Oceanic and Atmospheric Administration. While not all the listed agencies are involved in regulating LEO broadband constellations in particular, coordination among agencies can be difficult, and shifting regulatory responsibilities slows progress and exacerbates issues resulting from varying levels of proficiency on space-related matters.

The FCC regulates the frequencies that satellite constellations can use and, as such, is often the first stop for companies looking to begin operations. The commission, which has historically auctioned spectrum licenses on a first-come, first-served basis, is considering updating its auction rules for LEO-based satellite operators to ensure that operators licensed in earlier rounds have their spectrum access protected.[84] The FCC, through its mandate to issue licenses "if public convenience, interest, or necessity will be served thereby," has often gone beyond the direct regulation of spectrum use.[85] The agency made headlines after it denied one operator a license for the launch of small satellites (11 x 11 x 2.8 cm) due to concerns the satellites would be too small for adequate tracking and SSA.[86] Unable to keep pace with a rapidly evolving industry, the commission is planning to reorganize, potentially creating a new Space Bureau and an Office of International Affairs.[87]

To further complicate licensing for LEO constellations, satellite operators are not only regulated by their own governments but by global entities as well. Though approval for the design and launch of communications constellations first comes from the licensing authority of the corresponding government (e.g., the FCC in the United States), the only international regulatory body that approves satellites before launch is the ITU, part of the United Nations. The ITU—which includes two different member groups, composed of 193 countries and 900 private sector companies—is responsible for managing "the international coordination, notification and recording of the specific radio frequencies transmitted and received by satellites."[88] Because spectrum is a limited resource, the ITU process aims to establish impartial access while also limiting interference that may occur between satellite systems.[89] Due to availability and other technical considerations, operators need to share certain spectrum bands with one another.[90] The process for allocating spectrum is therefore extremely competitive. Representatives of the ITU member states license satellite systems, then file descriptions of the projects with the union, which shares the descriptions and findings with other member states. Prelaunch filings are made so that harmful interference between proposed projects can be resolved bilaterally between member states. Satellite filings are also required to be used within seven years from the date of the request or else the reserved spectrum is released.[91]

Because of the global nature of space, regulators also need to consider emerging and conflicting interests between U.S. firms and foreign competitors and between market incumbents and entrants. One of the largest bottlenecks to market dominance in LEO broadband is licensing: "The most difficult aspect of building a [low Earth orbit] broadband system is acquiring the spectrum, not building and launching satellites," according to Quilty Analytics.[92] For U.S. companies that compete against foreign firms facing different national regulatory structures, requirements, and enforcement capabilities, comparatively stringent domestic requirements are costly and dampen U.S. firms' first-mover advantage. Additionally, regulations regarding landing rights, ground stations and related infrastructure, and market access vary significantly by country.

High compliance costs notwithstanding, competition from national telecommunication companies and domestic LEO ventures in host countries is fierce. Domestic companies looking to defend their market share often lobby their governments to implement protectionist policies masquerading as regulatory requirements. For example, SpaceX's attempt to expand Starlink service into India was strongly opposed by OneWeb, a firm with substantial investment from Indian conglomerate Bharti Enterprises. Eventually, SpaceX's attempts to secure the necessary licenses stalled, and the company had to halt presales in the region. Some countries forbid foreign ownership over telecommunications infrastructure outright, forcing entrants to set up joint ventures with domestic firms or open locally owned and operated companies as a prerequisite for market access.[93] Conversely, the FCC Satellite Division often grants permission for U.S. market access to commercial satellites licensed by other countries.[94] There is a risk that asymmetric requirements between U.S. license holders and foreign-licensed companies with permission to operate in the United States may create an uneven playing field.

Meanwhile, staff shortages, a more complicated operating environment, multiple processing rounds, and poorly defined deadlines have elongated license approval timelines for satellite licenses.[95] Since LEO constellations involve many rapidly evolving technologies, by the time licenses are granted, the subjects of those licenses risk becoming obsolete. The pace of development in related technology often means that licenses, once granted, must be updated to reflect new advancements. This, in turn, slows down government review. Long licensing timelines across the entire space sector delay the process of bringing a product to market, resulting in market uncertainty and lower profit projections that dampen sector growth.[96] Navigating an onerous regulatory process—while also facing narrow profit margins and unforgiving business models of LEO broadband systems—can make it impossible for all but the largest, most well-resourced companies to obtain licenses.

6

Managing Large LEO Constellations

Risks and Operator Mitigation

As increased opportunities emerge in LEO, so do the risks—not only due to international competition but also due to the unforgiving space environment itself. The space domain is becoming more diverse, disruptive, disordered, and dangerous as more countries and companies begin to operate there. When looking at proposed LEO broadband networks, risks can include—but are not limited to—on-orbit collisions in space, disruptions to astronomy missions, and political discord between nations.

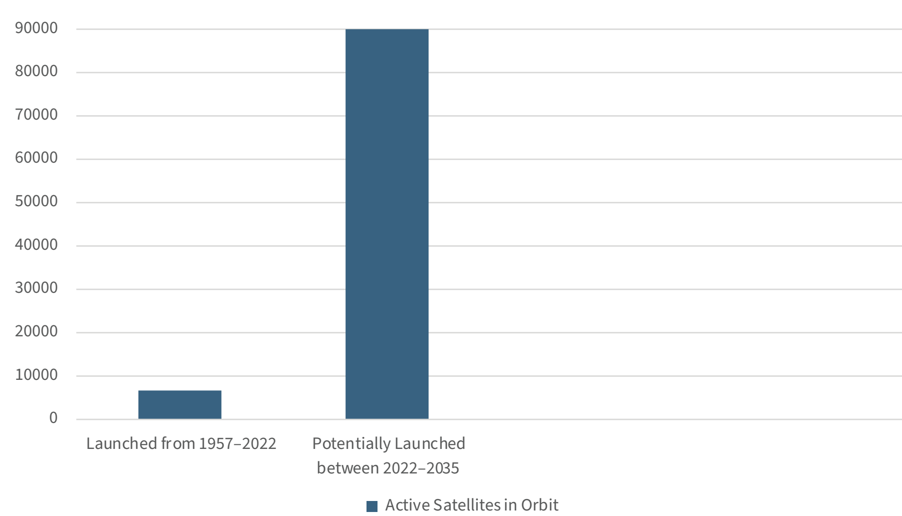
One of the greatest risks associated with the launch of large constellations is to the space environment itself; an increase in the number of satellites in orbit increases the potential for collisions. As of November 7, 2022, there have been about 14,450 satellites launched into Earth orbit. About 9,610 of these satellites are still in space—of which 6,800 are still functioning.[97] Government-conducted destructive anti-satellite (ASAT) tests have significantly contributed to debris creation, and upper-stage rocket bodies left in orbit have fragmented into thousands of large debris objects.[98] These activities have created over 27,000 pieces of trackable debris being monitored by DOD's Space Surveillance Network—not including pieces that are too small to detect.[99] These high-velocity pieces of "space junk" make operating in the space environment more dangerous, and the possibility of a collision increases the more objects enter orbit. SpaceX alone has requested FCC authorization for another 30,000 satellites (it has received authorization for 7,500 of the 30,000 as of December 2022).[100] OneWeb, Amazon, Telesat, and China SatNet constellation plans are similarly in the thousands. Together, proposed LEO broadband constellations could potentially add over 90,000 satellites into Earth orbit, vastly changing the operational domain. In April 2021, reports surfaced that SpaceX and OneWeb had an alleged close approach between their respective satellites. There was no collision, and both companies have differing opinions on the risk their satellites faced.[101] However, a significant increase in satellites orbiting in LEO could restrict additional space activities, including impacting future human spaceflight and launch schedules.

Starlink satellites have SSA capabilities on board and can perform avoidance maneuvers autonomously based on the satellite's knowledge of its current position and information about potential close approaches.[102] These capabilities have already proven to be necessary; Starlink satellites have reportedly had to maneuver over 1,700 times to avoid orbital debris from Russia's 2021 ASAT test.[103]

Although no satellites from the Project Kuiper constellation are currently in orbit, space safety and sustainability have been emphasized throughout Amazon's design process. Project Kuiper satellites will have active propulsion systems on board and be programmed to perform avoidance maneuvers if the risk of collision is estimated to be more than 1 in 100,000.[104] Additionally, the constellation's low altitude will increase the ability for satellites to be deorbited faster and more reliably. Kuiper satellites are scheduled to actively deorbit within one year of a completed mission and, if this fails, will naturally deorbit within 10 years. Satellites will have be held to a tight orbital tolerance, the distance in which a satellite can move in orbit, of within 7 kilometers (4.3 miles) to avoid overlapping with other large LEO systems.

OneWeb also has an SSA component via an agreement with LeoLabs to incorporate its Collision Avoidance service. This agreement adds another layer of operational safety to OneWeb satellites, allowing the on-orbit systems to receive real-time data regarding the location of space debris and other satellites. This LeoLabs service is also used by SpaceX and the Earth imaging company Planet, which operates a 200-satellite Earth-observation fleet.[105] In addition to the LeoLabs software, OneWeb satellites incorporate sustainable components, such as grappling fixtures and a magnetic docking plate so they can be deorbited or serviced in an active debris removal mission if necessary.[106] Because the satellites were designed in France, the fleet also is ready to comply with the France Space Operation Act, which mandates that all LEO satellite operators deorbit satellites at the close of their operational activity.[107] In October 2022, Iridium, OneWeb, and SpaceX released a set of "Satellite Orbital Safety Best Practices" through the American Institute of Aeronautics and Astronautics to "guide and improve cooperative operations in space."[108]

Figure 3: Current and Future Projection of Active Satellites in Orbit



Source: "Space Debris by the Numbers," European Space Agency, updated November 7, 2022, https://www.esa.int/Safety_Security/Space_ Debris/Space_debris_by_the_numbers; Authors' analysis.

Another risk to the space environment is the potential for satellites to interfere with astronomical observations. Astronomers have raised concerns that Starlink satellites have disrupted night-sky observations, blocking or interrupting telescope images, with the potential for further disruptions as more satellites from additional operators are launched into orbit. Environmental groups in France have been so vocal about this subject—as well as the pollution caused by launches—that Starlink's permit to operate in the country was temporarily overturned.[109] Starlink competitor ViaSat has also criticized the vast Starlink fleet's obstructions to astronomy and has filed court documents to stop it from launching more satellites based on environmental grounds, though this has not been successful.[110]

Responding to concerns, both Telesat and SpaceX have been working with the astronomy community to decrease the reflectivity of their satellites. Telesat CEO Dan Goldberg reported that its satellites would be kept to a smaller constellation and will orbit at a higher altitude to ensure Telesat is a responsible user of the space domain.[111]SpaceX has published details on the work it has undertaken to mitigate impacts to astronomy and has signed coordination agreements with the National Science Foundation to further collaborate on solutions. Changes to both the design and operation of the Starlink constellation have resulted in improvements to the brightness of satellites, mitigating the effect on astronomical observations.[112] Amazon is also working with the National Science Foundation and the American Astronomical Society to incorporate astronomers' concerns into current prototype plans.[113] According to an interview with the company, Project Kuiper is limiting the number of satellites in its constellation and choosing an operating altitude with an eye toward sustainability and convenience, in keeping with best practices recommended by astronomers and industry.[114] However, there is no permanent solution for astronomers using Earth-based telescopes. This challenge highlights a significant gap in the international regulatory system for space, as one country's approvals of constellations can affect people all over the world.

Outside the space domain itself, intense broadband competition also carries a political dimension. A researcher in a Chinese peer-reviewed journal wrote about the threat Starlink's spread posed to Chinese assets, that the country should "adopt a combination of soft and hard kill methods to disable some of the Starlink satellites and destroy the constellation's operating system."[115] Though the paper was taken down shortly after publishing, this sentiment is not unique in China. An opinion piece published in the Chinese military's official news site, China Military Online, wrote about Starlink's "unchecked expansion" and alleged it had an "ambition to use it [the system] for military purposes" that should alarm governments worldwide.[116] There has been no documented concern from Chinese media about the threats a domestic constellation may also pose to global space assets.

The trajectories of Starlink's satellites have continued to draw political attention, most vocally from China. In two separate events in July 2020 and October 2021, Chinese officials claimed Starlink satellites came so close to the Tiangong space station that astronauts had to shelter in place.[117] Chinese officials issued a complaint to the United Nations Office of Outer Space Affairs, to which the United States replied on January 28, 2022, refuting claims that Starlink satellites endangered the crewed space station and that the satellites involved "did not meet the threshold of established emergency collision criteria."[118] While this issue has not been formally concluded, it is a potent reminder that the accurate tracking of space objects will be crucial in supporting or disputing similar claims in the future. Additionally, China does not currently publish the Tiangong space station's planned maneuvers, unlike the National Aeronautics and Space Administration (NASA) does with the International Space Station, which could facilitate operator planning and coordination. This incident underscores the importance of having open avenues of communication as well as shared standards and data among all operators in the space domain.

LEO systems have the potential to play a role in geopolitical competition with other competitors as well. A large shift in the geopolitical relationship between the United States and Russia, the two longest-standing space powers, took place after Russia's invasion of Ukraine in February 2022. OneWeb had a launch of 36 satellites planned for March 4, 2022, from the Russian-operated Baikonur Cosmodrome in Kazakhstan, just a week after the invasion of Ukraine.[119] Operations at Baikonur were immediately halted in late February, impacting the satellites OneWeb had sent to be launched by a Soyuz rocket. As of November 2022, the 36 satellites remain in Russia and have not been returned to OneWeb, which reported a $229 million loss after the incident.[120] Looking for another provider, OneWeb turned to SpaceX, which operates competitor Starlink, to continue satellite launches to complete OneWeb's constellation. This is not the first time SpaceX has launched satellites for a competitor: its Falcon 9 rockets launched upgrades for an Iridium communications constellation until 2019.[121]

After Ukrainian officials issued a plea on Twitter at the onset of the Russian invasion of the country, Elon Musk pledged tens of thousands of Starlink user terminals to aid in connectivity around the country in March 2022. Furthermore, The *New York Times* reported that Ukrainian forces were using Starlink terminals to send targeting information to artillery and communicate with reconnaissance drones.[122] Starlink's involvement in the conflict opens the door to questions about commercial companies' involvement in zones of geopolitical conflict and what risks this poses to their assets. Days after civilian Starlink services were established in Ukraine, Musk reported on Twitter that Russian forces had jammed user-terminal access. He further stated that the company had pushed out software updates to its assets to harden them against further attacks.[123] The additional connections involved in operating a large LEO constellation increase the system's vulnerability to cyberattacks or even jamming. Cyber connections need to be hardened and encryption increased to ensure communications are safe and not tampered with. However, this would likely come at a higher cost and add latency to the network. Commercial companies should be aware of what this risk management would cost and adapt their security if more instances of malware attacks are made public.[124] Because commercial LEO broadband companies may be operational in conflict zones or support national-security missions, their systems will likely continue to be targets for electronic warfare or cyberattacks.

Policy Recommendations

The strength of U.S. private sector companies has led to cost reductions in launch services and satellite manufacturing and rapidly increased the pace of innovation in the space domain, all of which have led to the successful reemergence of space-based broadband operators. SpaceX is the first company to commercialize its LEO broadband constellation, allowing U.S. actors to take the lead in setting emerging standards, norms, and best practices. However, foreign competitors are close behind. U.S. government agencies can support and encourage—or, at a minimum, not hinder—commercial activity, uphold sustainability requirements for an increasingly congested orbit, and facilitate U.S. commercial growth, particularly in the broadband internet domain.

A common thread is that regulatory clarity, speed, and reform at the FCC will have an enormous impact as commercial competition intensifies. As the FCC continues to play the dominant role in regulating satellite communications, it should take care to strike the appropriate balance between burdensome regulation and market development. Providing additional clarity and establishing defined approval timelines, adhering to deadlines on public comment periods, and opening communication channels with commercial companies submitting licensing requests are a few ways it can achieve this goal.

To help address these issues, the FCC announced in November 2022 that it would open a new space bureau under its current International Bureau to improve commercial marketplace relations. The chairwoman of the FCC, Jessica Rosenworcel, conceded that the agency had not kept up with the rapid changes in the commercial space domain and stated that this office will "support the United States leadership and the emerging space economy, promote long term technical capacity to address satellite policies[,] and improve our coordination with other agencies on these issues."[125] At the time of publication, there is no timeline in place for this office to be fully functional, but assembling it should be a priority so that it can establish interagency communication and commercial market coordination as more companies launch their constellations.

Additionally, the FCC can increase coordination with international governing bodies. The regulations to which competing broadband companies are subject to can vary greatly, and U.S. companies may be held to unique standards that others in orbit are not. While the FCC and other regulatory bodies must maintain integrity in the regulatory process, it will only become more critical to coordinate with international partners to establish shared standards for operation in the space domain. The ITU could be a key partner for the United States and FCC in promoting common international norms and standards regarding shared spectrum. This can discourage dishonesty from actors with unclear motives in reserving spectrum and help identify deceptive actions by large actors.

As the Department of Commerce becomes more involved in the space domain, its SSA mission area will continue to increase in importance and affect every aspect of space. Increased SSA capabilities can include tracking even smaller debris, and current capabilities can successfully monitor objects 10 centimeters or larger, which would help create a more accurate picture of the operating environment for satellite operators around the globe. Ensuring that SSA data is widely accessible and that different tracking organizations' standards are similar can provide clarity and consistency for an increasingly congested domain. Because broadband operators of LEO constellations will have larger numbers of satellites than ever before, accurate SSA will be integral to the successful and sustainable operation of these networks.

The U.S. government should also emphasize interacting with the international community to establish shared norms of operation for space systems in orbit, starting with operators in LEO. By creating widely adopted rules of operation, the United States can be a leader in the domain and make it easier to identify abnormal, potentially nefarious behavior. Global operating standards can also emphasize space sustainability, protecting various orbital regimes from space debris and ensuring that others will still be able to use the domain in years to come. These norms could potentially expand to include reciprocal regulations, which would make it easier for satellite operators to operate in multiple countries at once. International regulatory agencies could even work together to simplify license applications, potentially even creating a joint license application where one application could be used to apply to many countries at once. This could simplify standards for commercial companies and shift the speed at which licenses are approved.

Finally, U.S. leaders should aim to increase soft power across the globe by working with commercial companies that can successfully operate broadband internet constellations and incorporate connectivity. The United States has a strong record of projecting soft power through space exploration, namely through NASA programs that have captivated the globe for decades. NASA has over 700 international agreements with more than 100 countries around the world, allowing the United States to maintain strong relationships with foreign governments through civil space agencies at times when collaboration may not be possible in other parts of government. The emergence of a strong U.S. commercial space sector that offers individual services extends the country's possible reach—but it could lose this strategic soft power if China is able to leverage its current BRI networks to implement SatNet in developing regions.

Conclusion

Today the United States profits significantly from its dominance in global networks, and U.S.-based commercial satellite networks have a significant head start. But as the race for space-based communication networks intensifies, it is important that the United States government enact policies and incentives to keep U.S. companies competitive internationally. Even once firms have accumulated the vast capital and expertise required for entry into the LEO broadband market, they face high compliance costs and uncertainty in navigating multilevel regulatory regimes. Licensing requirements persist through domestic, foreign, and international processes, which are at times opaque, unaligned, and unevenly applied, as regulators may not be keeping pace with industry's rate of innovation. Striking the right balance between appropriate regulation and market development is a perennial problem, one that should be reckoned with in real time.

Growing competition in the race to establish space-based broadband networks carries many risks to a rapidly growing space domain. These include environmental, technical, and political risks, not to mention the challenge posed by looming international competition from China. Beijing has its own plans for a national LEO broadband network that benefits from extensive state funding and the political support gained through its BRI. Leveraging its heavy economic presence in a large portion of BRI countries, China is positioned to negotiate regulatory concessions for its LEO system while discouraging the adoption of U.S. commercial services. A combination of diplomatic maneuvering, the bundling of hard infrastructure and digital services, and attractive pricing will likely make it difficult to compete with Chinese companies for market share in BRI countries.

Conversely, U.S. companies often face protectionist barriers and a complex regulatory landscape when looking to expand into foreign markets. Requirements regarding landing rights, ground stations and related infrastructure, and market access vary significantly by country. Future regulatory changes need to consider competition between domestic market incumbents and new entrants as well. As U.S. government agencies begin to regulate the thousands of SATCOM satellites that will be launched into LEO in the next five to ten years, they will need to establish shared norms of operation for on-orbit space systems, more clearly convey licensing standards and practices, and communicate heavily with both domestic commercial companies and the international community.

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FIGURE 3: CURRENT AND FUTURE PROJECTION OF ACTIVE SATELLITES IN ORBIT

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