Low-Orbit, High Stakes: Winning the LEO Broadband Competition

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Introduction

As of April 2022, 63 percent of the 8 billion people that make up the world's population use the internet - this leaves about 3 billion people unconnected.[1] One method governments and private commercial companies are attempting to bridge this digital divide is through space-based broadband internet. If successful, these efforts have the potential to quickly connect people around the globe as well as the space environment itself. Several countries are launching national initiatives to establish LEO constellations and capture large portions of the burgeoning market, unleashing extensive state-backed resources to do so.

Competition to provide broadband from satellite communication (SATCOM) is not a new concept. 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 constellations in low Earth orbit (LEO), but almost all ended in bankruptcy by the early 2000's.[2] As the same trends emerge 30 years later, will the new generation of satellite broadband based in LEO succeed? Today the barrier to entry to orbit is much lower as technology, materials, and launch capabilities are cheaper and more widely available. International competition is fierce to build, launch, and operate a low-cost and low-latency system that spans the globe as the demand for fast, reliable, and affordable internet services continues to grow. This fight for initial prowess in the satellite broadband domain has become one of the most important, least appreciated geostrategic developments underway.

The global satellite communications market is estimated to grow to $40 billion by 2030, largely driven by LEO-based ventures.[3] Satellite broadband revenues increased by 1.1 percent in 2021 and experienced an 11 percent jump – up to 3 million people – in global subscribers from the year prior.[4] The United States holds a strong lead in global satellite services, capturing 38 percent of industry revenue in 2021.[5] However, this industry, particularly in LEO, is becoming increasingly competitive. The Asian Development Bank estimates that LEO and MEO satellites will capture half the market for high throughput satellite communications by 2027.[6]

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[1] *Digital Around the World*, DataReportal, https://datareportal.com/global-digital-overview#:~:text=A%20total%20of%205%20billion,12%20months%20to%20April%202022.
[2] *Satellite internet failed 20 years ago, but this time is different*,"KrASIA, June 20, 2020, https://kr-asia.com/satellite-internet-failed-20-years-ago-but-this-time-is-different
[3] T. Werlé et al, *LEO Satellites: A Technology to Revolutionize Global Connectivity*" BCG, June 01, 2021, https://www.bcg.com/publications/2021/leo-satellites-unlock-connectivity-opportunity
[4] *State of the Satellite Industry Report*, Satellite Industry Association, 2022, https://sia.org/news-resources/state-of-the-satellite-industry-report/
[5] Ibid.
[6] J. Garrity and A. Husar, *Digital Connectivity and Low Earth Orbit Satellite Constellations: Opportunities for Asia and the Pacific,* Asian Development Bank, April 2021, https://www.adb.org/sites/default/files/publication/696521/sdwp-076-digital-connectivity-low-earth-orbit-satellite.pdf

Today, the United States profits significantly from its dominance in global networks.[7]The United States has committed a significant investment in space-based internet, to include proposed Department of Defense (DoD) efforts, as well as new U.S.-based commercial endeavors, of which SpaceX's Starlink and Amazon's Kuiper are the frontrunners. But as international competition of LEO for communications intensifies, it is imperative that the United States government enact policies and incentives to protect this dominant market share. Allies and partners of the United States are also involved in the new space broadband; Telesat LightSpeed is based in Canada and newly merged Eutelsat/OneWeb is supported by private funders as well as the government of the United Kingdom. Though companies across the globe are entering this satellite broadband market, perhaps the greatest competitor to the United States in the race to global connectivity through satellite broadband is China.[8]

Policymakers in Washington and many allied nations now appreciate the risks that Chinese vendors pose in 5G networks, subsea cables, and other vital communications links. But they have yet to consider the economic and strategic implications of LEO satellite constellations, which promise to dramatically improve 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 in their communications, accuracy in positioning services, and even enhanced early warning capabilities. An elite group of companies, primarily from the United States and Europe, are on the cutting edge of these efforts. China has its own plans for LEO broadband with consistent investments from state funding to pursue those ambitions and political ties to leverage through its Belt and Road Initiative. China has debuted plans for a constellation of almost 13,000 satellites in LEO to serve residential and business needs in the Chinese market, as well as to underdeveloped internet markets across the globe.[9]

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 megaconstellations and their effects on the space environment, the paper will then inventory understanding U.S. interests in space, China's vision in satellite broadband efforts and the competitive environment that may build, and risks of operating megaconstellations in low Earth orbit. Finally, the authors will conclude with recommendations for specific actors with an emphasis on U.S. government agencies.

Using Space to Build a Global Network

SATCOM 101

Satellites communicate both by sending and receiving signals from Earth through ground (or user) terminals and antennae, as well as between other satellites in a network. Since LEO satellites are in relatively close proximity to Earth—between 160 and 2,000 kilometers above the Earth's surface—user terminals can detect multiple satellites at once and connect with greater accuracy.[10] When satellites relay data to other satellites in space, it is called a

[7] J. E. Hillman and L. Rivas, *Global Networks 2030*, Reconnecting Asia, March 29, 2021, https://reconasia.csis.org/global-networks-2030-developing-economies-and-emerging-technologies/
[8] A. Jones, *China's megaconstellation project establishes satellite cluster in Chongqing*, SpaceNews, January 12, 2022, https://spacenews.com/chinas-megaconstellation-project-establishes-satellite-cluster-in-chongqing/
[9] L. Press, *Update on China SatNet's GuoWang Broadband Constellation - Can They Do It?* CircleID, February 03, 2022, https://circleid.com/posts/20220203-update-on-china-satnets-guowang-broadband-constellation-can-they-do-it
[10] *Our Network* OneWeb, https://oneweb.net/our-network

satellite crosslink. Crosslinks allow operators to reduce the number of terminals on the ground that a satellite needs to connect to, which increases the overall speed of the global network.[11]

Satellites not only operate in a particular altitude in orbit, but also in a particular frequency band on the radio spectrum. These radio frequency bands are a measurement of the rate of electromagnetic radio waves and denoted in units called hertz (Hz), which indicate the number of cycles in one second when a radio wave is transmitted.[12] There are two popular bands for satellite communication, the Ku-band and the Ka-band. The Ku-band has been used for decades for satellite services and is a lower frequency than the Ka-band. This means that the Ku-band is more resilient to interference from weather like rain and snow and is able to cover an entire continent with a single beam. In reverse, the Ka-band is more easily affected by harsh weather and has a smaller range, meaning there needs to be more ground infrastructure to maintain services in the Ka-band. However, the Ka-band uses a smaller antenna which allows for lower manufacturing and transportation costs, and is therefore less expensive to operate in than the Ku-band.[13]

Approval for the design and launch of satellite communications constellations begins with the licensing authority of the corresponding government. While different national authorities and processes vary greatly, the only international regulatory body that approves satellites pre-launch is the International Telecommunications Union (ITU). The ITU sits in the United Nations and is responsible for managing "the international coordination, notification and recording of the specific radio frequencies transmitted and received by satellites."[14] Because spectrum is a limited resource, the ITU process is in place to establish impartial access to the resource and at the same time limiting interference that may occur between satellite systems.[15] Representatives of the ITU member states license satellite systems, then file a description of the project with the ITU, who shares the description and findings with other member states. Pre-launch filings are made with the intent that any harmful interference between proposed projects can be resolved bilaterally amongst member states. Satellite filings must be used within seven years from the date of the request, or the reserved spectrum is released.[16] The ITU includes two different member groups, composed of 193 countries and 900 private sector companies.[17]

Advantages of Low Earth Orbit

Satellites are typically launched into one of three popular orbits: LEO at 160 to 2,000km, medium Earth orbit (MEO) at 2,000 to 35,786km, and geosynchronous orbit (GEO) at 35,786 to about 42,164km. All three orbits have varying advantages and challenges for satellites operating within them. For example, a constellation in GEO can

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[11] Commercial Company Interview
[12] J. Scarpati, *radio frequency (RF, rf),* Tech Target, February 2021, https://www.techtarget.com/searchnetworking/definition/radio-frequency
[13] *KA vs KU Band: Which is the Best for Satellite Broadband?* AID Forum, September 24, 2019, http://www.aidforum.org/topics/technology-data/ka-vs-ku-band-which-is-the-best-for-satellite-broadband/#:~:text=Ku%2Dband%20uses%20frequencies%20in,and%2C%20therefore%2C%20higher%20performance.
[14] *ITU and space: Ensuring interference-free satellite orbits in LEO and beyond*, ITU News, February 2022, https://www.itu.int/hub/2022/02/itu-space-interference-free-satellite-orbits-leo/#:~:text=ITU%20does%20not%20approve%20single,transmitted%20and%20received%20by%20satellites.
[15] *Handbook for New Actors in Space,* Secure World Foundation, https://swfound.org/media/205710/handbook_for_new_actors_in_space_2017_web2.pdf
[16] *ITU and space: Ensuring interference-free satellite orbits in LEO and beyond*, ITU News, February 2022, https://www.itu.int/hub/2022/02/itu-space-interference-free-satellite-orbits-leo/#:~:text=ITU%20does%20not%20approve%20single,transmitted%20and%20received%20by%20satellites.
[17] K. Cordell, *The International Telecommunication Union: The Most Important UN Agency You Have Never Heard Of*, CSIS, December 14, 2020, https://www.csis.org/analysis/international-telecommunication-union-most-important-un-agency-you-have-never-heard

have global coverage with only three satellites because of its distance from the Earth's surface - GEO is popular for communications and Earth imaging constellations for this reason. However, because the satellites are so far away from Earth there is a longer period of latency, or the time it takes for the signal to route to a satellite in GEO back down to Earth. In GEO this is about 0.25 seconds, compared to 0.003 seconds in LEO.[18]

The new generation of satellite internet suppliers are hosting satellites in LEO instead of the traditional GEO architecture for a multitude of reasons. Satellites launched into LEO are typically smaller than those that orbit in GEO, meaning that companies can launch more satellites into orbit with one launch with less fuel needed to reach the lower orbit. The close proximity of LEO to Earth also allows these satellites to be brought online more quickly. Because these satellites are 35 times closer to the Earth than satellites in GEO, communications from LEO have a lower latency. LEO satellite networks boast the speed of opening a webpage is around 8 times faster than a traditional satellite system, something that has become more important to consumers who want to interact online in near real time.[19] This means that satellite internet is capable of supporting high data throughput applications such as streaming, video conferencing, and real-time gaming. Current LEO broadband constellations are capable of upload speeds up to 13.89 megabits per second (Mbps), download speeds of 97.23 Mbps, and latency of 45 milliseconds.[20] For mobile customers, such as airline travelers or maritime shipping vessels, LEO's continuous coverage means quicker and more reliable broadband than currently provided through GEO and MEO-based services.

Bridging the Digital Divide

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.[21] Unlike other forms of internet delivery, satellite terminals—receivers for space-based signals that function similarly to traditional Wi-Fi routers—require only a clear line of sight and an electric connection. Fiber optic cables, digital subscriber lines (DSL), or copper-based cable internet, on the other hand, require extensive construction (e.g.: underground cable ducts or network tower construction) to become operational. While there is great potential for space-based broadband, it must be augmented by quality, reliability, and affordability in order to meaningfully expand coverage.

Broadband has been proven to be a critical enabler in participating in global "trade, employment, learning, leisure, and communications."[22] Access to the rapidly growing digital economy, contributing roughly 15.5 percent of global GDP, can prove transformational for the development of unconnected regions. Particularly in remote, hard to reach areas where building dedicated ground infrastructure is too expensive or simply not possible, LEO systems will be able to provide internet connections to populations that legacy technology is unable to reliably serve. In the case of outages or gaps in service, LEO constellations will potentially be able to boost the resiliency of city-wide urban networks. Although major barriers still exist to its wide adoption, LEO broadband constellations hope to provide a reliable opportunity to help fill the gaps in global connectivity.

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[18] T. G. Roberts, *Popular Orbits 101*, Aerospace Security Project, last updated June 14, 2022, https://aerospace.csis.org/aerospace101/earth-orbit-101/
[19] *Real-Time Latency: Rethinking Remote Networks*, Telesat, https://www.telesat.com/wp-content/uploads/2020/07/Real-Time-Latency_HW.pdf
[20] I. McKetta, *How Starlink's Satellite Internet Stacks Up Against HughesNet and Viasat around the Globe*, Ookla, August 4, 2021, https://www.ookla.com/articles/starlink-hughesnet-viasat-performance-q2-2021
[21] *Measuring digital developments Facts and Figures 2020*, International Telecommunication Union Development Sector, 2020, https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf
[22] J. Garrity and A. Husar, *Digital Connectivity and Low Earth Orbit Satellite Constellations: Opportunities for Asia and the Pacific*, Asian Development Bank, April 2021, https://www.adb.org/sites/default/files/publication/696521/sdwp-076-digital-connectivity-low-earth-orbit-satellite.pdf

Several companies are racing to complete the first LEO megaconstellation, a thousands strong network of satellites capable of continuous global coverage. These constellations, once complete, promise strong and reliable delivery of broadband everywhere on Earth. LEO constellations will augment legacy methods of internet delivery, working in tandem with technology such as fiber optic and copper cables to provide uninterrupted quality broadband.

LEO constellations have the potential to reshape global networks, both those on-orbit and on the ground. Additionally, while reliant on frequently placed ground stations to extend service, the development of optical intersatellite links – communication links that allow satellites within the same constellation to seamlessly transfer data between one another – will further reduce reliance on expensive ground infrastructure. One of the largest barriers to wide commercial adoption of LEO broadband services is affordability. While end-user terminals allow communities to bypass the large infrastructure needs of traditional broadband delivery, the production costs range anywhere from $1,000 for home use to $10,000 for airplanes (another potential market), and are prohibitively expensive for most in developing economies.[23] 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.[24] Presently-offered and future terminals are suspected to be highly-subsidized by companies in order to incentivize adoption and users. However, industry estimates the price of home terminals to fall to $150 to $300 by the 2030s.

Companies such as Verizon and Amazon are testing telecommunications integration with LEO satellites to create more robust fifth generation (5G) services.[25] The added competition to traditional broadband providers will drive down prices in previously monopolized markets. In August of 2022, SpaceX and T-Mobile announced an agreement which would enable next-generation Starlink satellites (to be launched in 2023) to communicate with cell phones that consumers own today, theoretically eliminating dead zones in the T-Mobile cellular network. This would enable customers to call, text, and possibly stream videos without connection to a cell tower.[26]

The high capital expenditure costs to manufacturing, launching, and maintaining a satellite constellation along with its constituent parts requires providers to charge high prices in order to recuperate these substantial early-stage investments. However, the average revenue per user (ARPU) in most developing markets is not currently high enough for companies to sustainably operate. Instead, it is likely that more privileged 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.[27]

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[23] C. Rachfal, *Low Earth Orbit Satellites: Potential to Address the Broadband Digital Divide*, Congressional Research Service, August 31, 2021, https://crsreports.congress.gov/product/pdf/R/R46896
[24] T. Werlé et al, *LEO Satellites: A Technology to Revolutionize Global Connectivity?* BCG, June 01, 2021, https://www.bcg.com/publications/2021/leo-satellites-unlock-connectivity-opportunity
[25] M. Dano, *Verizon, Amazon to integrate LEO satellites with 5G*, LightReading, October 26, 2021, https://www.lightreading.com/satellite/verizon-amazon-to-integrate-leo-satellites-with-5g/d/d-id/773056;
S. Liu et al, *LEO Satellite Constellations for 5G and Beyond: How Will It Reshape Vertical Domains?* UCL Discovery, https://discovery.ucl.ac.uk/id/eprint/10133208/1/LEO5GVertical.pdf
[26] M. Clark, *Satellite-to-phone companies are thrilled about SpaceX and T-Mobile, actually*, The Verge, August 27, 2022, https://www.theverge.com/2022/8/27/23324128/t-mobile-spacex-satellite-to-phone-technology-ast-lynk-industry-reactions-apple
[27] B. Blauer, *Data Watch: In the largest U.S. cities, the digital divide is a poverty problem*, Johns Hopkins University, July 21, 2021, https://bloombergcities.jhu.edu/news/data-watch-us-cities-poverty-broadband-divide

State of Commercial LEO Broadband

Today, the LEO satellite internet industry is heavily concentrated among few private companies and government-backed or -owned ventures. The high capital expenditure requirements for launching, maintaining, and manufacturing LEO megaconstellations, along with the competition over finite spectrum resources and near-Earth orbital space contribute to a market with few major players. 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 several underlying risks.

Private-sector investment into space companies exceeded $10 billion in 2021; 60 to 70 percent of which is now directed into LEO-related ventures.[28] Venture capital funds, encouraged by decreasing launch costs and the development of commercially viable applications, have also turned their attention towards space firms operating in LEO.[29] While investment is increasing, due to the long-term nature of the LEO broadband investment, current levels may not be enough to sustain a crowded industry.

The industry is primarily driven by large companies with vast monetary reserves or by state owned or -supported enterprises, a paradigm bolstered by structural and policy challenges. Building and operating large LEO constellations is incredibly complex and expensive. Amazon Kuiper's supply value chain, for example, includes an industrial network of over 600 international and domestic companies. McKinsey estimates a $5 to $10 billion price tag for deploying an operational LEO satellite constellation.[30] On top of that, recurring annual operating and maintenance costs are predicted to run companies $1 to $2 billion. High barriers to entry have resulted in the need for substantial private and venture capital funding for the industry. The two most advanced U.S. companies, SpaceX's Starlink and Amazon Kuiper, are underpinned by the large government contracts along with the vast resources and reserves of their parent companies and founders.

Already, several would-be LEO operators have been forced to scale back their ambitions, declare bankruptcy, or seek drastic measures to keep afloat. A United Kingdom-based LEO broadband startup OneWeb filed for Chapter 11 bankruptcy in 2020, only eight years after it was founded. Narrowly managing to escape default, the company received a bailout 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 alongside FCC permission to provide service in the United States, OneWeb is struggling to attract the levels of investment it needs to stay afloat.[31] In July of 2022 the company merged with Eutelesat, a GEO satellite operator backed by French and Chinese funding, to bridge its growing financial gap.[32]

China's Space Broadband Vision

China's space sector has historically been dominated by the China Aerospace Science and Technology Corporation (CASC). As a state-owned enterprise, CASC, along with its many subsidiaries, was tasked with the "research,

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[28] R. Brukardt et al, *Space: Investment shifts from GEO to LEO and now beyond*, McKinsey, January 27, 2022, https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-investment-shifts-from-geo-to-leo-and-now-beyond
[29] P. Besha and A. MacDonald, *Economic Development of Low Earth Orbit*, NASA, https://www.nasa.gov/sites/default/files/atoms/files/economic-development-of-low-earth-orbit_tagged_v2.pdf
[30] C. Daehnick et al, *Large LEO satellite constellations: Will it be different this time?* McKinsey, May 4, 2022, https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/large-leo-satellite-constellations-will-it-be-different-this-time
[31] M. Holmes, *Potential Eutelsat, OneWeb Merge Raises Questions for Analysts,* Satellite Today, July 25, 2022, https://www.satellitetoday.com/business/2022/07/25/potential-eutelsat-oneweb-merge-raises-questions-for-analysts/
[32] J. Rainbow, *Eutelsat and OneWeb agree multi-orbit merger plan*, SpaceNews, July 25, 2022, https://spacenews.com/eutelsat-and-oneweb-discussing-multi-orbit-merger-plan/

design, manufacture, test and launch of" all space-based activities.[33] Only over the last ten years has the slow emergence of non-government owned or operated space firms begun. Document 60, a policy directive issued in 2014 by the National Development and Reform Commission (NDRC), unlocked a small portion of the space sector to private financing and created the first Chinese commercial space companies.[34] A 2016 Space White Paper called for increased "cooperation with private investors," signaling a more relaxed approach to the restricted sector.[35] It wasn't until a 2019 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 shift greatly impacted China's space and satellite communications sector. That year, the country surpassed all but the United States in the number of space startups receiving funding as well as in the amount of funding received, drawing 16 percent of all global investments in space startups.[36]

The resulting flood of capital led to a boom in space startups. As those ventures mature, so will China's capacity to grow and operationalize its space-based assets. According to a declassified Defense Intelligence Agency report, China doubled the number of satellites in orbit from 250 to 499 between 2019 and 2021.[37] Accelerated by strong and well communicated political will, that number is expected to grow quickly moving forward. Auto manufacturer Geely, for example, is employing its deep manufacturing expertise to build a factory capable of producing 500 satellites per year.[38] According to Euroconsult, more than $1.9 billion has been invested into China's commercial space companies between 2014 and 2020, half of which came from private capital.[39]

China's space sector and commercial capabilities have seen dramatic changes over the last ten 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. Several operational satellites were launched in March 2022 that will eventually form a larger, multi-constellation, and interconnected Chinese "National Network" of LEO communications, Earth observation, and navigation satellites.[40] GalaxySpace, the Beijing startup responsible for the recent launch, intends on developing an integrated satellite-terrestrial 5G network on the back of a 1000 satellite-strong constellation.[41] Small in number in comparison to planned constellations of global competitors, ITU spectrum applications in 2020 indicate plans for

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[33] *Company Profile*, China Aerospace Science and Technology Corporation, http://english.spacechina.com/n16421/n17138/n17229/index.html
[34] *Developments in China's Commercial Space Sector,* The National Bureau of Asian Research, August 24, 2021, https://www.nbr.org/publication/developments-in-chinas-commercial-space-sector/
[35] *Full text of white paper on China's space activities in 2016,* The State Council The People's Republic of China, Updated December 28, 2016, http://english.www.gov.cn/archive/white_paper/2016/12/28/content_281475527159496.htm
[36] A. Jones, *Chinese commercial sector investment lagging in 2021*, SpaceNews, August 26, 2021, https://spacenews.com/chinese-commercial-sector-investment-lagging-in-2021/;
Start-Up Space, Bryce Space and Technology, 2020, https://brycetech.com/reports/report-documents/Bryce_Start_Up_Space_2020.pdf
[37] *Challenges to Security in Space*, Defence Intelligence Agency, 2022, https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf
[38] Reuters Staff, *China's Geely invests $326 mln to build satellites for autonomous cars*, Reuters, March 2, 2020, https://www.reuters.com/article/geely-china-satellite-autonomous/chinas-geely-invests-326-mln-to-build-satellites-for-autonomous-cars-idUSL4N2AV45H
[39] B. Curcio, *China's Space Industry in the Time of Covid-19*, Satellite Markets & Research, June 2020, http://www.satellitemarkets.com/pdf/pdf2020/jun20.pdf
[40] N. Wood, *China enters the LEO space race*, Telecoms,com, May 9, 2022, https://telecoms.com/513965/china-enters-the-leo-space-race/
[41] Z. Hongpei, *Chinese firm forges nation's first low-Earth orbit broadband communication test constellation*, Global Times, March 6, 2022, https://www.globaltimes.cn/page/202203/1254110.shtml

a Chinese constellation consisting of 12,992 satellites.[42] Referred to as GuoWang or StarNet, public ITU documents describe two sub-constellations 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.[43] Adopted in 2021, China's 14th Five-Year Plan explicitly outlined the goal of establishing an integrated, "globally covered and efficiently operated communication, navigation and remote sensing space infrastructure system."[44]

By allocating and directing resources towards competing enterprises, some of which were government backed, China is developing a space sector capable of producing the surrounding infrastructure and expertise to support its vision for a national space-based internet. Over the last two years however, shepherded by major CCP policy announcements and signals, the country's LEO communications market has trended towards consolidation. Investment, flowing hotly since the sector's majority opening in 2019, is beginning to cool and concentrate on fewer firms.[45] In April 2021, China's State-owned Assets Supervision and Administration Commission (SASAC), the body responsible for oversight over China's biggest SOEs, created China SatNet to manage the GuoWang constellation.[46] SASAC's direct creation and administration of SatNet places the company on the same level as China's three national telcos, 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.[47]

CASIC and CASC have respectively launched experimental satellites for their own LEO constellations, Hongyun and Hongyan, that aim to provide connectivity to China's remote regions and to select maritime and air travel customers. There is a large chance that plans for both constellations will be absorbed by SatNet's Guowang.[48]

China's Competitive Advantage

Leveraging the country's state-owned enterprises and its existing efforts under the Digital Silk Road initiative has the potential to create an extremely robust competitor. China SatNet, along with CASIC and CASC's LEO

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[42] L. Press, *A New Chinese Broadband Satellite Constellation*, CircleID, October 2, 2020, https://circleid.com/posts/20201002-a-new-chinese-broadband-satellite-constellation/
[43] Press Conference, The National Development and Reform Commission, https://www.ndrc.gov.cn/xwdt/xwfb/202004/t20200420_1226031.html;
A. Jones, *China's commercial satellite sector sees boost from 'new infrastructure' policy,* SpaceNews, May 15, 2020, https://spacenews.com/chinas-commercial-satellite-sector-sees-boost-from-new-infrastructure-policy/
[44] *The 14th Five-Year Plan for National Economic and Social Development of the Pepole's Republic of China and Outline of the Vision for 2035*, Xinhau News Agency, March 13, 2021, http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm
[45] P. Bingjing, *In the past ten years, the financing amount of my country's commercial aerospace track has reached 19 billion yuan, and rocket/satellite R&D companies have frequently received financing,*Yicai, August 9, 2021, https://www.yicai.com/news/101134891.html
[46] H. Reale, *The Long Arm of SASAC*, The Wire China, February 7, 2021, https://www.thewirechina.com/2021/02/07/the-long-arm-of-sasac/;
State-owned Assets Supervision and Administration Commission of the State Council, http://www.sasac.gov.cn/n2588030/n2588924/c18286531/content.html
[47] *What's up in Chinese Space this Week?* The Dongfang Hour, https://www.getrevue.co/profile/dongfanghour/issues/the-dongfang-hour-newsletter-issue-2-615781
[48] *What's up in Chinese Space this Week?* The Dongfang Hour, https://www.getrevue.co/profile/dongfanghour/issues/dfh-42-updates-from-china-s-answer-to-starlink-in-flight-connectivity-in-china-and-a-whole-lot-more-1040609

communications ventures, enjoy almost unrestricted funding, municipal government support, and significant regulatory leeway.

Following directives from the central government, municipal actors are heavily incentivized to invest in strategically-designated sectors. For example, the city of Wuhan has vowed to develop a local 100 billion yuan ($15.7 billion) space industry by 2025.[49] In a bid to host the Chinese "valley of satellites," Wuhan is offering millions in concessional financing to space companies. The city's pledges pale in comparison to China's richer coastal cities. Taking advantage of this sentiment, SatNet executives have traveled to multiple cities in China attempting to court local leaders, receive regulatory concessions, and develop synergies between SatNet and existing domestic industrial bases.[50] 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.[51] Chongqing, host to the majority of CASC's LEO Hongyan operations, has also signed a co-development agreement with SatNet for a new satellite industrial base.[52]

Regulatory and economic concessions at home are bolstered by China's foreign engagement through the Digital Silk Road (DSR) and the Belt and Road Space Information Corridor, part of its broader Belt and Road Initiative (BRI). China's 2021 Space White Paper referenced the Belt and Road Space Information Corridor as a key avenue through which to "strengthen cooperation on the application of .. communication satellites."[53] China has built ground stations and shares space supporting infrastructure with 38 partner countries. Since 2016, China has signed over 117 space cooperation agreements and 19 memorandums of understanding (MOUs) with at least 37 foreign governments.[54]

Given China's successful strategy of exporting terrestrial infrastructure through the DSR—up to 70 percent of 4G network infrastructure across Africa is Huawei-built—these agreements and engagements may yield extremely fruitful results for the country's aspirations of a globally adopted LEO broadband service.[55] Leveraging its heavy economic presence in a large portion of BRI countries, China is likely 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 competing with Chinese companies for market share in BRI countries difficult.

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[49] *Wuhan aims to become China's 'valley of satellites' in space initiative,* Reuters, March 17, 2022, https://www.reuters.com/technology/wuhan-aims-become-chinas-valley-satellites-space-initiative-2022-03-18/
[50] B. Curcio, *The Satcom Industry in China: Accelerating to 'China Speed'*, Satellite Markets & Research, July 5, 2021, http://satellitemarkets.com/satcom-industry-china-accelerating-china-speed
[51] https://www.shanghai.gov.cn/nw12344/20220216/4d49cd9c608c414ea0d790f59e43caef.html?utm_campaign=The%20Dongfang%20Hour%20Newsletter&utm_medium=email&utm_source=Revue%20newsletter; The Dongfang Hour, Twitter Post, February 16, 2022, 10:43pm, https://twitter.com/DongFangHour/status/1494155463315038211
[52] B. Curcio, *The Satcom Industry in China: Accelerating to 'China Speed'*, Satellite Markets & Research, July 5, 2021, http://satellitemarkets.com/satcom-industry-china-accelerating-china-speed
[53] *Full Text: China's Space Program: A 2021 Perspective*, The State Council The People's Republic of China, January 28, 2022, http://english.www.gov.cn/archive/whitepaper/202201/28/content_WS61f35b3dc6d09c94e48a467a.html
[54] P. Wood, *China's Ground Segment: Building the Pillars of a Great Space Power,* China Aerospace Studies Institute, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Space/2021-03-01%20Chinas%20Ground%20Segment.pdf?ver=z4ogY_MrxaDurwVt-R9J6w%3d%3d
[55] P. Gilbert, *African Operators, Governments Show Faith in Huawei,* Connecting Africa, July 26, 2019, https://www.connectingafrica.com/author.asp?section_id=761&doc_id=753041

Dominance in foreign markets comes with benefits beyond economic gains. China's heavy information and communication technology (ICT) presence along Belt and Road countries creates path dependencies, spreads techno-authoritarian norms and standards, and strengthens China's position in global networks.[56] The successful proliferation of Chinese LEO broadband service is likely to have similar impacts as China's presence in foreign terrestrial networks, providing Beijing with greater control over international data flows and extensive intelligence and coercive powers.[57]

Because of the role that LEO constellations have the potential to play in communications networks, countries that accept Chinese ground stations and grant the country landing rights will 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.[58] High levels of Chinese built and operated digital infrastructure incentivizes adoption of Chinese-crafted norms, standards, and data governance practices. This adoption in turn reduced compliance costs for purchasing other Chinese-origin ICT technology. For countries like Pakistan and Egypt, whose entire suite of digital infrastructure features heavy Chinese involvement from submarine cables and terrestrial fiber to 5G and satellite ground stations, the choice to integrate Chinese LEO broadband into its existing network stack is a relatively easy one.[59]

Security Implications for the United States

Today, the United States holds a competitive advantage in the competition over LEO broadband. Just under 50 percent of new companies seeking to operate in LEO originate in the U.S, with SpaceX and Amazon leading the way.[60] SpaceX's Starlink plans for a 12,000 satellite constellation, over 2,500 of which are already in orbit.[61] The company is the first to begin beta testing its service, which at time of publication is already in its second iteration and rapidly improving.[62] Amazon Kuiper, despite lagging behind Starlink on satellites in orbit, has received approval from the FCC to launch a smaller constellation of 3,236 satellites, with the first to be launched in late 2022. Kuiper's plans indicate broadband services to be available to consumers globally, as well as to integrate its broadband service into its existing network stack in partnership with Amazon Web Services (AWS) which has the potential to unlock significant value.[63]

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[56] J. E. Hillman, *Techno-Authoritarianism: Platform for Repression in China and Abroad*, Congressional Testimony, November 17, 2021, https://www.csis.org/analysis/techno-authoritarianism-platform-repression-china-and-abroad
[57] Ibid.
[58] European Chamber, https://www.europeanchamber.com.cn/documents/signup/en/pdf/762;
V. Wade, *IOT platforms for cities: A comparative survey*, ReadKong, January 2019, https://www.readkong.com/page/iot-platforms-for-cities-a-comparative-survey-5735143
[59] J. E. Hillman, *Pakistan's cautionary tale of digital dependence on China,* Nikkei Aisia, December 3, 2021, https://asia.nikkei.com/Opinion/Pakistan-s-cautionary-tale-of-digital-dependence-on-China
[60] L. A. Odell et al, *U.S. Low Earth Orbit Dominance Shifting with Gray Zone Competition*, Institute for Defense Analysis, June 2021, https://www.ida.org/-/media/feature/publications/u/us/us-low-earth-orbit-dominance-shifting-with-gray-zone-competition/d-22676.ashx
[61] S. Clark, *SpaceX passes 2,500 satellites launched for Starlink internet network,* Spaceflight Now, May 13, 2022, https://spaceflightnow.com/2022/05/13/spacex-passes-2500-satellites-launched-for-companys-starlink-network/
[62] J. Fomon, *Here's How Fast Starlink Has Gotten Over the Past Year,* Ookla, June 28, 2022, https://www.ookla.com/articles/starlink-hughesnet-viasat-performance-q1-2022
[63] A. Boyle, *Project Kuiper plus AWS: How Amazon's clous and satellite internet ventures mesh*, GeekWire, December 17, 2020, https://www.geekwire.com/2020/project-kuiper-plus-aws-amazons-cloud-satellite-internet-ventures-mesh/

Establishing efficient and affordable broadband services in LEO is not only a priority for privately funded industry to improve the connectivity of the average U.S. citizen, but the U.S. military network as well. 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 (SDA).[64] The NDSA will consist of layers of several military constellations in LEO. Each layer focuses on different aspects to enhance military connectivity, sensing, and communication.[65] One of the first to be launched in late 2022 will be the Transport Layer, which will provide broadband connectivity to U.S. military systems and will boast higher communications security functions, dynamic routing techniques, and blockchain. To support the SDA develop and demonstrate this LEO broadband advancement, the Defense Advanced Research Projects Agency (DARPA) created a project named Blackjack to launch up to 22 satellites into LEO to test military viability in orbit.[66]

In addition to developing indigenous military capability, the U.S. Space Force has shown interest in leveraging commercial capabilities for operation of military broadband networks to increase the resiliency of military 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. These services would be purchased through a "fee for service" model of acquisition, where the Space Force would be able to pay a fee to access particular bandwidth over a fixed amount of time for a fixed price.[67] Through this acquisition model, DoD has the opportunity to gain increasing resiliency in its communications network, if the aforementioned U.S.-based space internet providers prove successful. The option to switch providers at a moment's notice if one were to become compromised, would be hugely beneficial and add resiliency in a potential conflict.[68]

Procuring systems in the LEO broadband market is part of a larger effort from the Space Force to change its acquisition process. Leading this charge is the Commercial Satellite Communication Office (CSCO) which released a draft request ready for proposals for "Proliferated Low Earth Orbit Satellite-based Commercial Services."[69] DoD may also be interested in operating a portion of a commercial constellation as its own, and officials have confirmed initial meetings with commercial companies that would allow the U.S. military to separately operate a portion of a commercial constellation as a distinct network.[70]

United States Licensing and Economic Security

Planned launches, indicated by filings with regulatory agencies across the world, have increased exponentially over the last few years. Proposed megaconstellations would add almost 100,000 satellites into an orbit that supports less than 10,000 today. Regulatory agencies with jurisdiction over space and space-related activities are struggling to keep pace with private sector growth in managing megaconstellations, a task that is correspondingly growing in

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[64] V. Machi, *US Military Places a Bet on LEO for Space Security*, Via Satellite, June 2021, https://www.sda.mil/us-military-places-a-bet-on-leo-for-space-security/;
Transport, Space Development Agency, https://www.sda.mil/transport/
[65] *Broad Agency Announcement National Defense Space Architecture Systems, Technologies, and Emergine Capabilities*, p 5-10, Space Development Agency, January 13, 2022, https://sam.gov/api/prod/opps/v3/opportunities/resources/files/fd17422624ee4af3be54fc29a370c521/download?&token=
[66] N. Strout, *Is Project Blackjack still relevant?* C4ISRNET, February 13, https://www.c4isrnet.com/battlefield-tech/space/2022/02/13/is-project-blackjack-still-relevant/
[67] T. Hitchens, *Space Force eyes Iridium in quest for satellite broadband, say top company officials,* Breaking Defense, April 1, 2022, https://breakingdefense.com/2022/04/space-force-eyes-iridium-in-quest-for-satellite-broadband-say-top-company-officials/
[68] Ibid.
[69] S. Erwin, *DoD eager to leverage LEO broadband constellations,* SpaceNews, November 15, 2021, https://spacenews.com/dod-eager-to-leverage-leo-broadband-constellations/
[70] Ibid.

difficulty. The rise of the commercial space-based operations has forced new paradigms on a sector previously dominated by government and defense ventures, highlighting the need for updated regulation.[71]

Licensing requirements include allocating limited spectrum amongst 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 is unevenly split amongst the Department of Defense, the Federal Aviation Administration (FAA), the Federal Communications Commission (FCC), the Department of Commerce (DOC), the Department of State (DOS), and the National Oceanic and Atmospheric Administration (NOAA). Coordination amongst these agencies can be difficult, and shifting regulatory responsibilities slows progress and exacerbates issues resulting from varying levels of proficiency on space-related matters.

The National Space Council (NSC) was established in 1989 to "provide a coordinated process" between government agencies with regulatory jurisdiction over space.[72] After almost 25 years of inactivity, the NSC was reformed in 2017 to align U.S. commercial and security policy and strategy in space.[73] Vice President Harris, chair of the NSC, revealed during its August 2022 meeting that the Council will begin updating and developing a new rules framework for the country's "outdated" commercial space regulation.[74]

Although the NSC is well positioned to take leadership on these issues, its recent efforts follow the heels of federal agencies attempting to plug the perceived regulatory vacuum created by a lack of concrete Executive or Congressional direction. The FCC regulates the frequency that constellation satellite operators can operate in, and as such, is often the first stop for companies looking to begin operations. 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.[75] The agency made headlines after it denied a satellite operator an operating license due to tracking and space situational awareness (SSA) concerns.[76] In 2018, the FCC issued a Notice of Proposed Rulemaking (NPRM) seeking to revise orbital debris management requirements in its licensing process, placing the agency at the center of the conversation on the issue.[77] Two years later, the resulting update was pared back significantly due to widespread backlash from a range of critics, from industry groups to the House Science Committee, on potentially prohibitive and overly stringent requirements.[78] The current approach to regulation has thus far largely been reactionary to developments in the private sector. Clarifying and assigning new and existing

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[71] J. Rainbow, *Connecting the Dots: Getting satellite regulation up to speed,* SpaceNews, January 27, 2022, https://spacenews.com/connecting-the-dots-getting-satellite-regulation-up-to-speed/
[72] *Commercial space: Federal Regulation, Oversight, and Utilization,* Congressional Research Service, November 29, 2018, https://www.everycrsreport.com/files/20181129_R45416_448ecfba931aa7974dcb1c200f4d2a603ea42f0e.pdf
[73] *Reviving the National Space Council,* Federal Register, July 7, 2017, https://www.federalregister.gov/documents/2017/07/07/2017-14378/reviving-the-national-space-council
[74] J. Foust, *Harris says U.S. to update commercial space regulations,* SpaceNews, August 12, 2022, https://spacenews.com/harris-says-u-s-to-update-commercial-space-regulations/
[75] *Commercial Space: Federal Regulation, Oversight, and Utilization*, Congressional Research Services, November 29, 2018, https://www.everycrsreport.com/files/20181129_R45416_448ecfba931aa7974dcb1c200f4d2a603ea42f0e.pdf
[76] C. Henry, *FCC issues warning in wake of Swarm's unauthorized launch,* SpaceNews, April 13, 2018, https://spacenews.com/fcc-issues-warning-in-wake-of-swarms-unauthorized-launch/; *Dismissed-Without Prejudice,* Experimental Licensing Branch, December 12, 2017, https://apps.fcc.gov/els/GetAtt.html?id=203152&x=
[77] I. Christensen et al, *The FCC takes a leadership role in combating orbital debris,* The Space Review, April 20, 2020, https://www.thespacereview.com/article/3926/1
[78] C. Henry, *FCC punts controversial space debris rules for extra study,* SpaceNews, April 23, 2020, https://spacenews.com/fcc-punts-controversial-space-debris-rules-for-extra-study/

responsibilities would aid agencies such as the FCC in streamlining its work and ensure that regulatory responsibilities are carried out by the best suited regulators.

There have been previous attempts at reforming responsibilities among space regulators in the United States. The Obama administration intended to create a "mission authorization" ability for non-traditional commercial space services within the FAA, but was not able to implement its plans.[79] The Trump administration assigned the duty to the DOC Office of Space Commerce (OSC) where little to no progress has been made as of August 2022.[80] Through Space Policy Directive 3, the Trump administration also tasked the DOC OSC with leading space tracking management (STM) and SSA efforts in 2018, requiring the agency to coordinate with the DOD on managing and publicly releasing SSA data. Although intended to reduce the burden on an overextended DOD, U.S. Space Command continues to drain considerable resources in tracking close to 50,000 pieces of orbital debris.[81] Without the necessary expertise and resources, DOC OSC efforts have been mired in feasibility studies and budget restrictions. Officials estimate that Commerce will not be able to fulfill its assigned STM and SSA responsibilities until 2024.[82] The NSC's announcement of a new framework for space regulation provides a good opportunity to review recent structural changes, provide additional support, and course correct if necessary.

The risks to deficient management and regulation go beyond a poorly operated LEO environment; the absence of concrete Congressional direction and a maladapted regulatory structure makes for a complicated and often poorly defined process for U.S. companies. Outdated regulation and slow implementation imposes high compliance costs, uncertainty, and overburdensome requirements that already threaten to place U.S. companies at a competitive disadvantage with foreign entities. Moving forward, the NSC has the potential to better coordinate activities among federal agencies, efficiently divide regulatory authorities, readjust ill-fitting requirements, and speed unnecessarily lengthy licensing processes.

Through its work, the NSC must also 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."[83] For U.S. companies that compete against foreign firms facing different national regulatory structures, requirements, and enforcement capabilities, comparatively more stringent requirements are costly and dampen U.S. firms' first mover advantage. The FCC Satellite Division also grants permission for U.S. market access to commercial satellites licensed by other countries.[84] There is a risk that asymmetric requirements between U.S. license holders and foreign-licensed companies with permission to operate in the United States will create an uneven playing field.

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[79] I. Christensen, *Insight - Regulatory Reform is Not a One-off Event,* Secure World Foundation, May 4, 2018, https://swfound.org/news/all-news/2018/05/insight-regulatory-reform-is-not-a-one-off-event
[80] J. Foust, *Harris says U.S. to update commercial space regulations,* SpaceNews, August 12, 2022, https://spacenews.com/harris-says-u-s-to-update-commercial-space-regulations/
[81] S. Erwin, *Tracking debris and space traffic a growing challenge for U.S. military,* SpaceNews, August 9, 2022, https://spacenews.com/tracking-debris-and-space-traffic-a-growing-challenge-for-u-s-military/
[82] J. Foust, *Getting a jump on traffic: The sudden urgency of government-industry partnerships in space traffic management,* SpaceNews, April 7, 2022, https://spacenews.com/getting-a-jump-on-traffic-the-sudden-urgency-of-government-industry-partnerships-in-space-traffic-management/
[83] M. Sheetz, *In race to provide internet from space, companies ask FCC for about 28,00 new broadband satellites,* CNBC, November 5, 2021, https://www.cnbc.com/2021/11/05/space-companies-ask-fcc-to-approve-38000-broadband-satellites.html
[84] *Commercial Space: Federal Regulation, Oversight, and Utilization,* Congressional Research Service, November 29, 2018, https://www.everycrsreport.com/files/20181129_R45416_448ecfba931aa7974dcb1c200f4d2a603ea42f0e.pdf

Conversely, U.S. companies often face protectionist barriers and a complex regulatory landscape when looking to expand into foreign markets. Regulatory requirements over landing rights, ground stations and related infrastructure, and market access vary significantly by country. High compliance costs notwithstanding, competition from national telecom 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. 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 at securing the necessary licenses stalled and the company had to halt presales. Some countries outright forbid foreign ownership over telecoms infrastructure, forcing entrants to set up joint ventures with domestic firms or open domestic-owned and operated companies as a prerequisite for market access.[85]

Meanwhile, staff shortages, a more complicated operating environment, multiple processing rounds, and poorly defined deadlines have elongated license approval timelines.[86] 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 license requests, when allowed, must be updated to reflect new advancements. This, in turn, slows down government review. Long licensing timelines delay the process of bringing a product to market, resulting in market uncertainty and lower profit projections that dampen sector growth.[87] SpaceX's application to license its Starship spacecraft, for example, continues to face repeated delays, causing the company to change plans for priority operations and launch fewer satellites.[88] Operating within the narrow profit margins and unforgiving business models of LEO broadband systems can make navigating an onerous regulatory process impossible for all but the largest, most well-resourced companies.

Future regulatory changes need to consider competition between domestic market incumbents and new entrants as well. Spectrum is a precious and limited resource. Due to availability and other technical considerations, LEO operators must share the same spectrum bands with one another.[89] The process for allocating spectrum is therefore extremely competitive. The FCC, which has historically auctioned spectrum licenses on a first-come first-serve basis, is considering updating its auction rules for LEO-based satellite operators.[90] The issued NPRM describes an inflated first-mover advantage, where the FCC would ensure that operators licensed in earlier rounds have their spectrum access protected. While this would protect the investments of early movers, its implementation may bar new firms from entering the space altogether.

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[85] M. R. Camus, *Elon Musk's SpaceX links up with Filipino firms to bring Starlink services to OH*, Business Inquirer, October 29, 2021, https://business.inquirer.net/333388/elon-musks-spacex-links-up-with-filipino-firms-to-bring-starlink-services-to-ph
[86] J. Rainbow, *Bipartisan legislation seeks to reform FCC satellite licensing rules*, SpaceNews, February 14, 2022, https://spacenews.com/bipartisan-legislation-seeks-to-reform-fcc-satellite-licensing-rules/
[87] A. Kemna, *The impact of regulation*, McKinsey & Company, April 1, 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-impact-of-regulation
[88] M. Wall, *FAA delays environmental review of SpaceX's Starship 2 more weeks, to June 13*, Space.com, May 31, 2022, https://www.space.com/faa-spacex-starship-review-delayed-june-13; Jeff Foust, "FAA again delays completion of Starship environmental review," SpaceNews, March 26, 2022, https://spacenews.com/faa-again-delays-completion-of-starship-environmental-review/
[89] J. Rainbow, *FCC considers opening up more Ku-band to non-GEO satellite operators*, SpaceNews, August 5, 2022, https://spacenews.com/fcc-considers-opening-up-more-ku-band-to-non-geo-satellite-operators/
[90] *The FCC Report to Congress on Spectrum Auctions*, Federal Communications Commission Wireless Telecommunications Bureau, October 9, 1997, https://www.fcc.gov/sites/default/files/wireless/auctions/data/papersAndStudies/fc970353.pdf; J. Rainbow, *Connecting the Dots: Getting satellite regulation up to speed*, SpaceNews, January 27, 2022, https://spacenews.com/connecting-the-dots-getting-satellite-regulation-up-to-speed/

Managing Megaconstellations

Risks and Operator Mitigation

As competition heats up for dominance in launching megaconstellations in LEO designed for commercial broadband internet increases, so do the risks not only due to international competition, but 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 in space. While advancements in space open up many opportunities, they also open the door for more risk. When looking at proposed LEO broadband networks, risks can include but are not limited to on-orbit collisions in space, disrupting astronomy missions, political discord between nations, and instability caused by dual-use platforms.

One of the greatest risks with the launch of large constellations is to the space environment itself, with an increased potential for on-orbit collisions in space. As of May 10, 2022, there have been about 13,100 satellites launched into Earth orbit. About 8,410 of these satellites are still in space—of which 5,700 are still functioning. These activities have created about 31,380 pieces of trackable debris maintained by the U.S. Space Surveillance Network.[91] SpaceX alone is on track to launch 11,000 more satellites and is in the process of requesting permission for another 30,000. OneWeb, Amazon, Telesat, and China SatNet constellation plans are similarly in the tens of thousands. Together, proposed LEO broadband constellations could potentially add close to 100,000 satellites to Earth orbit, vastly changing the operational domain as we know it. More traffic by various satellite operators can make operations in the area much more difficult, and can put human spaceflight operations at risk.[92] A significant increase of satellites orbiting in LEO could potentially have an effect on additional space activities, including impacting launch schedules. In February of 2022, NASA submitted a note to the FCC stating a concern for the "unavailability of safe launch windows" due to increased on orbit activity from the Starlink constellation.[93]

Starlink has SSA capabilities onboard and satellites are able to perform avoidance maneuvers autonomously, based on the satellite's knowledge of its current position and information about potential close approaches that are uploaded to them.[94] These capabilities have already proven to be necessary, among reports that Starlink satellites have had to maneuver over 1,700 times to avoid orbital debris from Russia's 2021 anti-satellite test.[95]

Though no satellites from its constellation are currently in orbit, space safety and sustainability are a core tenant throughout the Kuiper design process. Kuiper satellites will have active propulsion systems onboard and plan to perform avoidance maneuvers if the risk of collision is more than 1 in 100,000.[96] Additionally, Kuiper's low altitude will increase the ability for satellites to be deorbited faster and with reliability. Kuiper satellites are scheduled to actively deorbit within one year of a completed mission, and in a failure scenario will naturally deorbit within 10 years. Satellites will have a tight orbital tolerance (+- 7 km) to avoid overlap with other large LEO systems.

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[91] *Space debris by the numbers,* The European Space Agency, last updated August 2022, https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers
[92] P. Belton, *Musk eyes 30,000 KEO sats - but how many are too many?* LightReading, February 16, 2022, https://www.lightreading.com/satellite/musk-eyes-30000-leo-sats---but-how-many-are-too-many/d/d-id/775286
[93] Note to Marlene Dortch, *Re: Report No. SAT-01598 Space Station Applications Accepted for Filing, Space Exploration Holdings, LCC,* United States Department of Commerce, February 8, 2022, https://cdn.arstechnica.net/wp-content/uploads/2022/02/NTIA-NASA-and-NSF-Fi.pdf
[94] J. Foust, *How to better manage space traffic: Aeolus/Starlink encounter shows emails and late-night phone calls no longer cut it,* SpaceNews, November 21, 2019, https://spacenews.com/how-to-better-manage-space-traffic-aeolus-starlink-encounter-shows-emails-and-late-night-phone-calls-no-longer-cut-it/
[95] R. Zafar, *Starlink Moved Its Satellites 1,700 Times To Evade Russian Missile Debris,* Wccftech, July 16, 2022, https://wccftech.com/starlink-moved-its-satellites-1700-times-to-evade-russian-missile-debris/
[96] Interview with Commercial company

OneWeb also has an SSA component, via an agreement with Australian SSA provider LeoLabs to incorporate *LeoLabs Collision Avoidance*. 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 operational satellites. This LeoLabs service is also used by SpaceX and Earth observation company Planet which operates a 200 satellites fleet.[97] In addition to the LeoLabs software, OneWeb satellites incorporate additional sustainable components, including adding fixtures or a magnetic docking plate in order to be de-orbited or serviced via an active debris removal mission if necessary.[98] Because the satellites have been designed in France, the fleet also is ready to comply with the France Space Operation Act which mandates all LEO satellite operators to decommission satellites at the close of their operational activity.[99]

Another risk to the space environment is light pollution and observation obstruction from these thousands of additional satellites. Astronomers have complained that Starlink satellites have gotten in the way of night sky observations, blocking or disrupting telescope images. Environmental groups in France have been so vocal about this subject that Starlink's permit to operate in the country was temporarily overturned.[100] Starlink competitor ViaSat has also been vocal about Starlink obstructions to astronomy, and have filed court documents to stop Starlink from launching more satellites based on environmental grounds. This avenue has not been successful.[101]

As an answer to the outcry from astronomers, both Telesat and Starlink have been working to decrease reflectivity of satellites. Additionally, Kuiper is working with the National Science Foundation and the American Astronomical Society to evolve current prototype plans to take astronomer concerns into account. According to an interview with the company, Kuiper is limiting the number of satellites in the constellation and maintaining a low operating altitude to keep with best practices recommended by astronomers and industry. [102] However, there is no permanent solution for astronomers using Earth-based telescopes. This particular challenge highlights a significant gap in the international regulatory system for space, as one country's approvals of megaconstellations can affect people all over the world.

Outside of the space domain itself, this intense broadband competition invites political risks. A researcher in a Chinese peer reviewed journal wrote about the competition Starlink posed to Chinese assets, and 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."[103] Though the paper was taken down shortly after publishing, this dialogue is not the only one of its kind circulating in China. An opinion piece published in the official news site of the Chinese

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[97] *Planet FAQ*, Planet, https://www.planet.com/faqs/#:~:text=Today%20we%20have%20approximately%20200,Planet%20is%20a%20data%20company.
[98] *LeoLabs Announces Operational Agreement with OneWeb*, LeoLabs, February 1, 2022, https://leolabs-space.medium.com/leolabs-announces-operational-agreement-with-oneweb-fde505c0262e
[99] S. Antonetti, *Down to Earth: how to deorbit satellites and save money*, Room, https://room.eu.com/article/Down_to_Earth_how_to_deorbit_satellites_and_save_money
[100] T. Bateman, *Amazon target Elon Musk's Starlink with dozens of Project Kuiper satellite broadband launches,* Euronews, June 4, 2022, https://www.euronews.com/next/2022/04/06/amazon-targets-elon-musk-s-starlink-with-dozens-of-project-kuiper-satellite-broadband-laun#:~:text=%22It's%20the%20result%20of%20two,place%20between%202024%20and%202027.&text=The%20first%20two%20prototype%20Project,%2Dyear%20period%2C%20Amazon%20said.
[101] *Starlink*,"eoPortal, May 24, 2019, https://directory.eoportal.org/web/eoportal/satellite-missions/s/starlink
[102] Interview with commercial company
[103] V. Gaur, *Why Starlink Scares China: Researchers Pitch Plan To 'Destroy' SpaceX Satellites*, The quint, May 31, 2022, ://www.thequint.com/tech-and-auto/tech-news/china-researchers-plan-to-destroy-spacex-starlink-satellites-why-afraid-internet-usa-ukraine-russia-teslla#read-more

military, *China Military Online*, wrote about Starlink's "unchecked expansion" and noted an "ambition to use it for military purposes" that should alarm governments internationally.[104]

Starlink's start in orbit has continued to draw political attention, most vocally from China. In two separate events in July 2020 and October of 2021, Chinese officials claimed Starlink satellites came so close to the China Space Station that astronauts had to shelter in place.[105] Chinese officials issued a complaint to the United Nations Office of Outer Space Affairs (UNOOSA). On January 28 of 2022, the United States replied to UNOOSA, 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."[106] While there was no formal conclusion to this issue, it is a potent reminder that the accurate tracking of space objects will be crucial in supporting or disputing similar issues in the future. This incident underscores the importance of open avenues of communication as well as shared standards and data between all satellite operators.

2022 saw a shift in geopolitical relationships between the United States and one of the longest standing space powers, Russia, after its invasion of Ukraine in February of 2022. After a plea on Twitter from Ukrainian officials in the onset of the Russian invasion of the country, Elon Musk answered with the delivery of tens of thousands of Starlink user terminals to aid in connectivity around the country in March of 2022. Further, *The Times* reported that Ukrainian forces were linked to Starlink terminals in the country to send targeting information to artillery to communicate with reconnaissance drones.[107] Starlink's involvement in the conflict does open the door to questions about commercial company involvement in zones of geopolitical conflict and any risks that commercial assets may incur.

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 cyber attacks and no additional cyber attacks have been publicly reported. The additional connectivity links involved in operating a large LEO constellation increase the system's vulnerability to cyber attacks like this. To ensure communications are safe and not tampered with, LEO constellations must harden cyber connections and increase encryption. However, this would likely come at a higher cost and add latency to the network. Commercial companies must be aware of what this risk management would cost, and adapt to the cyber environment if more instances of malware attacks are made public.[108]

Also affected by OneWeb had a launch of 36 satellites planned for March 4, 2022 out of the Russian Baikonur Cosmodrome in Kazakhstan, just days after the Russian invasion of Ukraine.[109] Operations at the Cosmodrome were halted, impacting satellites OneWeb had sent to be integrated onto the Soyuz launch vehicle. As of late March

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[104] Ibid.
[105] T. Hitchens, *US rejects charge that Starlink satellites endangered China's space station*, Breaking Defense, February 3, 2022, https://breakingdefense.com/2022/02/us-rejects-charge-that-starlink-satellites-endangered-chinas-space-station/
[106] Ibid;
US denial of SpaceX satellites' close encounters endangering China's crewed space station 'a move of shirking responsibility': FM, Global Times, February 10, 2022, https://www.globaltimes.cn/page/202202/1251961.shtml
[107] V. Gaur, *Why Starlink Scares China: Researchers Pitch Plan To 'Destroy' SpaceX Satellites*, the quint, May 31, 2022, https://www.thequint.com/tech-and-auto/tech-news/china-researchers-plan-to-destroy-spacex-starlink-satellites-why-afraid-internet-usa-ukraine-russia-teslla#read-more
[108] S. Waterman, *LEO Constellations connectivity offers risks and rewards execs warn*, Air Force Mag, April 7, 2022, https://www.airforcemag.com/leo-constellations-connectivity-offers-risks-and-rewards-execs-warn/
[109] Ibid.

2022, the 36 satellites were not returned to OneWeb and were being kept in Russia.[110] Looking for another launch 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, Falcon 9 rockets launched upgrades for an Iridium communications constellation up until 2019.[111]

Policy Recommendations

The strength of U.S. private sector companies has led to cost reductions in launch services, 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 a leading role in setting emerging standards, norms, and best practices. However, foreign competitors are close behind. U.S. policymakers must support domestic businesses to maintain this advantage by helping their expansion into foreign markets, supporting innovation, and responsibly reducing overburdensome regulatory barriers. U.S. government agencies can support and encourage commercial activity, uphold sustainability requirements for an increasingly congested orbit, and not hinder American commercial growth, particularly in the broadband internet domain.

In both research and interviews with commercial companies, a common thread is that FCC regulatory clarity, speed, and reform has the potential for enormous impact as commercial competition heightens. As the FCC continues to have the dominant role in regulating satellite communications, it must take care to strike the appropriate balance between burdensome regulation and free market development. Providing additional clarity on FCC 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.

Additionally, the FCC can increase interaction and understanding of standards in international countries. As competing broadband companies emerge in other countries, the regulations 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, coordinating with international partners to establish shared standards for operation in the space domain will only grow more crucial. The ITU could be a key partner for the United States and FCC to engage to promote common international norms and standards in addressing shared spectrum.

The FCC is not the only U.S. regulatory agency involved in the LEO broadband discussion. The National Telecommunications and Information Administration (NTIA) is an Executive Branch agency responsible for advising the White House on telecommunications and related policy issues which exists within the Department of Commerce (DoC). NTIA is primarily focused on the adoption and expansion of broadband internet access across the United States, including the use of spectrum by Americans and ensuring that the internet remains a tool for innovation and economic stimulation.[112] Although the NTIA is heavily involved in discussing internet regulations with the president, there is no evidence that the NTIA collaborates with the FCC in regards to the regulatory policy for broadband internet providers. The DoC, most likely through the NTIA, could work more regularly with the FCC to simplify and standardize regulatory practices for U.S. companies. In addition to working with other government agencies, commercial feedback should also be systematically incorporated.

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[110] L. Grush, *OneWeb turns to SpaceX for help after Russia refused to launch company's satellites,* The Verge, March 21, 2022, https://www.theverge.com/2022/3/21/22988867/oneweb-spacex-launch-agreement-russia-roscosmos-soyuz
[111] M. Brown, *War in Ukraine Forces Starlink Competitor OneWeb to Use SpaceX for launches*, Inverse, March 22, 2022, https://www.inverse.com/innovation/spacex-oneweb-ukraine
[112] *What's New at NTIA*, NTIA, https://www.ntia.doc.gov/

As the Department of Commerce (DoC) becomes more involved in the space domain, its SSA mission area will continue to increase in importance and impact every area of space. Increased SSA capabilities can include decreasing the size of trackable debris, currently at 10cm or larger, and can create a more known and comfortable operating environment for satellite operators around the globe. Ensuring that SSA data is widely accessible and that standards between different tracking organizations are similar can provide clarity and consistency to an increasingly congested domain.

The U.S. government should also put an emphasis on 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 be able to identify nefarious behavior that veers out of the norm. Global operating standards can also place an emphasis on space sustainability, protecting various orbital regimes from space debris and ensuring that others will be able to use the domain in years to come as well.

Finally, U.S. leaders should be working with commercial companies who are able to successfully operate broadband internet constellations and incorporate connectivity to increase soft power across the globe. The United States has a strong record of soft power through space exploration, namely through NASA programs which have captivated the globe for decades. NASA has over 700 international agreements with more than 100 countries around the world, which allows the United States to maintain strong relationships with foreign governments through civil space agencies in 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 possible reach of the United States.

Conclusion

Growing competition in the race to establish space-based broadband networks brings many risks to a rapidly growing space domain. These risks include environmental, technical, and political impacts ,but perhaps the biggest risk of all is the looming international competition from China. China has its own plans for a national LEO broadband network that benefits from consistent investments from state funding and political ties to leverage through its Belt and Road Initiative.

Today, the United States profits significantly from its dominance in global networks, and U.S.-based commercial networks have a significant head start compared to international competitors. But as competition for space-based communication networks intensifies, it is imperative that the United States government enact policies and incentives to protect this dominant market share. Once firms have accumulated the vast capital and expertise required for entry into the LEO broadband market, navigating multilevel regulatory regimes introduces high compliance costs and uncertainty. Licensing requirements persist through domestic, foreign, and international regimes, 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, and one that must be reckoned with in real time.