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THE COMMERCIAL SATELLITE INDUSTRY: WHAT'S UP AND WHAT'S ON THE HORIZON

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

OCTOBER 25, 2017

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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THE COMMERCIAL SATELLITE INDUSTRY: WHAT'S UP AND WHAT'S ON THE HORIZON

WEDNESDAY, OCTOBER 25, 2017

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:07 a.m. in room SR–253, Russell Senate Office Building, Hon. John Thune, Chairman of the Committee, presiding.

Present: Senators Thune [presiding], Nelson, Wicker, Fischer, Sullivan, Inhofe, Johnson, Capito, Gardner, Young, Cantwell, Klobuchar, Blumenthal, Markey, Peters, Baldwin, Hassan, and Cortez Masto.

OPENING STATEMENT OF HON. JOHN THUNE, U.S. SENATOR FROM SOUTH DAKOTA

The CHAIRMAN. Good morning. Welcome to today's hearing on the state of the commercial satellite industry and the promises of next-generation satellite technology to improve the lives of Americans. I believe we're at a critical moment in the development of satellite capability, and I'm excited to hear from our panel of distinguished witnesses today.

Satellite services available today offer residential broadband at speeds substantially greater than those available just a few years ago—download speeds that meet the Federal Communications Commission's definition of advanced telecommunications capability, and in some cases, without the strict data cap limits that have vexed users of satellite broadband in the past. Much of our television broadcast programming is delivered to broadcasters by satellite with extraordinary reliability, and millions of Americans receive their video service through direct broadcast satellite.

This summer, the FCC for the first time authorized access to the U.S. market to a provider using a proposed constellation of 720 satellites. OneWeb received approval to enter the U.S. market with an array of satellites to provide global, high-speed broadband, including in remote and hard-to-serve areas. For comparison, there are about 1,000 satellites total in operation today. This new type of service would place satellites in a much lower orbit than many of the satellites currently in operation.

Similarly, SpaceX seeks to bring its satellite expertise to bear with a proposal to deploy a constellation of thousands of satellites to provide high-speed broadband. If realized, these ambitious proposals could completely change consumer access to broadband in rural areas as well as cities across the country and around the world.

Satellite capability can also play a critical role in establishing communication after natural disasters, and it has been used by the Red Cross and others as part of the effort to reconnect the residents of Puerto Rico after the devastation caused by Hurricane Maria, as well as those affected by hurricanes in Texas and Florida.

As with the wireless services this Committee has examined at numerous hearings, spectrum is critical to satellite services. As the value of spectrum has skyrocketed with America's increasing demand for broadband, spectrum that previously had little value for mobile broadband use now faces competing demands.

It is essential that any evaluation of these competing demands accurately consider the full range of spectrum uses and how best to deliver broadband and other services to the American people. The specifics of how to balance such demands in the public interest—things like allocating spectrum between services and between licensed and unlicensed use; setting appropriate interference levels between terrestrial and satellite uses; and determining the size, number, and location of exclusions zones—are as important as they are complex. However, they are not the subject of today's hearing, as the FCC is addressing those matters in the ongoing Spectrum Frontiers proceeding and elsewhere.

But it is important to set the broad parameters of this discussion. We must ensure that next-generation technologies rise or fall on their merits, including their efficiency in the use of spectrum, and ultimately their ability to meet the demands of American households for reliable high-speed broadband.

Today we will have an opportunity to hear from some of the leaders and innovators in the field who are redefining satellite capability and who can explain what satellite services can offer to ongoing efforts to make broadband more available to all parts of the country and the world.

Wireline service, fixed and mobile wireless service, and satellite service all have a role to play in connecting Americans to next-generation broadband service.

Understanding satellite capability and the potential of next-generation satellite deployments will help inform this Committee regarding the costs and benefits of spectrum allocations, spectrum sharing, and related technology-neutral policies, among other things.

So I am pleased that we have such a distinguished panel to address these matters today, and I look forward to hearing their thoughts.

[The prepared statement of Senator Thune follows:]

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The CHAIRMAN. And I recognize Senator Nelson for his opening statement.

STATEMENT OF HON. BILL NELSON, U.S. SENATOR FROM FLORIDA

Senator NELSON. Thank you, Mr. Chairman.

Well, this is an exciting time because communications satellites are essential links in our globally connected world. They bounce television signals all over the planet and provide voice communication and Internet access to remote areas. And in a recognition of satellites' resiliency and reliability, first responders and those in disaster areas, like Florida after a hurricane, Texas, Puerto Rico, the Virgin Islands, they rely on satellite systems as their lifeline when other communications systems are down.

So the next generation of satellite-based communications systems holds even more promise. Large constellations, thousands of satellites, will provide broadband communications that rival the terrestrial counterparts, and it's going to make access even more affordable for broadband Internet. It's going to become a reality that broadband Internet in rural areas and remote areas that the terrestrial networks don't reach. Other constellations promise imaging services that could advance key Earth and climate science initiatives. And that's just the beginning of it.

Much of this new interest and investment in space is coming from the private sector. In fact, some have begun to call this the second great Space Age. And as it was for the first great Space Age, the epicenter—and I hate to be parochial here—the epicenter——

[Laughter.]

Senator NELSON.—is going to be the Cape. So goes——

Senator CANTWELL. [Clears throat.]

Senator NELSON. So goes—well, we'll let you do all your manufacturing out there——

[Laughter.]

Senator CANTWELL. We'll take—we'll take it, we'll take it.

Senator NELSON.—Senator Cantwell.

But as it was in the first great Space Age, so it now is in the commercial launch business. And thanks in no small part to the efforts of some of the companies here today and to our commitment to an ambitious civil and national security space program, the Cape is coming alive. The space industry has brought millions of dollars of investment to this country, along with thousands and thousands of jobs, lots of economic benefits, and a lot of spin-offs from the technology that is developed for the space program.

And so as we have been working with NASA, the FAA, and the Air Force, and our colleagues here in Congress, we are paving the way to a dramatic increase in commercial space activity at the Cape. And when I say "the Cape," that's the generic term, not just the physical Cape Canaveral, which is the Air Force station, but it also includes the Kennedy Space Center and the commercial activities that are going on there, which are very significant.

So take, for example, the commanding general of the 45th Space Wing, General Monteith, he told me recently that they now have the capability of supporting two launches in one day. Now, in the past, that could have never happened. In large part, that, in fact, is due to the autonomous destruct, and you don't have to have an Air Force lieutenant sticking there with his finger on the destruct button, but you have the autonomous destruct if a rocket were to go off the trajectory that it's supposed to be on, threatening populated areas.

And over the coming years, these launches are going to be able to deliver thousands of new satellites to orbit, cargo and crews to the International Space Station, and eventually new technologies, like in-space manufacturing. And on top of all that, we are building the vehicles that will return humanity to deep space. And, ladies and gentlemen, we're going to Mars, and the beginning of that is in 2 years with the launch of the largest rocket, most powerful rocket ever, the SLS with its spacecraft Orion. And that's just 2 years away.

So suffice it to say this, in fact, is not only an exciting time, it's a critical time, for the space program and space commercialization as well. And that's why it's such an important time to have our space agency led by an experienced and competent professional. The agency has not faced this critical of an inflection point since the Apollo program. If we stumble now, the impacts of our civil, commercial, and national space capabilities could be felt for decades to come.

And I want to thank the witnesses for being here. This is going to be an exciting discussion.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Nelson. And we have lots of wide open space and uncongested air space in South Dakota, too——

[Laughter.]

The CHAIRMAN.—so if you want to bring any of that technology our way, we welcome it.

We have a great panel, as you pointed out today. We have Ms. Patricia Cooper, who is the Vice President of Satellite Government Affairs at SpaceX; Mr. Mark Dankberg, who is the Chief Executive Officer of ViaSat; Mr. Stephen Spengler, who is the CEO of Intelsat; and Mr. Greg Wyler, who is the Founder and Executive Chairman of OneWeb.

So thank you all for being here. We'll start on my left, and your right, with Ms. Cooper, and then proceed. And if you would all, if you can, limit your oral remarks to about 5 minutes, it will give us optimum time to ask questions. And we'll make sure that all of your remarks get made part of the written record of this hearing. So thank you for being here.

Ms. Cooper.

STATEMENT OF PATRICIA COOPER, VICE PRESIDENT, SATELLITE GOVERNMENT AFFAIRS, SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX)

Ms. COOPER. Mr. Chairman, Ranking Member Nelson, and members of the Committee, I am pleased to be back today representing SpaceX and my more than 6,000 colleagues who are revolutionizing space technologies. Mr. Chairman, there's a space renaissance underway, and SpaceX is proud to be at the forefront of innovation.

My testimony today will outline SpaceX's plans to harness the platform of space for a new approach to broadband delivery. I will also recommend actions that the Committee can take to foster innovation, by streamlining regulations, driving efficient spectrum use, and protecting the safety of space.

SpaceX is designing, developing, building, and launching a constellation of over 4,000 satellites operating close to the Earth. We have designed our constellation to achieve an ambitious and compelling goal, connecting the hundreds of millions of Americans and billions of global citizens to high-speed broadband.

Our direct-to-consumer focus drives the large scale of our system, featuring substantial on-orbit capacity and to keep pace as broadband demand grows, and sophisticated techniques for frequency reuse.

From the outset, our constellation planning aimed to push the edge of innovation so that we can groom our coverage to match the peaks and valleys of broadband demand, interoperate flexibly with other users, and protect the space environment. Underlying these plans are the credentials that SpaceX has built over 15 years that demonstrate our capability to manufacture and operate complex space systems with unprecedented innovation, efficiency, scale, and affordability.

Unlike many other aerospace firms, SpaceX is heavily vertically integrated. We build our Falcon rockets and our Dragon spacecraft in-house from tip to toe, including propulsion systems, structures, avionics, and launch, all within the U.S.

Our space and launch heritage and our drive to innovate gives us a distinct edge in deploying our ambitious satellite project. SpaceX has successfully launched 42 flights of the Falcon 9, including 15 this year alone, landed 18 first stages and reused 3, and flown 13 supply missions to the International Space Station using our Dragon spacecraft. We will bring this experience to bear in our satellite project.

In space, our constellation will use dynamic antennas and optical links between the satellites to form an efficient mesh network. These advancements will allow us to reuse frequencies many times over to ultimately deliver far greater broadband capacity to consumers. As a company, we are deeply committed to maintaining a debris-free environment in space, and our satellite system has been thoughtfully designed to meet or exceed all existing requirements for safety of operations in space and upon deorbit.

On the ground, we are producing affordable, easy-to-install end user terminals that all but remove the incremental cost of new users joining our network. Here we avoid the dollars-per-mile terrestrial build-out costs and other obstacles that have made terrestrial broadband connections cost prohibitive for so many American communities.

The coming low-orbiting constellations hold enormous potential to finally bring broadband connectivity to all corners of America at speeds and latencies that today are available really only in the most populated areas.

Mr. Chairman, we lay out an ambitious goal, and we could use the Committee's help. To summarize my written statement, we urge the Committee to continue its work to modernize the regulatory framework for commercial launch operations, both at the FAA and at the FCC. Launch is the critical path to deploying satellite constellations, and licensing rules and spectrum allocations must be updated to reflect that new pace and number of launches. SpaceX is proud to launch our constellation from U.S. soil on American-made SpaceX rockets.

The Committee should endorse rules that foster spectrum sharing and technology advancement to make the best use of the airwaves. The FCC has already taken an important step by updating its rules for such satellite constellations, rightfully expecting operators to negotiate among themselves for spectrum sharing. Unfortunately, not all operators have chosen to invest in available technologies for spectrum efficiency. The Committee has an important oversight function to ensure that the rules of the road incentivize and support smart technology that can interoperate with other users on orbit and on the ground.

To protect the space environment, the Committee should encourage closer coordination among the many Federal agencies responsible for orbital safety policies and regulation. Congress should also consider additional investments in the Nation's infrastructure to track orbital objects even more precisely.

Finally, we ask for the Committee's vigilance to assure tech neutrality in any and all legislation or Federal programs designed to expand broadband infrastructure. Blanket exclusions of any qualifying technology from existing programs, like the Connect America Fund, should be rescinded so that new satellite constellations can be harnessed for high-quality broadband connectivity in every corner of America.

This is an exciting and dynamic time in the satellite industry. I thank the Committee for the opportunity to be here today and look forward to any questions.

Thank you.

[The prepared statement of Ms. Cooper follows:]

PREPARED STATEMENT OF PATRICIA COOPER, VICE PRESIDENT, SATELLITE GOVERNMENT AFFAIRS, SPACE EXPLORATION TECHNOLOGIES CORP. (SPACEX)

Mr. Chairman, Ranking Member Nelson, and Members of the Committee:

Thank you for the opportunity to participate in today's hearing. We appreciate the Committee's interest in exploring how advanced satellite technologies can expand broadband access within the United States and the policies that would foster that capability. SpaceX also appreciates that the Committee recognizes the potential of a new generation of U.S.-based low-Earth orbit ("LEO") or non-geostationary satellite orbit ("NGSO") satellite broadband system as an integral part of any strategy to augment high-speed Internet connectivity nationwide. NGSO satellite constellations intend to leverage emerging technologies in space and on the ground to provide reliable, high-speed, and affordable broadband service to customers throughout the United States and abroad.

SpaceX was founded in 2002 with the express goal of dramatically improving the reliability, safety, and affordability of space transportation. Today, SpaceX today is the world's largest launch services provider, measured by missions under contract and cadence of launch, with 42 successful Falcon 9 launches, including 15 in 2017 alone.

SpaceX has deployed over 65 commercial communications satellites since 2010. In addition to commercial satellite operators, SpaceX supports a diverse and growing set of satellite and space customers, including NASA, the Department of Defense, and allied international governments. We have signed contracts for nearly 70 missions on manifest, representing more than $10 billion. Under one of the most successful public-private programs ever undertaken with NASA, SpaceX also supports the Nation's civil space program through routine cargo resupply missions with our Dragon spacecraft to the International Space Station (ISS). Next year, we will have the awesome responsibility of launching NASA astronauts to space from U.S. soil for the first time since the Space Shuttle was retired in 2011. SpaceX is also a certified provider to the Department of Defense for national security space launch.

Leveraging our experience in space launch system and spacecraft design, development, production, and on-orbit operations, SpaceX is developing an innovative NGSO constellation. Our system is designed to reach directly to end users, and provide global broadband services at speeds, latencies and prices on par with terrestrial alternatives available in metropolitan communities. Accordingly, we filed applications with the Federal Communications Commission ("FCC") in November 2016 and April 2017 that detail those plans.

My testimony today will describe SpaceX's planned satellite constellation, including our capabilities and timelines, as well as offer a number of recommendations for the Committee's consideration to streamline regulatory processes, maximize planned government investment to accelerate broadband deployment, and ensure a safe, collaborative operating environment in space. Specifically, my testimony today will focus on the following areas:

(1) *Launch.* The importance of low cost launch enabled by rapid reusability and robust launch infrastructure to making large-scale, space-based broadband Internet services more viable today than ever before, and recommendations to improve the launch licensing regulatory framework both at the FCC and the Federal Aviation Administration (FAA);

(2) *Spectrum Efficiency.* Recommendations to ensure the efficient use of spectrum, including potential regulatory incentives for systems that invest in technologies that effectively share spectrum. The Committee should take proactive steps to encourage and reward companies that utilize and advance technologies that result in maximum spectrum sharing and efficiency.

(3) *Technology-Neutral Programs.* The need to update eligibility requirements for nationwide broadband infrastructure initiatives to ensure they are truly technology neutral, and do not needlessly preclude satellite systems with equivalent or better service from competing against more traditional broadband providers. This hearing is an important forum to review how satellite broadband has improved and can contribute to the Nation's connectivity goals, and how to incorporate such services into any national infrastructure initiative.

(4) *Space Safety.* The importance of ensuring that large satellite constellations will employ robust orbital debris and space safety protocols, including high reliability for individual spacecraft; the speedy, planned deorbit of satellites at the end of the useful life; the ability to implement active collision avoidance throughout a satellite's life; and transparency and information sharing.

Vertically Integrated Approach to Manufacturing and Extensive Space Operations Experience

As the leading domestic commercial space launch provider, SpaceX has restored the U.S. as a leader in global commercial satellite launch by percentage of market share. In developing its fleet of highly-reliable, affordable, and innovative launch vehicle systems, SpaceX has invested billions of private capital in sophisticated manufacturing processes, engineering and design know-how for space and launch systems, the infrastructure needed to launch satellite payloads into orbit, and technologies to make launch more affordable. These manufacturing, engineering and design capabilities are trusted by the U.S. civil and national security space community, commercial satellite operators, and international governments.

Looking forward, SpaceX intends to leverage its fifteen years of experience in space to develop and deploy a cost-effective and sophisticated broadband satellite constellation. Our vertically-integrated approach to this initiative—linking design, development, production, launch, and operations—lends a unique capability to address the challenges that stymied past generations that have considered low-earth orbiting communications constellations from space.

SpaceX's proven core competency is the manufacturing of complex space systems with increased efficiency, scale, and affordability. Here, SpaceX has a vertically-integrated approach to manufacturing uncommon within the aerospace industry. For Falcon, SpaceX manufactures over 70 percent of the value of the Falcon 9 in-house, including the first-and second-stage propulsion systems (Merlin 1D and MVacD), the tanks, composite structures, payload fairings, avionics, etc. Similarly, SpaceX produces the autonomous Dragon spacecraft in house, including the on-board propulsion systems (Draco and SuperDraco), pressure vessel, avionics, and all other major subsystems and components. SpaceX also has extensive test facilities at our Rocket Development facility in McGregor, Texas.

SpaceX will carry this vertical approach to design, manufacturing, and test into our satellite broadband constellation. SpaceX expects to manufacture in-house the majority of each spacecraft, leveraging the experience we have gained with Falcon and Dragon in manufacturing and specific systems, such as propulsion systems, avionics, and solar arrays, among others. We are uniquely positioned to apply these proven methods of reliability and cost-effectiveness to our planned broadband satellite constellation.

SpaceX's satellite constellation will also benefit from the company's extensive space operations experience, drawn from the Falcon 9 launch vehicle's 42 successful flights, 18 successful fist-stage re-entries and landings, and over 13 Dragon flights to and from the International Space Station (ISS). SpaceX can build upon the optimized guidance, navigation, and control ("GNC") systems that allow us to land our first-stage boosters on land and at sea with pinpoint accuracy. Similarly, our deep experience with orderly and safe de-orbit through routine Dragon missions to the

ISS has informed and enriched careful and detailed on-orbit operations and de-orbit planning for the satellite constellation. SpaceX is also drawing on the operational experience it has built with every Federal agency working on space-related issues—including FCC, FAA, NASA and DOD—to prepare and coordinate for the satellite constellation undertaking. This unique manufacturing, operational, and cross-agency engagement will advance the planning and operations of the satellite broadband constellation.

II. Expanding Broadband Access and Bridging the Digital Divide

SpaceX sees a robust market of continuously-growing demand for high-speed broadband both in the United States and worldwide. Connected consumers continue to increase requirements for speed, capacity, and reliability. And the volume of traffic flowing over the world's networks continues to skyrocket, with one vendor estimating that annual global Internet Protocol ("IP") traffic surpassed the zettabyte threshold in 2016—meaning that over 1,000 billion gigabytes of data was exchanged worldwide last year.[1] By 2020, that figure is projected to more than double (reaching a level nearly 100 times greater than the global IP traffic in 2005), global fixed broadband speeds will nearly double, and the number of devices connected to IP networks will be three times as high as the global population.[2]

However, as the Committee is aware, millions of Americans outside of limited urban areas lack basic, reliable access to broadband—even as worldwide demand for data skyrockets. We note a few important facts about the availability and quality of broadband access in the United States and worldwide:

— According to the FCC, 34 million Americans lack access to 25 megabits per second ("Mbps") broadband service, and 47 percent of the Nation's students lack the connectivity to meet the FCC's short-term goal of 100 Mbps per 1,000 students and staff. [3]

— The FCC has further noted that "there continues to be a significant disparity of access to advanced telecommunications capability across America with more than 39 percent of Americans living in rural areas lacking access to advanced telecommunications capability, as compared to 4 percent of Americans living in urban areas."[4]

— Connectivity levels are even lower for tribal communities, with "approximately 41 percent of Americans living on Tribal lands lacking access to advanced telecommunications capability."[5]

— In addition, nearly 10 million Americans living in non-rural areas also lack basic access to high-speed Internet service. As a general matter, the U.S. continues to lag behind other developed nations in both its broadband speed and in price competitiveness.

— Even in urban areas of the United States, a majority of Americans lacks more than a single fixed broadband provider from which to choose and may seek additional competitive options for high-speed service.[6] According to the FCC, "only 38 percent of Americans have more than one choice of providers for fixed advanced telecommunications capability," with only "13 percent of Americans living in rural areas having more than one choice of providers of these services compared to 44 percent of Americans living in urban areas."[7]

— Beyond the United States, the United Nations Broadband Commission for Sustainable Development recently noted that 4.2 billion people, or 57 percent of the world's population, are simply "offline" for a wide range of reasons—but predominately because the necessary connectivity is not present or not affordable.[8]

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[1] Cisco Visual Networking Index: Forecast and Methodology, 2015–2020, at 1 (June 6, 2016), available at *http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11–481360.pdf; see also http://blogs.cisco.com/sp/happy-zettabyte-day-2016.* To fathom the volume of a zettabyte, if one byte is a litter, then a zettabyte is the equivalent of 7080 Pacific Oceans. *See id.*

[2] Ibid.

[3] Federal Communications Commission, *2016 Broadband Progress Report,* (January 28, 2016), GN Docket No. 15–191, available at *https://apps.fcc.gov/edocs_public/attachmatch/FCC–16–6A1.pdf.*

[4] Ibid.

[5] Ibid.

[6] FCC, *2016 Broadband Progress Report.*

[7] Ibid.

[8] Broadband Commission for Sustainable Development, "Open Statement from the Broadband Commission for Sustainable Development to the UN High-Level Political Forum (HLPF)"

Continued

III. NGSO Satellite Constellations Offer Unique Advantages in Expanding Broadband Access

Satellites have traditionally served at the forefront of remote and rural connectivity, and often have helped to alleviate inequities in the availability of communications services, in part due to geographic reach. Historically, satellites first revolutionized the availability of international telephony, then pioneered global distribution of video content. More recently, satellite systems have introduced broadband connectivity for mobile platforms, such as aircraft and ships—establishing and supporting new markets and enhancing those businesses and their customer experience.

New constellations of sophisticated satellites operating close to the Earth add important prospects for remote connectivity, particularly where latency is critical. In adopting new rules for such NGSO systems and moving briskly on NGSO applications for U.S. market access and systems licenses, the Commission has underscored the vital role that NGSO systems can have for the broadband landscape of the future, and that this future is coming imminently.[9]

At its Open Meeting on September 26, 2017, the Commission adopted a Report and Order and Further Notice of Proposed Rulemaking removing "regulatory obstacles for companies proposing to provide [broadband] services via large, ambitious, non-geostationary-satellite orbit (NGSO), fixed satellite service (FSS) systems."[10] SpaceX supports the Commission's actions in this proceeding that update outdated NGSO rules, create greater regulatory certainty and add flexibility for next-generation NGSO systems that hold the promise of truly nationwide satellite broadband coverage at speeds and latencies comparable to terrestrial fiber-optics. Chairman Pai recognized the importance of NGSO systems, stating that "[a]s we strive to close the digital divide, we must be open to any and every technology that could connect consumers across the country.. . . The rules we adopt will promote the next generation of NGSO systems, which could expand broadband access where it's needed most."[11] Commissioner Clyburn similarly stated that "[t]oday, we take yet another step to close those gaping divides by updating and streamlining rules to facilitate the deployment of NGSO FSS systems, which have the potential to provide ubiquitous broadband services to all of our communities."[12]

SpaceX is unique in designing its system specifically to link consumers directly with high-speed, low-latency broadband connectivity. On orbit, SpaceX is employing advanced operational techniques and spacecraft technologies in order to maximize the capacity it can employ for high-speed broadband services, including high-degrees of re-use of valuable spectrum, and flexibility in interference mitigation, allowing our system to co-exist with other space-and ground-based systems. On the ground, affordable, easy-to-install end-user terminals can obviate the costs, environmental regulations, property rights issues, and other regulatory obstacles, that have precluded many unconnected end-users in smaller communities, or remote locations from comparable quality Internet access. Once the satellite capability is deployed on-orbit, the incremental costs of delivering broadband access to each new customer become agnostic to urban, suburban, or rural locations, in contrast to traditional terrestrial broadband networks.

SpaceX's constellation is designed fulfill its primary service objective of providing high-speed broadband directly to end users globally, both widely-dispersed locations and also more concentrated population areas with higher capacity demands. With many satellites in view, the constellation offers a diversity of path for reliability and also access for any given customer location, even those blocked from traditional satellite services by buildings, mountains, or other physical obstacles. Phased-array technology on-orbit and on-ground gateways and end-user terminals permit a large number of very narrow beams, reusing frequencies many times over to generate a level of capacity that can meaningfully bridge the broadband connectivity gap. The same phased array technology allows for dynamic beam formation, shaping, and direction, both to tailor capacity by demand profile and also to mitigate interference to space-and ground-systems. Spectrum sharing prospects with terrestrial systems sharing the same frequency bands are enhanced by the use of high-elevation angles

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(July 11, 2016), available at *http://broadbandcommission.org/Documents/publications/HLPF-July2016.pdf.*

[9] *Update to Parts 2 and 25 Concerning Non-Geostationary, Fixed-Satellite Service Systems and Related Matters,* IB Docket No. 16–408, Report and Order and Further Notice of Proposed Rulemaking, FCC 17–122 (rel. Sept. 27, 2017) ("NGSO Report & Order").

[10] Id., Statement of Chairman Ajit Pai (stating that he has circulated to the Commissioners orders granting U.S. market access to two more NGSO systems).

[11] *NGSO Report and Order,* Statement of Chairman Ajit Pai.

[12] *Id.,* Statement of Commissioner Mignon L. Clyburn.

for communications with earth stations and highly directional space station and earth station beams.

The combination of unique vertically-integrated manufacturing and design capabilities, proven production and operations experience, and highly-adaptable, leading-edge technology in space and on the ground gives promise for the SpaceX constellation to help close the digital divide, and bridge the current disparity in service between well-covered metropolitan consumers and their counterparts in rural or other "hard-to-reach" areas. Importantly, that urban-rural parity can also be sustained over future generational upgrades over the NGSO constellation, without requiring additional costly last-mile infrastructure upgrades.

This lag was noted by the Government Accountability Office ("GAO"):

> Access to affordable broadband telecommunications is vital to economic growth and improved quality of life across the country. In rural areas in particular, broadband can serve to reduce the isolation of remote communities and individuals. The provision of broadband Internet infrastructure and services in the United States is generally privately financed. However, rural areas can have attributes that increase the cost of broadband deployment, such as remote areas with challenging terrain, or make it difficult to recoup deployment costs, such as relatively low population densities or incomes. These attributes can decrease the likelihood that a broadband service provider will build out or maintain a network in a rural area. For these reasons, some rural areas lag behind urban and suburban areas in broadband deployment or service speed.[13]

Next-generation satellite systems operating in orbits close to the Earth, powered by innovative technologies to provide rapid data rates and minimal latency, can offer a way around this gap in broadband access in the United States.

IV. SpaceX's Proposed Satellite Constellation Architecture

As noted, SpaceX plans to leverage its unique space-based design, manufacturing, launch, and space operations experience for the planned NGSO constellation.

In particular, SpaceX aims to apply our experience in designing and manufacturing cutting-edge space to apply technology advancements like dynamic beam forming and phased array antennas in space and on the ground. These will ensure both unparalleled frequency re-use and spectral efficiency, as well as redundant and high-capacity infrastructure. The satellites' optical inter-satellite links will establish a "mesh network" in space through which the satellites will communicate with each other, further enhancing the capacity levels and network flexibility for faster and reliable broadband satellite service.

SpaceX's consumer focus sets it apart from most other proposed NGSO system. SpaceX has designed its system with the primary purpose of providing broadband service directly to end-users, particularly individual households and small businesses. Meeting this distinct direct-to-end-user goal demands far more on-orbit capacity, which in turn drives the larger number of satellites in the design and the focus on spectrum re-use efficiency. Initially, the SpaceX system will consist of 4,425 satellites operating in 83 orbital planes (at altitudes ranging from 1,110 km to 1,325 km). This system will also require associated ground control facilities, gateway earth stations, and end user earth stations.[14] Using Ka-and Ku-Band spectrum, the initial system is designed to provide a wide range of broadband and communications services for residential, commercial, institutional, governmental, and professional users worldwide. SpaceX has separately filed for authority to operate in the V-Band, where we have proposed an additional constellation of 7,500 satellites even closer to Earth, our Very Low Earth Orbit, or "VLEO," system. In the future, these satellites will provide additional broadband capacity to the SpaceX system and further reduce latency where populations are heavily concentrated.[15]

To implement the system, SpaceX will utilize powerful computing and software capabilities, which will enable SpaceX to allocate broadband resources in real time, placing capacity where it is most needed and directing energy away from areas where it might cause interference to other systems, either in space or on the ground. Because the satellites will beam directly to gateways or user terminals, the infra-

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[13] U.S. Government Accountability Office, *Rural Broadband Deployment: Improved Consistency with Leading Practices Could Enhance Management of Loan and Grant Programs,* (April 2017), GAO–17–301, available at *http://www.gao.gov/assets/690/684093.pdf.*

[14] Space Exploration Holdings, LLC, *Application for Approval for Orbital Deployment and Operation Authority for the SpaceX NGSO Satellite System* (November 15, 2016), Before the Federal Communications Commission, IBFS File No. SAT–LOA–20161115–00118.

[15] Space Exploration Holdings, LLC, *Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System* (March 1, 2017), Before the Federal Communications Commission, IBFS File No. SAT–LOA–20170301–00027.

structure needed on the ground—particularly in rural or remote areas—is substantially reduced, essentially addressing the "last mile" challenge and helping to close the digital divide. In other words, the common challenges associated with siting, digging trenches, laying fiber, and dealing with property rights are materially alleviated through a space-based broadband network.

SpaceX intends to continually iterate and improve the technology in the system, something that our satellite manufacturing cost profile and in-house launch capability uniquely enables. The ability to modify service as necessary, as well as refresh the technology of the satellite system through iterative spacecraft design changes and phased, continuous deployment, is critical to meet rapidly changing customer demands and responsibly utilize spectrum. This approach will ensure that the system remains adaptable to existing and future customer demands.

For the end consumer, SpaceX user terminals—essentially, a small flat panel, roughly the size of a laptop—will use similar phased array technologies to allow for highly directive, steered antenna beams that track the system's low-Earth orbit satellites. In space, the satellites will communicate with each other using optical inter-satellite links, in effect creating a "mesh network" flying overhead that will enable seamless network management and continuity of service. The inter-satellite links will further help SpaceX comply with national and international rules associated with spectrum sharing, which distinguishes our system from some of the other proposed NGSO constellations.

Overall, SpaceX has designed our system to achieve the following key objectives:

(1) *Capacity.* By combining the umbrella coverage of the LEO Constellation with the more intensive coverage from the VLEO Constellation, the SpaceX System will be able to provide high volume broadband capacity over a wide area. SpaceX will periodically improve the satellites over the course of the multi-year deployment of the system, which may further increase capacity.

(2) *Adaptability.* The system leverages phased array technology to steer dynamically a large pool of beams to focus capacity where it is needed. As noted, optical inter-satellite links will permit flexible routing of traffic on-orbit. Further, the constellation ensures that a variety of frequencies can be reused effectively across different satellites to enhance the flexibility, capacity and robustness of the overall system.

(3) *Broadband Services.* The system will be able to provide broadband service at fiber-like speeds, the system's use of low-Earth orbits will allow it to target latencies comparable to terrestrial alternatives. SpaceX intends to market different packages of data at different price points, accommodating a variety of consumer demands.

(4) *Efficiency.* SpaceX is designing the system from the ground up with cost-effectiveness and reliability in mind, from the design and manufacturing of the space and ground-based elements, to the launch and deployment of the system using SpaceX launch services, development of the user terminals, and end-user subscription rates.

SpaceX soon will begin the process of testing the satellites themselves, with the first two prototypes launching within the next several months. Following the successful demonstration of our space and ground technology, SpaceX intends to begin the operational satellite launch campaign in 2019. The remaining satellites in the constellation will be launched in phases through 2024, when the system will reach full capacity with the Ka-and Ku-Band satellites. The constellation will be operational well in advance of full deployment, and we expect to begin offering services commercially as early as deployment of 800 satellites.

SpaceX is highly experienced with cutting-edge debris mitigation practices and has deep ties with the domestic and international institutions tasked with ensuring the continued safety of space operations. SpaceX has designed its satellite constellation to meet or exceed all existing requirements for safety of operations in space and upon de-orbit of satellites, and SpaceX is deeply committed both to maintaining a debris-free environment in space and to disposing of orbital assets in a responsible and safe manner.

V. Overcoming the Cost of Large Constellation Deployment: Launch and Reusable Rockets

While rights of way and the high costs of terrestrial connectivity for rural remote areas historically has limited the reach of broadband, the cost of space launch has been the major obstacle to the deployment of large-scale broadband satellite constellations. Affordable access to space effectively limited the size of satellite constellations operating close to the earth, where shorter signal paths could lower overall end-to-end latency to levels comparable to modern mobile or fixed broadband.

By rethinking the launch vehicles design and production, SpaceX has driven down launch costs. Our work to recover and reuse rockets will enable truly revolutionary reductions in the speed and cost of space access. Every other launch vehicle provider in the world discards its rocket hardware after each launch. This practice is akin to throwing away an airplane after every leg of a trip. However, SpaceX has invested considerable internal resources to develop and implement reusability into the Falcon 9. Most of a launch vehicle's cost is concentrated in its first stage. SpaceX has incorporated advanced technologies that uniquely enable the Falcon 9 first stage to return to either a ground-based landing platform or an off-shore autonomous spaceport droneship after nearly every mission.

This year, SpaceX proved out this concept with the successful launch and landing of three flight-proven Falcon 9 boosters, placing high-value telecommunications satellites into orbit for commercial satellite operators. Each Falcon 9 first stage will soon be capable of at least 10 flights with no refurbishment and many more flights after minimal refurbishment, resulting in significant cost reductions.

Dramatically lower launch costs and the demonstrated capability to launch nearly every two weeks (or less) allows SpaceX affordably to deploy larger numbers of satellites for its own NGSO constellation at a pace not previously possible. Moreover, affordable access to space also allows SpaceX to refresh the constellation technology over time, driving down the cost of producing each satellite and making it easier to add capability to meet consumer demand and dynamically react to an evolving market.

VI. Policy Recommendations to Facilitate the Deployment of Space-Based Broadband Systems Safely and Efficiently

As the Committee considers policies that could facilitate the expansion of broadband access in the U.S., SpaceX offers the following recommendations:

(1) *FAA Commercial Launch License Regulations Require Modernization.* As noted, launch is the key enabling capability for the deployment of NGSO constellations, as well as other satellite platforms that are critical to expanding broadband access. As such, SpaceX recommends that existing FAA launch statutes and regulations be modernized and streamlined to adapt to higher numbers of launches at a more rapid cadence. The current FAA regulations were promulgated in a time when commercial spaces launches were rare, and launch was primarily the domain of the U.S. Government. However, as the industry transitions from a pace of a few commercial launches per year to a launch per week, or more, in the near future, and new U.S. launch providers consider entering the market, it is essential that FAA regulations be updated to avoid obstructing industry growth and innovation in the U.S. domestic commercial space launch industry.

(2) *FCC Commercial Launch Spectrum Licensing Process Should be Streamlined.* The FCC licenses the radio frequencies used by commercial launch operators during launch and reentry operations. Because launches originally were assumed to be by and for the government, there is no allocation for the spectrum used for commercial launchers. As a result, the FCC must use its experimental licensing rules through a cumbersome Special Temporary Authorizations (STA) process. This process is time-consuming for the applicant and the FCC, as each launch mission may have multiple STAs for launch, landing, and various short-range communications with the payload. Each STA is limited in validity to a maximum of six months; and is approved on a non-interference basis, with "special conditions" that ensure frequency coordination with other Federal users in the spectrum bands. In September 20, 2013, the FCC issued a Notice of Proposed Rulemaking (NPRM) addressing spectrum for non-federal space launch, in which it noted that the STA process is suboptimal as commercial space launches and other commercial operations in orbit grow in volume and frequency.

    The FCC's NPRM would remedy this problem by establishing co-primary, interference-protected allocation status for commercial space launch companies and would streamline the authorization process through standard, clearly-defined application and coordination processes. The growth of the U.S. commercial space launch industry necessitates the development of a streamlined, predictable spectrum licensing process to ensure the continued growth of the industry and the effective, efficient, and prudent use of radio frequencies.

    This NPRM, now pending for more than four years, proposes a specific allocation for non-federal space launch that would allocate specific frequencies commercial space launch companies. It would streamline the authorization process and allow for a single, five-year license for multiple like-missions (for example, all missions for the same customer to the same orbital plane). The allocation would be secondary to the Federal users already in the band, requiring the same coordination processes undertaken now to de-conflict any interference prior to each mission. Importantly, Federal agencies have agreed to this change, and the agency that represents Federal users of radio frequencies, the Department of Commerce's National Telecommunications & Information Administration ("NTIA") sent a letter to the FCC in September 2016 stating that Federal users of the frequency bands under discussion "strongly agree" with the proposed new rules.

SpaceX recommends that the Committee encourage the FCC to act now to adopt the proposed rules and then move quickly to develop implementing regulations that can allow frequency authorizations to cover multiple like launches. This long overdue action would save time and money, and it would help with long-term planning for both the FCC and industry.

(3) *Systems and Technology that Achieve Spectrum Efficiency Should be Rewarded.* The new generation of broadband NGSO constellations holds incredible potential to bring affordable, fiber-like broadband services to underserved and unserved areas of the United States. Investment in advanced technologies that provide spectral efficiency and operational flexibility are necessary for NGSO systems to increase access to reliable, high-speed broadband connectivity. How they share the valuable spectrum resources will be important to their operational efficiency and their ability to deliver quality broadband services. Unfortunately, not all aspiring operators have chosen to make the investment necessary to include many of these technologies in their proposed systems. As a result, some systems would not only make inefficient use of the spectrum they seek to use, but also may prevent other NGSO systems from efficiently sharing the available spectrum.

As such, the Committee should ensure that their rules do not unduly burden more flexible, adaptable systems with the responsibility of spectrum sharing with other less sophisticated systems. Any such outcome would impose an asymmetrical burden that is counter to the overall FCC goals of incentivizing efficient spectrum sharing. Spectrum sharing policies should ensure that all systems have equitable access to spectrum, avoid any warehousing of spectrum by non-operating systems, and incorporate sufficient flexibility to promote and accommodate spectrum coordination among operating systems. Given the advent of new space-based and ground technologies, spectrum sharing is most efficiently managed by using highly intelligent and flexible satellites, as this expands the range of potential sharing strategies available to the operators involved.

(4) *Spectrum Use Policy in the Ka-and V-Bands Should be Revised.* When drafted, FCC policies governing the use of spectrum by NGSO constellations—specifically in Ka-and V-bands—did not envision the potential of very large constellations operating in LEO. As a result, NGSO constellations are unduly restricted from using important segments of spectrum as compared to ground-based fixed systems. While the agency has granted waivers for NGSO systems to operate in parts of this spectrum on an unprotected, non-interference basis, this approach is not sustainable over the long-term, especially as these new NGSO systems come online.

Clear and reasonable rules must be developed to govern how multiple companies will share spectrum among NGSO systems. These rules are essential to the development and deployment of potential NGSO systems. Companies have proposed widely varying space architectures, ranging from highly-elliptical orbit systems operating from 8,000–43,500 km that focus on Arctic coverage to small constellations at medium Earth orbit at around 10,000 km above the Earth to several larger constellations operating in LEO at 1,000–3,000 km from the Earth.

The FCC recently issued a Report and Order to update rules for NGSO satellite systems, including deployment milestones, geographic coverage, and allocations of radio-frequency bands. The new rules also discussed how multiple NGSO operators should share valuable spectrum, specifying that the preferred method to address interference between two NGSO systems is operator-to-operator negotiations. Where operator-to-operator negotiations fail, the FCC recommended parameters to determine where operators could interoperate and where they would be required to simply divide frequency bands ("splitting spectrum").

Every NGSO applicant agreed that spectrum splitting is the least desirable and most inefficient approach to sharing frequencies, because it reduces capacity and services made available to consumers. The parameters that the FCC identified work well when sharing spectrum for downlinking from space, because downlinks already have power limits to protect other services so all NGSO systems operate at similar downlink power levels. However, when applied to uplinks to spacecraft in widely varying space architectures, the rules actually yield far more instances of mandated spectrum splitting because no comparable power limits exist. The wide disparity in uplink power levels often yield situations that defy coordination.

The Committee should encourage the Commission to open a further inquiry on how to best optimize spectrum use among non-homogeneous NGSO systems to elicit further technical input and regulatory consideration. This should include review of the uplink transmissions needed to traverse across higher NGSO orbits in a manner that does not create broad-based interference to other lower-situated NGSO systems. The FCC's inquiry should also examine the effect of beam-size on interference mitigation, since large geographic beams of some higher-altitude systems will operate without flexibility, and essentially nullify the flexibility of other NGSO systems. These technical inquiries should presume that the public interest is served by multiple successful NGSO systems, providing services to American consumers and using valuable spectral resources effectively.

(5) Satellite Ground Station Siting Rules Must be Modified. As part of its Spectrum Frontiers rulemaking, the FCC is reviewing the rules it set out for the siting of satellite gateways using the 28 GHz range (Ka-band) frequencies, including gateways supporting both geostationary and upcoming NGSO constellations. The current earth station siting rules are a complex mix of numerical caps of gateways per county, and geographic avoidance of population centers and arterial roadways. These rules were designed to balance the need to protect terrestrial operations with satellite operators' need to deploy satellite gateways in locations with access to Internet points of presence and backhaul facilities. However, the metrics defined for gateway siting are overly complex and difficult to interpret, and also may actually have the unintended effect of deterring satellite deployment in certain rural areas. Several satellite operators have suggested new metrics that would remove the per-county limit and recalibrate the siting rules.

The FCC should streamline the Ka-band satellite gateway siting rules to reflect reasonable real-world deployment scenarios for both existing and next-generation satellite gateway technologies and their terrestrial mobile broadband counterparts. The FCC should also exempt from its siting rules those satellite gateway earth stations that operate under the limit set to protect mobile broadband networks, including both any per-county cap and population coverage limits.

These clarifications will maintain reasonable interference protection for evolving terrestrial mobile networks while permitting the development of ground infrastructure needed to support NGSO satellite systems. Given that NGSO constellations could help provide broadband access to millions of previously unserved or underserved Americans, the FCC should adopt spectrum sharing rules that do not unduly constrain deployment of Ka-band satellite ground station facilities to support the delivery of innovative satellite services.

(6) Maintaining a Safe Space Environment. Any policy environment concerning orbital debris should minimize risk to space systems without imposing an unnecessary burden on responsible actors. Recent concern in this arena has been driven by the proliferation of small experimental satellites (micro-, nano-, and cubesats) that are not maneuverable; by recent debris collisions and end-of-life disassembly problems with aging geostationary satellites; and, to some extent, by the potential deployment of large NGSO constellations.

To reduce conjunction risks, policies should be pursued that encourage responsible and reliable satellite design and operation from launch to disposal. Future policies should balance a satellite's deorbit reliability with the risk of a premature failure when considering whether to extend the satellite's use after it reaches its design lifetime. Regulations can encourage and reward manufacturing designs that allow for easier tracking (*e.g.,* tracking reflectors) and are fault-tolerant and safe, particularly with respect to battery and propulsion systems. Such designs would utilize materials that diminish the risk of generating new debris from internal faults, impacts with untracked debris, or planned de-orbit reentries. Additionally, current international policy guidelines mandate satellites have the capability for disposal within 25 years; this time-frame should be shortened. Given the diverse Federal agencies employed with space regulation and policy matters, SpaceX welcomes the establishment of the National Space Council and encourages robust inter-agency dialogue to root agency policies in common objectives and premises, even if the diverse agency authorities and space missions under each agency's oversight results in distinct specific regulations.

SpaceX also supports broad sharing arrangements among space operators to increase the accuracy of ephemeris data and mitigate potential conjunction events, even while space activities expand. Expanded data sharing will augment reliance on the space surveillance network for positional information and reduce positional uncertainty, reducing unnecessary on-orbit maneuvers. In addition to increased data sharing among operators, the United States should consider investments in orbital object tracking radars and other systems to enhance the amount and quality of space surveillance data.

(7) Satellite Broadband Technology Should Not Be Excluded from FCC Broadband Incentives. The FCC is currently in the process of reviewing rules for and structuring the second phase of the Connect America Fund (CAF II). This program, with awards determined through a reverse auction, would support up to $1.98 billion in funding over ten years to support broadband expansion to areas of need across the country. The Commission has adopted rules providing different bidding weights to different tiers of speed, usage, and latency applicants might select. This is a reasonable means by which to ensure the best service receives the most favorable score in the bidding process, which is inherently in the interest of the American consumer.

However, current rules preclude all satellite systems from meaningful participation, simply because current-day geostationary satellite offerings do not meet the FCC's high-speed, low-latency criteria. Even if next-generation NGSO satellite providers could provide equivalent or better services than the top tiers outlined in the rules, these systems are still precluded for participating. This creates a false presumption that all satellite technologies are now and forever unsuitable for consumer broadband, and therefore ineligible for support in areas where NGSO systems are uniquely designed to serve customers competitively and cost-effectively. Conflating NGSO systems and traditional geostationary systems would be the same as the FCC prohibiting fiber systems from bidding because dial-up is not fast enough: just because both systems are hard wired does not mean that they are equivalent.

The original CAF rules also require a stand-alone voice telephony service, meaning that bidders for the fund cannot offer only internet-based Voice over IP ("VoIP") services like Skype or Vonage but must bundle a land-line-type service. This adds inefficiency and cost, and creates another bias against non-wireline bidders.

The FCC should remove constraints on any qualifying technology to participate, and update or eliminate the existing general preclusion for satellite bidders. By doing so, the FCC will demonstrate a clear commitment to results-based regulation, with a CAF II auction that supports broadband in the areas that need it in the most cost effective, administratively efficient way. Moreover, the Commission will achieve this goal while ensuring that every bidder—no matter what technology it might use—has a meaningful opportunity to participate. In addition, the Commission should remove the unnecessary requirement to provide standalone voice service rather than simply make voice-over-IP capabilities.

(8) Next Generation Satellite Systems are Broadband Infrastructure and Should Be Included in Any Infrastructure Legislation. The expansion of satellite broadband through U.S.-based constellations is, fundamentally, a national infrastructure project, even though many components of the infrastructure will be in space. In prior investment rounds and through funds like the Universal Service Fund ("USF"), satellite broadband was often an afterthought. For example, of the $6.9 billion awarded for broadband infrastructure through National Telecommunications and Information Administration's ("NTIA") Broadband Technology Opportunities Program ("BTOP") and the U.S. Department of Agriculture's Rural Utilities Service ("RUS"), only approximately $100 million went to satellite systems, or less than 1.5 percent of all funds appro-

priated.[16] In many ways, this was the result of limitations at the time on satellite capacity, high latency rates due to satellite distance from the Earth, and relatively slow data rates compared to terrestrial and mobile networks. It was also related to a general failure of imagination to make investment and subsidy structures applicable to satellite infrastructure and consumer hardware, since satellite systems have few "shovels in the ground."

However, as satellite-based broadband achieves speeds, latencies, and pricing equivalent to terrestrial and 5G wireless technologies, it becomes especially critical for Congress and Federal agencies to reconsider how these systems can participate in national infrastructure investment programs and other Federal initiatives to close the digital divide. Infrastructure associated with a satellite broadband system includes launch facilities, consumer terminals that are placed on homes or businesses, gateways that will be placed at potentially hundreds of Internet points of presence ("PoPs") throughout the United States that are used to route traffic, large antennas to track and control the satellites in space, and satellite operations centers. The satellites themselves are essentially infrastructure in the sky, a network that is not dissimilar to cell towers or underground fiber.

As such, SpaceX encourages the Committee to take steps to ensure that satellite-based broadband infrastructure is duly captured in any Federal infrastructure, incentive, or tax policy legislation undertaken to expand broadband access in the United States. Such an approach will not only ensure that Congress and regulatory agencies maintain a technology-neutral approach, but it will also ensure the U.S. Government and American consumers are positioned to benefit from the significant innovations and great promise of that satellite systems are poised to bring.

Mr. Chairman, I appreciate your invitation to testify before the Committee today. SpaceX looks forward to being part of the solution to expand access to high-speed, reliable, and affordable broadband Internet connectivity in the United States and worldwide.

The CHAIRMAN. Thank you, Ms. Cooper.

Mr. Dankberg.

STATEMENT OF MARK DANKBERG, FOUNDER AND CHIEF EXECUTIVE OFFICER, VIASAT, INC.

Mr. DANKBERG. Chairman Thune, Ranking Member Nelson, and members of the Committee, I'm Mark Dankberg, Co-Founder and CEO of ViaSat. Thank you for the chance to testify on the U.S. satellite industry and the critical role it plays in closing the digital divide in connecting millions of mobile devices and in our national defense.

ViaSat is an American success story. Started in my house 31 years ago, we've generated billions in revenue, gone public, and created almost 5,000 high-paying jobs.

Six years ago, we launched our first satellite to deliver truly competitive broadband services directly to rural America, to airlines, and even to Air Force One. Though a space newcomer, we're redefining satellite. Our first one had 100 times the bandwidth of a typical satellite; our second doubled that; and we're building one now 1,000 times better than the typical satellite still in use today.

The global satellite industry is valued at $260 billion a year. The U.S. has the largest share. Satellite service is the biggest segment and the economic engine for commercial space. Advances in space-

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[16] National Telecommunications and Information Administration, U.S. Department of Commerce, Broadband Technology Opportunities Program (BTOP) Quarterly Program Status Report (March 2017), available at *https://www.ntia.doc.gov/files/ntia/publications/ntia_btop_31st_qtrly_report.pdf;* and U.S. Department of Agriculture, Rural Utilities Service, Broadband Initiatives Program Final Report (December 2016), available at *https://www.rd.usda.gov/files/reports/RUS_BIP_Status_FinalReportDec_2016.pdf.pdf.*

craft and rockets depend on demand for satellite services. Communication is the largest piece of services, and broadband is the fastest growing part of communications.

Broadband satellite demand has skyrocketed as media and entertainment evolves from broadcast to Internet-enabled to on-demand service. If you've ever seen a frozen Internet videostream, you know the pain of slow broadband.

Today, we deliver faster Internet to hundreds of thousands of American homes. We've grown without subsidies, competing against much larger companies. We see the market work. When our service is faster, people choose ViaSat.

In 2012, our download speed was 12 megabits per second, above average back then. Our second-generation satellite reaches 100 megabits per second, again, above average for all U.S. broadband. We've invested heavily. We built our own payload factory, employing hundreds of people. In 5 years, we've invented three generations of satellites, aiming to bring fiber-like speeds to Americans left behind by other technologies. We're still designing even faster versions.

We're disrupting in-flight WiFi, too. Not long ago, airborne WiFi and the terrestrial wireless link, so slow and expensive, hardly anyone used it. We now bring satellite WiFi to every JetBlue flight free to every passenger and with enough bandwidth to stream video. It's so popular, there is often more connected devices than passengers. We have expanded to large portions of United and American Airlines, too.

We're exporting to international airlines. The global airline industry sees satellite WiFi as the future, with over 3 billion global passengers a year, and over 800 million in the U.S. We believe competition works.

ViaSat embraces the entrepreneurial spirit and competes with the largest companies in the world. Now there are dozens of startups and satellites in space, and we believe our success helps to inspire others.

But there's a threat to American satellite growth. Broadband needs spectrum. Our technology uses spectrum extremely efficiently. And we helped the FCC open the 28 gigahertz band for 5G while still enabling growth in satellite broadband by sharing the same band.

Yet, sadly, the FCC's most recent NPRM would take spectrum, long allocated for satellite growth, and designate it almost exclusively to terrestrial wireless. This is the 47 to 52 gigahertz band. We've been investing heavily in the technology that allows us to use the spectrum in the next 5 years. Such a policy decision would pick winners and losers, and stifle competition. The problem is not in accommodating 5G, it's in taking spectrum away from competitive satellite services and creating exclusivity by regulation.

It need not be a zero-sum game. There is no technical argument against spectrum sharing. ViaSat has put extensive technical studies on the record in spectrum frontiers from independent experts showing satellite terrestrial spectrum sharing can work. There is no policy reason to limit competition that can bring the best broadband services to American consumers, businesses, and government users.

In summary, demand for satellite broadband is at an all-time high. We're providing a service that is competitive with urban offerings, and we're uniquely suited to serving the rural Americans other technologies have left behind. There is much more innovation to come. Technology markets are dynamic and evolve in unexpected ways.

ViaSat is committed to serving all of America. We just need the spectrum tools to do so.

Thank you again for the opportunity to appear before you today on these important issues. And I'll be happy to answer questions that you may have.

[The prepared statement of Mr. Dankberg follows:]

PREPARED STATEMENT OF MARK DANKBERG, FOUNDER AND CHIEF EXECUTIVE OFFICER, VIASAT, INC.

Chairman Thune, Ranking Member Nelson, and Members of the Committee, I'm Mark Dankberg, co-Founder, Chairman and CEO, of ViaSat. Thank you for lhe chance to testify on the U.S. satellite industry—and the critical role it plays in closing the digital divide, in connecting millions of mobile devices, and in our national defense.

I've lived the American entrepreneurial dream. Since ViaSat started in my house 31 years ago, we've generated billions in revenue, gone public, and created almost 5,000 high-paying jobs.

Just six years ago, we started redefining satellite broadband when it was apparent that existing technology was not up to the task. We designed our first satellite to extend urban-quality broadband services to rural America, airlines, and even Air Force One. That satellite delivered 100 times the capacity of a typical, satellite and today provides 25 Mbps speeds to large parts of the Nation. Our second generation design, launched this year, doubles that capacity, covers the entire nation, and supports speeds of up to 100 Mbps. We're now building a third generation design with nationwide-coverage, 1,000 times the capacity of the typical satellite in use today, and support for fiber-like speeds. And we're designing even faster versions.

More capacity means better service. It allows us to keep up with the growing demand for our services, provide even more customers at urban quality offerings, and support the video-streaming services that Cisco estimates will represent 82 percent of Internet usage within a few years.

We see the market work. When our service is faster than the competition, people choose ViaSat. This is true not just in the consumer broadband sector, but also in the in-flight WiFi sector.

Before us, in-flight WiFi was slow and expensive, and hardly anyone used it. We have developed satellite-delivered WiFi !hat serves every JetBlue flight—free to every passenger and with enough bandwidth to stream video. It's so popular, there are often more connected devices than passengers. In fact, we connect over two million personal electronic devices per month on airplanes. And we have expanded to the United and American fleets.

We've invested heavily to serve the Americans others have left behind. We built our own factory to allow us to do what no one else was doing. And we're actively exporting this American satellite technology around the world.

ViaSat embraces the entrepreneurial spirit and competes with the largest companies in the world. There are now dozens of start-ups in satellite and space. We believe our success played a role in inspiring others. And ii is clear that advances in spacecraft and rockets depend on demand from commercial satellite operators like us.

But there's a threat to the ability to continue this American innovation and its ability to serve rural America. Broadband satellites need spectrum to achieve these goals.

Our technology uses spectrum extremely efficiently. Last year, we helped the FCC open the 28 GHz band for 5G mobile wireless while still enabling growth in satellite broadband, by sharing that same spectrum.

Yet, sadly, the FCC's most recent NPRM would take spectrum long-allocated for satellite growth and make it available almost exclusively for terrestrial wireless operations. This is the 47–52 GHz spectrum that we have been planning to use on our satellites in the next five years. Such a policy decision would pick winners and losers—and stifle competition. The problem is not in accommodating 5G—it's in taking spectrum away from competitive satellite services und creating exclusivity by regulation.

There's no technical argument against spectrum sharing. Since there's no technical reason, there's no policy reason to prevent limit competition, stifle the ability to bring the best broadband services to America consumers and government users, and foreclose the ability to provide services we can't even imagine today.

In sum, the demand for satellite broadband is at an all-time high, we are providing a service that is comparable to urban offering, and we're uniquely-suited to serving the rural Americans that our competitors have fell behind. The key to our ability to continue to innovate and drive developments in American technology is access to adequate spectrum.

ViaSat is committed to serving all of American. We just need the spectrum tools to do so.

Thank you for the opportunity to appear before you today to discuss these important issues. I would be pleased to answer any questions you might have.

ATTACHMENTS

Report on Satellite Earth Station Shielding Testing

Filed with FCC April 20, 2017, GN Docket No. 14–177.

Corrected 4/20/2017

Analysis of 1.8 meter Antenna Measurement Test Results for 27.5 – 28.35 GHz

Introduction

ViaSat has been a consistent proponent of spectrum sharing on reasonable and equitable terms throughout the FCC's Spectrum Frontiers proceeding (*Spectrum Frontiers*).[1] As part of that discussion, ViaSat has provided supporting information about the ability of satellite earth stations to co-exist with future terrestrial fixed and mobile services, including UMFU or 5G. This additional report, combined with independent, third party testing from industry-leading experts using state-of-the-art measurement gear and techniques, further substantiates ViaSat's previous submissions.[2]

Background

ViaSat previously submitted an "Analysis of EIRP density toward the horizon for ViaSat site licensed aggregation and interconnection facilities (AIF)."[3]

That analysis considered three antenna size classes that were representative of the earth stations employed or planned to be employed as AIFs for its three generations of High Capacity Service (HCS) satellites.

Subsequent to submittal of that analysis, ViaSat performed testing around an existing 1.8 m antenna at its Carlsbad, California headquarters and found no detectable signal level above the spectrum analyzer noise floor at each ground level measurement location.[4]

Following release of the *Spectrum Frontiers Order* in July 2016 and the adoption of sharing criteria for protected earth stations of -77.6 dBm/(m^2 * MHz) as measured 10 m above ground level (AGL), ViaSat engaged Comsearch to conduct measurements ("Comsearch Testing") around a 1.8 m antenna at 2 m (ground level) and 10 m AGL (the FCC-specified antenna height for measurement). A report of the Comsearch Testing is attached as Annex 1.

The goal of the testing was twofold. First, to determine whether free space loss conditions alone applied or whether additional losses were present along the azimuths to the various test

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[1] *See, e.g.*, Comments of ViaSat, Inc., Further Notice, GN Docket No. 14-177, et al., at 4 (Sept. 30, 2016); *Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Report and Order, 31 FCC Rcd 8014 (2016) ("*Spectrum Frontier Order*").

[2] ViaSat commissioned Comsearch, a national radio frequency expert consultancy. Comsearch engineers average over 15 years of field engineering experience, using state-of-the-art measurement equipment and techniques, with extensive propagation experience. URL: http://comsearch.com/services/site-services/rf-test-measurements/.

[3] ViaSat, Inc., Notice of *Ex Parte* Presentation, GN Docket No. 14-177, *et al.*, at Attachment 2 (Apr. 21, 2016) ("ViaSat April 21 *Ex Parte*").

[4] ViaSat, Inc., *Ex Parte* Letter, GN Docket No. 14-177, *et al.*, at 8 (July 7, 2016) ("ViaSat July 7 *Ex Parte*").

measurement locations. Second, to determine if the antenna transmitting at the nominal power density of a third generation AIF would meet the expected power flux density (pfd) value at the distance filed in the ViaSat April 21 *Ex Parte*.

Transmitting Antenna Characteristics

While minor performance differences due to different feed configurations can be expected, the 1.8 m antenna in question is representative of the type of 1.8 m antenna to be used for future AIFs for the ViaSat third generation HCS satellites. The antenna is roof mounted on a three-story building with parapet wall of varying height around the roof top. The parapet wall is part of the architectural design of the building and provides visual screening of roof top equipment such as HVAC units and other antennas. The height of the parapet wall varies between one and a half and three feet. In addition to the parapet wall, the roof of the building also includes a recessed area approximately two and half feet deep to further aid in screening roof-top equipment from view.

The 1.8 m antenna is mounted in the roof-top recessed area and aligned to point at the WildBlue-1 satellite at 111.1° W.L. The nominal pointing angles for this spacecraft are 168.8° azimuth and 50.1° elevation.

Because no measureable signal had been detected at ground level during prior testing, the testing with Comsearch was configured to use a CW carrier rather than a modulated carrier to provide a better C/N and increase the likelihood of signal detection at the various measurement locations. To operate the antenna, the testing used a standard ViaSat integrated assembly which incorporates a combined modem and radio frequency transceiver all in one module.

The power into the antenna feed was configured to be 0 dBW (1 W) and verified at the antenna feed port to be -0.4 dBW using calibrated test equipment prior to the start of testing. Comsearch verified that the bursting CW signal being transmitted at the frequency of 28212.5 MHz was readily observable at the roof-top location, inside of the parapet wall, with the spectrum analyzer configured to maximum hold.

Following confirmation of source signal calibration, Comsearch proceeded to make measurements at various locations in the area around the building at both ground level (2 m AGL) and at the FCC reference *Spectrum Frontiers Order* UMFU operational antenna height of 10 m AGL. Photos of the test locations and screen shots of the spectrum analyzer plots can be found in Section 3 of the Comsearch report, and a summary of the resultant signal level measurements are provided in Tables 4.1 and 4.2 in Section 4 of the Comsearch report.

Analysis

There are two parts to the analysis. The first part examines whether a signal was present at a location when Comsearch made their measurement, and if so how the signal compared to the predicted value assuming free space losses alone and whether there were additional losses in the path. The second part uses the measured signal values and other information about the ViaSat AIF to calculate the power flux density associated with each measurement. Both of these analyses are described below.

Signal Presence Measurement and Additional Losses Analysis

Comsearch performed measurements with calibrated test equipment using the industry standard signal substitution method, as recommended by the National Spectrum Management Association (NSMA).[5] The signal value results recorded in Tables 4.1 and 4.2 of the Comsearch report and represent the measured level of the CW carrier transmitted from the 1.8 m antenna system being tested, as reduced by path loss and additional losses between the antenna and measurement location. It should be noted that the recorded values suffixed with NF indicate that no signal was observed above the measurement system's noise floor (i.e., the recorded value was that of the noise floor in that instance). Because a spectrum analyzer functions like any other receiver, its noise floor is affected in the same way by signals (or interference) being received. The increase in the displayed response above the noise floor in dB is calculated as:

$10\ \log_{10}\left(1+10^{\frac{I/N}{10}}\right)$, where I and N are the actual interference and noise levels (1)

For example, if the received signal is equal to the noise floor, the two add in amplitude and the displayed response is twice that of the noise alone and a 3 dB rise above the noise floor is observed. A signal -12.2 dB lower than the noise floor results in a 0.25 dB increase in the displayed value. Given that no visible response was seen on the analyzer, the actual signal value then was likely more than 10 dB below the noise floor[6].

To determine the additional loss, if any, over and above free space path loss in the direction of the measurement location, the EIRP in the direction of the measurement location must first be determined.

To do this, antenna gain in the direction of the measurement location is added to the transmitter power being applied the antenna feed. Tables 4.1 and 4.2 of the Comsearch report contain the azimuths to and from the transmitting antenna, as well as the distance in meters. The Comsearch tables do not, however, reference the bearing along which the antenna is transmitting, nor is the elevation angle of the transmitting antenna included.

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[5] The National Spectrum Management Association (see URL: http://nsma.org/), Recommendation WG 4.88.013 Rev.1

[6] Spectrum Analyzer Noise Measurements, HP Application Note 150-4, 1974; and Spectrum Analyzer Measurements and Noise, Agilent Application Note 1303.

The transmit antenna's bearing and the elevation angle information are needed in order to determine the off-axis angle in azimuth and in elevation in order to determine the estimated off-axis gain discrimination in the direction of the signal measurement site. This information is provided in the Transmitting Antenna Characteristics section above. The operating azimuth angle of the 1.8 m antenna is 168.82° (as referenced to True North at 0°) and the elevation angle is 50.1°.

With this information and the antenna gain patterns, the EIRP density in the direction of the measurement site can be calculated. For example, for measurement Site 1, the azimuth angle from the transmitting antenna toward the measurement site is given as 170.29° in Table 4.1 of the Comsearch report. Subtracting the transmitting antenna's bearing toward WildBlue-1 of 168.82° from 170.29° yields an off-axis angle of 1.47°. By examining the manufacturer's antenna gain patterns, attached as Annex 2,[7] it can be seen that the off-axis gain discrimination in azimuth is 35 dB and the gain discrimination in elevation is 70 dB, so the larger of the two values is used. In reviewing the off-axis angles for each site, it can be seen that for all measurement locations, the larger 70 dB elevation off-axis gain discrimination value applies.

The nominal gain at 28.212.5 GHz is 52.59 dBi and the input power to the antenna is -0.4 dBW, so the EIRP toward the horizon is -0.4 dBW + (52.59 dBi – 70 dB) = -17.81 dBW.

Using the free space path loss (FSL) formula (2), the expected FSL for the 66.14 m distance is calculated in dB as 97.86 dB.

$$10\,log\left(\left[\frac{4\pi d}{\lambda}\right]^2\right) \qquad (2)$$

The expected measurement value is then the EIRP – FSL = -115.67 dBW. The actual measured value recorded for Site 1 in Table 4.1 was -137.51 dBW. The additional loss is then -115.67 dBW minus -137.51 dBW = 21.84 dBW.

The process was repeated for each of the measurement sites and measurement heights (2 m and 10 m) and the results are recorded in Table 1.

[7] Annex 2, General Dynamics Antenna Test Report.

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Measurement Location	Measurement Height (m)	Free Space Loss (dB)	Recorded Signal (dBW)		Expected Signal (dBW)	Additional Losses (dB)	
Site 1	10	97.86	-137.51		-115.67		21.84
Site 1	2	97.86	-158.19	NF	-115.67	≫	42.52
Site 2	10	98.30	-149.10		-116.11		32.99
Site 2	2	98.30	-155.56	NF	-116.11	≫	39.45
Site 3	10	103.43	-141.30		-123.24		18.06
Site 3	2	103.43	-159.65	NF	-123.24	≫	36.41
Site 4	10	107.46	-133.25		-125.27		7.98
Site 4	2	107.46	-160.00	NF	-125.27	≫	34.73
Site 5	10	111.46	-140.68		-129.27		11.41
Site 5	2	111.46	-147.78		-129.27		18.51
Site 6	10	112.33	-144.95		-130.14		14.81
Site 6	2	112.33	-154.82		-130.14		24.68
Site 7	10	110.59	-155.96	NF	-128.40	≫	27.56
Site 7	2	110.59	-158.19	NF	-128.40	≫	29.79
Site 8	10	109.03	-158.63	NF	-126.84	≫	31.79
Site 8	2	109.03	-158.63	NF	-126.84	≫	31.79
Site 9	10	111.04	-158.10	NF	-128.85	≫	29.25
Site 9	2	111.04	-159.44	NF	-128.85	≫	30.59
Site 10	10	112.47	-158.60	NF	-130.28	≫	28.32
Site 10	2	112.47	-158.77	NF	-130.28	≫	28.49
Site 11	10	98.87	-157.48	NF	-116.68	≫	40.80
Site 11	2	98.87	-158.78	NF	-116.68	≫	42.10

Table 1 Recorded vs Expected Signals and Additional Losses for Measurement Locations

Examining the results in Table 1 shows that in many cases for the 10 m reference height and for the majority of the 2 m height measurement locations, no signal was observed above the test equipment noise floor. The largest observed signal was at the Site 4 location. The measurement location also had the lowest additional losses above the expected free space loss of 8 dB. This result was anticipated because the terrain at that signal test location is approximately 20 feet above the terrain at the base of the building on which the transmitting antenna is located. Also, from the Comsearch photos it can be seen that the parapet wall on that area of the building where the transmitting antenna is located was at the lowest height and the measuring antenna had a line of sight view to the transmitting antenna. Raising the parapet wall in the direction of the higher terrain would provide additional blockage and increase the losses above the FSL.

Power Flux Density Measurement

The second part of the analysis is to determine the power flux density at each of the measurement locations. To use the Comsearch results meaningfully, the recorded signal level values must first be scaled to a reference bandwidth and converted to a flux density. That is, converted from dBW to dBW/(m^2 * MHz).

While the transmitted power of the unmodulated CW carrier from the 1.8 m antenna is known, to convert the power to a power density that represents the third generation AIF, the modulated bandwidth associated with that power level in normal operation must be known or calculated for use in the density conversion.

In the ViaSat April 16 *Ex Parte*, the antenna input density for the third generation AIF was projected to be -19.0 dBW/MHz. However, since that *ex parte* was filed, ViaSat has further reduced the expected nominal antenna input power density for this class AIF to -24.3 dBW/MHz.

The equivalent bandwidth over which the -0.4 dBW input power to the 1.8 m antenna would be spread in normal operation of a third generation AIF is then 10^(-0.4/10)/10^(-24.3/10) = 245.5 MHz.

To calculate the power density in dBW/MHz, the bandwidth adjustment in dB is calculated as 10 log (245.5 MHz/1 MHz) = 23.9 dB(MHz). This result is subtracted from the measured value to calculate the power density. For Site 1, this is -137.51 dBW – 23.9 dB(MHz) = -161.41 dBW/MHz.

To complete the conversion from power density to power flux density (pfd), the meter squared area gain is added to the power density.

Meter squared area gain = $10 \log \frac{4\pi}{\lambda^2} = 50.46$ dB/m^2 (3)

The measured pfd is then -161.41 dBW/MHz + 50.46 dB/m^2 = -111 dBW/(m^2 * MHz), or -81 dBm/(m^2 * MHz).

The conversion process was repeated for each of the measurement sites and measurement heights (2 m and 10 m) and the results were recorded in Table 2.

Corrected 4/20/2017

Measurement Location	Measurement Height (m)	Recorded Signal (dBW)		Power Density (dBW/MHz)	Power Flux Density (dBW/(m^2*MHz)	
Site 1	10	-137.51		-161.44		-110.98
Site 1	2	-158.19	NF	-182.12	≪	-131.66
Site 2	10	-149.10		-173.03		-122.57
Site 2	2	-155.56	NF	-179.49	≪	-129.03
Site 3	10	-141.30		-165.23		-114.77
Site 3	2	-159.65	NF	-183.58	≪	-133.12
Site 4	10	-133.25		-157.18		-106.72
Site 4	2	-160.00	NF	-183.93	≪	-133.47
Site 5	10	-140.68		-164.61		-114.15
Site 5	2	-147.78		-171.71		-121.25
Site 6	10	-144.95		-168.88		-118.42
Site 6	2	-154.82		-178.75		-128.29
Site 7	10	-155.96	NF	-179.89	≪	-129.43
Site 7	2	-158.19	NF	-182.12	≪	-131.66
Site 8	10	-158.63	NF	-182.56	≪	-132.10
Site 8	2	-158.63	NF	-182.56	≪	-132.10
Site 9	10	-158.10	NF	-182.03	≪	-131.57
Site 9	2	-159.44	NF	-183.37	≪	-132.91
Site 10	10	-158.60	NF	-182.53	≪	-132.07
Site 10	2	-158.77	NF	-182.70	≪	-132.24
Site 11	10	-157.48	NF	-181.41	≪	-130.95
Site 11	2	-158.78	NF	-182.71	≪	-132.25

Table 2 Calculated Power Flux Density for Measurement Locations

Examining the results in Table 2 it can be seen that all but one measured value was below the *Spectrum Frontiers Order* sharing criteria limit of -77.6 dBm/(m^2 * MHz). The measured value for Site 4 which had the highest terrain and lowest additional losses, was the only value which exceeded the FCC limit. The exceedance of the limit by 0.9 dB, would easily be mitigated by a modest increase in the parapet wall on that side of the building where terrain is higher.

Conclusion

While the transmitting antenna tested here normally operates in the conventional Ka band, and accordingly was not sited with 5G/UMFU sharing constraints in mind, this type of roof top mounting scenario is quite common for modest sized earth stations in urban or suburban commercial settings. Even with no special care taken to mitigate signal levels toward the horizon, the measured levels for all but one location were below the FCC's sharing criteria, and in many cases significantly so.

With some care used in new installations, it would be fairly easy to shield the antenna from nearby 5G/UMFU operations and thereby allow siting of earth stations close to fiber even in urban environments where 5G/UMFU will be or has deployed.

Corrected 4/20/2017

DECLARATION

I hereby declare that I am the technically qualified person responsible for preparation of the engineering information contained in this report, that I am familiar with Part 25 of the Commission's rules, that I have either prepared or reviewed the engineering information submitted with this report, and that it is complete and accurate to the best of my knowledge, information and belief.

REGISTERED PROFESSIONAL ENGINEER
DARYL T HUNTER
E 16610
ELECTRICAL
STATE OF CALIFORNIA

Daryl T. Hunter, P.E.
Senior Director, Regulatory Affairs
ViaSat, Inc.
6155 El Camino Real
Carlsbad, CA 92009

April 12, 2017

ANNEX 1—COMSEARCH REPORT

Corrected 4/20/2017

comsearch

A CommScope Company

RADIO FREQUENCY SIGNAL MEASUREMENT REPORT

Prepared For

ViaSat

Carlsbad, CA

Transmit Station
28 GHz

February 2017

19700 Janelia Farm Boulevard. - Ashburn, Virginia 20147, USA - 703.726.5500 - Fax 703.726.5597

Corrected 4/20/2017

TABLE OF CONTENTS

Corrected 4/20/2017

SECTION 1

INTRODUCTION AND BACKGROUND

1.1 Introduction

On-site Radio Frequency (RF) transmission measurements were performed on behalf of ViaSat, Inc. on February 14,2017 at their existing site in Carlsbad, CA. The purpose of the measurements was to determine relative RF levels in the 27.5-28.35 GHz band with respect to expected free space loss and to evaluate the effectiveness of using a typical rooftop earth station installation to screen transmissions from nearby terrestrial receivers. The purpose of this report is to document the results of these measurements:

- 1.8 Meter TX Antenna
- Satellite Arc: 111.1 Degrees West Longitude
- Frequency Considered: 28,212.5 MHz
- Transmit Power: 1 Watt / 30 dBm
- Type of Reception: CW
- Measured Rx Antenna Center Line: 10 meters Above Ground Level

1.2 Background

ViaSat, Inc requested that Comsearch perform receive level testing using a calibrated system to measure receive signal levels from a CW carrier being transmitted from a rooftop mounted 1.8-meter antenna in the areas surrounding the antenna. The antenna is located on the roof of a 3 story building, in the center portion of the roof, in a depressed area. The coordinates of the test transmit antenna are: 33° 0 7' 38.31"N and 117° 15' 55.13"W. The roof has a short parapet wall (varying between approximately 1.5 feet and 3 feet) at the edge but no other substantial items which would provide blockage. The antenna is located in a depression in the roof which is approximately 2.5 feet deep.

An unmodulated CW carrier was used because previous testing at ground level using a modulated carrier had resulted in no detectable signals. By using a CW carrier, the power density in the measurement bandwidth was increased considerably. Additionally, testing at both ground level (2 m) and 10 m were requested for the new tests in order to improve the likelihood of detecting a signal above the noise floor of the measuring equipment.

The ground test locations were determined by drawing multiple arcs at 50 meter distances from the building and where those circles intersected with the main beam, 45 and 90 degree off main beam locations. Tests were conducted as close as possible to those crossings where possible. Because of the lack of signals above the noise floor during previous tests and the difficulty of crossing the busy roadway to the West of the antenna with the boom lift, testing on that side of the street was planned only if testing there was deemed warranted.

The measurement sites are identified on a portion of a topographic map shown in Figure 1.2-1. An aerial photo of the site locations are shown in Figure 1.2-2.

1.3 Assumptions &Constraints

The analysis in this report is based upon the following assumptions and constraints.

- It was verified that during the measurement period the transmit antenna was active and operating at the specified transmit power ±1 dB.
- The signal identification and frequencies of the test carrier were specified by ViaSat.
- The actual ground elevation of the site is based on the data from the topographic map.

Corrected 4/20/2017

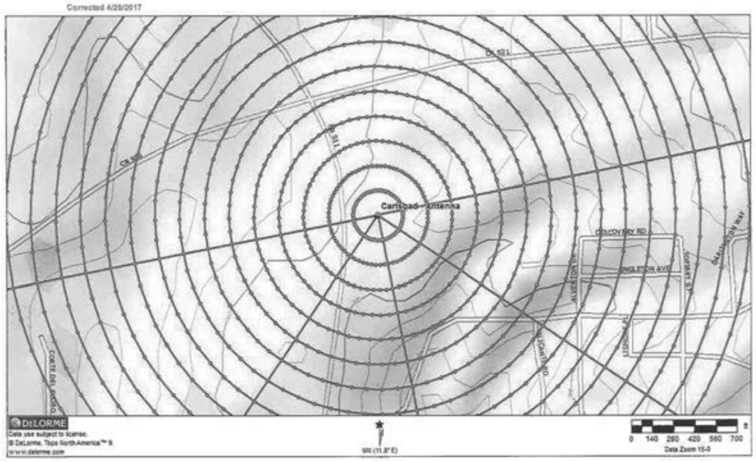

Figure 1.2-1 – Topographic Map

Corrected 4/20/2017

The green line is the main beam azimuth. Red dots show measurement locations,

Figure 1.2-2 – Aerial Photograph

SECTION 2

TEST PROCEDURE

2.1 Calibration

Figures 2.1-1 is the block diagram of the test set for all bands to be tested. All test equipment used was allowed a proper warm-up period prior to calibration. The test set was calibrated by the signal substitution method, as recommended by NSMA, utilizing a synthesized signal generator. The reference signal from the signal generator was adjusted for the center frequency of each band to be tested and measured with a thermal power meter for calibrated reference test level (-60 dBm). This calibrated reference signal from the signal generator was then injected into the end of the coaxial cable of the test set at the point, which normally connects to the test antenna. A spectrum analyzer then measured the reference test signal level after passing through the test set. Upon completion of the calibration process, a known reference level was obtained for the measurements that correspond to a given set of spectrum analyzer display readings.

The following formula is used to transform the measured signal level as read on the spectrum analyzer display (dBm) to an isotropic reference signal level (dBW_I) as seen at the point of test:

$$dBW_I = LI - EG - 30$$

Where: dBW_I = Isotropic level in dBW

LI = Level (dBm) of injected signal

EG = External Gain = Test antenna gain + LNA Gain

at 28 GHz: dBW_I = -60 dBm - 45.9 dB

= -105.9 dBm_I

In this instance, the spectrum analyzer displayed measured signal level of -60 dBm equates to an isotropic signal level of –105.9 dBm_I.

Figure 2.1-2 displays the spectrum photograph of the described calibration procedure employed during these measurements.

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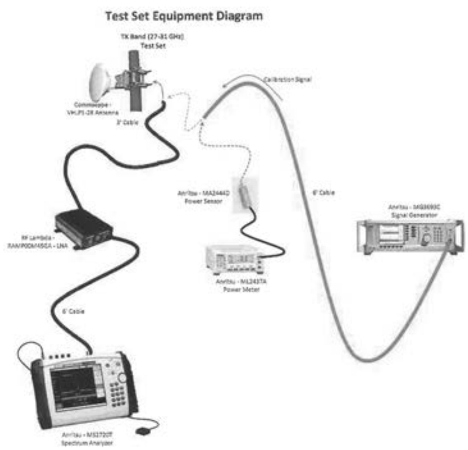

Figure 2.1-1 Receive Test Equipment Block Diagram

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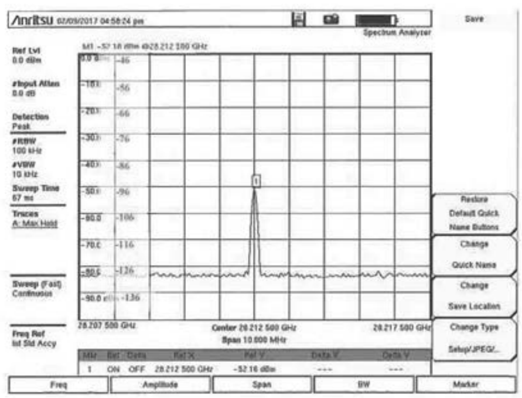

A -52.18 dBm , 28212.5 MHz signal indication on the spectrum photograph represents a -60 dBm signal being injected at the point where the test cable connects to the output of the test antenna.

Displayed reference level is equal:
-60 dBm injected signal
-45.9 dB external gain
-105.9 dBm$_I$; therefore, a displayed signal level of -70 dBm equals an isotropic level of -116 dBm$_I$

Adjusted measurement values (dBm$_I$) shown in red

Figure 2.1-2 Calibration Spectrum Photo 28 GHz

Corrected 4/20/2017

2.2 Methodology

The test equipment was set up and calibrated to measure the RF environment. Measurements were conducted at in such a way that would show if the signal from the transmitter was visible above the test equipment's noise floor for the 27.5-28.35 GHz band. After the equipment calibration was completed, the test antenna was mounted on a motorized boom lift and elevated to a height of 10 meters AGL. The tests were conducted by activating the peak hold function of the spectrum analyzer. This enabled the analyzer to maintain and display the maximum signal level received for the frequency under consideration. The test antenna was peaked while pointed at the transmit antenna to attempt to receive any signal from the transmit antenna. "

Table 3.1-1, item 8. The area on the roof where the TX antenna is located is depressed by approximately 2.5 ft deep.

In tables 4.1 & 4.1, NF = Noise Floor of test measurement system. (So readers won't confuse this with 5G or LMDS equipment NF).

SECTION 3

DATA PRESENTATION

The following section contains the tables and spectrum photos pertaining to the site location measured.

3.1 Carlsbad, CA

- Table 3.1-1 presents a site data sheet including all pertinent site information.
- Figures 3.1-1 and 3.1-2 are the photographs depicting the existing earth station site and test locations.
- Figures 3.1-3 (A) through 3.1-3 (V) are the RF spectrum photographs depicting the receive signal measured at the test sites.

Corrected 4/20/2017

TABLE 3.1-1

MEASUREMENT SITE DATA SHEET

1. SYSTEM NAME:	ViaSat, Inc	
2. CITY AND STATE:	Carlsbad, CA	
3. SITE IDENTIFICATION:	Carlsbad	
4. COORDINATES (TX Site): (NAD 1983)	LATITUDE:	33° 07' 38.31" N
	LONGITUDE:	117°15' 55.13" W
5. GROUND ELEVATION:	310 feet AMSL	
6. MEASUREMENT DATE:	February 14, 2017	
7. GEOSTATIONARY ARC RANGE:		
SATELLITE POSITIONS:	111.1° W	
AZIMUTH:	168.8°	
ELEVATION:	50.9°	

8. GEOSTATIONARY ARC VISIBILITY: The TX site is on a 3 story building with a short parapet wall. The TX antenna was also in an area of the roof that is depressed approximately 3 feet.

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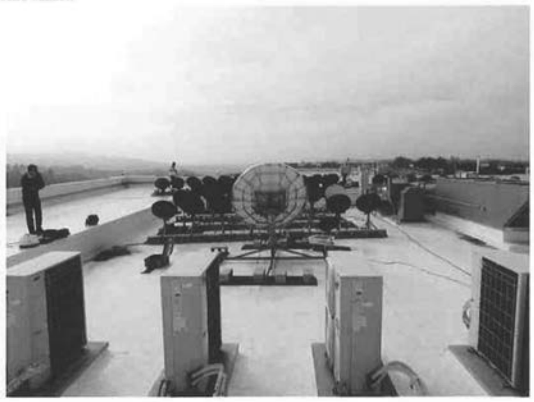
View of transmit antenna looking north

View of transmit antenna looking south

Figure 3.1-1 (cont.) Earth Station Site Photographs

Corrected 4/20/2017



View of transmit antenna looking south

View of transmit antenna looking west

Figure 3.1-1 (cont.) Earth Station Site Photographs

Corrected 4/20/2017

View from rooftop looking east

View from rooftop looking southeast

Figure 3.1-1(cont.) Earth Station Site Photographs

Corrected 4/20/2017

View from rooftop looking south

View from rooftop looking southwest

Figure 3.1-1 (cont.) Earth Station Site Photographs

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 1 at 10m AGL

View toward TX antenna on rooftop from Site 1 at 10m AGL (zoom)

Figure 3.1-2 Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 2 at 10m AGL

View toward TX antenna on rooftop from Site 2 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 3 at 10m AGL

View toward TX antenna on rooftop from Site 3 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 4 at 10m AGL

View toward TX antenna on rooftop from Site 4 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 5 at 10m AGL

View toward TX antenna on rooftop from Site 5 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 6 at 10m AGL

View toward TX antenna on rooftop from Site 6 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 7 at 10m AGL

View toward TX antenna on rooftop from Site 7 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 8 at 10m AGL

View toward TX antenna on rooftop from Site 8 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 9 at 10m AGL

View toward TX antenna on rooftop from Site 9 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 10 at 10m AGL

View toward TX antenna on rooftop from Site 10 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

View toward TX antenna on rooftop from Site 11 at 2m AGL

View toward TX antenna on rooftop from Site 11 at 10m AGL (zoom)

Figure 3.1-2 (cont.) Test Locations

Corrected 4/20/2017

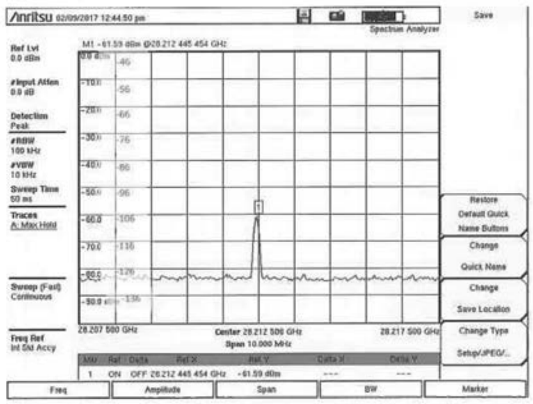


Figure 3.1-3 (A) Spectrum Photos 28 GHz - 100 kHz Res BW Site 1 at 10m AGL

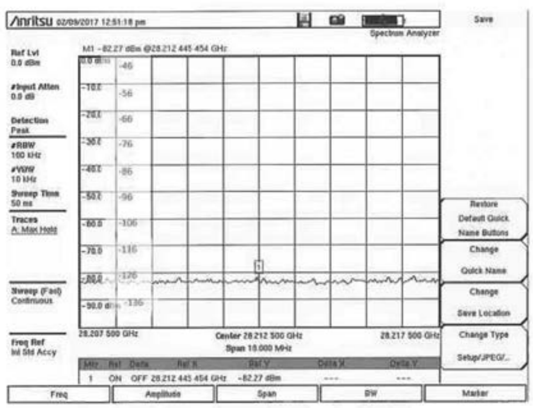


Figure 3.1-3 (B) Spectrum Photos 28 GHz - 100 kHz Res BW Site 1 at 2m AGL

Adjusted measurement values (dBmi) shown in red

Corrected 4/20/2017

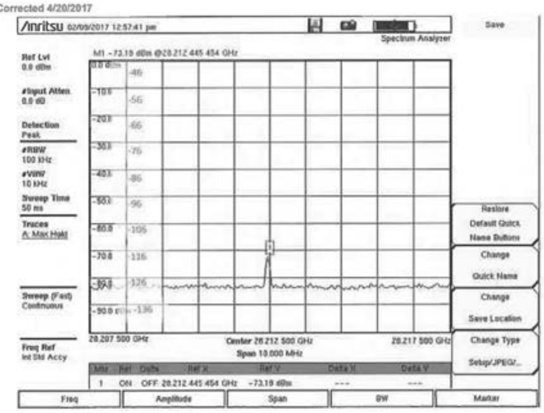


Figure 3.1-3 (C) Spectrum Photos 28 GHz - 100 kHz Res BW Site 2 at 10m AGL

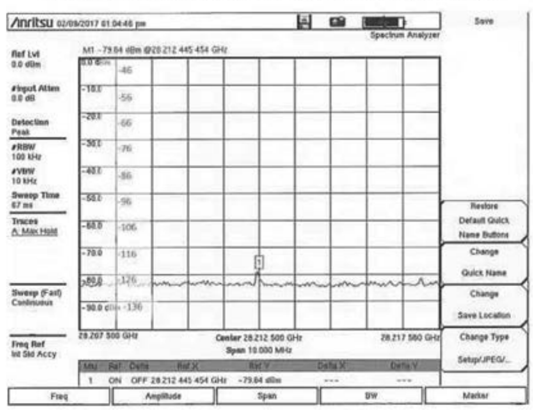


Figure 3.1-3 (D) Spectrum Photos 28 GHz - 100 kHz Res BW Site 2 at 2m AGL

Adjusted measurement values (dBm$_i$) shown in red

Corrected 4/20/2017

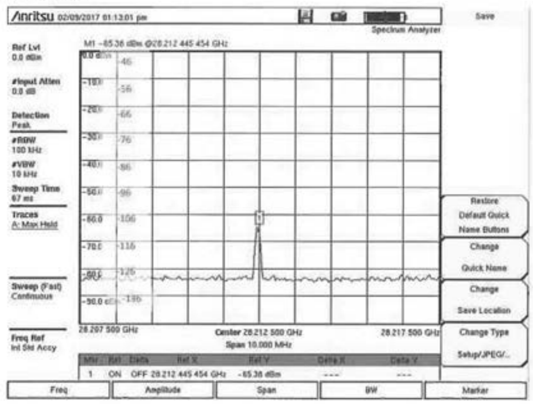


Figure 3.1-3 (E) Spectrum Photos 28 GHz - 100 kHz Res BW Site 3 at 10m AGL

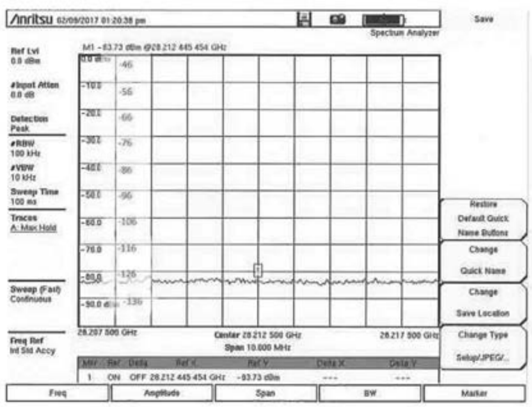


Figure 3.1-3 (F) Spectrum Photos 28 GHz - 100 kHz Res BW Site 3 at 2m AGL

Adjusted measurement values (dBm) shown in red

Corrected 4/20/2017

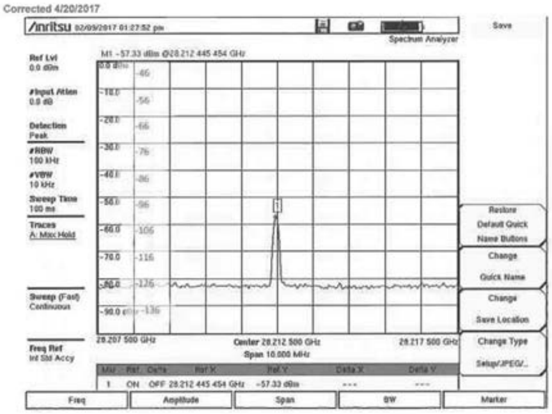


Figure 3.1-3 (G) Spectrum Photos 28 GHz - 100 kHz Res BW Site 4 at 10m AGL

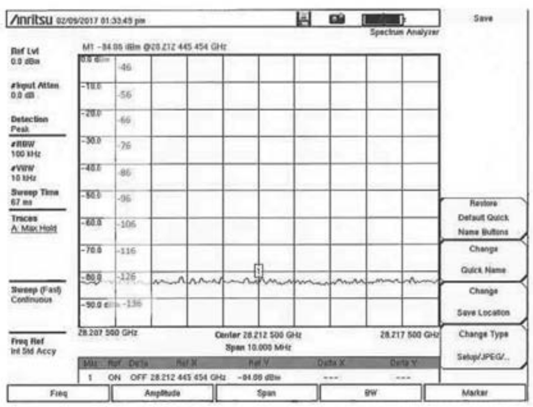


Figure 3.1-3 (H) Spectrum Photos 28 GHz - 100 kHz Res BW Site 4 at 2m AGL

Adjusted measurement values (dBm) shown in red

Corrected 4/20/2017

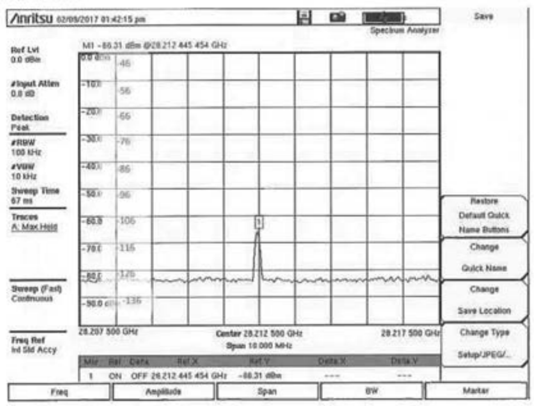


Figure 3.1-3 (I) Spectrum Photos 28 GHz - 100 kHz Res BW Site 5 at 10m AGL

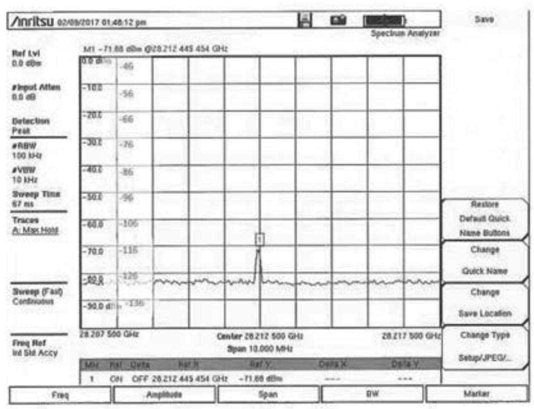


Figure 3.1-3 (J) Spectrum Photos 28 GHz - 100 kHz Res BW Site 5 at 2m AGL

Adjusted measurement values (dBm$_i$) shown in red

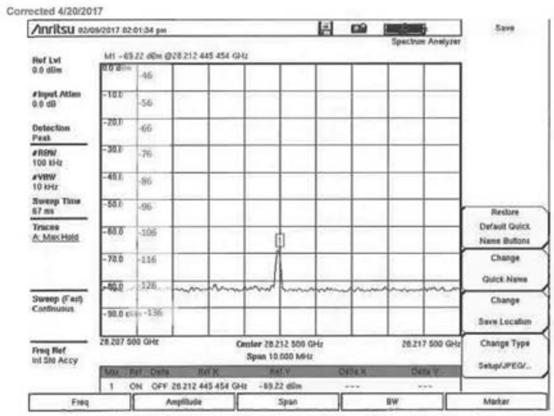


Figure 3.1-3 (K) Spectrum Photos 28 GHz - 100 kHz Res BW Site 6 at 10m AGL

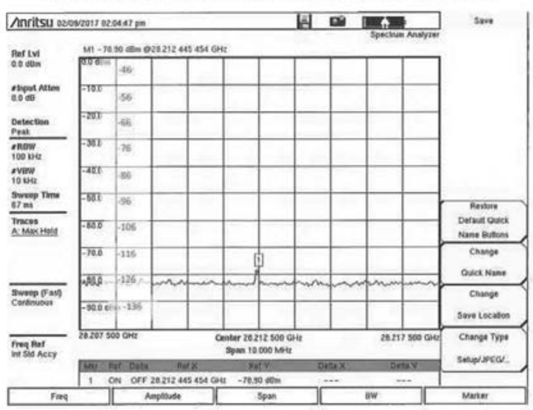


Figure 3.1-3 (L) Spectrum Photos 28 GHz - 100 kHz Res BW Site 6 at 2m AGL

Adjusted measurement values (dBm) shown in red

Corrected 4/20/2017

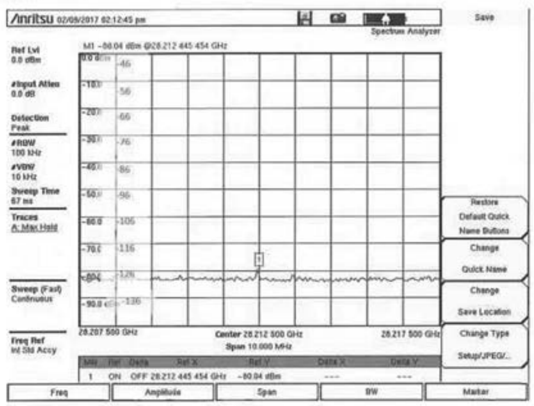


Figure 3.1-3 (M) Spectrum Photos 28 GHz - 100 kHz Res BW Site 7 at 10m AGL

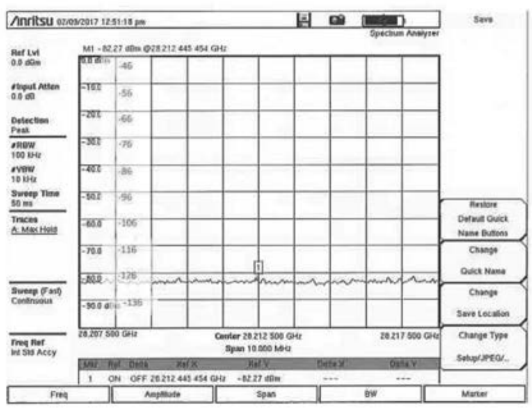


Figure 3.1-3 (N) Spectrum Photos 28 GHz - 100 kHz Res BW Site 7 at 2m AGL

Adjusted measurement values (dBmi) shown in red

Corrected 4/20/2017

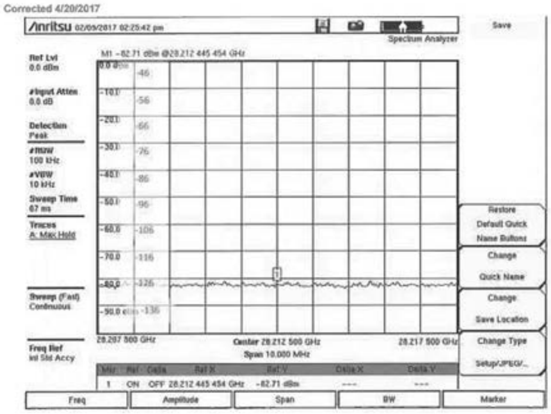


Figure 3.1-3 (O) Spectrum Photos 28 GHz - 100 kHz Res BW Site 8 at 10m AGL

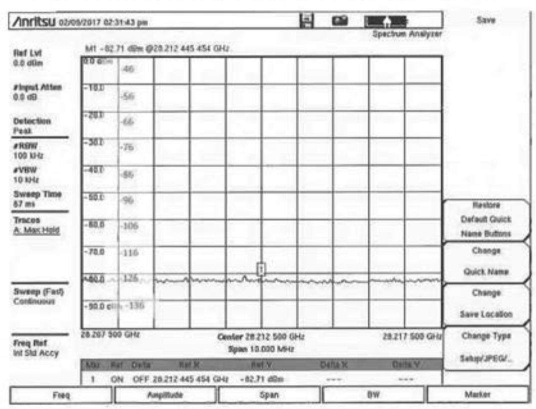


Figure 3.1-3 (P) Spectrum Photos 28 GHz - 100 kHz Res BW Site 8 at 2m AGL

Adjusted measurement values (dBm) shown in red

Corrected 4/20/2017

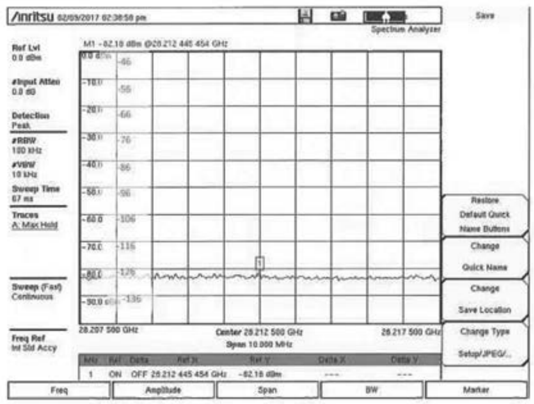


Figure 3.1-3 (Q) Spectrum Photos 28 GHz - 100 kHz Res BW Site 9 at 10m AGL

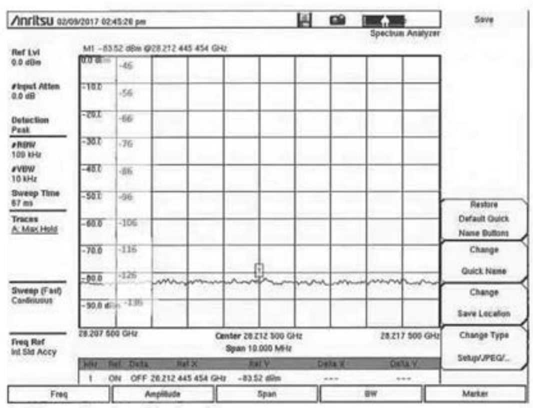


Figure 3.1-3 (R) Spectrum Photos 28 GHz - 100 kHz Res BW Site 9 at 2m AGL

Adjusted measurement values (dBm) shown in red

Corrected 4/20/2017

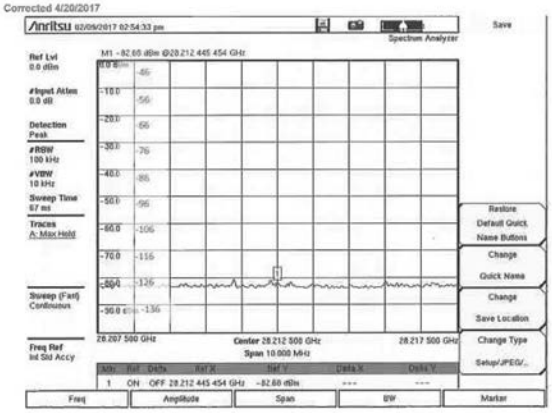


Figure 3.1-3 (S) Spectrum Photos 28 GHz - 100 kHz Res BW Site 10 at 10m AGL

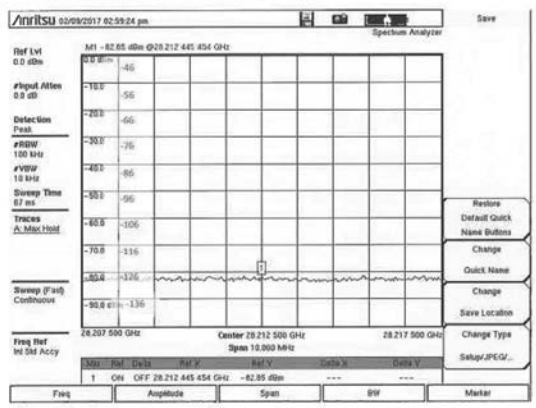


Figure 3.1-3 (T) Spectrum Photos 28 GHz - 100 kHz Res BW Site 10 at 2m AGL

Adjusted measurement values (dBmi) shown in red

Corrected 4/20/2017

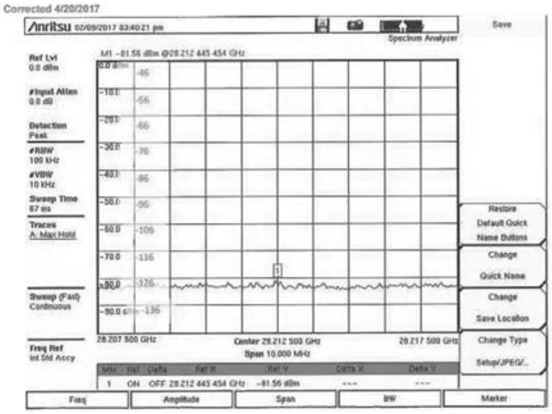


Figure 3.1-3 (U) Spectrum Photos 28 GHz - 100 kHz Res BW Site 11 at 10m AGL-82

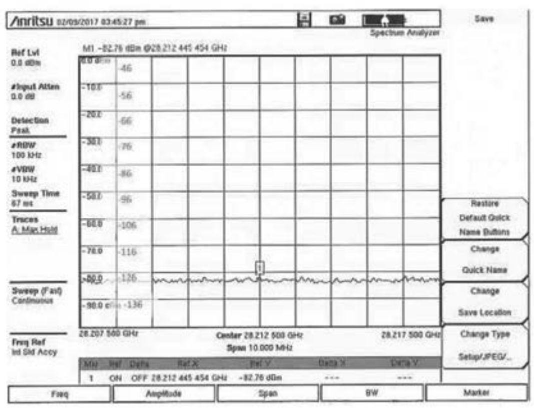


Figure 3.1-3 (V) Spectrum Photos 28 GHz - 100 kHz Res BW Site 11 at 2m AGL

Adjusted measurement values (dBm$_t$) shown in red

Corrected 4/20/2017

SECTION 4

SUMMARY OF RESULTS

The results of the measurements conducted at the ViaSat, Inc transmit site in Carlsbad, CA are presented in this section.

Ka-Band Measurements:

The tables on the next page contain the data collected during the RF Measurements on February 14, 2017.

Corrected 4/20/2017

Table 4.1
Data from RF Measurements at 10m Above Ground Level

Measurement Location	Latitude	Longitude	Azimuth From TX Antenna (°)	Azimuth to TX Antenna (°)	Test Antenna Height AGL (m)	Distance from TX Antenna (m)	Signal Value Recorded (dBm)	Signal Value Recorded (dBW)	Figure Number
Site 1	33.126722	-117.265194	170.29	350.29	10	66	-107.51	-137.51	3.1-3 (A)
Site 2	33.126778	-117.264917	147.79	327.79	10	69.5	-119.10	-149.10	3.1-3 (C)
Site 3	33.127194	-117.263972	95.76	275.76	10	126	-111.30	-141.30	3.1-3 (E)
Site 4	33.127583	-117.263194	81.23	261.23	10	200	-103.25	-133.25	3.1-3 (G)
Site 5	33.127222	-117.261917	91.72	271.73	10	317	-110.68	-140.68	3.1-3 (I)
Site 6	33.125778	-117.262028	118.97	298.97	10	350	-114.95	-144.95	3.1-3 (K)
Site 7	33.125611	-117.263000	131.08	311.08	10	286	-125.96 NF	-155.96 NF	3.1-3 (M)
Site 8	33.125444	-117.264028	149.86	329.86	10	239	-128.63 NF	-158.63 NF	3.1-3 (O)
Site 9	33.124667	-117.264583	166.9	346.9	10	301	-128.10 NF	-158.10 NF	3.1-3 (Q)
Site 10	33.124139	-117.264806	172.31	352.31	10	355	-128.60 NF	-158.60 NF	3.1-3 (S)
Site 11	33.127972	-117.265222	6.61	186.61	10	74.2	-127.48 NF	-157.48 NF	3.1-3 (U)

Table 4.2
Data from RF Measurements at 2m Above Ground Level

Measurement Location	Latitude	Longitude	Azimuth From TX Antenna (°)	Azimuth to TX Antenna (°)	Test Antenna Height AGL (m)	Distance from TX Antenna (m)	Signal Value Recorded (dBm)	Signal Value Recorded (dBW)	Figure Number
Site 1	33.126722	-117.265194	170.29	350.29	2	66	-128.19 NF	-158.19 NF	3.1-3 (B)
Site 2	33.126778	-117.264917	147.79	327.79	2	69.5	-125.56 NF	-155.56 NF	3.1-3 (D)
Site 3	33.127194	-117.263972	95.76	275.76	2	126	-129.65 NF	-159.65 NF	3.1-3 (F)
Site 4	33.127583	-117.263194	81.23	261.23	2	200	-130.00 NF	-160 NF	3.1-3 (H)
Site 5	33.127222	-117.261917	91.72	271.73	2	317	-117.78	-147.78	3.1-3 (J)
Site 6	33.125778	-117.262028	118.97	298.97	2	350	-124.82	-154.82	3.1-3 (L)
Site 7	33.125611	-117.263000	131.08	311.08	2	286	-128.19 NF	-158.19 NF	3.1-3 (N)
Site 8	33.125444	-117.264028	149.86	329.86	2	239	-128.63 NF	-158.63 NF	3.1-3 (P)
Site 9	33.124667	-117.264583	166.9	346.9	2	301	-129.44 NF	-159.44 NF	3.1-3 (R)
Site 10	33.124139	-117.264806	172.31	352.31	2	355	-128.77 NF	-158.77 NF	3.1-3 (T)
Site 11	33.127972	-117.265222	6.61	186.61	2	74.2	-128.78 NF	-158.78 NF	3.1-3 (V)

NF = Noise Floor of Test System

Corrected 4/20/2017

SECTION 5

CONCLUSIONS

5.1 Conclusions

Measureable signals above the measurement system's noise floor were observed at test sites 1 through 6 at 10 meters AGL. No measurable signals were observed above the measurement system's noise floor at sites 7 through 11 at 10 meters AGL.

Measureable signals above the measurement system's noise floor were observed at test sites 5 and 6 at 2 meters AGL. No measureable signals were observed above the measurement system's noise floor at all other sites at 2 meters AGL.

The highest observed signal was -103.25 dBm (-133.25 dBW) at site 4 at 10 meters AGL.

The values measured in this report are intended for use by ViaSat for incorporation into a larger analysis where ViaSat will perform the necessary calculations to convert the measured signals in dBm (dBW) to an equivalent power flux density in dBm/(m^2*MHz) and to determine, where possible, the effective signal attenuation over and above free space loss. As an element of a larger analysis, information in this report is not intended to be used on a standalone basis.

Report prepared by Roberson and Associates

Filed with FCC September 25, 2017, GN Docket No. 14–177.

Roberson and Associates, LLC
Technology and Management Consultants

SPECTRUM FRONTIERS: Q/V BAND SATELLITE-5G COEXISTENCE

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25 SEPTEMBER 2017

v1.0

This analysis was generated by Roberson and Associates, LLC for ViaSat.

Table of Contents:

1 Executive Summary

This analysis of a typical deployment scenario shows that small Fixed Service Satellite (FSS) Earth Stations (ES) with uplink transmissions between 47.2-50.2 and 50.4-52.4 GHz communicating with geostationary-orbit spacecraft can be located in the same urban areas as Fifth-Generation (5G) wireless Base Stations (BS) without the need for coordination.[1]

The analysis utilizes standard methodologies, parameters, metrics and models, extended and supplemented as necessary to support the specific scenario under study.

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. This metric is used to determine 99%, 98% and 95% probability geographic contours for $I_{es}/\eta_{bs} \leq -6$ dB.

The baseline confidence probability contour data has been evaluated with respect to absolute area, and also is described by way of example with respect to a specific urban region (i.e., Cook County, Illinois). The results indicate that any area where potential coexistence issues exist is very small, and the chances of such a circumstance actually arising in any given real-world deployment is extremely small.

The reported total 99% confidence probability contour area for $I_{es}/\eta_{bs} \leq -6$ dB is less than 0.0036 km^2, and the 98% contour less than 0.00042 km^2, which constitute less than 0.00009% and 0.00001% of Cook County, respectively. Furthermore, the overall probability likelihood that an individual 5G BS will actually experience $I_{es}/\eta_{bs} > -6$ dB is only 0.24% or approximately 1 chance in 416. Thus, the results of this analysis show that coexistence between FSS ESs and 5G BSs is feasible without the need for coordination.

Notably, these results are based on conservative assumptions, including path loss, use of peak side lobes (instead of actual lower values at different off-axis angles), considering only BS antennas with essentially omni-directional coverage, calculating much-higher confidence levels for received power density than commonly used, not accounting for attenuation from roof blockage, assuming all-outdoor 5G deployment, and never considering the operation of an ES at an elevation angle above a minimal value.

Moreover, the foregoing calculations do not take into account the mitigating effects of other factors, such as (i) inherent 5G BS antenna array techniques developed to allow 5G systems to cope with self-interference and interference between other 5G systems, or (ii) FSS ES physical isolation, both of which would virtually eliminate the chance of a real-world problem ever actually arising.

[1] Note: The results of this analysis depend on the characteristics of the satellite system at issue; the methodology readily could be applied to systems with other architectures or physical configurations.

2 SPECTRUM COEXISTENCE SCENARIO

2.1 Overview

This analysis provides a technical assessment for the case of a small Fixed Service Satellite (FSS) Earth Station (ES) transmitting to a spacecraft in geostationary orbit, and located near a Fifth-Generation wireless (5G) Base Station (BS). The assessment scenario under study is shown in the following figure.

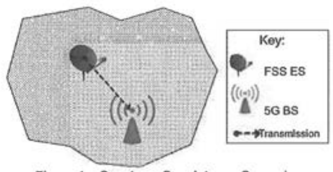

Figure 1. Spectrum Coexistence Scenario

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. The specific spectrum of interest is the Q/V bands (i.e., 47.2-50.2 and 50.4-52.4 GHz).

This assessment utilizes standard methodologies, parameters, metrics and models to the greatest possible extent. Where necessary these resources were extended/supplemented to support the specific scenario under study. Primary sources for this work can be found in [1]-[11].

The following sections describe the key components of this analysis.

2.2 FSS ES System

The information in this section on FSS ES system deployment and parameters was provided by ViaSat.

2.2.1 General Description

The FSS ES system uses an offset fed parabolic reflector antenna of approximate 1.8-meter diameter. It can be installed using ground mounts or on existing structures such as building roofs. The antenna boresight is pointed at a nominal vertical elevation angle of between 35 and 55 degrees relative to the horizon as dictated by the orbital location of the target satellite.

The power amplified (PA) output in this study is typically 7.15 milliwatts per right and left hand circular polarization for each 1 MHz of modulated bandwidth.

2.2.2 ES Antenna Pattern

To determine the ES antenna parameters needed for this study, an antenna being developed for this application was modeled by ViaSat. The design is based on a commercially available reflector. When in operation the ES antenna is pointed substantially upward in elevation and must have clear view of the sky in the direction of the target satellite. In order to assess the interaction with terrestrial 5G systems, the ES antenna gain well off the main beam is of primary interest.

The ES antenna performance data indicate that for 10 to 90 degrees from the main beam, the side lobe peaks plotted in dB as a function of angle are a straight line. This follows the process of M.1851 Table 5 [2]. Other literature (i.e., ECC PT1 #54 [3]) shows several examples of a reflector antenna with similar side lobe response. Therefore, the following side lobe mask as a function of the angular distance from the main beam is appropriate.

$$GAIN_{es}(\alpha) = -5 - \alpha/3 \quad (10^\circ \le \alpha \le 90^\circ) \qquad (1)$$

$$= -35 \qquad (\alpha > 90^\circ)$$

Where:

α = the arc distance to the main beam (not defined for $\alpha < 10^\circ$)

The following figure plots the mask of Equation (1).

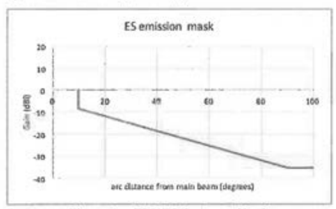

Figure 2. FSS ES Antenna Mask

The choice to use a mask matching the peaks (as opposed to the averages of the ripple) is conservative and ignores the possibility of lower sidelobes below this peak value in the final antenna design. However, this mask is more reflective of actual performance, compared with the 25.209 mask [4], which documents an upper bound regulatory limit.

2.3 5G BS System

2.3.1 General Description

The baseline deployment scenario used is described as the "Outdoor Urban hotspot" in Table 12 (Deployment-related parameters for bands between 45.5 GHz and 52.6 GHz) of [8]. These IMT-

2020 parameters were specified by the ITU [7] "to be used in sharing and compatibility studies for bands between 24.25 and 86 GHz."

- Antenna height (radiation center): 6 m (above ground level)
- Down-tilt: 10°
- Below rooftop base station antenna deployment
- Antenna polarization: Linear ±45°
- Horizontal/Vertical radiating element spacing: 0.5 of wavelength for both H/V
- 8x16 antenna array configuration

Continuing use of [8], we have selected the BS Noise Figure to be 12 dB as specified in the second table contained in Section 3 "System related parameters," column "37-52.6 GHz" (row 5.1).

2.3.2 BS Antenna Pattern

Since there are no commercial examples of 5G BS antennas in this band, a practical, conservative antenna performance model was needed. Using methods similar to M.2101 [5], the gain mask was determined from the theoretical linear array. An 8-element vertical by 16-element horizontal arrangement was assumed as it appears commonly in the literature.

The theoretical derivation of the normalized gain of a linear array is widely available. For example, [6] section 3, Equation 13.21 gives the normalized gain function with steering and uniform illumination. For this analysis, a broadside beam (i.e., no steering phase shift) with λ/2 element spacing is assumed. This results in the following equation.

$$AF_n = \frac{\sin(N\psi/2)}{N\sin(\psi/2)} \quad (2)$$

Where:

ψ = $\pi sin\phi$

ϕ = elevation angle above the main beam

Since there is a regular array of eight vertical elements, this results in the following elevation plot.

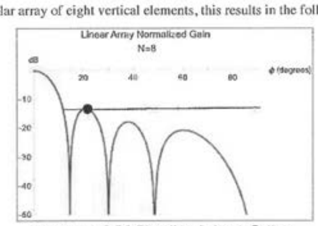

Figure 3. 5G BS Elevation Antenna Pattern

As the first side-lobe for this vertical configuration has a peak at approximately -13.3 dB, the mask was chosen to follow the theoretical value of the main lobe but limit the side-lobes to -13.3 dB. Because this analysis will be most sensitive to the sidelobe levels, the relatively small contribution of the element gain was not included. The peak gain is the product of the number of elements, so for the 8x16 array is $10\log_{10}(128)$ or 21 dB added to the normalized pattern.

In a similar manner, the horizontal gain of the 5G BS antenna is modeled based on a regular array of sixteen horizontal elements. This serves to narrow the main lobe of the pattern versus that of the vertical pattern. The relative gain in the horizontal pattern is shown in Figure 4 below for an assumed 120-degree sectored antenna. It is this pattern that will be used in determining the relative gain of the 5G BS as the antenna is rotated to different randomized orientations, per the methodology explained in Section 3.1.1. To simplify the analysis, a "block mask" of the pattern is employed, in which the relative gains of the main lobe (defined by the 3 dB beamwidth) and side lobes are constant as a function of angle. As with the elevation pattern, the relative gain in the side-lobes used in the analysis is also -13.3 dB. This approach is conservative, as it reflects the peak gains of the respective lobes, and does not factor in the lower actual gain of the side lobes and the associated nulls, as depicted in Figure 4.

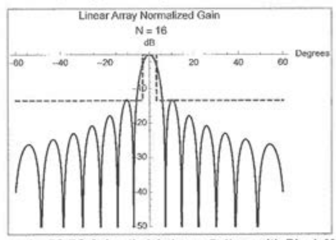

Figure 4. 5G BS Azimuthal Antenna Pattern with Block Mask

2.4 Coexistence Metric

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs} (dB). The following two sections describe the metric threshold selection and define the coexistence metric components.

2.4.1 Threshold Selection

Received power from an FSS ES is assessed as acceptable if $I_{es}/\eta_{bs} \leq -6$ dB.

The -6 dB I_{es}/η_{bs} threshold at the 5G BS demodulator input was selected to conform with an ITU Working Party 5D liaison to Task Group 5/1 for 5G system protection "*Irrespective of the number of cells and independent of the number of interferers*" [7]. This threshold is quite conservative. The 5G BS receivers are expected to be interference-limited because 5G is a multi-user system. Power received from other 5G co-channel transmissions will likely be much higher than receiver noise power η_{bs}. Received FSS ES power at 6 dB below the noise floor will cause a negligible increase in total received undesired power given the presence of 5G co-channel transmissions. In other words, a more realistic assessment of 5G receiver performance would utilize I_o/I_{CO} (where I_{CO} is the co-channel, same-system interference power density), which would produce more favorable results with respect to coexistence of FSS ES and 5G BS in real-world scenarios.

2.4.2 Component Definitions

2.4.2.1 Noise Power Density

The 5G BS noise floor power density (η_{bs}) is defined as follows:

$$\eta_{bs} = -204 + NF_{bs} \tag{3}$$

Where:

η_{bs}	=	5G BS noise floor power density at the demodulator input (dBW/Hz)
−204	=	Absolute noise floor (kTB) power density (dBW/Hz)
NF_{bs}	=	Noise Figure of the 5G BS (dB)

2.4.2.2 Received Power Density

The FSS ES received power density (I_{es}) is defined as follows:

$$I_{es} = P_{T,es} + G_{es:\theta,\phi} + G_{bs:\theta,\phi} + G_{p:es,bs} - PL_{es\rightarrow bs}(d) \tag{4}$$

Where:

I_{es}	=	Received power density of the FSS ES at the 5G BS demodulator input (dBW/Hz)
$P_{T,es}$	=	Transmit power density of the FSS ES (dBW/Hz)
$G_{es:\theta,\phi}$	=	Antenna gain of the FSS ES in the azimuthal (θ) and elevation (ϕ) directions of the 5G BS (dBi)
$G_{bs:\theta,\phi}$	=	Antenna gain of the 5G BS in the azimuthal (θ) and elevation (ϕ) directions of the FSS ES (dBi)
$G_{p:es,bs}$	=	Polarization gain between the ES and BS antennas (dB)
$PL_{es\text{->}bs}$	=	Path loss between the FSS ES and 5G BS (incl. fading and deployment factors, dB)
d	=	Three-dimensional distance between the ES and BS antenna locations (m)

2.5 Propagation Model

We have implemented path loss models according to the methods described in the most recent versions of 3GPP TR 38.900 [10]. This document is largely equivalent to ETSI TR 138.900, "Study on channel model for frequency spectrum above 6 GHz" [11]. These documents describe propagation models to be used in evaluating 5G systems at frequencies from 6 to 100 GHz.

The relevant scenarios include "Urban Micro–Street Canyon" (UMi-SC) and "Urban Macro" (UMa), described in sections 6.2 and 7.2 of these documents. The UMi-SC model pertains to situations where 5G BSs are deployed below the rooftop levels of surrounding buildings, while UMa corresponds to BSs deployed above rooftop levels.

2.5.1 Median Path Loss

For the UMi-SC and UMa scenarios, the path losses are characterized in terms of sets of equations for the median path loss as functions of the 2D distance between BS and User Terminal (UT), the heights above ground of the BS and UT antennae, and the center frequency of transmission. For each of the two scenarios, there are equations for LOS and NLOS path losses (pertaining to cases where there is or is not a line-of-sight between the BS and UT antennae). Equations for the probability of being LOS are also provided for each scenario, which are a function of the 2D distance.

Values for an example set of input parameters are shown in Figure 5. Three curves are included, those being LOS, NLOS, and Combined median path loss. The Combined curve is the sum of the LOS and NLOS curves weighted by the respective probabilities of the path being LOS or NLOS.

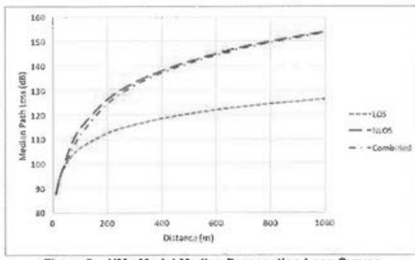

Figure 5. UMa Model Median Propagation Loss Curves

2.5.2 Log-Normal Shadowing

The models also include additive terms (in dB) to accommodate for statistical variation of the path loss to reflect location variability due to shadow fading, which is modeled according to a log-normal distribution (i.e. normal in dBs), with a specified standard deviation for each scenario and LOS/NLOS case.

Figure 6 shows example Probability Density Functions (PDFs) for a specific set of model input parameters. Three PDF curves are included, those being LOS, NLOS, and Combined path loss. The Combined curve is the sum of the LOS and NLOS curves weighted by the respective probabilities of the path being LOS or NLOS. Note that the LOS and NLOS curves have symmetric normally distributed PDFs while the Combined curve, being a weighted sum of the two constituent Normal curves, does not.

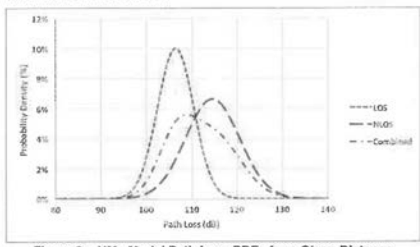

Figure 6. UMa Model Path Loss PDFs for a Given Distance

These PDFs will be used in the technical analysis to model probabilistic path loss, specifically to determine the probability that, at a given distance, the path loss will exceed the value necessary to achieve $I_{ex}/\eta_{bs} = -6$ dB.

Figure 7 shows the Cumulative Distribution Functions (CDFs) associated with the PDFs of Figure 6.

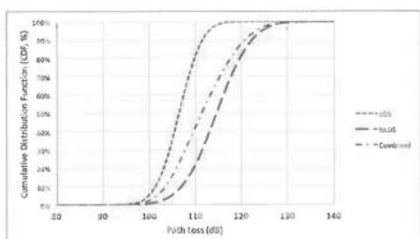

Figure 7. UMa Model Path Loss CDFs for a Given Distance

2.5.3 Path Loss Confidence Curves

The model can also be used to calculate path loss confidence curves. If a confidence value is specified, say X%, the path loss value for which there is a X% probability of being greater than or equal to as a function of distance can be determined. Figure 8 shows two path loss confidence curves (i.e., for 50% and 95% confidence values).

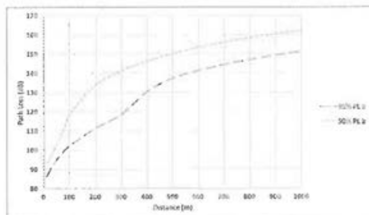

Figure 8. Example Path Loss Confidence Curves

Thus, at a distance of 500 m, there is a 50% likelihood that the path loss will be ≥ 150 dB and a 95% likelihood of being ≥ 137 dB. This path loss methodology will be used in the analysis to generate confidence curves for $I_{es}/\eta_{es} \leq -6$ dB.

2.6 System Description

A specific instance of the system under analysis is shown in Figure 9. Note that the environment is urban. The FSS ES antenna is located on the roof of a building (height 25 m, which is the recommended value for h_{BS} in the utilized UMa propagation model [11]) that is taller than most of the surrounding structures. The 5G BS antenna is located below the rooftops of the surrounding buildings (height 6 m). The 5G BS is placed "around the corner" relative to the FSS ES building to indicate that NLOS propagation is a possible case.

Figure 9. System Analysis Description

Additional details for the FSS ES and 5G BS characteristics/parameters can be found in sections 2.2 and 2.3, respectively.

Based on this system definition, we have selected the "Urban Macro" (UMa) propagation model [10]. The FSS ES plays the role of the "BS" and the 5G BS as the "UT" as defined in the UMa model. This is done because the UMa "BS" is defined as the device that is above surrounding rooftops while the UMa "UT" is defined to be below the rooftops.

In a LOS scenario, the highly unlikely "worst case" antenna configuration is that the boresights of both antennas are directly pointed at one another. We will allow the BS to be located along the full 360° around the fixed (in elevation and azimuth) ES. At each BS location, we will evaluate performance over the 360° range of random azimuthal BS antenna orientations.

3 Technical Analysis

3.1 Methodology

3.1.1 General Overview

Figure 10 shows a simplified view of the analysis methodology. Recall that we have previously specified necessary system parameters such as antenna heights, elevation angles, etc., which are assumed to be in place.

We evaluate the possibility that the 5G BS may be placed at different locations around the FSS ES, while the ES is at a fixed location with a fixed antenna direction. The angle θ is used to denote the angle of the BS's location with respect to the ES; θ is defined to be 0° when the 5G BS is located in the azimuthal direction of the boresight of the FSS ES antenna.

Additionally, the azimuthal direction of the antenna of the BS is evaluated as being randomly oriented over a 360 degree range with respect to the ES. The BS antenna is assumed to comprise three sectored antennae, each with a beam capable of being scanned over 120 degrees, so that as the BS antenna is rotated in a random direction over 360 degrees the ES will always be within a sector's beamwidth.

This assumption is conservative, as a more likely case would have only a single sectored antenna, in which case the ES could be located in the BS antenna's back-lobe for many orientations. This more realistic assumption would result in two primary consequences, one, in most cases even if the BS antenna is looking toward the ES antenna it will not be located within the main beam of the ES antenna, and two, often the back lobe of the BS antenna will be oriented toward the ES antenna.

This often will be the case because the ES will be oriented in a southerly direction toward the geostationary orbital plane over the equator, and most BSs can be expected to be located outside the narrow main lobe of the ES antenna.

Conversely, the probability of the ES being in the BS antenna's main lobe, as opposed to a side lobe, is based on the relative beamwidth of the main lobe with respect to that of the side-lobe, as shown in Figure 4.

As the 5G BS is placed at different angles around the ES, the value of d for which $I_{es}/\eta_{bs} \leq -6$ dB at a specified confidence level (X%) is calculated. The set of these points over 360° around the ES creates the probability contour. The red shaded region indicates where a 5G BS placement would result in $I_{es}/\eta_{bs} \leq -6$ dB at less than, and the green region where $I_{es}/\eta_{bs} \leq -6$ dB at greater than the specified confidence value (X%).

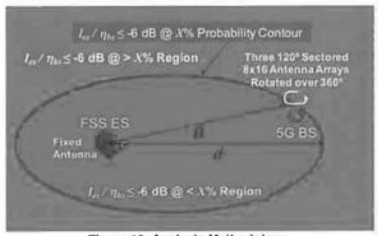

Figure 10. Analysis Methodology

Thus, the results of this analysis methodology enable insight into the sensitivity of 5G BS placement in the region of a FSS ES. The smaller the red region, the less sensitive the 5G BS is to placement.

We will calculate the probability contour using $X = 99\%$, 98% and 95%, that is, the I_{es}/η_{bs} will not exceed the -6 dB threshold at that distance with these confidence levels. The confidence levels are based in turn on the statistical distribution of the received power density at the specified distance. The statistical variability from which this distribution arises is due to two variability factors: (1) the log-normal variation of the path loss around the calculated median path loss, as explained in Section 2.5.2, and (2) the probability of the ES being in the main lobe or side-lobe of the 5G BS as it is oriented in random directions, as explained above.

3.1.2 Assumption Discussion

Throughout the analysis, attempts have been made to use reasonably conservative assumptions whenever possible in constructing the coexistence model, particularly for cases where there might be uncertainty in actual deployments of FSS and 5G systems (especially for 5G, for which no actual deployments exist). Such conservative assumptions include:

- The location of the ES at a relatively high elevation, and the subsequent use of the Urban Macrocell path loss model (UMa), which provides lower path loss values than the Urban Microcell model (UMi – SC), for both LOS and NLOS cases;
- The modeling of the BS and ES antenna based on the peak values of the side-lobes, as opposed to, for example, average side-lobe gains;
- The assumption of 3-sectored BS antennas which provide essentially omni-directional coverage, as opposed to single-sectored antennae for which an ES might be located in the low-gain back-lobes; Notably this analysis does not consider the types of network

architectures that might be employed for other types of 5G deployments such as fixed-wireless applications that would not use an omni-directional antenna;

- The use of 99%, 98%, and 95% confidence levels for assessment of received power density levels, with the 99% and 98% being extremely conservative as compared to the already conservative 95% protection target used in [9];
- The assumption in the baseline analysis that there is no additional path loss attenuation due to shadowing from rooftop deployments, which would provide substantial additional attenuation of ES signals in the areas closer in to the ES location;
- The assumption that the 5G BS sites are located outdoors when, particularly at the high frequencies in question, indoor deployments might dominate; and
- The assumption that the ES elevation angle is at a minimal value of 35 degrees, while the elevation could extend up to 55 degrees.

3.1.3 Mathematical Formulation

If we substitute equations (3) and (4) for I_{es}/η_{bs} (in dB) the resulting composite expression is:

$$I_{es}/\eta_{bs} = P_{T,es} + G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} + G_{p:es,bs} - PL_{es\rightarrow bs}(d) + 204 - NF_{bs} \qquad (5)$$

Note that in this formulation we have explicitly accounted for the fact that the elevation angle (ϕ) at which we must evaluate the FSS ES and 5G BS antenna patterns are functions of the distance between these antennas (d). Thus, given a specified I_{es}/η_{bs} value (e.g., -6 dB), we can solve for the distance (d) at which the antenna gains and propagation loss sum to the required value. That is:

$$I_{es}/\eta_{bs} - P_{T,es} - 204 + NF_{bs} - G_{p:es,bs} = G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} - PL_{es\rightarrow bs}(d) \qquad (6)$$

Note that all of the values to the left of the equal sign in equation (6) are defined constants as shown in Table 1.

Parameter	Description	Value
I_{es}/η_{bs}	Ratio of FSS ES received power density (*Ies*) to 5G BS noise floor power density (η_{bs}) at the demodulator input (dB)	-6
$P_{T,es}$	Total transmit (i.e., both polarizations) power density of the FSS ES (dBW/Hz)	-78.46
NF_{bs}	Noise Figure of the 5G BS (dB)	12
$G_{p:es,bs}$	Polarization gain between the ES and BS antennas (dB) [looking for supporting reference]	-3

Table 1. Constant Parameter Definitions

Substitution of these constant values results in the following equation.

$$-116.54 = G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} - PL_{es\rightarrow bs}(d) \qquad (7)$$

The evaluation of equation (6) has been implemented in an Excel spreadsheet. The path loss solution uses the Combined (i.e., the weighted combination of the LOS and NLOS components)

PDF to determine the solution for a specified confidence level (e.g., the *PL* has a 95% probability of being greater than x), as was discussed in Section 2.5.2.

3.2 Results

The following results pertain to a set of system parameters and models that was chosen from key standards documents [7],[8].

3.2.1 Baseline

The analysis methodology described in Section 3.1 was applied to the system as described in Section 2. For convenience, the FSS ES parameters discussed in Section 2.2 are summarized in Table 2.

Parameter	Description	Value
Antenna Vertical Elevation	Boresight relative to the horizon (degrees)	35°
Antenna Height	Meters above the ground	25
Power Amplifier Output	Power density per right and left hand circular polarization (dBW/Hz)	-78.46

Table 2. FSS ES Parameter Summary

The 5G BS parameters discussed in Section 2.3 are summarized in Table 3.

Parameter	Description	Value
Antenna Height	Meters above the ground	6
Antenna Down-tilt	Degrees	10°
Antenna Location	Below local rooftops	N/A
Antenna Polarization	Linear	±45°
Antenna Array Size	Elements	8x16
Receiver Nose Figure	dB	12
BS Deployment Density	#/km²	30

Table 3. 5G BS Parameter Summary

For the selected parameters of Table 1, Equation (7) shows the antenna port to antenna port coupling loss needed to keep I_{es}/η_{bs} from exceeding the -6 dB threshold is at least 116.54 dB. By combining the statistical variations of the path loss with those for the BS antenna gain variation due to random orientation of the BS azimuth, the following figure is the coupling loss at various confidence levels plotted as a function of separation distance.

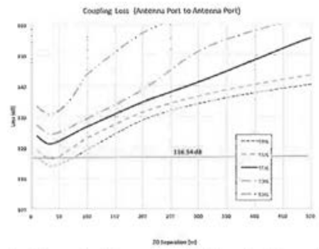

Figure 11. Antenna to Antenna Coupling Loss Confidence Curves

Note that at short separation distances, the elevation angles are large and antenna pattern losses dominate so for these parameters, the coupling loss has a minimum level at 35 m. Since only the 99 and 98 percentile confidence level curves have minima below the 116.54 dB threshold, only those two will provide non-trivial data for the subsequent analysis.

Figure 12 shows the results of the above described analysis. Only positive rotation angles are shown due to symmetry around 0°. The "Confidence Curve" shows the distance that the 5G BS would need to be placed from the FSS ES in order to achieve the specified $I_{es}/\eta_{bs} \leq$ -6 dB confidence level, absent consideration of any of the other factors discussed below. For example, for an angle θ (see Section 3.1.1) of 0° and a confidence level of 99%, the 5G BS would need to be placed at least 73 m from the FSS ES to achieve the specified result, absent the mitigating effects of other factors, such as inherent 5G BS antenna array techniques, and FSS ES physical isolation, as discussed in Sections 3.3.1 and 3.3.2. Note that the 95% plot is always 0 as explained above for Figure 11.

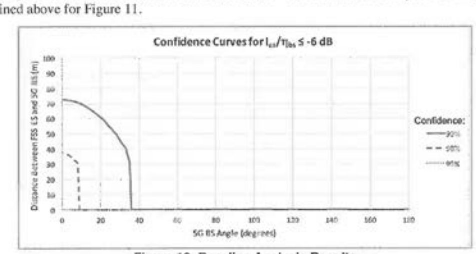

Figure 12. Baseline Analysis Results

Although Figure 12 is useful for obtaining distance information it does not provide a spatial context. This spatial contextual view is provided in Figure 13, which projects the distance data from Figure 12 onto a polar coordinate system.

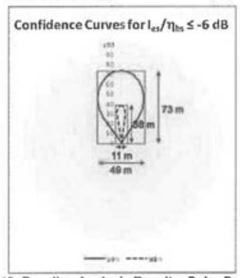

Figure 13. Baseline Analysis Results: Polar Projection

3.2.2 Coexistence Implications

Note that the area encompassed by the 99% contour is bounded by a rectangle of dimensions 73x49 m. Thus, the total area inside the 99% confidence curve is less than 0.0036 km^2.

The significance of a 0.0036 km^2 region can be assessed by comparison to a well-known urban county in which high capacity 5G mmWave BSs could likely be deployed, that being the Cook County, IL. Cook County is the second largest in the United States by population (2010 Census).

When "Cook County, IL" is entered into Google Maps, the returned region is shown by the light-red shaded area (see Figure 14). Note that the "Quick facts" section indicates that the population is 5.24 million and the area 4235 km^2.

Figure 14. Google Maps: Cook County, IL

Therefore, a 0.0036 km^2 area constitutes only 0.00009% of the Cook County area. Were we to make the simplifying assumption of uniform population density, the number of Cook County residents living inside the 99% contour is approximately 4.4.

Note that if we use the still extremely conservative 98% contour the area is 0.00042 km^2, which is 0.00001% of the area with only 0.5 residents living inside.

Thus, given the availability of FSS ES deployment location flexibility, these extremely small footprints clearly support successful coexistence. Note that this is a worst-case result, as it neglects any improvements due to FSS ES antenna physical isolation and 5G antenna array techniques (see Sections 3.3.1 and 3.3.2).

3.3 Additional Mitigation Factors

The following two sections will discuss two likely mitigation techniques, those being FSS ES physical isolation and 5G BS antenna array techniques.

3.3.1 FSS ES Physical Isolation

Figure 15 shows the geometric implications for the case in which the FSS ES antenna is mounted on a modestly sized building. Note that the ES antenna is mounted 2 m above the roof of a 23 m tall building, resulting in a 25 m deployment height. The ES antenna is located at the roof center, which is a 16x16 m square.

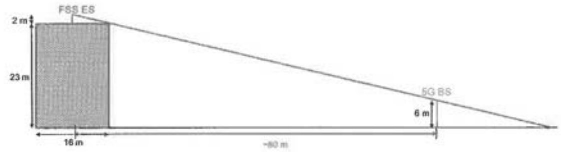

Figure 15. Geometry for Roof Blockage of FSS ES Signal

Drawing a line from the ES antenna that tangentially touches the building, we note that a 5G BS antenna that is 6 m above the ground will have "line of sight" to the ES antenna only at distances greater than approximately 80 m. If the BS is located closer than 80 meters then we would expect significant signal attenuation due to blockage by the roof itself. And, the closer the BS is to the building, the greater the R.F. attenuation due to roof blockage.

The FSS ES installation can be readily modified to provide additional R.F. isolation to a 5G BS. Figure 16 shows the case in which an R.F. barrier of height 0.5 m has been place on the roof edge in the boresight direction of the FSS ES antenna.

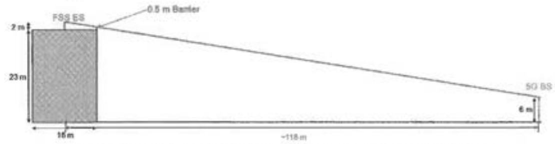

Figure 16. Geometry for Roof Plus Barrier Blockage of FSS ES Signal

Drawing a line from the ES antenna that tangentially touches the barrier top, we note that a 5G BS antenna that is 6 m above the ground will have "line of sight" to the ES antenna at a distance of approximately 118 m or greater.

In an open area, as the BS moves closer than 118 meters to the building blockage loss is primarily determined by diffraction loss. The height parameters used in Figure 16 were used to evaluate diffraction loss as a function of distance (2-D, from the ES antenna) at 50 GHz, with the resulting data shown in Figure 17 [12]. Note that at a distance of 100 m diffraction loss is greater than 7 dB, and at 90 m over 15 dB. Thus, significant additional diffraction loss can be expected.

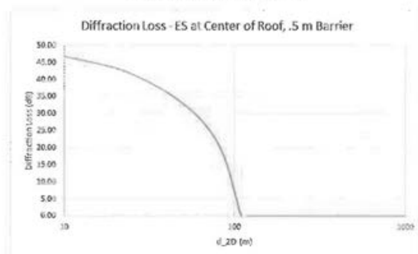

Figure 17. Diffraction Loss with a 0.5 m Barrier

Increasing the barrier height also increases to the "line of sight" distance and resulting diffraction loss at close-in distances. Given the directionality of the ES antenna, the barrier needs only be installed in the boresight antenna direction.

Certainly, scenarios can be envisioned that result in less favorable coexistence conditions. For example, the 5G BS antenna height could be increased to 10 or even 25 m, or the FSS ES antenna could be located off-center on the roof, or the building could be shorter and/or narrower. However, the above specific cases are intended to demonstrate that careful selection of ES deployment conditions can significantly enhance the ability of an FSS ES to coexist with a BS.

3.3.2 5G BS Antenna Array Techniques

Since it has direct and significant impact on system capacity and single user throughput, interference mitigation is a very active area in 5G research and standards. Many of the techniques developed for 5G systems to cope with self-interference and interference between co-existing 5G systems will provide an equal benefit against other co-existing systems, whether 5G or not. In order to provide some context in the area, examples of activity in each of the following classes are discussed.

3.3.2.1 Zero Forcing

Zero forcing is the 3D generalization of null steering in a cluttered local environment. Since there are multiple, indirect paths, this technique places a response null on any non-desired source. Thus, this technique is applicable in RF clutter environments using a Multiple Input – Multiple Output (MIMO) receiver. An example of work in this area can be found in "On the Performance of the MIMO Zero-Forcing Receiver in the Presence of Channel Estimation Error" [16], which discusses the performance of a MIMO Zero Forcing receiver with imperfect channel knowledge.

While MIMO techniques consider multiple paths through a cluttered environment, MultiUser MIMO (MU-MIMO) supports multiple users simultaneously. Thus MU-MIMO receivers are able to separate the signals from concurrent transmissions on the same frequency from different users. This is achieved by using the degrees of freedom provided by the multiple antenna and paths to separately isolate each individual signal. One relevant aspect of MIMO and especially MU-

MIMO is the suppression of other (non 5G) signals. Although, there is a paucity of literature of 5G MU-MIMO rejection of other wideband signals, there is a great deal on the ability to pick out a desired (or many desired) signals from a mix of other signals. An example of this capability is discussed in "LOS Throughput Measurements in Real-Time with a 128-Antenna Massive MIMO Testbed," [17], which provides performance results from a testbed designed to experiment with various aspects of Massive MIMO. Another paper, "AirSync: Enabling Distributed Multiuser MIMO With Full Spatial Multiplexing," [18] contains a study of a distributed Multi-User MIMO system using spatial multiplex and Zero Forcing that reports signal rejection of 25 dB.

3.3.2.2 Null Steering

Null steering is modifying the antenna pattern to produce a null in the direction of an interference source. As such, it implies a far field, plane wave model and is therefore commonly associated with phased arrays. When in an uncluttered RF environment, null steering works well. An example of work in this area can be found in "Optimization of Array Pattern for Efficient Control of Adaptive Nulling and Side Lobe Level," [14] which discusses an optimization technique applied to array synthesis with the constraint of reducing side lobe levels.

Null steering can achieve very deep rejections in many cases. "SoftNull: Many-Antenna Full-Duplex Wireless via Digital Beamforming," [15] analyses the performance of a transmit null steering algorithm to reduce self-interference for antenna structures supporting full-duplex operation, and reports reductions ranging from about 20 to 80 dB (see Figures 8-9 of [15]).

3.3.2.3 Antenna Side Lobe Control

The analysis provided in this paper assumes either standard reflectors for the ES and arrays with uniform amplitude taper for the BS antenna. These types of antennas, have a fairly high level of side lobes starting at -13.3 dB from the main beam. There exists a large number of techniques to further reduce the sidelobe level, each with its own characteristics; but industry standard antennas can readily achieve side lobe levels well below -20 dB. See "Side Lobe Level Reduction in Antenna Array Using Weighting Function," [13] which includes an analysis of various side lobe reduction techniques including a variety of commonly applied windows.

4 DISCUSSION OF RESULTS

The foregoing analysis of a typical deployment scenario shows that small Fixed Service Satellite (FSS) Earth Stations (ES) with uplink transmissions between 47.2-50.2 and 50.4-52.4 GHz, communicating with geostationary-orbit spacecraft, can be located in the same urban areas as Fifth-Generation (5G) wireless Base Stations (BS) without the need for coordination.[2]

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. This metric is used to determine the 99%, 98% and 95% probability contours for $I_{es}/\eta_{bs} \leq -6$ dB.

The baseline confidence probability contour data has been evaluated with respect to absolute area and also area relative to a specific county (i.e., Cook County, IL). The results indicate that for a

[2] Note: As noted earlier, the results of this analysis depend on the characteristics of the satellite system at issue; the methodology readily could be applied to systems with other architectures or physical configurations.

given ES, the area where a potential coexistence issue could exist is small, and the chances of such a circumstance actually arising in the real world is rare.

As reported in Section 3.2.2, the total 99% confidence probability contour area is less than 0.0036 km^2 and 98% contour less than 0.00042 km^2, which constitute less than 0.00009% and 0.00001% of Cook County, respectively. In order to assess how unlikely it is that a 5G BS will experience an I_{es}/η_{bs} greater than -6 dB, we will first utilize Figure 18, which is a magnified view of the region of interest from Figure 13.

We also have "turned around" the perspective to focus on confidence that the I_{es}/η_{bs} will be *greater than* (>) the -6 dB goal. So, if at a given distance the confidence of I_{es}/η_{bs} being ≤ -6 dB is X%, then the corresponding confidence that it will be > -6 dB is (100% - X%). Thus, the 99%, 98% and 95% regions become the 1%, 2% and 5% regions, respectively. Recall from Figure 11 that the 95 percentile curve never falls below the 116.54 dB threshold, so I_{es}/η_{bs} is less than -6 dB at all distances, and, we can therefore use the 5% percentile I_{es}/η_{bs} > -6 dB as a conservative ceiling value.

Therefore, the two regions of interest can be defined as follows:

- I_{es} / η_{bs} > -6 dB @ between 2% & 5% Region (Blue Shaded)
  - Area of the blue shaded rectangle
  - Size is ~420 m^2
- I_{es} / η_{bs} > -6 dB @ between 1% & 2% Region (Red Shaded)
  - Area of the red shaded rectangle minus area of the blue shaded rectangle
  - Size is ~3160 m^2

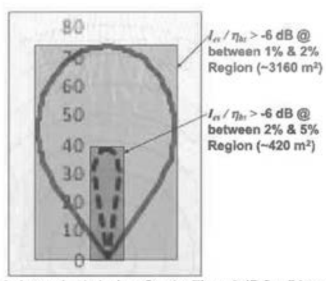

Figure 18. Approximate I_{es} / η_{bs} Greater Than -6 dB Confidence Regions

We can now make the conservative assumption that any 5G BS deployed in the red shaded region will have a probability of I_{es}/η_{bs} > -6 dB of 2% and in the blue shaded region of 5%. Thus, using the total region area (3160 m^2 + 420 m^2 = 3580 m^2) to weight these probabilities based on the individual region areas, the resulting probability of I_{es}/η_{bs} > -6 dB assuming a uniform likelihood of 5G BS placement is approximately 0.024.

We can now make the (also conservative) assumption that the FSS ES is deployed in an area where 5G BSs are deployed at the standard density (specified in Table 12 of [7]) of 30 per km^2. Thus, the expected number of BSs falling within the confidence regions under discussion is approximately 0.1. That is, the chance of a BS being in the confidence regions under discussion is roughly 1 in 10.

This assumption is conservative because there will be large areas of, for example, Cook County in which no 5G BSs will be deployed. Moody's Investor Service recently published information claiming that 5G system deployment will likely cover only 50% of the United States population [19].

However, even if a 5G BS happens to be deployed in the discussed confidence regions (0.1 probability), the probability that the BS actually will experience an I_{es}/η_{bs} > -6 dB is 0.024. Therefore, the total probability that a 5G BS will actually experience I_{es}/η_{bs} > -6 dB under the terms of this analysis is only 0.0024, or approximately 1 chance in 416.

Notably, these results are based on conservative assumptions, including path loss, use of peak side lobes (instead of actual lower values at different off-axis angles), considering only BS antennas with essentially omni-directional coverage, calculating much-higher confidence levels for received power density levels than commonly used, not accounting for attenuation from blockage, assuming all-outdoor 5G deployment, and never considering the operation of an ES at an elevation angle above a minimal value.

Moreover, the foregoing calculations do not take into account the mitigating effects of other factors, such as FSS ES physical isolation and inherent 5G BS antenna array techniques, which virtually eliminate the chance of a real-world problem ever actually arising.

Thus, the results of this analysis show that coexistence between FSS ESs and 5G BSs (using the deployment scenario described in this paper) is feasible without the need for coordination.

5 REFERENCES

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Roof and Ground Mount Satellite Earth Station-5G Sharing Analysis for 1.8 m Satellite Earth Stations.

Filed with FCC October 18, 2017, GN Docket No. 14–177.

Revised October 18, 2017

Fixed-Satellite Service Earth Station Receiver and 5G Coexistence (including Ground Mount Antennas)

1 Executive Summary

This analysis of a typical deployment scenario considers the case of small Fixed-Satellite Service (FSS) earth stations (ES) operating with downlink (space-to-Earth) reception in the 37.5-40 GHz band from geostationary-orbit (GSO) spacecraft. It shows that those FSS ES can be located in the same urban areas as a Fifth-Generation (5G) wireless network without the need for coordination.

The analysis, similar to the Roberson Report [1], utilizes standard methodologies, parameters, and metrics, and also uses published characteristics of the 5G IMT system [2]. This analysis also considers the case of a ground-mounted ES, in addition to that of a roof-mounted ES.

While the coexistence metric for FSS networks operating below 30 GHz has long been established as an increase in the thermal noise of the receiver of 6% commensurate with an I/N of -12.2 dB, the coexistence metric for FSS networks in the frequencies above 30 GHz is currently under consideration at the ITU. This analysis therefore considers a range of I/N values, namely -6, -10, and -12.2 dB.

The analysis considers a 1.8 meter earth station with the earth station antenna pointing in a fixed direction at a realistic elevation angle toward a GSO satellite, and uses a Monte Carlo simulation to place the earth station and the 5G cells (base station (BS) and associated user equipment (UE)) at random locations within a one kilometer square area. The simulation then develops statistics for earth station receiver I/N based on over one million random location samples that are then used to generate a cumulative distribution function (CDF) for the percent of locations where an I/N (-6, -10, or -12.2 dB) into the earth station receiver is exceeded.

The results demonstrate that the subject earth station can operate successfully inside a 5G deployment without the need for coordination because the earth station can operate in close proximity to the 5G network. The result is the same (i) in the case of a roof mounted 1.8 m antenna with 20 dB of additional attenuation from the roof line or parapet wall, and (ii) in the case of a ground mounted antenna in an enclosure, or with other screening, that provides 20 dB of additional attenuation.

2 Technical Analysis

Introduction

The study investigates the effect on an FSS receiver of a 5G system composed of several base stations and user equipment. In the simulation, which is performed using Visualyse Pro software from Transfinite, the FSS receiver is immersed inside the 5G distribution. The location of the ES is varied randomly within a one kilometer square area and then a number of 5G BS and associated UE stations are randomly placed within the area. The process is repeated for a million iterations with a snapshot taken at each iteration and a CDF of I/N versus location generated.

2.2 Characteristics of 5G (IMT-2020)

The 5G system parameters and deployment scenarios to be used in the sharing and compatibility studies are found in the ITU document that is being used internationally to analyze frequency sharing/interference between IMT systems (i.e., 5G) and FSS networks in frequency bands 24.25 GHz to 86 GHz [3].

The 5G systems setup is outlined in section 8 of Recommendation ITU-R M.2101. In this analysis, the following 5G parameters and configurations, and other salient methodologies, are used:

1. One million snapshots are used to generate the CDFs;
2. e.i.r.p. densities are -35.6 dBm/Hz for BS and -50.9 dBm/Hz for UE;
3. Micro urban hotspot below the roofline scenario with BS height at 6 m and UE at 1.5 m. All BS and UE are outdoor. One square kilometer area includes six BS and three active UE per BS. The BS and UE are placed inside that area;
4. The location of BS and UE vary for each snapshot. The UE are distributed in the area defined by the BS azimuth coverage of 120° degrees and up to 100 m from the BS. The BS azimuth coverage direction is random for every snapshot;
5. 20% network loading activity factor reduces the total number of active BS and UE by 80%;
6. There are 30 BS per km² and three UE that can be associated with each BS;
7. TDD factors reduces the simultaneous transmissions of BS by 20% and the UE by 80%;
8. At each snapshot, the following parameters are randomized:
    i. Locations of BS and the UE associated with that BS;
    ii. BS and UE antenna elevation and azimuth angles within a given sector depending on the link using beamforming antennas according to Recommendation ITU-R M.2101;
    iii. The BS and UE that are active (based on TDD factor);
    iv. The UE transmit power control level based on the UE proximity to the BS;
9. BS do not use power control in the downlink;
10. Reference emission bandwidth is 60 MHz for BS and UE;
11. The propagation model for the 5G system is from Doc. 5-1/36. Micro urban scenario is used with parameters from Recommendation ITU-R P.1411 "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz". The parameters for the non-line of sight path loss with the coefficients (from P.1411 Table 4) where α=5.06, β=-4.68, γ=2.02 and σ=9.33.

The results are presented as CDFs for:

1. BS antenna gain toward the UE;
2. Downlink carrier-to-noise C/N ratio.

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FIGURE 1

BS to UE antenna gain CDF

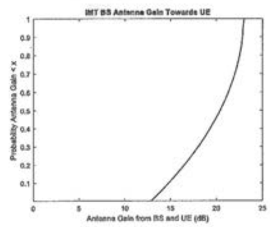
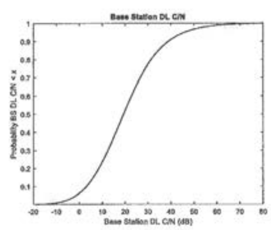


FIGURE 2

BS down link C/N



2.2 Characteristics of FSS systems

The FSS characteristics used in this analysis are shown in Table 1 below.

TABLE 1

FSS/BSS downlink parameters

Parameter	**Unit**	**1.8 m Diameter**
Frequency range	GHz	37.5-40
Noise bandwidth	MHz	50-500
Earth Station Antenna diameter	m	1.8
Peak receive antenna gain	dBi	55.4
Antenna receive gain pattern	–	Rec. ITU-R 465-6
System receive noise temperature	K	150
Minimum earth station elevation angle	°	35
Interference to Noise Ratio I/N	dB	-12.2, -10 and -6

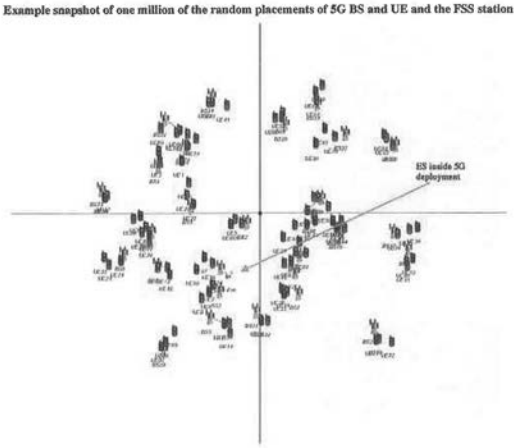
2.3 Analysis scenarios and assumptions

The 5G setup is as described above. The 5G stations and the FSS earth station are randomly placed at each snapshot as shown around a center point in the analysis area, which is one km^2. The snapshot in Figure 3 is taken from one of one million iterations. Note in Figure 3 the earth station icon is immersed inside the 5G distribution and surrounded by the icons for the various BS and UE stations.

In each iteration of the simulation, the orientation of the earth station and the 5G BS and UE stations will change. In some cases, the orientation of UE and BE stations will result in alignment with the main beam of the earth station and the BS antenna. In others, there will be an alignment with the UE beam, and so on. The Visualyse software's Monte Carlo process calculates and records the I/N into the ES receiver that results from that random placement of all the stations for that iteration.

FIGURE 3

Example snapshot of one million of the random placements of 5G BS and UE and the FSS station



The following assumptions are also used:

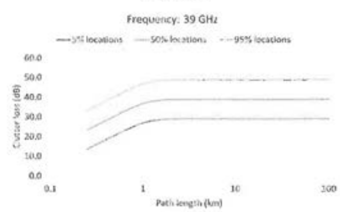
1. The 5G network scenario is as described above;
2. Clutter models used for the transmit link from 5G towards the FSS receiver are from Document ITU-R TG 5-1/38. Two models are used. The first is Recommendation ITU-R P.2001 "A general purpose wide-range terrestrial propagation model in the frequency

range 30 MHz to 50 GHz". The time percentages from 0 % to 100% are chosen randomly for each time sample. The other is Recommendation ITU-R P.2108 "Prediction of Clutter Loss" section 3.2. The clutter is applied at the 5G transmitter side as well as the FSS receiver side according to Recommendation ITU-R P.2108. The percent of locations for clutter is random between 0% and 100% for every sample[1];

3. The FSS center frequency is 39 GHz;
4. FSS antenna height is 12 meters or ground mounted;
5. For each BS, three UE are employed at center frequencies of 38.933 GHz, 39.0 GHz and 39.067 GHz;
6. Frequency dependent rejection (FDR) is accounted for;
7. Polarization loss is set to 3 dB;
8. The FSS coexistence criteria is under discussion within the ITU-R working parties. For this analysis -12.2 dB, -10 dB and -6 dB are considered. The percent of time exceedance is needed to determine compatibility;
9. FSS bandwidths are 50 MHz and 500 MHz;
10. The 5G emission mask in dBc and 60 MHz measurement bandwidth are shown below;
11. The FSS receiver selectivity are shown below. The selectivity filters have -80 dB per decade slope from the -3 dB point to -70 dB floor. A faster filter roll-off can provide better rejection;
12. The 12-meter-high roof mount FSS ES installation is used, with a roofline, parapet wall or other shielding providing an additional R.F. isolation of at least 20 dB to the 5G BS and UE configuration.
13. The ground mount FSS ES installation places the antenna mount at 2 m above ground and uses an enclosure similar to Figure 7 that provides an additional R.F. isolation of at least 20 dB to the 5G BS and UE stations.

FIGURE 4

Clutter loss



[1] Note these clutter models do not account for clutter closer than 250 m from the station.

FIGURE 5

5G emission masks

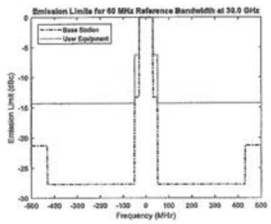


FIGURE 6

FSS receiver selectivity

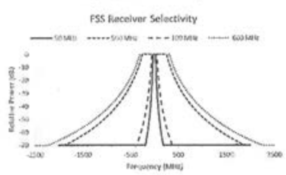


Figure 7

Fully Enclosed Ground Mount

3 RESULTS

The results of the simulations for the three I/N values are shown below.

TABLE 2

5G and roof mounted 1.8 m FSS ES summary of results

FSS Bandwidth (MHz)	50	500
Locations where -12.2 dB is not exceeded (%)	99.69	99.99
Locations where -10 dB is not exceeded (%)	99.87	99.99
Locations where -6 dB is not exceeded (%)	99.98	100

Table 2 indicates that with a greater than 99.69% confidence level (roughly 3 sigma) that a roof mounted earth station of the type considered here, and with the minimum additional 20 dB of attenuation reasonably expected of a roof top installation, could be deployed within a 5G network and not experience more than -12.2 dB I/N.

The CDF plot in Figure 8 below shows the percentage of simulation iterations where the I/N was greater than a given value. The plot shows that for the vast majority of random deployments of stations, the expected level of I/N was vanishingly small.

TABLE 3

5G and ground mounted 1.8 m FSS ES summary of results

FSS Bandwidth (MHz)	50	500
Locations where -12.2 dB is not exceeded (%)	98.756	99.396
Locations where -10 dB is not exceeded (%)	99.134	99.590
Locations where -6 dB is not exceeded (%)	99.614	99.812

Table 3 indicates that with a greater than 99.4% confidence level (nearly 3 sigma) that a ground mounted earth station of the type considered here, operating with a 500 MHz wide carrier (such as that used by ViaSat), and with the minimum additional 20 dB of attenuation reasonably expected of a block wall enclosure, could be deployed within a 5G network and not experience more than -12.2 dB I/N. Based on ViaSat's previous testing,[2] it is actually more reasonable to expect 25 dB to 30 dB of attenuation from such a block wall enclosure. Factoring in such higher signal attenuation, for example, the 98.756% value becomes 99.5% with 25 dB of such attenuation, and it becomes 99.784% with 30 dB of such attenuation.

The CDF plot in Figure 9 below shows the percentage of simulation iterations where the I/N was greater than a given value. The plot shows that for the vast majority of random deployments of stations, the expected level of I/N is vanishingly small.

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[2] See reference [4].

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FIGURE 8

5G System and 1.8 m Diameter FSS ES at height of 12 m CDFs

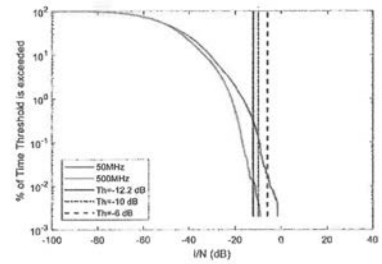
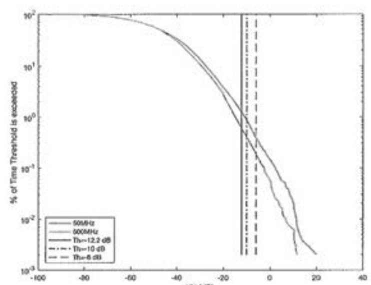


Figure 9

5G System and 1.8 m Diameter Ground Mounted FSS ES CDFs



4 Conclusion

The analysis above shows that when a roof mounted or ground mounted 1.8 m diameter FSS is placed inside a 5G distribution in an urban clutter zone, and the roof line, a parapet wall, block wall enclosure, or other shielding provides at least an additional 20 dB of attenuation over normally expected clutter losses, the potential impact on the FSS receiver is negligible and coordination of stations is not required.

This result is consistent with measurements taken of a roof mount transmit earth station at 28 GHz which demonstrated the positive impact of locating the earth station in such a typical roof mount configuration [4], where in most cases the attenuation was greater than 20 dB, and more than 40 dB or beyond the measurement capability of the test equipment in many cases, and with the Roberson report which considered the uplink (Earth-to-space) scenario in an urban setting and that also concluded that coexistence is feasible without coordination because the transmit earth station can operate in close proximity to the 5G network.

5 References

[1] Roberson Report, attached to ViaSat, Inc. Ex Parte Submission in GN Docket No. 14-177, September 25 2017

[2] ITU WP5D Liaison to TG 5/1

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[4] Carlsbad Report, attached to ViaSat, Inc. Ex Parte Submission in GN Docket No. 14-177, April 20, 2017

REGISTERED PROFESSIONAL ENGINEER DARYL T HUNTER E 16610 ELECTRICAL STATE OF CALIFORNIA

Daryl T. Hunter, P.E.
Chief Technology Officer, Regulatory Affairs
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October 18, 2017

The CHAIRMAN. Thank you, Mr. Dankberg.

And before I turn to Mr. Spengler, I'll just say we're going to have a vote at 10:30. We try to rotate Members so that we have people here to cover it, and we'll just keep right on rolling. But thank you.

Mr. Spengler.

STATEMENT OF STEPHEN SPENGLER, CHIEF EXECUTIVE OFFICER, INTELSAT

Mr. SPENGLER. Thank you, Chairman Thune, Ranking Member Nelson, and members of the Committee.

I'm proud to lead Intelsat, the world's leading provider of satellite services. We have a fleet of 50 satellites, a sophisticated terrestrial infrastructure. We operate the first truly global network for video broadband that covers 99 percent of the world's populated regions.

Our ultimate goal is a world with ubiquitous connectivity and no communications boundaries. To make that a reality, we have invested billions in high-speed satellite technology. We've been pioneering satellite communications since 1965 when we launched the first commercial communications satellite, Early Bird, at the dawn of the Space Age. Four years later, we transmitted the pictures of Neil Armstrong's first step on the Moon to the world. Today, 50 years later, we're a public company listed on the New York Stock Exchange with over $2 billion in annual revenues, and we employ 1,000 people here in the U.S., with the majority based in Clean, Virginia.

We're committed to taking the next giant leap forward for satellite technology in the 21st century, whether that's launching next-generation satellites or preparing for innovative smaller, lighter ground antennae.

While Intelsat is largely a business-to-business company, our customers are in media, maritime, aviation, telecom and enterprise networking, the U.S. military, and emergency services. They rely on Intelsat to provide broadband video, secure satellite communications, and mobility services. In media, we distribute video programming for most of the U.S. broadcasters and programmers, including CBS, NBC, Disney, ABC, Fox, Discovery Channel, Turner, and HBO. In the air, we're a major supplier of WiFi broadband connectivity for airlines such as United, Southwest, and Delta; and on the oceans, to major cruise ship companies.

In rural America, satellite bridges the last mile, where cell towers and fiber don't reach. In Alaska, for example, we help provide connections to enable telemedicine for residents and distance education for K–12 students. And in the U.S. military, we're proud to bring the Nation's soldiers, sailors, airmen, and Marines the critical communications capabilities they need to carry out successful missions around the globe.

Satellite solutions are uniquely sustainable during natural disasters. When fiber is cut, cell towers washed away, the electricity is out, and other means of communications are down, satellites remain in place in outer space. We provided disaster recovery and emergency services to locations such as Puerto Rico and the U.S. Virgin Islands after the recent devastating hurricanes. We announced this week that in Puerto Rico, Intelsat is working with U.S. antenna manufacturer Yenta and telecom operator Liberty to deliver necessities and Internet connectivity to residents.

This is an exciting time for the satellite industry. Given the insatiable demand for affordable connectivity everywhere and at all times, satellite is converging with other telecommunications technologies to build one common telecommunications infrastructure. Intelsat designed and now has in service a high-performance, next-generation satellite platform, Intelsat Epic. Intelsat Epic offers greater efficiency in the use of spectrum and more powerful and affordable services for customers.

We all know about the connected car. Intelsat is leading the way with a satellite solution for the future where software will be as important to our transportation as the latest design features. Satellites will work seamlessly with terrestrial networks in the connected car environment. Some applications will run over the wireless network, but cars will get their software updates over satellite. The broadcastability of satellite from point-to-multipoint is highly efficient. Car companies can update thousands of cars at once, and these connections are more secure.

Satellite networks can operate fully separate from the public network, dramatically reducing the cyber threat entry points, making automated cars safer for all citizens.

Intelsat has also invested in and partnered with OneWeb to utilize the power of a combined multiple constellation solution that will enhance the worldwide connectivity for mobility, wireless extensions, and military services.

Finally, in response to a recent FCC proceeding, Intelsat is leading with a creative market-based approach in proposal that will pave the way for joint use of C-band radio spectrum in the United States without risking significant reliability issues in interference for American television viewers. This spectrum is highly prized for both satellite television distribution and 5G wireless services to millions of American homes and consumers, and we've proposed a solution that allows for both sectors to flourish.

At a time when access to secure and reliable communications impacts everything from the economy to national security, Intelsat is playing a major role innovating for our Nation's infrastructure.

Thank you.

[The prepared statement of Mr. Spengler follows:]

PREPARED STATEMENT OF STEPHEN SPENGLER, CHIEF EXECUTIVE OFFICER, INTELSAT

Chairman Thune, Ranking Member Nelson and members of the Committee, thank you for the opportunity to appear before you today. I am Stephen Spengler, Chief Executive Officer of Intelsat and I'm pleased to have this opportunity to speak on behalf of our company, our customers and the many communities around the world that we serve via satellite.

Our Company

Intelsat is the world's leading provider of satellite services. With a fleet of 50 high-speed satellites, and a sophisticated terrestrial infrastructure, we operate the first truly globalized network for video and broadband that covers 99 percent of the world's populated regions. Our goal is a world with ubiquitous connectivity and no communication boundaries. We have invested more than $2 billion in high-speed satellite technology to make more efficient use of spectrum, which enables more affordable broadband connections for businesses, machines and people.

Intelsat has the capability to serve citizens and organizations everywhere, from remote, rural regions in the U.S. to the world's mega cities and to emerging regions that have been able to advance education, health services and economic prosperity through increased connectivity.

I have seen first-hand how broadband connectivity and information communications technology can transform and empower communities. Our investments in innovation and new services such as hybrid terrestrial and satellite networks have helped to make this possible. Digital connectivity and inclusiveness is critical to our ability to grow our economy here in the U.S. Satellites play an instrumental role in the infrastructure that enables this connectivity.

We pioneered the satellite communications industry. Intelsat was originally conceived as a multi-country treaty organization at the dawn of the space age. We designed and launched the first commercial communications satellite, Early Bird, in 1965 and "live via satellite" was born. We broadcast the first live international satellite TV production in 1967, which featured the Beatles' first performance of *All You Need Is Love.* We transmitted the pictures of Neil Armstrong's first small steps on the moon. Today, 50 years later, we remain committed to taking the next giant leap for satellite technology—whether that's launching our high-throughput Intelsat Epic ^{NG} next generation satellites, preparing for a new era in lower earth orbit satellite constellations or investing in the next generation of smaller, lighter ground antennae that you will soon see appearing on planes, ships and other vehicles.

Intelsat today is a public company listed on the New York Stock Exchange (NYSE: I). We have annual revenue of more than $2 billion, committed future orders of $8 billion, and we employ 1,000 employees in the U.S., the majority of whom are based in McLean, VA.

What We Are Doing Today

We are largely a business-to-business company, but Intelsat services enable many aspects of the daily lives of your constituents. Our customers in media, maritime, aviation, enterprise networks, the U.S. military, and emergency services rely on Intelsat to provide broadband, video, secure satellite communications and mobility services.

In media, we distribute video programming for all of the major U.S. broadcasters and programmers including Disney, Fox, Discovery Channel, Turner, HBO and CBS. Hundreds of millions of U.S. citizens experience our services when they watch an HBO movie, the Olympics or the Super Bowl. The cable industry delivers 1,500 channels to 61 million subscribers through 5,000 "headends," or key points of distribution for cable providers. As a satellite provider, we can deliver HD channels to those 5,000 sites at 99.999 reliability, which ultimately costs the consumer only pennies. No other technology can deliver these economics.

In aviation, WIFI inflight is so important to airline passengers that it's become more essential than extra legroom. Intelsat has invested in its global fleet to support the global aero and mobility markets. We are a major supplier of broadband connectivity to airlines such as United, Southwest and Delta through infrastructure providers. We have made great strides to support these providers as they develop new services for domestic as well as international air routes. Intelsat also provides aeronautical broadband connections for senior government leadership.

At sea, demand for bandwidth has grown exponentially. Just a few years ago, a cruise-going family might have brought a single laptop and a cell phone aboard ship. Today, cruise companies find that the average family boards a ship with 10 connected devices. And they expect the same performance at sea that they have at home in the U.S. The demand for connectivity aboard a ship is a solution that only satellite can satisfy and Intelsat serves major cruise lines.

Intelsat provides critical network connectivity for many businesses overseas and even here in the U.S., complementing terrestrial networks. Our corporate data network helps the oil and gas industry to operate efficiently in remote geographies and ocean environments. They require satellite services to connect to their rigs, providing not only operational connectivity, but also broadband services that allow the crews to communicate with family members while on location. Whether it is transmitting data from seismic exploration ships, supporting mission-critical drilling operations or employee communications, satellite services are critical to the production of oil and energy in the U.S. and beyond. Retailers use satellite to create customized broadcast networks to educate their employees and for transaction-based services, such as pharmacy and credit card applications.

In rural communities across America, satellite bridges the last mile where cell towers and fiber don't reach. For example, in rural Alaska, through a partner, we provide connections to enable telemedicine for residents, distance education for K–

12 classrooms and virtual field trips for students to places like the Baseball Hall of Fame, zoos and aquariums located in the lower 48.

We are also very proud to partner with the U.S. military to bring the Nation's soldiers, sailors, airmen and marines the critical communications capabilities they need to successfully carry out their mission around the globe and here at home, both in the sky and on the ground. Whether it's manned or unmanned aerial vehicles, communications on the move, or social and recreational welfare, Intelsat satellites carry the signal for our military and our troops.

Satellite solutions, which offer sustainable connectivity, are unique in their ability to provide near-instant communications networks in areas where disasters have crippled terrestrial infrastructure. When fiber is cut, cell towers washed away, the electricity is out, and other means of communication are down, satellites remain in place in outer space. We provided disaster recovery and emergency services to locations such as Puerto Rico and the U.S. Virgin Islands after the devastating impact of Hurricanes Harvey, Irma and Maria. Intelsat provides the communications that are vital in enabling medical services and simply connecting people to loved ones concerned for their welfare.

This week we announced that in Puerto Rico, Intelsat is working with U.S. antenna manufacturer Kymeta to deliver mobile communications to Liberty Global. Three vehicles, dubbed Liberty 1, 2 and 3 are travelling throughout Puerto Rico for the remainder of the year to deliver necessities and Internet connectivity to residents. Working with Kymeta's roof-mounted, electronically steered flat panel antennas which are installed on the vehicles, this combination delivers high-speed, reliable Internet connectivity to residents, helping the islands and their residents return to normal, day-to-day activities.

What's On the Horizon

The satellite industry is at an exciting inflection point. Given the insatiable demand for affordable connectivity, everywhere, and at all times, satellite is converging with other telecommunications technologies to build one common telecommunications infrastructure. The demand is ubiquitous and satellite is a part of the solution. To that end, Intelsat has been innovating in the design of our satellites and is advancing new antenna technologies. We understand that connectivity is critical to economic growth in the U.S. and around the world and we have invested in innovation that will ultimately improve the lives of citizens and move our society forward.

Intelsat designed and now has in service a high-performance, next generation satellite platform—Intelsat Epic,^{NG} which offers greater efficiency in the use of spectrum and more powerful and affordable services for customers.

We have all read about the connected car and the autonomous car. Intelsat is leading the way with a satellite solution for the future, where software will be as important to our transportation as the latest design feature. For example, luxury cars currently are designed to include over 100 million lines of code—that's about 14 times more than even a Boeing 787 Dreamliner jet. Auto manufacturers are excited about the potential of being able to monitor vehicles and their systems remotely and provide simultaneous software updates to all the owners of a particular model using the point-to-multipoint broadcast feature of satellite. What a game changer to think that the car you buy today will get better and safer as new software features become available. The elimination of the need to bring cars into the dealership for simple code updates will save money and time for manufacturers and drivers.

Satellite will work seamlessly with terrestrial networks in a connected car environment, with some applications—such as nearby traffic problems—running over the wireless network. Other applications, like software and mapping updates, will be assigned to satellite. Not only is the broadcast feature more efficient, reaching millions of drivers with one signal, it is also more secure.

Whereas every wireless connection represents a cyber threat with respect to a network, satellite networks can operate fully separate from the public network, reducing the cyber entry points dramatically, making automated cars safer for all citizens.

Intelsat has invested in our partner Kymeta which is inventing a new type of satellite antenna designed specifically for the connected car and other mobility applications.

Intelsat has also invested in, and partnered with, OneWeb. OneWeb is a startup low-earth orbit (LEO) satellite company and you will hear from its founder and Executive Chairman, Greg Wyler next. Utilizing the power of a combined, multiorbit Lower Earth/Geostationary solution will also enhance the worldwide connectivity for mobility, wireless extension and military services.

Finally, we all know that with this ubiquitous connectivity demand comes a relentless demand for access to more spectrum. Spectrum is key to all communication services—satellite included. Intelsat has recently taken a leadership role on an initiative that could bring more reliable and faster broadband services to millions more Americans. In response to a recent FCC proceeding, we have proposed a market-based solution that would pave the way for joint use of C-band radio spectrum. This spectrum is highly prized for both satellite television distribution and 5G wireless services.

Sharing C-band spectrum under traditional circumstances can create significant reliability issues and interference, putting viewing audiences and other users at risk. U.S. media companies depend on C-band for program distribution, whose characteristics allow transmissions of pristine quality. But we recognize that 5G is the next generation of mobile technology and satellite will play an important role in extending 5G services rural and remote communities.

Our creative proposal, developed with Intel, provides a framework for managed, joint-use of the C-band spectrum in the U.S. market that may enable wireless and other service providers to accelerate their deployment of 5G. Unless the joint-use of spectrum is managed in a way that respects the needs of all users, companies that have invested billions of dollars in infrastructure will be at risk. Whether they're watching Monday Night Football or a Nickelodeon cartoon, American television viewers expect—and deserve—high quality images and 100 percent uptime. Our proposed plan offers a win for everyone. We believe it's time for the satellite operators and others industry participants to embrace this opportunity to create more economic opportunity for themselves, American business and U.S. citizens.

We are now in a productive dialogue with a number of stakeholders to turn this proposal into a reality. We are grateful to the FCC for its openness in considering market-based solutions that will result in the highest and best use of spectrum and accelerate innovation in this country.

Conclusion

We appreciate the Committee's interest in learning more about our evolving industry and the impact the industry has on various customers. At a time where access to secure and reliable communications impacts everything from the economy to national security, Intelsat is pleased to be playing a major role in innovating our Nation's infrastructure. Intelsat is dedicated to envisioning the future and enabling connectivity everywhere and anywhere on the planet.

Senator WICKER [presiding]. Thank you very much, Mr. Spengler. Mr. Wyler.

STATEMENT OF GREG WYLER, FOUNDER AND EXECUTIVE CHAIRMAN, WORLDVU SATELLITES LIMITED (ONEWEB)

Mr. WYLER. Thank you, Senator Wicker, Ranking Member Nelson, and members of the Committee. Thank you for the opportunity to testify before the U.S. Senate about OneWeb's mission to bridge the digital divide. We will spend billions to build the world's first large-scale constellation and launch our fleet in the coming months.

We will begin bridging the American digital divide in 2019 by enabling low-latency broadband coverage for every home, school, and hospital in Alaska. In 2020, we will reach every square mile of America. This means a brighter future for the nearly half of Americans with substandard Internet access, primarily in rural areas. This will be a foundation for ubiquitous 5G service, the Internet of Things, connected vehicles, telemedicine, and online education.

Our initial system, with peak speeds of 500 megabits per second, is just the beginning. Our second constellation, planned for 2021, will enable ultra high speeds beyond 2.5 gigabits per second, faster than fiber, direct to every rural home using a small lightweight antenna.

We have a third constellation planned for 2023, which will continue to increase our total capacity until we can support 1 billion consumers globally by 2025. In total, we look to invest nearly $30 billion to achieve our mission of fully bridging the global digital divide by 2027, and this will start right here in the United States.

Today, total satellite capacity is a few terabits per second. OneWeb will have 7 terabits per second in its first constellation, over 120 terabits per second in its second, and has achievable plans to reach nearly 1,000 terabits per second, that's one petabit per second, by 2025.

Over the past few years, we have raised nearly $2 billion from caring shareholders with industry and distribution expertise, including Softbank, Qualcomm, Hughes, Intelsat, Coca-Cola, the Airbus Group, and the Virgin Group.

To build this system, we needed to break new ground in satellite development. In March, we began construction of the world's largest purpose-built satellite manufacturing facility in Exploration Park, Florida. This $85 million project will soon produce 15 satellites per week. This factory is creating 250 high-paying jobs—high-paying engineering jobs—with multiplier effects for the regional economy.

With thousands of satellites to manufacture, hundreds of rockets to order and launch, and billions of people to connect to our system, this is not easy. But today, OneWeb satellites are under construction, the rockets are in place, and our first launch is in May.

OneWeb was founded with the mission of enabling affordable access for everyone, and we must do so while protecting our precious space environment. I have spent the past 15 years on this mission. It's a life's mission and one deeply held by all of us.

In 2003, I began connecting hundreds of schools and communities in Rwanda, building the first fiber to the home and the first 3G network in Africa. With each connection, I saw the impact on individuals and communities. I also saw the potential of small ISPs and telecom operators, which is why OneWeb will partner with, rather than displace, local operators and aspiring entrepreneurs.

In 2007, I founded O3b networks, which has launched 12 satellites. O3b has the distinction of not only being the fastest and lowest latency satellite system to date, but also the only NGSO broadband system to not have gone bankrupt, which illustrates the challenges and fragility of this industry.

This is hard, but we must overcome these challenges responsibly. Together we must lead in setting the global standards for protecting our fragile space environment because the consequences if we do not are dire: space debris, reentry casualties. These are serious risks which come from substandard components and a lack of an adequate regulatory environment.

We know that a single impact between satellites can cause thousands of debris fragments. At OneWeb, we recognize the responsibility of being on the leading edge, and as the first to launch a large constellation, we have taken great care not to physically overlap our orbit altitude with prior filed systems to reduce the risk of inter-constellation debris creation. These best practices have been adopted by others, as there remain many altitudes for safe space operations.

Ranking Member Nelson, Senator Wicker, and the members of the Committee, thank you for the opportunity to testify today. We know you understand the moral urgency of this mission. We know you see the issues as you visit rural townships and populations where millions of Americans live without access. We are not here to ask you to get behind us with CAF or other government subsidies; we are here to stand by your side and bring connectivity, jobs, and economic prosperity by connecting people in rural America to their opportunities.

[The prepared statement of Mr. Wyler follows:]

PREPARED STATEMENT OF GREG WYLER, FOUNDER AND EXECUTIVE CHAIRMAN, WORLDVU SATELLITES LIMITED (ONEWEB)

Chairman Thune, Ranking Member Nelson, and Members of the Committee, thank you for the opportunity to testify before the United States Senate about OneWeb's mission to bridge the digital divide with our exciting new satellite technologies. This is a great time to discuss our progress as we are investing over $4 billion to build the world's first large scale satellite constellation, and will begin launching our fleet in the coming months.

In 2019 we will begin bridging the American digital divide by making low latency broadband available for every citizen in Alaska. The next year, OneWeb's broadband will reach every square mile of America and its territories, leaving no one behind. This means a brighter future for the half of America with substandard access to the internet, primarily in rural areas, and will be a foundation for ubiquitous 5G service, enabling the Internet of Things, connected vehicles, telemedicine and online education. Importantly, as a global system, we will connect American small businesses to the 50 percent of global markets that currently have limited or no access.

Our initial system with peak speeds of 500mbps is just the beginning. Our second constellation, planned for 2021, will augment the first and increase this speed, up to 2.5gbps, for every rural home. Beyond this we have a third constellation planned for 2023 which will continue to increase our total capacity until we can reach 1 billion users globally by 2025. In total we will potentially invest nearly $30 billion to achieve our mission of fully bridging the global digital divide by 2027.

OneWeb's capacity is more in line with a terrestrial system than historical GEO satellites. For instance, the total GEO satellite capacity today is several terabits per second (tbps). In comparison, OneWeb will have seven tbps in its first constellation, over 120 tbps in its second, and approach one Petabit per second (1000 tbps) by 2025.

Importantly, access to our services will be simple. The services will be offered by local ISPs and telecom providers. The terminals will be small, inexpensive, and lightweight so they can be installed by anyone. They will be low power so they can operate from built-in batteries or a solar panel. This unique aspect of OneWeb's system design will be a game-changer for those with intermittent power or those without power in emergency situations, rural areas and developing countries.

With thousands of satellites to build, hundreds of rockets to order and launch, and billions of people to connect to our system, this is not easy. But we have made significant progress. OneWeb's production satellites are under construction. The rockets are in place and our first launch is in May.

OneWeb's System Design and Accomplishments

In the past few years, OneWeb has made remarkable progress towards achieving its mission. As the first filed and announced direct to consumer NGSO constellation, OneWeb has been a trailblazer in design and manufacturing, and has achieved many milestones:

- Formed in 2012, years before any other applicant, OneWeb designed and filed for the first NGSO system capable of providing low cost consumer broadband;
- OneWeb has raised nearly $2 billion in equity from shareholders with deep industry and distribution expertise, including Qualcomm, Hughes, Intelsat, Coca-Cola, Airbus Group, the Virgin Group, and the Softbank Group;
- OneWeb is one of the world's largest launch purchasers and has reserved and/or manifested launch capacity from Blue Origin, Arianespace and Virgin Galactic;
- As the first applicant at the FCC, we spearheaded the use of NGSO spectrum combined with a sustainable satellite design to reach rural populations, and received the first U.S. market access grant from the FCC in June 2017; and
- OneWeb innovated the first low-cost, high performance NGSO satellites for mass production, leading to the creation of the world's first and largest purpose-

built production satellite factory responsible for 250 new engineering jobs in Exploration Park, Florida.

To build this system we needed to break new ground in satellite manufacturing. Earlier this year we did just that, and our $85 million specialized facility in Florida will soon start production. Capable of producing 15 satellites per week, this new factory has also had multiplier effects for the regional economy. For instance, this summer RUAG, a space components manufacturer, moved its facilities from Switzerland to Titusville, FL to be near our factory. Their foreign direct investment in America is creating 80 new jobs in an area which has been hit hard following the retirement of the Space Shuttle.

Figure 1: OneWeb Satellites Factory under construction in Exploration Park, FL

Our Mission

OneWeb was founded with the mission to bridge the digital divide.

I have spent the past 15 years focused on this mission, one that is deeply held by many if not all of you. After selling my first company which specialized in semiconductor cooling technologies, I traveled to Rwanda, Africa. It was then a country torn by history and without connectivity. In 2003, I began connecting hundreds of schools and rural communities to the internet, building the first fiber to the home and the first 3G network on the continent.

Figure 2: Fiber installation in 2003 in Kigali, Rwanda

With each connection, we saw the positive impact of community access on education, telemedicine and opportunity. I saw children who, for the first time, could explore their personal interests as deeply as they liked. With local teams, we pushed the boundaries to deploy the newest technologies in some of the hardest to reach and neediest rural populations in the world. It was there that I also saw the potential of small ISPs and telecom operators, which is why OneWeb will partner with, rather than displace, local operators and aspiring entrepreneurs, and much of our systems revenue will remain in the communities that it connects.

In 2007, I founded O3b Networks, which stands for the "other three billion" and has launched 12 satellites. O3b has several distinctions. Not only is it the fastest and lowest latency satellite system to date, but it is also the only NGSO communications system to not have gone bankrupt. Today O3b, now fully owned by SES, is considered a success, but there is an important lesson here. This is a fledgling industry where failure is normal, and building these systems requires a deep and passionate commitment for something more than just financial returns.

In 2012, I founded OneWeb, continuing the commitment to close the digital divide. Today, I am glad to see the Committee properly considering the leading role new satellite technologies can play in next generation broadband systems which will have higher performance, better reach and resiliency for emergencies.

Recently, Hurricane Harvey disrupted terrestrial communications networks across the southeastern U.S. Hurricane Maria also brought catastrophic damage to Puerto Rico, making cellular service almost nonexistent after damaging nearly 90 percent of cell sites.[1] In the aftermath of these natural disasters, satellite networks provide vital connectivity faster than any other option. And the faster communities reconnect, the faster recovery starts. OneWeb's highly resilient network will provide another level of critical connectivity to first responders and victims when tragedy strikes.

Challenges and Recommendations

Bridging the Digital Divide must include sustainable development. This means bridging the divide without harming space for future generations. We cannot overlap constellations in a way that would risk creating space debris, or endanger humans on Earth by using less expensive materials which do not degrade on re-entry. OneWeb has been focused on sustainable space development since the beginning.

We know that a single impact in space can cause thousands of debris fragments, fouling orbital altitude ranges for hundreds, if not thousands, of years. The Iridium/Cosmos event is just one of several costly, environmentally damaging examples. To prevent collisions and a cascading of damaging events, large scale constellations must have a minimum altitude spacing (MAS) for safety.

We were the first to design a large constellation and took great care not to overlap any prior filed system. For the sake of future generations, we cannot take the collision risk of overlapping constellations. There are many altitudes available for safe, separated operation, yet with tens of thousands of satellite filings in process, overlapping may happen as there are currently no meaningful regulations on this matter.

The last significant U.S. regulation on space debris is more than 20 years old. The international treaty called the Outer Space Act was adopted in 1967. This has created a regulatory gap, and while many countries are drafting papers, this is a place where the United States can take a leadership position and drive standards of excellence and stewardship worldwide. NASA is conducting a study on large constellations due later this year, and at a minimum this can inform such standards.

We have worked with the industry, including Boeing, to develop best practices for an appropriate MAS. A MAS of 125km can help isolate the impact of any single system which suffers a collision. While many satellites have onboard propulsion and accurate station-keeping, we also know that satellites fail, and when they do the potential for collision rises. In such a case, keeping safe distances between constellations protects against cascading events.

OneWeb is also pioneering the use of grappling mechanisms for the removal of satellites. We will include these grappling mechanisms on all of our satellites for future space tugs, and we hope to open source these designs so every constellation may use a standard grappling interface to remove failed satellites. The development of satellite service technologies, like those at the West Virginia Robotic Technology Center, will play an important role in protecting altitudes from the many potential failed satellites.

[1] *https://www.washingtonpost.com/news/the-switch/wp/2017/09/28/this-is-how-bad-cell-service-in-puerto-rico-is-right-now/?utm_term=.d0502b304c7c*

OneWeb also pioneered new standards calling for de-orbit within five years. We carry enough onboard propulsion to safely and accurately de-orbit each satellite. We are glad to see others adopting this practice as well, as it is crucial to ensure satellites do not remain in the small and fragile LEO environment.

Related to the five year de-orbit period, we have also ensured our satellites will disintegrate on re-entry. We do not use materials which will survive de-orbit. While more expensive and more challenging, it is the proper practice rather than facing the possibility of fragments on the ground, and possibly causing re-entry casualties. While there is an old rule requiring individual satellites to have less than a 1:10,000 chance per year of causing a re-entry casualty, this rule needs to be updated to apply to large constellations that, unchecked, will drop tens of thousands of fragments.

Space is an unforgiving environment. Satellites can fail, and re-entry is always a concern. Just last year China lost control of its Space Station Tiangong-1. Operating at 349km, its re-entry date is predicted between October 2017 and April 2018. While this is only a single space object, the largest fragments that survive re-entry are predicted to be 220lbs. This is a near-term reminder that we should keep a vigilant eye on space-related safety as we look to launch thousands of objects over the coming years.

The positive news is that space safety can be straightforward when thoughtful, common-sense rules are applied. Operating costs and engineering challenges may increase slightly, but abiding by such minimum rules ensures satellites will continue to play a larger role in the Nation's and the world's communications ecosystem, and that the American space sector will continue to grow.

We look forward to working with the Committee, other stakeholders, Federal regulators, and others to address these issues and ones yet to emerge.

Conclusion

Mr. Chairman, Ranking Member Nelson, and Members of the Committee: thank you for the opportunity to testify today. As you have seen, we are on the cusp of bridging the digital divide using new incredibly high-performance satellite technologies.

We know you understand the moral urgency of this mission. We know you see the issues as you visit rural townships and populations, where millions of Americans live without access to quality education, telemedicine and entrepreneurial opportunities.

We are not here to ask you for Connect America Funding or other government subsidies. OneWeb was able to raise its funding because its novel technologies can sustainably achieve this goal without relying on such subsidies.

We are here to stand by your side, and with many others, help bring connectivity, jobs and economic prosperity to rural America and the world's rural populations.

STATEMENT OF HON. ROGER F. WICKER, U.S. SENATOR FROM MISSISSIPPI

Senator WICKER. Thank you very much. And thank you to all of our witnesses.

Mr. Dankberg, let me begin with you. As you know, I'm from a rural state, and many members of this Committee are from rural states, and we are very much interested in bridging the digital broadband divide in those areas.

Recently, Senator Cortez Masto and I introduced the Streamlining Permitting to Enable Efficient Deployment of Broadband Infrastructure Act, the SPEED Act, and it deals with the permitting process for deployment of broadband. This will give—this will help accelerate deployment in rural America in such areas as 5G.

As you know, Congress and the President are working on infrastructure, and we would like to deal with that as soon as we get through with the tax packages, our next big issue.

What are your thoughts on how Congress can ensure that satellite providers can be included in any broadband infrastructure proposal?

Mr. DANKBERG. Thank you, Senator Wicker, for your question. We are very anxious to participate in delivering broadband more to rural America. The thing that we would find the most useful would be to have a technology-neutral policy which would allow whatever infrastructure investment is made to deliver the greatest amount of broadband service to the greatest number of people with the best service at the lowest prices. That would be our suggestion for getting the most value out of investment that we make.

Senator WICKER. Well, OK. Technology-neutral in terms of where we put the investment, should this be done at the FCC level or according to the statute?

Mr. DANKBERG. Yes, and one of the opportunities, and the CAF program, the Connect America Fund program, has been mentioned already. The Connect America Fund program has a concept of a reverse auction where different providers using different technologies could make bids to say, "How much would it cost to deliver this broadband to this area with these features?" And there are different technology attributes that the FCC has looked at: one of the dominant ones is speed, another one is bandwidth, a third one is latency, a fourth one is price.

What we see in the market—and our experience in the in-flight connectivity business is a good example of this—is that the things that really dominate users' perception of the quality of broadband is the speed of service that they get and the amount of bandwidth that they get, that is, not having to have usage caps that would limit the amount of bandwidth that they use. And the next one would be, it's tied to both of those, would be price.

So our recommendation would be to use something like a reverse auction process, but to use market-based factors that would reflect the desires of subscribers for getting the best service that they can. And that would also allow the government to achieve the greatest penetration of subscribers that is possible, given that amount of money.

Senator WICKER. Are we going to need to amend the statute on that, or does the agency already have the authority?

Mr. DANKBERG. So far, our perception is that the FCC has not weighted it in a market-reflective way, that the weighting that they've put on latency is so high that a satellite service—I'm going to give you an example—a satellite service that would deliver one or two hundred megabits per second at a given price and to more people would be penalized so severely that a lower latency service of even 10 or 25 megabits per second may be selected in the auction. We don't think that those weighting factors accurately reflect what subscribers really want in a broadband service.

Senator WICKER. Ms. Cooper, were you wishing to weigh in on that issue?

Ms. COOPER. Yes. Thank you, Senator. We agree that there is some review needed of any program that's looking at broadband partly because you want every tool available to you as you try and reach every citizen in your state.

For the Connect America Fund, we found for us the latency issue is not our chief concern because we believe our low Earth system will have latencies in 25 to 35 milliseconds. But we found an area where satellites have simply been precluded from bidding because the last generation of satellites didn't meet some of those speed and latency requirements. So instead of a wholesale exclusion of an entire category of technology, we would just recommend that the Committee look at any of the programs or Federal incentive or infrastructure programs to ensure that anything that qualifies, any technology that meets those requirements, can bid.

I would just say that satellites are sort of structured differently in that the incentive is not to build the infrastructure. All the companies here are investing and building in the connectivity. The infrastructure on the ground, whether it's to an end location, a terminal for the consumer, or potentially some gateways to manage traffic, is where that sort of scale is going to come in, and we may end up coming back to you with some recommendations to make sure those elements can be captured as well. But none of us here, certainly not SpaceX, are counting on that investment in our space constellation to come to fruition.

Senator WICKER. Thank you.

Ms. Cortez Masto, it appears you are next. The last shall be first.

Senator CORTEZ MASTO. Thank you. Thank you, Mr. Chair. I know my colleague Senator Sullivan has to preside, so I defer to him. He wanted to ask a question.

STATEMENT OF HON. DAN SULLIVAN, U.S. SENATOR FROM ALASKA

Senator SULLIVAN. Thank you, Senator Cortez Masto.

Mr. Chairman, I just have one quick question before I go preside, and it's to Mr. Wyler.

Mr. Wyler, you talked about space debris, and Senator Booker and I have had some concerns about this. The Department of Defense Space Surveillance Network currently tracks 22,000 pieces of orbital debris that no longer serve a useful purpose.

Can you—and perhaps, Ms. Cooper, if you want to weigh in on this—can you talk about what your concerns are? And of the Federal agencies we have tracking this, nobody seems to be in charge. Who should be in charge?

Mr. WYLER. Thank you for the question. It's very important, Senator Sullivan. One, if there is a collision of satellites, we will—all the opportunities you heard today, all the wonderful things we could do for humanity and rural populations will vanish in the blink of an eye. We cannot have that. We have to make sure that all of the satellite systems have their own altitudes, that they're not all at the same place physically at the same time.

And so while we're tracking 22,000 space debris, a huge number of space debris was created at about 800 kilometers a few years ago when Iridium and Cosmos satellites hit each other, creating thousands of new fragments to track. These fragments then hit each other again and create new fragments, creating more and more space debris. As space debris numbers rise, they will impact and have impacted many other satellites.

So the important thing to do, first of all, is to just keep things separated. Make sure everybody is at their own altitudes, like airplanes, or cars driving on other sides of the roads. This is a physical issue.

Now, who should oversee this? That's a very interesting question. Right now, the FCC does not have the tools to do it. NASA is studying this at great length. And the FAA is looking into it. It's really up to you, in the Congress and the House, to determine what we should be doing next and to form some sort of a committee and oversight and take the lead for America in what needs to be done because we will lead this for the rest of the world, which is asking the exact same questions.

Senator SULLIVAN. Thank you.

And, Mr. Chairman, I'd like to yield back full-time to Senator Cortez Masto, who was kind enough to let me skip in line so I can go preside. Thank you.

The CHAIRMAN [presiding]. Thank you, Senator Sullivan.

And we'll go to Senator Cortez Masto.

STATEMENT OF HON. CATHERINE CORTEZ MASTO, U.S. SENATOR FROM NEVADA

Senator CORTEZ MASTO. Thank you. Thank you, Mr. Chair.

Thank you all first of all. Great conversation today. As you know, I'm from Nevada, 17 counties, 15 of which are rural, and rural broadband is so important. So I think this conversation is incredible. I'm very excited about the future.

I want to follow up on the line of discussion that we've had, though, about the use of reverse auctions and the process that should be allowed to reflect the consumers' wants. And I appreciate you bringing up C-band with latency and price.

Can you talk a little bit about how proposed satellite Internet offerings and what they provide to consumers? Do your proposed satellite Internet offerings provide consumers with unlimited broadband access, or are there going to be data usage caps imposed to manage that capacity? I'll ask all of you, whoever. Yes, thank you.

Mr. DANKBERG. OK, yes, I'll start with that. Yes. So we have plans of both types, we have both effectively unlimited plans, and we have plans that have usage caps. The plans that have usage caps, we try to set the usage caps at levels that most people would not hit. What we have found in the market is that hitting the usage caps is basically the greatest source of dissatisfaction for users, so in our new satellites, what we've done is we've put—and I mentioned this in my testimony—we've put more than double the bandwidth that we had in our first-generation satellite and our second one. The third generation that we're building is 10 times.

And the upshot of all that is that we're working on plans that will eliminate usage caps for more and more of our subscribers, that we'll be able to go to market with competitively priced plans without usage caps.

Senator CORTEZ MASTO. Thank you. And that was my follow-up, was, Is it going to be cost competitive? And that's the intent, is to be cost competitive and do away with the usage caps is what I'm hearing.

Mr. DANKBERG. Yes, yes. That is—that is exactly right.

Senator CORTEZ MASTO. OK. I'm happy to hear from——

Ms. COOPER. Thank you for that question. I think, like ViaSat, SpaceX is an engineering company. We love solving difficult problems. And the limiting factor here is the amount of capacity that you have on orbit that you can share among your consumer—consumers and customers. For our part, we are looking at pushing the boundaries of the capacity of each satellite and then, of course, having many of them, over 20 in view from any spot in the U.S. So customers can aggregate capacity where there is a concentration of demand and diffuse capacity where those end users are different, more widely geographically dispersed locations.

By building more capacity on orbit, we'll be able to network—manage our network and groom our capacity in a different way. We are still several years away from providing customer service, so we can't answer with the kind of specificity that ViaSat can with their existing customers, but the real trick that we're focused on now is removing the upper limit of capacity constraints that drive those kinds of network management questions.

Senator CORTEZ MASTO. Thank you. I didn't know if the other——

Mr. SPENGLER. Yes. Intelsat is a bit different than other—others on the panel today. We are a business-to-business provider, we're providing infrastructure to operators: it could be a wireless operator that is looking to extend services into remote and rural areas, it could be a provider of WiFi in-flight broadband, or they use our network.

So our responsibility and our focus is developing that infrastructure that is extremely efficient and very cost effective, delivering the speeds that those providers need.

Senator CORTEZ MASTO. OK.

Mr. SPENGLER. And so the end user customers are really the customers of our customers and partners.

Senator CORTEZ MASTO. OK.

Mr. WYLER. So all this talk of subsidies is confusing for me as a entrepreneur. We've raised billions of dollars and are raising billions more because we are building a system that can operate and meet the needs of people, not meet the needs only if the government gives us money to help it meet the needs.

Now, I cut my teeth in Africa building systems for people who made two dollars a day, you know. So they, of course, couldn't afford subsidies, but we had to build a system that could meet their needs, right? Because in those countries, they don't have anybody giving them anything. So if we were to raise this kind of money to build a system, it really needs to be able to operate without subsidies. It needs to be able to provide services at affordable rates for the people in these communities.

So that's where all the subsidy conversation—I think we're in this point where it's like subsidy is a given, now let's figure out how to dish it out. Well, why don't we invent technologies that doesn't need—that don't need subsidies, like most every consumer product people in this room today buy? So this is where I'm sort of trying to figure out, I think we're taking the subsidy as a given as opposed to saying maybe we should have technologies that don't need it, and focus on that.

Senator CORTEZ MASTO. And your technology is one that will address the consumer's need and the consumers'——

Mr. WYLER. We're addressing market——

Senator CORTEZ MASTO. Yes.

Mr. WYLER.—where the hardest hit—this is where I spent my time—we're addressing the system to focus on the people in the most need and to do it in a profitable way, to meet their needs, and provide broadband that gives them oxygen-like capacity. They wake up in the morning, they have it, they don't think about it, just like we take every breath every day.

Senator CORTEZ MASTO. Thank you.

I notice my time is up. Thank you very much. I appreciate you being here.

Thank you, Mr. Chair.

The CHAIRMAN. Thank you, Senator Cortez Masto.

Senator Hassan.

STATEMENT OF HON. MAGGIE HASSAN, U.S. SENATOR FROM NEW HAMPSHIRE

Senator HASSAN. Thank you, Mr. Chair. And thank you and the Ranking Member for holding this hearing.

And to our witnesses today, thank you so much for being here and for the work you do.

Mr. Wyler and Ms. Cooper, I just wanted to start with a question for the two of you, and, first of all, thank you for your testimony.

I come from a very rural and geographically diverse state. We're small, but we've got mountains, we've got seacoast. And just a few weeks ago, thanks to the Chairman and Ranking Member, we had a field hearing in New Hampshire to explore the issue my constituents face when it comes to connectivity. And one of the more humorous parts of the hearing was when one of the providers said we have to be careful not to build duplicative capacity, and my constituents were like we just would like capacity, you know, we're not worried about duplication yet.

So I guess the question is, How can satellite provide a broadband solution for states like mine? And what's the role of satellite in a 5G America, especially with so many of our places, even though the maps may say we've got connectivity, but in reality, our citizens will tell us they don't?

So, Ms. Cooper, why don't we start with you.

Ms. COOPER. Thank you. That's a terrific question. I think it's the problem that all of us here are geared to solve using different architectures and different technology approaches, but I think it underlies the goal that all these companies here on the panel have.

For us, we are looking at these constellations of satellites with multiple satellites in view so that you're not bound to one single path to reach a specific satellite. You would have multiple paths to multiple satellites, which we think will allow some currently blocked customers to have access to an infrastructure of high-speed capability and reliability.

And then the next step is to make sure that the customer can afford a service that is appropriate to what their demands are, and that's the next step, of ensuring that you drive the cost down of making lots of satellites, which is I think a strong suit of SpaceX and using our manufacturing and innovation history to drive the costs of other complex satellite and launch systems downward. So, and also then the cost of deploying those systems has to be driven down, certainly a factor of our launch heritage and our reusability.

So all those pieces bring to bear these two problems. One of them is making sure you actually can reach the customer, and the second is making sure that the infrastructure that you're building that will be available, always on, is costly—cost effective and easily deployed from an architecture perspective. That's I think our approach.

Senator HASSAN. Thank you.

And, Mr. Wyler, did you want to comment?

Mr. WYLER. Sure. Sure. Growing up in Boston on the border of New Hampshire and spending all the weekends there, I know—I know your state well, and I understand the issues and the challenges, especially when you get in the White Mountains where you actually can't see through the mountain to hit satellites. And so lots of people—and this is sort of the same problem in Alaska and a lot of the northern states——

Senator HASSAN. Right.

Mr. WYLER.—with a lot of satellites, you can't see, you literally just can't see them.

So our satellites remain very high in altitude, almost straight up at all times, so you always have a vision of one or two or multiple more satellites at a time.

The key is the terminal. The key is to have something small, lightweight, inexpensive. And the size is actually less important than the weight and the cost. And that's where people get—no one in rural New Hampshire, they're not going to care whether it's 1 foot, 2 foot, or 10 feet. They're going to care, "Is it cheap? Can I install it easily? And do I get really good Internet access?"

Senator HASSAN. Right.

Mr. WYLER. So what we're doing is bridging—we're flipping rural on its head. We're making rural faster than suburban, and so it's no reason that rural has to have that penalty.

Senator HASSAN. OK. Thank you.

And, yes, Mr. Spengler.

Mr. SPENGLER. Yes, I just wanted to add to that. I think we all believe that to bridge the digital divide, it's going to take a combination of a lot of different technologies to get there. It may be direct-to-consumer by satellite, it may be enabling terrestrial networks in new ways.

But I think people don't realize today that satellite is currently in the backbone of a lot of wireless networks around the world who are providing 2G and 3G services in lesser developed countries. And Intelsat today is providing 4G services, helping wireless companies extend their network in 4G in the U.S. So 5G is an extension of that.

And we firmly believe that when it comes to rolling out 5G across the country, it is not going to get everywhere without the support of satellite, and satellite solutions are going to be essential to reaching those hard-to-reach locations and extending those capabilities out there in the future.

Senator HASSAN. Thank you.

And, Mr. Dankberg, did you have anything to add?

Mr. DANKBERG. No, I think that satellites today, if you look at—we think a great model is satellite TV where 30—over 30 million people have satellite TV. And our ability to provide satellite Internet basically corresponds exactly to satellite TV, a competitive service.

Senator HASSAN. Well, thank you. I see my time is up. I have two other questions that I'll submit to you for the record, one about planning for resiliency in the light of natural disasters, and the other about debris in space, and I look forward to your answers. Thanks.

The CHAIRMAN. Thank you, Senator Hassan.

Senator Nelson.

Senator NELSON. I saw firsthand what satellite communication does in a place like Puerto Rico, since so much of it was—you couldn't communicate because there wasn't electricity, even though they were bringing in temporary cell towers. So I was provided a satellite phone when I went.

I'm curious as we're going forward, talk about the role that your satellites will play with regard to something like autonomous vehicles.

Mr. SPENGLER. I can start. So as I mentioned in my opening remarks, we see satellite as playing a important role in the connected vehicle. And, again, the connected car is not just going to be connected by satellite, it's going to be connected by all sorts of wireless technologies, as it is today, and we know the cars are getting more and more sophisticated.

So it's leveraging each communication's technology for its particular role and leveraging its strength to provide a safe environment for cars and safe environments on the roads that will ultimately lead to the fully autonomous vehicle.

What we're working on is a technology partnership with an antenna company that will shrink satellite antennas so that they're small enough to fit into the roof of a car, the company is called Kymeta, and this will enable software download to mapping downloads on a point-to-multiple-point basis to thousands and thousands of cars at one time. Keeping that data up to date is going to be essential for safety and enabling those future features in cars.

Senator NELSON. And how does that integrate with the GPS system?

Mr. SPENGLER. Well, GPS, of course, is connecting cars today, and it already exists. And so it is all going to be tied together through software and systems in the car at one point in time to make sure that they're all working together to enable a safe environment for passengers on the roadways.

Senator NELSON. And as you answer, Mr. Wyler, also bring in spectrum. There's a real competition for spectrum by terrestrial-based broadband services as well as satellite. So what's the right balance?

Mr. WYLER. Excellent question. And I like that you started this off with the first responder because this was actually an initial focus. We put a lot of resources into developing an antenna that would go on the top of a car or be built in, which also includes LTE and 3G connectivity for the passengers in the surrounding area.

And a unique feature of this for a first responder. So imagine a fire vehicle, a fire truck, and you put the antenna on it, and wherever you go, when the AT&T or Verizon signal falls down, it's listening to the signal strength, and it turns on in milliseconds, maintaining your call. It tells your phone, "Hey, I'm here, I'm your local antenna," when the signal strength is low, and then when the signal strength comes back up, it automatically shuts off.

A unique feature of this is as the vehicles come together, they actually know where each other are and form their own network. So you could walk among the vehicles with your normal cell phone and be using your current cellular operator, whichever you have, in any country of the world.

So this would be unique and important for places like Puerto Rico, for instance, and Florida, where a hurricane comes, and every police officer and every fire vehicle and every emergency vehicle will actually be its own cell system with the resiliency that satellite brings it.

Senator NELSON. So, Ms. Cooper, now, there are a dozen applications in front of the FCC for various new satellite constellations. So what challenge does this pose to your company? And how are we going to have coordination and spectrum-sharing protocols in the future?

Ms. COOPER. Thank you, Senator. Part of that space renaissance that I referenced is an excitement about using this concept of low Earth orbiting satellites to solve complex problems on Earth. There were 32 different proposals filed at the ITU, and 11 of those companies have filed either to ask for a U.S. license for their constellation, such as ours, or a license to provide a foreign system with service to the U.S.

Not all of those will succeed. This is a complex set of problems. There's an engineering and design and investment and concept and bring-to-market problems that all need to be kind of brought to bear.

Companies like SpaceX love to solve these kinds of difficult complex problems, and we think we have a real edge because we can draw through our design and manufacturing technique and our launch capability to deploy this kind of system.

The FCC has done a terrific first step to review and update the rules for this kind of satellite constellation, which hadn't been updated in about 15 years. And they rightfully put the onus on sharing spectrum on the operators to share and negotiate and coordinate. And if they can't come to agreement, the FCC will designate and split the bands. Every applicant in the round said that is the least effective outcome, is to have the FCC dictate and divide and designate spectrum. So the best outcome will be between smart systems, better incentivized to continue to innovate, and incentivize to continue to coordinate.

And this is also true internationally. The ITU has similar encouragements internationally for other governments to apply for systems to coordinate operator to operator, and make the best use of the airwaves by applying those negotiations and smart technologies.

Thank you.

The CHAIRMAN. Thank you, Senator Nelson.

Senator Gardner.

**STATEMENT OF HON. CORY GARDNER,
U.S. SENATOR FROM COLORADO**

Senator GARDNER. Thank you, Mr. Chairman.

And thank you all for your testimony and time today. This is an incredibly exciting technology that we continue to develop and that you continue to deploy, and I thank you for it.

It used to be when I was growing up that satellite communications had sort of a James Bond feel to it. If you saw a satellite phone, it was the size of a cinderblock, and it was really amazing that you could see that. We advanced then to, you know, cell phone technologies and the bag that dimmed the headlights on the car when you plugged it in. So then, you know, we see this—what I think you've done is sort of the democratization of satellite technology through broadband deployment, and it's incredible, particularly for a state like mine, where we have vast swaths of rural areas from the high plains on the east side to the beauty of the mountains and the valleys as a result, and some of the challenging terrain when it comes to communication on the western part of Colorado.

And so, Mr. Dankberg, obviously I greatly appreciate your presence in Colorado, the work you do, the hundreds of employees that you have there. I appreciate what you do to help connect all of us. My staff informs me they are not pleased with your connections on in-flight satellite efforts because I can send them e-mails and articles and they're very upset at that.

[Laughter.]

Senator GARDNER. But I appreciate it, so thank you.

In the 1980s, your business was started and grown dramatically since then. You talked about in-flight satellite. We've had talk on autonomous vehicles, vehicle-to-vehicle communication, what satellites can do in terms of that. What other areas can satellites provide for that unique niche, too, as well as satellite technologies may be preferred in certain circumstances? If you can talk about those two ideas.

Mr. DANKBERG. Yes. Thank you, Senator Gardner. And also thank you for your leadership on the AIRWAVES bill and your recognition of the importance of satellite.

One of the areas that we haven't talked about very much is our national defense and homeland security. And satellite provides a capability to connect people anywhere and to protect them. And there are many applications that we do for the Defense Department with satellite communications. We identify the locations of friendly troops and avoid fratricide, it's a very important application.

One of the things I mentioned in my testimony is that we provide Internet connectivity to the entire U.S. VIP fleet, including Air Force One and Air Force Two, so that the leaders of our country can remain in contact with the ground no matter what's going on and get up-to-date information over the Internet.

Another really, really important one is for our troops overseas. And so one of the big advantages of the satellites that we've developed that have so much more bandwidth than conventional satellites is that we can make very, very small terminals and put them on platforms like helicopters. And so V–22, Marine Corps, now has the ability to remain in contact with their troops while in flight at broadband speeds. We also provide support for Border Patrol as well, whether it's in the oceans or over deserted areas. All these areas are very uniquely suited for satellite.

And then the other point is the types of satellites that we're making are so new that the amount of bandwidth we provide is on the order of 100 times that which is available through organic DoD satellites. So the Department of Defense is a very heavy user of commercial satellite systems, especially ours and the networks that we provide.

Senator GARDNER. Well, you think about the advancements, if you go through some of the documentation of September 11, 2001, and you talk about the experience that President Bush was having on Air Force One while they were watching what was happening on that day, they were relying on over-the-air transmission, right?

Mr. DANKBERG. Yes.

Senator GARDNER. They didn't have a feed that could give them consistent reliable communications to watch the news to see what was unfolding. Now, of course, you can provide that. So I think, again, just the national security component of this is so critical and shouldn't be overlooked.

Ms. Cooper, you talked a little bit about the constellation efforts that you're making at SpaceX. You mentioned in your testimony that there will be prototype launches over the next several months, and if you need the space for launch, we certainly have plenty of space for launch in Colorado.

With the launch campaign beginning in 2019 with phases of satellites launching through 2024, I mentioned the wide swaths in Colorado. If low-latency, high-speed satellite constellations were an option for rural constituents in Colorado, it would mean obviously a big step in overcoming the digital divide. When do you think constituents like mine in rural Colorado, rural America, could benefit from this? Would they see it in 2019? How long would it take? Would they be the first to benefit from this? How would that look?

Ms. COOPER. So our current deployment plans have us sending up two test satellites within the next few months so we can verify the technology we've been designing and building from scratch, and then starting our launch campaign in about 2019, and launching the entire constellation over the course of about 5 years. So we would expect to provide commercial service, as early as 800 satellites deployed, which is probably in the 2020–2021 timeframe. It certainly would be available throughout the United States including in Colorado. As a Kansan, we'd like to help you out.

Senator GARDNER. Well, just don't take our water, that's all I ask.

[Laughter.]

Senator GARDNER. So just the final thing, and I've run out of time here, is CAF-II, you mentioned tech-neutral language for things like CAF-II funding. I think it's very important. I didn't get a chance to ask that. I asked you and Mr. Dankberg the same question. But I think that's very important, that we have to make sure that tech neutrality remains a central element of the work that we do.

Thank you for your time.

The CHAIRMAN. Thank you, Senator Gardner.

Senator Inhofe.

STATEMENT OF HON. JIM INHOFE, U.S. SENATOR FROM OKLAHOMA

Senator INHOFE. Yes, thank you, Mr. Chairman. Being new on the Committee, I'm not as familiar as some of the rest of mine, with these issues. However, Mr. Dankberg, I have been the Ranking Member on the Senate Armed Services Committee, and we very interested in the applications that we have and that we enjoy. How are we with our competition over there? Tell me who else is out there that we're competing with in this realm.

Mr. DANKBERG. Which other nations?

Senator INHOFE. Yes. Well, adversaries.

Mr. DANKBERG. Adversaries? Yes——

Senator INHOFE. I won't make you—I won't ask you to make that determination as who are our adversaries, but go ahead.

Mr. DANKBERG. Yes. So satellite has been very, very instrumental in use in the Middle East and in Africa in dealing with ISIS and terrorists in terms of surveillance and reconnaissance. The issue is that now we're dealing with potential and more near-peer adversaries, and we have a number of issues and vulnerabilities. And so the things that I have described that provide more bandwidth to end users also provide more resilience and jam protection to our forces in the field.

The good thing is that largely because of the American system and the opportunities in the U.S., the U.S.—this is really important, I think. This is an area, the types of technology that you've heard from everybody on the panel, is an area where the United States has clear technology leadership over pretty much every country. And we do work internationally, including all of the countries, including some that may eventually be adversaries.

I think that making spectrum available and providing a supportive environment for satellite will keep us in the lead relative to all of our adversaries. I think we do have a strong lead now in satellite communications.

Senator INHOFE. Yes. Where are we with Russia right now?

Mr. DANKBERG. Again, so the Russians—the underlying technology that we have described, all of us are describing, is what's called spot beam satellites. The spot beam satellites basically reuse frequencies extremely efficiently. You've heard about that, LEO and GEO.

Senator INHOFE. Yes.

Mr. DANKBERG. No other country has the technology yet that we do for spot beam technology, probably a factor of 10 behind what we've been doing in the United States. But I can tell you that Russia, China, India, Brazil, all of the space-faring nations are very, very interested in this, and if we don't support our satellite industry, I feel that we could fall behind.

Senator INHOFE. Yes. Mr. Spengler, did you want to make a comment?

Mr. SPENGLER. Yes, I just want to add just something to that, and I agree with everything that Mr. Dankberg said about the importance, the tactical importance, of satellite communications to military missions for our military. But just maybe to take his last thought a little bit further. It is vitally important that the commercial satellite industry is integrated into the strategy and planning of military SATCOM as well.

Senator INHOFE. Yes.

Mr. SPENGLER. And what we've seen over the time period of recent conflicts is how critical the commercial industry has been to those missions, and we think that it needs to be sustained in a very resilient way, that we can integrate strategies commercially and with MILSATCOM to provide this leadership well into the future.

Senator INHOFE. OK. I appreciate that.

Mr. Dankberg, I appreciate also what you're doing in my State of Oklahoma. We've got some 20,000 homes with you, and, of course, when you put this on American Airlines, all the installation takes place in my home city of Tulsa. And I know that some of the rest of you are actually launching satellites right now to reach some of the rural areas which I'm concerned about in Oklahoma.

But, Mr. Wyler, I know that you're not—it's not the same company you had when you and I talked before, when you were talking about your activities in Africa, and it's a different company now. Are you still involved in Africa? And I'd like to use the rest of my time having you explain to me—I just got back from Tanzania, Rwanda, Burundi, Ethiopia, and I've kind of specialized in Africa now for 20 years. So I'm interested in the problems they're having over there, how I can be of help to some of these countries, because they look to me as one who might be able to help them. So would you comment on that?

Mr. WYLER. Sure. Thank you. Thank you. Africa, obviously, I spent a great deal of time there, and the challenges, if you look at the 17 SDGs from the United Nations, all these challenges about gender equality and water and education, every single one of those challenges, the underlying requirement is connectivity. You can't measure it, you can't manage it, without connectivity.

And so Africa is just like America in our rural areas. There is no ability to bring broadband because the terrestrial infrastructure is too expensive. We still spend a lot of our energy with Africa. We've been working with a lot of African nations. Like the Government of Rwanda is an investor in OneWeb as well as many other places around the world.

So we're—they're counting on us to help solve this problem, help to bridge this divide, because the cost structure of other technologies is just too high.

Senator INHOFE. Well, it's interesting you mentioned Rwanda, because I had dinner with Paul Kagame just less than a week ago, and he brought this up. This is a great concern there. But go ahead.

Mr. WYLER. Yes, and he's becoming Chairman of the African Union and leading the technological revolution of Africa. So Africa is going to have more youth than any other continent in the world over the next 10 years. It's growing very fast in population, but it's also growing in economy. The economics of each country is growing really fast, and they're needing and utilizing more broadband. If we stranglehold that broadband in any way, that continent will have trouble growing, it will have trouble allowing the youth who are hungering for information to experiment and understand.

Senator INHOFE. Yes. Well, my time has expired, but maybe for the record, because a couple other countries have brought this up to me, one being the Prime Minister of Ethiopia, and has a great deal of interest.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Inhofe.

Senator Peters.

STATEMENT OF HON. GARY PETERS, U.S. SENATOR FROM MICHIGAN

Senator PETERS. Thank you, Mr. Chairman, and thank you to our panelists and for your great testimony here today. It's certainly an important topic and an exciting topic of the future. We appreciate you sharing your thoughts here today.

This industry has been around a while, and we've been in space a while, and now we have thousands of active satellites orbiting the Earth with thousands more rocket bodies and hundreds of thousands of pieces of debris cluttering near-Earth space as well.

On top of that, the companies that are here before us, you're going to be putting more stuff up into space as well. And so we've been very fortunate I think so far, we haven't seen any high-speed collisions, or a limited number of those at least, but certainly each collision, as you know, exponentially increases the odds of having other collisions as a result of the debris that's thrown out there.

So, Mr. Wyler, my question to you is that your testimony provided some detail about your debris mitigation strategy and how it exceeds the U.S. Government's best standards, which you cited as being outdated, that we currently have. Would you propose that the mitigation strategies your company is following, namely, the 125-kilometer minimum altitude spacing and 5-year limit for deorbit could be followed as best practices for the whole industry?

Mr. WYLER. Oh, for sure. Space debris, as you mentioned, is a critical component. And everything we're talking about doing for Africa, it will be gone if we end up with a space debris problem because our orbital altitudes will be gone. So the 125 kilometers, which was actually adopted as well by Boeing, and others have been keeping orbital separation, is really, really critical to making sure that if there is an intra-constellation collision where one operator might have failures of satellites and smash into their own satellites, that those debris will have a limitation on how much debris they cast into other altitudes.

And your own University of Michigan students who now work at OneWeb have done a lot of calculations on this to show the tail and the falling off. So you have of looking at both debris greater than 10 centimeters and greater than—less than 10 centimeters, and if you look at that, it really starts to dive off around 125 and 150 kilometers, the total amount of debris that makes—when you model two satellites hitting each other using the NASA debris orbiting models.

So that separation is critical. It's just like lanes in a highway. I mean, you can't be going in the same place at the same time. So——

Senator PETERS. Well, certainly, the benefits are pretty clear, as you just articulated. What are some of the challenges for us to be able to accomplish that?

Mr. WYLER. Well, I think it's really a regulatory question because it's very easy to do, and there are plenty of altitudes for people to be in. And everyone knows where everyone else is. So we filed and put our satellite constellation out there years before everybody else in terms of this renaissance. And the people before us, the Globalstar and Iridium, we kept a good distance between them. And so most everybody usually respects the filing systems and says, "OK, there's where these are. I'm going to be away from them so I don't have a chance of any erroneous issues causing a catastrophe."

Right now, there are no rules, I mean no substantive rules. That's why we don't even quote the current rules, because it's really—it's really not relevant. They were done in 1967, so the Outer Space Act, right?

So the big challenge is for America to take a leadership position in this and then call in other nations and say, "Other nations, this is what we're doing. Would you join us in this? Can we talk about this? But we're already taking these constraints upon ourself." And other nations will follow, yearning to.

I saw at the FCC, because of all these different constellations and ideas and concepts that have been sort of put to them, the FCC has gotten letters from other nations and other—the European Space Agency and other space agencies, saying, "Please don't—," you know, "Be very careful. It's not just your space," right? So we have to be careful, but we have to—and it's a global world, but we have to take a leadership position and have every—all these other nations follow us, and we have that opportunity today.

Senator PETERS. I see the other panelists shaking their heads, so I want to give them an opportunity to weigh in as well.

Ms. Cooper, do you want to start?

Ms. COOPER. Absolutely. I think you would be hard-pressed to find a company with more invested in the future of space than SpaceX. We certainly count on a space environment that allows for future inventiveness and exploration, and we've approached our constellation with that responsibility in mind.

I would just add there are a couple other elements to this. We absolutely will participate and continue to drive forward the caliber of operations and expectations for space operations.

There are a couple other elements I wanted to add. The first is, you know, the design of the spacecraft itself is important, the materials you choose. The spacecraft burns up on reentry. The compartmentalization of systems, that you can maintain control even if you happen to get dinged by the harsh environment of space, your survivability and your resilience in space is important.

Your concept for how you operate on orbit is also important. The ability to maneuver in that sort of sandstorm of space, your plan for how to respond if there's a collision, and how to deorbit at the end of your operations are all critical.

Finally, you have to know what's on orbit, not just the other spacecraft, but the debris, and we would really like to continue our conversations that we've been having with the Department of Defense and with NASA on how to continue to improve the quality of inputs, about our understanding of the space environments, that we can maneuver smartly when there is a maneuver.

SpaceX is designing our satellites to be able to maneuver thousands of times in their lifespan, and we're bringing to bear the reliability that NASA entrusts for us to take human NASA astronauts to the Space Station to bear in that responsibility of operating in space.

I know that the FCC is about to issue some new rules for very small satellites, cubesats, micro-sats, particularly the kind that are used for experimentation, and we think that's the kind of leadership role that the U.S. needs to take, not just for the U.S. environment, but for the global space environment, to balance the role that space can take for research and inspiration and also preserving that environment for future activity.

Senator PETERS. Well, I appreciate that. My time is expired, but, Mr. Spengler, you've been—if you can be brief in your concurrence of what you've heard.

Mr. SPENGLER. Sure. We've been operating in the geostationary orbit for decades, and that's an orbit with hundreds of satellites, not thousands, but—and there has been defined rules on how to operate there, and it's required a lot of cooperation between satellite operators to share that space well.

We took the initiative with several other operators to create the Space Data Association to enhance that engagement with each other so that in that arc, the industry itself is taking ownership and responsibility for sharing information and making sure that it's safe and secure for the long term.

But now when you're talking about thousands of satellites in a lower Earth or mid Earth orbit, it gets more complex. And I agree with Mr. Wyler, I don't think we can just leave that up to industry cooperation, we're going to need some help and leadership from government to help make that a safe and secure environment for well into the future as well.

Senator PETERS. Right. Thank you for your testimony. I appreciate it.

Senator INHOFE [presiding]. Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL, U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thank you, Mr. Chairman.

I'm concerned about some of the reports that we've seen from the intelligence community and other sources that Russia and China and perhaps even terrorist organizations are pursuing a range of anti-satellite technology, in fact, efforts designed to threaten our military effectiveness and the satellites that may be used for civilian purposes. Other countries are aggressively developing the jamming and hacking capabilities that could cripple our military technology and surveillance, our navigation systems and communication networks. These technologies can be unleashed on civilian capabilities as well, including commercial satellites.

So my question to each of you is, How concerned are you by the potential hacking capabilities of other countries or other hazards that may come from them or from nongovernmental threats?

Ms. COOPER. Thank you. It's an excellent question, and as a company that operates one of the most technologically sensitive activities—launch capability—we take this very seriously and have deep experience and heritage in the protection of those systems that we will bring to bear to this satellite system.

I would also note that the supply chain is a particular vulnerability for space systems. And we have chosen to bring a high percentage of our manufacturing in-house, and maintain U.S. control of that, and we're proud that our satellites will not only be built in the U.S., have high U.S. content, they will also be launched on U.S. rockets from U.S. soil without any involvement from foreign launchers or certainly Russian capability.

Thank you.

Mr. DANKBERG. Yes, thank you, Senator. I think it's a very, very important question. Because we work with the military and the Defense Department, we do get support from them on dealing with especially cybersecurity, and we also provide cybersecurity for defense satellites. So we have a good understanding of what the threat environment is. But I do believe that for a privately held company to deal with state actors is probably asking more than those privately held companies are capable of.

I think the U.S. has taken—has had dominance in space for so long that, in some sense, we may take that for granted. And I think it's not something that we should take lightly.

One of the solutions that we think is definitely possible is the types of satellites that we're talking about for commercial are so much less expensive and so much—so easy to replicate, that that's one of the ways that we at least, from a national defense perspective, can obtain some amount of assurance that we'll have a reliable capability in space is to use, whether in the geosynchronous arc or the in low Earth orbit arc, multiple satellites that provide the capabilities that we need so we can make the economics of damaging our capability in space overwhelmingly expensive.

Mr. SPENGLER. As a provider to U.S. military, DoD, and other applications, we have built our network with the highest level of cybersecurity for those specific customer sets, and have a regular engagement and dialogue with that sector. So we're very familiar with the issues and the challenges. That has even led us to design our current generation, next-generation, satellites, Intelsat Epic, with some very specific feature sets that manage and deal with intentional jamming and hacking that can occur on tactical missions that could be absolutely devastating if they're not dealt with quite—quite quickly.

So it is critically important. There's no question about this. And it's where we have continual focus in these areas.

Mr. WYLER. So cybersecurity is obviously very important, but I'll bring up something else. China not that long ago shot a satellite at 1,000 kilometers from the ground. They're not the only ones that can do it. If you put all these satellites in the same orbital altitude, you are literally shooting two birds with one bullet.

Orbital spacing allows one satellite constellation to have a calamity without involving the other satellite constellations. So as the U.S. Government, which has been very active in looking at how constellations can provide very high-speed, low-latency connectivity for its troops in the field, it should want—I assume it will want that resiliency and that capability and that assurance of continued service, and not make it really easy for a competitor or another nation to take out the entire thing at one shot.

Senator BLUMENTHAL. I think these answers have been very illuminating. My time has expired, and even if I had another hour probably, we would not have enough time to exhaust all of the important ramifications of this area. But essentially space is lawless right now.

Space is the Wild West, and it's vulnerable to cyber, to physical interference, as you've just suggested, with missiles launched either from space or from ground, and we need to be prepared for the threats to our commercial and civilian satellites as well as to the military satellites that we have there.

So thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Blumenthal.

Senator Markey.

STATEMENT OF HON. EDWARD MARKEY, U.S. SENATOR FROM MASSACHUSETTS

Senator MARKEY. Thank you, Mr. Chairman, very much.

We have come a long since Intelsat and Inmarsat had a monopoly, and I always enjoyed back in the 1980s and 1990s, break up the monopolies and to make it possible for there to be more competition. And we have come now to a new era, and this requires a lot of thought in order to unleash all of the potential for good which is out there.

So, Mr. Wyler, if I can begin with you, you have raised a lot of money, you are going to deploy a lot of satellites. And I guess my big question to you is—the softball right across home plate for you—what's the difference between you and all these preceding companies that have tried to achieve the very same result in space in terms of providing low-cost access to the Internet to citizens, not only in rural parts of America, but around the planet?

Mr. WYLER. Thank you for the question, Senator Markey. I get asked this a lot of question—a lot of times. And why now? Why can we do it now that we couldn't do it before, because a lot of people have tried? We've known the potential, but we haven't had the technology to accomplish it.

I think it starts—our system, as you had me testify 10 years ago, maybe 15, about deploying fiber to the home in Africa, it starts with understanding who needs what, and the needs of those consumers and those people in these rural populations, and designing for the lowest common denominator of customer. How do you build something that's affordable? We had an earlier conversation about CAF funding and all these subsidies. Why are we talking about subsidies? We should be building something that's affordable in the first place, to the GDP-adjusted cost structure of the environment that we're going to be serving.

So what's happened now is that we're able to provide a service that is very low latency, which is key to the 30——

Senator MARKEY. Very low?

Mr. WYLER. Low latency.

Senator MARKEY. Low latency.

Mr. WYLER. Low latency.

Senator MARKEY. Low latency means what?

Mr. WYLER. Latency is the roundtrip time between you and the server on the other side. So you send a signal up to the satellite, down to some gateway, some server, and then back.

Senator MARKEY. You mean it's fast.

Mr. WYLER. It's fast.

Senator MARKEY. OK. Yes. That's another way of saying "low latency"?

Mr. WYLER. Fast, yes.

Senator MARKEY. OK, fast.

[Laughter.]

Mr. WYLER. When you click, it shows up.

Senator MARKEY. OK, yes, I got it.

Mr. WYLER. And there are a lot of standards for this. For instance——

Senator MARKEY. Our job is to translate into English all acronyms. OK?

[Laughter.]

Mr. WYLER. Right.

Senator MARKEY. So that our constituents understand what we're talking about.

Mr. WYLER. It's super critical for things like AR and VR, which——

Senator MARKEY. For what?

[Laughter.]

Mr. WYLER. Sorry. Virtual reality—OK?—and augmented reality.

Senator MARKEY. Yes.

Mr. WYLER. So the ability to create a videogame on this table while you watch with your new iPhone, this requires very low latency, this—this speed.

Senator MARKEY. Very—very—it can move very fast.

Mr. WYLER. Very fast.

Senator MARKEY. For reality and for augmented reality.

Mr. WYLER. And for augmented reality.

Senator MARKEY. Yes. And people can decide which is better.

Mr. WYLER. Yes.

[Laughter.]

Senator MARKEY. Reality or augmented.

Mr. WYLER. Exactly.

Senator MARKEY. Yes. We're actually living in that era right now.

Mr. WYLER. 5G services demand low latency.

Senator MARKEY. Yes.

Mr. WYLER. So we've been able to create a system that is designed for 5G services so that you can roll out 5G anywhere.

Senator MARKEY. So when can the first person on the planet be expected to be able to subscribe to your service and have it delivered? When do you expect that to happen?

Mr. WYLER. 2019.
Senator MARKEY. 2019. And where will that customer be do you expect?
Mr. WYLER. Sitting in Alaska. Hopefully in Barrow or some other—not in Anchorage.
Senator MARKEY. Yes. So you think it will be an American?
Mr. WYLER. It will be in America.
Senator MARKEY. OK. Where will the first customer outside of the United States be who will be able to subscribe?
Mr. WYLER. We'll be covering Europe and we'll be covering Africa, South Africa, and other areas around there. Also Argentina and all around a lot of emerging and rural markets.
Senator MARKEY. So will all of that be in 2019?
Mr. WYLER. 2019 will be the beginning customers. 2020 they will all be covered.
Senator MARKEY. So all of Europe will be covered?
Mr. WYLER. 2020? Yes.
Senator MARKEY. And not all of Africa, but South Africa?
Mr. WYLER. Most of Africa will——
Senator MARKEY. Most of Africa will be covered?
Mr. WYLER. Yes.
Senator MARKEY. Will it be all of South America or just Argentina and——
Mr. WYLER. A big chunk in 2020. Most of—most of South Africa—South America will be covered in 2020.
Senator MARKEY. OK. And, again, this is, you know, commercial. And what will it cost the average customer to be able to purchase this?
Mr. WYLER. Well, we're—well, there are two things: the acquisition cost and the cost of service. So the acquisition cost, if your antenna and your terminal is in the $100 to $150 range, you're going to have real trouble in communities, enabling community infrastructure to be there. If your cost—when I started this company, based upon my work in Africa, I shot for, How do we make affordable Internet access for someone who has a two-dollar-a-day income?
Senator MARKEY. Right.
Mr. WYLER. Which means 10 cents a day.
Senator MARKEY. OK. So in 2019——
Mr. WYLER. Yes.
Senator MARKEY.—in 2020 at the latest, you're on track to get this done?
Mr. WYLER. Yes.
Senator MARKEY. And you're going to accomplish it?
Mr. WYLER. Yes.
Senator MARKEY. Your investors are prepared to run the risk that you won't be just a repetition of what's happened——
Mr. WYLER. We have a lot of investors and a lot of eyes watching us, yes.
Senator MARKEY. OK. And how many total satellites will you have up there?
Mr. WYLER. In 2020, we should be able to hit about 800 or 900.
Senator MARKEY. In 2020.

Mr. WYLER. And then it will climb to probably another—about 2,000 or 2,200 in 2021.

Senator MARKEY. So 2,200 satellites. When Motorola was doing Iridium, they named it after the 77th element of Mendeleev's chart of elements. They had 77, right? And so you have just vastly expanded it with smaller satellites to ensure that there is ubiquitous coverage.

Mr. WYLER. The key is making these satellites smaller and smaller. The——

Senator MARKEY. And I think the key question I think for Americans is going to be, Will the price that you're offering in Alaska or rural South Dakota or Massachusetts, will that be on a scale that is equivalent to what you're going to be offering in Africa or in South America?

Mr. WYLER. So we partner with the local providers, the ISPs, and let them—work with them to help them set the prices and let them set the prices for the hyperlocal environments. So the prices will change around the world, but it will be dealt with—the prices will be managed by the local—the local Internet service providers.

Senator MARKEY. So you're saying you will be partnering with Comcast and AT&T in the United States in order to set the price for American consumers?

Mr. WYLER. That's a great question. They don't cover most of the United States. So we'll be partnering with a lot of other people. And we're happy to also partner with them, but there will be competition between the partners——

Senator MARKEY. So you're saying in the parts of America where you're going to target, it will be mostly those areas unserved by those large ISPs, and as a result, you'll be partnering with the smaller companies——

Mr. WYLER. Yes.

Senator MARKEY.—in smaller towns all across the country and trying to devise a price point that will bring a profit to the ISP and to you.

Mr. WYLER. Correct, and to hopefully spur new ISPs and new entrepreneurship in those regions.

Senator MARKEY. Right. So that very——

Do you mind, Mr. Chairman, just so I can understand?

The CHAIRMAN. [Shaking head no.]

Senator MARKEY. I appreciate it. So this very low price point that you mentioned earlier for, let's say, Africa or South America, is that also going to be something that you're seeking to achieve that to be the lowest cost provider, comparatively speaking, across the United States?

Mr. WYLER. Yes. We're seeking to be affordable for everybody in every state, and so we will hopefully be the lowest cost provider. The price will change. It may not be that low in some states, but it will be affordable to the people with their local GDP.

Senator MARKEY. Mm-hmm. Do you have already existing contracts with those ISPs, or are they to be negotiated in the——

Mr. WYLER. We have a number of MOUs already with them that were set up and ready to go. If you look at our investor base, which includes Hughes and includes Softbank, which has a number of telecom companies, including Sprint, we're working very closely to make sure we can get rural coverage. It's a passion and a drive and what we're going to succeed.

Senator MARKEY. So do you already know what that price point is going to be because of the already negotiated contracts?

Mr. WYLER. We know that we have the flexibility for that price point to move to what is affordable within the regions.

Senator MARKEY. Uh-huh.

Mr. WYLER. So we actually took a very unique approach to this. Rather than saying, OK, it's $30 a month or $50 a month, we've said, "OK, let's work together in your region for your area and let you set the price because you're the expert about what's going on in rural South Dakota, you know what the farmers there can afford and what they can pay and what the competitive prices are."

Senator MARKEY. Yes. And so—and, finally, is the service which these people are going to receive comparable to the service that people receive in Boston?

Mr. WYLER. I—speaking as a customer of someone in Boston, I don't want to achieve that, better.

[Laughter.]

Mr. WYLER. So watching the circle go around.

Senator MARKEY. No, I hear you.

Mr. WYLER. So we've designed a system that really uses spectrum very efficiently. We're actually asking the question, Why can't rural be faster? So we're shooting for 2021 to achieve 2.5 gigabits per second of capacity direct to a rural home. So there should be no—in the new technological age, there should be no penalty for being in rural populations. Those people who want to stay there and want to be educated and want to stay with their parents and build businesses should be able to, and that's what we're trying to achieve, and I think we are.

Senator MARKEY. Well, I saw what you did in Rwanda. You came and we had you testify. It was an incredible concept. You executed it, and it transformed Rwanda. OK? No one would have ever thought broadband in Rwanda would work so successfully. It's really transformed their future. Hopefully here this concept also is executed because I think the potential is unlimited in terms of transforming information and competition, not just in the United States, but around the planet. So thank you.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Markey. And I'm glad you settled once and for all what latency actually is.

[Laughter.]

The CHAIRMAN. We have a whole new way of explaining speeding tickets in this country, using high latency—low latency.

Let me just ask a couple of general questions as we wrap up here, to all of you, and feel free to jump in here. What are the major factors right now that are affecting investment in next-generation satellite technology?

Ms. Cooper.

Ms. COOPER. So at SpaceX, we're not at this point going out to seek outside investment for this project. But I would say the capability to undertake a complex problem is definitely a differentiating factor, the ability to not only conceive of it, but actually deploy the manufacturing design that's responsible and undertake the space operations in a way that preserves the space environment I think are going to be rewarded.

I think the work that my colleagues here on the panel have done in terms of advancing the caliber of satellite services continuously over the last few years has also generated an enormous amount of investment interest and excitement about what the space environment and what the satellite sector can do.

Thank you.

The CHAIRMAN. Anybody else?

Mr. DANKBERG. I think there are really two factors. One is this notion of a space renaissance where there has been a large increase in investment in space I think is absolutely true. You see a lot of startups. One of the big reasons is because there are companies working on reducing the cost of access to space, and that's basically democratizing the environment.

But there are, I would say, two issues. The number one issue is access to spectrum. For communications, no communications system can really achieve the level of cost effectiveness and performance that we want and the level of competition Senator Markey has raised without access to spectrum.

And I think that the real issue here is not dedicating spectrum only to satellite at the detriment of some other, it's really working on sharing because there is a finite amount of spectrum, and that is a very, very important area.

I'll tell you, at the next level down, and it's not quite as important, is the one that we touched on a little bit here, which is the question of subsidies. And the real issue of subsidies, I kind of agree with Greg, is that we work on a free market basis. We don't expect subsidies in order to be able to provide a good broadband product at a competitive price anywhere in the U.S. We can do that without subsidies.

I do think that we should think about what the effect is of subsidies on market distortion and how that reflects what it is that the market really wants, and I think that's—I wouldn't put that at the level of the spectrum issue, but it's something I think for the government to consider.

The CHAIRMAN. OK.

Mr. SPENGLER. What we've encountered in recent years, and it has been said many times today, is this renaissance in space and satellite communications, and as a result, there is robust investment. There is robust investment in innovation, there are sources of capital that are supporting investment, and I think that all ties to the recognition that the future network is an integrated network, it's a single network, it is a telecom network that will have many parts to it: satellite, wireless, fiber. And so it is really driving a lot of this innovation that's happening.

I think the next big area for enhanced investment and free market investment is really on the ground technologies. And it has been referenced a few times today, investments have been made on satellites and enhancing the performance, the cost, but we also have to continue to invest on the ground—the terminals, the user devices that customers have, to make them smaller, cheaper, simpler to install, and easy—and that way we'll be fully integrated.

The CHAIRMAN. Mr. Wyler.

Mr. WYLER. So as the only sort of startup in the room, we've had to go out and raise our share of capital, and we have a very wide and broad base of investors. I'll say sort of the two big things.

Spectrum certainty, spectrum certainty, spectrum certainty, and repeat that so we know it. We should not play with spectrum. You should not play with people's foundations. If you went to Verizon and said, "We're thinking about taking back the 700 megahertz," or whatever, the 1.9, you know, "maybe it would just halt investment overnight."

Don't play with the spectrum. This stuff that we're doing takes 7 years to build and tens of billions of dollars to do it at the scale we're talking about. If you play with spectrum, you play with the investors' understanding and viewpoint of the solidity of your project, which already has many other dynamics.

The second thing is space debris. If there's an accident in space, you will see a halt to investment. So unless we take a leading position on this—and it's not just from the U.S., lots of people can launch satellites, we need to take a leading position in the U.S. and have all other countries work with us, and they're eager to do so, so that we can keep satellites in their own lanes, because if they hit, the whole thing is gone.

The CHAIRMAN. Right.

Mr. WYLER. So these are the places where you, on your bench, in your position, are speaking not just for investment for the future, but you're the voice of the people with no way to speak, the people in the future generations who also want to have access to space, the people in the rural populations who know that this is the only way they're going to get broadband that's equivalent or better than that in the suburbs, and be part of the rest of the world and be part of the rest of America economically and socially.

So those are the two things: spectrum certainty and space debris certainty.

The CHAIRMAN. All of you have talked about how the satellite constellations that you have proposed are raising a number of issues for the FCC and for various other international entities. But do you feel that the FCC has the tools currently that it needs to properly address the issues that are raised by satellite constellations along the lines of what you proposed today?

Ms. COOPER. I would just say I think the FCC has done a laudable job in a very complex issue area. They have just undertaken an update of the rules for these kinds of constellations that had been sort of dormant since the last generation of low Earth orbiting satellites. Those rules will give us a much better platform to kind of pivot to this next newer unfolding generation. They did things like extending the milestones by which you need to deploy a constellation, which is especially important if you have larger constellations. And as ViaSat has noted, the ability to be able to deploy those is contingent on launch capability, which is something we feel very strongly about our capabilities there.

They've also really laid the expectations in terms of sharing spectrum to be firmly on the operators to try and figure out how to interoperate with each other, interoperate and protect the satellites that are above us, and also make sure that we can work with the terrestrial operators.

The thing that I would say that would be most useful, I think, from the Committee in terms of the Commission is to make sure there's a reflection of this opportunity with space-based systems in the expectations of spectrum, that there are two kind of key underlying principles. One is you should use, avail, every technology that's possible to try and be a more efficient user of the spectrum, and also be incentivized for any group of parties, whether it's terrestrial and satellite or within the satellite sector at different orbital hierarchies to try to apply technology for spectrum sharing. That's going to serve the American consumer better because you'll get better services through the same amount of frequency bands. I think those are the two principles that the FCC is going to benefit from in terms of direction from this Committee.

On space debris, I think the recommendation for the agencies to work together and pool their common and diverse experiences to continue to evolve that sort of foremost role of the U.S. in terms of maintaining a safe environment, that's a successful next step. We were pleased to see the formation of the National Space Council, we're pleased to have participation in the first meeting, and expect to be involved in every one of the agencies that's active in space policy.

Thank you.

The CHAIRMAN. Thanks.

Yes, go ahead quickly.

Mr. DANKBERG. I think the FCC certainly has the skills and the resources to manage spectrum. And one of the things that's helped us is the FCC's willingness to entertain new spectrum-sharing strategies within the satellite sector itself. That was part of what made our satellites more effective. And then also recently with the 28 gigahertz spectrum frontiers, the FCC—and we did reach agreement on spectrum sharing between terrestrial 5G and satellite, so we know that's possible.

I think that especially recently there has been a very strong focus on 5G wireless and the FCC, possibly to the detriment of other technologies, satellite being one. The other one that I would put in a plug for, and this really goes to some of Senator Markey's questions, is we're a little bit unique because we are a direct retailer.

So we not only drive down the cost of delivering broadband, but we then set the prices to our subscribers. And in dealing with—we also deal in Mexico, where we can provide broadband at the price points today that Mr. Wyler was talking about in Africa.

The thing that makes that possible is unlicensed spectrum because when we deliver bandwidth through other carriers, they're the ones, as Mr. Wyler said, that are setting the price points. With the access to unlicensed spectrum, we can go to Native Americans, Indian reservations, national parks, and deliver services directly to people's phones with unlicensed spectrum. And that's an area that there is really not a very strong advocacy within the FCC. I think that that's one area that could use more support.

The CHAIRMAN. OK.

Mr. SPENGLER. I think the FCC, like a lot of regulators that are dealing in the digital world have challenges because things are moving so fast, there is so much change, and I think that's where industry and the private sector and the market can be of benefit in terms of helping solve some of these challenges.

We're coming to the FCC with all kinds of new models that we haven't gone to before where we're talking about partnering with different satellite operators, different kinds of arrangements, and it's all to develop new services for different parts of the world, and in the U.S. in particular.

We recently responded to a Notice of Inquiry from the FCC on the C-band. And the C-band right now, back to some of the comments that have been made, is being sought after by the wireless industry. Currently, it's being used by satellite broadcasters to distribute programming to cable head ends, to retransmitters all around the country, and millions of Americans get their television through the C-band distribution.

What we've done is we said, look, we don't believe that sharing can work in the traditional sense, and we proposed a new solution, and we proposed a solution with Intel saying let the industry work on this together, let the market decide how we can free up spectrum in that band to allow the growth of 5G wireless, which we believe in, we all want that happen, but also give some certainty and surety to the broadcasters and the television viewers around the country, a scheme where there's joint use, that the market can decide the best way to clear that spectrum, and that we can bring a solution to the FCC. They have a lot of things on their plate, and this is one that the industry could potentially solve together in this particular case.

The CHAIRMAN. Mr. Wyler.

Mr. WYLER. I'd actually slightly disagree with Mr. Dankberg. The FCC is probably underresourced in some areas. Just a slight disagreement there. Generally, they've been doing an excellent job. There are places where they are just overwhelmed with new technologies and new ideas, and in this digital age, that changes so fast.

Certainly, I'll just—you know, in the latest proceeding, the ability for NGSOs to interfere with GSOs, they've just given us sort of a hall pass and said, "Go ahead and work it out later." It's kind of interesting because they're supposed to protect the GSOs. Now, being on the beneficial side of that, I shouldn't be saying anything bad about it, but I think it's a bit—it was generous, let's say, and unexpected to let us do that.

I think in terms of space debris, they are trying, they really are. They're putting out questions to people with kind of everybody has got these different ideas with how they're going to put their—where they're going to put their satellites and whether they're going to crash into each other or not, and people—and they're asking them for more data. But they're not equipped for that, they're not designed for space debris, because they're a spectrum—they're spectrum focused, right? They're in electrons, not in physical objects hitting each other.

So some committee, some way of giving them some tool with NASA, with the FAA, with others, maybe a Presidential commission, maybe a congressional or Senate commission, I don't know, but some way of giving them some oversight and some support in dealing with this because right now, since—basically their arms are tied, they're frozen, they don't know what to do with it because there is no good answer with the current—if you launched all these satellites, you'll definitely have space debris. So now what do they do? And who's in charge of that?

The CHAIRMAN. OK. Got it. All right. Well, thank you all. And I appreciate very much your——

Senator MARKEY. Can I just ask one question?

The CHAIRMAN. Yes.

Senator MARKEY. Your questions have been great, so it just prompted one question, which goes back to Mr. Dankberg on the historic role of unlicensed spectrum and what you think that role should be in this space right now. Can you talk about that just for a minute, please?

Mr. DANKBERG. Yes. Thank you. One of the things—if you look at some of the things that are really different in the satellite industry compared to, say, 5 or 10 years ago, there are two that are big ones.

One is—and the history of Intelsat shows most of the time satellite companies had to work through other telecom providers because their customers were the telephone companies or the wireless carriers.

The other one is if you wanted to provide video transmission, you had to work with a content owner or a TV station for distribution. What's really different now and is very liberating in the satellite industry is that you have million—you have billions of phones going around which have WiFi capability. So now a satellite operator, if they can deliver a transmission at lower cost than a terrestrial operator, you can create real competition by going to them through unlicensed spectrum, but only if that unlicensed spectrum is truly available and has the ability to reach those people.

The other big, big change is that now you're seeing these over-the-top video services where an individual subscriber can basically make an arrangement directly with a service provider, like it could be Disney, it could be Sling, Hulu, and that now transmission is really a commodity that you can just deliver to that subscriber, greatly reduce their cost without having to go through someone else.

So for the first time, satellite is no longer just a cost input to somebody else, but it has the ability to compete in two-way transmission.

Senator MARKEY. So you're saying, if I may, I just want to put it into my consumer perspective, you're saying that these multiple satellite competitors, in an unlicensed spectrum world down below, has more potential for identifying markets that they could move into and provide services at an even lower cost because that spectrum is unlicensed, and you don't—the company terrestrially doesn't need a return on investment because it's unlicensed at that point. It's a much lower cost——

Mr. DANKBERG. Yes.

Senator MARKEY.—overall, and it puts a pressure on the market that otherwise would not be there because consumers will be opting out and heading in that direction.

Mr. DANKBERG. Yes, and if I could elaborate just for a second, we are doing services in Mexico and in Africa. In Africa, we work with an organization called RASCOM, which is an organization of all the African states. We need to go through cellular operators there. A cellular operator would need to go into a village and invest $50,000 to $100,000 to put a cell tower in. In Mexico, we can do it directly using our own satellites, and for $1,000, put in a WiFi hotspot.

So that—we've talked a lot about technology, which is exciting, but the business model changes are very important, and seeing regulations that support those would be very, very helpful.

The CHAIRMAN. OK. Thank you, Senator Markey.

Well, great panel, great questions, great answers. It's a fascinating field, and one that we obviously want to do everything we can to support and encourage and see that we are doing everything we can to make sure that people all over the country and all over the world, in the South Dakotas of this country and other places around the world, have access to everything that comes with technologies, and broadband, and the opportunities associated with it.

So we appreciate the good work that you all are already doing, and we'll look forward to working with you and encourage you as you encounter issues, challenges, that you think we ought to be attending to and articulating policy about, to share that with us. But this I think has been very, very helpful, and we'll look forward to other opportunities to hear from you again.

I will just say to our panelists that if you could respond to any questions that are submitted by members of this Committee, we'll try our best to ensure that we close the record out in a matter of a couple of weeks. So we'll try and get our Members to get their questions for the record to you, and then if you could, as promptly as possible, get those responses back, it would be most appreciated.

So with that, we will conclude. Thank you all very much.

[Whereupon, at 12 p.m., the hearing was adjourned.]

A P P E N D I X

Response to Written Questions Submitted by Hon. Maggie Hassan to Patricia Cooper

Question 1. With the recent hurricanes and tropical storms devastating Florida, Texas, and Puerto Rico, I'd like to talk a little bit about emergency preparedness. If things go according to plan with this industry, in a matter of years our planet will be covered with low-orbiting satellites providing broadband to every corner of the Earth. That comes with a major responsibility to bring people back on line after storms and disasters. How is the industry thinking about emergency preparedness, and backup power? Is having an all-of-the-above approach to connectivity that incorporates satellite, fixed, and mobile broadband a good idea to make sure we can rebuild after disasters?

Answer. Maintaining reliable Internet access in the aftermath of a natural disaster can be critical when carrying out rescue operations, assisting survivors, and beginning the recovery process. The unprecedented destruction and humanitarian crises caused by Hurricanes Harvey, Maria, and Irma revealed the significant role satellite communications play in disaster relief. For those in the affected areas, where the existing communications infrastructure was either damaged or decimated, satellite communications provided the initial connectivity for first responders and consumers alike.

When operational, SpaceX's planned non-geostationary orbit (NGSO) satellite constellation will ensure that its users anywhere in the world can maintain access to reliable, high-speed Internet connections, VOIP, and 5G backhaul, even in the event of an emergency that disrupts the power grid. SpaceX's constellation will connect its end-users directly to its satellites via small, rooftop mounted terminals, which will be available with a small solar panel. This allows for operational connections even with local power outages. Additionally, because SpaceX's satellite constellation will be optically linked in space, Internet traffic from the affected area can be routed in space to Internet gateways well away from the disaster zone, allowing for connectivity even when local communications have been severed.

An "all-of-the-above" approach to connectivity is important in order to ensure responders, aid groups, government authorities, and affected citizens can maintain connectivity after a disaster and in the recovery months following an event. Accordingly, in any future infrastructure legislation, SpaceX supports a technology neutral approach to both emergency communications services and more general broadband infrastructure deployment. Currently, satellite-based broadband systems are excluded from some sources of Federal infrastructure funding for broadband deployment. The aim of emergency communications and broadband deployment efforts should be to multiply the means of broadband access nationwide, and to ensure rapid and resilient broadband availability following an emergency—regardless of the type of technology used.

Question 2. One issue this Committee has discussed at previous hearings is the issue of space debris.

According to NASA, there are over 500,000 pieces of debris orbiting the earth. This debris ranges in size from non-functional satellites, to fragmented debris as small as specks of paint. This debris travels around the earth at speeds of up to 17,500 miles per hour, roughly ten times faster than a bullet. At these speeds, even the tiniest bits of debris can cause damage, and windows on the Space Shuttle were replaced because of damage from tiny debris. With the increasing launches of microsatellites and decreasing launch costs it is now easier than ever to launch craft into low earth orbit, and the problem is likely to increase many times over. Do you believe that current processes and regulations in the United States are sufficient to mitigate the increase in space debris? How can we work to address this issue?

Answer. In developing its broadband constellation, SpaceX has focused from the outset on design, technology, and operations that will preserve and protect the space environment for current and future operations. SpaceX is committed to exceeding all U.S. and international space safety standards in the deployment and operation of its satellite constellation, and to advancing new best practices for safe orbital operations and orbital debris mitigation. This includes leveraging the high-tech manufacturing expertise and spaceflight experience SpaceX has gained providing launch transportation services for a diverse set of customers, including NASA and the Department of Defense.

Based on this experience, SpaceX is incorporating the following best practices into its broadband constellation to fulfill its commitment to safeguarding space safety:

(1) *Satellite Design:* SpaceX satellites are being designed and built specifically to maximize control of a spacecraft throughout its lifespan, even in the rigorous space environment. Each SpaceX satellite is being designed with redundant, fault tolerant capabilities to ensure they can survive failures and encounters with space debris. SpaceX is leveraging its extensive experience in resilient spacecraft design, including its heritage with the Dragon crewed spacecraft that is undergoing human-rating approvals to transport NASA astronauts to the International Space Station. SpaceX is carrying over similar critical redundancies into its satellite constellation, shielding its satellites from micrometeorites, and engineering components to withstand an impact in the event of a collision.

(2) *On-orbit Operations:* SpaceX satellites are being designed to maneuver regularly, both in order to avoid tracked debris and to maintain a safe separation within the constellation and with other spacecraft, space stations, and constellations. This ability to process data about potential orbital obstacles and autonomously maneuver satellites to avoid a collision is a critical safety element. SpaceX is again able to leverage its experience with its Dragon cargo capsule, which NASA has approved to autonomously approach the International Space Station, disembark, and reenter Earth's atmosphere. This is among the most challenging and demanding close-approaches in space. SpaceX's satellites will use on-board, highly efficient solar-electric propulsion systems that are capable of autonomous daily maneuvers, adding up to thousands of maneuvers over the course of their lives, in order to avoid potential collisions. Even if the risk of impact with space debris is deemed highly unlikely, the satellites will course correct autonomously to avoid the remote possibility of a collision.

(3) *Safe Space Operations:* SpaceX is developing a detailed operations plan that includes an orderly orbital disposal protocol that maintains control of each spacecraft, while rapidly deorbiting. The spacecraft are being designed out of materials that will disintegrate in the Earth's atmosphere at the end of their useful lives, reducing risks on the ground. After completion of their useful lifespan, SpaceX anticipates that, typically within one-year, its satellites will reenter the Earth's atmosphere and disintegrate, far sooner than the twenty-five year international standard.

(4) *Government collaboration:* SpaceX works closely to coordinate the development of its satellite constellation with all relevant government, industry, and international stakeholders. SpaceX has experience working with every Federal agency involved in space safety, notably with NASA's Orbital Debris Program Office (ODPO) and the Department of Defense's Joint Space Operations Center (JSpOC). For the past year, SpaceX has been testing its risk analysis and collision avoidance software via a series of extensive debris tracking simulations with JSpOC. This software, in coordination with JSpOC's orbital debris data, will allow SpaceX satellites to maneuver autonomously to avoid collision risks—even when these risks are determined to be highly improbable.

SpaceX is deeply invested in a space environment that is viable for future operations, development, and exploration. We believe that a combination of approaches including satellite design, operational responsibility, and collaboration can help ensure a healthy, viable space environment for generations to come.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO MARK DANKBERG

Question 1. With the recent hurricanes and tropical storms devastating Florida, Texas, and Puerto Rico, I'd like to talk a little bit about emergency preparedness. If things go according to plan with this industry, in a matter of years our planet will be covered with low-orbiting satellites providing broadband to every corner of the Earth. That comes with a major responsibility to bring people back on line after storms and disasters. How is the industry thinking about emergency preparedness, and backup power? Is having an all-of-the-above approach to connectivity that incorporates satellite, fixed, and mobile broadband a good idea to make sure we can rebuild after disasters?

Answer. All types of communications technologies are required to survive and rebuild after natural disasters. Satellite networks are composed of diverse space and ground infrastructure providing significant advantages that allows them to remain operational during and after natural disasters as compared to local terrestrial communications infrastructure that may be damaged or destroyed and take weeks or months to restore.

Federal, state and municipal public agencies, including FEMA and NGO recovery organizations and everyday consumers use satellites to provide robust services and business continuity when other networks are damaged, overloaded or unavailable. Satellite communications also provides a load sharing or surge capacity solution and enable the creation of instant communications infrastructure.

ViaSat currently has broadband satellite coverage of the continental United States plus Hawaii and Alaska, soon to be extended to the U.S. Virgin Islands and Puerto Rico. During the recent events in Texas and Florida, the NGO recovery teams deployed ViaSat portable satellite broadband terminals to help volunteers connect online to provide critical medical support, place people in shelters, and continue to heal the impacted communities.

Below is a comment from an Exede (ViaSat) customer after hurricane Harvey:

> "I just went through the Hurricane/Tropical Storm Harvey here south of Seguin, TX. That storm came within 20 miles of us. How do I know this? Because my Exede Internet stayed up the whole time! The winds and rain were ferocious and I was quite frankly pleasantly surprised when my Internet connection continued without a burp. I was able to monitor the storm, keep in touch with friends and even watch Netflix. I've always liked the Exede service but this time it survived the 'Hurricane' test. Keep up the good work, Exede, and thank you for being there when all else was in turmoil }:-)"

Question 2. One issue this Committee has discussed at previous hearings is the issue of space debris.

According to NASA, there are over 500,000 pieces of debris orbiting the earth. This debris ranges in size from non-functional satellites, to fragmented debris as small as specks of paint. This debris travels around the earth at speeds of up to 17,500 miles per hour, roughly ten times faster than a bullet. At these speeds, even the tiniest bits of debris can cause damage, and windows on the Space Shuttle were replaced because of damage from tiny debris. With the increasing launches of microsatellites and decreasing launch costs it is now easier than ever to launch craft into low earth orbit, and the problem is likely to increase many times over. Do you believe that current processes and regulations in the United States are sufficient to mitigate the increase in space debris? How can we work to address this issue?

Answer. ViaSat has several U.S. geostationary spacecraft authorizations for its current broadband space operations and has applied for a medium-Earth orbit system. ViaSat works with its satellite manufacturers and vendors to assess and design its spacecraft to limit the probability of accidental explosions, ensure safe flight operations during the service life of its satellites, and to facilitate appropriate post-mission spacecraft disposal in order to preserve a safe space environment. ViaSat's U.S. authorizations contain conditions to ensure that the highest orbital debris standards and best practices for space operations are designed into and maintained while operating the spacecraft.

It is important that the United States remain a leader in the development and implementation of space debris best practices and mitigation. In fact, the development of safe flight practices and disposal procedures in the United States, led by NASA and DoD over the years, has encouraged other space faring nations and commercial operators to adopt similar procedures leading to an excellent safety track record, even though there have been a few unfortunate incidents over the years. Continuing to encourage industry best practices in partnership with government satellite operators, is the swiftest and most effective way to ensure that the latest techniques are incorporated into existing and future spacecraft and operations. It also requires government and commercial operators to timely share flight data and routinely cooperate on an operational level.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MAGGIE HASSAN TO STEPHEN SPENGLER

Question 1. With the recent hurricanes and tropical storms devastating Florida, Texas, and Puerto Rico, I'd like to talk a little bit about emergency preparedness. If things go according to plan with this industry, in a matter of years our planet will be covered with low-orbiting satellites providing broadband to every corner of the Earth. That comes with a major responsibility to bring people back on line after storms and disasters. How is the industry thinking about emergency preparedness, and backup power? Is having an all-of-the-above approach to connectivity that incorporates satellite, fixed, and mobile broadband a good idea to make sure we can rebuild after disasters?

Answer. Hybrid networks and solutions are essential to disaster recovery. Due to the geographical challenges that many of our customers face around the world, fixed and mobile network operators are already integrating satellite into their networks to provide resiliency and redundancy should their terrestrial network be rendered inactive due the effects of a hurricane, flood, earthquake or more extreme natural or man made disasters. For example, given the broad scope of the connectivity challenges following Japan's 2011 earthquake, Japan's mobile network operators have turned to Intelsat to fully integrate our satellite network into their own. By doing so, they will have increased resiliency and redundancy in case of a natural disaster as well as have a way to extend their networks and bring much needed connectivity to communities in the more remote areas of the country.

During the devastating Hurricane Season of 2017, Intelsat provided communications services using its Globalized Network and IntelsatOne Flex managed service, a customizable offering that aggregates space segment, the Intelsat Epic ^{NG} high throughput satellites and the IntelsatOne terrestrial network into a simplified, unified ecosystem to quickly deliver bandwidth where it was needed most. Intelsat's support efforts began even before the first storm approached land, initiating disaster recovery and restoration plans for customers across the media, broadband and mobility sectors with operations established in the projected paths of the storms. In some cases, customers transitioned hub operations and relocated staff to Intelsat teleport locations, maintaining unimpaired operations throughout the storms. With broadcasters being significantly impacted by the flood in Houston, Intelsat's Galaxy 16 satellite was used to provide vital connectivity to re-establish services and ensure that critical news coverage reached residents and those outside the area.

Intelsat, Liberty Global and Kymeta teamed up to provide critical connectivity to Puerto Rico, whose infrastructure suffered catastrophic damage due to Hurricane Maria. Three Kymeta-Intelsat enabled vehicles crisscrossed 29 remote towns from October through December 2017. The vehicles were equipped with Kymeta KyWay™ flat panel, beam-forming, electronically-steered terminals that leveraged Intelsat's satellite connectivity. Despite the lack of any electrical power or cellular service, the low power-consuming terminals provided Internet access using the vehicles to power the communications system.

Intelsat also worked with AT&T and Verizon to provide VSAT services to restore communications for enterprise customers. Intelsat's Ku-band broadband service helped banks and pharmacies open for customers again as well as providing communications support for the Puerto Rican government and FEMA.

These are just a few of the many examples of the importance of hybrid connectivity when it comes to disaster relief. By incorporating the reach, resiliency and redundancy of satellite technology into a fixed/mobile network, operators will harden their networks, help ensure that critical connectivity is available to assist with medical needs, recovery efforts and play a role in maintaining or rebooting a region's wireless infrastructure so that people's lives can return to normal.

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According to NASA, there are over 500,000 pieces of debris orbiting the earth. This debris ranges in size from non-functional satellites, to fragmented debris as small as specks of paint. This debris travels around the earth at speeds of up to 17,500 miles per hour, roughly ten times faster than a bullet. At these speeds, even the tiniest bits of debris can cause damage, and windows on the Space Shuttle were replaced because of damage from tiny debris. With the increasing launches of microsatellites and decreasing launch costs it is now easier than ever to launch craft into low earth orbit, and the problem is likely to increase many times over. Do you believe that current processes and regulations in the United States are sufficient to mitigate the increase in space debris? How can we work to address this issue?

Answer. The potential for increased space debris is a concern for all operators. Intelsat is a founding member of the Space Data Association, a voluntary group formed for the purpose of encouraging and enabling the sharing of satellite flight data for both commercial and government satellites. We have long held the belief that sharing data and complete transparency is essential to safe space operations. With new constellations in lower earth orbit (LEO) fast approaching, it is more critical than ever that we increase the level of data sharing and transparency among the international satellite operators.

While non-geostationary constellations will operate at a lower altitude than Intelsat's geostationary satellites, our satellites will still traverse those orbits during launch and orbit-raising to the geostationary orbit, so there is concern about debris potential even in those lower altitudes, particularly given the number of satellites required to cover the earth. In addition, many nanosats/cubesats are less agile and pose both navigational and Space Situational Awareness challenges (SSA). This is in contrast to geostrationary satellites which are more flexible and at the end of their maneuver life, our geostationary satellites are boosted to a graveyard altitude in accordance with FCC requirements—generally approximately 300 km above GEO.

In our view, the keys to successful Space Situational Awareness are: accuracy, actionable data, transparency, reasonable regulation and cooperation. To achieve that, we recommend the following:

- *Regulation* needs to be appropriate to support spaceflight safety, but not limit innovation. We need appropriate regulation as debris mitigation standards applied to a geosynchronous satellite may be different than those of a large constellation of nano-satellites in low-earth orbit with little room to maneuver. And with the FAA taking a leadership role in the regulatory arena, this could lead to a more rational international framework than exists today.
- *Actionable Data/Transparency.* The industry needs need accurate, actionable data. As a result, there is a need for a technical capability to catalog the date, integrate the various formats and throw out the outliers. The growing data collection, exploitation and dissemination requirements far outpace the ability of cumbersome government acquisition processes to keep up. The commercial capabilities in this area are revolutionary, and several companies have offerings that would solve many of today's issues and anticipate those of tomorrow. It is our understanding that the U.S. Government leadership is aware of these capabilities and seeks to take advantage of them.
- *Realistic covariance.* This is currently missing from JSpOC and commercial capabilities could provide fill that void.
- *Systematic debris retrieval service.* The same way people of come together to clean up the Everest base camp, government should come together to clean up space of all unwanted debris.

The Geosynchronous orbit is the *most valuable piece of real estate* that we have in Space. It should be protected by all means. While we need the U.S. to lead, we also need an International solution. We need to encourage government action as a public service for all international satellite operators and recommend an international pilot program that addresses the points above. That way, every satellite operator and launch service provider will design and operate their assets in a manner consistent with preserving a safe space environment for future generations

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RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. CORY BOOKER TO GREG WYLER

Question. Mr. Wyler, you suggested a possible Commission to deal with space debris issues. What do you think should be the goals of this Commission?

Answer. Bridging the Digital Divide must include sustainable development and the responsible stewardship of space. Today there are almost no rules for space traffic. Companies and countries can fly satellites in almost any location or altitude without regard to what is already there. This has led to overlapping system designs which, if built, have a high risk of physical collision. Companies and countries can also design satellites focused on cost without regard to safety. Issues like re-entry casualty risk can be all but ignored, allowing companies to use lower cost materials which do not burn up on re-entry and will impact the ground. As constellations grow to thousands of satellites, the continuous re-entry and earth impact create significant potentially uncontrollable hazards.

This is precisely why space debris and space traffic management are in need of U.S. leadership. The U.S., as the largest market for services, has an opportunity to create a set of rules which govern these important space debris issues. These rules would be welcome globally by many other concerned nations.

The FCC is trying to address space debris, but its current role is limited. The FCC regulates the use of satellite spectrum, rather than in-orbit collisions or re-entry casualty risk. Even if the FCC could take a more active role, many satellite types, such as those for imaging or sensing, will not even need FCC approval for their activities.

This proposed Committee (whether under an existing Department, Committee, or Commission) should include a team with deep knowledge of these space debris and re-entry casualty issues and have the goals of:

(1) Ensuring any space objects for which U.S. authorization is sought meet a minimum common-sense standard to prevent space debris, including:

   a. Safe altitude separation,

   b. Designing for demise to minimize re-entry casualty risk.

   c. Adequate positional knowledge and maneuvering capability,

   d. Prompt satellite disposal upon decommissioning, and

(2) Providing leadership on the global issues of space debris and re-entry casualty risks. The Committee should seek the advice of and work with, the FAA, NASA, and other U.S. agencies and organizations to promote minimum safety standards for space traffic.

(3) Supporting other agencies faced with space debris related issues and reviewing the impact of satellite licensing with respect to U.S. liability for space debris under the 1967 Outer Space Treaty.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY MAGGIE HASSAN TO GREG WYLER

Question 1. With the recent hurricanes and tropical storms devastating Florida, Texas, and Puerto Rico, I'd like to talk a little bit about emergency preparedness. If things go according to plan with this industry, in a matter of years our planet will be covered with low-orbiting satellites providing broadband to every corner of the Earth. That comes with a major responsibility to bring people back on line after storms and disasters. How is the industry thinking about emergency preparedness, and backup power? Is having an all-of-the-above approach to connectivity that incorporates satellite, fixed, and mobile broadband a good idea to make sure we can rebuild after disasters?

Answer. Satellites are the most reliable method of communications. Until now, their use has been limited by their cost, the high latency leading to a poor quality of service, and the size/difficulty of installing the satellite receiving terminal. OneWeb has designed and manufactured a new generation of satellites which overcome these prior obstacles. OneWeb's new terminals will be small, lightweight, and, most importantly, low-power. OneWeb's terminals can run on batteries for short durations or be powered by a small solar panel for longer durations.

OneWeb was designed to operate in the most economically challenged emerging markets. These markets similarly have limited to no local power available and few structures to permanently mount large heavy satellite equipment. This "work anywhere" capability also makes OneWeb's terminals ideal for providing network connectivity during emergency situations.

OneWeb's mobile terminals will enable first responders and families to have continuous connectivity regardless of the local cellular coverage. The mobile terminals can be placed on a vehicle and will include a small cell and WiFi to connect devices to the Internet. These mobile terminals will facilitate 100 percent coverage of the United States, augmenting Firestone's planned coverage.

With regard to bringing people back online, OneWeb will produce easy-to-install terminals in high volume, much like any other consumer products. OneWeb will work with government and industry bodies to support adequate stocking and strategic placement of its terminals to support continued connectivity during terrestrial outages caused by emergencies or natural disaster events.

Question 2. One issue this Committee has discussed at previous hearings is the issue of space debris. According to NASA, there are over 500,000 pieces of debris orbiting the Earth. This debris ranges in size from non-functional satellites, to fragmented debris as small as specks of paint. This debris travels around the Earth at speeds of up to 17,500 miles per hour, roughly ten times faster than a bullet. At these speeds, even the tiniest bits of debris can cause damage, and windows on the Space Shuttle were replaced because of damage from tiny debris. With the increasing launches of micro-satellites and decreasing launch costs it is now easier than ever to launch craft into low Earth orbit, and the problem is likely to increase many times over. Do you believe that current processes and regulations in the United States are sufficient to mitigate the increase in space debris? How can we work to address this issue?

Answer. As mentioned above, unfortunately, the current processes and regulations are insufficient to adequately address the risk of space debris. The last significant U.S. regulation on space debris is more than 20 years old. The international treaty called the Outer Space Act was adopted fifty years ago, in 1967, long before the advent of the commercial space industry. This has contributed to a dynamic in which satellite technology and networks have evolved far beyond the regulatory regime created to address space debris issues. While many countries acknowledge this reality and are currently drafting papers addressing this topic, the current environment presents a unique opportunity for the U.S. to assume a leadership position and drive standards of excellence and space stewardship worldwide.

As you have correctly pointed out, debris generation is a serious issue and just a single impact can cause thousands of new debris fragments which will damage entire altitudes for thousands of years. These impact and re-entry casualty risks can be minimized if Congress creates a regulatory regime empowered to enact simple common-sense rules that would address critical issues, such as preventing overlapping constellations or the launching of satellites manufactured with lower grade materials that do not burn up during re-entry and will impact the ground.

Today there are still many altitudes available for safe, separated operation, and there are many ways to design satellites so they burn up upon re-entry. However, without meaningful regulations to ensure best practices, companies and countries can launch virtually any space object with no minimum orbit separation from others and no minimum design requirements.

Space is the proverbial Wild West.

To properly tame this frontier, Congress should consider the formation of a Space Debris Committee as a central figure to spearhead the protection of our space ecosystem and ensure it is maintained as an accessible resource for generations to come.

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