Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)	GN Docket No. 14-177
	)	
Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5-28.35 GHz and 37.5-40 GHz Bands	)	IB Docket No. 15-256
	)	
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band	)	RM-11664
	)	
Amendment of Parts 1, 22, 24, 27, 74, 80, 90, 95, and 101 To Establish Uniform License Renewal, Discontinuance of Operation, and Geographic Partitioning and Spectrum Disaggregation Rules and Policies for Certain Wireless Radio Services	)	WT Docket No. 10-112
	)	
Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5-38.5 GHz, 40.5-41.5 GHz and 48.2-50.2 GHz Frequency Bands; Allocation of Spectrum to Upgrade Fixed and Mobile Allocations in the 40.5-42.5 GHz Frequency Band; Allocation of Spectrum in the 46.9-47.0 GHz Frequency Band for Wireless Services; and Allocation of Spectrum in the 37.0-38.0 GHz and 40.0-40.5 GHz for Government Operations	)	IB Docket No. 97-95

To: The Commission

COMMENTS OF
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SUMMARY

The satellite communications industry is a critical contributor to the global effort to make broadband Internet access readily available to all people, including those in rural and remote areas that remain unserved or underserved by terrestrial communications technologies. As the Commission has repeatedly acknowledged, there exists "a stark contrast in service between urban and rural America" and "Americans who live in rural areas are ten times more likely to be unserved than their urban counterparts."[1] Broadband satellite systems offer the ability to finally correct this enduring disparity.

To bridge the digital divide and provide very high speed broadband services to consumers regardless of location, broadband satellite systems must have access to sufficient spectrum in millimeter wave ("mmW") frequencies to bring the benefits of high-speed broadband to all consumers in the United States. The V-band, in particular, is a critical growth band for the satellite communications industry, providing the sole remaining greenfield spectrum that is suitable for broadband satellite communications systems.

In contrast, 5G proponents and the Commission have identified at least ten candidate spectrum bands for 5G.[2] Some of these bands may present spectrum sharing challenges for the newly-created Upper Microwave Flexible Use Service ("UMFUS"). When considered in the aggregate, however, these ten spectrum bands include far more spectrum than the Commission

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[1] *See* Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, *2016 Broadband Progress Report*, 31 FCC Rcd 699, 701, 750-51, ¶ 121 (2016).

[2] The adopted UMFUS spectrum bands include the 27.5-28.35 GHz ("28 GHz") band, the 37.5-38.6 GHz ("37 GHz") band, and the 38.6-40.0 GHz ("39 GHz") band, while the candidate UMFUS spectrum bands include the 24.25-24.45 GHz and 24.75-25.25 GHz band ("24 GHz band"), the 31.8-33.4 GHz ("31 GHz") band, the 42.0-42.5 GHz ("42 GHz") band, the 47.2-50.2 GHz ("47 GHz") band, the 50.4-52.6 GHz ("50 GHz") band, the 71-76 GHz ("70 GHz") band, and the 81-86 GHz ("80 GHz") band.

has ever before considered for a newly proposed communications service, especially where technical standards and potential business plans remain in the earliest stages of development.

Given the critical importance of the V-band to the future of broadband satellite services, and their tremendous public interest benefit, the Commission should refrain from making any identification for UMFUS in the 47 and 50 GHz bands and instead rely on its previously identified spectrum – the 28, 37, and 39 GHz bands – along with certain of the other proposed bands as amply sufficient to serve the spectrum requirements of future UMFUS sytems.

If UMFUS identifications are made in the 47 and 50 GHz bands, the Commission should do so in a manner that ensures that broadband satellite systems are able to use this important satellite growth spectrum in a reasonably unfettered manner. Broadband satellite systems require access to a full 5 GHz of paired spectrum in the V-band to serve the high speed data requirements of consumers both in rural areas of the country and on a competitive basis in major population centers.

First, broadband satellite systems require access to 5 GHz of downlink spectrum for data-intensive forward links to serve ubiquitously-deployed, receiving end user terminals. The spectrum requirements for these forward link end user services include unfettered primary access to the 40.0-42.0 GHz band and shared opportunistic access to the 37/39 GHz and the 42 GHz bands.

Second, broadband satellite systems must have sufficient access to 5 GHz of matching uplink spectrum for gateways used to serve the forward links to receiving end user terminals. The total spectrum available for these gateway uplinks must match exactly with the spectrum used for forward downlinks to end user devices. The spectrum requirements for these gateway uplinks include coordinated access to the entire 47 GHz band and the 50.4-52.4 GHz portion of

the 50 GHz band. Satellite gateways will be able to share the 47 and 50 GHz bands with UMFUS systems as long as sufficient accommodations are made to ensure that satellite gateways can be located in large numbers in enough rural locations to meet broadband capacity requirements. In contrast, the significant restrictions on gateway placement that were adopted for the 28 GHz band (*i.e.*, the 0.1 percent test) would be far too constraining to allow the deployment of very high data rate broadband satellite systems in the V-band.

Third, part of the 5 GHz of uplink spectrum for broadband satellite systems must include unfettered access to 3 GHz of uplink spectrum in the 47 GHz band in order to operate ubiquitously-deployed, transmitting end user terminals. To bridge the digital divide and provide a truly competitive option to terrestrial services, satellite operators must have sufficient bandwidth to provide very high speed data rates and be able to locate these transmitting end user terminals at the home or office of each of its subscribers across the United States. Some level of spectrum sharing may be possible between these satellite end user terminals and UMFUS systems, particularly UMFUS devices that operate solely indoors or on a secondary, opportunistic basis. Although the sidelobe emissions from transmitting satellite end user terminals will be confined to a relatively small area, the anticipated deployment of satellite end user terminals will be sufficiently dense to leave few "white spaces" where UMFUS systems could operate outdoors on an unencumbered basis.

Fourth, part of the 5 GHz of downlink spectrum for broadband satellite systems must include 3 GHz of downlink spectrum to operate receiving gateways. These facilities will only receive downlink signals and can be coordinated with UMFUS systems in the 37/39 GHz band using the Commission's adopted 0.1 percent approach, or they can operate on an unrestricted basis in the 40.0-42.0 GHz band. Thus, although Boeing anticipates access to sufficient

gateway downlink spectrum in the V-band, the Commission spectrum access decisions in the mmW bands will have a direct effect on the ability of new broadband satellite systems to deliver service throughout the United States and globally.

As the Commission acknowledges, other measures are also important to facilitate the operation of broadband satellite systems in the V-band. The Commission should remove the outdated restriction on satellite end user terminals in the 37/39 GHz band. Such end user devices can receive signals in the 37/39 GHz band without causing interference to (or being detected by) UMFUS systems in this spectrum.

The Commission should also permit satellite systems to operate space-to-Earth transmissions in the 37/39 GHz band at the power flux density ("PFD") levels adopted by the International Telecommunication Union ("ITU") for this spectrum. Technical studies provided by Boeing show that the 12 dB tighter limits that were adopted by the Commission more than a decade ago in an effort to segment this spectrum are no longer needed. Instead, satellite systems can operate in the 37/39 GHz band at the higher ITU limits without resulting in harmful interference to UMFUS systems or incumbent spectrum users.

The Commission should also advance additional spectrum sharing opportunities that exist in the 42 GHz band. The Commission is considering in its Further Notice the identification of the 42 GHz band for UMFUS systems. If the Commission does make the 42 GHz band available for UMFUS, it should do so on the same shared basis as is being considered for the 37/39 GHz band. Specifically, satellite end user terminals could receive signals in the 42 GHz band on a shared opportunistic basis with UMFUS systems, just as the Commission is considering for the 37/39 GHz band.

Finally, the Commission should refrain from making any spectrum identification decisions regarding the 70, 80 and above 90 GHz bands until more is known about the technological developments of mmW communications systems in these very high spectrum bands. Although currently-available technology does not support the operation of broadband satellite systems in these very high frequencies, the Commission should not foreclose the potential for satellite technology to achieve these capabilities in the future. At the very least, the Commission should await the outcome of ITU studies before making any firm decisions about the future use of spectrum at 70 GHz or above.

The Commission should, however, investigate the potential for additional unlicensed spectrum in the frequencies above 90 GHz, and for allowing unlicensed operations outdoors in portions of the 92-95 GHz band. The Commission should also await the outcome of ongoing studies on permitting the use on aircraft of unlicensed spectrum in the 57-71 GHz band.

In making these recommendations, Boeing acknowledges the Commission's goal of ensuring the United States remains a leader in the deployment of broadband communications systems using mmW technology. Fortunately, the United States has a strong lead in mmW capabilities, having first developed and employed these technologies for the U.S. military and for operating U.S. government satellite systems. The Commission should therefore take steps to preserve continued U.S. leadership in mmW communications capabilities by ensuring that sufficient spectrum is identified for both terrestrial and satellite-based mmW communications services. The Commission should also facilitate shared use of mmW spectrum on a co-primary basis whenever possible.

Given the vast number of spectrum bands that the Commission is identifying for UMFUS, the spectrum sharing accommodations that Boeing requests in these comments are eminently

reasonable. Further, they are necessary to ensure that broadband satellite systems are able to provide very high data rate broadband services to *all* Americans and thus permanently remedy the persistent urban-rural divide that the Commission has repeatedly identified in consumer access to essential broadband services.

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To: The Commission

COMMENTS OF
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Section 706 of the Telecommunications Act of 1996 requires the Commission to take immediate corrective steps if "advanced telecommunications capability" is not "being deployed

to *all* Americans in a reasonable and timely fashion," including "by removing barriers to infrastructure investment and by promoting competition in the telecommunications market."[3]

The Commission has repeatedly concluded that advanced telecommunications capability is not being deployed to all Americans in a reasonable and timely fashion.[4] As the Commission has documented, an "urban-rural digital divide persists and is significant."[5] The Commission explains that

- "Americans who live in rural areas are ten times more likely to be unserved than their urban counterparts."
- "The rural-urban disparity in deployment of these services may prevent small businesses in rural areas from competing successfully in the 21st century economy."
- "The disparity is even more severe for Americans on rural Tribal lands, where 68.2 percent lack access to fixed access service at 25 Mbps/3 Mbps or higher."[6]

Although the Commission has diligently pursued universal service support mechanisms to address the substantial urban-rural divide, a more expedient and dependable solution would be to encourage market-based infrastructure investment and new intermodal competition. Specifically, the Commission should take immediate corrective steps by adopting rules that promote the launch and operation of global satellite systems that can provide very high data rate broadband communications services to all locations in the United States (and the world) on a comprehensive and geographically uninterrupted basis.

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[3] 47 U.S.C. § 1302(b) (*emphasis added*).

[4] *See* Inquiry Concerning the Deployment of Advanced Telecommunications Capability to All Americans in a Reasonable and Timely Fashion, *2016 Broadband Progress Report*, 31 FCC Rcd 699, 701, 750-51, ¶¶ 4 and 120-24 (2016) ("*2016 Broadband Progress Report*").

[5] *See id.* (statement of Chairman Thomas Wheeler).

[6] *Id.*, ¶ 121.

Boeing recently announced the development of a non-geostationary satellite orbit ("NGSO") fixed-satellite service ("FSS") system that can operate in the V-band to provide very high data rate services to all consumers.[7] Boeing's NGSO FSS system provides a dramatic opportunity to bridge the digital divide without protracted build out delays or public subsidies. The satellite system would offer very low latency and bi-directional data rates that exceed the Commission's targets for next-generation advanced telecommunications capabilities. Further, the aggregate capacity of Boeing's NGSO FSS system would be sufficient to serve all Americans in most areas of the country (including rural, remote, and tribal areas), while providing an attractive and competitive option for consumers in major population centers.

Importantly, the Commission does not have to make a choice between authorizing broadband satellite services in the V-band and identifying additional spectrum for 5G. As Boeing has shown, the same technological developments that have opened mmW spectrum for broadband deployment also enable sharing between 5G and broadband satellite systems. As the Commission has acknowledged, Boeing has provided technical studies showing that spectrum sharing between satellite receive terminals and UMFUS systems is feasible in the 37/39 GHz band.[8] Minimally burdensome spectrum sharing is also possible in the 50.4-52.6 ("50") GHz band and, to a lesser extent, in the 47.2-50.2 ("47") GHz band.

Facilitating spectrum sharing in mmW spectrum is critical. Boeing's NGSO FSS system would provide much needed assurance that mmW spectrum will be used expeditiously to

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[7] *See* The Boeing Company Application for Authority to Launch and Operate a Non-Geostationary Low Earth Orbit Satellite System in the Fixed Satellite Service (S2966), SAT-LOA-20160622-00058 (filed June 22, 2016).

[8] Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, et al., GN Docket No. 14-177, et al., Report and Order and Further Notice of Proposed Rulemaking, FCC 16-89, ¶ 498 (July 14, 2016) ("*Order*" or "*Further Notice*").

serve all Americans, as Congress directed, and not just those "in densely populated areas."[9] Spectrum sharing in the V-band will also ensure that radio frequencies are used intensively, thus adhering to the Act's mandate that spectrum be used equitably and efficiently.[10] As the President's Council of Advisors on Science and Technology ("PCAST") observed in its 2012 Report to the President, spectrum sharing is an "essential element" of the Federal spectrum architecture and "[t]echnology innovations of recent years make this transformation eminently achievable."[11] These findings are equally true with respect to non-Federal spectrum, particularly after four additional years (since 2012) of technological development, and the report's findings serve as an important principle for the Commission.

Enabling spectrum sharing in the V-band is also critical because of its significant consequence for the future of the commercial satellite industry.

I. ALTHOUGH SPECTRUM SHARING IS POSSIBLE IN THE V-BAND, THE COMMISSION SHOULD CONSIDER THE CRITICAL IMPORTANCE OF THE V-BAND TO THE FUTURE OF THE COMMERCIAL SATELLITE INDUSTRY

As the Commission has recognized, mmW technology is allowing terrestrial and satellite communications systems to operate in increasingly high spectrum bands. Atmospheric conditions, however, place practical limits on the upper-most bands that can be employed by satellite systems in a cost-effective manner using currently feasible technology.

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[9] Letter from Brian M. Josef, Assistant Vice President, Regulatory Affairs, CTIA, GN Docket No. 14-177, at 2 (May 24, 2016) ("*May 24 CTIA Letter*").

[10] The Communications Act further mandates the Commission to manage spectrum resources "to make available, so far as possible, to all the people of the United States . . . rapid, efficient, Nation-wide, and world-wide" communications services, 47 U.S.C. § 151, and "the equitable distribution of radio service throughout the nation." 47 U.S.C. § 307(b).

[11] President's Council of Advisors on Science and Technology ("PCAST"), Report to the President, "*Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth*" (July 2012) (*available at* https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf).

The V-band is the only greenfield spectrum that remains available for the future growth of broadband satellite systems using currently feasible technology. The Ka-band is quickly becoming crowded, while the 70 GHz band and above present atmospheric attenuation that makes it extremely difficult to close satellite communications links using current or anticipated near-term technology.

In contrast, 5G proponents and the Commission have identified numerous candidate spectrum bands for 5G, including the 24 GHz band, the 28 GHz band, the 32 GHz band, the 37 GHz band, the 39 GHz band, the 42 GHz band, the 47 GHz band, the 50 GHz band, the 70 GHz band, and the 80 GHz band.[12] Boeing acknowledges that some of these bands present spectrum sharing challenges for the Commission's newly created Upper Microwave Flexible Use Service ("UMFUS"). When considered together, however, these ten spectrum bands unquestionably include vastly more spectrum than the Commission has ever before considered as the initial allocation for a newly proposed communications service.

In furtherance of its public interest obligations, the Commission must consider all of its candidate UMFUS spectrum bands in the aggregate, rather than on a binary basis for each discrete frequency segment. Only in this way can the Commission properly balance the anticipated spectrum needs of UMFUS with the legitimate spectrum requirements of other important communications services including broadband satellite systems.

Given the critical importance of the V-band to the future of broadband satellite services, the Commission would best serve the public interest by refraining from making any

[12] The adopted UMFUS spectrum bands include the 27.5-28.35 GHz ("28 GHz") band, the 37.5-38.6 GHz ("37 GHz") band, and the 38.6-40.0 GHz ("39 GHz") band, while the candidate UMFUS spectrum bands include the 24.25-24.45 GHz and 24.75-25.25 GHz band ("24 GHz band"), the 31.8-33.4 GHz ("31 GHz") band, the 42.0-42.5 GHz ("42 GHz") band, the 47.2-50.2 GHz ("47 GHz") band, the 50.4-52.6 GHz ("50 GHz") band, the 71-76 GHz ("70 GHz") band, and the 81-86 GHz ("80 GHz") band.

identification for UMFUS in the 47 and 50 GHz bands, and instead rely on its already identified bands, along with some of its other proposed bands, as amply sufficient to serve the spectrum needs of UMFUS.

To the extent that the Commission is committed to authorizing UMFUS in the 47 and 50 GHz bands, however, Boeing believes that spectrum sharing is possible between UMFUS and broadband satellite systems in much of this spectrum. As the Commission has recognized, however, spectrum sharing in the 47 and 50 GHz bands will not be as easy as in the 37/39 GHz bands.[13] First, spectrum sharing between UMFUS and transmitting satellite gateway facilities will necessitate reasonable accommodations by licensees in both services. Second, spectrum sharing between UMFUS and ubiquitously-deployed transmitting satellite user terminals will present even more difficult spectrum sharing challenges.

Nevertheless, given the vast number of spectrum bands that the Commission is identifying as candidates for UMFUS, the spectrum sharing accommodations that Boeing requests in these comments are eminently reasonable. Further, they are necessary to ensure that broadband satellite systems are able to provide very high data rate broadband services to *all* Americans and thus permanently remedy the persistent urban-rural divide that the Commission has repeatedly identified in consumer access to essential broadband services.

[13] *Further Notice*, ¶ 411 (observing that spectrum sharing in the 47 and 50 GHz bands "is more complicated, particularly when the FSS user equipment is transmitting").

II. BROADBAND SATELLITE SYSTEMS MUST HAVE ACCESS TO 5 GHZ OF PAIRED SPECTRUM IN THE V-BAND TO BRIDGE THE BROADBAND DIGITAL DIVIDE

An important question raised by the Commission in its Further Notice addresses the quantitative spectrum requirements of broadband satellite systems operating in the V-band.[14] As the Commission is aware, consumer and enterprise demand for broadband data is voracious and rapidly growing. The growth of technologies, services, and businesses all rely on the ever-increasing availability of fast, high-capacity data connections. As the Further Notice observes, regulators around the world are preparing to accommodate an eventual 1,000-fold increase in traffic demand and speeds in excess of 10 gigabits per second.[15] This unceasing demand for increased speed and higher data rate services exists throughout the United States, including in non-urban areas where satellite systems excel in providing cost-effective, two-way communications services.

It is therefore critically important to design and authorize broadband satellite systems that have adequate speed and capacity to address consumer requirements, both in terms of sufficient speed for individual end users, and sufficient capacity to satisfy widespread demand. In this regard, the Commission has previously considered the potential for broadband satellites to remedy the urban-rural digital divide and apparently found them lacking with respect to speed,[16] latency,[17] and system capacity.[18] To address these perceived shortcomings, several measures are required.

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[14] *See id.*, ¶ 501 (asking whether there is a need and demand for satellite downlink user equipment in the 37.5-40.0 GHz band that cannot be addressed in the 40.0-42.0 GHz band).

[15] *Further Notice*, ¶ 9.

[16] *See 2016 Broadband Progress Report*, ¶¶ 3, 48.

[17] *See id.*, ¶ 67.

First, the use of low Earth orbit ("LEO") NGSO satellite systems can resolve concerns about latency for those broadband data services that are latency sensitive. Boeing's NGSO FSS system, for example, operating at a LEO altitude of approximately 1,200 kilometers, reduces satellite roundtrip transit time to about 20 milliseconds. This results in latency well below the 150 millisecond "mouth-to-ear" threshold recommended by the International Telecommunication Union ("ITU") for "[r]eal-time, jitter sensitive, high interaction" applications such as voice and video calling.[19]

Boeing has also designed its NGSO FSS system to address the Commission's concerns about data speed and system capacity. Each of Boeing's satellites will use phased array antennas and narrow beam forming to produce thousands of small cells on the Earth's surface that will efficiently re-use high-capacity mmW spectrum across a large constellation of relatively small satellites. The aggregate capacity of Boeing's NGSO FSS system will be sufficient to concurrently provide data speeds well in excess of 25 Mbps down/3 Mbps up to all Americans in most areas of the country (including rural and remote areas), while providing an attractive and competitive option for consumers in well-served population centers.

Technical and economic limits exist, however, on the amount of spectrum reuse and efficiency that can be achieved using increasingly large satellite constellations and tightly focused transmit and receive beams. Broadband satellite systems must have access to sufficient spectrum to enable these newly-developed mmW technologies to function. Broadband satellite systems will also need to share spectrum both with other satellite network, federal services, and

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[18] *See id.*, ¶ 47 n.162.

[19] *Further Notice*, ¶ 31 (quoting International Telecommunication Union, Telecommunication Standardization Sector, Series G: Transmission Systems and Media, Digital Systems and Networks, G.1010 at 8, Appx. 1 (Nov. 2001) (ITU Series G.1010)).

UMFUS licensees. Such sharing can be expected to reduce the overall speed and throughput that satellite operators can achieve using each megahertz of spectrum that is available.

Given these realities, it is critically important for broadband satellite systems to have access to a full 5 GHz of spectrum of paired spectrum in the V-band, including:

- 5 GHz of downlink spectrum for data-intensive forward links to serve ubiquitously deployed end user terminals (*i.e.*, 37.5-42.5 GHz),
    - 3 GHz of which should be available for gateways used to receive the transmissions from transmitting end user terminals (*i.e.*, portions of the 37.5-42.5 GHz).
- 5 GHz of matching uplink spectrum for gateways used to serve the forward links to end user terminals (*i.e.*, 47.2-50.2 GHz & 50.4-52.4 GHz),
    - 3 GHz of which should be available for ubiquitously deployed transmitting end user terminals (*i.e.*, 47.2-50.2 GHz), and

As indicated above, highly efficient broadband satellite systems, such as Boeing's, will be able to operate their end user terminals and gateways in the same spectrum. Other FSS systems may need to segregate their end user and gateway spectrum resulting in 2.5 GHz of spectrum available for each function.[20] In either event, the overall spectrum requirements will be significant. This is especially true with respect to the most data-intensive communications link of all, the forward (downlink) transmissions to end users, and the gateway uplinks that support these forward transmissions. The overall spectrum needs for these two important functions are addressed further below.

A. Consumer Expectations for Very Reliable High Speed Broadband Necessitate the Use of 5 GHz of Downlink Spectrum to Serve End Users

As the Commission is aware, broadband services are highly asymmetric, with users demanding far more download capacity as compared to upload capability. This is reflected in

[20] Such segregation would result in 2.5 GHz for user downlinks, 2.5 GHz for user uplinks, 2.5 GHz for gateway downlinks, and 2.5 GHz for gateway uplinks.

the Commission's definition of broadband, which is currently set at 25 Mbps/3 Mbps, or a ratio of more than 8 to 1. The sources of this tremendous downlink data demand are many, and are evolving rapidly, as new applications and usage patterns drive increased need for connectivity and Internet access. Figure II-1 illustrates the current data demand for Internet usage in both the download and upload directions. The data reflect a download to upload ratio of approximately 6 to 1, which is consistent with usage studies that Boeing has reviewed. As broadband services become more available, total demand and patterns of usage can be expected to change somewhat as applications evolve. For example, personal cloud storage backups, media sharing via social networking, and the ever increasing use and quality of video communications have greatly increased the upload direction traffic.

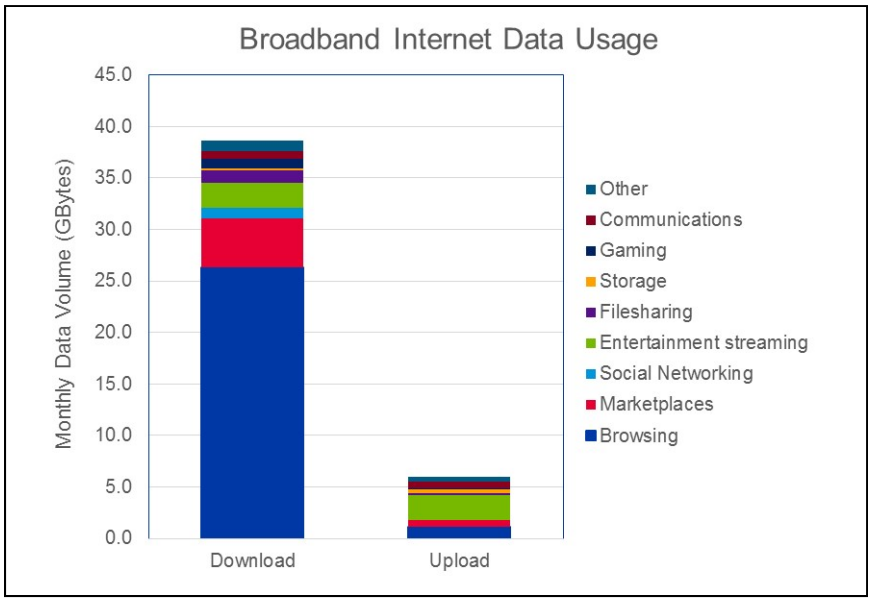

Figure II-1. Current Broadband Internet Data usage in Download and Upload directions[21]

Figure II-2 shows the projected global growth of broadband demand through 2020 for various regions of the world.

[21] Data derived from Sandvine Global Internet Phenomena Reports, June 2016, available at https://www.sandvine.com/trends/global-internet-phenomena/

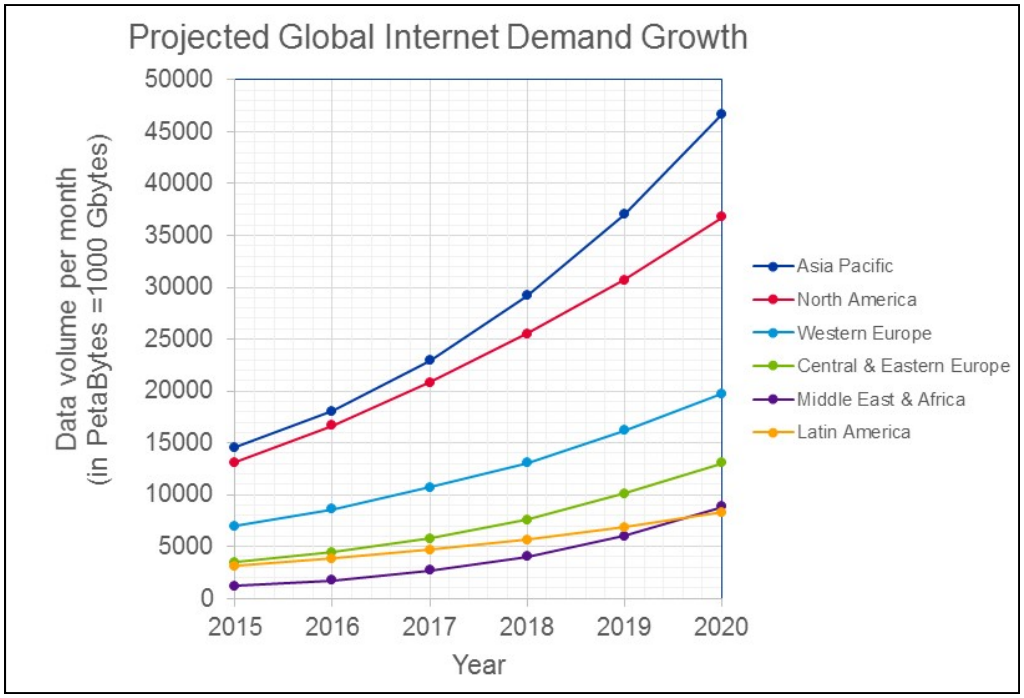

Figure II-2. Projected Global Internet Demand Growth (2017-2020)[22]

Anticipating this need, Boeing has designed its Global Broadband NGSO FSS network to satisfy the large majority of the anticipated consumer demand for broadband in rural and remote areas, and to serve on a technically transparent basis a significant market share of consumer demand in suburban and urban populated areas. Boeing's broadband service leverages the V-band spectrum allocated for FSS services and delivers broadband speeds that satisfy and significantly exceed the Commission's broadband targets, allowing for inevitable changes in usage patterns and growth in demand. To achieve these important capabilities, however, Boeing's NGSO system will need access to a full 5 GHz of downlink spectrum, including full access to the 40.0-42.0 GHz band, shared access to the 37.5-40.0 GHz band, and shared access to the 42.0-42.5 GHz band.

[22] Cisco Visual Networking Index Forecast and Methodology, 2015–2020, Table 8 (available at http://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.pdf) ("*Cisco Visual Networking Index Forecast*").

The need for spectrum is apparent when considering the expanded need for broadband data shown above and the diversity of populated areas both globally and within the United States. Figure II-3 depicts this range of demand. With full access to 5 GHz of V-band spectrum, the Boeing NGSO system can provide a fully complementary service to terrestrial wired and wireless options for users in metropolitan, suburban, and rural areas. Boeing's spectrum sharing methods will further allow UMFUS deployments to proceed in parallel in all of these areas, addressing the compelling needs for consistent broadband mobile connectivity and growth in the densest demand areas.

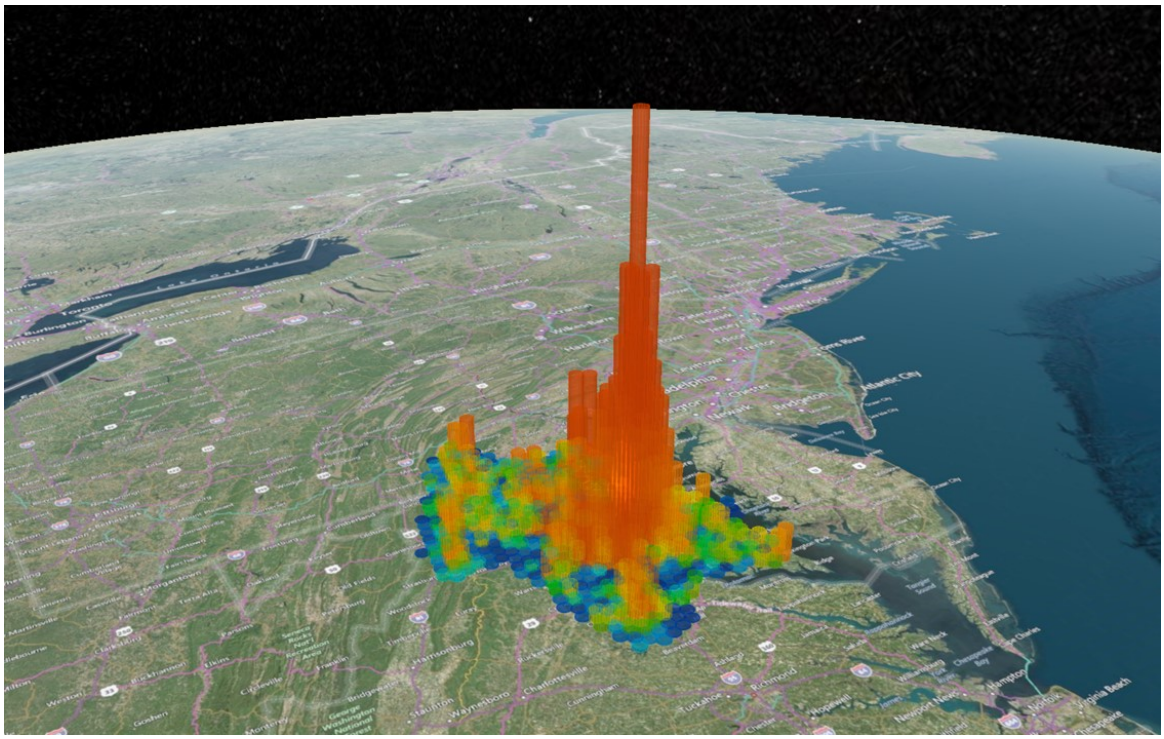

Figure II-3. Range of Broadband Demand from Rural to Urban Areas[23]

In seeking access to a full 5 GHz of downlink spectrum to satisfy the massive projected demand for broadband capacity nationwide, Boeing has emphasized that its system will be able to share spectrum on a co-frequency basis with other broadband satellite systems in the V-band,

[23] Data derived from *Cisco Visual Networking Index Forecast* demand data combined with publically available population density tables.

including other NGSO and geostationary ("GSO") systems. As discussed in subsequent sections of these comments, Boeing's NGSO FSS system will also be able to share large portions of the V-band with UMFUS licensees as long as reasonable regulatory measures are adopted defining the characteristics of both services.

Boeing has designed its NGSO FSS network to satisfy nearly all anticipated consumer demand for broadband in rural and remote areas (employing speeds that exceed the Commission's broadband targets) and to serve on a technically transparent basis a significant market share of consumer demand in heavily populated areas. To achieve these important capabilities, however, Boeing's NGSO system will need access to a full 5 GHz of downlink spectrum, including full access to the 40.0-42.0 GHz band, shared access to the 37.5-40.0 GHz band, and shared access to the 42.0-42.5 GHz band.

B. Broadband Satellite Systems Must Have Access to a Matching 5 GHz of Gateway Uplink Spectrum in the V-band to Support End User Downlinks

A simple rule in satellite technology is that all downlink transmissions made to end users by satellites must first be received by the satellites using gateway uplinks. Most satellites effectively act as a "bent pipe" or a "mirror in the sky," re-transmitting the signals that they receive. As a result, broadband satellite systems cannot provide high data rate downlink services to end users unless they have access to sufficient gateway uplink spectrum to match on a one-to-one basis the end user downlink spectrum.

Boeing's NGSO FSS system therefore needs access to the entire 47 GHz band (47.2-50.2 GHz) and to the entire 50.4-52.4 portion of the 50 GHz band to operate transmitting gateways.[24]

[24] Given this identified need, Boeing has filed a Petition for Rulemaking with the Commission seeking the adoption of an allocation for FSS in the 51.4-52.4 GHz band. *See* Petition for Rulemaking of The Boeing Company, RM-11773 (June 22, 2016). Boeing urges the

As explained in a later section of these comments, Boeing's gateways will be able to share the 47 and 50 GHz bands with UMFUS systems and other satellite system licensees as long as reasonable accommodations are employed by all users.

C. Broadband Satellite Systems Must Have Unfettered Access to 3 GHz of End User Uplink Spectrum in the 47 GHz Band to Support Consumer Demand for Two-Way Services

Because of the asymmetric nature of broadband communications, broadband satellite systems do not require as much capacity for end user uplink communications as they require for end user downlink communications. Nevertheless, since all modern broadband communications systems are inherently two-way, the end user return path is critical. Further, satellite end user terminals, like other relatively small end user devices, are unable to transmit as much data (in terms of bits per second) for each megahertz of available spectrum as compared to satellite downlink transmissions. Even a download-to-upload ratio of 6-to-1 may require a downlink-to-uplink bandwidth ratio of as little as 2-to-1 depending on the modulation schemes used and the relative capability of the user terminals. Therefore, although less spectrum is required for end user uplink transmissions as compared to end user downlink transmissions, the ratio is not a direct reflection of the Commission's target 8 to 1 ratio, *i.e.*, 25 Mbps /3 Mbps.[25]

Broadband satellite systems therefore need access to at least 3 GHz of unencumbered uplink spectrum to operate transmitting satellite end user terminals. To satisfy a portion of this requirement, ITU footnote 5.516B identifies 2 GHz of uplink spectrum for high-density FSS

Commission to proceed forward with this petition expeditiously potentially by incorporating it into the Spectrum Frontiers proceeding.

[25] Although the Commission has identified a target data rate ratio of 8 to 1, Boeing's market studies indicate an actual need for broadband transmission capabilities that more approximates a ratio of 6 to 1.

operations in the 48.2-50.2 GHz (Earth-to-space), paired with the 40-42 GHz (space-to-Earth).[26] The Further Notice acknowledges this international identification and suggested pairing of the 48.2-50.2 GHz band with the 40.0-42.0 GHz band for V-band FSS operations.[27] Although this is a strong start, Boeing believes that a full 3 GHz of uplink spectrum is required for transmitting satellite end user terminals, including largely unfettered access to the immediately adjacent 47.2-48.2 GHz spectrum.

Boeing and other operators of broadband satellite systems will also need to be able to position two-way end user terminals at the home or office of each of their subscribers. Boeing, for example, will offer its broadband service in a wide variety of markets, ranging from heavily populated suburban and urban regions to rural communities providing common, ubiquitous two-way Internet access to meet the Commissions broadband goals. Boeing's service cannot succeed in this manner if any significant limits exist on the placement of its two-way end user terminals.

Boeing's end user terminals will be highly directional and will transmit upwards only above a 45 degree elevation angle. Nevertheless, the sidelobe emission field from each end user terminal will be appreciable particularly given the short distances that can be expected between satellite end user terminals and UMFUS mobile devices. Boeing will need to deploy very large numbers of two-way end user terminals at homes and offices throughout the country in order to achieve substantial market penetration. As a result, it is very unlikely that there would be significant usable "white spaces" between adjacent satellite end user terminals within which mobile devices of other communications services could consistently operate.

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[26] ITU Footnote 5.516B; *see* 47 C.F.R. § 2.106 n.5.516B.

[27] *Further Notice*, ¶¶ 411, 421.

As a result, Boeing's transmitting end user terminals will not be able to share uplink spectrum with UMFUS systems that are widely deployed, at least not on a co-primary basis, or in outdoor locations. Boeing is willing to explore spectrum sharing scenarios that would not encumber the placement of its end user terminals in the 47 GHz band, such as restricting UMFUS systems to indoor locations, or permitting them in any location, but subject to accepting interference from existing or future satellite end user terminals. The specific proposals raised in the Further Notice, however, would not be acceptable absent modification.

First, the Further Notice considers the possible use of a database or Spectrum Access System ("SAS"), but suggests that such a system would be used to restrict satellite end users by determining "where their user equipment could transmit without causing interference to terrestrial operations."[28] As noted above, no company can successfully operate a broadband communications system that would be attractive to end users if significant limits are imposed on their ability to place end user terminals at subscriber locations. Boeing therefore cannot accept this proposal.

Second, the Further Notice suggests the possibility of employing a first-come, first-served approach for the placement of transmitting satellite end user terminals and UMFUS systems.[29] Although Boeing anticipates launching its NGSO FSS system well before UMFUS systems are constructed in the V-band, Boeing will need to be able to add new end user terminals on an ongoing basis without potentially being blocked from a subscriber location by an UMFUS system. Therefore, a first-in-time approach would be incompatible with the marketing of a broadband communications service that would be attractive to end users.

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[28] *Id.*, ¶ 413.

[29] *See id.*, ¶ 415.

Third, the Further Notice suggests the possibility of band segmentation.[30] Boeing is reluctant to support band segmentation because Boeing believes that spectrum sharing is possible between transmitting satellite end user terminals and UMFUS systems in the 47 GHz band. The placement of UMFUS systems, however, would need to be restricted, such as to indoor locations, or operated on an opportunistic basis as compared to satellite end user terminals. The record of this proceeding has identified many possible UMFUS applications that could operate under such conditions, such as unlicensed systems that could scan between available channels, or indoor systems that would be well protected by building attenuation. Boeing suggests that the 47 GHz band be considered for such uses.

If, however, the Commission deems band segmentation to be appropriate, then satellite systems will require a full 3 GHz of uplink spectrum to support transmitting end user terminals, preferably comprising the 47 GHz band. A full 3 GHz will be needed to accommodate the very high data rate transmission requirements of end users. 3 GHz of spectrum will also be needed to facilitate spectrum sharing between multiple satellite systems, including FSS systems operating with NGSO and GSO constellations. Therefore, the Commission should identify the 47 GHz uplink band as primarily and preferentially to be employed for broadband satellite system Earth-to-space operations.

III. BOEING'S NGSO FSS GATEWAYS CAN SHARE THE 50 GHZ BAND WITH UMFUS SYSTEMS USING APPROPRIATE ACCOMMODATIONS

As the Commission acknowledges in the Further Notice, as compared to spectrum sharing in the 37.5-40 GHz band, spectrum sharing between UMFUS and FSS in the 47 and 50

[30] *See id.*, ¶ 414.

GHz bands "is more complicated, particularly when the FSS user equipment is transmitting."[31] Nevertheless, such spectrum sharing is feasible.

Individually-licensed satellite gateways can share the 50 GHz band with UMFUS systems operating with reasonable exclusion zones.[32] Satellite gateways are similar to UMFUS base stations in that they will transmit very narrow directed beams. Unlike UMFUS base stations, satellite gateways will always transmit upward toward satellites. For example, Boeing's satellite gateways will always transit at an elevation angle no lower than 45 degrees. The sidelobes from the transmissions of satellite gateways, however, could prevent UMFUS base stations from successfully receiving the weaker signals from its mobile user terminals. Further, satellite gateway sidelobes could also prevent UMFUS user terminals from receiving signals from UMFUS base stations if those user terminals are close to the satellite gateways. Figure III-1 depicts the uplink spectrum sharing situation and potential interference between NGSO FSS gateways and an UMFUS deployment.

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[31] *Id.*, ¶ 411.

[32] Boeing's discussion on spectrum sharing between satellite gateways and UMFUS systems is focused on the 50 GHz band even though satellite gateways will need access to both the 47 and 50 GHz band. As discussed in the prior section of these comments, however, the rules governing spectrum sharing in the 47 GHz band should reflect the operation of transmitting satellite end user terminals in that spectrum

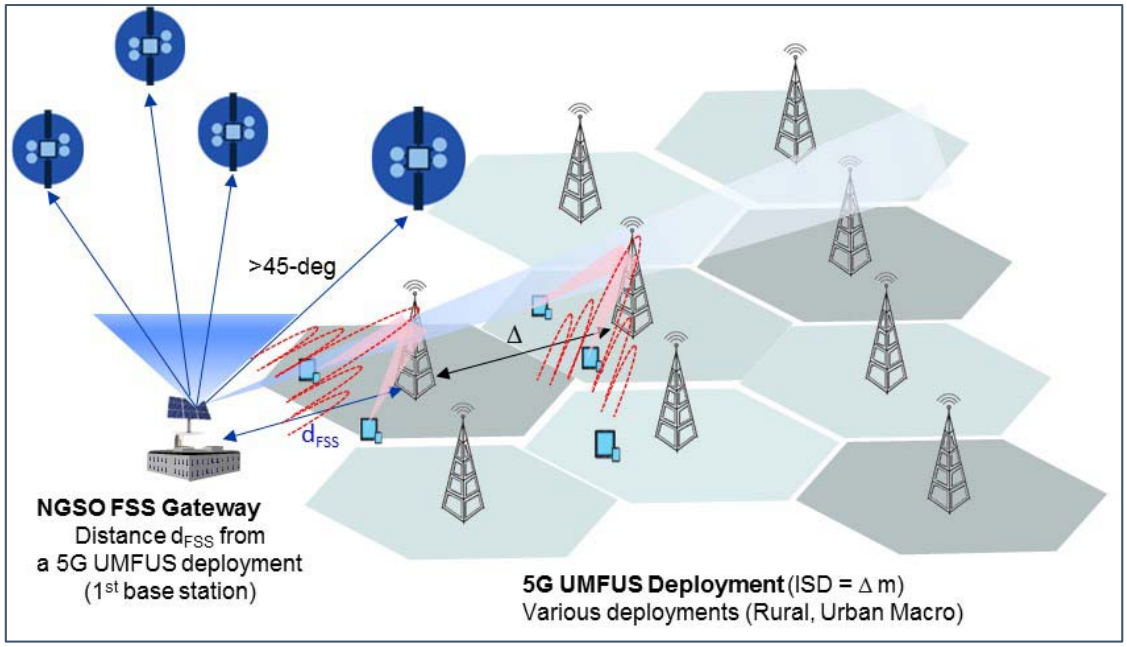


Figure III-1 –NGSO FSS Gateways and UMFUS Uplink Band Sharing Illustrated

In the Further Notice, the Commission requests comment on several possible methods for the coordination of gateway earth stations and possible UMFUS deployments in the 47 and 50 GHz bands. Boeing intends to locate its gateway facilities only in rural areas, well away from the likely markets for UMFUS systems. Boeing cannot, however, locate its gateways using the Commission's proposed restrictions that are based on quantities of gateways in individual counties or Partial Economic Areas ("PEAs"). To support the broadband demand growth to 2020 and beyond to 2025, Boeing will need to construct and operate several thousand gateways in the United States. The gateways for other V-band satellite systems will need to be accommodated as well. These numbers exceed what can be accommodated using the Commission's one to three gateways per county or PEA limitations.[33] In addition, the further proposed limits on the total FSS-to-UMFUS exclusion zone area of up to 0.1 percent of the population within counties or

[33] This count represents a minimum number of spatially separated gateway sites. Each such site already operates with multiple antennas and multiple beams to service multiple satellites in the field of view.

PEAs, are well intentioned, but are similarly too restrictive to achieve the capacity requirements of planned FSS satellite systems.

Boeing has completed an initial assessment of its planned gateway locations and of the potential exclusion zones wherein interference levels to UMFUS base stations may be excessive. Boeing's analysis has determined that, even with a large gateway count, Boeing's required FSS gateway-to-UMFUS exclusion zones will affect less than 0.1 percent of the total population of the United States. The necessary distribution of Boeing's gateways within counties or PEAs, however, exceeds the 0.1 percent limitation in many of those low-density counties or PEAs where 0.1 percent of the population consists of a relatively small number of people. These results can be improved by further analysis of the interference conditions (propagation, line-of-sight) rather than attempting to achieve fixed PFD limits at specified ranges.[34] They can also be improved by employing cooperative and selective siting methods wherein both FSS systems and UMFUS operators disclose their actual locations, antenna sizes, base station sector orientations, and other site specific capabilities. Nevertheless, even employing these additional measures, Boeing's gateway deployment requirements will not be able to comply with either a restriction of 1 or 3 sites per county or PEA, or a restriction of affecting no more that 0.1 percent of the population of each county or PEA.

Therefore, Boeing provides the following recommendations for enabling non-burdensome spectrum sharing between UMFUS systems and satellite gateway facilities in the 50

[34] Boeing has assessed interference between FSS gateway and UMFUS base stations in a variety of ways, using both interference to noise ratios (I/N) as well as the resulting PFD levels incident at the UMFUS base station or FSS gateway. Boeing's analyses indicate a range of potential exclusion zones (from less than 1 kilometer to 5 kilometers) based on propagation and LOS conditions, for various I/N ratios up to 0 dB. These assessments, however, also indicate that the -77.6 dBm/m2/MHz PFD level suggested by the Commission for 28 GHz coordination may need to be adjusted to protect FSS gateway and UMFUS base stations from interference.

GHz band. One measure would be to require satellite system operators to maintain a database of their gateway locations so that UMFUS system operators can take operational measures to avoid interference from the gateways. For example, if a mobile UMFUS user terminal moves too close to the line of sight ("LOS") of a satellite system gateway, the UMFUS terminal could be directed by its network to transmit back to its base station on return link frequencies that are outside the 50 GHz band. It is anticipated that all or most UMFUS end user terminals will be able to transmit on multiple bands, likely including legacy cellular bands. This capability will be needed to address numerous situations in which UMFUS user terminals will be able to receive UMFUS signals using the 50 GHz band, but will not be able to close a return link back to the serving base station due to such factors as building attenuation, foliage, rain fade or countless other factors.

A second recommendation for spectrum sharing between satellite gateways and UMFUS systems in the 50 GHz band would be to maintain a first-in-time coordination approach for UMFUS base stations and satellite gateways in rural areas. This system would be very similar to the one proposed by AT&T and EchoStar with respect to the 28 and 37/39 GHz bands.[35] It would also be comparable to the UMFUS licensing approach proposed by the Commission for the 70 and 80 GHz bands.[36] Satellite gateways would be prohibited in urban and semi-urban areas where UMFUS licenses would be issued through auction on an exclusive basis for each

[35] See Letter from Stacey G. Black and Jennifer A. Manner, GN Docket No. 14-177, et al. (Apr. 6, 2016) (laying out sharing framework, including definition of urban core areas); Letter from Stacey G. Black and Jennifer A. Manner, GN Docket No. 14-177, et al. (May 19, 2016) (providing detailed coordination guidelines). SIA does not propose that the Commission implement a safe harbor approach such as that previously proposed in these submissions.

[36] *Further Notice,* ¶ 440 (proposing a Spectrum Access System-based regulatory framework for the 17-76 and 81-86 GHz bands).

county or PEA. AT&T/Echostar proposed an exclusion area of about 5 to 10 miles around the center point of major urban centers where satellite gateways would be prohibited.

Outside of these exclusion zones, satellite gateway licenses would be issued on a site-specific basis using a co-primary first-in-time spectrum sharing approach with UMFUS systems. Granted, a co-primary spectrum sharing approach may not function compatibly with geographic area auctions for UMFUS licenses. Instead, UMFUS licenses for non-urban core areas could either be issued on a non-exclusive nationwide basis (similar to point-to-point microwave licenses) or on a site (or link) specific basis. In either case, UMFUS licensees would identify specific locations for base stations (or links for point-to-point systems) and receive protection for those locations and their surrounding coverage areas if they construct and bring them into operation within a relative short period, *i.e.*, one or two years.

Site licenses for satellite gateways could be issued in a similar manner. Once a proposed location for a gateway is identified in an FCC license application, the gateway licensee would receive protection for that location and could retain its coordination priority as long as the gateway is brought into operation within a relatively short period (again, one or two years) after the license is granted by the Commission. Subsequently built UMFUS systems could not claim protection from such gateway facilities.

By employing such approaches, the Commission can facilitate intensive spectrum sharing between UMFUS systems and satellite gateways in the 50 GHz band without appreciably burdening either type of spectrum use. Thus, if the Commission does create an UMFUS allocation in the 50 GHz band, the Commission should further its public interest mandate by concurrently adopting these co-primary spectrum sharing measures to enable intensive and highly efficient use of the 50 GHz band to provide very high data rate services to all Americans.

IV. THE COMMISSION SHOULD AUTHORIZE SATELLITE END USER RECEIVERS TO OPERATE ON A SHARED BASIS IN THE 37/39 GHZ BAND

As Boeing explained above, there is a pressing need for satellite end user terminals to have access to a full 5 GHz of downlink spectrum in the V-band to serve the forward link requirements of subscribers, including allowing shared access in the 37/39 GHz band. Boeing appreciates the Commission's apparent recognition of this need by seeking "specific examples and data" on whether FSS needs to use the 37/39 GHz band for user terminals given its access to the 40.0-42.0 GHz band. As Boeing explained in Section II.A. above, by far the most data intensive link in a broadband communications system in the forward path to the end user. Data requirements on this forward path are increasing exponentially and will continue to increase at this pace in the future. To serve these data transmission requirements, Boeing will require access to 5 GHz of space-to-Earth forward link capacity, including primary access to the 40.0-42.0 GHz band and opportunistic access to the 37/39 GHz and the 42 GHz bands.

Boeing has demonstrated that satellite end user terminals can operate successfully in the 37/39 GHz bands despite the presence of UMFUS systems. The same narrow beamforming that makes UMFUS communications possible in mmW spectrum facilitates sharing with satellite earth station receivers. Boeing can also employ such techniques as satellite diversity, physical screening, directional nulling, and other mitigation strategies to address specific spectrum sharing situations between its satellite user terminal receivers and UMFUS base stations.

Boeing has also proposed the creation of a confidential database of UMFUS base station locations in the 37/39 GHz band that could be used by broadband satellite operators to assist in the placement of their satellite end user receivers. The maintenance of such a database would not result in an appreciable burden to UMFUS licensees. UMFUS licensees will need their own records of where their base stations are located and, unlike end user terminals, such base stations

cannot be moved by subscribers. Further, no risk exists that such a database could reveal proprietary UMFUS subscriber location information since the database would only identify the locations of base stations, not user terminals.

Regardless of whether the Commission supports the creation of a confidential database of UMFUS base stations in the 37/39 GHz band, the Commission should remain focused on the fact that the satellite industry is seeking access to the 37/39 GHz bands for satellite end user *receivers*. Such terminals cannot cause interference (or be detectible) by UMFUS licensees operating in the 37/39 GHz band. No legitimate justification exists for continuing to exclude satellite user terminals from the 37/39 GHz band and the goal of spectrum efficiency mandates the elimination of this outdated restriction. Boeing therefore urges the Commission to remove the prohibition on satellite end user terminals that exists in footnote 3 of Section 25.202(a)(1) of the Commission's rules. The anticipated benefits of spectrum sharing between satellite end user receivers and UMFUS systems in the 37/39 GHz band will be tremendous in ensuring that mmW spectrum is used to provide competitive, very high data rate broadband services to all Americans regardless of where they are located.

V. THE COMMISSION SHOULD AUTHORIZE SATELLITE SYSTEMS TO TRANSMIT IN THE 37/39 GHZ BAND AT THE HIGHER ITU POWER LEVELS

The Further Notice seeks comment on whether to permit satellite operators to downlink in the 37.5-40.0 GHz band at the PFD levels that were adopted globally by the ITU for this spectrum rather than the 12 dB tighter limit adopted by the Commission more than a decade ago. Authorizing satellite systems to operate at higher power levels "would be consistent with terrestrial use of the 37.5-40.0 GHz band"[37] because it would not result in harmful interference

[37] *Further Notice*, ¶ 499.

to (or affect appreciably) the operation of terrestrial systems. The existing outdated restriction was adopted prior to the development of the advanced mmW technologies that now make robust spectrum sharing between satellite and terrestrial services possible.

In Boeing's prior submissions during the Spectrum Frontiers proceeding, Boeing demonstrated that satellite downlink transmissions at the internationally recognized ITU PFD level would have no material adverse impact on terrestrial operations in the band.[38] In response to the Commission's Further Notice, Boeing has included significant additional analyses of the potential interference impact of satellite downlink transmissions on terrestrial operations. Boeing's discussion herein includes a review of the methodology for interference calculations as well as a summary of Boeing's prior *ex parte* analyses findings, followed by extensive additional analyses of satellite downlink operations and its negligible impact on UMFUS operation.

A. Operations of a Single Satellite at Power Levels at the ITU PFD Level Causes no Appreciable Interference into UMFUS Receivers

In Boeing's prior submissions during the Spectrum Frontiers proceeding, Boeing demonstrated that satellite downlink transmissions at the internationally recognized PFD level would have no material adverse impact on terrestrial operations in the band.[39] The calculations are based on computing the level of additional noise introduced at the UMFUS receiver by the

[38] *See* Letter from Bruce Olcott, Counsel to The Boeing Company, GN Docket No. 14-177 (July 7, 2016) ("*July 7th Boeing Letter*").

[39] *See id.*

arriving signals with the given PFD. Specifically, Boeing calculated the total interference-to-noise ratio at the UMFUS receiver, INR_{dB}, using:

$$INR_{dB} = (I/N) = PFD + G_r - 10\log_{10}(4\pi/\lambda^2) - k - T_r$$

where:

PFD = incident satellite signal power flux density in dBW/m2/MHz

λ = wavelength in m; $\lambda \sim= (0.3/F_c)$ where F_c is in GHz

G_r = Isotropic gain of the 5G receiver in the direction of the arriving PFD signal, in dBi

K = Boltzmann's constant, -228.6 dB W/K-Hz

T_r = 5G receiver noise temperature in dB/K, calculated as $10\log_{10}(T_b+290*[10^{(NF/10)}+1])$ where T_b= background temperature (usually 290K for terrestrial background and/or rain) and NF = noise figure of the 5G receiver in dB

The noise floor increase due to the interference-to-noise (I/N) ratio above is computed as simply:

$$(I/N)_{deg} = 10\log_{10}(10^{(INR/10)}+1)$$

This methodology is commonly used in the industry to show potential decreases in sensitivity due to interference at receivers, and has been used extensively in the Spectrum Frontiers proceedings by many parties.

In Boeing's *ex parte* letter of July 7, Boeing showed that the $(I/N)_{deg}$ degradations to UMFUS are less than 0.5 to 0.6 dB using highly conservative assumptions regarding the UMFUS receivers. For a mobile user handset with G_r=13 dBi and NF=7 dB, and assuming the mobile user beam is mis-pointed away from its base station and is instead pointed directly at a radiating satellite operating at the ITU PFD limit of -105 dBW/m2/MHz, Boeing's analysis computed a degradation of at most 0.6 dB. This was reflected in the following Table V-1, which was first included in Boeing's July 7 ex parte letter.

MOBILE USER CHARACTERISTICS				Broadside (horizontal Beam)						
Linear array dimension	Array Configuration	Total Elements	Peak Gain	Rolloff (relative gain) at 45-deg offset*	Absolute Gain at 45-deg offset	Satellite Interference Level after antenna gain	5G receiver Noise density	Interference to Noise ratio, I_{SAT}/N_{5G}		5G link degradation
(cm)			(dBi)	(dBr)	(dBi)	(dBW/MHz)	(dBW/MHz)	(dB)	(%)	(dB)
1.55	1x4 or 2x2	4	10.0	0.0	10.04	-148.2	-137.0	-11.3	7.5	0.31
3.10	1x6 or 2x3	6	11.8	0.0	11.80	-146.5	-137.0	-9.5	11.2	0.46
1.55	1x8 or 2x4	8	13.0	0.0	13.05	-145.2	-137.0	-8.2	15.0	0.61

Table V-1 – Worst-case FSS interference into Mobile Handsets*
(with handset beams mis-pointed at satellite)

In the case of UMFUS base stations, Boeing's prior analysis included a full range of potential base station sizes, operating in the nominal case with a 0 degree downtilt and horizontal (or lower) scanned beams. Boeing's analysis also included a case where the base station is generating skyward pointed beams for mobile users located above the base station height up to 35 degrees above the horizon. Tables V-2 and V-3 re-summarizes these results, again showing degradations for any scanned base station beams to be below 0.4 dB.

BASE STATION CHARACTERISTICS				Broadside (horizontal Beam)						
Linear array dimension	Array Configuration	Total Elements	Peak Gain	Rolloff (relative gain) at 45-deg offset	Absolute Gain at 45-deg offset	Satellite Interference Level after antenna gain	5G receiver Noise density	Interference to Noise ratio, I_{SAT}/N_{5G}		5G link degradation
(cm)			(dBi)	(dBr)	(dBi)	(dBW/MHz)	(dBW/MHz)	(dB)	(%)	(dB)
1.55	4x4	16	16.1	17.4	-1.34	-159.6	-139.0	-20.6	0.9	0.04
3.10	8x8	64	22.1	27.5	-5.41	-163.7	-139.0	-24.7	0.3	0.01
4.65	12x12	144	25.6	27.6	-1.98	-160.2	-139.0	-21.3	0.7	0.03
6.20	16x16	256	28.1	31.0	-2.94	-161.2	-139.0	-22.2	0.6	0.03
12.40	32x32	1024	34.1	35.6	-1.45	-159.7	-139.0	-20.7	0.8	0.04

Table V-2 – Worst-case FSS interference into Base Station – Horizontal Beams (or below)

BASE STATION CHARACTERISTICS				35-degree scanned beam						
Linear array dimension	Array Configuration	Total Elements	Peak Gain	Rolloff (relative gain) at 45-deg offset	Absolute Gain at 45-deg offset	Satellite Interference Level after antenna gain	5G receiver Noise density	Interference to Noise ratio, I_{SAT}/N_{5G}		5G link degradation
(cm)					(dBi)	(dBW/MHz)	(dBW/MHz)	(dB)	(%)	(dB)
1.55	4x4	16	16.1	9.5	6.52	-151.7	-139.0	-12.8	5.3	0.22
3.10	8x8	64	22.1	13.1	8.97	-149.3	-139.0	-10.3	9.3	0.39
4.65	12x12	144	25.6	21.5	4.12	-154.1	-139.0	-15.2	3.0	0.13
6.20	16x16	256	28.1	22.6	5.53	-152.7	-139.0	-13.8	4.2	0.18
12.40	32x32	1024	34.1	24.5	9.60	-148.7	-139.0	-9.7	10.7	0.44

Table V-3 – Worst-case FSS Interference into Base Station – 35 Degree Upwards Scanned Beams

As noted in Boeing's July 7 *ex parte* letter, such operating modes with 35-degree elevation angles or higher are extremely unlikely. Further, if these situations are occurring in a

cluttered urban environment as posited by Straight Path,[40] the satellite receive signal PFD itself would be experiencing significant additional attenuation due to the urban environment. Therefore, it is evident that satellites can operate successfully in the 37/39 GHz band using the higher ITU PFD limits without resulting in appreciable interference to UMFUS systems.

B. The Aggregate Interference From Multiple Satellites Should be Calculated Using an Equivalent PFD Approach

In considering whether to permit satellite systems to operate in the 37/39 GHz band using the higher ITU PFD levels, an important question involves the potential impact of multiple satellites serving the same geographic location using the same spectrum. Efficient spectrum sharing techniques, such as satellite diversity, permit multiple satellites (potentially operated by unaffiliated operators) to use the same spectrum to serve the same location and avoid interference into each other by directing beams to and from satellites at different points in the sky.

The potential impact on UMFUS systems of such co-frequency operations cannot be determined accurately simply by adding the PFD levels from multiple satellites. Because the satellite transmissions will approach UMFUS receivers from different directions, the potential impacts to the UMFUS receivers will vary significantly. Instead, the appropriate approach to determine the aggregate impact of multiple satellites on UMFUS receivers in the 37/39 GHz band is by calculating the aggregate equivalent PFD (ePFD) of multiple satellites on UMFUS systems. Such an approach provides conservative and appropriate results and has been used

[40] *See* Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 et al., at 3 (June 23, 2016) ("*Straight Path June 23 Letter*"). Straight Path argues that, given the number of tall buildings in the United States, there will be a need for upwards-pointing base station beams. *See id.* This is similar to Urban Micro scenario where the base station beams may indeed be steered upwards, but in which satellite LOS is essentially blocked by the same nearby buildings.

extensively by the Commission and by satellite operators for coordination among FSS NGSO systems, as well as GSO and terrestrial systems.[41]

An aggregate ePFD approach relies primarily on a model of the intended receiver, including its gain and antenna pattern, along with the noise figure, to compute an I/N ratio (and degradation) similar to the worst-case single PFD analyses described above. The ePFD methodology can also be used to determine the interference introduced by a satellite system when operating either in clear sky conditions or using power control during rain to overcome fading.

In the case of a large satellite system such as Boeing's proposed NGSO system, multiple satellites would be within the field of view of a single ground point, providing overlapping coverage and multiple beams radiating into the overlapping ground regions. During a heavy rain fade event, each of the satellites that are necessary to provide capacity to a given ground site will raise its signal power to combat rain fade. Though it is a conservative assumption, each of the signal paths from the satellites may be experiencing the localized ground area rain fade, even though the satellite signals arrive from widely different directions. This situation is depicted graphically in Figure V-1.

[41] *See*, *e.g.,* Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range, FCC 00-418, *Report and Order and Further Notice of Proposed Rule Making,* ET Docket No. 98-206, 16 FCC Rcd 4096 (Dec. 8, 2000) (employing an ePFD approach to address aggregate interference from multiple NGSO satellites operating in the Ku-band).

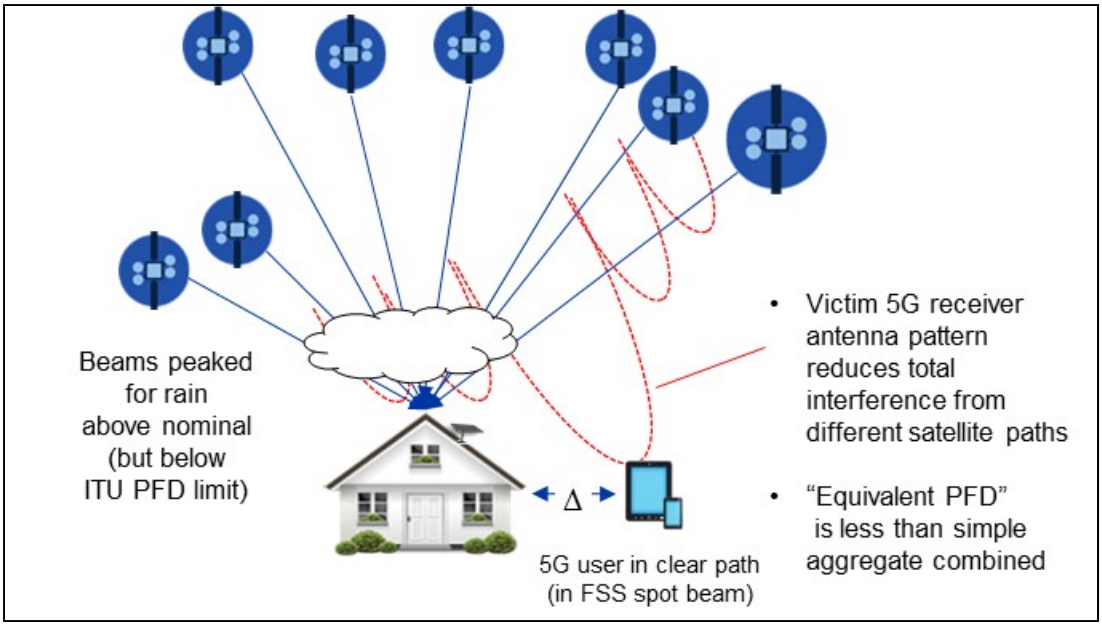


Figure V-1 – Aggregate Satellite Interference Scenario and ePFD in Rain

Boeing calculated such rain fades using the most recent ITU recommendations (e.g. ITU R.618-12)[42] and by applying additional power to each satellite beam as necessary to achieve system capacity and availability goals. The scenario depicted above in Figure V-1 assumes that the victim receiver is somehow in a clear-sky path with no rain loss experienced. The PFD of all incident satellite signals are computed with this assumption, without regard to the correlation of the rain fades among the satellite propagation paths. As the Commission noted in the Further Notice, "the problem is that rain will rarely be uniformly present throughout a spot beam's footprint, leaving at least some terrestrial stations unshielded or inadequately shielded by rain and, hence, vulnerable to any increase in the spot beam's PFD level."[43] Though Boeing disagrees in part with this assumption (*i.e.*, there are several mature models which demonstrate

[42] Recommendation ITU-R P.618-12, "Propagation data and prediction methods required for the design of Earth-space telecommunication systems" (July 2015) (available at http://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.618-12-201507-I!!PDF-E.pdf).

[43] *Further Notice,* ¶ 497.

the correlation of rain fade across several kilometers of distance),[44] Boeing adopts this worst-case assumption of mixed rain with sporadic clear-sky paths to inspire confidence in the ability to share the 37/39 GHz band under extremely unlikely adverse weather conditions.

With multiple signals incident on the UMFUS receiver, it is clear that the total incident PFD will be raised beyond the PFD of a single satellite due to the non-coherent combining or aggregation of the individual PFDs. Due to the different angle of arrivals, however, the various satellite signals experience different gains from the victim receiver's antenna and do not contribute equally to the total interference power. The ePFD metric, which is commonly used to regulate receive interference contributions among satellite systems, correctly captures the aggregate interference effect from different angles of arrival. Specifically, an "ePFD" utilizes the antenna gain pattern of the victim receiver to compute the combined received power after antenna gain is applied to the incident signals, and expresses this total interference as the equivalent flux density that would generate the same interference contributions if it were received at the peak of the antenna beam pattern:

$$ePFD = 10log_{10}\left(\sum_{k=1}^{Nsats} 10^{\frac{(G_r^k(\theta_k,\phi_k)+PFD_k)}{10}}\right) - \left(G_{r-pk}\right)$$

where:

N_{sats} = Number of total NGSO satellites radiating beams at the particular ground point
PFD_k= incident PFD of the kth NGSO satellite at the ground point
$G_r^k(\theta_k, \phi_k)$= Gain of the 5G victim receiver antenna in the direction toward the kth NGSO satellite, in dBi
G_{r-pk}= Peak gain of the 5G victim receiver (usually G_r (0,0) at boresight), in dBi
[NOTE: The units of ePFD will be the same as PFD_k, *i.e.*, dBW/m2/MHz.]

[44] ITU R.618-12, ¶ 2.2.4.1; *see also* "On the Relationship Between the Spatial Correlation of Point Rain Rate and of Rain Attenuation on Earth-Space Radio Links", Luini and Capsoni, IEEE Transactions on Antennas and Propagation, October 2013

The ePFD can be used to compute the total expected interference degradation at a victim UMFUS receiver for all satellites using the $(I/N)_{deg}$ equation exactly as above, *e.g.*, INR_{dB} = [ePFD + $G_{r\text{-}pk}$ -10log$_{10}$($4\pi/\lambda^2$)– k – T_r] and is therefore the appropriate metric to use in calculating aggregate interference into UMFUS receivers.

C. Aggregate ePFD Levels Can be Calculated Using UMFUS Reference Receivers and Their Alignment and Pointing Scenarios

To successfully use the ePFD methodology, a model of UMFUS receive terminals must be established, along with assumptions regarding the operational pointing of the UMFUS antennas. The 3GPP Channel Modeling Report referenced previously contains both antenna models and reference scenarios for three outdoor 5G deployment scenarios.[45] This data was used extensively by many parties in the Spectrum Frontiers proceedings and represents the prevailing assumptions of a large consortium of suppliers and operators concerning UMFUS deployments and operations. In terms of UMFUS receiver equipment, Table V-4 summarizes the overall representative parameters used for each of the three UMFUS devices (base station, transportable/CPE, and mobile handset/devices) authorized in the Spectrum Frontiers Order. UMFUS victim receiver antenna patterns are modeled using the 3GPP channel modeling report over a range of handset and base station array sizes. To ensure the highest noise level cases are considered, Boeing includes handset sizes of 16 elements (4x4), and transportable/CPE and base station sizes ranging from 64 (8x8) elements up to 1024 elements (32x32).

[45] *See* 3rd Generation Partnership Project Technical Specification, "Channel model for frequency spectrum above 6 GHz (Release 14)," 3GPP TR 38.900 V1.0.0 (2016-06), Section 7.3 - Antenna models.

5G UMFUS Unit Type	Elements	Size	Peak Gain (dBi)	Noise Figure (dB)	EIRP Density (dBmi/100 MHz)
Base Station	64	8x8	21.1	5.0	75.0
Base Station	256	16x16	27.1	5.0	75.0
Base Station	1024	32x32	33.1	5.0	75.0
Transportable CPE	32	4x8	18.0	7.0	55.0
Transportable CPE	64	8x8	21.0	7.0	55.0
Mobile/Handset	8	4x2	13.0	7.0	43.0
Mobile/Handset	16	4x4	16.0	7.0	43.0

Table V-4 – UMFUS Units and Receive Characteristics

Regarding deployment scenarios, Figures V-2 and V-3 illustrate the reference scenarios for Urban Micro, Urban Macro, and Rural Macro deployments as described in the 3GPP Channel Modeling report.[46] The worst-case (highest) elevation angles from the base stations towards mobile users are also shown in each figure. For the Rural Macro and Urban Macro cases, the base station beams are pointed to users that are located at or below the horizon. The 3GPP Report uses downtilting of up to 12 degrees for taller base stations in the Rural Macro scenario. Boeing's July 7 *ex parte* letter analysis presented in Table V-2 above demonstrates that, as long as the aggregate PFD from multiple satellites is below the ITU PFD limit, these UMFUS base stations will experience no more than a 0.05 dB degradation.

[46] *See id.* at Section 7.2 – Scenarios.

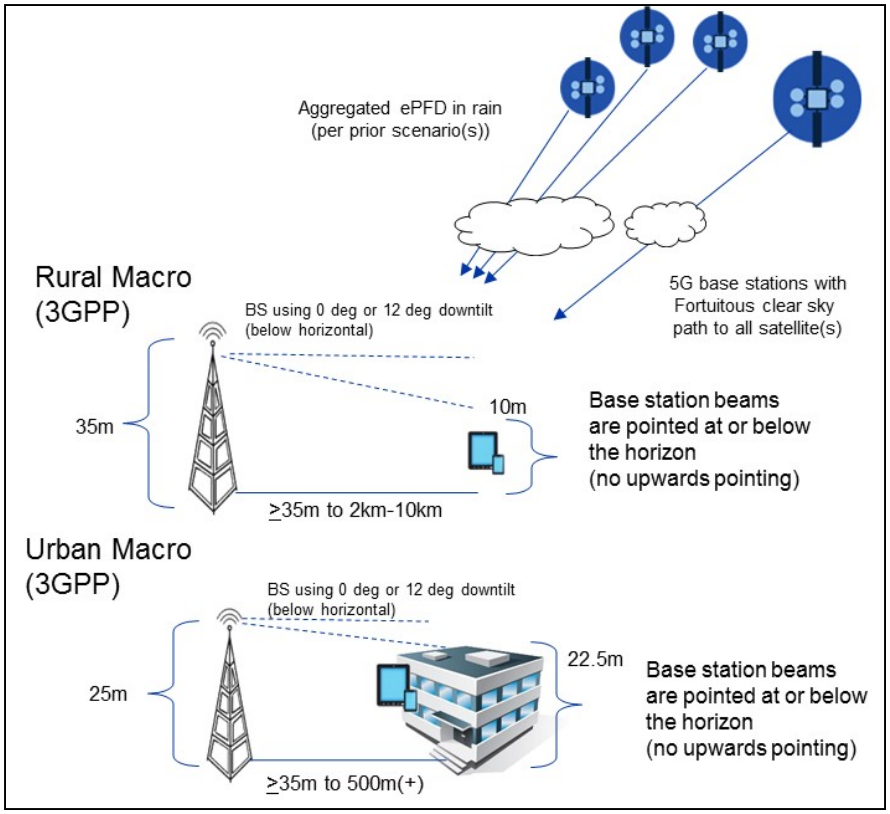


Figure V-2 – 5G Reference Scenarios for Urban Macro and Rural Macro Cases

With respect to the Urban Micro street corridor case, depicted in Figure V-3 below, this includes the possibility of skyward pointing base station beams, with elevation angles of 51.4 degrees at a minimum street distance of 10 meters to a user within a 22.5 meter office building. This is consistent with a typical base station array design with a 120 degree scan sector (representing at maximum 60 degree upward scan angle from horizontal). These extreme scans represent only a small fraction of the UMFUS base station scan range and user locations. Further, there is only a very small period of time when the base station beam might overlap an ascending or descending satellite (all of which, in the case of Boeing's constellation, operate above a 45 degree elevation angle) with an active spot beam pointed at the base station region.

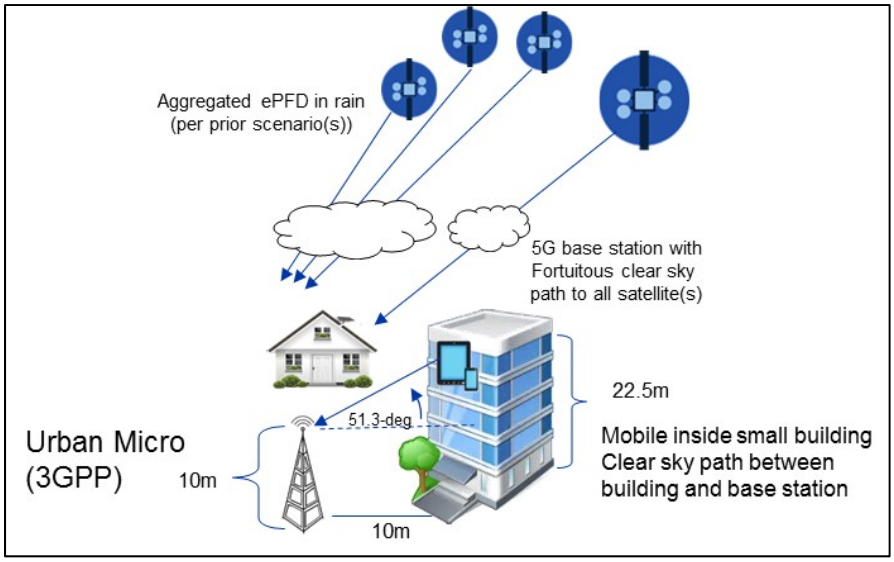


Figure V-3 – 5G Reference Scenarios for Urban Micro Case

Employing these different reference UMFUS receiver types and deployment scenarios, it is possible to calculate the aggregate ePFD levels that would be experienced by UMFUS systems resulting from the co-frequency operation of multiple satellites in the 37/39 GHz band. As provided in the following section, the results of these calculations show that aggregate emissions from multiple satellites will not cause appreciable interference to UMFUS systems.

D. The Aggregate ePFD Introduced by Multiple Satellites into UMFUS Reference Receivers is Minimal and Will Not Disrupt UMFUS Operations

The combinations of UMFUS receive equipment types and deployment scenarios that are discussed in the previous section of these comments are listed below in Table V-5 and result in three sharing scenarios for review.

SCENARIO	DESCRIPTION	5G receivers used	5G Receiver pointing cases
1) Mobile Users receive interference	FSS Downlink interference into 5G UMFUS mobile users	Mobile/Handset (4x2 and 4x4)	Mobile handset accidentally mis-pointed directly at a satellite
2) Transportable Users receive interference	FSS downlink interference into 5G UMFUS transportables	Transportable CPE (4x8 and 8x8)	Transportable beam pointed at base station per a)Urban Micro, b) Urban Macro, or c) Rural scenarios
3) Base Station receive interference	FSS downlink interference into 5G UMFUS base stations	• Base station sizes from 8x8 to 32x32 • 120-deg sector coverage (max 60-deg skyward beam scan) • 0-deg downtilt Applies to both cases (random ptg and Urban Micro)	a) Base station beam randomly pointed within the coverage sector b) Base station beam pointed a UE's distributed per Urban Micro scenario

Table V-5 – 5G Reference Receivers and Pointing Scenarios for ePFD/Interference Assessments

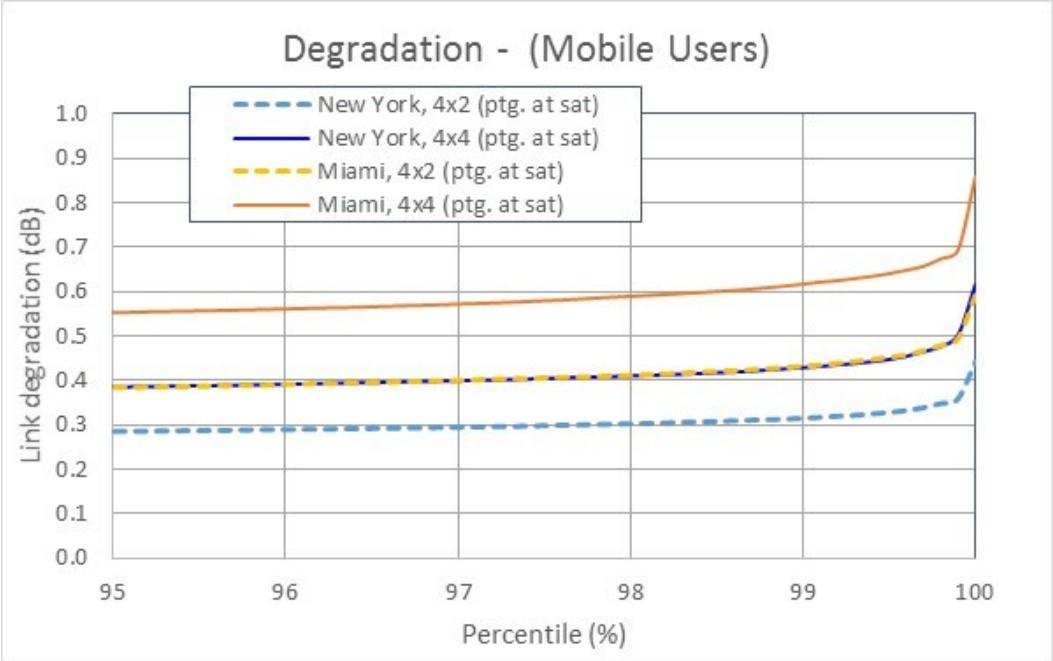
In Scenario 1, Boeing's ePFD analysis demonstrates that even a mis-pointed UMFUS mobile user can withstand operation of multiple satellites operating with ePFD levels at the ITU PFD limit. For Scenario 2 the ePFD levels are measured with transportable beams configured to point towards the base station in any of the 3GPP scenarios. Similarly, for Scenario 3, the ePFD levels were initially computed with the base station beam pointed randomly within the entire 120-degree scan sector. In Scenario 3, Boeing also ran the Urban Micro case with the base station beams pointing at the mobile users distributed per the 3GPP UE distribution (which generally reduced the elevation pointing of the base station as users were located further from the base station itself).

The results of Boeing's analysis of all three downlink interference scenarios in Table V-5 are reported in Table V-6. As expected, satellite operations into mobile receivers shows the least degradations – less than 0.65 dB with 99.5 percent confidence – with the mobile beam mis-pointing at one satellite and worst-case FSS power control/weather conditions.

Scenario	5G receiver	Location	ePFD (dBW/m2/MHz)		Link degradation (noise increase), dB	
			99%	99.5%	99%	99.5%
1 – Mobile Users	Handset 4x2	New York	-108.1	-107.9	0.31	0.33
	Handset 4x4		-109.7	-109.5	0.43	0.45
1 – Mobile Users	Handset 4x2	Miami	-106.7	-106.5	0.43	0.45
	Handset 4x4		-108.1	-107.8	0.62	0.64
2a – Transportable CPE	CPE (8X8)	New York	-128.2	-127.5	0.020	0.022
2b – Transportable CPE	CPE (8x8)	Miami	-127.5	-126.7	0.022	0.026
3a - Base Stations (random ptg)	64 elem (8x8)	New York	-116.5	-115.0	0.42	0.55
	256 elem (16x16)		-125.1	-120.4	0.24	0.65
	1024 elem (32x32)		-135.0	-131.2	0.10	0.23
3a - Base Stations (random ptg)	64 elem (8x8)	Miami	-116.4	-115.0	0.42	0.60
	256 elem (16x16)		-127.0	-121.5	0.15	0.50
	1024 elem (32x32)		-135.2	-132.0	0.10	0.19
3b - Base Stations (Urban Micro)	64 elem (8x8)	New York	-129.3	-128.5	0.023	0.027
	256 elem (16x16)		-127.0	-136.0	0.016	0.018
	1024 elem (32x32)		-144.2	-143.2	0.012	0.014
3b - Base Stations (Urban Micro)	64 elem (8x8)	Miami	-129.0	-128.0	0.026	0.031
	256 elem (16x16)		-136.1	-135.5	0.018	0.022
	1024 elem (32x32)		-135.4	-142.6	0.014	0.017

Table V-6 – Results of ePFD and Interference Degradations into 5G Receivers

The probability distribution of ePFD and link degradations $(I/N)_{deg}$ into mobile receivers in high rain loss areas, such as in New York and Miami, are illustrated in Figure V-4. These areas represent the two worst-case locations within the continental United States ("CONUS") with the highest combination of rain loss and population density. To serve these locations, satellite systems will need to use power control to raise the power on its satellites serving these areas in order to address the high data consumption demand in these regions. As can be seen, the maximum ePFD level ranges from the ITU limit of -105 dBW/m2/MHz to a power level of -110 dBW/m2/MHz. The corresponding link degradations are less than 0.65 dB with 99.5 percent confidence with a worst-case handset mispointed directly at a serving satellite.



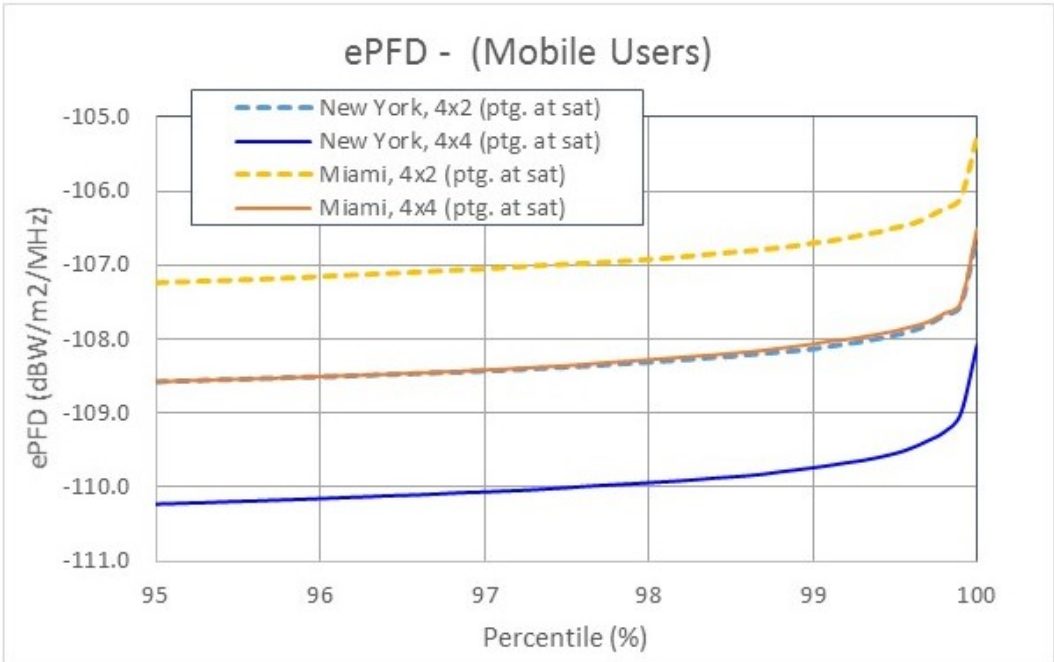
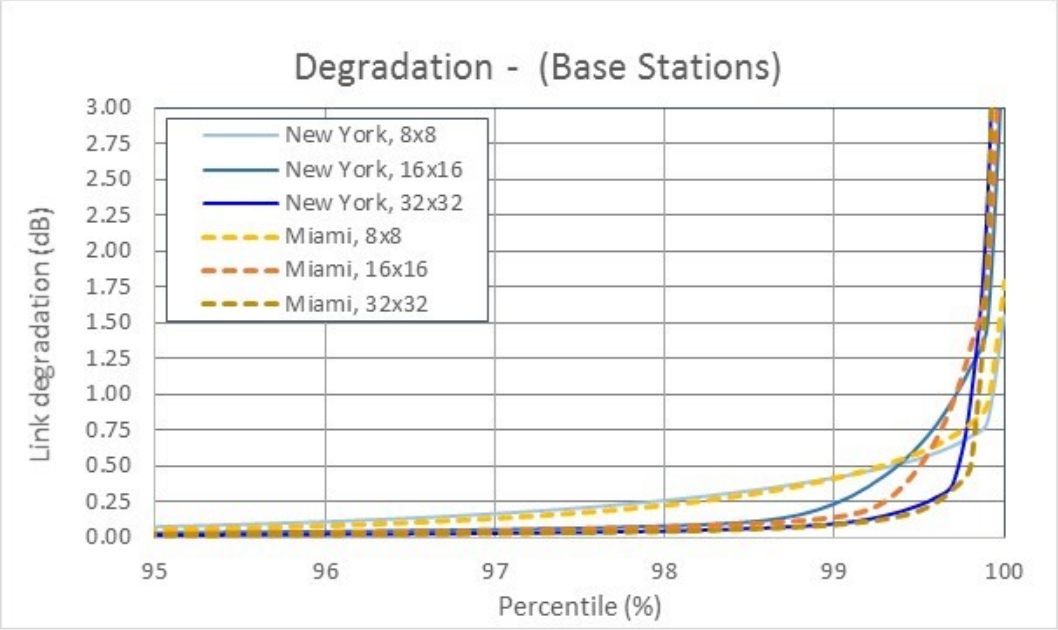


Figure V-4 – NGSO FSS Downlink ePFD and Link Degradations into UMFUS Mobile Handsets

The ePFD and link degradations into UMFUS base station receivers are illustrated in Figure V-5 for the same two worst-case CONUS locations. For Scenario 3a, the link degradation into UMFUS base stations are also less than 0.65 dB at a 99.5 percent confidence level assuming the base station is randomly pointing within a full 120-degree sector. If the base station is instead pointing at a user within an Urban Micro cell with ISD=200m, the upward

pointing range decreases and possible degradations reduce to less than 0.05 dB. In the case of transportable/CPE equipment, the results indicate similarly low values of less than 0.05 dB with the CPE pointing at its associated base station. These results for CPEs are consistent with the results for base stations because the CPE has nearly equal gain to a small base station, but has a higher noise figure (See Table V-2 addressing receiver characteristics).



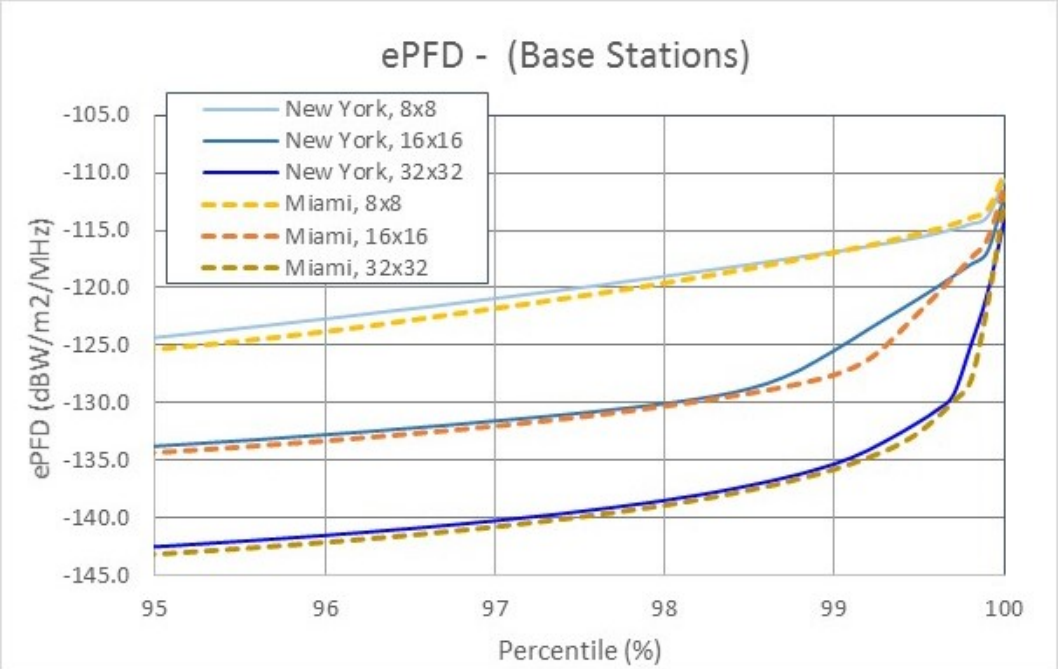


Figure V-5 – NGSO FSS Downlink ePFD and Link Degradations into UMFUS Base Stations

Boeing's analysis provides a confidence statistical simulation of FSS NGSO orbital locations and UMFUS beam pointing. It is worth repeating, however, the various assumptions of worst-case conditions that were included in these statistical analyses:

- Operation of the satellites in rain but with clear-sky path losses for the victim 5G receiver. This assumption alone represents a 99% worst-case rain condition, meaning that all of the confidence levels above are actually one to two orders of magnitude low (i.e., the 99.5% levels shown above are in fact only occurring less than 10% of the time, meaning an overall 99.95% confidence);

- Direct mis-pointing of the 5G beams at one of the satellites is allowed for the mobile handset cases (Scenario 1);

- Boeing's statistical simulations also include additional large random amplitude and phase errors (consisting of 1 dB 1σ amplitude and 15-deg 1σ Gaussian phase errors) within the 5G beamforming process. These errors degrade the 5G beam sidelobe performance and account for hardware implementation allowances within 5G handsets or base stations.

Based on this analysis, it can be concluded that ePFD levels can be defined for satellite systems that ensure that FSS operations do not cause appreciable interference to UMFUS receivers.

E. Based on Boeing's Analysis, the Commission Should Authorize Satellite Downlink Operations in the 37/39 GHz Band at ePFD Levels that are the Same as the ITU PFD Levels

Boeing's analysis presented herein demonstrates conclusively that downlink spectrum sharing is possible between FSS satellites (both GSO and NGSO) and the newly authorized UMFUS service. The analysis also demonstrates that satellite systems can operate individual beams up to the 12 dB higher ITU PFD limits without causing appreciable interference into UMFUS receivers. Similarly, ePFD limits can be set for UMFUS receivers that are positioned within FSS satellite operations in rain fades. In order to incorporate these measures into the

FCC's rules, Boeing proposes the following initial PFD and ePFD regulations for satellite downlinks in the 37/39 GHz band:

i) Any single FSS satellite (GSO or NGSO) operating in the 37.5-40.0 GHz band shall limit the PFD of any signal arriving at elevation angles above 25 degrees to -105 dBW/m2/MHz (existing ITU limit), under all propagation conditions including rain losses. The FSS satellite may apply any proposed power control to combat rain fades, but the PFD is to be computed with the power control applied and using clear-sky path loss conditions.

ii) Any single FSS satellite (GSO or NGSO) operating in the 37.5-40.0 GHz band shall also limit the aggregate PFD of all its beam emissions to less than -105 dBW/m2/MHz as received at any point within the field-of-view of the satellite operating at elevation angles of above 25 degrees, under all propagation conditions including rain losses. The FSS satellite may apply any proposed power control to combat rain fades, but the PFD is to be computed with power control applied and using clear-sky path loss conditions.

iii) For an FSS NGSO constellation, all satellites operating in the 37.5-40.0 GHz band shall limit their aggregate emissions to comply with the equivalent PFD levels stated below:

a. ePFD into a UMFUS mobile user of less than or equal to -108 dBW/m2/MHz for a mobile receiver defined with 16 dBi peak gain and antenna pattern defined for a 4x4 array pursuant to the 3GPP channel modeling report. The UMFUS mobile device beam may be pointing in any direction.

b. ePFD into a UMFUS base station of less than or equal to -128 dBW/m2/MHz for a base station receiver defined with 33 dBi peak gain and antenna pattern defined for a 32x32 array pursuant to the 3GPP channel modeling report. The base station array broadside aligned parallel with the ground plane using a 0 degree downtilt. The UMFUS base station beam is pointing randomly over a 120-degree coverage sector.

c. All FSS satellites providing service to a single ground area may apply any proposed power control to combat rain fades, but the ePFD is to be computed with the power control applied by all satellites and using clear-sky path loss conditions

d. ePFDs calculated above represent the 99%-tile confidence level achieved under worst-case rain conditions as measured over satellite motion and UMFUS beam pointing conditions

Boeing recognizes that it may be necessary to evaluate additional cases involving UMFUS reference antennas and deployment scenarios and Boeing looks forward to working with the Commission and other interested parties to consider these cases. Boeing is confident that such additional analysis will verify that satellites can operate in the 37/39 GHz band at PFD and ePFD levels that do not exceed the ITU PFD limits without causing appreciable interference to terrestrial operations, such as UMFUS receivers.

VI. TO THE EXTENT THAT THE COMMISSION PERMITS UMFUS OPERATIONS IN THE 42.0-42.5 GHZ BAND, IT SHOULD BE ON A SHARED BASIS WITH BROADBAND SATELLITE SYSTEMS

The Further Notice proposes to authorize UMFUS mobile services in the 42.0-42.5 GHz band and seeks comment on protecting radio astronomy from UMFUS operations.[47] If the Commission does authorize UMFUS in the 42.0-42.5 GHz band, the Commission should do so on a shared basis with receiving satellite end user terminals, just as the Commission is considering for the 37/39 GHz band.

In advocating for a shared approach, Boeing is aware that the Commission declined in its Order to adopt an allocation for FSS in the 42.0-42.5 GHz band.[48] The Commission appears to have based this decision solely on its assertion that "there is less reason to further expand FSS operations to the 42 GHz band" given the fact that the Order gave FSS access to the 37/39 GHz band and preserved the access of FSS to the 40.0-42.0 GHz band.[49] This conclusion disregards the fact that, as explained in previous sections of these comments, FSS systems will legitimately need access to a full 5 GHz of downlink spectrum in the V-band to meet the broadband data

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[47] *See id.*, ¶ 403.

[48] *See Order*, ¶ 368.

[49] *Id.*

demands of consumers, while sharing the spectrum with other satellite systems and other services.

Further, as in the case of the 37/39 GHz band, the Commission is not required to make a choice between satellite and UMFUS systems in the 42 GHz band, both services can share the spectrum in a complementary fashion. Receiving satellite end user terminals can operate in the 42 GHz band without causing any interference to (or being detected by) UMFUS systems.

For many years, the Commission maintained a proposal to make the 42 GHz band available for use by broadband satellite systems. The band is immediately adjacent to the 40.0-42.0 GHz FSS allocation and, as the Commission acknowledged in 2010 when it first proposed an FSS allocation in this band, FSS systems can use spot beams to selectively transmit to discrete geographic areas and therefore could protect radio astronomy operations in the adjacent 42.5-43.5 GHz band.[50]

Therefore, Boeing takes no position on whether UMFUS systems should be authorized to operate in the 42 GHz band. If the Commission does authorize UMFUS in this spectrum, however, it should do so while concurrently concluding that the band can and should be shared with receiving satellite end user terminals. The Commission's statutory mandate to manage spectrum resources in an efficient manner arguably requires this result.

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[50] Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5-38.5 GHz, 40.5-41.5 GHz and 48.2-50.2 GHz Frequency Bands; Allocation of Spectrum to Upgrade Fixed and Mobile Allocations in the 40.5-42.5 GHz Frequency Band; Allocation of Spectrum in the 46.9-47.0 GHz Frequency Band for Wireless Services; and Allocation of Spectrum in the 37.0 - 38.0 GHz and 40.0-40.5 GHz for Government Operations, IB Docket No. 97-95, *Third Notice of Proposed Rulemaking*, FCC 10-186, ¶ 18 (Oct. 29, 2010) ("*V-Band Third NPRM*"); *see also* Comments of SIA, Docket No. 97-95, at 5 (Jan. 6, 2011).

VII. THE COMMISSION SHOULD PRESERVE THE ABILITY FOR FSS, HAPS AND UNLICENSED SPECTRUM USE IN THE 70/80 GHZ AND ABOVE 90 GHZ BANDS

The history of satellite communications technology provides a clear record of constant evolution from the initial deployment of lower-frequency and lower bandwidth systems towards the operation of broadband satellite systems, currently operating at all bands up to and including the V-band. The inevitable technological trend of rapid innovation makes satellite usage of 70 and 80 GHz bands, or above 90 GHz, a likelihood in the reasonably foreseeable future, particularly for such functions as satellite gateway feeder links.

This said, some of the factors that make satellite communications in these bands relatively difficult, such as atmospheric attenuation, would be of less significance for relatively short-range services, such as UMFUS or high altitude platform services ("HAPS"). Therefore, while Boeing believes that the 70 and 80 GHz bands are more appropriate for UMFUS than the 47 or 50 GHz bands (the latter two of which are critically needed for broadband satellite systems), Boeing urges the Commission to refrain from adopting any measures that could preclude the operation of satellite or HAPS systems in these higher spectrum bands in the future. Instead, given the significant uncertainty that exists with respect to the anticipated use by 5G of these upper spectrum bands, it would be prudent for the Commission to refrain from taking any action on the 70, 80 or above 90 GHz bands at least until the outcome of ITU spectrum sharing studies that are currently underway in advance of the 2019 World Radiocommunication Conference ("WRC-19").

At the same time, Boeing remains concerned about the spectrum resources available for unlicensed spectrum use. Boeing's manufacturing facilities employ modern tooling and fabrication machines that rely on wireless data links to receive instructions, report status, and

communicate among themselves. Boeing's research and development teams are also exploring applications new applications for radio communications spectrum in mmW bands for such uses as detecting defects in manufactured surface materials. Such devices could operate as Part 15 devices, but would need to be used in various environments, including outdoors.

Currently, Section 15.257 of the Commission's rules permits unlicensed use of the 92-95 GHz band, but restricts such operations to indoor locations. Boeing urges the Commission to identify a portion of this spectrum, or other spectrum in higher mmW frequency above 90 GHz, for unlicensed operations that can be conducted in all environments, including outdoors.

VIII. THE COMMISSION SHOULD ADOPT REASONABLE RESTRICTIONS REGARDING UMFUS ANTENNA HEIGHT AND UMFUS DEVICE EIRP DENSITY BANDWIDTH SCALING

The Further Notice seeks comment on appropriate limits for UMFUS antenna height and raises a series of questions regarding the thresholds and corresponding reductions in power that should be applied to transmitters operating at higher antenna heights.[51] Boeing believes that the antenna height and EIRP limits proposed in the Further Notice, *i.e.*, proposed Section 30.202(e), are appropriate particularly given the increased likelihood of clear LOS conditions as the base station tower height increases.

In the Further Notice, the Commission also seeks comments on the value that would exist in adopting bandwidth scaling limits for mobile and transportable classes of UMFUS devices, just as the Commission did for base stations.[52] Specifically, the Commission's Order established rules for scaling of EIRP with bandwidth for UMFUS base stations, explaining that "[f]or channel bandwidths less than 100 megahertz the EIRP must be reduced proportionally and

[51] *Further Notice*, ¶¶ 505, 506.

[52] *Id.*, ¶¶ 507, 508.

linearly based on the bandwidth relative to 100 megahertz."[53] In a footnote, the Commission notes that "[u]nlike the EIRP limit for base stations, this EIRP limit is not scaled depending on the signal bandwidth."[54]

Boeing strongly recommends that the Commission extend its EIRP versus bandwidth scaling approach to all UMFUS devices, including transportable and mobile stations, as proposed in the Further Notice. Failure to do so would invalidate the technical assumptions and analyses presented in this docket by both the 5G community and the satellite industry, all of which were relied upon heavily by the Commission in the Order.[55] Specifically, if the UMFUS mobile and transportable devices observe only the authorized EIRP level of the original Order, and operate in channel bandwidths less than 100 MHz, they could introduce interference densities that are virtually unlimited and could be many dB's higher (for example, up to 20 dB higher if operated in a 1 MHz bandwidth) than previously assumed. Similarly, interference analysis between terrestrial services (*i.e.*, UMFUS to Fixed Services, Federal services, and Radio Astronomy) would all by heavily impacted by unrestricted deployment of outdoor mobile or transportable UMFUS devices with no limits on EIRP density. Boeing therefore urges the Commission to formalize its implicit assumption of constant maximum EIRP density for all UMFUS devices by revising the language of the Order to mandate a maximum EIRP *density* of 43 dBMi per 100 MHz for mobile stations, and 55 dBmi per 100 MHz for transportables. Such a revision would be entirely consistent with the prevalent proposed operating modes (TDD) for UMFUS

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[53] *Order,* Appendix A Rules, §30.202(a)*,* Power Limits.

[54] *Id.*, ¶ 285.

[55] References that rely on the EIRP densities of UMFUS handsets as being no greater than 43 dBmi *per 100 MHz* and transportable CPEs as being no greater than 55 dBmi *per 100 MHz* are numerous. *See, e.g., Order*, ¶¶ 282, 288, 290, and 291.

operations and would support similar performance for networks utilizing FDD operations as well, and would limit interference among the UMFUS providers and all other services using mmW spectrum.[56]

In supporting this proposal, Boeing acknowledges that higher density operations may be conducive to selected device types within extremely cluttered environments, such as indoor use within a building. Boeing would support the use of higher density transmissions for indoor-only applications to combat fading due to interior wall penetration conditions. Such an approach could be applied to mmW spectrum bands that permit UMFUS operations only in indoor environments. Although no such indoor-only bands have been identified thus far by the Commission, Boeing has proposed the use of an indoor-only approach to facilitate spectrum sharing between UMFUS and transmitted satellite end user terminals in the 47 GHz band.

IX. BOTH WORST-CASE AND STATISTICAL ANALYSES OF INTERFERENCE BETWEEN FSS AND UMFUS SERVICES SHOULD BE USED TO DEVELOP SPECTRUM SHARING RULES

In the Further Notice, the Commission seeks comment on a key question: "[w]hen applying transmitter or receiver isolation factors such as antenna directionality, should a degree of statistical probability be associated with the factor versus the assumption of worse case interference?"[57] A similar and related question is also posed: "[h]ow much isolation could one typically assume due to antenna beam forming techniques?"[58]

Throughout this proceeding, Boeing has used both worst-case and statistical analyses to assess interference impacts and demonstrate successful conditions for sharing spectrum between

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[56] *See, e.g., Order*, ¶¶ 96, 266-269.

[57] *Further Notice*, ¶ 512.

[58] *Id.*, ¶ 513.

FSS and terrestrial systems. Based on this analysis, Boeing has consistently maintained that the use of beamforming and power control by UMFUS and satellite systems will enable sufficient isolation between FSS and UMFUS users to allow efficient spectrum sharing. A valid analysis of such spectrum sharing potential requires a statistical analysis to address the anticipated mobility of both UMFUS terminals and NGSO satellites in the sky. Boeing's proposed NGSO FSS system introduces a "mobility" effect due to the motion of the LEO satellites and continuous tracking of the earth-station and satellite antenna beams.

To perform such a statistical simulation requires a dynamic, time varying model of UMFUS and FSS systems. Such models have been used by many parties throughout the Spectrum Frontiers proceeding. Although these models seem complicated, they are based on the same antenna models and interference calculations as the "worst-case" analyses. With well-defined assumptions and operational conditions, statistical models can estimate the interference that may be experienced by a substantial majority of users a large percentage of the time (*e.g.*, 95% to greater than 99.5%).

The relevance and use of statistical analyzes, as well as the effectiveness of beamforming and power control for reducing interference, was recognized by the Commission in at least two cases within the Order; the first case being the comments on 28 GHz uplink sharing,[59] and the second case being the establishment of coordination limits for base station and UMFUS sharing and exclusion zones.[60] In each case, the Commission recognized the validity of statistical

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[59] *Order*, ¶ 294. The Commission notes the dependencies and reductions in interference based on downtilting, beamforming and sidelobe suppression, and power control.

[60] *Id.*, ¶ 312 (noting that "Intel's proposed PFD was based on *worst case assumptions* about the receive antenna gain", and subsequently concluding "We believe that this assumption is *overly conservative*." and that "…a lower antenna gain is typically computed in the simulation towards the earth station since the receive beam is pointed in the direction of the transmitting UE, and it is *statistically unlikely* to coincide with the direction towards the earth station").

simulations as being necessary to identify operational interference, and to determine the relative antenna isolation between operational systems sharing a frequency band.

Therefore, Boeing strongly urges the Commission to require that statistical analyses be presented to address potential UMFUS interference into and from other services. As presented in these comments, the basis for such statistical models should use a series of documented assumptions by the parties, including:

i) the 5G deployment operational scenario being modeled (e.g. Urban Macro, Rural), including base station heights, locations, and sectorization, distributions of user devices, and time/frequency plans;

ii) the parameters of the specific UMFUS 5G devices being modeled including EIRP, gain, noise figure, and antenna pattern modeling parameters;

iii) general rules and assumptions for application of power control on operational links; and

iv) a similar set of parameters of the second system sharing the band, *e.g.*, an FSS system or a terrestrial FS system. For FSS systems, these can include satellite locations and orbital parameters; expected space station beam quantities, EIRP and/or PFD levels, noise figure, G/T and beamwidths, antenna pattern modeling parameters for off-axis sidelobes; and expected earth station and gateway characteristics.

For the UMFUS models, the parameters in items i) through iii) are similar to the 3GPP specification of the "Large Scale Calibration" scenarios,[61] which have been used to generate statistical distributions of Urban Macro and Urban Micro scenario SNR, C/I, and NLOS path losses.[62] For FSS systems, much of the information defined above is available in FCC Applications as well as other published information regarding the operational FSS systems.

In conclusion, to address the specific questions raised by the Commission in the Further Notice, Boeing recommends that statistical analysis results be required and reviewed by the

[61] "Channel model for frequency spectrum above 6 GHz (Release 14)," 3GPP TR 38.900 V1.0.0 (2016-06), Table 7.8.1, "Simulation assumptions for large-scale calibration."

[62] 3GPP R1-164802, "E-mail discussion summary of the large scale calibration," *available at* http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/R1-164802.zip.

Commission. The "degree of statistical probability" to be achieved may vary in certain scenarios, however, Boeing routinely reviews the highest confidence levels (ranging from 90% to 99.5+% confidence) to ensure very low likelihood of interference impacts to operational users. Given the use of narrow-beamwidth antenna beamforming systems and appropriate power control, using such high confidence levels greatly reduces the expected interference from the absolute worst-case assumptions. With regard to the question of "[h]ow much isolation could one typically assume due to antenna beam forming techniques?,"[63] this depends upon the specific beamforming antenna configuration, beamforming algorithm, and implementation errors within the antenna and RF devices. High isolation is typically achievable at high confidence levels for larger antennas and narrower beams. Analytical bounds exist to estimate the statistical confidence of sidelobe levels or nulling during beamforming processes,[64] and errors can be introduced directly into antenna simulations (as demonstrated in our downlink interference modeling in Section V of these comments) to emulate these effects.

X. AVAILABLE 5G DEPLOYMENT SCENARIOS AND MODELING APPROACHES CAN BE CONSISTENTLY USED IN DEVELOPING SPECTRUM SHARING RULES FOR UMFUS AND OTHER SPECTRUM USERS

In the Further Notice, the Commission seeks comments on a variety of important topics related to spectrum sharing and modeling of interference between UMFUS systems and other terrestrial or FSS systems, observing "[t]here are several factors that are common to the interference effects in both directions to and from 5G stations, including antenna beam forming, the location and height of antennas, and the propagation distance and environment between other

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[63] *Further Notice*, ¶ 513.

[64] *See, e.g.,* R.J. Mallioux, *Phased Array Antenna Handbook*, Artech House, 1994, Chapter 7, "Array Error Effects", including section 7.2.4 "Peak Sidelobes", and chapter references.

systems and the 5G stations."[65] During the development of its NGSO FSS satellite system, Boeing constructed a comprehensive and mature set of models that leverage the recent available data on several of the topics identified by the Commission. Boeing's comments on each of these areas are included below.

Scenarios for 5G deployment modeling: In assessing UMFUS and FSS interference cases, Boeing has reviewed the references listed below:

> [1] "5G-PPP-use-cases-and-performance-evaluation-modeling_v1.0.pdf," The 5G Infrastructure Public Private Partnership (5GPPP), April 25, 2016.
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> [2] "5G_Outdoor Scenario Descriptions_11.24.15," National Institute of Science and Technology, *5G Millimeter Wave Channel Alliance,* November 2015.
>
> [3] "Channel model for frequency spectrum above 6 GHz (Release 14)," 3GPP TR 38.900 V1.0.0, June 2016.
>
> [4] "Study on 3D channel model for LTE (Release 12)" 3GPP TR 36.873 V12.2.0 (2015-06), June 2016.

Among these references, Boeing believes the 3GPP reports [3] and [4] represent the most relevant information from the broadest consortium of existing providers and equipment suppliers. Section V of 3GPP report [3] illustrates three relevant outdoor 5G operating scenarios: the Urban Micro, Urban Macro, and Rural Macro deployment scenarios. The outdoor scenarios presented by the National Institute of Science and Technology, 5G Millimeter Wave Channel Alliance, report [2] reflect Urban Micro deployments that contain similar information to the 3GPP Urban deployments. The 5GPPP report [1] contains a variety of scenarios including Dense Urban and Broadband Everywhere scenarios with additional specific use cases for autonomous cars, Internet of Things, and other specialized applications.

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[65] *Further Notice*, ¶ 512.

Within the 5GPPP Dense Urban scenarios there are many similar urban deployments, including references to the 3GPP Urban scenarios. For example, all Urban Macro scenarios in the 5GPPP report in Table 7 utilize base station heights of 25 meters and cell sizes/inter-site distances ("ISDs") of 250 to 500 meters, which are similar to the 3GPP Urban Macro model. Similarly, all Outdoor Small Cell configurations in the 5GPPP report in Table 8 utilize base station heights of 10 meters and cell sizes/ISD from 50 to 100 meters. Rural scenarios in Table 9 from 5GPPP also match the 3GPP values of 30 to 35 meter base station height and a range of 1732 to 4330 meter ISD for cell sizes. Boeing concludes therefore that the 3GPP Urban Micro, Urban Micro, and Rural Macro scenarios are representative of a wide range of planned 5G deployments.

Propagation modeling for FSS and Terrestrial Systems: The Commission seeks comment on which propagation loss models (*e.g.*, Close In ("CI") and/or alpha-beta-gamma ("ABG")), and their associated measured data, would be the most appropriate to use when analyzing inter-service interference between terrestrial-based transmitters and victim receivers of different services. Boeing uses a form of the CI model that requires a single path loss exponent ("PLE") and a frequency-dependent constant to define the path loss equation. To determine the PLE, Boeing relies upon the following sources of measured propagation information:

> [1] "38 GHz and 60 GHz Angle-dependent Propagation for Cellular & Peer-to-Peer Wireless Communications", Rappaport et. al., IEEE ICC 2012 - Wireless Communications Symposium.
>
> [2] "Millimeter-Wave Omnidirectional Path Loss Data for Small Cell 5G Channel Modeling", IEEE Access Journal, SPECIAL SECTION ON ULTRA-DENSE CELLULAR NETWORKS, September 2015.
>
> [3] "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation", Akdeniz and Rappaport, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 32, NO. 6, June 2014.

[4] "Channel model for frequency spectrum above 6 GHz (Release 14)", 3GPP TR 38.900 V1.0.0 June 2016.

Boeing's modeling typically selects the most appropriate of these propagation models to determine the NLOS losses expected in each environment. When using NLOS conditions, we select the appropriate model using guidelines described below.

a) Rural Macro NLOS Losses: In rural conditions reflecting a lightly cluttered terrain model and a taller base station, Boeing utilizes the PLE derived from references [1] and [2] based on measured data at the UT-Austin campus. The 3GPP Rural Macro model in reference [4] allows the effective PLE to vary from 2.3 to 3.2 over a very short distance, reflecting greatly increased clutter that was not found during measurements in reference [1].

b) Urban Macro or Urban Micro NLOS Losses: Boeing uses and recommends the use of the 3GPP channel modeling losses described in reference [4] for Urban Micro and Urban Macro conditions. The optional model for these contains PLE=3.0 which is aligned with NYU measurements exhibiting PLE=3.1. Occasionally, Boeing may apply PLE=3.4 to 3.7 in these cases to determine dense urban street corridor losses.

c) Outdoor-to-Indoor Penetration Losses: Boeing primarily analyzes interference effects on receivers operating outdoors, as satellite downlink signals are unlikely to penetrate indoor regions, and any satellite uplink signals sharing a propagation path will experience nearly identical fading once the signals enter the same building. Boeing, however, does use the 3GPP channel modeling report [4] outdoor-to-indoor loss recommendations when modeling the EIRP necessary for 5G devices (particularly, base stations) to overcome losses for the users located in these conditions.

Overall, it is Boeing's conclusion that the CI model is accurate and representative of NLOS path losses. Boeing uses this model and selectively chooses the most appropriate approximate PLE that matches available data from the relevant frequency and environment. In addition, in order to fully understand the interference limits, Boeing routines uses clear LOS as a minimum bound for path loss. Although this case is rarely realistic except for short ranges, it provides a convenient check for other conditions.

Rain loss modeling for FSS and Terrestrial Links: Modeling of additional losses due to weather and rain is required to understand certain interference situations, particularly those involving power control. As noted previously in these comments, Boeing uses the most recent ITU recommendations, in particular ITU R.618-12, to compute weather and atmospheric related propagation losses for satellite links.[66] Similarly, Boeing uses a series of ITU Recommendations (ITU P.837, ITU R.P.530-13, and ITU R.P.838-3) to compute the rainfall rates and rain attenuation for terrestrial links and the propagation paths between FSS earth stations and 5G UMFUS devices.[67]

XI. THE COMMISSION SHOULD CONTINUE ITS CONSIDERATION OF UNLICENSED SPECTRUM USE ON AIRCRAFT IN THE 57-71 GHZ BAND

As Boeing indicated in its initial comments in the Spectrum Frontiers proceeding, it would be appropriate for the Commission to remove its precautionary prohibition on unlicensed transmissions in the 57-71 GHz band onboard aircraft. The low power level of onboard wireless communications devices, combined with the substantial attenuation of aircraft skin and

[66] ITU R.618-12, "Propagation data and prediction methods required for the design of Earth-space telecommunication systems", July 2015.

[67] ITU-R P.837-6, "Characteristics of precipitation for propagation modeling", Feb 2012 ITU-R P.838-3, "Specific Attenuation Model for Rain for Use in Prediction Methods", Mar 2005 ITU-R P.530-16, "Propagation Data and Prediction Methods Required for the Design of Terrestrial LOS Systems," July 2015.

free space losses, provide a high degree of assurance that use of the 57-71 GHz band on aircraft would be imperceptible to radio astronomy stations.

In the Order and Further Notice in this proceeding, the Commission indicates that it requires further technical analysis and sharing studies regarding the types of unlicensed devices that would operate on aircraft in the 57-71 GHz band and the measures that will exist to ensure that they do not result in harmful interference to radio astronomy observations in a portion of the spectrum.[68] To this end, Boeing has been working with aerospace companies and mmW equipment manufacturers to fully analyze and test of the propagation characteristics of mmW transmissions in the 57-71 GHz band onboard aircraft. Initial results demonstrate that emissions from mmW systems onboard aircraft will not cause interference to incumbent systems utilized by CORF. These recent study efforts complement previous studies showing that the metal surfaces of aircraft skin create substantial attenuation of mmW transmissions, particularly emissions in an upward direction toward radio astronomy satellites. Boeing is working with others in the industry to document the results of these studies and will submit them to the Commission (and to CORF) for consideration in this proceeding when they have been finalized.

XII. CONCLUSION

As the Commission recognizes, newly available technologies are enabling the use of mmW spectrum bands for very high data rate communications services. These technologies will be employed both by terrestrial and satellite-based communications systems to make new services available to consumers throughout the United States and the world. Only satellite-based systems have the ability to make mmW communications services available to all consumers regardless of their location, ensuring that the long-standing digital divide between

[68] *Further Notice*, ¶ 515.

rural and urban areas is permanently bridged. In furtherance of its statutory public interest obligation to bridge the digital-divide and ensure that spectrum resources are used to serve *all* Americans, the Commission should take the steps recommended by Boeing in these comments to make available sufficient spectrum in mmW frequencies for the operation of very high data rate, next-generation broadband satellite systems on a shared basis with other proposed spectrum uses.

Respectfully submitted,

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