Spectrum and the Technological Transformation of the Satellite Industry

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[1] AT&T, a member of SIA, does not necessarily endorse all conclusions of this study.

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2. Executive Summary

2.1. What the satellite industry does for the U.S. today

Nearly every person in America uses satellite technologies, whether watching the news, surfing the Internet on a plane, navigating with a GPS-enabled map, or checking the weather.

- The global satellite industry serves annually **220 million** satellite pay-tv subscribers, **34 million** satellite radio customers, **2 million** broadband customers, a large portion of the **1 billion** airline passengers, **14 million** cruise passengers, and **1.5 million** connected devices worldwide.
- The satellite industry added **$117.9 billion** to the US economy in 2018 and is growing at 4%. Essential satellite services include pay TV, radio, broadband internet and remote sensing. The satellite industry provides terrestrial network distribution, backhaul, connectivity, and many other services.
- Over **250,000 Americans** work in the satellite industry, and it adds **20,000 well-paying jobs** annually.
- The satellite industry offers highly specialized, encrypted communications and applications for national security to the US military valued at **$31.5 billion** annually.
- The satellite industry works closely with public safety professionals and first responders, offering communications and applications worth **$18B** annually.

2.2. What the satellite industry offers going forward

The satellite industry is poised to do even more for the U.S. because it has lowered costs, made its technology more convenient, and has strengthened its connectivity offering.

- The satellite industry's new and expanded services include high speed broadband at **100 Mbps**. Satellite broadband is available in all 50 states, providing service to the entire continental U.S. The satellite industry will play an increasing role to deliver broadband connectivity to America's **128 million households** and **6 million businesses**, a total addressable market of **$300 billion** today.
- The satellite industry can **close the Digital Divide** equitably and cost-effectively for some **20 Million Americans** not online today and at no cost to taxpayers. While satellite broadband is competitively priced, some economists suggest that the value of broadband to consumers and society is worth hundreds of thousands of dollars per connection. Moreover,

satellite technologies are the most cost-effective means to connect the remaining half of the world's population that is not online today.

- Many satellite industry segments in the US are expected to grow significantly in the future. Satellite remote sensing is predicted to grow to **$5.7 billion annually by 2022**; satellite broadband to **$4.3 billion in 2028**; maritime connectivity to **$5.3 billion by 2027;** and inflight connectivity to **$5 billion by 2030.** Satellite navigation is another important industry segment. While the sale of navigation chips amounts to a few billion annually, the total market value for downstream applications is in the multiple billions of dollars.
- Satellite technologies are part of the 3GPP standards for **5G**, the fifth-generation telecommunications standard, and the satellite industry is poised to play an integral role in 5G, an industry predicted to generate **$2.2 trillion over the next 15 years**.

The satellite industry is in a technological transformation and is evolving like the internet and mobile industries, serving more users, offering greater capacity, increasing efficiency, and lowering cost.

2.3. Innovation in the satellite industry

The satellite industry has invested heavily in research and development to create the next generation of satellite technologies. The satellite industry is being transformed by thousands of entrepreneurs and startups with Silicon Valley-style ambition and inventiveness. Satellite technologies are increasingly desired by the venture and investor community.

- Nearly **$20 billion** in investment in high throughput satellites (HTS) offering 500 Gigabits of capacity, a 400% increase over earlier satellites. HTS can deliver internet broadband at **100 Mbps** with significantly reduced latency.
- Some **$13 billion** of venture capital has been invested in satellite technology startups, notably Low (LEO) and Medium Earth (MEO) Orbit satellite systems. Many of these startups will be acquired by established players or will go public.
- Satellite technologies are part of the **5G standards** including multi, fixed, mobile, and hybrid cell connectivity; network resilience, edge network delivery, direct to node broadcast, and Internet of Things connectivity.
- By implementing assembly line production, satellite manufacturing has achieved a **drastic increase in speed and quality** with a **drastic reduction in cost.** Notably the new OneWeb facility in Orlando, FL reports producing 150-kilogram satellites per day.
- Satellite design and form factors have been reinvented with improved software, components, and materials. Satellite architectures now

include LEO and MEO satellites, mesh networks, and cubesat constellations.
- Satellite industry innovations are democratizing the market and pioneering new business models, applications, and startups.

The satellite industry's innovations are creating unique and valuable services and capabilities that no other network can match. The capabilities ensure Scalability, Connectivity, Ubiquity, Mobility, Speed, Performance, Reliability, Security, and Resilience.

3. Introduction

3.1. Overview

Satellite technologies are essential to the U.S. economy, technological innovation, national security, and global leadership. Nearly every American already uses satellite technologies, from their smartphone GPS to TV broadcasts transmitted over satellites. Satellite technologies will enable new industries and applications in 5G including enhanced mobile broadband and streaming video; improved connectivity on moving vehicles on land, air, and sea; the enabling of the Internet of Things (IoT) and Machine to Machine (M2M) communications; temporary networks for concerts and sporting events; backhaul services; extension and enhancement of mobile coverage; and emergency communications and disaster recovery.[2] Data analytics from remote sensing technologies are improving agricultural yields, aiding in urban planning and water management, mapping disaster zones, and utilizing change recognition to monitor compliance with international treaties. The satellite industry is poised to revolutionize connectivity and remote sensing data analytics, taking advantages of technological innovations in areas such as mass manufacturing, increases in computational capabilities, and rapidly dropping costs of user terminals. This report outlines the satellite industry's vision and the spectrum requirements necessary to make it possible.

The satellite industry has undergone a massive transformation in its 60-year history, beginning in the 1950s with the U.S. government's space race with the Soviet Union where all satellite functions were highly classified, to the subsequent commercialization of satellite technologies to deliver communications, content, and connectivity worldwide, provide GPS and weather forecasting to the general public, and make available high-resolution satellite imagery of the entire Earth. During this time, satellite architectures have also changed; the commercial industry historically has featured most of its communications satellites in Geosynchronous (GSO) orbit, an orbit 22,236 miles (35,785 km) above Earth where satellites appear stationary relative to any fixed location on Earth and provide coverage of entire continents, while singular remote sensing satellites operated in Low Earth Orbit (LEO) below 1200 miles (1931 km). Today, while high capacity

[2] "Satellite Solutions for 5G." The European Conference of Postal and Telecommunications Administrations. Electronic Communications Committee. 18 May 2018.

communications satellites remain at GSO and large exquisite remote sensing satellites operate individually in LEO, more than 20,000 Non-Geostationary (NGSO) communications satellites of altitudes less than 6000 miles (9656 km) and constellations of up to thousands of satellites have applications either approved or pending at the FCC, and constellations of up to hundreds of remote sensing satellites the size of a lunch tray populate LEO. The impact of these innovations has already been felt across economic sectors, notably transportation, healthcare, energy, manufacturing, agriculture, consumer services finance, and defense/homeland security.

3.2. Spectrum Basics

Data can be delivered over radio spectrum in space just as it is transported over an earthbound cable, fiber or mobile network. The licenses or permissions to use a frequency, also called allocations, can be envisioned as a series of roads of different sizes, for example superhighways, two lane roads, and streets. Some frequency bands are used to transport data over long distances while others are better suited for short hauls. People experience different frequencies when they watch TV, hear the radio, speak on a mobile phone, access WiFi, or stand in the millimeter wave scanner in the airport. Just as there are medians built between the roads, there are “medians” designated between frequency allocations. Called buffers or guard bands, they minimize the interference among different services.

Like other wireless services, satellite technologies use radio spectrum, which is the portion of the electromagnetic spectrum that includes the frequencies from 300 Hertz to 300 GHz. They are a function of two enabling elements of spectrum: (1) propagation, the ability to transmit signals or information; and (2) throughput, how much information is transmitted for the given spectrum. As such, the physical properties of spectrum are important as they relate to the kind of services and applications they can deliver and how well. The International Telecommunications Union (ITU) defines satellite communications as “space radiocommunications: Any radiocommunication involving the use of one or more space stations or the use of one more reflecting satellites or other object in space.”[3]

The satellite industry’s capabilities depend on access to an adequate supply of spectrum and a finite amount of interference. Spectrum is the prerequisite for

[3] International Telecommunications Union. Article I, Section 1, 1.5-1.8. https://life.itu.int/radioclub/rr/art1.pdf

the satellite industry to serve annually 220 million pay TV customers, 34 million satellite radio customers, and over 2 million broadband customers worldwide.[4] Similarly, customers on airplanes and ships no longer consider connectivity while on board an option, but rather it has become an expectation as people travel. Without access to spectrum, these customers and future users will not get the services they demand.

Inadequate spectrum or changes in spectrum allocation can have major consequences for any industry, but it has particularly significant consequences for the satellite industry. Satellite systems have long development paths, are complex, and require considerable time and upfront costs to plan, build and launch. This also applies to upgrades, which must be planned and financed far in advance and must last for many years for the business to be viable. The on-orbit lifespan of a satellite can be upward of fifteen years and new innovations are providing ways to extend this lifespan even further. In addition, once satellites are on orbit the frequencies on which they operate cannot be adjusted. Loss of spectrum on which the satellite is capable of operating can reduce its capacity and impacts the ability to obtain a return on the investment as well as impacting the consumer, public safety and defense customers relying on its capabilities.

3.3. Satellite Industry Segments

The service segment of the satellite industry can be described in a few categories: Communications, which includes television and radio services (the largest segment by revenue and customers) and broadband internet services (large and growing segment) including 5G and in-flight and maritime services; remote sensing; and Global Navigation and Satellite System (GNSS; e.g., the Global Positioning System, GPS) services.

3.3.1. Satellite Communications

Developments in satellite communications parallel the evolution of the mobile industry and the internet industries in their ability to increase customers and capacity at lower unit costs. Over time, wireless technologies have come to complement and may ultimately replace wireline technologies. Just as the mobile phone has supplanted the landline telephone, high speed internet broadband delivered over 4G and 5G networks increasingly substitutes for copper, cable, and fiber networks. High speed and high throughput satellite technologies

[4] Satellite Industry Association and Bryce Space and Technology. 2019 State of the Satellite Industry Report (SSIR 2019). May 2019. https://www.sia.org/ssir_preview/

compliment and compete with 4G and 5G technologies. Increasingly satellite will be the broadband network of choice not only because of its lower cost (an advantage for half of the world's population not online today), but because of its ability to do what no other network can do.

The European Conference of Postal and Telecommunications Administrations (CEPT) observed in its "Satellite Solutions for 5G" report that satellite technologies offer *scalability* because they leverage "across a wide area, multicast capabilities together with local caching in the cloud as close as possible to the end user, significant 'statistical multiplexing benefits' can be gained, leading to a more efficient use of overall bandwidth and more reliable service."[5]

The economic advantages of wireless networks are intuitive; it costs significantly less build a network with towers and receivers rather than dig trenches and lay wires to each premises. Signals can transverse the radio spectrum in infinite directions, but on wireline networks, they can do so only travel two directions. Satellite networks also have the egalitarian feature of *ubiquity*; they are available to anyone anywhere in the same quality. A satellite signal does not degrade because the receiver is on a mountaintop, in a trench, in a forest, on the sea, or in the stratosphere.

Satellite networks enable *mobility*; people and objects can move at 500 miles per hour (804 kph) and still maintain a satellite connection. Because satellite beams can be both broad and specific, satellite technologies enable *connectivity* with a near infinite number of objects on Earth and in space, making it an ideal platform for IoT.

Satellite technologies also have *performance* advantages. Light and radio signals reach users at large distances faster through outer space than across a fiber optic wire. All things being equal, a financier in London can communicate with Los Angeles in 48 milliseconds via a Low Earth Orbit (LEO) mesh network versus over fiber optic network, which takes 96 milliseconds.[6] A satellite network also offers *security* in that the data path can be defined and controlled in advance whereas transmissions over multiple terrestrials networks never take the same path; earthbound networks have to accommodate hops, loops, and exchanges, which also introduce cyber threats and delays. As such, the banking industry will increasingly use Low and Medium Earth Orbit satellites to serve customers

[5] Supra CEPT "Satellite Solutions for 5G."
[6] Varrall, Geoff. *5G and Satellite Spectrum, Standards, and Scale*. Artech House, 2018.

across large geographic areas.[7][8]

While one segment of the satellite industry envisions global broadband connectivity via mesh networks, another segment has reinvented the classic GSO satellite. The new generation of GSOs have cost and scale advantages, using spot beams and frequency reuse to increase capacity more than seventy-five times, and offer an exponential increase in throughput with 100 Mbps download speeds for broadband internet today.

Satellite companies use GSOs for two-way, high throughput communication.[9] Targeted beams are directed to and from fixed locations on Earth (e.g. home or office) and fast-moving terminals and vehicles (airplanes, cruise ships, delivery trucks etc.). A network can include, for example, satellites, uplinks from ground stations, feeder links from ground stations or other satellites in space, and downlinks with Earth Exploration Satellite Services (EESS).

Communications satellites provide *resilience*. Satellite ground terminals are rapidly deployable with quick set-up. Services are available immediately following a major disaster, while cell sites may take months to service, allowing emergency responders to communicate and retail services to return online. Redundancy of satellites and ground stations make satellite services virtually impenetrable to physical attacks.

3.3.2. Remote Sensing

Remote sensing is defined by the U.S. Geological Survey as "the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area."[10] The remote sensing industry has also benefitted from advances in satellite manufacturing capabilities and the exponential increase computational capacity

[7]"First Dedicated Satellite for the Banking Industry - IHS Technology," IHS, August 17, 2016, https://technology.ihs.com/582622/first-dedicated-satellite-for-the-banking-industry.
[8] Guglielmo S. Aglietti, "Satellite Tech Takes Connectivity into New Dimensions," Financial Times, September 10, 2018, https://www.ft.com/content/aac53d86-8101-11e8-af48-190d103e32a4
[9] K_a, short for "K-above" because it is the upper part of the original but now obsolete Cold War NATO K band, which was split into three bands because of rain fade, rendering frequency unusable for long range transmission. K is an abbreviation for "kurz", German for short.
[10] "What is remote sensing and what is it used for", U.S. Geological Survey, https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used?qt-news_science_products=3#qt-news_science_products

afforded by Moore's law. The industry has transformed from 10 ft government-owned satellites with 262 ft resolution in the 1970s Landsat program, to commercial satellites that provide 0.8 ft resolution today and others that image the entire planet at 3 ft resolution daily. While satellites at other wavelengths were previously the purview of only government agencies, the cubesat form factor (satellites constructed of 4"x4"x4" cubes, usually stacked in a 3 unit form) has allowed companies to break into Synthetic Aperture Radar (SAR), GPS radio occultation to provide commercial weather data, and radio frequency (RF) mapping. Each of these services requires reliable communications links to downlink high volumes of data.

This offers important information for the conduct and measurement in many scientific fields including meteorology, climate science, Earth science, and geology. In applications for oceanography, information is collected and processed from millions of sensors and receivers, for example from buoys, gliders, markers, profilers and autonomous underwater vehicles (AUV). Remote sensing is used to map the oceans, facilitate the cleanup of oil spills; monitor animals to reduce poaching, illegal extraction and habitat loss; measure the impact of climate change to forests; study remote terrains and isolated areas such as Antarctica, and so on.

The U.S. is also poised to reap benefits from enhanced satellite imaging/sensing data which will dramatically improve weather forecasting, law enforcement, emergency response, agricultural yields, market forecasts (through techniques such as counting cars in parking lots), monitoring of remote oil and gas facilities, international treaty verification, and more. For example, remote sensing can be used to map forest fires from space, allowing rangers to see a much larger area than from the ground; track clouds to help predict the weather; watch erupting volcanos; watch for dust storms; track the growth of a city versus changes in farmland or forests over several years or even decades, and map the ocean floor (e.g., its mountain ranges, deep canyons, and "magnetic striping").[11] Remote sensing technologies can improve efficiency and yield of fields and crops through management of analytics (temperature, water level, soil, plant diagnostics, etc.) and integration with software systems and dashboards.

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[11] Jon B. Christopherson, Shankar N. Ramaseri Chandra, and Joel Q. Quanbeck, "2019 Joint Agency Commercial Imagery Evaluation—Land Remote Sensing Satellite Compendium," USGS Numbered Series, Circular (Reston, VA: U.S. Geological Survey, 2019), http://pubs.er.usgs.gov/publication/cir1455.

3.3.3. Satellite Navigation

The Global Navigation and Satellite Systems (GNSS), of which the Global Positioning System (GPS) was the first, has played a major role in the creation of downstream applications which impact the lives of nearly everyone in the U.S. With origins in the 1960s, and a predecessor, NAVSTAR, launched from 1974-1985, the first GPS constellation became fully operational in 1995. Initially, signals were degraded for public use through selective availability, a process which was halted in 2000, making GPS ten-times more accurate overnight.[12] The first mobile phone with GPS, Benefon Esc!, was manufactured shortly before this change in 1999, with others quickly following and takin advantage of the enhanced accuracy.[13] While the first commercial receiver, the NAVSTAR Navigator, was launched in 1981, the first handheld receiver, the Magellan Nav 1000, was not created until 1989, and first in-car system was 1995's Guidestar for Oldsmobile 88.[14]

With the promulgation of smartphones for the everyday user in the late 2000s, GPS found itself not just in the hands of select car users, but nearly the entire country who relies on services such as Google Maps for navigation. With the growth in smartphone apps came apps completely dependent on this space-based service, such as Uber and Lyft, or those to whom location plays a central role such as Tinder and Yelp.

The GNSS market is broad with applications for navigation; mapping and surveying, and variety of other uses including location-based services, precision timing, precision-guided weapons, emergency services, aviation, transportation, weather prediction, photographic geocoding, skydiving, wreck diving, and social networking. It is difficult to estimate the entire downstream revenue. One study suggests that GNSS. The sale of GNSS chips alone totals some $4 billion globally and is growing at CAGR 7 percent.[15] However, this figure does not

[12] Sullivan, Mark, "A brief history of GPS", PC World, 9 Aug 2012, https://www.pcworld.com/article/2000276/a-brief-history-of-gps.html

[13] Sullivan, Mark, "A brief history of GPS", PC World, 9 Aug 2012, https://www.pcworld.com/article/2000276/a-brief-history-of-gps.html

[14] "The Evolution of Portable GPS", Ohio University, https://onlinemasters.ohio.edu/blog/the-evolution-of-portable-gps/

[15] Global Reports Store. "GNSS Chip Market By Receiver (Global Positioning System (GPS), Beidou Navigation Satellite System, Global Navigation Satellite System (GloNASS) ,Galileo) By Implementation Type (Road Construction,Railways, Agriculture) - Global size Analysis and Industry Forecast, 2018-2025." October 23, 2018.https://www.globalreportsstore.com/report/gnss-chip-market-by-receiver-global-positioning-system-gps-beidou-navigation-satellite-system-global-

capture the service revenue delivered on hundreds of applications.

navigation-satellite-system-glonass-galileo-by-implementation-type-road-constructionrail-ways-agriculture-global-size-analysis-and-industry-forecast-2018-20

4. Satellite revenue is $277B today, on route to a $1T space economy

The global satellite industry reached $277B in 2018, out of a total $360B space economy, growing at 3 percent annually. The U.S. comprised 43 percent of the total, or $118B, and grew 25 percent faster than the rest of the world.[16] The space industry is one of the top 20 industries by revenue in the U.S.[17]

Satellite industry revenue includes satellite services, satellite manufacturing, satellite launch, and ground equipment. While the satellite industry is expected to deliver stable revenue in video distribution and consumer services, the industry will continue to innovate, invest, and grow in emerging areas such as high speed broadband for homes and businesses (competing head on with terrestrial providers); 5G related services; inflight and maritime connectivity; remote sensing, and internet backhaul.

Satellite services provide $126.5B in worldwide revenue, of which $124.4B is communications. These revenues cannot be compared to the terrestrial broadband industry directly as a large part of satellite services are offered on a wholesale basis. Resellers offer it as value added services or bundle it with other services. Satellite services revenue also excludes downstream revenue from an increasingly large market of geospatial analytics and GNSS-based applications. Euroconsult estimates the combination of satellite remote sensing data and value added services to have reached $4.6B in 2017 (of which $3.2B is value-added), with forecasts reaching $5.7B by 2027 (6% CAGR).[18] The increasing use of remote sensing services in defense and commercial applications are significant factors driving the growth of the remote sensing services market. Furthermore, the growth of Big Data analytics in remote sensing, cloud computing, Artificial Intelligence (AI), IoT, and wireless/broadband access are anticipated to fuel the demand for remote sensing services. Petabytes of data are being collected daily, overhauling a system where analysts used to scour each image

[16] Satellite Industry Association and Bryce Space and Technology. 2019 State of the Satellite Industry Report (SSIR 2019). May 2019. https://www.sia.org/ssir_preview/
[17] "Aerospace Industry Spotlight | SelectUSA.Gov," accessed June 27, 2019, https://www.selectusa.gov/aerospace-industry-united-states.
[18] Sima Fishman, "Earth Observation: State of Play and Future Prospects", Euroconsult USA, Advisory Committee on Commercial Remote Sensing (ACCRES) Meeting, 18 October 2018

individually. Instead, remote sensing is moving toward a future where decision-making is automated, or at least simplified, by using change detection algorithms, and this data feeds directly into other tools (e.g., resource management software).[19]

The National Institute of Standards And Technology (NIST), estimates that GPS has generated $1.7T in economic benefits since its beginnings in the 1980s, with huge impact to telecommunications ($6856B), telematics ($325B), location-based services ($215B), surveying ($48B), oil and gas ($46B), electricity ($16B), mining ($12B), and agriculture ($6B), with 90% of benefits having accrued since 2010. They estimate that a loss of GPS would have a $1B per day impact, with potential to be 50% larger if during the April/May planting seasons.[20]

Satellite industry jobs are in high demand, especially jobs for satellite software engineers which are growing at a rate of 40 percent year over year.[21] This job's median wage of $83,640 is almost twice the national median wage of $44,644. Already the satellite industry employs some 217,000 people, including 72,000 in the design and development of next generation satellite technology, 73,000 in the satellite services industry, 55,000 in satellite launches, and more than 18,000 in domestic manufacture of satellite ground equipment.[22]

The importance of space to the future of the U.S. can be encapsulated in the relaunched National Space Strategy, which revived the National Space Council after 24 years, and incorporates the national security, commercial, and civil priorities for America in space. The Strategy recognizes the importance of protecting America's assets in space, including access, infrastructure, and astronauts, and acknowledges that the commercial industry will play a key role in U.S. advancement in space[23]

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[19] GEOBUIZ 2018 Edition, Geospatial Media and Communications, 2018

[20] O'Connor, A.C., Gallaher, M.P., Clark-Sutton, K., Lapidus, D., Oliver, Z.T., Scott, T.J., Wood, D.W., Gonzalez, M.A., Brown, E.G., and Fletcher, J. 2019, June. Economic Benefits of the Global Positioning System (GPS). RTI Report Number 0215471. Sponsored by the National Institute of Standards and Technology. Research Triangle Park, NC: RTI International.

[21] "Satellite Telecommunications - May 2016 OES Industry-Specific Occupational Employment and Wage Estimates," United States Department of Labor, accessed June 27, 2019, https://www.bls.gov/oes/2016/may/naics4_517400.htm.

[22] SSIR 2019

[23] "President Donald J. Trump Is Unveiling an America First National Space Strategy," The White House, accessed June 21, 2019, https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/

Secretary Ross and the Department of Commerce "truly believe that today's four-hundred-billion-dollar global space economy will quickly grow to one-trillion dollars, and perhaps to three-trillion dollars by 2040," noting a series of converging innovations have improved the technical, commercial, and regulatory conditions for satellite technologies, that have created a paradigm shift in the industry.[24] Director of the Office of Space Commerce, Kevin O'Connell, notes that disruptive innovation is going to be the driver of this growth in the change of traditional business models, such as remote sensing verticals beyond defense, including mapping, agriculture, and insurance, as well as new services including satellite servicing, space debris removal, and additive manufacturing.[25]

4.1. Creating the Trillion Dollar Space Economy: Technological Innovations

4.1.1. Increased Throughput

The insatiable demand for data from consumer and enterprise has driven major investment and innovation to enhance the throughput of satellite technologies. Some 80 percent of internet traffic is video, and Americans consume more internet data per capita than any nation.[26] By increasing and duplicating spot beam technology, High Throughput Satellites (HTS) can achieve 400 percent more throughput than earlier Fixed Satellite Service (FSS). Some 30 satellite operators have committed some $19 billion to HTS.[27] This transformation essentially reboots the satellite network's capability and reinvents the broadcast and broadband business with capabilities for massive multicasting (e.g. video, HD/UHD TV, as well as other non-video data) as well as unicasting to millions of end user devices and applications.

Consider how this kind of innovation transformed other networks. The DOCSIS

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[24] Remarks by U.S. Commerce Secretary Wilbur L. Ross at the Advisory Committee On Commercial Remote Sensing, 4 June 2019, https://www.commerce.gov/news/speeches/2019/06/remarks-us-commerce-secretary-wilbur-l-ross-advisory-committee-commercial

[25] Kevin O'Connell, "Remarks on the Trillion Dollar Space Economy", 27 November 2018, https://www.space.commerce.gov/remarks-on-the-trillion-dollar-space-economy/

[26] Complete Visual Networking Index (VNI) Forecast (2017-2022). https://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

[27] Research and Markets. "Global High Throughput Satellites Vertical Market Analysis & Forecasts 2017-2025." July 24, 2017. https://www.globenewswire.com/news-release/2017/07/24/1056037/0/en/Global-High-Throughput-Satellites-Vertical-Market-Analysis-Forecasts-2017-2025.html

1.0 innovation allowed cable operators to increase speeds 10-fold, from 4 Mbps to 40 Mbps. The innovation of digital subscriber line (DSL) signal processing meant that a telephone company could offer a new business line—broadband access--in addition to telephony. Speeds increased from 0.056 Mbps to 10 Mbps, a 180-fold improvement. The satellite industry is poised to reap the gains of even greater throughput performance.

The exponential increase in HTS has been achieved by optimizing spectrum in every possible way in order to obtain the maximum bandwidth.[28] HTS achieve greater capacity through the implementation of multiple spot beam technology, greatly increasing the total number of beams deployed. HTS utilize a design like that used by the cellular industry in which spot beams are separated from one another by a combination of frequency and polarization. This technology enables service to a larger number of users while driving a significant drop in cost per megabyte. Solid-state power amplifiers, more sensitive receivers, and reconfigurable phased array antennas also improve transmission.[29]

A single HTS today has significantly more capacity than earlier versions. Each Viasat-3 satellite, launching in 2022, will have 1 Tbps capacity, more than 8 times the capacity of the current Viasat fleet,[30] and EchoStar XXIV will launch in 2021 with 500 Gbps capacity;[31] both will have 100Mbps download speeds. Constellations of NGSO satellites will add additional capacity; SES's second generation medium-Earth-orbit NGSO constellation, mPOWER, which is expected have 10 Tbps of capacity alone –is roughly 10x the total industry capacity a few years ago.[32] The combination of satellites' improved throughput along with an increase in the number of ground stations and satellites in orbit allows the satellite industry to participate substantially in 5G.

Along with the increased throughput is the processing and storage capability

[28] Tim Gallen, "Emerging Trends in Satellite Communications: High Throughput Satellites in LEO, MEO, and GEO," www.mwee.com, February 22, 2018, https://www.mwee.com/design-center/emerging-trends-satellite-communications-high-throughput-satellites-leo-meo-and-geo.
[29] Ibid
[30] "High-Capacity Satellite System", Viasat, https://www.viasat.com/products/high-capacity-satellites
[31]Xplornet and Hughes Announce Agreement for EchoStar XXIV Satellite Capacity to Deliver High-Speed Broadband to Rural Canada", Hughes, 22 April 2019 https://www.hughes.com/resources/press-releases/xplornet-and-hughes-announce-agreement-echostar-xxiv-satellite-capacity
[32] 03B Mpower. SES.COM https://www.ses.com/networks/networks-and-platforms/o3b-mpower. Accessed June 21, 2019.

that allow satellites to deliver content and store it closer to the end user, thereby saving network resources.[33]

4.1.2. 5G Integration

Users of 5G networks will expect access anywhere and anytime with high quality. To make this possible, 5G network providers will need to integrate a range of technologies to ensure seamless access, coverage, and quality. In practice 5G networks will not be merely infrastructure deployed by mobile operators, but also operators of fixed, terrestrial and satellite networks. Each technology will play a special role, but the service will be integrated so that the user experience is seamless. In this way, 5G will be a true “network of networks” or “system of systems” described in Recommendation ITU-R M.2083 on the IMT2020 Vision.[34] 5G is an access technology which sits on top of different networks using licensed, unlicensed, and shared spectrum. For example, fiber networks will extend their reach by using 5G. Moreover, 5G improves upon other terrestrial network technologies with increased speed, lowered latency, improved security, and increased capacity.

Satellite technologies will have a key role in 5G and is part of the 5G standard defined by the the 3rd Generation Partnership Project (3GPP), the international organization which develops the standards for mobile wireless communications.[35] The 3GPP notes many areas in which satellite communications are equal substitutes for 5G terrestrial networks, for example in isolated/remote areas and with aircrafts or vessels that cannot be covered by terrestrial 5G networks. Satellites can also reinforce the 5G service reliability by providing service continuity for M2M/IoT devices or for passengers on board moving platforms (e.g., passenger vehicles-aircraft, ships, high speed trains, and busses) and ensuring service availability anywhere especially for critical communications, such as railways, maritime activities, aeronautical communications, and so on. Satellites also enables 5G network scalability by providing efficient multicast/broadcast resources for data delivery towards the network edges or even user terminals.

Satellite technologies will play an increasing vital role in the backhaul portion of

[33] “Study on NR to Support Non-Terrestrial Networks,” 3GPP, accessed June 19, 2019, https://portal.3gpp.org/ngppapp/CreateTdoc.aspx?mode=view&contributionUid=RP-181393.

[34] “M.2083 : IMT Vision - "Framework and overall objectives of the future development of IMT for 2020 and beyond." International Telecommunications Union. Approved September 2015. https://www.itu.int/rec/R-REC-M.2083

[35] 3rd Generation Partnership Project (3GPP), “Release 16,” accessed June 18, 2019, https://www.3gpp.org/release-16.

the network, which comprises the intermediate links between the core network, or backbone network, and the small subnetworks at the edge of the network. So-called backhauling or tower feeding refers to high bit-rate connectivity with individual 5G cells and the ability to multicast the same content.[36] Satellite technologies will also deliver aggregated IoT traffic to multiple sites.

5G realizes the so-called low and ultra-low latency applications (remote surgery, high frequency financial trading, etc.) because the computing power is brought away from a central server in the core of the network, to the edge closer to end user. Traffic does not need to travel from the end user to a server, but instead is processed “locally,” thus maintain speed. The backhaul portion thus pushes updates when needed to the edge of the network.

A role for Non-Terrestrial Network components (aka satellite) in the 5G system is defined for the following verticals: transport, public safety, media and entertainment, eHealth, energy, agriculture, finance, and automotive. Following are some the specific satellite use cases define in the 5G standards for Release 16.

Multi connectivity: Users in underserved areas (home, small offices, big events, and ad-hoc facilities) are connected to the 5G network via multiple network technologies and benefit from speeds of 50 Mbps or greater. Delay sensitive traffic may be routed over short latency links while less delay sensitive traffic can be routed over the long latency links.[37]

Fixed cell connectivity: Users in isolated villages or industry premises (mining and offshore platforms) access 5G services and benefit from 50 Mbps+.

Mobile cell connectivity: Passengers on board vessels or aircrafts access 5G services and benefit from 50 Mbps+.

Network resilience: Some critical network links requires high availability which can be achieved through the aggregation of two or several network connections in parallel. The intent is to prevent complete network connection outage.

Trunking: Trunking is a method for a system to provide network access to many clients by sharing a set of lines or frequencies instead of providing them individually. This is analogous to the structure of a tree with one trunk and many

[36] Supra CEPT “Satellite Solutions for 5G.”
[37] “Study on NR to Support Non-Terrestrial Networks.”, The 3rd Generation Partnership Project. June 15, 2018.
https://portal.3gpp.org/ngppapp/CreateTdoc.aspx?mode=view&contributionUid=RP-181393

branches. Trunking is used to deliver high bit-rate video, IoT and other data to a central site. A network operator will also use trunking to deploy or restore 5G service in an isolated area (not connected to public data network), for example for disaster relief. A network operator may want to interconnect various 5G local access network islands not otherwise connected.

Edge network delivery: Media and entertainment content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, and Mobile Edge Computing's Virtual Network Function updates are transmitted in multicast mode to a RAN equipment at the network edge where it may be stored in a local cache or further distributed to the user's equipment. The intent is to off load popular content from the mobile network infrastructure especially at the backhaul level.

Mobile cell hybrid connectivity: Passengers on board public transport vehicles (e.g. high speed/regular trains, buses, and river boats) access reliable 5G services. They are served by a base station which is connected by a hybrid cellular/satellite connection. The cellular connectivity may be intermittent and/or support limited user throughput.

Direct To Node broadcast: TV or multimedia service delivery to home premises or on board a moving platform.

Wide area IoT service: Global continuity of service for telematic applications based on a group of sensors/actuators (IoT devices and/or batteries activated or not) scattered over or moving around a wide area and reporting information to or controlled by a central server.

These sensors and/or actuators may be used for the following telematics applications:

Automotive and Transport

- High density platooning
- High definition map updates
- Traffic flow optimization
- Vehicle software updates
- Automotive diagnostic reporting
- User base insurance information (e.g. speed limit and driving behavior)
- Safety status reporting (e.g. air-bag deployment reporting)
- Advertising based revenue
- Context awareness information (e.g. neighboring bargain opportunities based on revenue)
- Remote access functions (e.g. remote door unlocking).

Transport
- Fleet management
- Asset tracking
- Digital signage
- Remote road alerts
- Container tracking
- Tracking devices

Agriculture
- Livestock monitoring
- Environmental sensing
- Farm monitoring

Energy
- Critical surveillance of oil/gas infrastructures (e.g. pipeline status)
- Smart grid infrastructure
- Renewables monitoring
- Water monitoring

Local area IoT service: Group of sensors that collect local information, connect to each other and report to a central point. The central point may also command a set of actuators to take local actions such as on-off activities or far more complex actions. The sensors/actuators served by a local area network may be in a smart grid sub-system (advanced metering) or on board a moving platform (e.g. container on board a vessel, a truck or a train).

Direct to mobile broadcast: Public safety authorities want to be able to instantaneously alert/warn the public (or specific subsets thereof) of catastrophic events and provide guidance to them during the disaster relief while the terrestrial network might be down.

Automotive industry players want to provide instantaneous Firmware/Software Over The Air services (FOTA/SOTA) to their customers wherever they are. This will include information updates such as map information including points of interest (POI), real-time traffic, weather, and early warning broadcasts (e.g. floods, earthquakes and other extreme weather situations, as well as terror attacks), parking availability, infotainment, etc.

Media and entertainment industry can provide entertainment services in vehicles (cars, buses, and trucks).

Wide area public safety: Emergency responders, such as police, fire brigade and medical personnel can exchange messaging and voice services in outdoor conditions anywhere they are and achieve continuity of service in multiple mobility scenarios.

Local area public safety: Emergency responders, such as police, fire brigade, and medical personnel can set up a tactical cell wherever they need to operate. This cell can be connected to the 5G system via satellite to exchange data, voice and video-based services between the public safety users within a tactical cell or with the remote coordination center.

According to Ericsson, half of the world's population will have access to 5G by 2025.[38] 5G networks are projected carry a quarter of all global mobile data traffic by 2025, some 136 exabytes per month, a quintupling of traffic from today. North America has the highest monthly usage per smartphone, reaching 8.6GB at the end of this year.

The move to 5G will be an evolution; the same network elements can offer a blend of 4G and 5G services. Satellite technologies are already in play for direct to consumer services. Additionally, satellite enables 5G and broadband backhaul, the intermediate links between the network core or backbone and subnetworks at the *edge* of the network. Broadband companies contract with satellite providers to transport packets to and from that backbone network. With 5G, the level of this traffic will increase exponentially.[39]

4.1.3. Dramatic cost reduction in building and launching satellites

In the past, satellites were manufactured in clean rooms with white-coated lab technicians. Today however, the satellite industry has implemented smart, robot-enabled assembly line technologies to construct satellites faster, less expensively, and with greater precision and incorporation with high-tech elements. One such facility was opened by Airbus and OneWeb on Florida’s Space Coast in 2019 and produces two 150-kilogram satellites per day.[40] Meanwhile, the satellite imaging and analytics company Planet manufactures its 3 unit 5.2 kg LEO satellites in downtown San Francisco.[41]

The satellite industry has realized significant cost reduction in the construction of satellites and network components including transceivers, panels, dishes, platforms and so on. This is achieved through a combination of improved manufacturing, 3D printing, and enhanced materials, but also streamlined design

[38] “Mobile data growth outlook”. Ericsson. Accessed June 21, 2019. https://www.ericsson.com/en/mobility-report/reports/november-2018/mobile-data-traffic-growth-outlook
[39] Michail Katsigiannis, “A Demand Model for Mobile Data Traffic in the 5G Era: Case of Finland,” 2018, https://doi.org/10.4018/978-1-5225-5323-6.
[40] Sandra Erwin. “With a new satellite factory in the U.S., Airbus eyes opportunities in military space.” Space News. July 6, 2018 https://spacenews.com/with-a-new-satellite-factory-in-the-u-s-airbus-eyes-opportunities-in-military-space/
[41] Anna Escher, “Inside Planet Labs’ new satellite manufacturing site.” TechCrunch. November 2018. https://techcrunch.com/2018/09/14/inside-planet-labs-new-satellite-manufacturing-site/

which uses modular, standardized components. Similarly, the cost to launch satellites has also been reduced through process and component innovation and greater fuel efficiency.

To put the change into perspective, consider that an earlier Space Shuttle launch cost $1.5 billion in the 1980s, with payload cost of $54,500/kg, whereas today's SpaceX's Falcon 9 is $62 million, or $2720/kg, reducing the cost to LEO by a factor of 20. [42] This development can both improve the satellite industry's profitability and make resources available for other activities. Notably these lowered costs have also facilitated the market entry of new players and development of different network architectures. The continued learning from commercial satellite launch impacts the space industry, military space, NASA, and human flight.[43]

Satellites have also benefitted from Moore's law, enabling the miniaturization of satellites and the "CubeSat", a miniature satellite in multiples of 10 cm × 10 cm × 11.35 cm (~ 4 in × 4 in × 4.5 in) cubic units, weighing 1.33 kilograms (2.9 lb) per unit, made of commercial off the shelf components.[44] There are over 580 nanonsatellites (satellites <10 kg, of which Cubesat is the most common form factor), in orbit as of June 2019.[45] The satellite market has changed significantly with angel, venture, and other private investments, and startup companies are becoming increasingly important to the industry, as well as the partnership of commercial ventures with established government and military actors.[46] [47]

Just as the falling cost of the mobile phone from $10,000 to $20 (while increasing in quality) made the device available to everyone, the drastically reduced costs of launch and manufacturing in the satellite industry have had a similar effect; even an elementary school has launched a satellite into space.

Historically, like other network industries, the satellite industry was dominated by a few large players aligned closely with the national defense establishment

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[42] Harry W. Jones. "The Recent Large Reduction in Space Launch Cost." 48th International Conference on Environmental Systems. ICES-2018-81. 8-12 July 2018, Albuquerque, New Mexico.
[43] "The New Rockets Racing to Make Space Affordable," accessed June 20, 2019, https://www.bloomberg.com/graphics/2018-rocket-cost/.
[44] CubeSat Design Specification Rev.13The CubeSat Program, Cal Poly SLO. https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/56e9b62337013b6c063a655a/1458157095454/cds_rev13_final2.pdf
[45] Erik Kulu. "Nanosats Database". Accessed June 27, 2019 https://www.nanosats.eu/
[46] Supra Goldman Sachs.
[47] Bryce Space and Technology. Startup Space Report 2019. https://brycetech.com/reports.html

and space authorities such as the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). While those partnerships are still important and increasingly enjoyed by startup players, the innovation in satellite technologies has largely opened and "democratized" market entry, such that individual researchers, scientists, and entrepreneurs can leverage existing rockets to launch their satellites.

Within the past three years, over 100 new satellite/space start-ups have emerged across various segments. At the beginning of 2019, there were some 2100 satellites in orbit. Applications for over 20,000 satellites have been filed at the FCC for Non-Geostationary-Satellite Orbit (NGSO) satellite constellations in just the past few years. The explosive development means that the satellite industry needs to procure new spectrum and optimize existing spectrum.

While the GEO type of satellite network benefits from large area coverage and high capacity, it gives rise to use cases for other types of satellites, networks, and constellations in lower orbits, the so-called Medium Earth Orbit (MEO) and Low Earth Orbit (LEO) satellites. Just as on Earth as in space, there is no one perfect network for everything, and satellite networks evolve to meet different demands. Many of these networks are called "cell satellites" because they have a similar architecture and topology to terrestrial cellular networks.[48]

NGSO satellites come as low as several hundred kilometers above the Earth, minimizing latency due to their close proximity to Earth. One of the deployed NGSO projects is the O3b system, which offers 192 Gbps total throughput, up to 1.6 Gbps throughput per beam and low latency of <150 milliseconds, providing fiber-like speed for services.[49] This kind of speed and low latency means that 5G can perform on satellite as on terrestrial 5G networks.

In addition to satellites in space, user devices, and Earth-based sensors, satellite systems include ground components such as mission control operations centers to manage the spacecraft, ground stations to distribute the payload data and communicate the remote measurements or telemetry, remote terminals with support staff and equipment, and facilities to test, integrate, and launch. These ground components can also be a connected network used by different parties

[48] "5G and Satellite – It's Complicated – Space IT Bridge," accessed June 28, 2019, https://www.spaceitbridge.com/5g-and-satellite-its-complicated.htm.
[49] "7 Reasons Why Satellite Broadband Will Connect the Unconnected," *ICTworks* (blog), March 1, 2018, https://www.ictworks.org/7-reasons-satellite-broadband-will-connect-unconnected/.

in different geographies and managing multiple satellites.

The ground station equipment market is expected to grow by a compound average growth rate of more than 6% during the period 2019-2023.[50] Ground network control centers communicate with satellites to manage the observation process. The ground component has also been improved to be portable to different and remote locations and thus minimize upfront costs.

4.1.4. Increased satellite flexibility via software-defined components

Software-defined networking (SDN) technology is an approach to network management that enables dynamic, programmatically efficient network configuration in order to improve network performance and monitoring making it more like cloud computing than traditional network management. SDN is being applied to the architecture of satellite networks. Benefits include easier management of network components, reduced complexity, lowered cost, and improved resource allocation and network performance.[51]

4.1.5. Optical Communications

Optical is the next frequency domain of what were traditionally radio communications satellites. Optical communications payloads are substantially less mass and power than RF payloads, and are substantially higher bandwidth—currently mutli-Gbps speeds whereas cutting edge RF technology is at 100 Mbps.[52] NSR estimates this market will produce $4B in revenue by 2028, with 96% of this demand driven by inter-satellite links for megaconstellations. The satellite remote sensing market can also greatly benefit from this technology, as downlink speeds are a bottleneck.[53]

4.1.6. Advanced analytics

Analytics is the discovery, interpretation, and communication of meaningful patterns in data; and the process of applying those patterns towards effective decision making. Organizations use analytics to describe, predict, and improve

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[50] "Global Satellite Ground Station Equipment Market 2019-2023," Technavio, July 2019, https://www.technavio.com/report/global-satellite-ground-station-equipment-market-industry-analysis.

[51] Ye Miao et al. "Software Defined Integrated Satellite Terrestrial Network: A Survey." Springer Nature Singapore Pte Ltd. 2017. https://pdfs.semanticscholar.org/db82/ce600831a1c696715e5e4fd468dce1be4989.pdf

[52] "Optical Satellite Communications: The Future Is Bright", Space Angels, 9 October 2017, https://www.spaceangels.com/post/optical-satellite-communications-the-future-is-bright

[53] Shivaprakash Muruganandham, "When Will Optical Satcom See The Light?" 8 May 2019, https://www.nsr.com/when-will-optical-satcom-see-the-light/

performance. There are many applications in the satellite domain because of the size and scale of the data collected, and there are special analytics platforms that interface with satellite technologies. The analytics platforms are integrated with the constantly updated satellite information to perform large-scale image processing and extract industry-specific insights.[54] The solutions can be tailored to the enterprise. When it comes to the Internet of Things (IoT), it is not just about connectivity for 20 billion or more connected objects, managing the data flow, and collecting vast amounts of information. It is also about capturing the value of the data and performing analysis on the data to produce value.

The remote sensing industry has found value lies in downstream analytics. Euroconsult estimated that 70% of satellite remote sensing revenue in 2017 was from value added services, a number that will surely increase as technology improves.[55] Already, analytics from the industry have transformed entire sectors such as agriculture and retail, providing larger profit margins through predictive analytics.

In data collection, challenges can be scalability, the threat of single point or system failure, time stamping, and securing transactions. Blockchain, a sequential distributed database found in cryptocurrencies derived from bitcoin (a virtual currency), enables peer-to-peer contractual behavior without a third party to "certify" the transaction.[56] Firms with unmanned sites and offshore platforms use satellites to provide connectivity for facility monitoring and instantaneous management. Examples include transcontinental voyagers, pipelines across deserts, oil drilling stations somewhere in the sea, and fiber-optic cables connecting the continents.[57] Firms will use blockchain technologies and analytics platforms that interface and are embedded in the satellite network in order to manage these systems.

NASA and ESA already have blockchain projects underway.[58] With $101 million

[54] "Airbus and Orbital Insight Partner on The OneAtlas Platform to Build World-Class Geospatial Analytics," Airbus, accessed June 28, 2019, https://www.airbus.com/newsroom/press-releases/en/2018/09/airbus-and-orbital-insight-partner-on-the-oneatlas-platform-to-b.html
[55] Euroconsult, 2019
[56] CoinBundle Team, "Blockchain & Internet of Things (IoT) - CoinBundle," Medium, December 27, 2018, https://medium.com/coinbundle/blockchain-internet-of-things-iot-be58703617c9
[57] "How Satellite Communication Is Enabling Global Coverage for IoT," *IoT Tech Expo* (blog), June 26, 2017, https://www.iottechexpo.com/2017/06/iot/how-satellite-communication-is-enabling-global-coverage-for-iot/.
[58] "Blockchain and Space: The Companies," *SpaceQ* (blog), May 13, 2019,

raised in venture capital, the Blockstream Satellite Network is streaming blockchain transmissions from five satellites strategically positioned in orbit around Earth to reach all major land masses.[59]

4.2. Creating the Trillion Dollar Space Economy: Impact on Major Economic Sectors

Satellite technologies impact almost every major economic sector in the United States, driving communications, data analytics and process management, and position, navigation and timing (PNT) services. This section outlines the impact of satellite technologies to major North American Industry Classification System (NAICS) sectors.

4.2.1. Information

Satellite communications networks offer many technical capabilities which taken together make them unique if not superior to terrestrial networks.[60] Satellites technologies *complement* terrestrial technologies through interconnection and backhaul for copper, cable, mobile, and fiber networks.[61] Satellite technologies increasingly *compete* with terrestrial networks. Satellite technologies can *create* entirely new services and capabilities for society. Satellites are largely powered by solar energy and have limited energy and maintenance costs. They can last 15 years with minimal maintenance costs. **Satellite technology do what no other networks can do.**

Connectivity—Satellite networks link people, things, and places together on Earth and in space so that they can convey information in mutually understood formats in multiple directions.

Ubiquity—Satellite networks are available to everyone in their footprint in the same quality.[62] This brings superior connectivity because satellite can reach

https://spaceq.ca/blockchain-and-space-the-companies/.

[59] Michael del Castillo, "Who Needs Verizon? Blockstream Broadcasts Entire Bitcoin Blockchain From Space," Forbes, December 17, 2018, https://www.forbes.com/sites/michaeldelcastillo/2018/12/17/who-needs-verizon-blockstream-broadcasts-entire-bitcoin-blockchain-from-space/.

[60] Daniel J. Bem, Tadeusz W. Wieckowski, and Ryszard Zielinski, "Broadband Satellite Systems," Communications Surveys & Tutorials, IEEE 3 (January 1, 2000): 2–15, https://doi.org/10.1109/COMST.2000.5340721.

[61] Admin, "Backbone Networks Analysis," Fiber Optic Solutions (blog), July 1, 2016, http://www.fiber-optic-solutions.com/analysis-backbone-networks.html.

[62] Supra reference "7 Reasons Why Satellite Broadband Will Connect the Unconnected."

places where other networks can't.[63] Ubiquity is both a technical and economic concept. Beams can be directed to any location on Earth with equal strength,[64] and assuming the same receiver, this capability means that the cost to deliver to any location on the Earth is the same within the same network.

Mobility— Satellite networks enable work on the go. This means that a satellite connection can be maintained with fast moving objects (e.g. airplanes flying at 500 knots or even Mach speeds) while maintaining high quality and throughput. This technology is used by airlines, cruise lines, trains, buses, trucks, and any other fleet of moving vessels.

Performance—Satellite networks have been engineered to improve quality and speed relative to that deployed just a few years ago and now achieve speeds of 100 Mbps or higher.[65] One innovation has been to develop smaller, lighter satellites which can orbit the Earth in closer proximity to Earth so that distance to transmit signals is shortened..[66]

Historically, satellite networks have been described as having high latency, the length of time that data travels between its source and destination measured in milliseconds. For some applications such as email, it is not noticeable to users that a message has a few milliseconds delay, but it is for videogames and videocalls.Non-geostationary satellite systems have reduced latency, so it is comparable to fixed internet technologies such as cable and fiber optics. [67]

Security—Satellite networks offer end to end control. A path to the destination can be defined in advance and repeated around the Earth and through space. In terrestrial communications, the path of travel is not necessarily known in advance and may never repeated. Earthbound communications are a mishmash of

[63] Nathan Hurst, "Why Satellite Internet Is the New Space Race," PCMag UK, July 30, 2018, https://uk.pcmag.com/features/116630/why-satellite-internet-is-the-new-space-race.
[64] "Satbeams - World Of Satellites at Your Fingertips," Satbeams Web and Mobile, accessed June 18, 2019, http://www.satbeams.com/.
[65] "Viasat Announces Highest-Speed, Unlimited Satellite Internet Service - Nationwide | Viasat," accessed June 18, 2019, https://www.viasat.com/news/viasat-announces-highest-speed-unlimited-satellite-internet-service-nationwide.
[66] *"IADC Space Debris Mitigation Guidelines"*. INTER-AGENCY SPACE DEBRIS COORDINATION COMMITTEE: Issued by Steering Group and Working Group 4. September 2007. Region A, Low Earth Orbit (or LEO) Region – spherical region that extends from the Earth's surface up to an altitude (Z) of 2,000 km
[67] Doug Mohney, "Big Promise of LEO Satellite Broadband Will Require Big Bucks – Space IT Bridge," accessed June 18, 2019, https://www.spaceitbridge.com/big-promise-of-leo-satellite-broadband-will-require-big-bucks.htm.

different networks, hops, switches, exchanges, and so on. As such there are many variables with can impact transmission.

While the concept is not necessarily limited to mesh networks, a key value proposition is speed bundled with control and security, essential characteristics for certain financial functions and autonomous transport. Mesh networks are suggested to cut time in half communications traversing the earth.

Indeed in 2018 a Chinese-European team performed the first intercontinental quantum key distribution by relaying signals between multiple ground stations located in China and Austria, a method perceived as more secure than the traditional public key cryptography.[68]

Reliability—Satellite networks have a feature in that they are always on, especially when other networks are down, whether because of weather, disasters, emergencies, or accidents. As such, satellite networks are essential for the military and first responders. Reliability is also desired by industries with mission critical functions such as financial technology which perform real time trades.

Portability—Satellite networks can be set up quickly in new locations. When a mobile cell tower is down, a wire is cut, or the power is out, satellite networks can start up immediately.

These advantages are seen across satellite communications sectors:

4.2.1.1. Pay TV and Radio Broadcast

The satellite-based broadcast market has developed significantly over the years since the first home satellite TV receiver was advertised for $36,500 in the 1979 Neiman-Marcus Christmas catalogue.[69] Today almost all video programming is carried over satellite systems. Satellite operators have vastly increased the efficiency of spectrum, processing, and storage to improve the quality of satellite services to a level comparable, if not superior, to copper, cable, mobile, and fiber networks.

By the end of 2018, some 35 million U.S. households subscribed to satellite

[68] Tomasz Nowakowski. "China's 'Micius' satellite demonstrates intercontinental quantum key distribution for the first time." Space Flight Insider. January 22, 2018. https://www.spaceflightinsider.com/organizations/china-national-space-administration/chinas-micius-satellite-demonstrates-intercontinental-quantum-key-distribution-first-time/
[69] Howard F. Didsbury, 21st Century Opportunities and Challenges: An Age of Destruction Or an Age of Transformation (World Future Society, 2003).

television.[70] Overall, there are over 74 million pay TV customers out of 119 million total (free and paid) TV customers in the United States. [71] . Satellite TV customers receive over 400 channels and many channels provide Ultra High Definition or HD/4K audio and visual quality.[72]

SiriusXM launched service as separate companies XM Radio and Sirius in 2001, merging in 2008. Today SiriusXM offers 150 radio channels to 34 million customers, delivering over $6 billion annually in revenue in 2018.[73]

4.2.1.2. Broadband Internet Services

Broadband or high-speed internet is a crucial input to the information economy. Despite billions of dollars spent annually on broadband subsidy programs from a dozen federal agencies, 21.3 million Americans still did not subscribe to broadband technology that meets the FCC's definition of broadband 25 Mbps download/3 Mbps upload at the end of 2017.[74] Ten percent of American adults do not use the Internet at all, with one-fifth of this group citing cost as the reason.[75]

Satellite broadband is available across entire the continental United States, with no difference in service offerings for subscribers, regardless of location. It can be deployed at significantly less cost than terrestrial networks and does not strain public budgets; satellite providers continue to deploy high-capacity satellites

[70] Todd Spangler and Todd Spangler, "Cord-Cutting Sped Up in 2018: Biggest Pay-TV Ops Shed 3.2 Million Subscribers Last Year," Variety (blog), February 13, 2019, https://variety.com/2019/biz/news/cord-cutting-2018-accelerate-us-pay-tv-subscribers-1203138404/.
[71] "Nielsen Estimates 119.9 Million TV Homes in the U.S. for the 2018-2019 TV Season," Nielsen, July 8, 2018, https://www.nielsen.com/us/en/insights/article/2018/nielsen-estimates-119-9-million-tv-homes-in-the-us-for-the-2018-19-season.
[72] Waseem Ahmed, "All Satellite List: Complete Free to Air Satellite TV Channel List in the US," King of Sat Dish Network Satellite TV Dth Best Live TV Streaming News (blog), accessed June 21, 2019, https://www.sattvdishdth.net/2019/04/all-satellite-list-free-to-air-tv-channels-usa.html.
[73] Sirius XM Holdings, Inc. "SiriusXM Beats 2018 Subscriber Guidance and Issues 2019 Guidance," accessed June 21, 2019, http://siriusxm2019cr.q4web.com/investor-overview/press-releases/press-release-details/2019/SiriusXM-Beats-2018-Subscriber-Guidance-and-Issues-2019-Guidance/default.aspx.
[74] 2019 Broadband Deployment Report. Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/2019-broadband-deployment-report
[75] Monica Andersen et al. "10% of Americans don't use the internet. Who are they?" Pew Research Center. April 22, 2019. https://www.pewresearch.org/fact-tank/2019/04/22/some-americans-dont-use-the-internet-who-are-they/

without subsidies needed to provide service to the most remote consumers. As cities have gone bankrupt building their own fiber networks and the effectiveness of federal programs can still be improved,[76] increasingly satellite providers are viewed as prudent, responsible actors which can connect people to the internet with little to no assistance from the government and provide a more resilient technology and lower cost to connect currently unserved users.

The market for satellite-based broadband is still relatively young but has experienced an exciting development. In the last decade, satellite operators have combined new satellite technologies with new forms of distribution to deliver high throughput satellites (HTS). This is revolutionizing the broadband industry as satellite is increasingly competitive with terrestrial options on a price/performance basis. Over 2 million Americans access the Internet via satellite technologies today. Hughes is the market leader, with 1.5 million customers in 2017.[77] This technological transformation means that people across the U.S. can increasingly access the internet at download speeds of 25-100 Mbps,[78] speeds that exceed the FCC's definition of broadband (25 Mbps down, 3 Mbps up) and compete head on with terrestrial broadband networks.[79]

Some 20 million Americans do not have access to a fixed line broadband connection meeting the FCC's broadband definition. All Americans in the Continental U.S., regardless of where they live, can access at least two satellite broadband providers. It is increasingly clear that satellite is the most cost-effective way to deliver quality broadband to remote communities, while in urban areas satellite is becoming cost-competitive and comparable in speed to terrestrial options.

Access to broadband service can transform the lives of the previously unconnected. The broadband multiplier effect reflects the amount that consumers save, make, and share by using broadband. One study suggests the amount is

[76] Broadband USA. "Searchable Database of Funds". Accessed June 27, 2019. https://broadbandusa.ntia.doc.gov/new-fund-search NTIA compiled a database of more than 50 federal broadband programs, spanning a dozen federal agencies with billions of dollars for broadband grants, loans and other resources.

[77] Mark Sullivan, "This New Wave Of Satellite Broadband Could Challenge Cable And Fiber," Fast Company, March 13, 2018, https://www.fastcompany.com/40542241/this-new-wave-of-satellite-broadband-could-challenge-cable-and-fiber.

[78] "Satellite Internet In the United States at a Glance," Broadband Now, accessed June 21, 2019, https://broadbandnow.com/Satellite.

[79] "The FCC 'Broadband' Definition Has Changed. Here Is What It Means.," Broadband Now (blog), February 10, 2018, https://broadbandnow.com/report/fcc-broadband-definition/.

equal to $12,000/household,[80] however the value to some households could be many times higher. Plum Consulting issued a report on the value of spectrum to the British economy and estimated the net present value of satellite links at USD $40 billion from 2012-2021.[81] Adjusting its metrics for the U.S. economy, such a measure would total $337B for 2021-2030.

The satellite industry is well positioned to compete in the growing U.S. consumer market for fixed and wireless broadband estimated at $300 billion.[82] The high speed, industrial grade technology is also appropriate for the enterprise, including some 6 million business in the U.S., 135,000 K-12 schools, more than 5000 colleges and universities, and some 6000 hospitals. Satellite technologies are also well-positioned to deliver 5G services directly to consumers and enterprises.

4.2.1.3. 5G

It is important to understand that 5G is a 3GPP telecommunications standard used across a number of network technologies, and not solely a mobile standard. In the same way that WiFi extends different types of broadband connections (copper, fiber, and coax), 5G includes many technologies, overlays other networks and can extend their reach. Fiber to the premises (FTTx) providers will extend their networks with 5G in the same way that operators providing broadband via carrier grade Wi-Fi switch their Wi-Fi out with 5G in licensed, unlicensed or shared spectrum. For example, most new smartphones support Voice Over Wi-Fi or Voice (VoWi-Fi) or Voice Over LTE (VoLTE). This means that smartphones can receive calls even if connects via a competitor's network.

The move to 5G is driven by a number of factors, including but not limited to competition from mobile operators to capture fixed line broadband revenue, the need to defend historical investments by upgrading networks, innovation in mobile technologies which increase efficiency and throughput, demand for mobile

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[80] "The Multiplier Effect of Broadband and the Income of American Households" (Internet Innovation, December 12, 2017), https://internetinnovation.org/wp-content/uploads/MultiplierEffectBroadbandWhitepaper.pdf.

[81] Tony Lavender, "Valuing the Impact of Spectrum Useon the UK Economy" (Plum, March 2019), https://www.techuk.org/images/documents/March_2019_-_Valuing_the_impact_of_spectrum_use_on_the_UK_economy_-_UK_SPF.pdf?_cldee=amVubmlmZXIubWFubmVyQGVjaG9zdGFyLmNvbQ%3d%3d&recipientid=contact-a2abc7a41723e81181145065f38b4641-7fa97398c31d43ee95ed0907243d3225&esid=87898e2d-9cb2-4de1-a5f2-32e8dbbfec2c.

[82] A calculation based upon publicly available information of broadband providers.

services, increases in mobile traffic, and so on. This has led to a massive world-wide spectrum reallocation characterized by industry demand for higher frequencies, most notably millimeter wave spectrum in the U.S.[83] This is coupled with a movement for unlicensed spectrum and spectrum sharing.

A separate 2017 study, based upon benchmark multiples from 3G and 4G networks, suggested that 5G will add 3 million jobs and add $500 billion to the U.S. economy beginning in 2025.[84] The satellite industry will play an integral role in providing 5G services, starting in those segments which only it can serve, notably in-flight and maritime broadband, remote sensing, and continuous coverage for the IoT. As customers and industries experience the ubiquity of satellite, that expectation will carry over to other fields. In that way, satellite and mobile technologies will likely co-evolve, both complementing, cooperating, and competing with each. This interplay will drive demand for both technologies.

4.2.1.4. In-flight and Maritime Connectivity services

In the same way that mobile phone technologies influenced the market for voice telephony, satellite technologies have influenced the broadband market. In addition to using satellite solutions for home and office broadband, satellite broadband is increasingly demanded on airplanes, trains, and cruise ships to enable mobility or working on the go.

In 2018, there were 1 billion passengers on domestic and international flights in the U.S., 777.9 million being domestic travellers.[85] Increasingly these individuals will access satellite broadband inflight. Viasat has implemented satellite broadband on 1312 aircraft and expects to reach 2000 aircraft.[86] Inmarsat has some 1000 aircraft connected.[87] Millions of customers use in flight broadband via satellite every month, whether they travel in and out of cities or across oceans or

[83] Musey, J. Armand and Keener, E. Barlow, The Spectrum Handbook 2018 (October 1, 2018). The Spectrum Handbook 2018 Summit Ridge Group, LLC . Available at SSRN: https://ssrn.com/abstract=3259782

[85] "2018 Traffic Data for U.S Airlines and Foreign Airlines U.S. Flights," Bureau of Transportation Statistics, March 21, 2019, https://www.bts.dot.gov/newsroom/2018-traffic-data-us-airlines-and-foreign-airlines-us-flights.
[86] "Pressure Grows for Free Inflight Broadband Internet at US Majors," Runway Girl (blog), May 27, 2019, https://runwaygirlnetwork.com/2019/05/27/pressure-grows-for-free-inflight-broadband-internet-at-us-majors/.
[87] "Inmarsat Celebrates 1,000th Installation of next-Generation Inflight Broadband Solutions," Inmarsat (blog), accessed June 21, 2019, https://www.inmarsat.com/press-release/inmarsat-celebrates-1000th-installation-of-next-generation-inflight-broadband-solutions/.

land masses. The North American revenue for inflight broadband is estimated to be $462 million in 2019, growing at an average rate of 20 percent, and reaching over $5 billion annually by 2030.[88] Over the decade is it expected to bring a stream of revenues equaling $27 billion.

Maritime connectivity, with retail revenue today of $2.5 billion, is expected to generate $5.3 billion by 2028, some $41 billion in cumulative revenues for the period growth of 7.8% from 2018 – 2028.[89] There are some 28 million cruise passengers globally, half of which make their voyage from the U.S. The average age of a passenger is 47 and the average cruise length is 7 days.[90] This represents a lucrative captive audience for satellite broadband, which made up nearly $400M of the $2.5B maritime market in 2018.[91]

Increasingly people work on the go, and access to broadband is important. Improved connectivity during transit is increasingly expected. With inflight and maritime services, millions of people have been able to increase their productivity on trains, airplanes, and cruise ships. These services increase the value of the transportation and travel/tourism sector. Indeed, many would not take a cruise because internet connections were not available or were too difficult or expensive.[92]

4.2.2. Transportation

Satcom not only provides passengers with connectivity aboard planes, trains, ships, and buses, it provides critical logistical support for transportation. Between 2001-2016, satcom provided $3B in savings for the aviation industry, with $1.1B of that savings from improving air traffic control and $1.9B from increased operational efficiencies. The benefit to the industry grew 35% annually between 2013 and 2016, suggesting huge potential growth in this segment of the

[88] Commercial Opportunities of Passenger Connectivity for the Global Airline Industry," London School of Economics and Political Science, September 2017, http://www.lse.ac.uk/business-and-consultancy/consulting/consulting-reports/sky-high-economics.aspx
[89] "Maritime SATCOM Markets", 7th Edition report, NSR. 2019 (NSR, 2019). https://www.nsr.com/research/maritime-satcom-markets-7th-edition/
[90] "Cruise Lines International Association (CLIA) Reveals Growth in Global and North American Passenger Numbers and Insights," Cruise Line Industry Association, April 9, 2019, https://cruising.org:443/news-and-research/press-room/2019/april/clia-reveals-growth.
[91] NSR, 2019
[92] "The Race for Faster WiFi on board cruise ships." Ship Technology. May 15, 2018 https://www.ship-technology.com/features/race-faster-wifi-board-cruise-ships/

industry.[93]

Of the $2.5B in maritime satcom profits in 2018, approximately half came from merchant ships.[94] Maritime satcom allows for ship tracking and data transmission. Additionally, satcom will prove crucial in the burgeoning market for semi-autonomous and eventually autonomous vessels.[95]

Satcom is already used extensively for the tracking of trucks, but with the move to autonomous vehicles will come a reliance on satcom to provide upgrades to vehicle software and maps or multicasting of road conditions. McKinsey estimates that automotive data connectivity services will exceed $100B by 2030,[96] suggesting a large market for satcom use.

GPS impact in telematics alone (fleet dispatch and management) was the source of $50.4B in revenue in 2017. Maritime and aviation also rely on GPS technology; while aviation has alternative navigation systems, maritime would lose $10.4M/month in revenue in the event of a GPS outage.[97]

4.2.3. Agriculture

The farms of today rely heavily on satellite services for connectivity, weather forecasting, and precision agriculture which combines GNSS and remote sensing technologies with data analytics to optimize yield. NIST estimates that GPS alone created $729.8M in economic value in precision agriculture in 2017.[98] USDA estimates that rural broadband has the ability to create an additional $18-23B in

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[93] "The benefits of SATCOM to Airlines", Helios, 2017 https://www.inmarsataviation.com/content/dam/inmarsat/aviation/benefits/operational-efficiencies/Helios%20Study%20-%20Airline%20Benefits%20of%20Satcom%20-%20A%20Report%20for%20Inmarsat.pdf

[94] NSR, 2019

[95] Debra Werner, "Satellite Operators Offer Communications for Autonomous Ships", Space News, 18 October 2018 https://spacenews.com/satellite-operators-offer-communications-for-autonomous-ships/

[96] "Automotive Revolution: Perspective Toward 2030", McKinsey & Company, January 2016 https://www.mckinsey.com/~/media/mckinsey/industries/high%20tech/our%20insights/disruptive%20trends%20that%20will%20transform%20the%20auto%20industry/auto%202030%20report%20jan%202016.ashx

[97] NIST, 2019

[98] NIST, 2019

economic value through precision agriculture technologies.[99] Today, over half of all respondents in a survey of worldwide agriculture companies with >500 employees utilize Industrial IoT (IIOT).[100] Agricultural IIOT combines GPS, remote sensing data, and connected sensors to provide large cost savings: 4.5% with yield mapping (reporting on previous yields in specific area), 2.4% with GPS soil mapping (mapping composition and micronutrients), 2.7% with guidance systems (tractor and combine steering hardware in addition to GPS software), and 3.7-3.9% with variable rate technologies (using the aforementioned data to apply different levels of input across the field).[101] These applications have substantial environmental impact, burning 40% less fuel due to VRT, decreasing water usage by 20-50%, and reducing chemical applications by up to 80%.[102]

The benefits of IIOT are not limited to crops; livestock farming is also heavily impacted by sensor technologies. Sensors reduce cattle infanticide by 75%, wearables decrease the cost of medication by 15% per animal and reduce finishing time by 4-6 weeks, while livestock management software can reduce costs by $6 per 20kg of production.[103]

More precise weather forecasting combined with data analytics also has the ability to provide huge cost savings to farmers. Agricultural economic output has a strong correlation with weather, with a variation 12.1% of agricultural Gross Domestic Product (GDP) due to weather.[104] USDA estimates that next generation precision agriculture weather modeling can save $1.3B/year, 30% which is attributable to connectivity, with satellite data providing a large portion of the additional value.[105] NOAA's ADAPT-N program, which utilizes satellite climate and weather data to determine nitrogen fertilizer optimization, has the potential to save corn farmers $2.7B/year, and eliminate $1.7B/year in nitrate drinking supply pollution costs.[106] Commercial weather offerings through technologies such

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[99] "A Case for Rural Broadband: Insights on Rural Broadband And Next Generation Precision Agriculture Technologies", USDA, April 2019 (USDA, 2019)
[100] "Industrial IIOT on Land and At Sea: Agriculture". Inmarsat Research Programme, 2018
[101] David Schimmelpfennig and Robert Ebel "Sequential Adoption and Cost Savings from Precision Agriculture", Journal of Agricultural and Resource Economics
[102] USDA, 2019
[103] USDA, 2019
[104] Lazo, et al., "U.S. Economic Sensitivity to Weather Variability", American Meteorological Society, June 2011 https://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS2928.1
[105] USDA, 2019
[106] "ADAPT-N for Agriculture", National Centers for Environmental Information, National Oceanic and Atmospheric Administration, https://www.ncdc.noaa.gov/success/adapt-n-agriculture

as GPS radio occultation satellites, which are able to provide high-precision atmospheric models due to refraction of GPS signals, will be vital in providing better weather predictions for the sector which depends on it most.

4.2.4. Mining, Oil, and Gas

Open pit surface mines rely extensively on GPS, from mapping deposits to designing mines. GPS helps direct digging operations, increases efficiency in operations and equipment allocation, tracks material, reduces the risk of hazards, decreases labor costs of surveying and more. In 2017, the net productivity benefit of GPS in open pit surface mines was $1.1B.[107]

As oil and gas sites are located in remote areas, they rely on satcom for operation. Retail revenues for the overall satcom energy market, dominated by oil and gas, amounted to $800M in 2018, with projected growth to $1.2B in 2028.[108]

Remote sensing allows for the identification of new oil and gas reservoirs, monittors ground motion indicative of gas distribution, reduces the risk of accidents in gas storage through uplift and subsidence monitoring, improves offshore platform monitoring, aids in environmental management, and detects/maps spills. Natural resources made up 9% ($126M) of the satellite remote sensing data sales and 14% or ($448M) of the value-added services market, while energy made up 6% of the data sales ($84M) and 8% ($256M) of the value-added services market in 2017.[109]

4.2.5. Utilities

Electricity utilizes 6 out of every 10 in-service satcom units in the energy sector; much of this enables smart grid applications. The electrical utility satcom sector realized $80M in revenue in 2017, with projected growth to $300M in 2027 as increased bandwidth and further applications drive growth.[110]

The electrical sector additionally is reliant on the precision timing signal from

[107] NIST, 2019
[108] "Energy SATCOM Markets, 8th Edition", NSR, August 2019 https://www.nsr.com/research/energy-satcom-markets-8th-edition/
[109] Fishman, 2018
[110] Brad Grady, "The 'Other' Energy Satcom Markets", NSR, 10 May 2018 https://www.nsr.com/the-other-energy-satcom-markets/

GPS to synchronize the grid and detect problems in infrastructure; it is estimated that precision timing netted the electrical sector $15.8B in savings from 2010-2017.[111]

Remote sensing is critical to the utilities sector in mapping—it is used in siting, transmission line modeling, vegetation determination, and inspection.[112] Remote sensing also is utilized in water management; it can monitor surface water and precipitation, as well as detect aquifer capacity by monitoring land subsidence with SAR as well as changes in gravitational pull caused from the loss of water.[113]

4.2.6. Healthcare

Satcom is critical for providing telehealth services to remote areas of the country which do not have access to fixed broadband or local doctors, or to service members in distant locations without access to specialists. Satellites are uniquely capable of providing exceptional telehealth service, due to the national coverage of satellites, use of highly secure communications technologies, and their resiliency in the event of extreme weather events.[114] India is investing heavily in satellite telemedicine, using it to connect the 80% of its population that lives in rural areas to doctors at 100 hospitals across the country, and providing continuing medical education to doctors in remote areas.[115]

Satellite remote sensing has many public health applications. The mapping of remote villages during the Ebola epidemic in The Democratic Republic of Congo in 2018 allowed for faster emergency response.[116] Satellites regularly monitor air

[111] NIST, 2019
[112] Eric Merten, "Beyond transmission: How remote sensing speeds inspection and management of distribution networks", 12 March 2019 https://www.utilitydive.com/news/beyond-transmission-how-remote-sensing-speeds-inspection-and-management-of/550217/
[113] "Scientists use satellites to measure vital underground water resources", National Science Foundation, 19 July 2018 https://nsf.gov/news/news_summ.jsp?cntn_id=295988
[114] "Enabling Healthcare Connectivity in the United States through Satellite Broadband", Hughes, https://ecfsapi.fcc.gov/file/10524992411811/Health%20Care%20Connectivity_White%20Paper_05242017.pdf
[115] "Telemedicine: HealingTouch Through Space", ISRO, http://www.televital.com/downloads/ISRO-Telemedicine-Initiative.pdf
[116] Dan Jablonsky, "Seeing a Better World Is Built on Business Success", Maxar, 17 July 2018, https://blog.maxar.com/earth-intelligence/2018/seeing-a-better-world-is-built-on-business-success

and water quality, are used to map the potential spread of diseases such as malaria,[117] and track food insecurity via organizations such as the Famine Early Warning System Network.[118]

4.3. National Security and Public Safety

While consumers may be the largest group of users of satellite technologies, the U.S. government (at all levels), the intelligence community, and the military relies on satellites to achieve their many mission critical objectives, including secure communications with forces and allies. The American military defends the 330 million people of the United States and its territories; some 10 million Americans living abroad, and some $98 trillion in assets of U.S. based companies, households, and government.[119] It also protects the people and assets covered by the North Atlantic Treaty Organization and some 40 other alliances.

Conflicts within and between war-tarn countries can make long term infrastructure projects difficult, and satellite offers a fast, reliable, and economic solution for this area. These are and other trends drive the military communications market, expected to grow from $31.50 billion in 2018 to $37.67 billion by 2023, at a compound annual growth rate (CAGR) of 3.6% from 2018 to 2023.[120]

Remote sensing services, both government owned and commercially procured, are critical for the intelligence community. According to Euroconsult, defense markets made up approximately $860M of $1.4B in satellite Earth Observation (EO) commercial data sales in 2017, and $0.58B of the $3.2B Value-Added Services (VAS) market (much of the defense VAS work is done in-house).[121] As commercial capabilities increase in revisit rate and diversify further into non-optical wavelengths, this data will prove increasingly critical for government use. It will allow change detection of sites important to national security without the devotion of exquisite government satellite technologies to monitoring, provide more advanced weather forecasts which will in turn enable more advanced planning

[117] Maquins Odhiambo Sewe, et al., "Using remote sensing environmental data to forecast malaria incidence at a rural district hospital in Western Kenya", Nature, 1 June 2017, https://www.nature.com/articles/s41598-017-02560-z

[118] "Famine Early Warning Systems Network", USAID, http://fews.net/about-us

[119] Federal Reserve. https://www.federalreserve.gov/releases/z1/20190606/html/b1.htm

[120] "Military Communications Market worth $37.67 billion by 2023." Markets and Markets. N.d. https://www.marketsandmarkets.com/PressReleases/military-communications.asp

[121] Sima Fishman, "Earth Observation: State of Play and Future Prospects", Euroconsult USA, Advisory Committee on Commercial Remote Sensing (ACCRES) Meeting, 18 October 2018

of military operations, allow the government to utilize non-classified imagery sources with allies to verify hostile or illegal actions, and encourage the government to shift resources to technologies not available on the commercial market.

Public safety communications incorporate both satellite and terrestrial networks, however satellite networks play a critical backup and network of last resort role, as terrestrial networks can become damaged, disconnected, or sabotaged by weather, disaster, or attack. Satellite receivers are highly resilient, and portable ground stations can connect with satellites quickly. The critical communications market supporting public safety and disaster response was worth $18B alone in 2018.[122] Satellite provides a key part of this market and is a reliable backstop when other technologies fail. Following the devastating Hurricane Maria in 2017, satellite was the only viable means of communication for some time.[123]

[122] Thomas Lynch, “Critical Communications Market Worth $18 Billion by 2019, IHS Says - IHS Technology,” June 1, 2016, https://technology.ihs.com/579277/critical-communications-market-worth-18-billion-by-2019-ihs-says

[123] Amber Corrin, “How a New Satellite Terminal Feature Was Critical to Puerto Rico’s Recovery,” C4ISRNET, January 4, 2018, https://www.c4isrnet.com/c2-comms/2018/01/04/how-a-new-satellite-terminal-feature-was-critical-to-puerto-ricos-recovery/; Doreet Oren, “The Power of Satellite” (Gilat, n.d.), https://www.gilat.com/wp-content/uploads/2018/01/Gilat-Article-Satellite-Magazine-2018-Power-of-Satellite.pdf

5. Spectrum Policy for the Satellite Industry

5.1. Optimal Spectrum Policy

Spectrum policy is fundamental to economic development and national security. Without adequate access to the radio spectrum, satellite technologies will not grow. Modern spectrum allocation is the most important regulatory accomplishment of the 20th century, enabling the efficient use of scarce resources and enabling market access[124] Over the last generation, a regulatory consensus has emerged which recognizes that effective spectrum management is crucial to ensuring prosperity. The overall goals of spectrum policy should be the rollout of services, reduction of regulatory barriers, and promotion of innovation. The good news is that increasing sophistication and technological innovation have refined the models, tools, and mechanisms of spectrum analysis to increase the likelihood of finding the optimal balance of administrative and market-based allocations.

Satellite operators have a different set of requirements for spectrum access versus terrestrial wireless operators. Commercial satellite operators and operators of satellite ground stations will either seek a license to operate or a grant of market access through the FCC in order to operate within the U.S. Operators applying for market access grants are companies whose initial space station licenses to operate were granted by another nation, but who seek authorization to access the U.S. market for communications operations.[125] International companies and operators which have launched their satellite under the authority from another country will fall into this category.

Depending on the rules for sharing, commercial satellite use of spectrum that is allocated for federal use may be authorized when the services are viewed as necessary and certain conditions and approval are met by the National Telecommunications and Information Administration (NTIA).[126] However, non-federal

[124] Telecommunications Regulation Handbook (1st Edition), ITU and World Bank. 2011. Accessed June 21, 2019, http://www.infodev.org/articles/telecommunications-regulation-handbook-1st-edition. See further "The ICT Regulation Toolkit. Radio Spectrum Management: Striking a Balance Between Market Flexibility and Regulation" http://www.ictregulationtoolkit.org/toolkit/5

[125] § 25.137.

[126] §2.102(c).

operators may not expect protection from harmful interference with their operations in these bands.[127]

These differences are important because even though satellite operators do not enjoy the same regulatory conditions as other industries, they compete directly with other networks for the same customers and the same services.

5.2. The Five Keys of Good Spectrum Policy

The five keys of good spectrum policy are transparency, technological neutrality, international coordination, flexibility, and sustainability.[128] The goal of spectrum management is to promote transparent, non-discriminatory, and economically efficient spectrum management policies that provide regulatory certainty for market actors.

Transparency means that policy is conducted such that others can see what actions are performed and why; that participants have access to the same information; and that regulatory decisions are not arbitrary, random, or based on whim. Transparency entails respect for due process, for example conducting consultations on spectrum policies and procedures before changing national frequency allocation plans and before making decisions likely to affect service providers. Another element is to publish goals and procedures so that they are visible to the public. Conducting spectrum management in this way delivers accountability. Regulatory authorities and participants take responsibility for their actions, and as a result, spectrum decisions have certainty and reliability. Spectrum decisions are long-lived, and the process to develop and launch a satellite can take years. Participants desire a stable set of rules which will transcend day to day politics and allow for long-term planning. These qualities are essential for attracting investment.

Technological neutrality means not favoring one technology over another. It demands that regulators refrain from using regulations to push the market to their preferred structure and picking technological winners. The goal of technological neutrality is for the consumers to pick the winners, to maximize

[127] §2.102(e).
[128] "Handbook on National Spectrum Management,", Annex 3: Best practices for national spectrum management, September 14, 2015, https://www.itu-ilibrary.org/science-and-technology/handbook-on-national-spectrum-management_pub/80c5a2ed-en
"Global Symposium for Regulators 2015," ITU, June 2015, https://www.itu.int/en/ITU-D/Conferences/GSR/Pages/GSR2015/default.aspx.

innovation, create conditions for the development of new services, reduce investment risks, and stimulate competition among different technologies. Ideally regulators will make decisions that are technologically neutral and which allow for evolution of new radio applications. Regulators should also give industry the freedom and flexibility to deploy their choice of technologies. Neutrality requires that similar applications offered by different radiocommunication services (e.g. fixed and wireless, satellite and terrestrial) are not subject to disparate regulatory treatment.

International coordination seeks to align domestic spectrum policies with international recommendations to achieve faster take-up of technologies and economies of scale. Countries adopt harmonized frequency plans defined by the International Telecommunications Union Radiocommunication Sector (ITU-R) and regional bodies in order to facilitate the implementation of competition. Countries work in collaboration with regional and international bodies to develop coordinated regulatory practices. This coordination streamlines regulation, can remove regulatory barriers to free circulation and global roaming of radiocommunication equipment, provides for economies of scale and promotes agreed data formats and data elements for exchange of data and coordination purposes.

While each nation is sovereign and makes its own spectrum decisions, certain aspects of spectrum policy are internationally negotiated to ensure that commerce and communication can occur across borders. As such, a nation's spectrum policy needs to be consistent with international treaties. This is particularly important for satellite technologies which coverage and business models transcend borders.

Flexibility: Flexibility refers to ease of adaption and modification. Policies for flexible spectrum promote innovation, allow for the evolution of services and technologies, and facilitate entry by new competitors into the market. Importantly, policies must balance the desire to foster innovation with the need to control congestion and interference. Flexibility should minimize barriers to entry and provide incentives for small market players by allowing them to begin operations on a small scale at low cost, without onerous rollout conditions. Satellite operators of any size should be allowed to try new technologies, gain experience, and test market demand for various services.

In some cases, satellite operators have or are willing to vacate lower bands for use of terrestrial mobile communications and recouping resources for investment in new technologies and allocations. Regulators should be open to voluntary exploration led by the parties when appropriate.

Sustainability: While each Administration seeks its imprimatur on spectrum policy, there is a growing agreement to develop a longer-term policy to foster sustainability for spectrum policy beyond any one administration. A sustainable policy continues to realize common goals, for example space exploration and commerce, from one administration to the next. Bipartisanship has long been a feature of U.S. technology policy, and it enables long-term technology policy planning and implementation. For example, in October 2018 a Presidential Memorandum was issued on “Developing a Sustainable Spectrum Strategy for America’s Future” directing the Secretary of Commerce to lead the creation of a long-term spectrum plan, a report expected in July 2019.[129] In addition the White House Office of Science and Technology Policy and the Wireless Spectrum R&D Interagency Working Group released reports on research and development priorities for wireless communications noting the importance and role of satellite technologies to and ensure American leadership in terrestrial wireless and satellite technologies for 5G and beyond.[130][131] A “whole-spectrum solution” is proposed which encompasses scientific research, technology, policy, legislation, operations, and economics.

The Memorandum recognizes the importance of R&D in

- Pursuing spectrum flexibility and agility to use multiple bands and new waveforms
- Improving near real-time spectrum awareness
- Increase spectrum efficiency and effectiveness through secure autonomous spectrum decision making.

Now that the U.S. faces increased global competition, security risks, and unprecedented opportunities in commercial space, the need to ensure

[129] “Developing a Sustainable Spectrum Strategy for America’s Future.” Presidential Memoranda. October 25, 2018. https://www.whitehouse.gov/presidential-actions/presidential-memorandum-developing-sustainable-spectrum-strategy-americas-future/
[130] “Research and Development Priorities for American Leadership in Wireless Communications”, https://www.whitehouse.gov/wp-content/uploads/2019/05/Research-and-Development-Priorities-for-American-Leadership-in-Wireless-Communications-Report-May-2019.pdf
[131] “Emerging Technologies and their Expected Impact on Non-Federal Spectrum Demand”, https://www.whitehouse.gov/wp-content/uploads/2019/05/Emerging-Technologies-and-Impact-on-Non-Federal-Spectrum-Demand-Report-May-2019.pdf.

sustainable bipartisan satellite policy is paramount.

5.3. Satellite and the FCC's 5G Policy

The FCC has taken a great interest in 5G and has developed detailed policies to promote it. While on its face this violates the notion of technological neutrality, it is rational that the FCC should adopt the necessary regulatory measures to wireless technologies, which consumers and enterprises overwhelmingly demand. To maintain the balance of technological neutrality within the wireless domain, the FCC should adopt a similarly robust plan for satellite technologies with the same goals as the FCC has defined for 5G: spectrum optimization, infrastructure investment and deployment, and regulatory modernization toward a framework that reflects the reality of satellite networks. Greater FCC attention to satellite technologies follows the 3GPP standards for 5G as well as satellites critical role to close the digital divide, ensure national security, and maintain global leadership.

The FCC has adopted a plan to promote the growth of 5G, called the 5G Fast Plan, and it is built on three components of spectrum, infrastructure policy, and deregulation.[132] This spectrum strategy makes large swaths of high, mid, and low-band spectrum available to mobile operators. In the high band, this include auctions in the 24 and 28 GHz bands and the forthcoming 37, 39, and 47 GHz auctions. "With these auctions, the FCC will release almost 5 gigahertz of 5G spectrum into the market—more than all other flexible use bands combined," notes the FCC. The FCC hopes to make an additional 844 megahertz available through the 2.5 GHz, 3.5 GHz, and 3.7-4.2 GHz proceedings (notably a repurposing of spectrum used by the satellite industry). In lower bands, the FCC wants to change rules for the 600, 800, and 900 MHz bands so that mobile operators can use them.

These allocations follow significant efforts the FCC has made over the last decade to make additional spectrum available for the mobile industry including the AWS-3, AWS-4, H-Block, 600 MHz incentive auction, and the 3.5 GHz Citizens Broadband Radio Service (CBRS) proceeding.

The FCC has fulfilled its mandate to create policies for the mobile industry. However, it has not developed a plan to promote growth in the satellite industry. The FCC four statutory requirements which require its attention to satellite include

[132] FCC's 5G Fast Plan. Federal Communications Commission. https://www.fcc.gov/5G, Accessed June 27, 2019

(1) Promoting competition, innovation and investment in broadband services and facilities; (2) Supporting the nation's economy by ensuring an appropriate competitive framework for the unfolding of the communications revolution; (3) Encouraging the highest and best use of spectrum domestically and internationally; and (4) Providing leadership in strengthening the defense of the nation's communications infrastructure.[133]

Going forward, satellite technologies should be a key priority for the agency, not only for reasons of global competitiveness and security, but for competition in the broadband market and in closing the digital divide.

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[133] What We Do. Federal Communications Commission. Accessed June 27, 2019. https://www.fcc.gov/about-fcc/what-we-do

6. Conclusion

Nearly every person in America uses satellite technologies, whether watching the news, surfing the Internet on a plane, navigating with a GPS-enabled map, or checking the weather.

The satellite industry is poised to do much more for America because it has lowered **costs**, made its technology more **convenient**, and has strengthened **connectivity**.

The satellite industry is in a technological transformation and is evolving like the internet and mobile industries, serving more users, offering greater capacity, increasing efficiency, and lowering cost.

The satellite industry has invested heavily in research and develop to create the next generation of satellite technologies. The satellite industry is being transformed by thousands of entrepreneurs and startups with Silicon Valley-style ambition and inventiveness. Satellite technologies are increasingly desired by the venture and investor community.

The satellite industry's innovations are creating unique and valuable services and capabilities that no other network can do. The capabilities ensure Scalability, Connectivity, Ubiquity, Mobility, Speed, Performance, Reliability, Security, and Resilience.

The satellite industry is critical to the economy, internet connectivity, technological competitiveness, national security, and global leadership. The satellite industry has invested tens of billions in research & developments, and it drives hundreds of billions of dollars in revenue to the US annually. The industry needs to secure the relevant spectrum and spectrum policy to move to the next stage.

7. Appendix

7.1. Current Spectrum Allocation Overview

The Satellite Industry makes use of various frequencies within the radio spectrum portion of the electromagnetic spectrum depending on the nature of the operation being conducted. There is a balance between the cost of the spectrum license, technological capabilities, the properties of the band being used, and the allocation of spectrum by regulatory bodies. Certain frequency bands naturally lend themselves to certain services. For example, extremely low frequency bands may function well for submarine communication, but do not function well for transmitting large amounts of data, and therefore would not work for broadcast.[134] Most satellite industry spectrum use occurs between VHF-band and W-band depending on the service provided. This overview highlights current spectrum use in the United States by commercial satellite operators who are licensed to operate through the Federal Communications Commission (FCC).

7.2. Current Regulatory Regime in the United States

Commercial satellite companies' operations making use of the radio spectrum are regulated by the FCC. Part 25 of the FCC's regulations govern satellite communications and most operators must apply for licenses pursuant to the appropriate sections of Part 25 depending on factors such as the orbital location of the satellites, the nature of the communication service, etc. Part 5 governs experimental licenses, and occasionally an operator will apply for experimental use of spectrum pursuant to those regulations. Commercial satellite operators who sought a license for their satellite in a foreign country, but who wish to access the United States spectrum market will apply for a Market Access Grant from the FCC.[135] Part 97 governs amateur use, including amateur satellite services, "for qualified persons of any age who are interested in radio technique solely with a personal aim and without pecuniary interest. These services present an opportunity for self-training, intercommunication, and technical investigations."[136]

The U.S. Table of Frequency Allocations divides frequency use within the United States by federal and non-federal use. Commercial Operators almost exclusively

[134] Peter Miller, *Ka-band - The Future of Satellite Communication?*, WWW.TELE-SATELLITE.COM (Jun. 9, 2007), http://www.tele-satellite.com/TELE-satellite-0709/eng/feature.pdf.
[135] FCC Satellite Communications, 47 C.F.R. § 25.137.
[136] "Amateur Radio Service", FCC, 6 July 2017, https://www.fcc.gov/wireless/bureau-divisions/mobility-division/amateur-radio-service

fall into the non-federal use category. Any designated frequency allocation may be subject to footnotes that further specify use within the frequency bands. Footnotes that being with "US" (e.g. US315) indicate that all United States-based operations in the designated frequencies are subject to it, those beginning with "NG" (e.g. NG527A) indicate that non-federal users would be subject to it, and footnotes that begin with "G" apply only to federal use.[137] Moreover, multiple non-federal uses may be allocated in the same frequency. Those uses that are given primary allocation are written in all caps, while those with secondary allocation are not.[138] An online version of the table is available publicly and updated frequently to reflect any regulatory changes.[139]

Commercial satellite operators will either seek a license to operate or a grant of market access through the FCC. Operators applying for market access grants are companies whose initial space station licenses to operate were granted by another nation, but who seek authorization to access the U.S. market for communications operations.[140] International companies and operators who have launched their satellite under the authority from another country will fall into this category.

Commercial satellite use of spectrum that is allocated for federal use may be authorized under special circumstances when the services are viewed as necessary and approved by NTIA. Operations shall conform with conditions set out by the FCC and NTIA, operate in accordance with NTIA rules governing the service to which the frequencies involved are allocated, shall not cause harmful interference to federal stations and shall immediately terminate if harmful interference occurs, and must be certified as necessary by the federal agency involved.[141] However, non-federal operators may not expect protection from harmful interference with their operations in these bands.[142]

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[137] 47 C.F.R. § 2.105(d)(5)(ii)(iii)(iv).
[138] 47 C.F.R. § 2.105(c)(i)(ii).
[139] § 2.106; *see also* FCC ONLINE TABLE OF FREQUENCY ALLOCATIONS (Oct. 5, 2018), https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf [hereinafter Table of Frequency Allocations].
[140] § 25.137.
[141] §2.102(c).
[142] §2.102(e).

7.3. Types of Commercial Satellite Operations

Commercial satellite operators provide an array of services for both consumers and governmental entities. The services and their corresponding regulations can be divided broadly as such:

Abbreviation	Name	Definition	Common Spectrum Use/Allocation
FSS	Fixed Satellite Services	"A radiocommunication service between earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radiocommunication services."[143]	S-band, C-band, X-band, Ku-band, Ka-band, V-band, W-band, Q-band, E-band
MSS	Mobile Satellite Services	"A radiocommunication service: – between mobile earth stations and one or more space stations, or between space stations used by this service; or – between mobile earth stations by means of one or more space stations. This service may also include feeder links necessary for its operation."[144]	VHF-band, UHF-band, L-band, S-band, Q-band, V-band
EESS/MetSat	Earth Exploration Satellite	"A radiocommunication service between	VHF-band, UHF-band, S-band, X-band, Ka-band

[143] Int'l Telecomm. Union [ITU] Radio Regulations (2016) No. 1.21, http://search.itu.int/history/HistoryDigitalCollectionDocLibrary/1.43.48.en.101.pdf.
[144] ITU Radio Regulations No. 1.25.

	Services/Meteorological Satellite Service	earth stations and one or more space stations, which may include links between space stations, in which: – information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites; – similar information is collected from airborne or Earth-based platforms; – such information may be distributed to earth stations within the system concerned; – platform interrogation may be included. This service may also include feeder links necessary for its operation."[145]	
TT&C/SOS	Telemetry, Tracking and Command/Space Operation Service	"A radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space telecommand. These functions will normally be provided within the service in which the space station is operating."[146]	VHF-band, UHF-band, S-band, C-band, Ku-band, Ka-band
SDARS	Satellite Digital Audio Radio Service	"A radiocommunication service in which audio programming is digitally transmitted by one or more space	S-band

[145] ITU Radio Regulations No. 1.51.
[146] ITU Radio Regulations No. 1.23 "Space Operation Services".

		stations directly to fixed, mobile, and/or portable stations, and which may involve complementary repeating terrestrial transmitters, telemetry, tracking and control facilities."[147]	
RNSS	Radionavigation Satellite Services	"A radiodetermination-satellite service used for the purpose of radionavigation. This service may also include feeder links necessary for its operation."[148] "Generally for the safe operation of ships and aircraft."[149]	L-band
BSS	Broadcast Satellite Services	"A radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-satellite service, the term "direct reception" shall encompass both individual reception and community reception."[150]	Ka-band, Ku-band
ISS	Inter-satellite Services	"A radiocommunication service providing links between artificial satellites."[151]	22.55-23.55 GHz, 24.45-24.75 GHz, 54.25-58.2 GHz, 59.3-71 GHz

[147] 47 C.F.R. § 25.201.
[148] ITU Radio Regulations No. 1.43.
[149] ITU Radio Regulations No. 1.45, 1.47.
[150] ITU Radio Regulations No. 1.39.
[151] ITU Radio Regulations No. 1.22.

7.4. Commonly Used Frequency Bands

7.4.1. VHF/UHF Bands (30-300 MHz and 300-3000 MHz)

The VHF (Very High Frequency) and UHF (Ultra High Frequency) bands are, despite their names, the lowest frequency bands in the radio spectrum to be used by the commercial satellite industry. VHF/UHF bands are primarily designated for Non-voice Non-geostationary Mobile Satellite Service (NVNG MSS), and portions of the UHF band are also used for Earth Exploration Satellite Services (EESS). These bands, due to their lower frequency, are not capable of transmitting of large amounts of data and therefore are not used for satellite broadcasting or voice services.[152]

7.4.1.1. Definitions, Allocation, and Authorization

47 C.F.R. §25.202(a)(3) designates the following frequencies for use "by the non-voice, non-geostationary mobile-satellite service (NVNG MSS):

FCC Band Designation	Definition and Area of Operation	Additional Requirements
137-138 MHz	NVNG MSS space-to-Earth (s-E)	NVNG MSS operating in these bands are required to engage in coordination and time-sharing with NOAA for the protection of NOAA satellite operations.[153]
148-150.05 MHz	NVNG MSS Earth-to-space (E-s)	
399.9-400.05 MHz	NVNG MSS Earth-to-space (E-s)	
400.15-401 MHz	NVNG MSS space-to-Earth (s-E)	NVNG MSS operating in these bands are required to engage in coordination and time-sharing with the DOD.[154]
401-402 MHz		
402-403 MHz		
449.75-450.25 MHz		

7.4.1.2. Commercial Satellite Use

ORBCOMM currently has exclusive use of the frequencies 137-138 MHz and

[152] *See supra*, note 1.
[153] 47 C.F.R. §25.259.
[154] §25.260.

400.15-401 MHz within these bands that are allocated for commercial satellite services. This is known as the "Little LEO band" by the FCC.[155] ORBCOMM operates NVNG mobile satellite services at these frequencies. The FCC proposed in its Small Satellite NPRM of 2018 that sharing in these bands with other small satellite operators may be possible and opened the prospect for comment.[156]

The VHF and UHF bands are also used for Telemetry, Tracking and Command (TT&C), Earth Exploration Satellite Services (EESS), and Meteorological Satellite Service. Spire was recently granted authority to operate in the 401-403 MHz and 449.75-450.25 MHz bands for uplink and TT&C "to provide maritime monitoring, meteorological monitoring, and earth imaging services.", and additionally has an application pending for 399.9-400.05 MHz[157] Planet Lab operates in the UHF-band 401-402 MHz (space-to-Earth) and 449.75-450.25 MHz (Earth-to-space) for TT&C.[158]

Portions of both the VHF and UHF bands are also designated for use by amateur satellite operators, or those who seek to operate a satellite without pecuniary interest.[159] Occasionally universities and other educational institutions will seek authority to operate under the FCC rules governing amateur satellites, however the commercial satellite industry does not use this authorization mechanism as companies naturally have a pecuniary interest in their satellite operations.

7.4.2. L-Band and S-Band (1-2 GHz and 2-4 GHz)

The L-band and S-band encompass the next lowest frequencies for commercial

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[155] *See e.g.*, FCC, *In the Matter of Terrestrial Use of the 2473-2495 MHz Band for Low-Power Mobile Broadband Networks; Amendments to Rules for the Ancillary Terrestrial Component of Mobile Satellite Service Systems*, Report and Order, IB Dkt. No. 13-213, FCC 16-181, (rel. Dec. 23, 2016), 2 fn. 2 ("'LEO' is an acronym for Low-Earth Orbit, and generally refers to orbits at altitudes of less than 2000 kilometers. The term 'Big LEO' was coined to distinguish systems using the 1610-1626.5 MHz and 2483.5-2500 MHz bands, which operate with voice and higher data-rate capabilities, from "Little LEO" systems, that do not provide voice service and generally operate with lower data rate capabilities.").
[156] FCC, *In the Matter of Streamlining Licensing Procedures for Small Satellites*, Notice of Proposed Rulemaking, 33 FCC Rcd 4152 (6), 28 (Apr. 17, 2018) [Hereinafter Small Satellite NPRM].
[157] *See* FCC, SATELLITE POLICY BRANCH, Report No. SAT-01363, PUBLIC NOTICE: ACTIONS TAKEN, (Dec. 7, 2018); Spire Global, Inc. Application, File No. SAT-LOA-20151123-00078, Attachment Exhibit A at 7, 9, https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=107390&acct=782809&id_form_num=12&filing_key=-278556
[158] *See* FCC, SATELLITE POLICY BRANCH, Report No. SAT-01023, PUBLIC NOTICE: ACTIONS TAKEN, (Jun. 20, 2014) https://licensing.fcc.gov/ibfsweb/ib.page.FetchPN?report_key=1051181.
[159] 47 C.F.R. Part 97. *See also* FCC, AMATEUR RADIO SERVICE, https://www.fcc.gov/wireless/bureau-divisions/mobility-division/amateur-radio-service (last visited Mar. 29, 2019).

satellite use after the VHF/UHF bands and occur at the boundary between UHF and the Super High Frequency (SHF) bands, designated by the ITU as bands falling between 3 and 30 GHz.[160] In the United States, the L-band runs from 1-2 GHz and the S-band runs from between 2-4 GHz; however only portions of each of these broader bands are allocated for commercial satellite use in the United States. The L-band is used today for mobile satellite services (MSS) with frequencies authorized for ancillary terrestrial component (ATC) operations. The S-band is used for satellite radio, data, and voice.

7.4.2.1. Definitions, Allocation, and Authorization

47 C.F.R. § 25.103 defines several types of mobile satellite services within the L and S-bands:

FCC Band Designation	Definition and Area of Operation	Additional Requirements
1.5/1.6 GHz MSS bands	Mobile-Satellite Service provided in any portion of the 1525-1559 MHz space-to-Earth band and the 1626.5-1660.5 MHz Earth-to-space band.	"[t]he use of the frequencies 1544-1545 MHz and 1645.5-1646.5 MHz is limited to distress and safety communications."[161] In the bands 1525-1544 MHz, 1545-1559 MHz, 1626.6-1645.5 MHz and 1646.5-1660.5 MHz, a non-Federal licensee in the MSS may also operate an ancillary terrestrial component in conjunction with an MSS license.
1.6/2.4 GHz MSS bands	A Mobile Satellite Service that operates in any portion of the 1610-1626.5 MHz and 2483.5-2500 MHz bands.	The 1.6/2.4 GHz MSS Band has authorized use in frequencies 1610-1626.5 MHz (User-to-Satellite Link); 1613.8-1626.5 MHz (Satellite-to-User Link (secondary)); and 2483.5-2500 MHz (Satellite-to-User Link).[162]
2 GHz MSS bands	A Mobile-Satellite Service that operates in any	Has authorized use in frequencies 2000-2020 MHz (User-to-Satellite Link) and

[160] ITU Radio Regulations No. 2.1.
[161] 47 CFR §25.202(a)(4)(iii)(B).
[162] §25.202(a)(4)(i).

	portion of the 2000-2020 MHz and 2180-2200 MHz bands.	2180-2200 MHz (Satellite-to-User Link).[163] 2000-2020 MHz and 2180-2200 MHz are co-primary with the AWS-4 band.
2200-2290 MHz **2025-2110 MHz** **(EESS/ISL/SpaceOps bands)**		

The United States Table of Frequency Allocations further stipulates allocation on a more detailed level within the band and describes certain frequencies with the following footnotes:[164]

Frequencies	Foot-note	Description
1530-1544 MHz **1626.5-1645.5 MHz**	US315	MSS will operate on a secondary basis to maritime mobile-satellite distress and safety communications.
1525-1544 MHz **1545-1559 MHz** **1610-1645.5 MHz** **1646.5-1660.5 MHz**	US380	Authorizes MSS operators "to operate an ancillary terrestrial component in conjunction with its MSS network."
1549.5-1558.5 MHz **1651-1660 MHz**	US308	"Those requirements of the aeronautical mobile-satellite (R) service that cannot be accommodated in the bands 1545-1549.5 MHz, 1558.5-1559 MHz, 1646.5-1651 MHz and 1660-1660.5 MHz shall have priority access with real-time preemptive capability for communications in the mobile-satellite service. Systems not interoperable with the aeronautical mobile-satellite (R) service shall operate on a secondary basis. Account shall be taken of the priority of safety-related communications in the mobile-satellite service."
1545-1559 MHz **1646.5- 1660.5 MHz**	US309	Authorizes "transmissions from terrestrial aeronautical stations directly to aircraft stations, or between aircraft stations, in the aeronautical mobile (R) service…when such transmissions are used to extend or supplement the satellite-to-aircraft links."
1610-1626.5 MHz	US319	"Federal stations in the mobile-satellite service shall be limited to earth stations operating with non-Federal space stations,"

[163] §25.202(a)(4)(ii).
[164] *See* 47 C.F.R. § 2.106; *see also* Table of Frequency Allocations, *supra* note 7.

7.4.2.2. Commercial Satellite Uses

7.4.2.2.1: L-Band:

Globalstar and Iridium make use of the portion of 1610-1626.5 MHz that is allocated for Mobile Satellite Services.[165] "Globalstar is now authorized to operate in the 1610-1617.775 MHz frequency band on an exclusive basis, and Iridium is authorized to operate in the 1618.725-1626.5 MHz band on an exclusive basis. Globalstar and Iridium are required to share the frequency band located between their two respective exclusive frequency assignments, i.e., the 1617.775-1618.725 MHz frequency band."[166] The voice and data services provided in these bands go to an array of customers in such varied fields as "maritime, oil and gas, mining, forestry, construction and transportation industries, as well as to first responders."[167]

Currently the 1525-1559 MHz and 1626.5-1660.5 MHz segments of the L-band are licensed to Inmarsat and Ligado.[168] Inmarsat provides an array of services in the L-band including: Broadband Global Area Network services (BGAN), maritime satellite services, and aviation communication services, as well as Internet of Things (IoT) and satellite phone services.[169] Ligado plans to develop satellite-supported 5G services using its L-band spectrum.[170] Ligado's L-band mobile satellite network operates throughout North America providing Push-to-Talk (PTT) two-way radio, switched voice, and data services to end users in the industrial,

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[165] *See* Small Satellite NPRM, *supra* note 24, at 29. Additionally, The FCC's 2018 Small Sat NPRM took note of Globalstar and Iridium's experimental use of portions of this band for intersatellite links, which technically falls outside of the authorized allocation use under the Table of Frequency Allocations. The Small Sat NPRM suggested expanding use in this band to allow for such inter-satellite links as well as expanding access for MSS to other small satellite operators in addition to Globalstar and Iridium.

[166] FCC, *In the Matter of Third Report and Analysis of Competitive Market Conditions with Respect to Domestic and International Satellite Communications Services Report and Analysis of Competitive Market Conditions with Respect to Domestic and International Satellite Communications Services*, 30, IB Dkt. Nos. 09-16, 10-99; FCC 11-183 (rel. Dec. 13, 2011), https://www.fcc.gov/reports-research/reports/satellite-competition-reports/satellite-competition-report-3rd-annual.

[167] *Id.*

[168] For a discussion of the licensing history for this L-band spectrum and Inmarsat's and Ligado's historic use of the bands, *see supra* note 35 at 22-27.

[169] *See Our Satellites*, INMARSAT, https://www.inmarsat.com/about-us/our-satellites/ (last visited Mar. 29, 2019) (describing Inmarsat 4 satellite).

[170] *Ligado Networks and Partners to Develop 5-G Technologies in L-band*, LIGADO NETWORKS, (Oct. 29, 2018), https://ligado.com/press/ligado-networks-partners-develop-5g-technologies-l-band/.

public safety, and government sectors. Ligado is also authorized to operate an ancillary terrestrial component in this band and is planning to deploy standards-based technology for 5G IoT service and device operation on both satellite and terrestrial networks.

Portions of this band are also allocated for Radionavigation Satellite Services (RNSS), particularly 1164-1215 MHz (s-E) and 1559-1610 MHz (s-E) (s-s). Currently, Leidos and Intelsat are the two U.S.-authorized commercial operators with approved licenses to use portions of this spectrum to provide RNSS.[171] Intelsat's approved license for the Galaxy 30, which has not yet launched, includes a Wide Area Augmentation System (WAAS)[172] payload with the goal of "enhancing accuracy of GPS signals for WAAS-certified avionics during FAA approved phases of flight."[173] This is an example of a commercial satellite operator providing for government-run services as the WAAS program has been developed and managed by the FAA to improve aviation safety and precision.[174] RNSS operates partially in the L-band for space-to-Earth (s-E) communication, as well as in the C-band for Earth-to-space (E-s) communication. All of the authorized commercial licenses for RNSS use frequencies between 6597.58 and 6686.70 for their Earth-to-space RNSS communication.

7.4.2.2.2: S-Band:

Commercial satellite use of the S-band in the United States consists mostly of Satellite Digital Audio Radio Service (SDARS), commonly referred to as satellite radio. Currently, Sirius XM[175], is authorized to operate at various frequencies between 2320-2354 MHz (s-E) and 7025-7075 MHz (E-s). Five satellites (space stations) are currently operating on-orbit and two more have been approved but have not yet launched as of the most recent update to the FCC's approved Space Station list. A number of MSS satellites additionally use S-band, including the

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[171] *Approved Space Station List*, FCC, https://www.fcc.gov/approved-space-station-list (last visited on March 29, 2019) (the list was updated as of Dec. 3, 2018).

[172] For a description of WAAS capabilities and benefits *see GNSS Frequently Asked Questions – WAAS*, FAA, (Dec. 20, 2016 4:58:19 PM), https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/faq/waas/.

[173] *See Approved Space Station List, supra* note 40; *see also* Intelsat License LLC, Galaxy 30 Legal Narrative https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=114456&acct=783256&id_form_num=15&filing_key=-305276.

[174] *Id*. at 9.

[175] Former authorizations for use were transferred to the new company when Sirius Satellite Radio, Inc. and XM Radio, Inc merged in 2012. https://www.fcc.gov/proceedings-actions/mergers-transactions/xm-and-sirius.

Globalstar constellation.[176]

The S-band is also used by commercial satellite operators for necessary Telemetry, Tracking, and Command (TT&C), essentially the ability of the operator to monitor, control, and communicate with its own satellite. Often TT&C operations will be authorized to occur within the same band of operations as a given satellite service, however in some instances TT&C operations must occur in a separate band.[177] The S-band is often used for such TT&C purposes. For example, Viasat and Aerospace advertise various antennas for TT&C that function in the 1435 to 2300 MHz frequencies.[178] Additionally, multiple operators are authorized to use portions of the band, such as 2025-2110 MHz (E-s) for TT&C specifically.[179]

Portions of the S-band are also used by Earth Exploration Satellite Services (EESS). Commercial EESS is a growing area of the commercial satellite industry as private operators have been able to innovate and create state-of-the-art capabilities for Earth observation.[180] For example, Spire has been authorized to operate in "Phase I satellites using the 2020-2025 MHz band for downlink" and in 2200-2290 MHz (s-E) in later phases of operation.[181] Blacksky has been authorized to provide EESS using 2025-2110 MHz (E-s) for TT&C operations.[182] Astro Digital is authorized to operate in 1615-1617.775 MHz (s-s) and 2483.5-2495 MHz (s-s) for its not-yet-launched Landmapper satellite.

7.4.3. C-band (3.4 – 6.725 GHz)

The C-band has traditionally been allocated for Fixed Satellite Service (FSS)

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[176] *See Approved Space Station List supra* note 40.

[177] NTIA, OFFICE OF SPECTRUM MANAGEMENT, NTIA SPECIAL PUBLICATION 94-31, U.S. NATIONAL SPECTRUM REQUIREMENTS: PROJECTIONS AND TRENDS (1995) Chapter 5 "In Orbit TT&C", https://www.ntia.doc.gov/legacy/osmhome/EPS/openness/sp_rqmnts/space5.html.

[178] *See L-, S-, and C-band Range Fixed and Mobile Telemetry Systems*, VIASAT, https://www.viasat.com/sites/default/files/media/documents/range_telemetry_systems_015_web.pdf (last visited Mar. 29, 2019); *Telemetry, Tracking and Command (TT&C) Products*, AEROSPACE, (last visited Mar. 29, 2019), https://aerospace.honeywell.com/en/products/space/satellite-products-and-systems/small-satellite-specific-bus-products/telemetry-tracking-and-command-ttc-products.

[179] *See, e.g.*, *Approved Space Station List supra* note 40: Blacksky; Planet Labs Flock; Worldview 1, 2, 3; Worldview 4.

[180] SATELLITE INDUSTRY ASSOCIATION, STATE OF THE SATELLITE INDUSTRY 2017 14-15 (2017) https://www.sia.org/wp-content/uploads/2017/07/SIA-SSIR-2017.pdf.

[181] *See Approved Space Station List supra* note 40: Spire Global.

[182] *See id.*: Blacksky.

operation and has been considered the backbone for the bulk of direct broadcasting television and radio satellite services. The C-band's frequency range allows for the transmission of significant amounts of data without being subject to rain fade and other weather-related interference due to the size of the waves in this band.

7.4.3.1. Definitions, Allocation, and Authorization

47 C.F.R. Section 25.103 defines the C-band for satellite service use as the Conventional C-band and the Extended C-band:

FCC Band Designation	Definition and Area of Operation	Additional Requirements
Conventional C-band	The 3700-4200 MHz (space-to-Earth) and 5925-6425 MHz (Earth-to-space) FSS frequency bands.	Available for use by Earth Stations on Vessels (ESV's) [183]
Extended C-band	3600-3700 MHz (space-to-Earth); 5850-5925 MHz (Earth-to-space); 6425-6725 MHz (Earth-to-space) FSS frequency bands.	

The United States Table of Frequency Allocations further stipulates allocation on a more detailed level within the band:[184]

Frequencies	Footnote	Description
3600-3650 MHz	US107	Earth stations whose applications were filed prior to July 23, 2015 will operate on a primary basis, and those filed and constructed after that date will be allocated spectrum on a secondary basis.
3600-3650 MHz **5850-5925 MHz**	US245	Limits non-federal FSS use to "international intercontinental systems and is subject to case-by-case electromagnetic compatibility analysis."
3650-3700 MHz	NG169	Earth stations grandfathered in by December 1, 2000 will continue to operate on a primary basis and those constructed later will operate on a secondary basis.
3700-4200 MHz	NG457A(a)	Provides for authorization of Earth Stations on Vessels (ESVs) to communicate with GSO satellites and while they are docked may have coordination renewed for up to 180 days, however, while in motion, ESVs may not claim protection from interference from non-

[183] 47 C.F.R. §25.202(a)(8).
[184] *See* 47 C.F.R. § 2.106; *see also* Table of Frequency Allocations, *supra* note 7.

		federal fixed services.
5850-5925 MHz	NG160	Provides that "the use of the non-Federal mobile service is limited to Dedicated Short Range Communications operating in the Intelligent Transportation System radio service."
6525-6700 MHz	US342	Requires that "all practicable steps shall be taken to protect the radio astronomy service from harmful interference."

7.4.3.2. Commercial Satellite Use

The C-band has long been considered optimal for satellite broadcast operations as it is much less susceptible to weather-related interference than many other bands, such as the Ka-Band.[185] Currently, the bulk of approved satellite space stations engaging in FSS operate in the C-band.[186] Customers who rely on commercial satellite operators' transmissions in the C-band include the many companies that make up the membership of the National Association of Broadcasters and National Public Radio, as examples. Intelsat and SES both have a significant number of licenses to operate in the C-band, providing an array of fixed satellite services.[187] Other operators in the authorized to use portions of the band include ABS Global, Eutelsat, Globalstar, Leidos (providing RNSS only), New Skies Satellites, and Telesat Canada.

The C-band is also available for use for TT&C, which are generally at the frequency band edges, purposes and approved for use in new, innovative ways to extend the life of satellites in orbit. For example, Space Logistics Inc. was recently approved to operate a satellite using C-band frequencies 5925 – 6425 MHz (uplink) and 3700 – 4200 MHz (downlink) for TT&C purposes.[188] Space Logistics' MEV-1 is designed to extend the life of currently operating satellites by docking with its customers satellites and "performing the station keeping and attitude control functions for the satellites as a combined vehicle stack ("CVS")."[189]

[185] *See supra* note 2, at 6-7.
[186] *See Approved Space Station List supra* note 40.
[187] *See id.*
[188] Space Logistics, LLC Mission Extension Vehicle-1 Application Narrative at 5 https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=109966&acct=513732&id_form_num=12&filing_key=-289016. *See also, Approved Space Station List supra* note 40. TT&C in the Ku-band was also approved for this satellite.
[189] Space Logistics, *supra* note 58, Narrative at 1. Space Logistics has contracted with Intelsat for its first mission to extend the life of Intelsat 901.

Viasat also advertises TT&C antennas using frequencies 4.7 to 5.1 GHz.[190]

7.4.4. X-band (7-11.2 GHz)

The United States Table of Frequency Allocations stipulates allocation within the band:[191]

[190] *L-, S-, and C-band Range Fixed and Mobile Telemetry Systems*, VIASAT, https://www.viasat.com/sites/default/files/media/documents/range_telemetry_systems_015_web.pdf (last visited Mar. 29, 2019).

[191] *See* 47 C.F.R. § 2.106; *see also* Table of Frequency Allocations, *supra* note 7.

7.4.4.1. Definitions, Allocation, and Authorization

Frequencies	Footnote	Description
10.7-10.95 GHz **11.2-11.45 GHz**	5.441	The use of the bands 4500-4800 MHz (space-to-Earth), 6725-7025 MHz (Earth-to-space) by the fixed-satellite service shall be in accordance with the provisions of Appendix 30B. The use of the bands 10.7-10.95 GHz (space-to-Earth), 11.2-11.45 GHz (space-to-Earth) and 12.75-13.25 GHz (Earth-to-space) by geostationary-satellite systems in the fixed-satellite service shall be in accordance with the provisions of Appendix 30B. The use of the bands 10.7-10.95 GHz (space-to-Earth), 11.2-11.45 GHz (space-to-Earth) and 12.75-13.25 GHz (Earth-to-space) by a non-geostationary-satellite system in the fixed-satellite service is subject to application of the provisions of No. 9.12 for coordination with other non-geostationary-satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the fixed-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed-satellite service and of the complete coordination or notification information, as appropriate, for the geostationary-satellite networks, and No. 5.43A does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated.
10.7-11.7 GHz	NG52 NG527A	NG52 Except as provided for by NG527A, use of the bands 10.7-11.7 GHz (space-to-Earth) and 12.75-13.25 GHz (Earth-to-space) by geostationary satellites in the fixed-satellite service (FSS) shall be limited to international systems, i.e., other than domestic systems. Earth Stations in Motion (ESIMs), as regulated under 47 CFR part 25, are an application of the fixed-satellite service (FSS) and the following provisions shall apply: (a) In the band 10.7–11.7 GHz (space-toEarth), ESIMs may be authorized to communicate with geostationary satellites, subject to the condition that these earth stations may not claim protection from transmissions of non-Federal stations in the fixed service. (b) In the bands 11.7–12.2 GHz (space-toEarth), 14.0–14.5 GHz (Earth-to-space), 18.3– 18.8 GHz (space-to-Earth), 19.3–19.4 GHz (space-to-Earth, 19.6–20.2 GHz

		(space-toEarth), 28.35–28.6 GHz (Earth-to-space), and 29.25–30.0 GHz (Earth-to-space), ESIMs may be authorized to communicate with geostationary satellites on a primary basis. (c) In the band 17.8–18.3 GHz (space-to-Earth), ESIMs may be authorized to communicate with geostationary satellites on a secondary basis. (d) In the bands 18.8–19.3 GHz (space-to-Earth) and 28.6–29.1 GHz (Earth-to-space), ESIMs may be authorized to communicate with geostationary satellites, subject to the condition that these earth stations may not cause harmful interference to, or claim protection from, non-geostationary-satellite systems in the fixed-satellite service."
11.7-12.2 GHz	NG43 5.485 5.488	In the band 11.7-12.2 GHz, protection from harmful interference shall be afforded to transmissions from space stations not in conformance with ITU Radio Regulation No. 5.488 only if the operations of such space stations impose no unacceptable constraints on operations or orbit locations of space stations in conformance with No. 5.488. In Region 2, in the band 11.7-12.2 GHz, transponders on space stations in the fixed-satellite service may be used additionally for transmissions in the broadcasting-satellite service, provided that such transmissions do not have a maximum e.i.r.p. greater than 53 dBW per television channel and do not cause greater interference or require more protection from interference than the coordinated fixed-satellite service frequency assignments. With respect to the space services, this band shall be used principally for the fixed satellite service. The use of the band 11.7-12.2 GHz by geostationary-satellite networks in the fixed-satellite service in Region 2 is subject to application of the provisions of No. 9.14 for coordination with stations of terrestrial services in Regions 1, 2 and 3. For the use of the band 12.2-12.7 GHz by the broadcasting satellite service in Region 2, see Appendix 30.

Much of the X-band is allocated for Federal use for EESS, Radiolocation, and

Radionavigation.[192] Frequencies 8025-8400 MHz are subject to US258 which stipulates that "the Earth exploration-satellite service (space-to-Earth) is allocated on a primary basis for non-Federal use. Authorizations are subject to a case-by-case electromagnetic compatibility analysis."

7.4.4.2. Commercial Satellite Uses

Commercial Satellite Operators have been approved to use portions of the X-band between 8025-8400 MHz (s-E) for EESS operations.[193] Some operators have received approval on the condition that they coordinate use of the band with NASA in order to avoid any harmful interference with NASA's use of the X-band.[194] As discussed *supra* EESS operations by commercial satellite operators provide the government as well as private customers with high resolution imagery of the Earth.

Additionally, XTAR, a U.S.-based commercial satellite operator, provides secure communications services for exclusively government and military operational needs in the X-band providing coverage over Africa, Europe, the Middle East, and portions of Asia.[195]

7.4.5. Ku-band (10.95-14.5 GHz)

In addition to the C-band, the Ku-band is one of the major bands utilized by fixed satellite services. Particularly the Ku-band is used for direct-to-home (DTH) broadcasting, i.e. satellite TV. The Ku-band is more susceptible to rain-fade and weather-related interference than the C-band, but still provides reliable communication and a larger amount of data capacity.

7.4.5.1. Definitions, Allocation, and Authorization

47 CFR Section 25.103 defines portions of the Ku-band for satellite services in a variety of ways:

FCC Band Designation	Definition and Area of Operation	Additional Requirements

[192] *See* Table of Frequency Allocations, *supra* note 7.
[193] *See Approved Space Station List supra* note 40: Blacksky Global, LLC; Planet Labs, Inc.; DG Consents Sub, Inc. (Worldview 1, 2, 3, and 4); Terra Bella (Skysat).
[194] See e.g. Planet Labs, Inc. Application for Planet Labs Flock Attachment Exhibit 43 at 1 https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=101245&acct=476603&id_form_num=12&filing_key=-255329.
[195] *See* XTAR, http://xtar.com/ (last visited Mar. 29, 2019); *see also* Jason Baits and Lon Rains, *Profile: Taking a Risk on X-band*, SPACE NEWS, (May 2, 2005), https://spacenews.com/profile-taking-risk-x-band/.

Conventional Ku-band	11.7-12.2 GHz (space-to-Earth) and 14.0-14.5 GHz (Earth-to-space) FSS frequency bands.	11.7-12.2 GHz and 14.0-14.5 GHz are available for ESV use and for use by Vehicle Mounted Earth Stations (VMES) and Earth Stations Aboard Aircraft (ESAA)[196]
Extended Ku-band	10.7-11.7 GHz (space-to-Earth), and 12.7-13.25 and 13.75-14.0 GHz bands (Earth-to-space) FSS frequency bands.	10.95-11.2 GHz and 11.45-11.7 GHz are available for ESV, VMES, and ESAA use.[197]
DBS service	"A radiocommunication service in which signals transmitted or retransmitted by Broadcasting-Satellite Service space stations in the 12.2-12.7 GHz band are intended for direct reception by subscribers or the general public. For the purposes of this definition, the term direct reception includes individual reception and community reception." [198]	

Additionally, the various frequencies allocated for satellite services use within the band are subject to several footnotes in the U.S. Table of Allocations:

Frequencies	Footnote	Description
10.7-11.7 GHz	US131	NGSO licensees providing FSS must coordinate with specific radio astronomy observatories listed in the footnote for the protection of the radio telescope facilities also operating in the band.
10.7-11.7 GHz	US211	requires that "applicants for airborne or space station assignments are urged to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference."
10.95-11.2 GHz **11.45-11.7 GHz**	NG527A	allows Earth Stations in Motion (ESIMs) to communicate with GSO satellites "subject to the condition that these earth stations may not claim protection from transmissions of non-Federal stations in the

[196] 47 C.F.R. §25.202(a)(8); (a)(10)(11).
[197] *Id.*
[198] §25.103.

		fixed service."
11.7-12.2 GHz	NG143	"protection from harmful interference shall be afforded to transmissions from space stations not in conformance with ITU Radio Regulation No. 5.488 only if the operations of such space stations impose no unacceptable constraints on operations or orbit locations of space stations in conformance with No. 5.488
11.7-12.2 GHz	NG527A(b)	allows ESIMs to communicate with GSO satellites on a primary basis

7.4.5.2. Commercial Satellite Use

The Ku-band is used for services such as "direct-to-home ("DTH") satellite service, including high-definition ("HD") video programming."[199] Direct-TV alone, which operates exclusively in the Ku and Ka-bands has millions of subscribers in the United States.[200] Echostar operates satellites in the Ku-band as well to provide Dish Network with DBS and FSS for its millions of subscribers.[201] In addition to HD programming, 3D programming capabilities are used in the Ku-band.[202] Additional Ku-band authorized operators include ABS Global, Eutelsat, Globecomm, Intelsat, Ligado, New Skies, SES, Space Logistics (subsidiary of Northrup Grumman), Telesat Canada, and OneWeb.[203]

The Ku-band may also be used for TT&C, generally at the frequency band edges. See *supra* for details of the approved Space Logistics MEV-1, which was approved to operate TT&C in both the C-band as well as frequencies 13.75 – 14.5 GHz (E-s) and 11.45 – 12.25 GHz (s-E) of the Ku-band.[204] The Ku-band has also been approved for TT&C in frequencies 11.7005 GHz (s-E) 11.701 GHz (s-E) and

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[199] *See e.g.* DirectTV Enterprises LLC APPLICATION FOR AUTHORITY TO LAUNCH AND OPERATE DIRECTV KU-79W, A KU-BAND SATELLITE, AT 79° W.L., (Feb. 28, 2012), http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=97348&acct=624514&id_form_num=12&filing_key=-240367.
[200] *Id.* at 2.
[201] *See* In the Matter of EchoStar Satellite Operating Corporation Application for Authority to Launch and Operate the EchoStar 16 Satellite at 61.5° W.L. (Sep. 2, 2011), http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=95328&acct=687461&id_form_num=12&filing_key=-233242. On May 20, 2019 EchoStar announced an agreement to transfer this business to Dish Network.
[202] *Id.*
[203] *See Approved Space Station List supra* note 40.
[204] Space Logistics, *supra* note 58, Narrative at 5.

14.0005 GHz (E-s) 14.4995 GHz (E-s).[205]

7.4.6. Ka-band (17.3-30 GHz)

The Ka-band has become increasingly popular for high-speed internet connectivity and provides for additional spectrum to the Satellite industry. The Ka-band is susceptible to rain fade, which makes it less ideal for direct TV broadcast, however, in recent years, advances in technology have allowed commercial satellite operators to achieve high-speed broadband connectivity using the Ka-band.[206]

7.4.6.1. Definitions, Allocation, and Authorization

47 CFR Section 25.103 defines some portions of Ka-band used for satellite services as such:

FCC Band Designation	Definition and Area of Operation	Additional Requirements
Conventional Ka-band	18.3-18.8 GHz (space-to-Earth), 19.7-20.2 GHz (space-to-Earth), 28.35-28.6 GHz (Earth-to-space), and 29.25-30.0 GHz (Earth-to-space) frequency bands, which the Commission has designated as primary for GSO FSS operation.[207]	Frequencies 22.55-23.00 GHz, 23.00-23.55 GHz, 24.45-24.65 GHz, and 24.65-24.75 GHz are authorized for inter-satellite services, i.e. space-to-space communication links.[208]
17/24 GHz Broadcasting-Satellite Service	A radiocommunication service involving transmission from one or more feeder-link earth stations to other earth stations via geostationary satellites, in the 17.3-17.7 GHz (space-to-Earth) (domestic allocation), 17.3-17.8 GHz (space-to-Earth) (international allocation) and	Frequencies 17.3-17.7 GHz (space-to-Earth) are available for GSO systems Broadcasting-Satellite Services so long as the receiving Earth Stations are outside of the United States.[210]

[205] *See e.g.*, *Approved Space Station List supra* note 40: MSAT-2.
[206] *See e.g.*, *High Capacity Satellite Systems*, VIASAT, https://www.viasat.com/products/high-capacity-satellites (last visited Mar. 29, 2019); *Our Satellites*, INMARSAT, https://www.inmarsat.com/about-us/our-satellites/ (last visited Mar. 29, 2019).
[207] 47 C.F.R. **§** 25.202(a)(1)(i) ("[i]n the 27.5-28.35 GHz band, the FSS (Earth-to-space) is secondary to the Upper Microwave Flexible Use Service authorized pursuant to part 30 of this chapter, except for FSS operations associated with earth stations authorized pursuant to §25.136." [language current as of march, 2019].).
[208] **§**25.202(a)(5).
[210] **§**25.202(a)(9).

	24.75-25.25 GHz (Earth-to-space) bands.[209]	

The United States Table of Frequency Allocations further stipulates allocation on a more detailed level within the band:

Frequencies	Footnote	Description
17.3-17.7 GHz **17.7-17.8 GHz**	US271	Provides that "the fixed-satellite service (Earth-to-space) is limited to feeder links for broadcasting-satellite service."
17.3-17.7 GHz	US402	gives primary allocation to certain federal FSS satellites and associated earth stations.
17.3-17.7 GHz	NG163	limits the use of broadcasting-satellite services to GSO satellites.
17.7-17.8 GHz	US334(b)	Stipulates that "the FCC shall also coordinate with NTIA all applications for new stations and modifications to existing stations that support the operations of Multichannel Video Programming Distributors (MVPD) in these areas, as specified in the aforementioned regulations."
17.8-18.3 GHz **18.3-18.6 GHz** **18.8-19.3 GHz** **19.3-19.7 GHz** **19.7-20.2 GHz**	US334	generally requires coordination between federal and non-federal satellites and allows certain federal satellites to operate on a primary basis.
17.8-18.3 GHz	US519	stipulates that "[t]he band 18-18.3 GHz is also allocated to the meteorological-satellite service (space-to-Earth) on a primary basis. Its use is limited to geostationary satellites and shall be in accordance with the provisions of Article 21, Table 21-4 of the ITU Radio Regulations."
18.3-18.6 GHz **18.6-18.8 GHz** **18.8-19.3 GHz**	US139	allows for experimental licensing under 47 C.F.R. Part 74.
18.3-18.6 GHz **18.6-18.6 GHz**	NG164	limits the "use of the band 18.6-18.8 GHz by the fixed-satellite service is limited to geostationary satellite networks."
18.3-18.6 GHz **18.6-18.8 GHz** **19.7-20.2 GHz** **28.32-29.1 GHz**	NG527A	allows Earth Stations in Motion (ESIMs) to communicate with GSO satellites "subject to the condition that these earth stations may not claim protection from transmissions of non-Federal stations in the

[209] § 25.103. ("For purposes of the application processing provisions of this part, the 17/24 GHz BSS is a GSO-like service. Unless specifically stated otherwise, 17/24 GHz BSS systems are subject to the rules in this part applicable to FSS.").

29.25-29.5 GHz **29.5-30.0 GHz**		fixed service."
18.6-18.8 GHz	US255	stipulates certain power flux density limits for operators.
18.8-19.3 GHz **28.35-29.1 GHz**	NG165	stipulates that "geostationary-satellite networks in the fixed satellite service shall not cause harmful interference to, or claim protection from, non-geostationary-satellite systems in the fixed-satellite service."
19.3-19.7 GHz **29.1-29.25 GHz**	NG166	provides that between 19.4-19.6 GHz use "by the fixed-satellite service is limited to feeder links for non-geostationary-satellite systems in the mobile-satellite service."
22.55-23.55 GHz	US145	refers to power emissions within the band.
22.55-23.55 GHz	US278	US278 allows NGSO inter-satellite links to operate on a secondary basis to GSO inter-satellite links
22.55-23.55 GHz[211]	US342	"all practicable steps shall be taken to protect the radio astronomy service from harmful interference."
24.75-25.25 GHz	NG65	states that "stations in the fixed and mobile services may not claim protection from individually licensed earth stations authorized pursuant to 47 CFR 25.136."
29.25-29.5 GHz	NG535A	stipulates that "The use of the band 29.25-29.5 GHz by the fixed-satellite service is limited to geostationary satellite networks and to feeder links for non-geostationary-satellite systems in the mobile-satellite service."

7.4.6.2. Commercial Satellite Use

Increasingly, commercial satellite companies operating in the Ku-band have added Ka-band capabilities to replacement and recently launched satellites to expand their service coverage area.[212] The Ka-band has also been approved for TT&C use by satellite operators.[213] Upper portions of this band have undergone changes to allow for more flexible use of the spectrum by the FCC's "Spectrum Frontiers" initiative, discussed in greater detail below.[214] The Ka-band is most

[211] Only portions of this frequency range are subject to US342.
[212] *See e.g.* SES Americom Inc. Application for Modification of AMC-15 Fixed-Satellite Space Station License at 1-2 (Mar. 17, 2017); Skynet Satellite Corporation APPLICATION FOR AUTHORITY TO LAUNCH AND OPERATE TELSTAR 12 VANTAGE SATELLITE AT 15° W.L. at 1, (Oct. 10, 2014).
[213] *See e.g.*, *Approved Space Station List supra* note 40: DirectTV 11 (using 29.56165-29.57165 GHz (E-s) for TT&C only.).
[214] FCC, *In the Matter of Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, 3rd Report and Order, 33 FCC Rcd 5576 (9) (2018), https://docs.fcc.gov/public/attachments/FCC-18-73A1.pdf [hereinafter Spectrum Frontiers 3rd R&O].

often used for FSS, is used for satellite broadband by Hughes and Viasat, has been approved for use in EESS operations[215], and is widely used for Direct-to-Home broadcasting in addition to the Ku-band by DirectTV, DISH Operating, and Echostar..[216] Additional authorized FSS operators in the Ka-band include Audacy's NGSO constellation[217], Intelsat, Iridium, O3B, SES, Telesat Canada, ViaSat, and OneWeb.[218]

7.4.7. Q-band (33 GHz to 50 GHz) and V-band (50 GHz to 75 GHz)

The Q-band and V-band have become more accessible to commercial satellite operators as technology advancements and innovation has increased. Currently, several portions of the bands are available for FSS, BSS, MSS, EESS, and ISS use for non-federal operators.

7.4.7.1. Definitions, Allocation, and Authorization

Section 25.202(a)(ii) stipulates that "[u]se of the 37.5-40 GHz band by the FSS (space-to-Earth) is limited to individually licensed earth stations. Earth stations in this band must not be ubiquitously deployed and must not be used to serve individual consumers." Portions of the V-band are specifically available for inter-satellite services (ISS) as well: 54.25-56.90 GHz, 57.00-58.20 GHz, 65.00-71.00 GHz.[219]

Type of Service	Q and V Frequencies Allocated for Use
FSS	37.5-42 GHz 47.2-48.2 GHz 50.4-51.4 GHz 71-76 GHz 81-86 GHz
BSS	40.5-42 GHz 74-76 GHz
MSS	40-40.5 GHz 40.5-41 GHz (secondary) 46.9-47 GHz 50.4-51.4 GHz 66-71 GHz
EESS	56.9-57 GHz 59-59.3 GHz 65-66 GHz

[215] *See supra* note 27 for more information on AstroDigital's EESS operation.
[216] *See Approved Space Station List supra* note 40; *see also* Ku-band on use of DTH services.
[217] *See infra* note 96 for a discussion on Audacy's constellation.
[218] *Id.*
[219] 47 C.F.R. § 25.202(a)(5).

ISS	54.25-56.90 GHz 57-58.20 GHz 65-71 GHz

The United States Table of Frequency Allocations further stipulates allocation on a more detailed level within the bands:

7.4.7.2. Q-band

Frequencies	Footnote	Description
37.5-38 GHz **38-39.5 GHz** **39.5-40 GHz**	NG63	"In the band 37.5-40 GHz, earth station operations in the fixed-satellite service (space-to-Earth) shall not claim protection from stations in the fixed and mobile services, except where individually licensed earth stations are authorized pursuant to 47 CFR § 25.136."
39.5-40 GHz	US382	"In the band 39.5-40 GHz, Federal earth stations in the mobile-satellite service (space-to-Earth) shall not claim protection from non-Federal stations in the fixed and mobile services."
40.5-41 GHz **41-42 GHz**	US211	Requires that "applicants for airborne or space station assignments are urged to take all practicable steps to protect radio astronomy observations in the adjacent bands from harmful interference."
47.2-48.2 GHz	US297	"The bands 47.2-49.2 GHz and 81-82.5 GHz are also available for feeder links for the broadcasting satellite service."
47.2-48.2 GHz	NG65	States that "stations in the fixed and mobile services may not claim protection from individually licensed earth stations authorized pursuant to 47 CFR 25.136."

7.4.7.3. V-band

Frequencies	Footnote	Description
50.4-51.4 GHz	US156	Stipulates maximum unwanted emissions power levels for earth stations operating in these bands.
56.9-57 GHz	US532	Stipulates that EESS "shall not receive protection from the fixed and mobile services operating in accordance with the Table of Frequency Allocations."
59-59.3 GHz	US353	Allows "space-based radio astronomy observations may be made on an unprotected basis."

7.4.7.4. E-band

Frequencies	Footnote	Description
71-76 GHz **81-86 GHz**	US389	Provides that "In the bands 71-76 GHz and 81-86 GHz, stations in the fixed, mobile, and broadcasting

		services shall not cause harmful interference to, nor claim protection from, Federal stations in the fixed-satellite service" to any of the 28 military stations listed in the footnote.

7.4.7.5. Commercial Satellite Use

The bands above 30 GHz, while having a high capacity for data, are more easily affected or obstructed by weather-related conditions like rain.[220] Spectrum in this area has been viewed as well-suited for satellite or fixed microwave applications and "is currently used by a variety of services, including satellite, fixed microwave, and radio astronomy, and is expected to be important for the next generation wireless technology (5G)."[221]

Hughes has been approved for a license to operate in the Q/V bands to provide broadband services to be used for 5G connectivity.[222] The approved satellite, which has not yet launched, will also be operating in the Ka-band.[223] In particular, Hughes plans to target rural and remote areas that do not otherwise have access to such high-speed internet access.[224] The services will also include emergency communications services to be used in the event of natural disasters, etc.[225]

Audacy has also been authorized to operate a constellation of NGSO satellites that will use the following frequencies in the Q/V-bands: 32.3-33 GHz, 37.5-42 GHz, 47.2-50.2 GHz, 54.25-56.9 GHz, 57-58.2 GHz, and 65-71 GHz.[226] Audacy's constellation will offer "inter-satellite backhaul service for commercial and scientific spacecraft" as well as "deliver[ing] communications to customers via a cloud-

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[220] U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-18-71, INTERNET OF THINGS: FCC SHOULD TRACK GROWTH TO ENSURE SUFFICIENT SPECTRUM REMAINS AVAILABLE 7 (2017), https://www.gao.gov/assets/690/688450.pdf.
[221] *Id.* at 7, 13.
[222] Hughes Network Systems, LLC Application for HNS-95W Narrative at 1-2, https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=111888&acct=181872&id_form_num=12&filing_key=-296076.
[223] *See Approved Space Station List supra* note 40: HNS-95W.
[224] Hughes Narrative *supra* note 92 at 5.
[225] *Id.* at 6.
[226] *See Approved Space Station List supra* note 40: Audacy; *see also* Audacy Attachment Narrative Exhibit at 2 (Table 1: Audacy Network Proposed Frequency Bands) http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=110219&acct=356129&id_form_num=12&filing_key=-289974 [hereinafter Audacy Narrative].

based secure virtual private network."[227]

SpaceX, Telesat, Kepler Communications, and LeoSat have also been approved for use of V-band spectrum for satellite communications constellations.[228]

[227] Audacy Narrative *supra* note 96 at 5-6.
[228]Henry, Caleb, "FCC Approves SpaceX, Telesat, LeoSat, and Kepler Constellations", 15 November 2018, https://spacenews.com/fcc-approves-spacex-telesat-leosat-and-kepler-internet-constellations/