TECHNICAL APPENDIX

Technical Overview of the HVNET System

A.1 Executive Summary

In accordance with Section 24.114(d)(1) of the FCC's rules, this Technical Appendix provides an overall description of Hughes Network Systems, LLC's ("Hughes") proposed non-geostationary satellite orbit ("NGSO") system (the "HVNET System" or "System"), including its facilities, operations, services provided, and spectrum resources to be utilized. The HVNET System will provide reliable, secure low-latency broadband connections to virtually everywhere on Earth using a constellation of 1,440 satellites in low Earth orbit ("LEO"). This Technical Appendix also provides additional information required under Section 25.114 and other Part 25 rules, including a detailed orbital debris mitigation plan and a demonstration of compatibility with terrestrial, geostationary satellite orbit ("GSO"), and other NGSO operations.

A.2 HVNET System Description

The HVNET System will provide reliable, secure low-latency broadband connections to virtually anywhere on Earth using a constellation of 1,440 satellites, consisting of 40 satellites in each of 36 LEO planes at 1,150 km altitude. The HVNET System will have the capability to adaptively steer satellite capacity where needed by users, and is designed for flexibility and maximum frequency reuse. The System will make maximum use of Hughes' global satellite managed network to match service types to customer needs.

The HVNET satellite constellation provides broad global capacity and allows for smaller user terminal antennas due to its relatively low altitude. Each satellite will also have the capability to tailor its footprint as required by means of a phased-array user beam antenna.

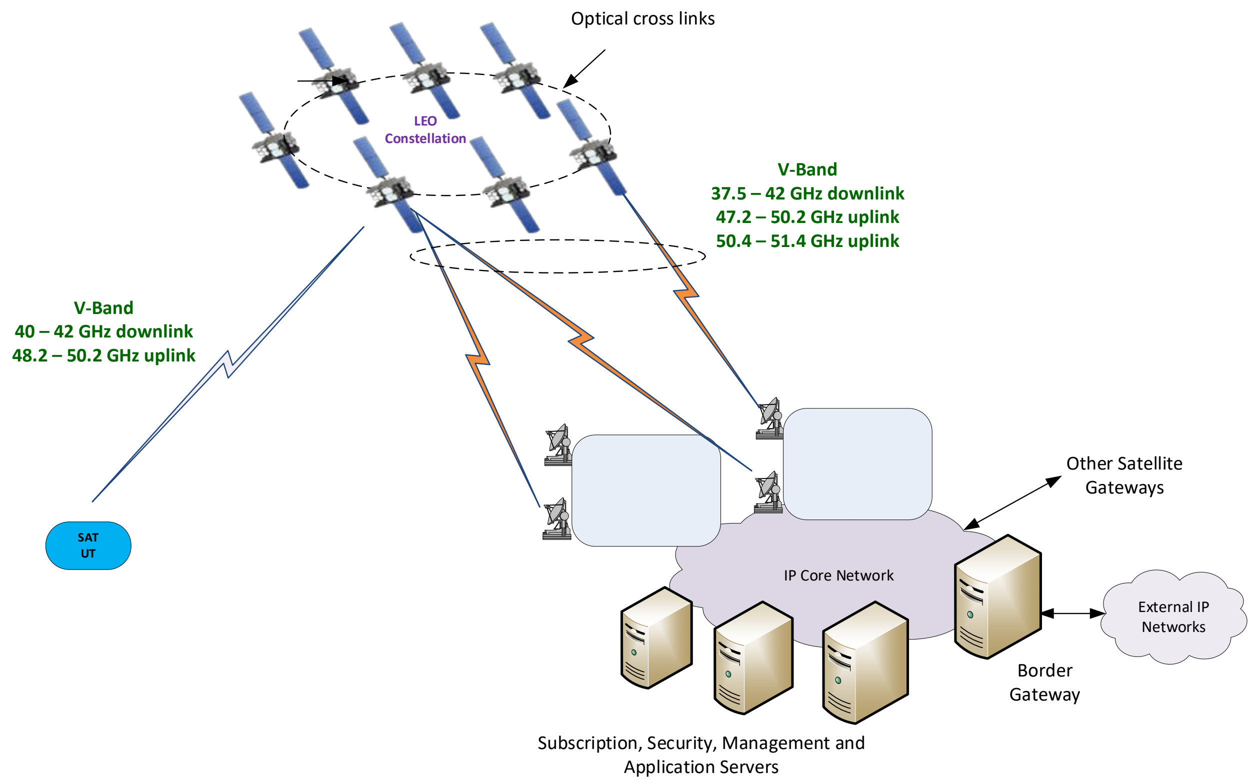
HVNET user and gateway links operate in the V-band, as specified in Section A.2.1.2 below. User traffic will be routed on board each satellite utilizing Software Defined Network ("SDN") capability.

For ground connectivity, Hughes will implement a global network of approximately 20 to 40 ground gateway stations, including an expected 3 to 5 gateways located in the United States. Each gateway station consists of an array of tracking antennas with appropriate radiofrequency ("RF") and modem capability, traffic routing scheduling and management systems, and fiber connectivity.

The entire network will be managed by a unified ground network, including Hughes' Satellite Control Center ("SCC"), Network Operation Center ("NOC") and SDN.

An overview of the entire HVNET network is shown in Figure 1 below.

Figure 1. Overall Architecture of the HVNET Network



A.2.1 HVNET Satellite Constellation and Frequency Plans

A.2.1.1 Constellation Design

The HVNET system utilizes 1,440 LEO satellites to provide low-latency and comprehensive global coverage including all parts of the United States. HVNET satellites operate in 36 orbital planes at an altitude of 1,150 km[1] and with an inclination of 55 degrees.

The orbit inclination was chosen to provide the most efficient coverage of major populations areas of the world that lie between 55 degrees North and 55 degrees South latitude. Due to their relatively short transmissions path, the HVNET satellite network supports low-latency transmissions and small user antenna sizes (as small as 11 in).

HVNET satellites will operate at a user terminal minimum elevation angle of 56 degrees for a user located at any latitude between 55 degrees North and 55 degrees South, as shown in Figure 2 below.

[1] To avoid collisions within the constellation, Hughes will make use of a moderate amount of altitude variation such that safe radial separations exist at plane intersections.

Figure 2. HVNET Satellite Antenna Steering and User Look Angle

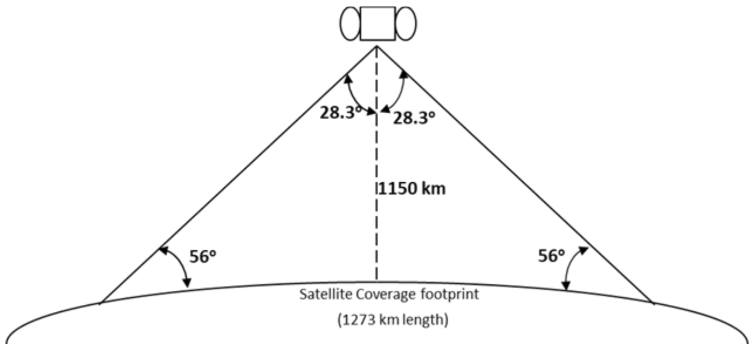


Table 1 below provides a summary of the orbital parameters for HVNET satellites.

Table 1. HVNET Orbit Plan

Orbit Planes	Satellites per Plane	Orbit Inclination	Total Satellites	Minimum User Look Angle
36	40	55 degrees	1,440	56 degrees
Altitude	**1,150 km**			
* The phased array satellite antenna design enables Alaska coverage using extended satellite steering angles up to 52.8 degrees.				

Figure 3 below provides an example of coverage of several HVNET satellites over the United States.

Figure 3. HVNET Constellation Partial View

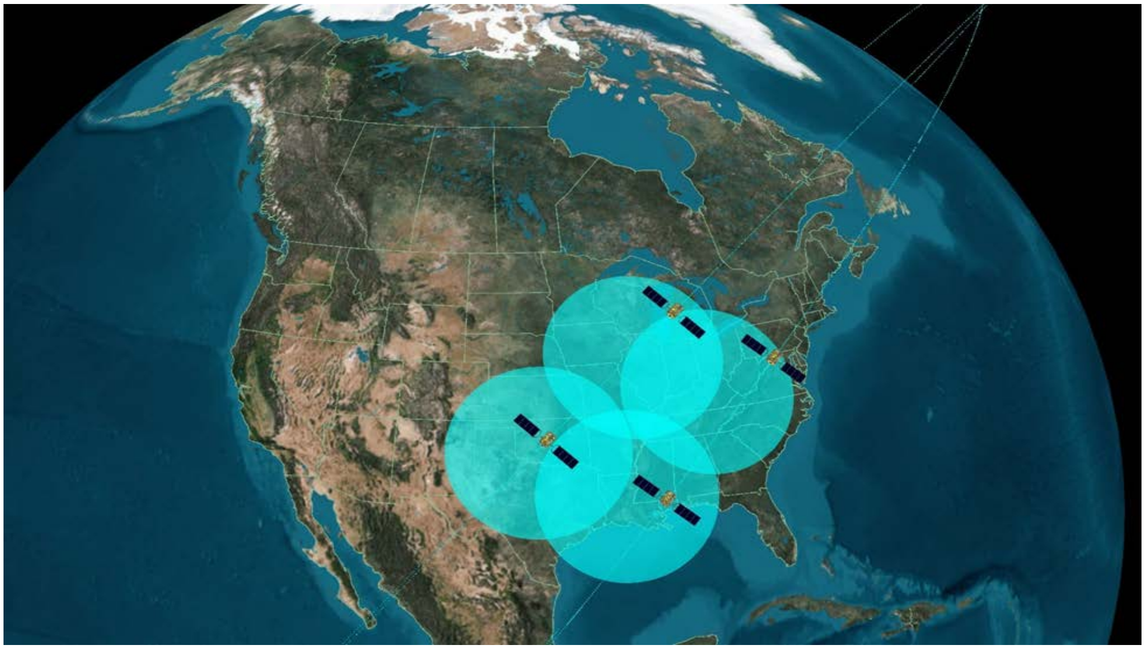
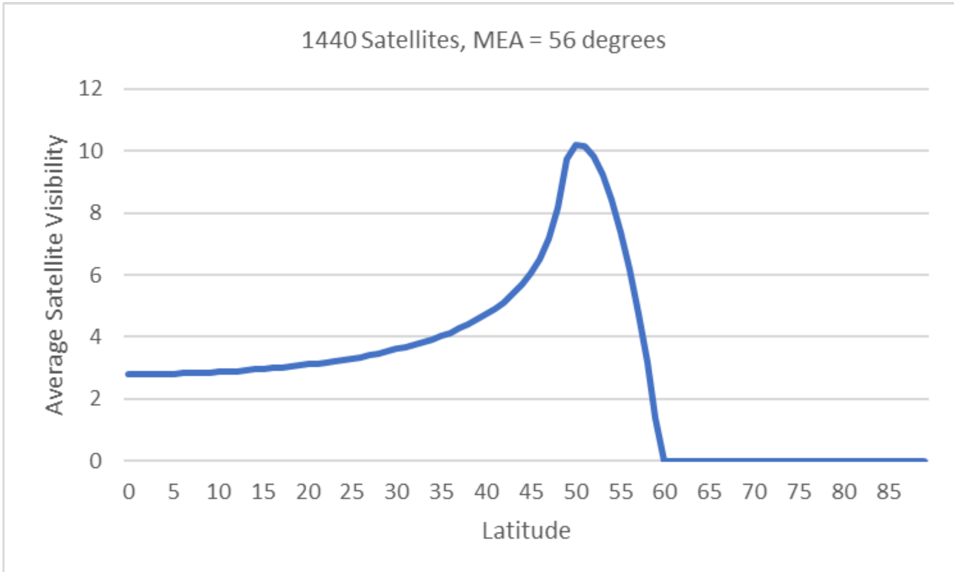


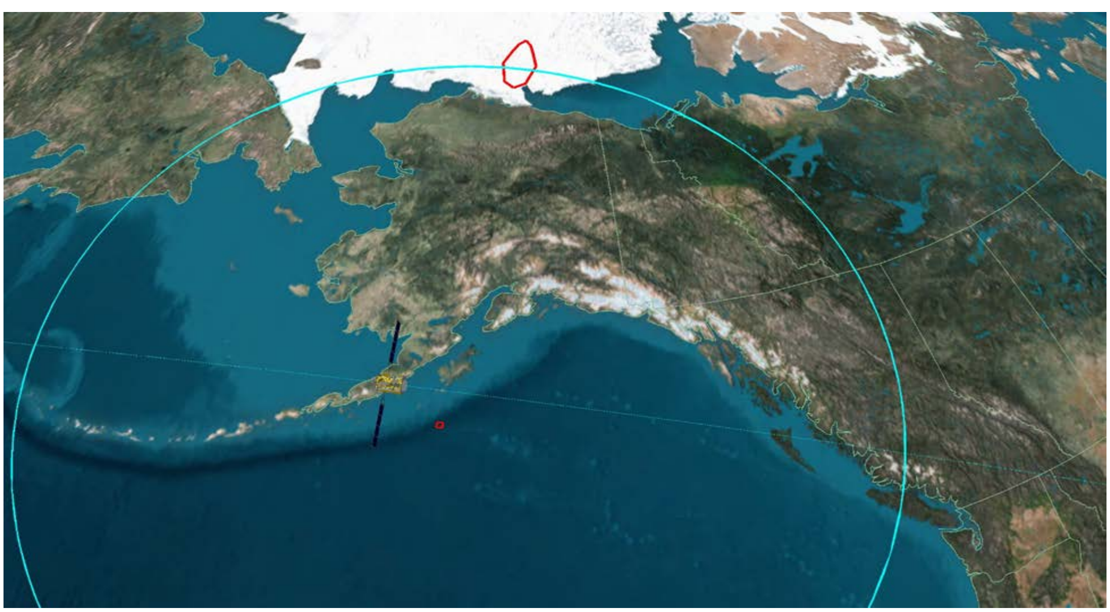
Figure 4 below identifies the average number of visible satellites as a function of latitude with a minimum elevation angle of 56 degrees. For user terminal locations at up to approximately 57 degrees latitude, an average of two or more satellites will be visible.

Figure 4. Average Number of Visible HVNET Satellites As Function of Latitude



The phased-array user link satellite antenna also has the capability to provide extended coverage to areas above 55 degrees latitude by using extended beam steering. When satellite beam steering is extended to 52.8 degrees, HVNET satellites will provide 100% coverage of Alaska, as shown in Figure 5 below (with blue contours delineating the coverage area of one HVNET satellite and red contours delineating the coverage area of one spot beam at the coverage limit). The System design also permits satellites to be pitched and rolled towards Alaska coverage, when required, to improve link performance.

Figure 5. Alaska Coverage Example



A.2.1.2 Frequency Plans

The HVNET System will utilize V-band frequencies listed in Table 2 below. Dual polarizations will be used on both user and gateway links to provide maximum capacity within the allotted band. Each link is fully regenerated on board the satellite so that the most efficient modulation and coding can be used for the specific conditions of that link at that time.

Table 2. HVNET V-band Frequency Plan

Link	Downlink	Uplink	Polarization
Satellite ↔ User	40.0 GHz to 42.0 GHz	48.2 GHz to 50.2 GHz	LHCP & RHCP
Satellite ↔ Gateway	37.5 GHz to 42.0 GHz	47.2 GHz to 50.2 GHz 50.4 GHz to 51.4 GHz	LHCP & RHCP
Telemetry, Tracking and Command	37.5 GHz to 37.6 GHz 41.9 GHz to 42.0 GHz	47.2 GHz to 47.3 GHz 50.1 GHz to 50.2 GHz	LHCP & RHCP

The TT&C channel size can vary from 2.5 to 20 MHz on the uplink, and 2.5 to 10 MHz on the downlink as needed to meet the information requirements of the link in question. Numerous channels are needed to communicate with multiple satellites. The channels start at the edge of the service band and have been selected to minimize interference into other satellite networks. On-orbit TT&C communications are performed through a gateway beam on the satellite, while omni antennas are used for specific situations, including launch and early-orbit phase operations. The satellite downlink TT&C channels may also be used as beacon frequencies that assist with ground station antenna pointing and uplink rain fade compensation.

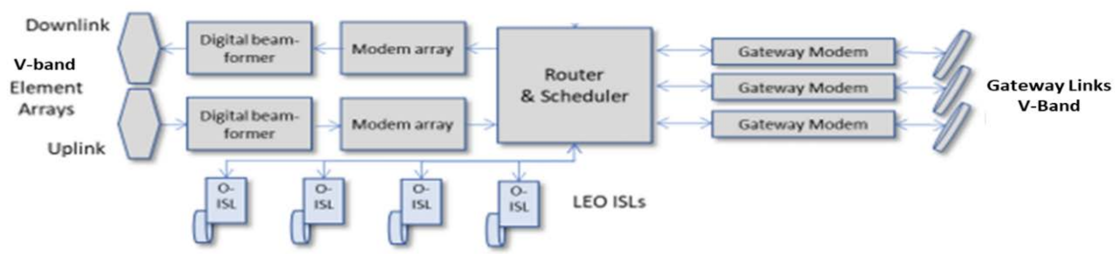
The use of phased array antennas in user links allows the flexibility of servicing small hot spots with very high capacity per square mile or larger spots to provide lower capacity per square mile depending on the demand. User beams can be steered to provide earth-fixed coverage of a given location by updating the beam aiming up to a maximum satellite steering angle or equivalent user terminal elevation angle or until a better positioned satellite is available to cover that location. Satellite handovers of user traffic are handled seamlessly in the system such that the end user is unaware of such events. In addition to beam, satellite and gateway handovers, the system will also support frequency handovers to mitigate interference and accommodate spectrum constraints. Here, a beam can be re-assigned to a new frequency plan based on resource plans generated by the System Network Control for different satellites covering different geographical regions.

HVNET is a high-throughput system capable of delivering more than 1 Gbps to a user in a downlink beam, depending on spectrum availability and user terminal type. The minimum user downlink channelization is 50 MHz. Multiple 50 MHz channels can be aggregated into wider channels up to 500 MHz in bandwidth. The minimum user uplink channelization is 25 MHz. Multiple 25 MHz channels can be aggregated into wider channels up to 100 MHz in bandwidth in the uplink direction.[2] The user data traffic is demodulated within the satellite payload where a routing and scheduling function will route the data to the appropriate downlink. A given user beam can operate in one or both polarizations to provide maximum flexibility and serve capacity based on demand.

A.2.2 HVNET Satellites

HVNET satellites are designed to support low-cost manufacturing. Optical inter-satellite links ("O-ISLs") are used between adjacent satellites in-plane and cross-plane. Multiple gateway links are provided per HVNET satellite, and each of these links will utilize a gimballed parabolic antenna. Additional links are provided to allow continuity during gateway handovers and rain diversity. The uplinked gateway signals are demodulated and routed to the payload traffic processing subsystem. From there, user packets are routed to the user traffic scheduler component; inter-satellite packets are routed to the appropriate O-ISL link. The user traffic scheduler will apply appropriate parameters to the user link phased array antenna to downlink the data. A block diagram of the satellite payload is shown in Figure 6 below.

Figure 6. HVNET Block Diagram



Spot beams in the user link can be placed anywhere in the satellite coverage area dynamically. Figure 7 below illustrates a satellite spot beam in the user downlink.

Figure 7. Example of HVNET User Spot Beam

[2] Consistent with Section 25.114(c)(4)(i), as the space station can vary channel bandwidth in a particular frequency band with on-board processing, only the range of frequencies in that band over which the beam can operate and the polarization plan are provided in Schedule S.

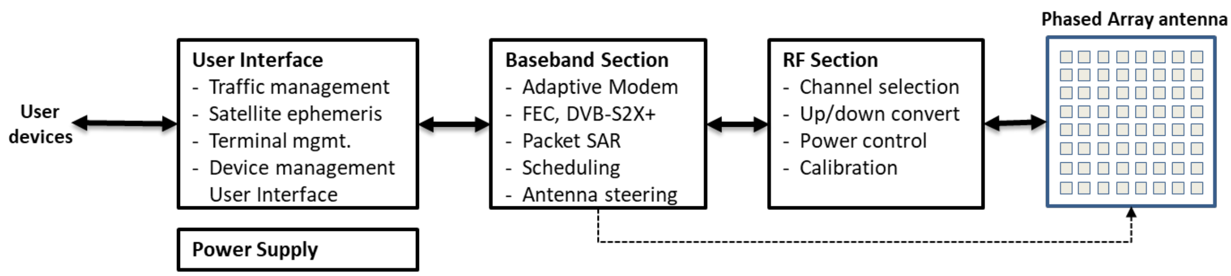
A.2.3 HVNET Ground Segment

A.2.3.1 Customer User Terminals

Hughes envisions several different fixed and mobile user terminal types based on the user environment, mobility and capacity needs. These can range in antenna size from 28 cm (11 in) to 1.0 m (40 in) in diameter. Hughes plans to support a range of applications and will focus on developing fixed, aeronautical, maritime, and land mobile user terminals. Hughes also plans to develop user terminals that support military use, provide high security and reliability, and are available for rapid deployment.

The functions and capabilities of the user terminal will vary based on the type of application. A generalized functional diagram is shown in Figure 8 below. The terminal modem sections utilize adaptive coding and modulation ("ACM") and LDPC/DVB-S2X+ forward error correction ("FEC") to achieve performance very close to the theoretical limit. Although DVB-S2X is shown here, other candidates such as 5G-NR codes may also be applicable. Hughes' preliminary analysis indicates that the satellite-to-user link with a 60 cm user terminal antenna will achieve an efficiency of more than 3.5 bits/symbol in clear sky.

Figure 8. User Terminal Block Diagram



A.2.3.2 Gateway Stations

Gateway stations form the heart of the ground network and serve to route all user data between the satellite network and terrestrial networks. In addition, the gateway network incorporates system management, security, and business functions to assure network reliability and business integrity. The HVNET System will incorporate a worldwide network of gateways sized to accommodate the areas served. Hughes plans to deploy approximately 20 to 40 gateways worldwide, including an expected 3 to 5 gateways located in the United States.

Each gateway incorporates these major functions:

- Antennas – an array of tracking parabolic antennas, ranging from 1.8 to 5 m (3 m is nominal). The number of antennas required per gateway will vary as a function of the gateway location and the expected user traffic load.
- RF equipment – each antenna is equipped with power amplifiers for the required frequency bands and RF conversion equipment to interface with baseband components.
- Baseband & signal processing – equipment to process air links from the satellites including high throughput adaptive modems, error corrections and packet handling equipment.
- Traffic processing – specialized routers to handle traffic needs and route user data packets appropriately.
- Anchor and point of presence – specialized router to recognize user traffic streams and connect to the external core network.

- Common equipment for functions such as timing and control, antenna management, resource management, element management and satellite ephemeris management.

A.2.3.3 Network Operation Center

The NOC performs four major functions:

- network management (Fault, Configuration, Accounting, Performance and Security or "FCAPS") for all the network elements, including gateways;
- spectrum management, a database of all available spectrum within the worldwide network;
- global resource management ("GRMS") to develop resource plans, including satellite ephemerides, satellite capabilities and beam data, and capacity planning including administrative regions; and
- element management system to perform operations on specific network elements.

The NOC performs critical functions to keep the network operating efficiently and within prescribed regulatory bounds. It contains servers for managing subscriptions, security, management, and applications. It also serves as an interface point for coordination with other satellite and terrestrial networks.

A.2.3.4 Satellite Control Center

The SCC communicates with the satellites via dedicated TT&C stations located strategically to maximize access while minimizing the required number of TT&C stations. In addition, to facilitate communication with the large number of satellites in the network, each gateway station will have the capability to provide contact between the satellite and the SCC during normal operations. The communications will take place using the normal traffic antenna and the gateway.

The SCC will coordinate and control all post-launch mission operations, including orbit raising, routine maneuvers, constellation management, and end of life processes including de-orbiting. TT&C will utilize a high degree of automation to improve reliability, integrity, and efficiency of the operations.

A.3 Geographic Coverage

With its planned satellite steering angle of 28.3° and associated minimum earth station elevation angle of 56°, the HVNET satellite constellation's field of view coverage over the world, including U.S. territories such as Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa, is shown in Figure 9 below; and the field of view coverage over all of the continental United States ("CONUS"), Hawaii, Puerto Rico, and the U.S. Virgin Islands is shown in Figure 10 below. Additionally, as noted in Section A.2.1.1 and further shown in Figure 5 above, HVNET satellites will cover all of Alaska when satellite beam steering is extended to 52.8 degrees.

Figure 9. HVNET *Satellite Field of View Coverage over the World*

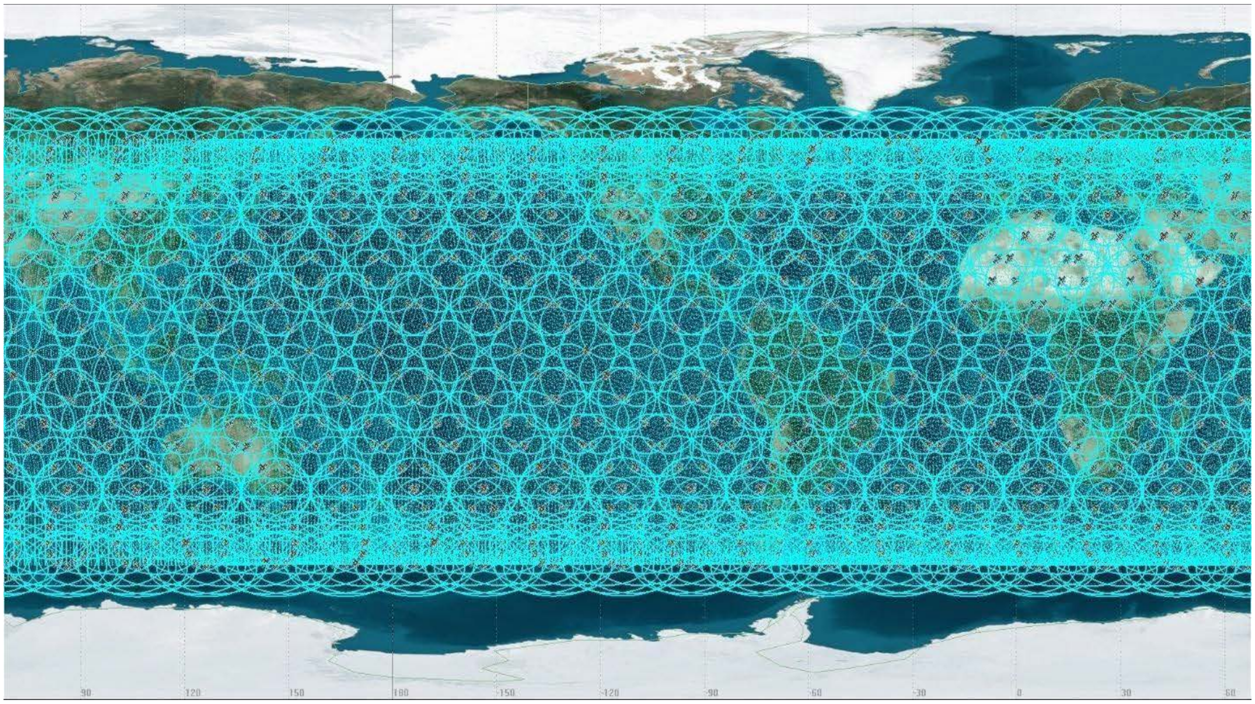
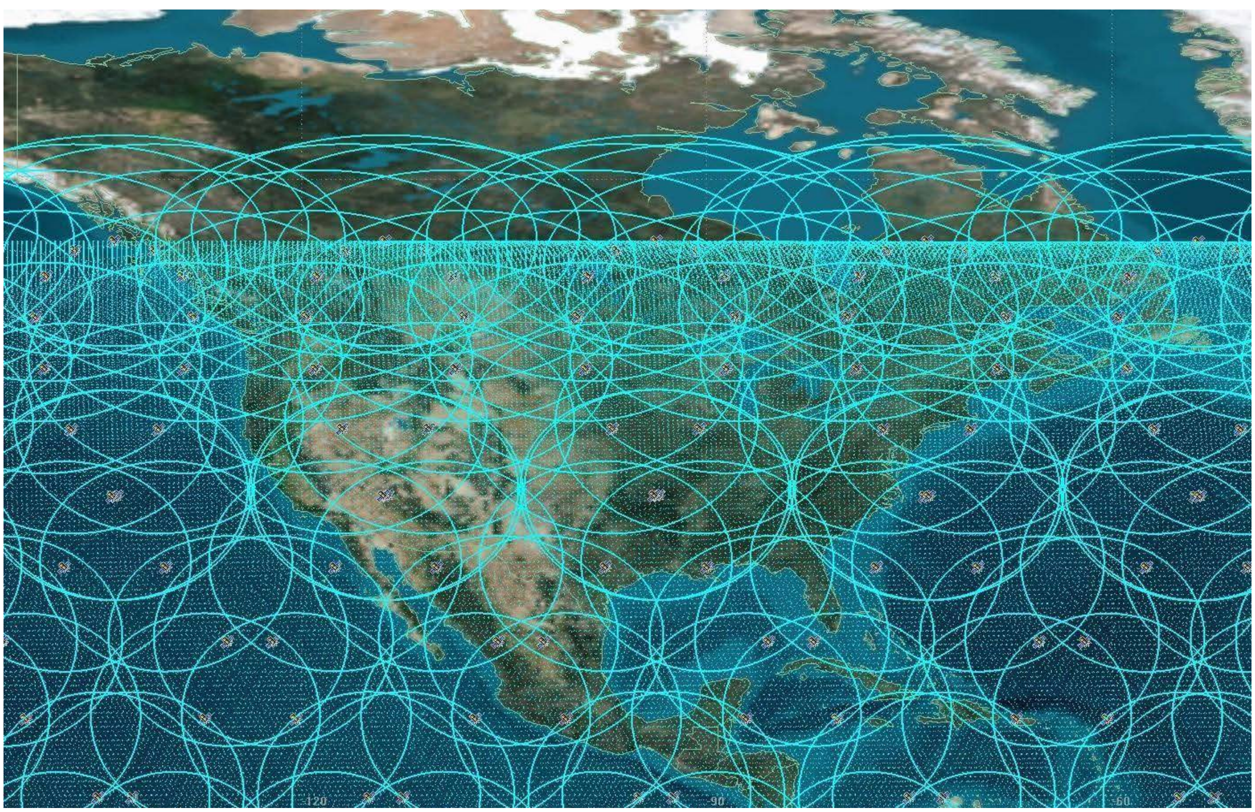


Figure 10. HVNET *Satellite Field of View Coverage over CONUS, Hawaii, U.S. Virgin Islands and Puerto Rico*



A.4 Spectrum Sharing

In the following sections, Hughes provides information showing compliance with applicable power flux density ("PFD") limits to protect terrestrial services under Sections 25.208(r), (s), and (t) and 25.146(a)(1) of the Commission's rules and Article 21 of the ITU Radio Regulations ("Article 21"). Additional sharing issues, including sharing with GSO FSS, GSO Broadcasting-Satellite Service ("BSS"), and other NGSO FSS systems, are also discussed below.

A.4.1 Compliance with PFD Limits to Protect Terrestrial Services

Table 3 below provides a summary of the applicable PFD limits to protect terrestrial services in the V bands downlink frequencies used by the HVNET.[3] The peak EIRP density of each HVNET gateway beam is varied as a function of the satellite steering angle as shown below. This variation in EIRP density is taken into account in determining the PFD levels.

Section 25.208(r) includes limits for NGSO operations both under assumed free space conditions and during periods when the FSS system raises power to compensate for rain-fade conditions at the earth station. In the Spectrum Frontiers Second Report and Order, the Commission found that the record did not establish conditions under which FSS could operate at a higher PFD consistent with terrestrial use of the band. However, that Order did not delete a note to Section 25.208(r), which states that the conditions under which satellites may exceed the PFD limits for free space conditions to compensate for the effects of rain fading have not yet been defined and provides that the conditions and extent to which the free space limits can be exceeded will be the subject of a further rulemaking by the Commission.[4] Hughes' operations in the 37.5-40.0 GHz band will be in conformance with the Commission's rules and the Table of Frequency Allocations, and it will comply with FCC mechanisms for sharing with Upper Microwave Flexible Use Service (UMFUS), but it requests flexibility to operate within higher PFD limits that may be adopted in a future Commission proceeding.

Table 3. Applicable V-band PFD Limits

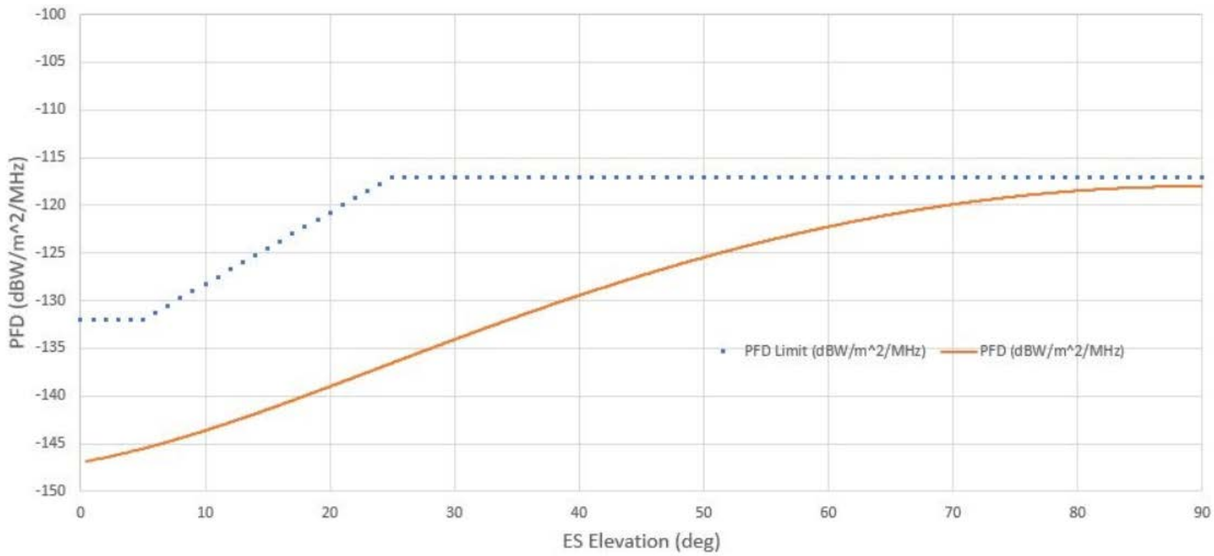
Frequency Band (GHz)	FCC Rule Section	Propagation Conditions	Limit in dB (W/m^2) for Angle of Arrival (δ) Above Horizontal Plane			Reference Bandwidth
			0°-5°	5°-25°	25°-90°	
37.5-40	25.208(r)	Free Space	−132	−132 + 0.75 (δ−5)	−117	1 MHz
		Rain Fade	−120	−120 + 0.75 (δ−5)	−105	1 MHz
40-40.5	25.208(s)	Free Space	−115	−115 + 0.5 (δ−5)	−105	1 MHz
40.5-42	25.208(t)	Free Space	−115	−115 + 0.5 (δ−5)	−105	1 MHz

[3] The limits in Sections 25.208(r)(1), 25.208(s) and 25.208(t) apply to PFD generated under assumed free-space propagation conditions.

[4] *See Telesat Canada, Petition for Declaratory Ruling to Grant Access to the U.S. Market for Telesat's V-Band NGSO Constellation*, Order and Declaratory Ruling, 33 FCC Rcd 11469 (2018).

HVNET operations in the 37.5 – 37.6 GHz band will comply with the applicable PFD limits, as shown in Figure 12 below.

Figure 11. HVNET Space Station PFD and Section 25.208(r)(1) PFD limits in the 37.5-37.6 GHz band (TT&C)



HVNET operations in the 37.5-40 GHz band will comply with the applicable PFD limits, as shown in Figures 13 and 14 below.

Figure 12. HVNET Gateway Beam Peak EIRP Density as Function of Satellite Steering Angle in the 37.5-40 GHz Band (Feeder Downlink)

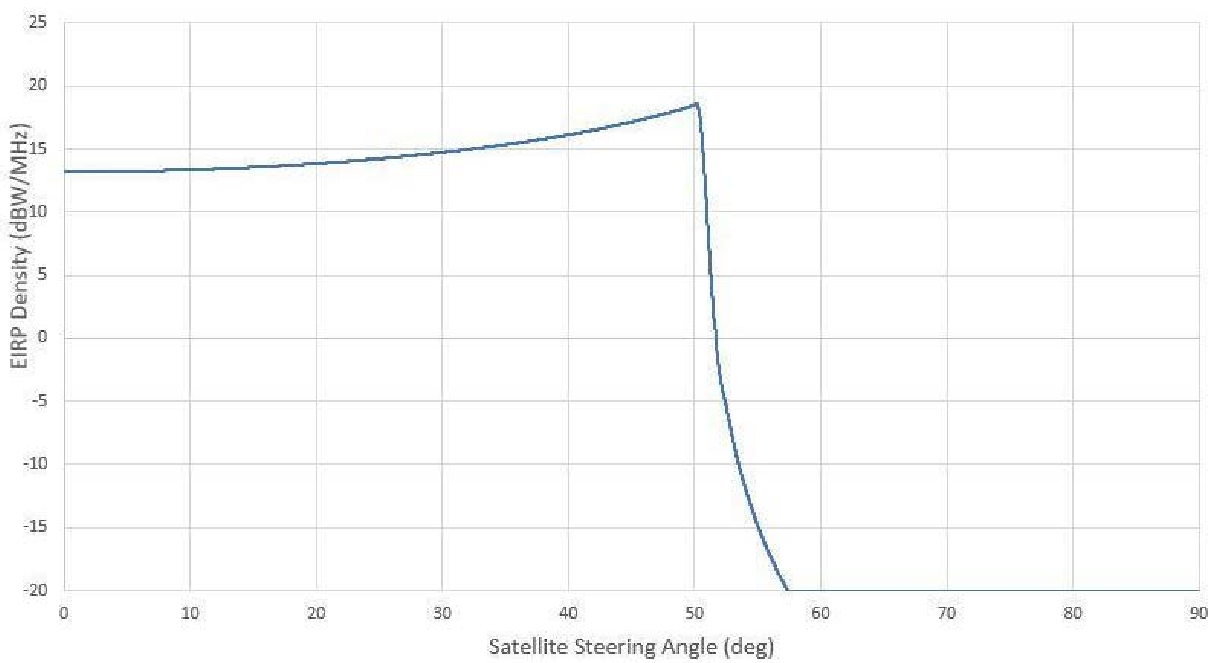
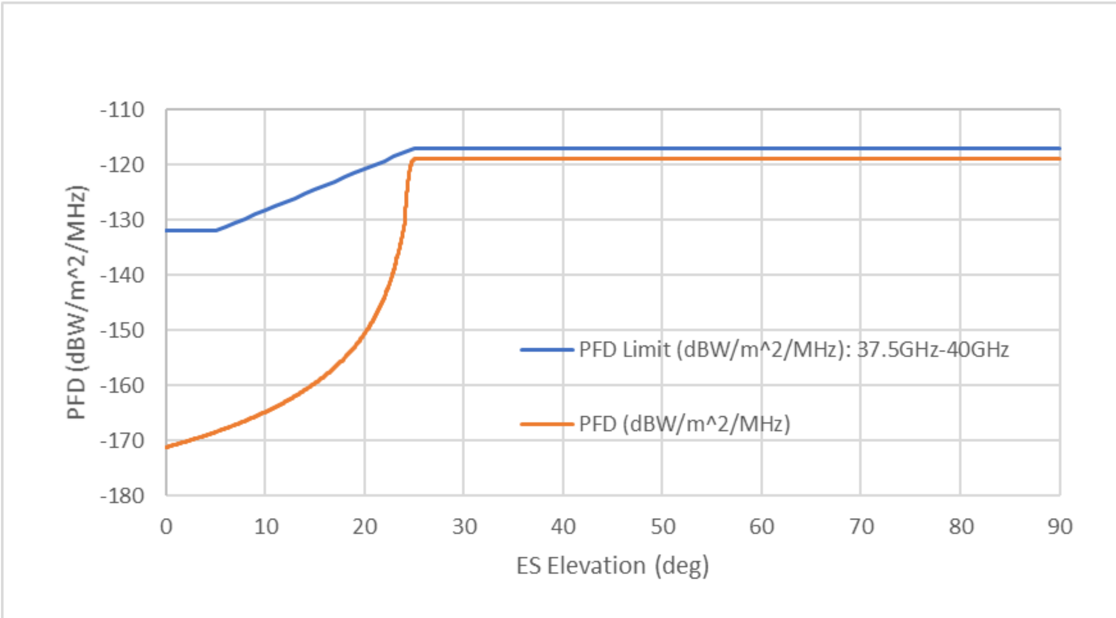


Figure 13. HVNET PFD and Section 25.208(r)(1) PFD limits in the 37.5-40 GHz Band (Feeder Downlink)



HVNET operations in the 40.0 – 42.0 GHz band will comply with the applicable PFD limits, as shown in Figures 15 through 18 below.

Figure 14. HVNET *Gateway Peak EIRP Density (dBW/MHz) As Function of Satellite Steering Angle in the 40-42 GHz Band (Feeder Downlink)*

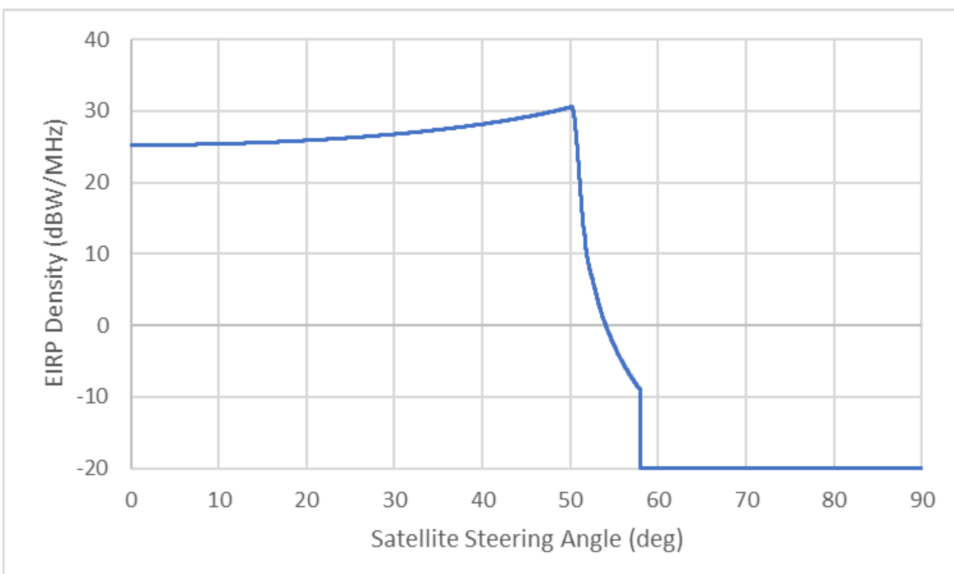


Figure 15. HVNET Space Station PFD and Section 25.208(s) and (t) PFD limits in the 40-42 GHz Band (Feeder Downlink)

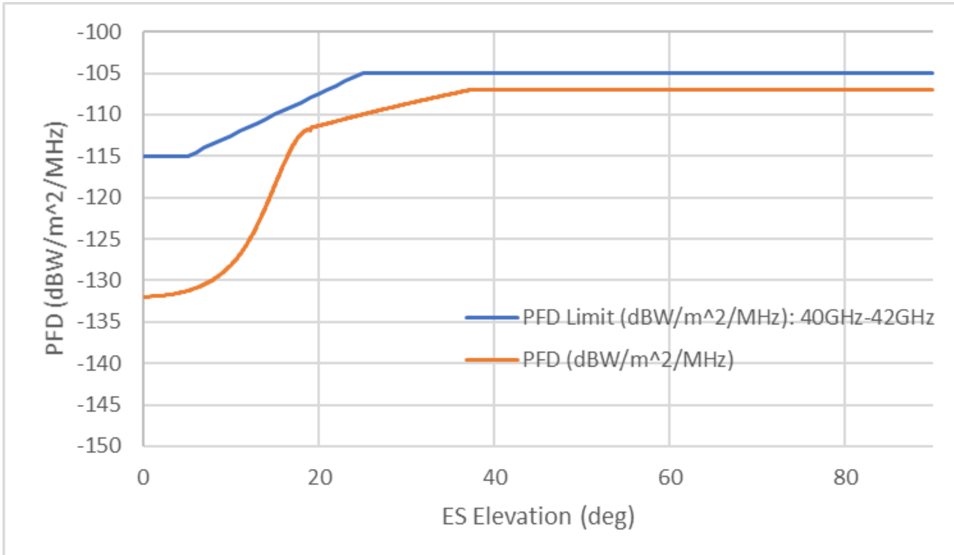


Figure 16. HVNET Space Station PFD and Section 25.208(s) and (t) PFD limits in the 40-42 GHz Band (User Downlink)

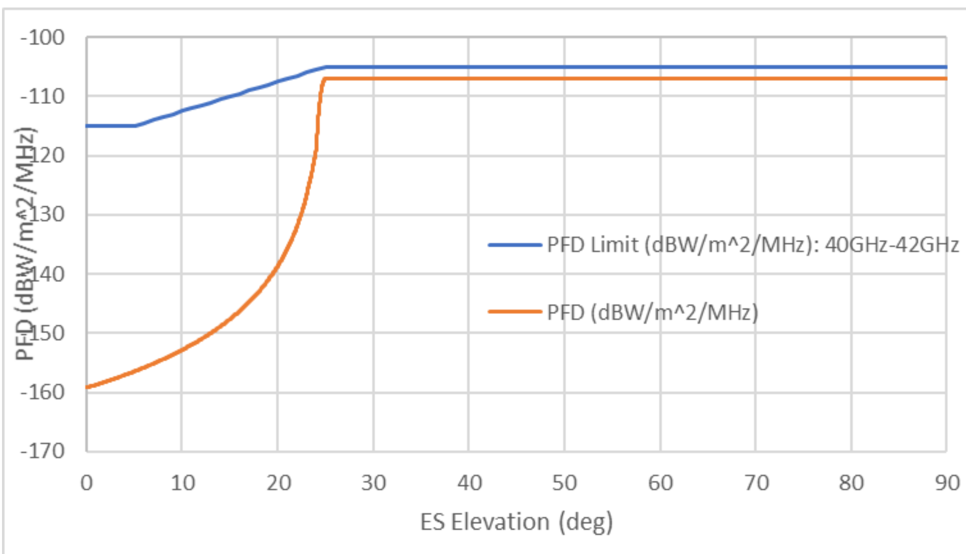


Figure 17. HVNET User Beam Peak EIRP Density As Function of Satellite Steering Angle in the 40-42 GHz Band (User Downlink)

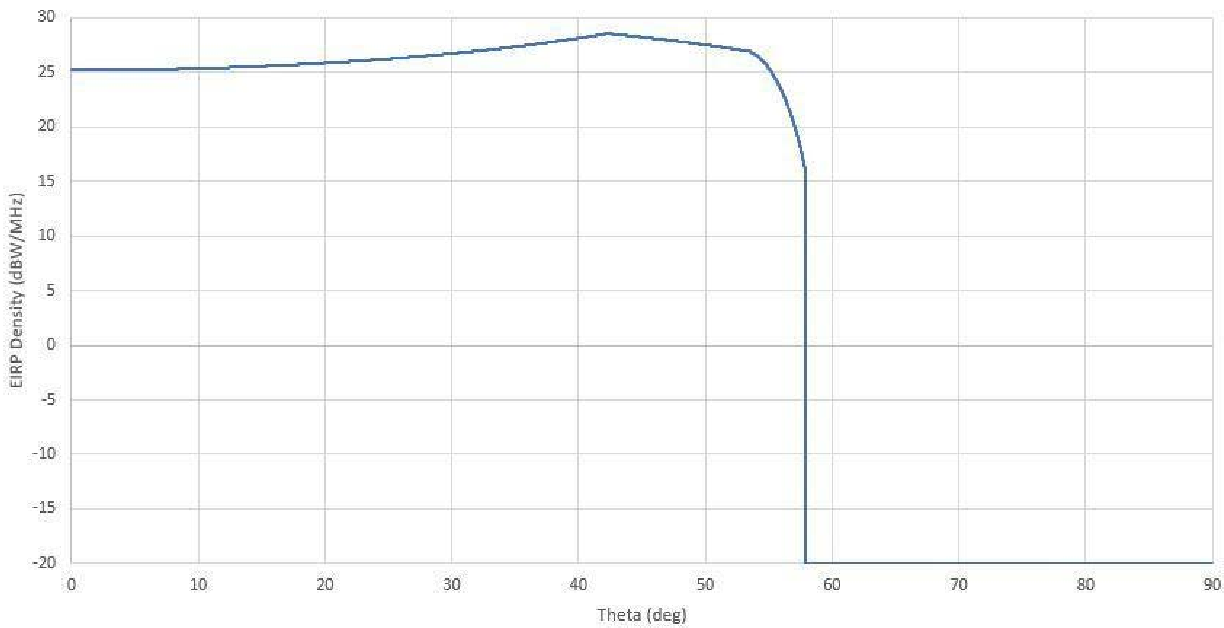
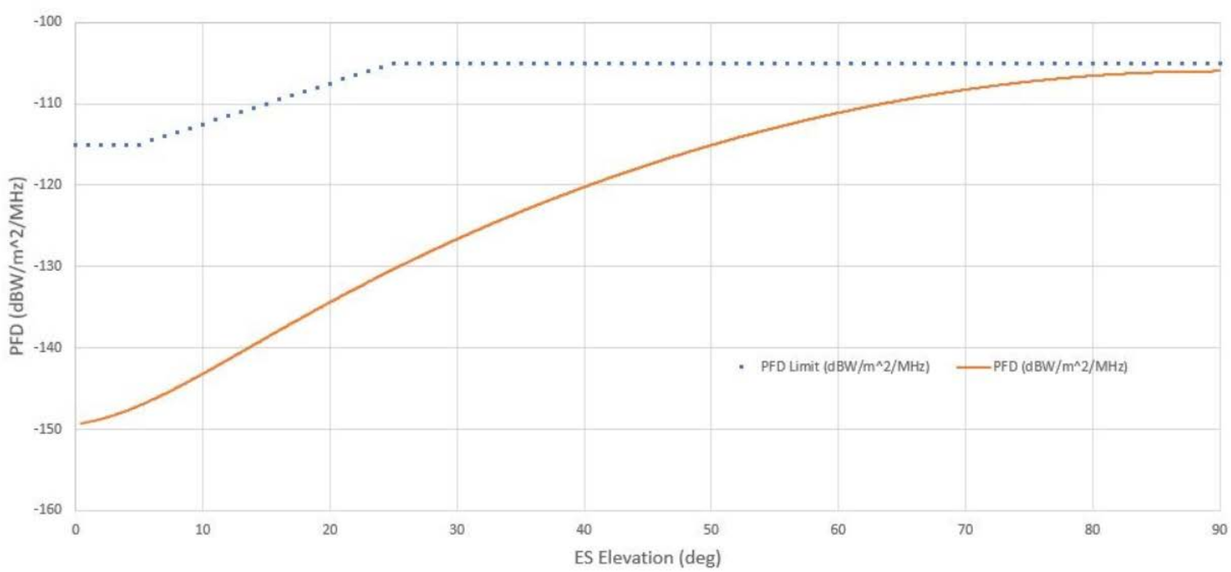


Figure 18. HVNET Space Station PFD and Section 25.208(t) PFD Limits in the 41.9-42.0 *GHz Band (TT&C)*



A.4.2 Interference Protection of GSO Satellite Systems

In accordance with Section 25.289 of the FCC's rules, HVNET operations in the 37.5-42 GHz, 47.2-50.2 GHz and 50.4-51.4 GHz bands will not cause unacceptable interference to, or claim protection from, GSO FSS or GSO BSS networks.

A.4.3 Sharing with Other NGSO FSS Systems

Internationally, footnotes to the International Table of Frequency Allocations require coordination between co-frequency NGSO FSS systems in the V-band pursuant to No. 9.12 of the ITU Radio Regulations. In accordance with Section 25.261(b) of the FCC's rules, Hughes will coordinate in good faith with other V-band NGSO FSS systems authorized in the United States.

HVNET is designed to share with other NGSO FSS systems, including those authorized in the prior processing round and those proposed in this processing round, by operating multiple satellites in view of a given earth station.

Given that HVNET satellites will be capable of communicating with multiple gateways, Hughes can also mitigate in-line events with HVNET gateway links by muting transmissions to or from a satellite and communicating with a different gateway. Another mitigation technique that could be employed is the temporary use of alternative licensed frequencies. Where needed and feasible, the HVNET processing capability allows the System to operate at a higher spectral efficiency to make up for loss in spectrum.

In addition, as required under Section 25.146(e), Hughes will make available ephemeris data for its constellation to other authorized, in-orbit satellite operators in a manner that is mutually acceptable.

A.4.4 Other Sharing Issues

The following subsections address additional sharing and compatibility issues.

A.4.4.1.1 37.5-40.0 GHz

Hughes will coordinate with Federal space research service ("SRS") facilities in the 37.5-38.0 GHz band and will support the FCC's coordination with NTIA with respect to Federal fixed and mobile services in the 37.5-38.6 GHz band.

A.4.4.1.2 40-42 GHz

Hughes will coordinate its NGSO gateway downlink operations with Federal SRS facilities in the 40-40.5 GHz band and support any necessary FCC coordination with NTIA with respect to Federal satellite services in the 40-41 GHz band.[5]

A.4.4.1.3 47.2-48.2 GHz and 50.4-51.4 GHz

HVNET's U.S. gateway uplink operations in the 47.2-48.2 GHz and 50.4-51.4 GHz bands will be subject to obtaining additional earth station authorizations and consistent with the Commission's rules.[6]

[5] This coordination is pursuant to Recommendation ITU-R SA.1396, "Protection Criteria for the Space Research Service in the 37-38 GHz and 40.0-40.5 GHz Bands."

[6] *See* 47 C.F.R. § 25.136(d), (e).

A.4.4.1.4 48.2-50.2 GHz

HVNET's U.S. service and gateway uplink operations in the 48.2-50.2 GHz band will be subject to obtaining additional earth station authorizations and consistent with the Commission's rules.[7] Hughes also will coordinate with RAS stations in the 48.94-49.04 GHz band.[8]

A.5 Orbital Debris Mitigation

Hughes is an experienced satellite operator with deep understandings of the complexities involved with satellite development, deployment, and operations. This experience has also fostered a genuine appreciation for the value and fragility of the space environment upon which we all rely. Hughes believes that all space stakeholders play a part in ensuring the long-term sustainability of space activities, and we are committed to incorporating industry best practices for debris mitigation into the design of our system from its earliest stages.

Hughes' debris mitigation plan for the HVNET satellite constellation is subject to direct and effective regulatory oversight by the licensing authority of Germany, thus satisfying the Commission's debris mitigation requirements.[9] Nonetheless, Hughes' debris mitigation plan is provided below, consistent with the Commission's existing requirements under Section 25.114(d)(14).[10]

Although the spacecraft manufacturer for the HVNET System has not yet been selected and the Commission's new debris mitigation requirements under revised Section 25.114(d)(14) have not become effective, Hughes will seek and obtain Commission approval of any plan modifications to the extent required following the effectiveness of the Commission's revised Section 25.114(d)(14).

A.5.1 Spacecraft Hardware Design

Hughes will assess and limit the amount of debris released in a planned manner during normal operations. The satellites will not employ any releasable shrouds or component covers, and launch vehicle separation mechanisms will be designed to retain any debris that may be created during satellite deployment. In short, Hughes will not intentionally release any debris during the normal deployment and operation of its system.

Hughes will assess and limit the probability that a collision with small debris or meteoroids would cause a loss of control and prevent post-mission disposal of the satellites. Hughes understands that hypervelocity particle strikes pose a threat to the functionality of satellites and will consider a variety of techniques in designing its spacecraft to protect critical components and minimize potential consequences of small-particle impacts (*e.g.*, incorporation of shielding, strategic placement of components, providing for functional redundancies, etc.). Once the satellite design is sufficiently mature, Hughes will use NASA's Debris Assessment Software (DAS) to confirm that the probability that

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[7] *See id.* § 2.106.

[8] *See id.* § 2.106 n.US342.

[9] *See id.* § 25.114(d)(14)(v).

[10] *See id.* § 25.114(d)(14).

such small-particle impacts would cause loss of control and prevent disposal activities is 0.01 or less per spacecraft, consistent with revised Section 25.114(d)(14)(ii).

A.5.2 Minimizing Accidental Explosions

Hughes will assess and limit the probability of accidental explosions during and after completion of mission operations. Hughes recognizes that internal energy sources on a satellite can build to explosive levels if not properly managed and will employ industry best practices to avoid such situations with its constellation of satellites. Such practices may include the use of leak-before-burst ("LBB") design standards for battery cells and pressurized vessels, and the incorporation of fault detection, isolation, and recovery ("FDIR") algorithms in the satellites' power subsystems. Also, the propulsion systems that will be used on the satellites will not release persistent liquid droplets or effluents of any kind that represent a persistent hazard to other spacecraft.

Furthermore, the satellites will have the capability to permanently deplete all internal energy sources (including chemical, pressure, and kinetic) that could credibly build to sufficient levels to cause structural failure and create debris. The specific mechanisms for depletion, as well as the procedures and conditions for passivation, will be developed in concert with Hughes' satellite development program.

A.5.3 Safe Flight Profiles

Hughes will assess and limit the probability of collision with other large objects (10 cm or larger in diameter) during the total orbital lifetime of an HVNET satellite, including any de-orbit phases. Hughes has not yet finalized the physical dimensions of the satellites or the full mission profiles and timelines for deploying and disposing of them. Therefore, a complete statistical assessment of collision risk with known large objects must be deferred until these characteristics are determined. At that time, NASA's DAS program will be used to assess this risk to confirm that the probability of collision with other large objects is less than 0.001 per spacecraft, consistent with revised Section 25.114(d)(14)(iv)(A)(1).

Hughes has carefully selected the operational altitude of 1,150 km for its constellation in part because of the relatively low-resident populations of active satellites and debris in the region. Hughes is aware of only a few deployed or proposed satellite systems that are U.S.-licensed or authorized for U.S. market access within 50 km of its proposed constellation, as listed in Table 4 below. OneWeb has already deployed a number of satellites in its constellation at approximately 1,200 km. Additionally, SpaceX is licensed to operate V-band satellites at altitudes from 1,110 to 1,150 km, but has not yet deployed any satellite at these altitudes. Hughes will establish an appropriate operating range around 1,150 km so as to minimize an overlap in altitude with other satellites authorized and deployed at or near the same altitude.

Table 4. Other U.S.-authorized NGSO Satellite Constellations Around 1,150 km

System	Altitude (km)	Status
OneWeb	1,200	partially deployed
SpaceX	1,110-1,150	not yet deployed

Hughes will monitor its satellites' trajectories for predicted conjunctions with known objects, and upon receipt of a conjunction warning, will take all necessary and possible steps to assess and mitigate the resultant collision risk. This includes executing maneuvers using the satellites' propulsion systems to increase separation distances, as warranted.

If its satellite has a close approach with another active satellite, Hughes will contact the other operator and coordinate with the other operator on the execution of any evasive maneuver. To assist in these coordination efforts, Hughes will also make contact information for its operations center available to other operators and will share its satellite ephemeris and maneuvering activities as necessary to mitigation the potential for collisions.

To the extent that the satellites, during a mission or de-orbit phase, will transit through the orbits used by inhabitable spacecraft such as the International Space Station, Hughes will coordinate with NASA or other spacecraft operators to maintain a safe operating distance of at least 25 km, thus minimizing the risk of collision and avoid posing operational constraints to the inhabitable spacecraft.

HVNET satellites will also be easily trackable with current technologies. While specific physical dimensions are not yet finalized, the satellites will be significantly larger than 10 cm in diameter, making light work for the U.S. Space Surveillance Network and emerging commercial Space Situational Awareness service providers to detect and track every satellite in the constellation. Furthermore, each satellite will have a GPS receiver on-board, and Hughes' Satellite Control Center will maintain high-accuracy orbit solutions for its fleet. Each satellite will have a unique identifier in its downlink to assist in confirming acquisition post-launch and with command security. Prior to launch, Hughes will register its satellites with the 18th Space Control Squadron or successor entity and will continue coordination throughout the mission to ensure that the latter has the most accurate tracking and maneuvering information available.

Hughes' constellation consists of multiple planes of satellites, and station-keeping requirements will be set in accordance with payload requirements as the design matures. To avoid collisions within the constellation, Hughes will make use of a moderate amount of altitude variation such that safe radial separations are maintained at plane intersections. This will increase flight safety, lessen station-keeping requirements under nominal operational conditions, and substantially reduce the potential for collision with other satellites even under scenarios involving satellite anomalies or failures.

While the mean altitudes of each plane will be actively maintained, the System is designed to be tolerant of the natural periodic variations in semi-major axis as well as natural periodic and secular perturbations in other orbital parameters. As mentioned above, some additional altitude margin will also be used to reduce the radial density of the constellation. However, the difference between the highest apogee and the lowest perigee of the constellation will be constrained to +/- 30 km. As alluded to above, Hughes will skew this operational range slightly downward, in the name of safety, in order to prevent any altitude overlap with OneWeb's constellation. Inclination will be maintained within one degree, and the right ascension of ascending node will regress secularly and will therefore cycle through the entire range of 0˚ to 360˚.

These orbital maintenance tolerances are summarized in Table 5 below.

Table 5. Constellation Tolerances

Parameter	Tolerance
Highest apogee altitude	1,160 km
Lowest perigee altitude	1,100 km
Inclination	± 1°
Right ascension of ascending node	0° - 360˚

Each satellite in the constellation will be equipped with an active propulsion system capable of maintaining the orbital parameters above, as well as executing responsive collision avoidance maneuvers and post-mission disposal maneuvers. As certified in Section A.6 below and pursuant to revised Section 25.114(d)(14)(iv)(A)(5), upon receipt of a space situational awareness conjunction warning, Hughes will review and take all possible steps to assess and, if necessary, mitigate the collision risk.

A.5.4 Post-Mission Disposal

At the conclusion of their operational missions, HVNET satellites will be disposed of through atmospheric reentry. Specifically, the propulsion systems will be used to reduce the altitude of the satellites in phases. Upon decommissioning, a LEO satellite first will be moved to a circular staging orbit just below the operational constellation. Its perigee will then be lowered though a series of apogee-centered maneuvers that places the satellite into an elliptical orbit resulting in rapid decay via atmospheric drag and uncontrolled reentry into the atmosphere. The entire disposal process is anticipated to take less than five years, which is well below the 25-year timeline stipulated in NASA's Technical Standard.

The satellite mass is not yet finalized, and the specific propulsion system and fuel type have not yet been chosen, so it is not possible at this time to determine the amount of fuel that must be reserved for disposal operations. However, the satellite specification will require adequate fuel budgets and margins to perform these maneuvers, and this fuel will be reserved for disposal purposes throughout the mission.

While Hughes will have the capability to passivate its satellites, it intends, under nominal disposal conditions, to retain full operational control of the LEO satellites after completion of disposal maneuvers, rather than depleting on-board energy sources and losing contact with its assets. Hughes believes safety is enhanced by doing so in two important ways. First, passivation is intended to prevent accidental explosion stemming either from environmental deterioration or the development of anomalous conditions on the spacecraft. By deorbiting within five years of decommissioning and by continuing to monitor and operate its satellites, Hughes will be able to continue to actively respond to any conjunctions its satellites may subsequently encounter with other known objects, while ensuring that explosive conditions are highly unlikely to develop. Second, the retention of on-board energy sources will aid with the eventual destruction of the satellite during atmospheric reentry, facilitating more complete disintegration and lessening the amount of material that might otherwise reach the Earth's surface and pose a risk of human casualty.

Further, Hughes will design its satellites to disintegrate as thoroughly as possible during atmospheric reentry in order to limit the amount of material that survives to reach the ground. Once its satellite design has been finalized, Hughes will use NASA's DAS to confirm that the casualty risk is less than 0.0001 (*i.e.,* 1 in 10,000) per spacecraft, consistent with revised Section 25.114(d)(14)(vii)(D)(2)(b).

Prompt and reliable disposal operations are critical to maintaining safety and preserving a clean operating environment for Hughes, as well as for other space operators. Hence, high priority is placed on disposal assurance, and reliability will be addressed through a combination of robust satellite design, parts screening, system testing, and health monitoring, thus ensuring a successful disposal probability of at least 0.9 per spacecraft, with a goal of achieving an even higher probability of success, consistent with revised Section 25.114(d)(14)(vii)(D)(1). Disposal reliability will be specified in Hughes' satellite design requirements and verified through a reliability analysis on the final satellite design and a rigorous ground testing program.

A.6 Certification

Hughes certifies that upon receipt of a space situational awareness conjunction warning, Hughes will review and take all possible steps to assess and, if necessary, mitigate the collision risk.[11]

[11] *See Mitigation of Orbital Debris in the New Space Age*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd 4156, App. A (Final Rules) (2020) (adopting revised Sec. 25.114(d)(14)(iv)(A)(5)).

ENGINEERING CERTIFICATION

I hereby certify that: (i) I am the technically qualified person responsible for preparation of the engineering information contained in this application; (ii) I am familiar with Part 25 of the Commission's rules; (iii) I have prepared or reviewed the engineering information contained in this application; and (iv) the engineering information contained in this application is complete and accurate to the best of my knowledge and belief.

/s/ Channasandra Ravishankar
Channasandra Ravishankar
Senior Vice President, Engineering