omnispace

August 30, 2024

VIA ELECTRONIC FILING

Ira Keltz
Deputy Chief
Office of Engineering and Technology
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RE: May 17, 2024 Notice of Ex Parte Communication, GN Docket No. 23-65 and IB Docket No. 22-271; Call Sign WW9XPI, File Nos. 2479-EX-ST-2023, 0519-EX-ST-2024, 0661-EX-ST-2024

Dear Mr. Keltz:

Thank you for your correspondence dated June 27, 2024, requesting additional information regarding Omnispace, LLC's ("Omnispace") May 17, 2024 filing[1] in the above-referenced proceedings (the "May 17 Ex Parte") regarding the harmful interference that Space Exploration Holdings, LLC ("SpaceX") is causing to Omnispace's primary mobile-satellite service ("MSS") operations in the 1990-1995 MHz band. Please find below responses to your questions.

Question 1: *What is the noise floor in Omnispace's current service area?*

a. *How does that compare to the noise floor measured over Asia?*
b. *Is the noise floor higher in the service area than in the area in the U.S. where the measurements were performed?*

Response: Omnispace performed the noise floor measurements described in its May 17 Ex Parte while its Omni-F2 satellite ("F2") was over Asia in an area where it had line-of-sight visibility to the SpaceX low-earth orbit ("LEO") Starlink satellites passing over Washington state at an altitude of 355 kilometers, but where the Earth would block F2's view to the land mass of the United States over which T-Mobile has deployed terrestrial G block base stations. Therefore, the noise floor during the F2 measurements was lower than if F2 had been able to see the United States which includes thousands

[1] *See* Letter from Mindel De La Torre, Chief Regulatory and International Strategy Officer, Omnispace, LLC, to Marlene H. Dortch Secretary, FCC, GN Docket No. 23-65 and IB Docket No. 22-271; Call Sign WW9XPI, File Nos. 2479-EX-ST-2023, 0519-EX-ST-2024, 0661-EX-ST-2024 (May 17, 2024).

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of base stations transmitting in the G block frequencies. However, it is not only possible, but likely, for an Omnispace LEO satellite serving areas outside the U.S. to be similarly positioned with a view to Starlink satellites serving the U.S. and conducting secondary, nonconforming transmissions in the 1990-1995 MHz band, but not to the U.S. land mass. In those situations, the interference power from the Starlink satellites will be significantly stronger than the F2 measurements described in the May 17 Ex Parte because the Omnispace and SpaceX satellites will be considerably closer than F2 was to the experimental Starlink satellites (~17,000 kilometers).

For example, using simple math,[2] for an Omnispace satellite at 600 km altitude, Earth's horizon will be 2,830 km away. Assuming G block base station antennas are 30 meters high, this distance to the tip of the transmitting base station antennas will be a little farther at 2,850 km. Thus, the entire land mass of the continental U.S. will be over the horizon when an Omnispace satellite at 600 km altitude is over southern Colombia. This means that the noise from the terrestrial G block base stations will be blocked by the Earth, as it was for F2. However, that same Omnispace satellite will have a view to Starlink satellites orbiting at 355 km altitude at a distance of nearly 5,000 km. That means that the Omnispace satellite will have a line-of-sight view to nearly every Starlink satellite over the eastern United States – an area bounded by a line that is roughly from Portland, Maine to Chicago, Illinois to El Paso, Texas. In addition, any Starlink satellites serving customers in the U.S. from over much of the Atlantic, the Gulf of Mexico, or most of Mexico will also be visible. Each of these Starlink satellites will have at least 11 dB more interference power than measured by F2[3] and many could have 17 dB more interference power.[4]

Therefore, measurements described in the May 17 Ex Parte *understate* the unacceptable level of interference that SpaceX's secondary, nonconforming transmissions in the 1990-1995 MHz band will cause to Omnispace's primary operations in the band in Omnispace's service areas.

Question 2: *Does Omnispace view terrestrial mobile operations in the U.S. as a source of harmful interference and how do operational stations in that service affect its measurements?*

Response: Yes, while Omnispace views terrestrial mobile operations in the U.S. as a source of harmful interference to MSS operations in the 1990-1995 MHz band outside of the U.S., Starlink's proposed non-conforming use of the G block will substantially and materially worsen the interference conditions Omnispace faces outside of the U.S. The attached study prepared by RKF Engineering Solutions, LLC ("RKF Engineering") documents the increased harmful interference that Starlink's proposed non-conforming use will create.

Question 3: *What does Omnsipace's signal look like when Omnispace is carrying traffic, particularly over South America? Please provide spectrum analyzer plots, preferably with the same reference bandwidth as requested by the question below. What is your C/N ratio when you are carrying traffic (actual, average or*

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[2] The Pythagorean Theorem, assuming the Earth's radius is 6,378 km.

[3] F2 was 17,000 km from the Starlink satellites it measured which introduced 183 dB of path loss. The distance from the Omnispace satellite to the farthest Starlink satellite will be 5,000 km, or about 172 dB of path loss. Thus, the path loss in the LEO-to-LEO scenario will be about 11 dB less than the interference measured by F2.

[4] This assumes that the closest Starlink satellites serving points in the U.S. could be off the coast of Florida only 2,400 km from the Omnispace satellite, or about 166 dB of path loss. This is 17 dB less path loss than F2 and thus 17 dB more interference power.

typical expected received levels) and what is the measured noise floor during this scenario without the Starlink received noise floor increase, what is the measured C/N ratio of your traffic with that increase factored in?

Response: Neither Omnispace nor SpaceX has commenced commercial operations in the 1990-1995 MHz band. Omnispace intends to commence the first phase of its commercial operations in 2026. While SpaceX has been testing its LEO satellites in the 1990-1995 MHz under experimental authorization, SpaceX has not shared with Omnispace its testing transmission schedules and satellite locations.[5] Due to these factors, it is difficult for Omnispace to gather the measurements the Commission requests at this time.

Question 4: *The FCC would like to see measurements, including an active Omnispace signal, as SpaceX's satellites pass overhead where Omnispace is providing service, both with and without active SpaceX transmissions.*

a. *Please provide noise floor measurements over the same reference bandwidth as the interference measurements.*
b. *How does the overhead pass affect data rates?*
c. *Please include both clear sky and rain fade conditions.*

Response: Neither Omnispace nor SpaceX has commenced commercial operations in the 1990-1995 MHz band. Omnispace intends to commence the first phase of its commercial operations in 2026. While SpaceX has been testing its LEO satellites in the 1990-1995 MHz under experimental authorization, SpaceX has not shared with Omnispace its testing transmission schedules and satellite locations.[6] Due to these factors, it is difficult for Omnispace to gather the measurements the Commission requests at this time.

Question 5: *What are the inputs and assumptions used for the Monte Carlo analysis?*

Response: Sections 2.1 and 2.2 of the attached report by RKF Engineering describe the inputs and assumptions used for the Monte Carlo analysis.

Question 6: *What are the actual Omnispace antenna patterns (especially at relevant sidelobe angles) and the actual SpaceX antenna patterns used in the interference analyses and power calculations.*

Response: Section 2.1.2 of the attached report by RKF Engineering describes the antenna patterns used in the simulation for both the Omnispace and SpaceX non-geostationary orbit satellite antennas.

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[5] Omnispace was able to obtain the measurements described in its May 17 Ex Parte through F2 due to a chance encounter between F2 and the SpaceX satellite conducting testing activities in the 1990-1995 MHz band at the same time that the SpaceX satellite was transmitting.

[6] Omnispace was able to obtain the measurements described in its May 17 Ex Parte through F2 due to a chance encounter between F2 and the SpaceX satellite conducting testing activities in the 1990-1995 MHz band at the same time that the SpaceX satellite was transmitting.

Thank you for your attention to this matter. Please do not hesitate to reach out with any further questions.

Sincerely,

/s/__________
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Enclosures

Assessment of Interference to Authorized S Band Satellite Systems' Uplink Created by SpaceX's Non-conforming Use of the 1990-1995 MHz Band As Satellite Downlink

August 2024

Prepared by:

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Innovative Solutions for Satellite and Wireless Communications

Executive Summary

SpaceX and T-Mobile have launched numerous satellites and conducted tests which utilize the PCS G-block spectrum allocation – the 1910-1915 MHz/1990-1995 MHz block that is licensed by the Federal Communications Commission on a nationwide basis in the United States to T-Mobile for terrestrial use – as the basis for a space-based Direct-to-Device (D2D) or Supplemental Coverage from Space (SCS) service operating under 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE) standards.

However, such repurposing of the G-block terrestrial spectrum for satellite use does not conform to the International Telecommunication Union's global 2 GHz mobile-satellite service (MSS) allocations. SpaceX will operate MSS using the 1990-1995 MHz block as downlink, whereas the rest of the world operates MSS uplink in this and adjacent bands in accordance with the ITU Radio Regulations. The entire 1980-2010 MHz band is used as MSS uplink (i.e., Earth-to-space) in Regions 1 and 3, as well as in many Region 2 countries. While the 2000-2020 MHz band is allocated in the United States, Canada, and Mexico as MSS uplink, most Region 2 countries expand the MSS allocation to include 1990 to 2020 MHz as the MSS uplink.

This report analyzes the risk of interference from SpaceX's planned Starlink MSS downlink operations in the G-block (1990-1995 MHz) in U.S. territories to MSS worldwide uplink operations in the 1980-2010 MHz band. The analysis considered co-channel interference, adjacent channel interference, and overload to an exemplar non-geostationary orbit (NGSO) satellite constellation (victim) with a typical altitude of 600 kilometers. As shown in this study, beyond the 5 megahertz of G-block spectrum directly impacted by SpaceX's use of MSS uplink spectrum as their downlink, up to 30 megahertz of the victim satellite's uplink spectrum may be degraded as the result of Out of Band (OOB) interference from the Starlink constellation if the FCC relaxes the required OOB emissions limits specified in the SCS rules to those proposed by SpaceX.

This study provides a rigorous assessment of typical and worst-case performance degradation values from the growing Starlink NGSO constellation operations in U.S. regions, including the continental United States, Hawaii, Alaska, and Puerto Rico to the victim NGSO satellite constellation serving areas outside these U.S. regions.

The analysis is based upon a 2°-by-2° grid of victim satellite locations encompassing the globe. For each victim satellite location, an interference histogram is calculated for 500 victim satellite pointing directions. The histogram consists of the interference statistics from the Starlink satellites covering the U.S. territories over 1,000 random Starlink satellite constellation instances. The final grid of histograms is used to create contour maps for the median I/N and top 5% worst-case I/N values.

In the absence of satellite modeling details from SpaceX, a baseline analysis is conducted by modeling the Starlink satellite conservatively to give less interference. In addition, an alternate analysis is done for the co-channel interference assessment, where the Starlink satellite is modeled differently incorporating some of the design methodologies mentioned in SpaceX's original NGSO application.

As the study shows, without additional mitigation, even for the baseline analysis, the predicted in-band interference risk will be significant. With a co-channel aggregate I/N threshold of -6 dB, the interference from SpaceX's Starlink operations in the United States can impact NGSO operations as far away as South America, the United Kingdom, and Japan. The co-channel interference results worsen for the alternate modeling of the Starlink satellite.

As discussed in Section 3.2, SpaceX has been proposing progressively looser out-of-band emissions (OOBE) limits to the FCC. The recent SpaceX relaxation attempts described in Section 3.2.4 significantly increase interference risk. In addition to co-channel operations in the 1990-1995 MHz band, there can also be significant interference into the adjacent 1980-1995 MHz and 1995-2010 MHz bands. As such, Starlink operations could impact the entire 30 megahertz of the victim's satellite uplink spectrum.

The risk of overloading the victim satellites was found to be small.

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1. Introduction

SpaceX and T-Mobile have embarked on a plan to utilize the PCS G-block spectrum allocation – the 1910-1915 MHz/1990-1995 MHz block that is licensed on a nationwide basis in the United States to T-Mobile for terrestrial use by the FCC – as the basis for a space-based Direct-to-Device (D2D) or Supplemental Coverage from Space (SCS) service operating under 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE) standards.[1]

However, the requested G-block spectrum assignment for SCS does not conform to the ITU's global 2 GHz MSS allocations. The entire 1980-2010 MHz band is used as MSS uplink (i.e., Earth-to-space) in Regions 1 and 3, as well as in many Region 2 countries. While the 2000-2020 MHz band is allocated in the United States, Canada, and Mexico as MSS uplink, most Region 2 countries expand the MSS allocation to include 1990 to 2020 MHz as the MSS uplink.

This inverse operation proposed by SpaceX/T-Mobile – i.e., operating high-power MSS downlink (space-to-Earth) in the band used for MSS uplink – creates a new, unforeseen and previously unanalyzed interference for the MSS operators: satellite-to-satellite interference. Historically, for the ITU-compliant L-band and S-band MSS satellite operators, the only coordination for sharing spectrum between satellite operators was interfering user terminal (UT) to a victim satellite and interfering satellite to victim UT.

This new and unproven SpaceX/T-Mobile proposal adds a SpaceX interfering satellite to victim satellite scenario by creating a situation where the extremely high-power SpaceX Starlink satellites (58 dBW EIRP as per their ITU filings)[2] must be considered as an interferer to a victim satellite at significant distance from Starlink's U.S. operations. This new consideration must be analyzed because antenna sidelobes from the interfering Starlink direct radiating array (DRA) will have only Free Space Loss to attenuate before impacting the victim satellite's DRA antenna.

This report studies the interference scenarios created by this unconventional spectrum use.

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[1] Space Exploration Holdings, LLC Application Accepted For Filing, Public Notice, DA 23-338 (Apr. 18, 2023); ICFS File No. SAT-MOD-20230207-00021.

[2] SpaceX has two German filings that deal with the 2 GHz band: the MARS-VLS filing uses the 1980-2010 MHz band consistent with ITU MSS allocations and directionality. However, SpaceX's second German filing, the MARS-ULS API identifies the 1990-1995 MHz band as downlink spectrum as requested in the SpaceX G-Block Modification Application. These two filings have been mirrored in U.S. filings at the ITU under the names USASAT-NGSO-MLVS and USASAT-NGSO-MULS.

1.1 Approach

This case study aims to capture typical and worst-case performance degradation values from proposed Starlink NGSO constellation operations to an exemplar victim NGSO constellation (victim) serving areas outside the U.S. regions of the continental United States, Hawaii, Alaska, and Puerto Rico (CONUS, HI, AK, PR). For a given victim satellite location, the aggregate interference from all visible Starlink satellite interferers is calculated. A histogram of I/N values is collected across random Starlink satellite position instances, Starlink beam pointing assignments, and victim satellite pointing directions.

The Monte Carlo simulation assumes that the Starlink constellation serves fixed beam locations on the ground uniformly covering U.S. regions (CONUS, HI, AK, PR). Two different beam diameters on the ground are assumed: 20 km and 40 km. The Monte Carlo simulation is run with 1,000 sets of Starlink satellite positions calculated from its orbital parameters for random time instances within a 10-year span. Beam centers on the ground are served by the highest elevation angle Starlink satellite in view as long as that satellite (already serving other beams) has available transmit power to serve the additional beam and as long as the elevation angle is above 30 degrees (see Section 2.1.2).

In the absence of SpaceX describing exactly how their satellite parameters are adjusted to maintain a constant power flux-density (PFD) on the ground, RKF uses two methodologies to model the Starlink satellite: one in which the satellite transmit power per beam is held constant (a.k.a. *baseline* method), and another which is based on a description in SpaceX's original NGSO application[3] in which both satellite transmit power and antenna gain are adjusted (a.k.a. *alternate* method). The *baseline* method assumes that SpaceX has fine control of the beamforming and adjusts only the gain to maintain a constant PFD on the ground. The *alternate* method assumes that SpaceX varies the beam gain in steps and then adjusts the power to maintain a constant PFD on the ground.

SpaceX's Schedule S Technical Report (Starlink Schedule S)[4] has four beam gains for the Starlink satellite beams. In the *alternate* method, the satellite would adjust the gain in steps as a function of satellite nadir off-pointing to just compensate for the higher path loss. In between the gain steps, the satellite transmit power is adjusted to maintain a constant PFD on the ground.

Since the *baseline* method uses a continuous gain as a function of nadir off-pointing, it varies the beam shape to maintain approximately a constant beam illumination area on the ground. This results in constant transmit power in each beam to maintain the same PFD on the ground. On the other hand, in the *alternate* method, where the gain is varied in a limited number of discrete steps per Starlink Schedule S, higher transmit power would be needed in between the gain steps to maintain the same PFD on the ground. As such, the *baseline* method would result in less interference compared to the *alternate* method; and

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[3] *See Application of Space Exploration Holdings, LLC for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System*, ICFS File No. SAT-LOA-20161115-00118, Attachment A Technical Information to Supplement Schedule S at 7 (filed Nov. 15, 2016).

[4] *See* Application for Modification of Authorization for the SpaceX Gen2 NGSO Satellite System to Add a Direct-to-Cellular System, Schedule S at 5 and 6, ICFS File No. SAT-MOD-20230207-00021 (Feb. 7, 2023); ULS File Nos. 0010303032, 0010303084, 0010303124, and 0010303146.

regardless of what SpaceX is actually doing, since they are adjusting transmit power in some way,[5] the *alternate* method demonstrates that the interference results will be worse compared to the *baseline* method, regardless of the exact parameters SpaceX is adjusting and how they are adjusting them.

The notional victim satellite constellation has an altitude of 600 km, as per 3GPP Rel 17[6] Set 1 LEO considerations. A 2°-by-2° grid of victim satellite locations is defined encompassing the globe. For each time instance, each victim satellite in the grid is simulated with 500 random antenna pointing directions where the minimum elevation angle to the satellite is equal to or greater than 30 degrees.

For each victim satellite location, an interference histogram is calculated. The histogram consists of the interference statistics from the Starlink satellites covering the U.S. territories over 1,000 random Starlink satellite constellation instances and 500 victim satellite pointing directions for each of the Starlink satellite constellation instances. The final grid of histograms is used to create contour maps for the median I/N and top 5% worst-case I/N values.

2. Study Assumptions

This section provides the details on the Starlink and victim satellite parameters and models used. It also provides the interference protection criteria used.

Details on the operation of the Starlink constellation are sparse. As such, reasonable operating assumptions were made where details were not available.

2.1 Starlink Satellite Deployment

2.1.1 Starlink Satellite Constellation

Starlink is planning a constellation to provide direct-to-device (D2D) communications. Table 1 shows the orbital parameters for the planned constellation from SpaceX's November 14 filing at the FCC.[7] The inclination angles were adopted from Starlink Schedule S. Orbital Planes 1 and 2 are each modeled having 28 planes of 120 satellites each. However, Plane 3 is irregular, having 24 planes with 28 satellites and 4 planes with 27 satellites. To simplify the simulations, Plane 3 was modeled assuming 28 planes with 28 satellites. The extra 4 satellites that were added have an insignificant impact on the results.

[5] Letter from Jameson Dempsey to Marlene H. Dortch, GN Docket No. 23-135 and ICFS File No. SAT-MOD-20230207-00021 (Nov. 14, 2023) at A-1: "As the satellite steers the transmitting beam, *it adjusts the transmit power* to maintain a constant power flux-density ("PFD") at the surface of the Earth, compensating for variations in antenna gain and path loss associated with the steering angle." (Emphasis added.)

[6] https://www.3gpp.org/ftp/Specs/archive/36_series/36.763/36763-h00.zip, Table 6.2-4.

[7] Letter from Jameson Dempsey to Marlene H. Dortch, GN Docket No. 23-135 and ICFS File No. SAT-MOD-20230207-00021 (Nov. 14, 2023) at A-7.

Table 1: Starlink satellite constellation orbital parameters

	Orbital Plane 1	Orbital Plane 2	Orbital Plane 3	
Total number of Satellites	3360	3360	780	
Altitude (km)	525	530	535	
Number of Planes	28	28	24	4
Number of Satellites per Plane	120	120	28	27
Inclination (deg)	53	43	33	

2.1.2 Starlink Satellite Beams

Based upon SpaceX's representations to the FCC, the full constellation of Starlink D2D satellites will maintain a PFD on the ground of -89 dBW/m^2/MHz. As mentioned in Section 1.1, the Starlink satellite is modeled in two ways to maintain this PFD level on the ground. In the *baseline* method, the satellite transmit power is held constant and the antenna gain is varied, while in the *alternate* method, both the satellite transmit power and antenna gain are varied. This section provides more details on these two methodologies.

Baseline Method

For the *baseline* method, assuming a PFD of -89 dBW/m^2/MHz, Table 2 shows the derivation of the beam transmit power for a Starlink beam pointed toward a minimum elevation angle of 30 degrees and with a maximum peak beam gain of 38 dBi.

Table 2: Starlink Satellite power per beam calculation (baseline method)

	Values
Satellite max EIRP (dBW)	58[8]
Satellite antenna peak gain (dBi)	38[9]
Satellite total transmit power over all beams (dBW)	20 (=58-38)
Max PFD on the ground (dBW/m^2/MHz) over each beam	-89
Spreading Loss (m^2)[10]	130.6
Satellite EIRP per beam (dBW/MHz)	41.6 (= -89+130.6)
Satellite transmit power per beam (dBW/MHz)	3.6 (=41.6-38)

The Starlink satellite radio frequency transmitted power is calculated from the maximum EIRP (58 dBW) and antenna peak gain of 38 dBi. This means that the satellite transmitter power over all beams is 20 dBW as shown in Table 2. The beam at an elevation angle of 30 degrees in Table 2 can transmit at 3.6 dBW/MHz to meet the -89 dBW/m^2/MHz PFD limit on the ground.

For the simulations, each Starlink satellite is assumed to keep beam power constant for all elevation angles greater than or equal to 30 degrees. In order for this to work, it is assumed that each Starlink satellite would turn off antenna elements for elevation angles greater than 30 degrees, reducing the gain while keeping the PFD on the ground and beam power from the satellite constant. If each beam requires 3.6 dBW (as in Table 2), then each satellite can support up to 43 simultaneous beams.

Alternate Method

In the *alternate* method, adopting a methodology similar to SpaceX's original NGSO application, the range of possible off-nadir pointing angles is split into four regions corresponding to the four beam gains in Starlink Schedule S (29, 32, 35, and 38 dBi). Given that the design in SpaceX's original NGSO application corresponded to a different frequency and satellite constellation, a conservative methodology that yields less interference is adopted while incorporating SpaceX's design features in that filing. For instance, the highest gain of 38 dBi is assumed to be at the edge of coverage (at minimum elevation angle 30 degrees) to reduce the interference to other SpaceX beams and other systems.

For each off-nadir pointing region, the number of antenna elements is kept constant, while the transmit power is adjusted to compensate for changes in slant range and scan loss. Within each off-nadir pointing region, the number of antenna elements is chosen to match one of the four beams with maximum gains of

[8] *See* SpaceX Schedule S at 17 and 20.

[9] *See* SpaceX Schedule S at 17 and 20.

[10] Spreading loss assumes 30 degrees elevation angle from ground to the Starlink satellite at 525 km or 530 km altitude. The spreading loss is 130.7 m^2 for a Starlink satellite at 535 km altitude.

29, 32, 35, and 38 dBi as given by the Starlink Schedule S. The off-nadir pointing angles thresholds for adding antenna elements are chosen to create equal jumps in gain for every transition. Figure 1 shows the resulting antenna gain values (including the scan loss) as a function of a Starlink satellite off-nadir pointing angle from 0 degrees (nadir) to 53 degrees off-nadir (corresponding to 30 degrees elevation angle from the ground).

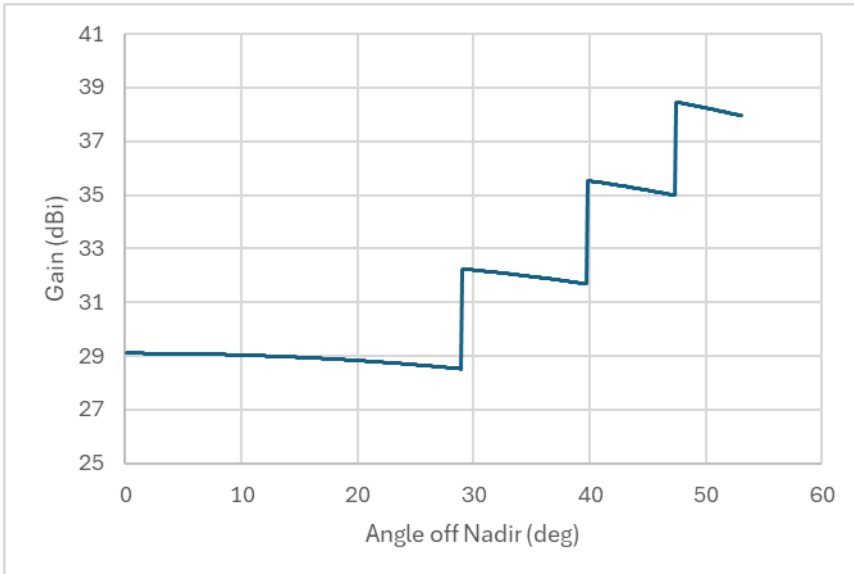

Figure 1 – Starlink satellite antenna gain adjustment as a function of off-nadir pointing angle (alternate method)

To maintain a PFD of -89 dBW/m^2/MHz on the ground, as shown in Figure 2, the transmit power used for the beam is adjusted based on the off-nadir pointing angle and the antenna gain values in Figure 1.

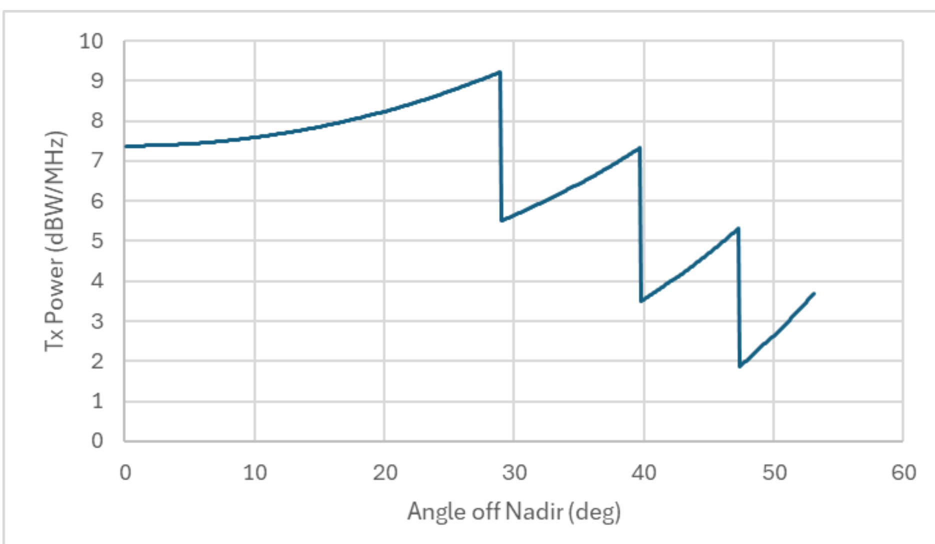

Figure 2 – Starlink satellite transmit power per beam as a function of off-nadir pointing angle (alternate method)

Since the maximum EIRP and antenna peak gain are the same as the baseline case, the Starlink satellite total transmit power over all beams is limited to 20 dBW (as in the baseline method). Since each beam's transmit power may be different, the total number of simultaneous transmitting beams may vary from satellite to satellite but the aggregate power over all beams will be at most 20 dBW.

For both (baseline and alternate) analyses, it is further assumed that Starlink service areas on the ground are fixed. Two different service area laydowns over U.S. regions were assumed in the study. In the first, beam diameters on the ground were 40 km and in the second they were 20 km.

With 40 km diameter beams, adjacent satellite beam antenna patterns will overlap 4 to 5 dB down from the peak gain. This should be sufficient isolation to support 3 frequency reuse, with each beam having a 1.4 megahertz channel using a range of modulation and codepoints associated with D2D operation.

A higher system capacity can be achieved with 20 km diameter beams. However, adjacent beam gains would overlap only about 1 dB down from peak. In this case, a higher frequency reuse would be required for a uniform laydown. The Starlink Schedule S describes eight 1.4 megahertz channel centers within the 5 megahertz available bandwidth (1990 to 1995 MHz). There is also a 5 megahertz channel bandwidth. Starlink could operate a pseudo frequency reuse across the overlapping 1.4 megahertz channels or over a single 5 megahertz channel. In the pseudo frequency reuse scheme, adjacent beams would be assigned different non-overlapping 180 kHz physical resource blocks (PRBs). In a 5 megahertz channel, for example, each beam could be assigned 3 or 4 PRBs for a 7-frequency reuse or 2 PRBs per beam for a 12-frequency reuse. Figure 3 shows an example of a 7-frequency reuse.

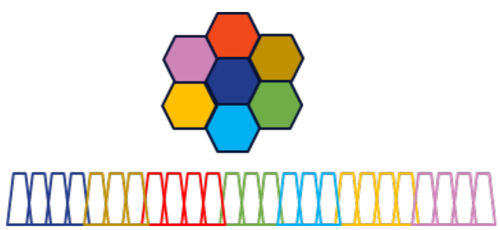

Figure 3 – Example of a seven frequency reuse pattern with a 5 megahertz channel (25 PRBs)

The Starlink satellite DRA is modeled using Recommendation ITU-R S.1528-0 *recommends 1.3* following the example in Annex 1. Note that for off-axis angles not covered by *recommends 1.3, recommends 1.2* is used. Although this recommendation was developed for fixed satellite service, there is no reason to think that mobile satellite antennas would be any different. The ideal far sidelobe level L_F of 0 dBi is assumed, and the near sidelobe level L_N (in *recommends 1.2*) is -20 dB relative to the peak value as recommended by Recommendation ITU-R M.1184-3 Table 4B. A circularly symmetric beam is assumed (i.e., assuming z = 1 in *recommends 1.2*). Finally, the one-half the 3-dB beamwidth (d_B.) is set per *recommends 1.2*, in the absence of this information from SpaceX.

In their February 13 filing at the FCC,[11] SpaceX stated that "out-of-band emissions toward the back of the satellite are 20 dB below peak." However, using S.1528 antenna pattern results in more than 30 dB attenuation at 90° from nadir (instead of 20 dB per SpaceX). As such, using S.1528-0 to model a Starlink satellite's antenna pattern would underestimate the interference levels from Starlink satellites.

2.2 Victim Satellite Deployment

An exemplary victim satellite constellation was assumed for this study. The parameters were selected for low Earth orbit (LEO) operating characteristics as required to support 3GPP Non-Terrestrial-Network (NTN) New Radio (NR) service. This analysis can also easily be expanded to consider other victim constellations in the future.

The notional victim satellite constellation has an altitude of 600 km, as per 3GPP Rel 17[12] Set 1 LEO considerations. The victim satellite DRA's diameter is 3 m, with a peak gain per beam of 36 dBi. The victim satellite receiver system noise temperature is assumed to be 550 K. A 2°-by-2° grid of victim satellite locations is defined encompassing the globe.

Consistent with the Starlink assumptions, the victim satellite DRA receive antenna is modeled using Recommendation ITU-R S.1528-0 *recommends 1.3*. The far sidelobe level of 0 dBi is assumed, and the near sidelobe level L_N is -20 dB relative to the peak value as recommended by Recommendation ITU-R M.1184-3 Table 4B. A circularly symmetric beam is assumed.

For the victim satellite downlink PFD calculation, to ensure the coordination limits are met for the victim satellite pointing directions analyzed, the victim satellite is assumed to operate with 10 dBW transmit power per beam and 36 dBi peak gain over a 5 megahertz channel (4.5 megahertz occupied bandwidth). This results in an EIRP level that is 2 dB lower than the Starlink maximum EIRP density at 30 degrees elevation angle. The transmit antenna is modeled similar to the receive antenna per the previous paragraph.

2.3 Interference Protection Criteria

This analysis considers victim satellite co-channel and adjacent channel interference as well as overload effects.

Per Recommendation ITU-R M.1184-3, sharing criteria between mobile satellite systems are still under study. A conservative I/N threshold of -6 dB is used for co-channel sharing in this study. This criterion was adopted based on criteria used for other similar sharing scenarios as described below:

[11] Letter from David Goldman to Marlene H. Dortch, GN Docket Nos. 23-65, 23-135, ICFS File No. SAT-MOD-20230207-00021, and ULS File Nos. 0010303032, 0010303084, 0010303124, and 0010303146 (Feb. 13, 2024) at page 1 of Attachment A.
[12] https://www.3gpp.org/ftp/Specs/archive/36_series/36.763/36763-h00.zip, Table 6.2-4.

- Recommendation ITU-R S.1432 describes criteria for sharing between Fixed-Satellite Service (FSS) systems. The protection criterion of I/N = -10 dB is used when the victim system is practicing frequency re-use and -6 dB is used for victim systems not practicing frequency reuse.
- Recommendation ITU-R M.1086 for sharing between geostationary Earth orbit MSS to MSS uses a protection criterion of I/N = -12.2 dB.
- Resolution 679 (WRC-23) (h) specifies criteria for evaluation of time varying interference into NGSO satellite systems operating at Ka-band as follows: "there are no protection criteria for evaluation of time-varying interference into non-GSO satellite systems established in ITU-R; therefore, the following protection criteria were used as a basis for sharing studies involving links between two non-GSO space stations and interfered-with non-GSO FSS systems: I/N of 0 dB not to be exceeded more than 0.02% of the time, -6 dB no more than 0.6% of the time and -10.5 dB no more than 20% of the time."

Note that from the above references, the highest long-term interference threshold is I/N = -6 dB.

For the adjacent channel interference, the protection criterion of I/N = -20 dB was adopted from Recommendation ITU-R S.1432 assuming that all non-coprimary sources of interference come from MSS operation in adjacent channels which makes the use of this protection criterion a conservative assumption.

Finally, for the overload of the victim satellite receiver, per Recommendation ITU-R M.1461-2 (section 2.1.1), an overload threshold level of -55 dBm corresponding to a 1 dB compression point at +10 dBm and low-noise amplifier gain of 65 dB is assumed. These values and the estimated overload threshold level are reasonably conservative.

3. Sharing Results & Conclusions

3.1 Co-channel Interference

A Monte Carlo simulation was run with 1,000 independent random time instances. For each time instance, the Starlink satellite positions are calculated according to their orbital parameters. Beams uniformly covering the U.S. regions (CONUS, HI, AK, PR) are served by the Starlink satellites that have the highest elevation angle to the service area as long as the minimum elevation angle is greater than 30 degrees and the satellite has available power (i.e., it is serving less than 43 beams in the baseline case).

Each victim satellite, in the 2°-by-2° grid of satellites encompassing the globe, is assigned 500 random pointing directions, uniformly over the satellite field of view where the minimum elevation angle is 30 degrees. Victim pointing directions that exceed an international border PFD limit of -108.8 dBW/m^2/MHz[13] towards U.S. territories plus 12 miles off-shore are excluded from the analysis.

[13] Coordination threshold per WRC-19 for satellite downlink transmissions in 2170-2200 MHz band to IMT UEs, *see* ITU Resolution 212 (Rev. WRC-19) Annex.

For each victim satellite location and pointing direction, the aggregate interference from all Starlink satellites to the victim satellite is calculated. Interference paths that include earth blockage are ignored in the aggregate interference calculation. Their contribution is considered to be negligible.

The aggregate interference-to-noise $\left(\frac{I}{N}\right)_{K,R}$ to a victim satellite, K, with a random pointing direction, R, is given by Equation (1).

$$\left(\frac{I}{N}\right)_{K,R} = \sum_{M} \sum_{b=1}^{\leq 43} 10^{(I_{M,b}/10)} - N \quad \text{(dBW/MHz)} \qquad (1)$$

where,

- $I_{M,B}$ is the interference from the M[th] Starlink satellite transmitting in beam b as calculated in Equation (2)
- N is the victim satellite receiver noise power density, k T B (= -141.195 dBW/MHz)
    - k is boltzman's constant
    - T is the satellite receiver system temperature = 550 K
    - B is bandwidth = 1 MHz

$$I_{M,b} = P_{M,b} - P_r + G_{tx}(M,b) - FSPL + G_{rx}(K,R) \quad \text{(dBW/MHz)} \qquad (2)$$

where:

- $P_{M,b}$ is the transmit power density in Starlink satellite beam b of the M[th] Starlink satellite (dBW/MHz)
- P_r = 10*log10(3), is the power reduction assuming a Starlink satellite employing three frequency reuse, as only 1/3[rd] of the frequencies are co-frequency (dB)
- $G_{tx}(M,b)$ is the off-axis gain in the direction of the victim satellite per S.1528 from transmit beam b of the M[th] Starlink satellite (dBi)
- $G_{rx}(K,R)$ is the off-axis receive gain of the K[th] victim satellite with random pointing direction R in the direction of the Starlink interfering satellite per S.1528 (dBi)
- $FSPL$ is free space path loss using a center frequency of 1992.5 MHz (dB)

For each victim satellite location, $\left(\frac{I}{N}\right)_{K,R}$ histograms are calculated. The histograms consist of the interference statistics from the Starlink satellites covering the U.S. territories over the 1,000 Starlink satellite constellation instances and 500 victim satellite pointing directions. From these histograms, the median and top 5% worst-case (i.e., highest) values are extracted. For the *baseline* analysis, Figure 4 and Figure 5 show heatmaps of the median and 5% worst-case aggregate I/N for a Starlink service area diameter of 40 km. Figure 6 and Figure 7 show median and 5% worst-case aggregate I/N results for a Starlink service area diameter of 20 km.

In these figures, the border between the yellow and the green color is where the aggregate I/N is -6 dB (the co-channel interference protection criterion per Section 2.3). As indicated, the area of unacceptable interference (orange to dark burgundy grids) can extend down into South America and Iceland in the best-case scenario (40 km-diameter beams, median case), as well as the United Kingdom and Japan in the case of 20 km-diameter beams.

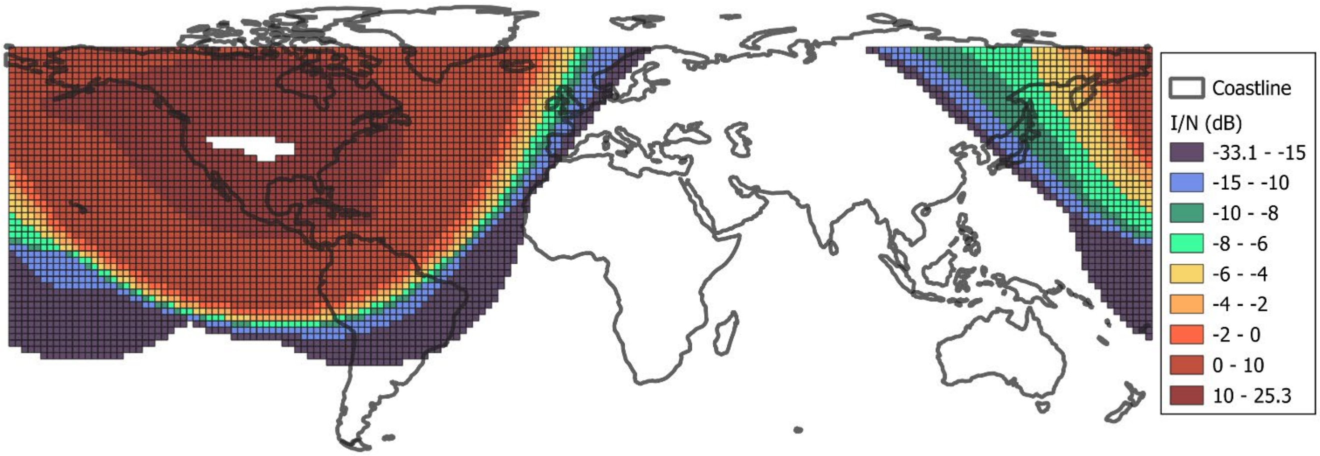

*Figure 4 – **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (baseline)*

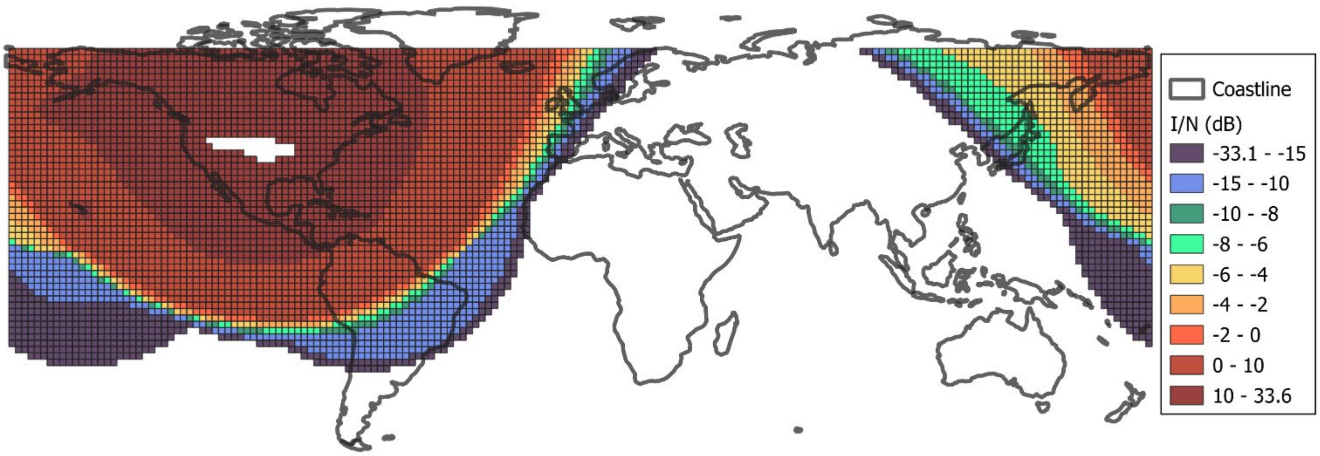

*Figure 5 – **40 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (baseline)*

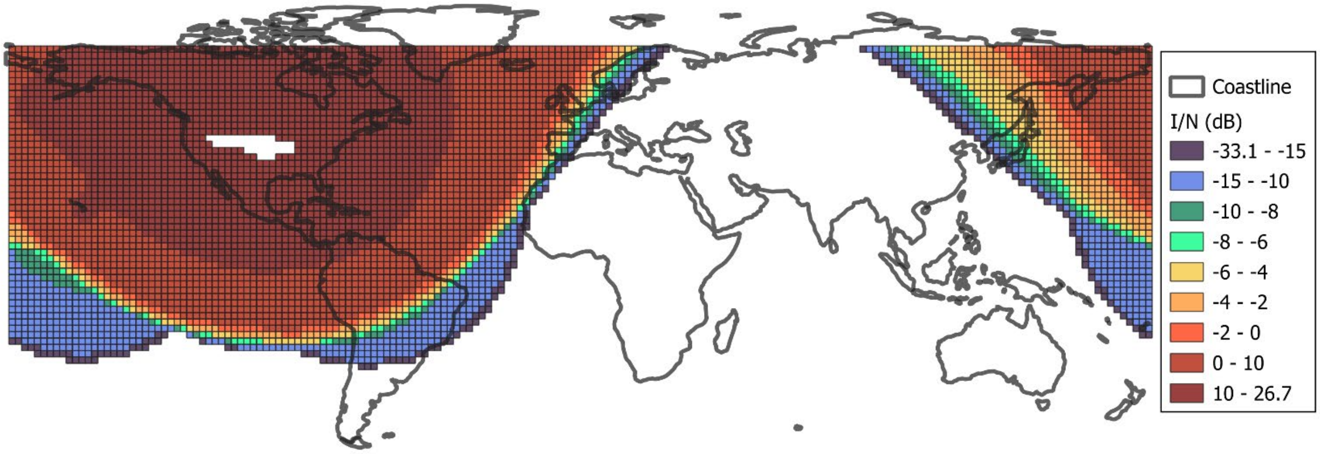

*Figure 6 – **20 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (baseline)*

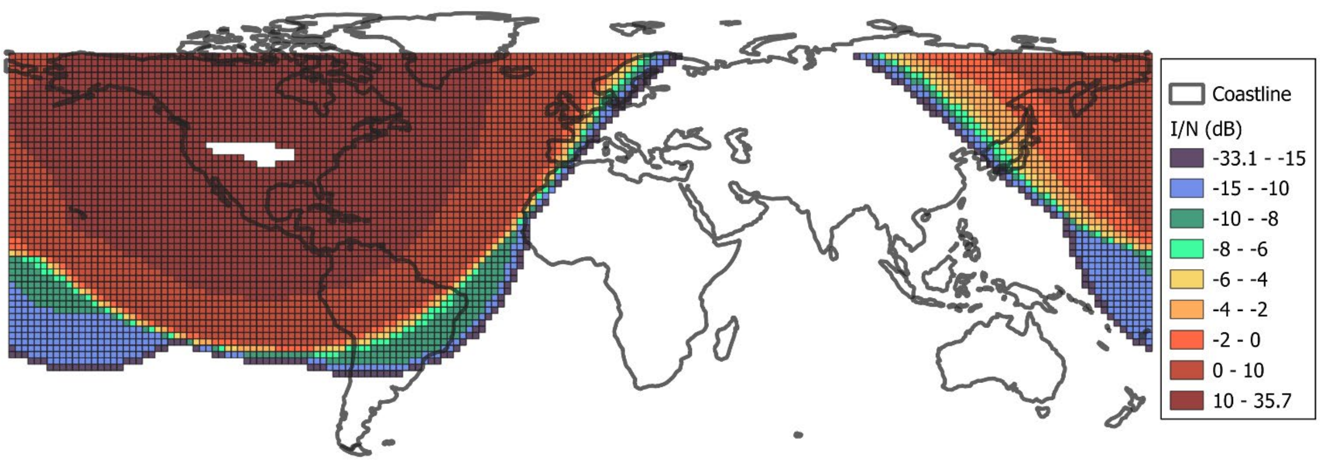

*Figure 7 – **20 km Beam Diameter: 5% worst-case** I/N at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (baseline)*

Next, Figure 8 to Figure 11 below show the results using the *alternate* modeling of the Starlink satellite. The results show that the alternate method results in higher interference levels (in exceedance of -6 dB I/N) and over larger regions. Notably, some of the '-6 dB I/N exceedance' regions that are added with the alternate method (from the baseline) are marked with a red arrow in these figures.

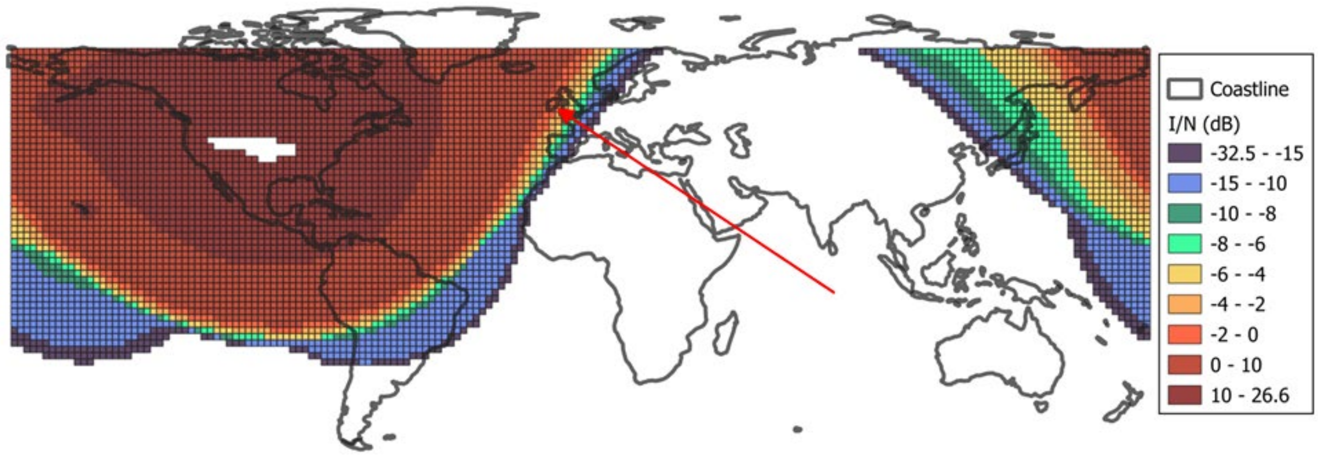

*Figure 8 – **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (alternate)*

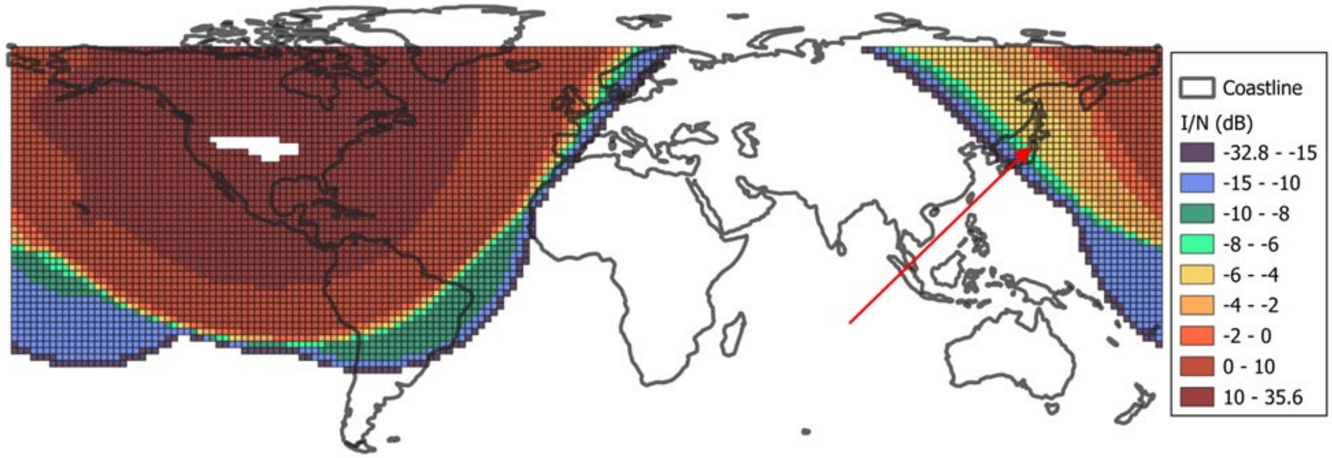

*Figure 9 – **40 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (alternate)*

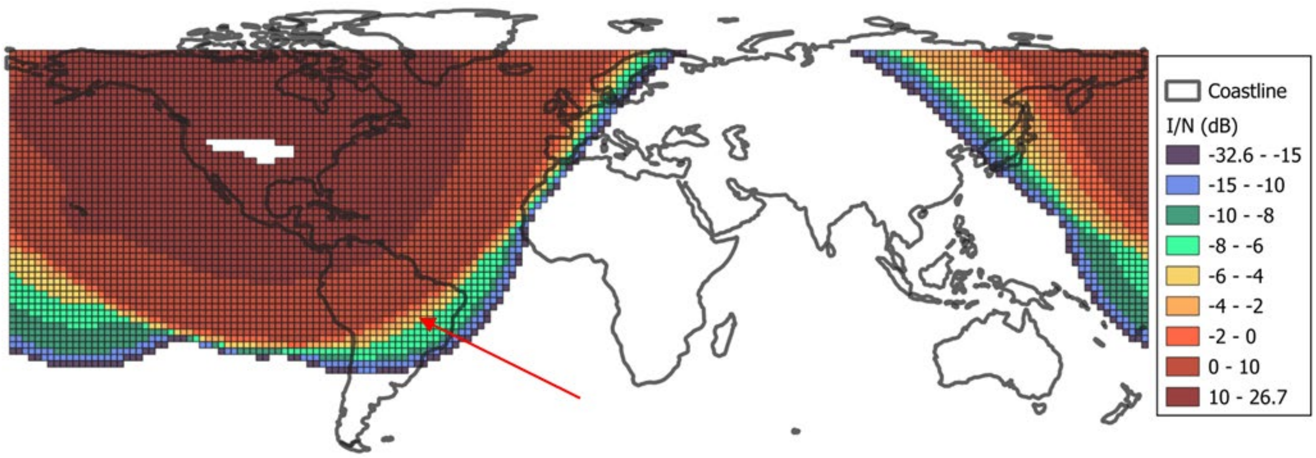

*Figure 10 – **20 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (alternate)*

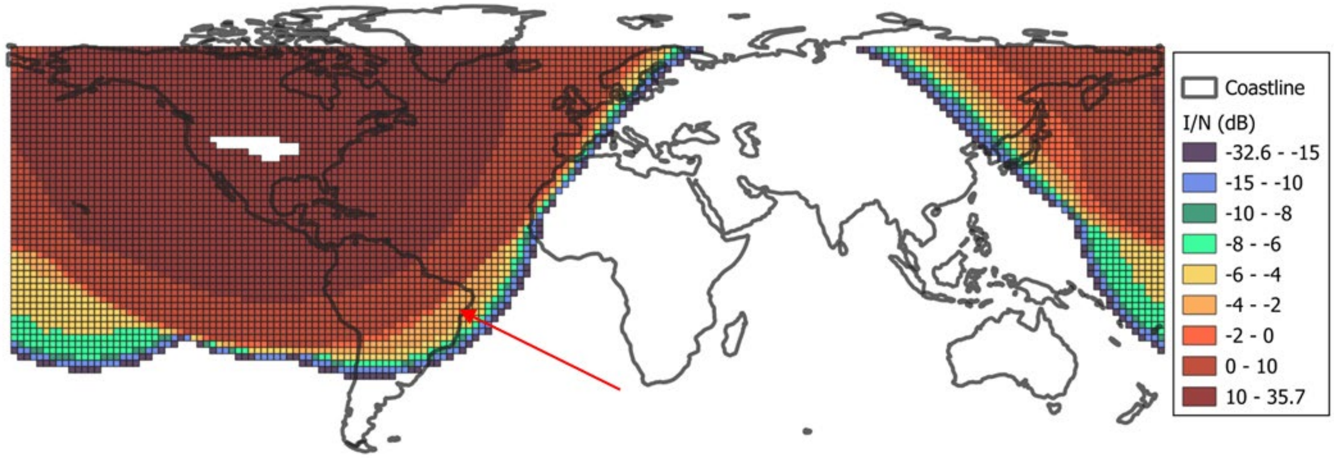

*Figure 11 – **20 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' transmissions over the victim satellite channel (1990-1995 MHz) (alternate)*

3.2 Adjacent Channel Interference

The victim satellite has an MSS uplink allocation from 1980 to 2010 MHz in most regions. In this section, the interference from Starlink satellite OOBE to the victim satellite's adjacent channels outside of 1990-1995 MHz is analyzed using the baseline method in modeling the Starlink satellite from Section 2.1.2. Given that the alternate method results in more co-channel interference, the adjacent channel interference will be as bad or worse than the baseline.

Since February 2023, SpaceX has claimed that they can meet various OOBE limits in various formats. In the following subsections, the Starlink satellite's out of band performance was modeled according to those limits to assess the resulting adjacent channel interference.

3.2.1 FCC 47 CFR § 24.238 OOBE Limit

In SpaceX's February 2023 filing at the FCC,[14] SpaceX claimed they could meet the FCC 47 CFR § 24.238 OOBE limit for broadband PCS equipment below:

> "The power of any emission outside of the authorized operating frequency ranges must be attenuated below the transmitting power (P) by a factor of at least 43 + 10 log(P) dB."

Assuming a 5 megahertz victim satellite channel and Starlink satellite with maximum total power of 20 dBW, the required OOBE attenuation would be 63 dB (=43+20).

The aggregate adjacent-channel interference power for a given victim satellite can be found by applying this attenuation level to the co-channel interference results. It is assumed that the OOBE levels are dominated by Starlink's 1.4 megahertz channel closest to the band edge. The adjacent channel interference results are shown in Figure 12 and Figure 13 below for the 40 km beam diameter median I/N (lowest

[14] *See* SpaceX Schedule S, Attachment A at 11.

interference scenario) and the 20 km beam diameter worst 5% I/N (highest interference scenario), respectively. The figures indicate that with the FCC 47 CFR § 24.238 OOBE limit, no harmful interference (I/N ≥ -20 dB) occurs.

Note that the dark purple color shows the area of the globe where there is a noise floor rise due to OOBE visible to the victim, however the level is well below the level of interference considered to be harmful. The clear areas show where there is no interference due to earth blockage or where the victim cannot operate without exceeding the international border PFD limit of -108.8 dBW/m2/MHz towards U.S. territories plus 12 miles off-shore.

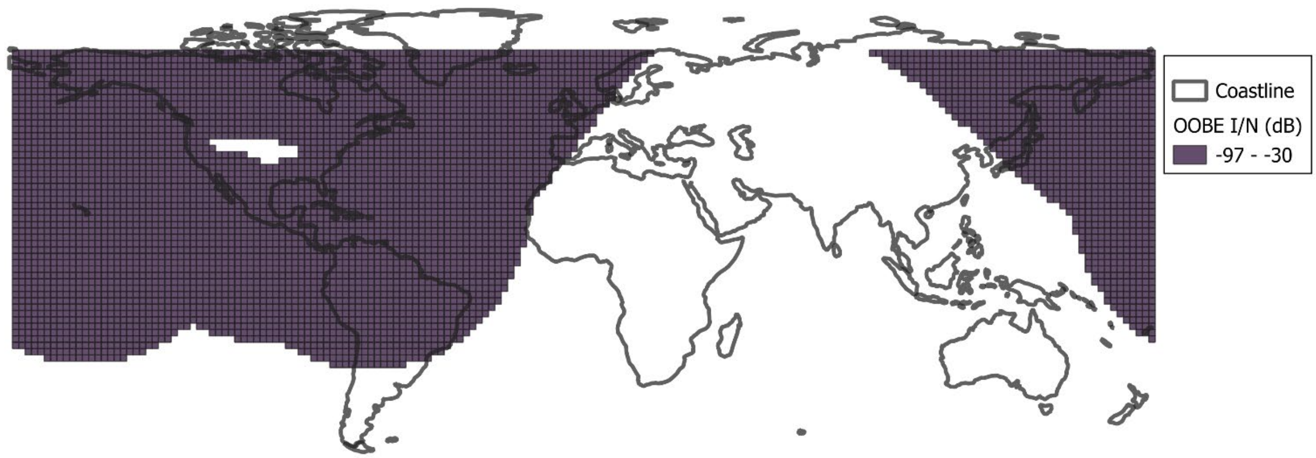

*Figure 12 – **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using the **43+10log(P) limit** (baseline)*

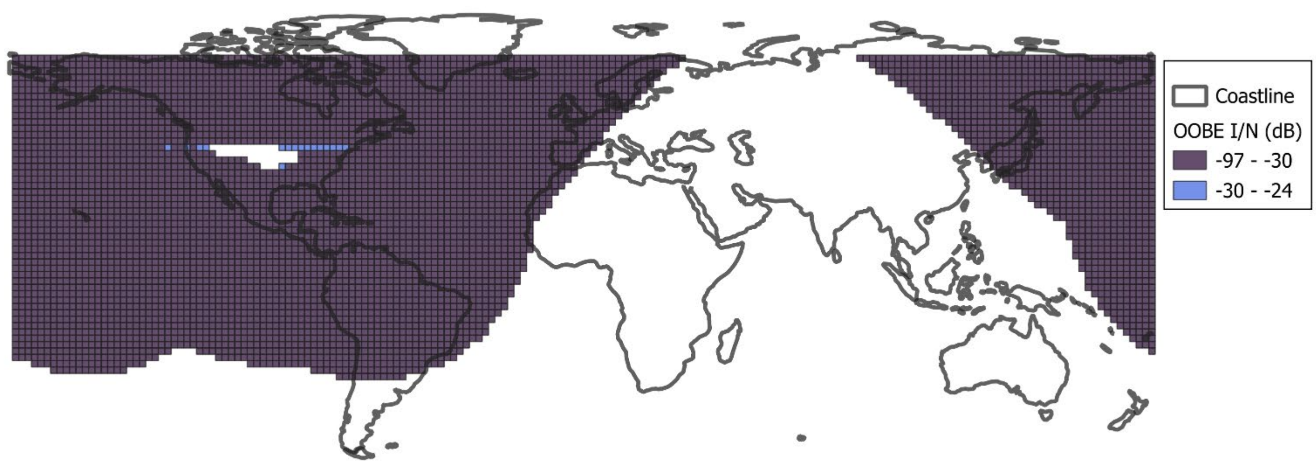

*Figure 13 – **20 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using the **43+10log(P) limit** (baseline)*

3.2.2 OOBE Limits per February 13, 2024 Filing

In SpaceX's February 13, 2024 filing at the FCC,[15] SpaceX's max OOBE EIRP density chart, shown below in Figure 14, shows an OOB EIRP level of 4.4 dBW/MHz (= -55.6 dBW/Hz + 10*log10(10^6)) in the nearest adjacent channels. Assuming that the Starlink satellite peak in-band EIRP of 58 dBW is split over three channels, the EIRP per channel is 53.2 dBW/MHz. This results in an OOB attenuation level of **48.8 dB** over 1985-1990 MHz and 1995-2000 MHz.

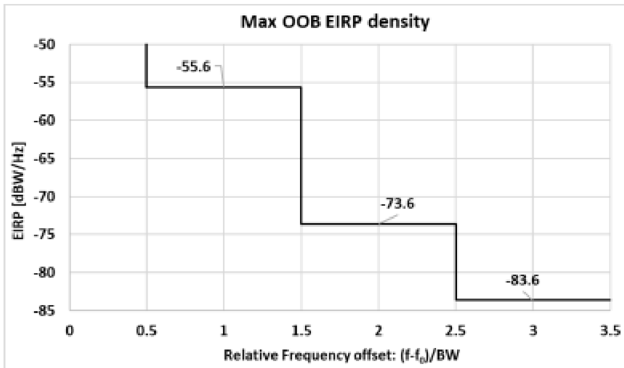

Figure 14 – SpaceX's OOBE mask (Feb. 13, 2024 filing)

The adjacent channel interference results over 1985-1990 MHz/1995-2000 MHz are shown in Figure 15 and Figure 16 below for the 40 km beam diameter median I/N (lowest interference scenario) and the 20 km beam diameter worst 5% I/N (highest interference scenario), respectively.

In these figures, the border between the yellow and the green color is where the aggregate I/N is -20 dB (the adjacent channel interference protection criterion per Section 2.3). The figures indicate that with the OOB attenuation level of 48.8 dB, no harmful interference (I/N ≥ -20 dB) occurs for the 40 km beam diameter median I/N scenario. However, for the 20 km beam diameter 5% I/N scenario, the interference limit is not met in parts of Canada and Mexico over 1985-1990 MHz/1995-2000 MHz.

[15] Letter from David Goldman to Marlene H. Dortch (Feb. 13, 2024), Attachment A at 1

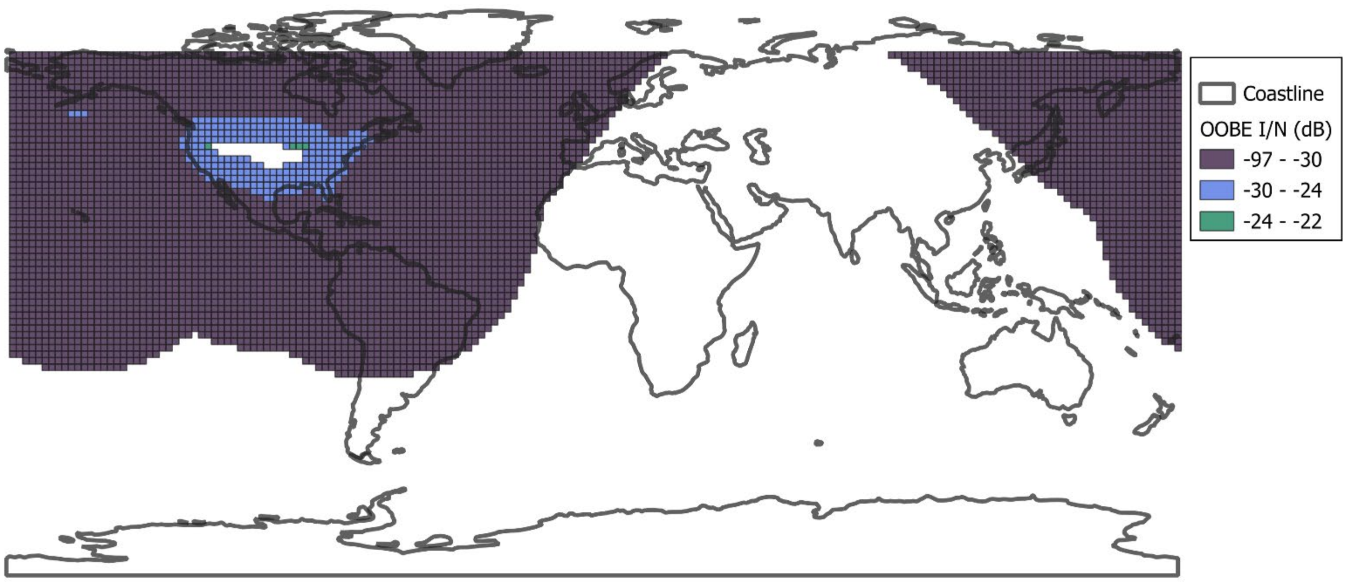

*Figure 15 - **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **48.8 dB OOB attenuation over 1985-1990 MHz/1995-2000 MHz** (baseline)*

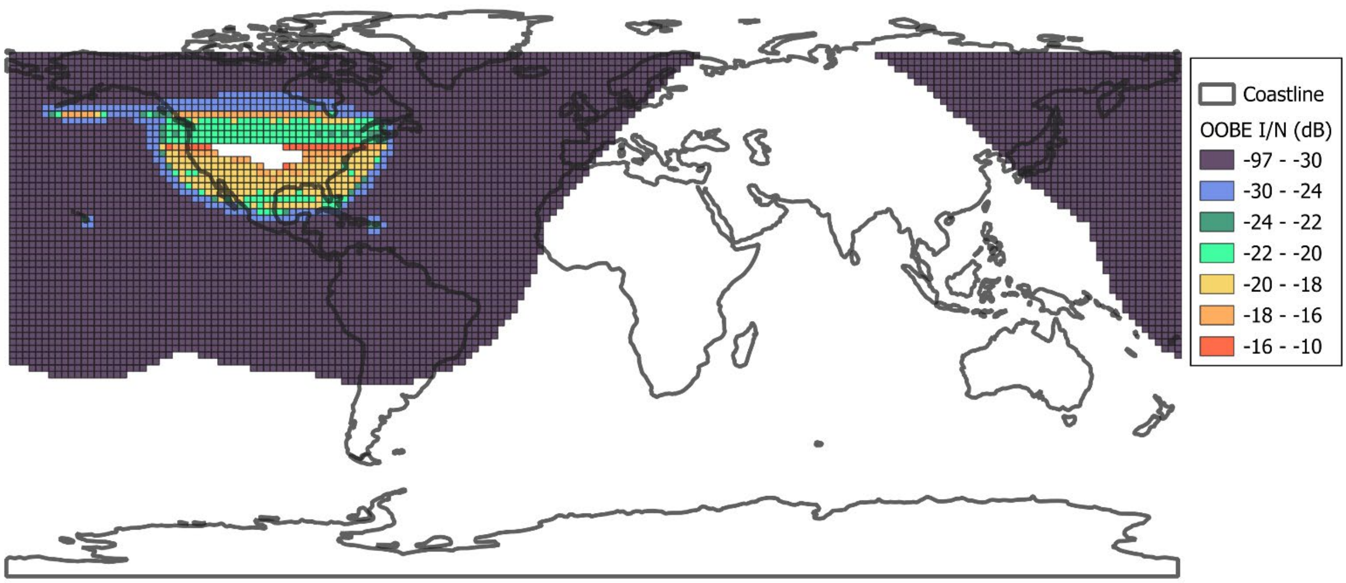

*Figure 16 - **20 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **48.8 dB OOB attenuation over 1985-1990 MHz/1995-2000 MHz** (baseline)*

The other two OOB EIRP density levels of -73.6 dBW/Hz and -83.6 dBW/Hz correspond to 18 dB and 28 dB lower than the nearest adjacent band level, respectively. These result in an OOB attenuation level of 66.8 dB over 1980-1985 MHz and 2000-2005 MHz and an OOB attenuation level of 76.8 dB over 1975-

1980 MHz and 2005-2010 MHz. Since these two levels are lower than the 63 dB OOB attenuation level in Section 3.2.1, as indicated in that section, no harmful interference (I/N ≥ -20 dB) occurs over frequencies below 1985 MHz and frequencies above 2000 MHz.

3.2.3 OOBE Limits per May 30, 2024 Filing

In SpaceX's May 30, 2024 filing at the FCC,[16] SpaceX argued that an appropriate aggregate PFD limit on the Earth's surface should be at least **-113.5 dBW/m^2/MHz**, which comes from AT&T's -107.5 dBW/m^2/MHz user equipment (UE) receiver noise floor plus -6 dB I/N over the broadband PCS spectrum of 1975-1990 MHz.

The aggregate power would be dominated by a single beam. Compared to the beam's in-band PFD level on the ground of -89 dBW/m^2/MHz, the proposed limit results in a 24.5 dB OOB attenuation level over 1980-1990 MHz and 1995-2010 MHz (by symmetry).

The adjacent channel interference results are shown in Figure 17 and Figure 18 below for the 40 km beam diameter median I/N (lowest interference scenario) and the 20 km beam diameter worst 5% I/N (highest interference scenario), respectively.

The figures indicate that with the 24.5 dB OOB attenuation level, the area of unacceptable interference (yellow to dark burgundy grids) in the best-case scenario (40 km-diameter beams, median case) can extend down into South America (Figure 17). In the worst-case scenario (20 km-diameter beams, 5% worst-case) unacceptable interference extends to Iceland (Figure 18).

[16] Petition for Reconsideration of Space Exploration Holdings, LLC, GN Docket No. 23-135 and SB Docket No. 22-271 (May 30, 2024) at 9.

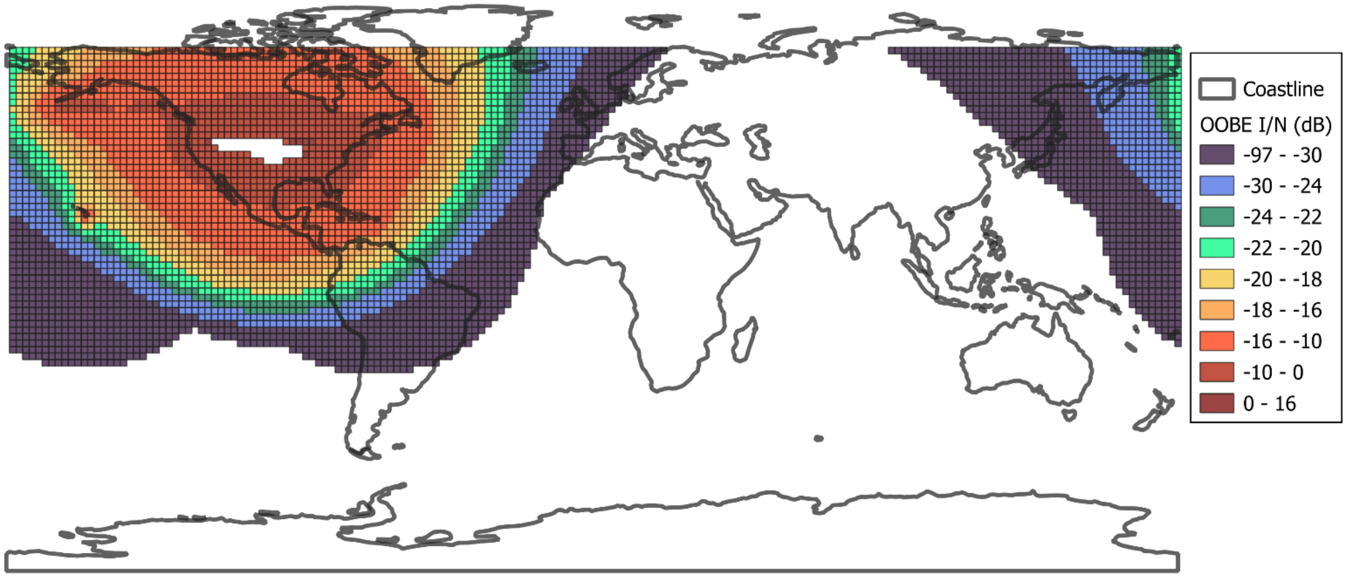

*Figure 17 - **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **24.5 dB OOB attenuation** (baseline)*

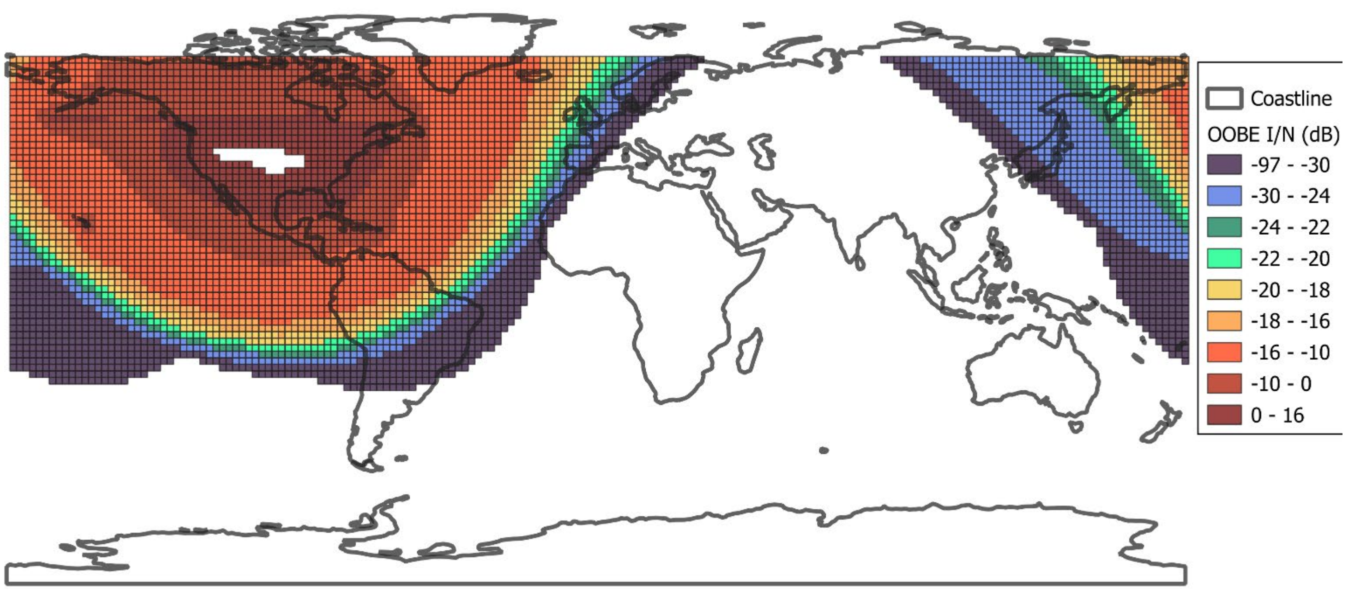

*Figure 18 - **20 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **24.5 dB OOB attenuation** (baseline)*

3.2.4 OOBE Limits per June 6, 2024 Filing

Most recently, in SpaceX's June 6, 2024 filing at the FCC,[17] SpaceX argued that the aggregate PFD limit on the Earth's surface should be **-110.6 dBW/m^2/MHz**. This limit is also derived from AT&T's -107.5 dBW/m^2/MHz UE receiver noise floor which is over the broadband PCS spectrum of 1975-1990 MHz.

The aggregate power would be dominated by a single beam. Compared to the beam's in-band PFD level on the ground of -89 dBW/m^2/MHz, the proposed limit results in a 21.6 dB OOB attenuation level over 1980-1990 MHz and 1995-2010 MHz (by symmetry).

The adjacent channel interference results are shown in Figure 19 and Figure 20 below for the 40 km beam diameter median I/N (lowest interference scenario) and the 20 km beam diameter worst 5% I/N (highest interference scenario), respectively.

Similar to the previous limit, the figures indicate that with the 21.6 dB OOB attenuation level, the area of unacceptable interference (yellow to dark burgundy grids) in the best-case scenario (40 km-diameter beams, median case) can extend down into South America (Figure 19). In the worst-case scenario (20 km-diameter beams, 5% worst-case) unacceptable interference extends to the United Kingdom (Figure 20).

[17] Letter from David Goldman to Marlene H. Dortch, GN Docket Nos. 23-65, 23-135, ICFS File No. SAT-MOD-20230207-00021, and ULS File Nos. 0010303032, 0010303084, 0010303124, and 0010303146 (June 6, 2024) at 2.

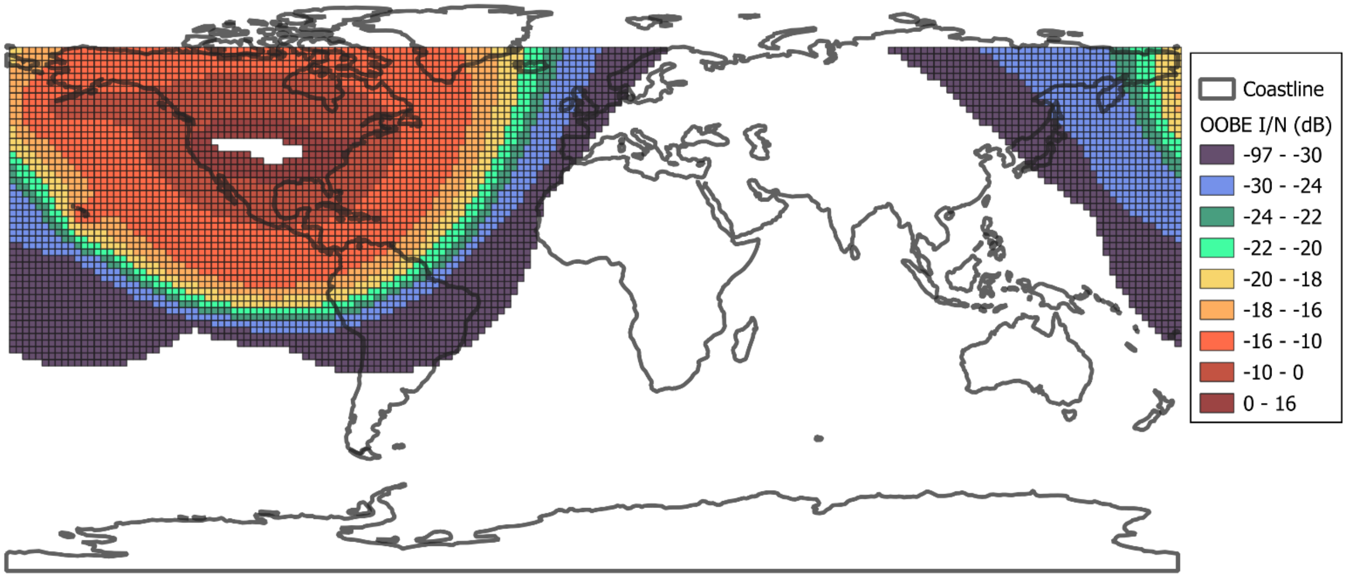

*Figure 19 - **40 km Beam Diameter: Median I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **21.6 dB OOB attenuation** (baseline)*

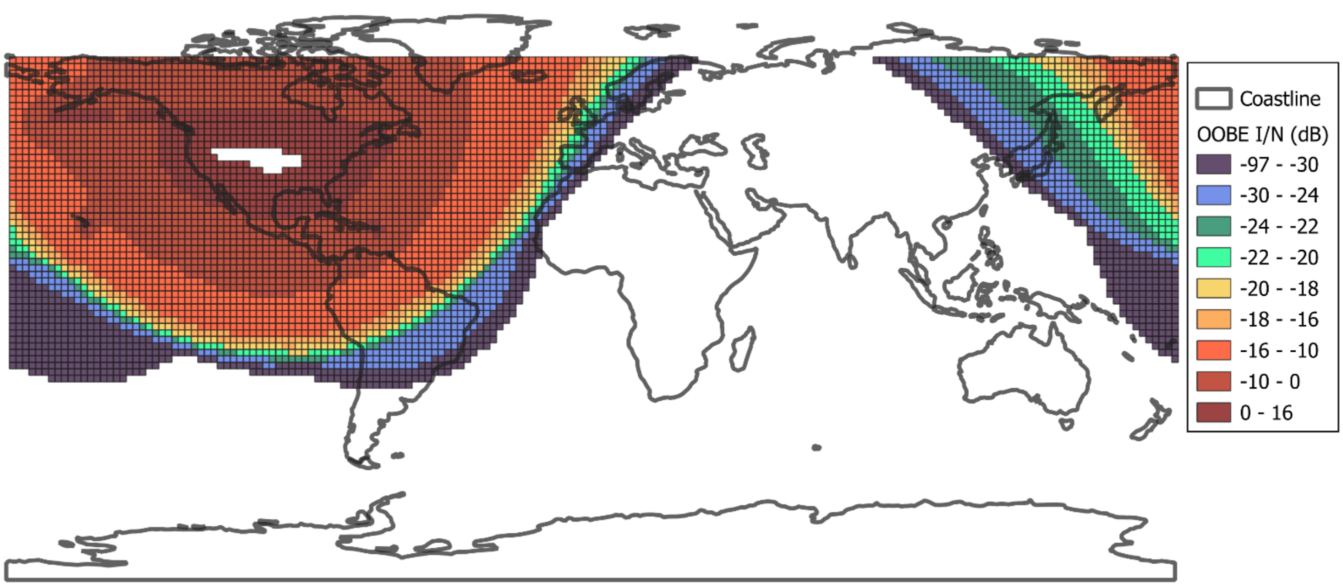

*Figure 20 - **20 km Beam Diameter: 5% worst-case I/N** at each victim satellite in the grid from Starlink satellites' OOBE, using **21.6 dB OOB attenuation** (baseline)*

As discussed above, depending on which OOBE limits are adopted, there can be a significant risk of interference into the adjacent bands. Using SpaceX's latest proposed OOBE limits (Section 3.2.4), in addition to co-channel operations in the 1990-1995 MHz band, there can also be significant interference into the adjacent 1980-1995 MHz and 1995-2010 MHz bands. As such, Starlink operations could impact the entire 30 megahertz of the victim's satellite uplink spectrum.

3.3 Overload

In this section, the risk of overload from Starlink transmissions into a victim satellite is evaluated. Overload results when the total received power (including Starlink interference and the desired received power) exceeds a threshold level (-55 dBm) per Section 2.3.

In the link budget in Table 4 below, the maximum desired power received at the victim satellite is derived. This link budget assumes a victim UT transmit gain of 0 dBi and no body or shadowing loss.

Table 3: Link Budget derivation of maximum total desired received power at the victim satellite

Parameter	Unit	Value
UT transmit Power	dBm	23
UT maximum transmit antenna gain	dBi	0
UT bandwidth	MHz	0.200
Maximum number of simultaneously transmitting UTs		25 (= 5 MHz (victim satellite bandwidth) / 0.2 MHz per UT)
Range	km	600
Frequency	MHz	1992.5
Path loss (FSPL)	dB	154
Victim satellite receive antenna gain	dBi	36
Body loss	dB	0
Polarization mismatch	dB	3
Shadowing loss	dB	0
Desired received power from all UTs at the victim satellite	dBm	-84.02

The maximum co-channel interference I/N from the simulations in Section 3.1 (Figure 5) is 35.7 dB (over 1.4 megahertz) which scales to 40.5 dB (over the victim satellite's 5 megahertz bandwidth). Given the noise power (N) of -141.195 dBW/MHz, the maximum interference power received at a victim satellite pointing outside the United States is -65.9 dBm. The total received power at the satellite, including the desired signal would be -65.88 dBm, which is still well below the overload level of -55 dBm postulated.

3.4 Conclusions

This report analyzed the risk of interference from SpaceX's Starlink MSS downlink operations in the G-block (1990-1995 MHz) in U.S. territories to MSS uplink operations around the world in the 1980-2010 MHz band. The analysis considered co-channel interference, adjacent channel interference, and overload to a victim satellite constellation with an altitude of 600 km. The planned SpaceX operation is non-standard. The interference from a satellite downlink into a satellite uplink is new. The victim satellites will see interference from many Starlink satellites as the only isolation is free space path loss and antenna off-pointing.

As indicated in this study, without additional mitigation, the predicted in-band interference risk will be significant. With a co-channel aggregate I/N threshold of -6 dB, in the baseline modeling of the Starlink satellite, the interference risk can extend from Starlink operations in the United States to South America, the United Kingdom, Iceland, and Japan. The interference levels and areas are worsened when the alternate method is applied.

As discussed in Section 3.2, SpaceX has been proposing progressively looser OOBE limits to the FCC. The recent SpaceX relaxation attempts described in Section 3.2.4 significantly increase interference risk. In addition to co-channel operations in the 1990-1995 MHz band, there can also be significant interference into the adjacent 1980-1995 MHz and 1995-2010 MHz bands. As such, Starlink operations could impact the entire 30 megahertz of the victim's satellite uplink spectrum.

The risk of overloading the victim satellites was found to be small.