MVDDS 12.2-12.7 GHz
Co-Primary Service Coexistence

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Table of Contents

Table of Figures

About the Author

Tom Peters is a radiofrequency engineer with more than twenty years of industry and government experience in network deployment, design and regulation. Mr. Peters currently serves as a Senior Advisor at the international law firm of Hogan Lovells US, LLP. He previously served as Chief Engineer of the Wireless Telecommunications Bureau of the United States Federal Communications Commission, where he helped develop the agency's National Broadband Plan and guided numerous spectrum policy proceedings to resolution. Mr. Peters started his career in wireless at LCC International, a global engineering consulting firm, where he helped design wireless networks all over the world. At LCC, Mr. Peters was a Director and responsible for Engineering Design Services in Latin America, and later in Europe and Asia-Pacific. He subsequently addressed technical regulatory and spectrum policy matters at Nextel Communications, where he served as Director of Technology Development. He then co-founded Wireless Strategy, LLC, a strategic engineering consulting firm.

Mr. Peters' analysis was aided by Alan Pate. Mr. Pate contributed to this analysis through his application of LIDAR mapping techniques to deployment models of 5G MVDDS. Mr. Pate has more than 30 years of experience in military-satellite, commercial-satellite and terrestrial-wireless communications. He founded Waverley LLC, a wireless consulting company, that offers network-mapping and business-planning services across a variety of spectrum bands, including the 12 GHz band. Mr. Pate holds a BSc degree in Physics from the University of St. Andrews, Scotland.

I. Executive Summary

Explosive consumer demand for mobile broadband and the new imperative of supporting an unprecedented number of intelligent devices on wireless communications networks have focused renewed attention on identifying additional spectrum for wireless broadband use. This study analyzes whether and under what conditions the 12.2-12.7 GHz band could support fifth-generation (5G) wireless broadband.

Three separate communications services may currently use the 12.2-12.7 GHz band on a co-primary basis in the United States: (1) the Broadcast-Satellite Service (BSS); (2) the Multichannel Video Distribution and Data Service (MVDDS); and (3) the Non-Geostationary Orbit Fixed Satellite Service (NGSO FSS). In a series of decisions in the early 2000s, the FCC concluded that MVDDS licensees could share with direct broadcast satellite (DBS) television receivers in the BSS allocation, but only subject to stringent limitations on MVDDS.[1] Using the best data available at the time, the FCC found that two-way MVDDS operations had the potential to cause harmful interference to DBS receivers by casting too much power over too wide and area.[2] The FCC was also unable to identify adequate shielding from terrain obstacles and other impediments to consistently ensure

[1] *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range et al*., Memorandum Opinion and Order and Second Report and Order, 17 FCC Rcd 9614 (2002), http://bit.ly/1r72PAs ("*2002 MVDDS Order*"); *see also Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the KU Band Frequency Range*, Third Report and Order, 18 FCC Rcd 13468 (2003), http://bit.ly/1PuccWA ("*MVDDS Third R&O*") (revising service area definition and substantial service requirements for MVDDS); *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, Second Memorandum Opinion and Order, 18 FCC Rcd 2324 (2003), http://bit.ly/1PuccWA ("*MVDDS Second MO&O*") (addressing certain petitions for reconsideration); *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, Third Memorandum Opinion and Order, 18 FCC Rcd 2307 (2003), http://bit.ly/1UosH2g ("*MVDDS Third MO&O*") (addressing certain petitions for reconsideration); *Amended Parts 25 and 101 of the Commission's Rules Governing Multichannel Video Distribution and Data Service in the 12.2 – 12.7 GHz Band*, Order, 19 FCC Rcd 9727 (May 28, 2004), http://bit.ly/1UDO4Qh (resolving incorrect rule publication in the Federal Register); Fourth Erratum to *MVDDS Second R&O*, 19 FCC Rcd 17734 (Sept. 17, 2004), http://bit.ly/28iafCT; Third Erratum to *MVDDS Second R&O*, 17 FCC Rcd 15849 (Aug. 14, 2002), http://bit.ly/1X45Dw2; Second Erratum to *MVDDS Second R&O*, ET Docket 98-206 (June 7, 2002), http://bit.ly/22ETr54; First Erratum to *MVDDS Second R&O*, ET Docket 98-206, (June 4, 2002), http://bit.ly/1U1rZuN; *Amendment of Parts 2 and 25 of the Commission's Rules to Permit Operation of NGSO FSS Systems Co-Frequency with GSO and Terrestrial Systems in the Ku-Band Frequency Range*, First Report and Order and Further Notice of Proposed Rule Making, 16 FCC Rcd 4096 (2000), http://bit.ly/1t8oEle ("*2000 MVDDS Order*") (allocating the 12.2-12.7 GHz band for NGSO FSS service downlinks on a primary basis and proposing technical and service rules for MVDDS to operate on a co-primary with NGSO FSS).

[2] *2002 MVDDS Order* ¶ 62.

the installed base DBS receivers that now numbers more than 30 million would not suffer harmful interference under more permissive MVDDS service rules than the FCC ultimately adopted.[3]

Our analysis challenges both findings from the technical study the FCC relied upon in 2002. Using current-generation technology profiles and business cases, we modeled three likely 5G deployments:

- point-to-point (PtP) fixed links;
- urban canyon small cells; and
- indoor small cells.

We then employed newly available ultra-high-resolution imagery of buildings and terrain to analyze the degree of attenuation that potential 5G operations would receive from all obstacles to signal propagation, whether topographical, morphological or constructed. Certain simplifying assumptions were used where necessary to avoid excessive computational complexity, but we generally sought to rely upon worst-case assumptions to address uncertainty. Our preference for worst-case assumptions tended to overstate the risk of potential interference, but we adopted this posture intentionally to help demonstrate how much additional margin for coexistence would exist if more realistic operating assumptions were used.

Our in-depth analysis of 5G deployment scenarios and our use of real-world data on terrestrial ground-attenuation features allowed us to reach two fundamental conclusions:

- First, MVDDS licensees *can* deploy two-way 5G services in the 12.2-12.7 GHz band even with the current level of protection that DBS enjoys today from MVDDS licensees.
- Second, MVDDS licensees *cannot* deploy two-way 5G services in the 12.2-12.7 GHz band without overwhelming NGSO FSS operations even under the current rules, notwithstanding new 5G deployment architectures and newly available high-resolution ground-obstacle data.

In other words, while coexistence between DBS and MVDDS is feasible within limits, coexistence between NGSO FSS and MVDDS is not – perhaps not even under the current MVDDS rules.

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[3] *Id.* at App. G, Description of Model Used for Determining Regional EPFD Levels and Satellite Outage Analysis Results ("the analysis does not take into account natural and man-made shielding or other propagation losses that would minimize the impact of MVDDS to the DBS customer").

II. Introduction and Background

The FCC established the MVDDS to provide "consumers with TV programming and Internet connectivity from terrestrial transmitters."[4] In authorizing the service in 2000, the FCC required MVDDS to be a one-way service and adopted other "exacting" technical constraints to permit MVDDS to share with DBS receivers as well as with non-geostationary satellite orbit (NGSO) receivers in the Fixed-Satellite Service (FSS).[5] The FCC licensed MVDDS in 214 geographic areas called MVDs through competitive bidding conducted in January 2004 and December 2005.[6] Each geographic license is comprised of one spectrum block of 500 contiguous megahertz at 12.2-12.7 GHz. Licensees can divide the block into any size channels. MVDDS systems may not cause harmful interference to stations in Canada or Mexico.[7]

The MVDDS 5G Coalition submitted a petition April 26, 2016 that asked the FCC to initiate a rulemaking proceeding on a series of rule changes intended to permit MVDDS licensees to use the 12.2-12.7 GHz band for two-way mobile broadband communications.[8] The FCC sought comment on this petition May 9, 2016.[9] In its petition, the Coalition sought several changes to the rules governing MVDDS.[10] First, the Coalition called for the elimination of section 101.1407's prohibition on two-way MVDDS communications and asked the FCC to add new language in section 101.1411 that would allow any common

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[4] *See generally Multichannel Video Distribution and Data Service,* FCC (May 3, 2006), http://fcc.us/25qTwOR.

[5] *See 2000 MVDDS Order* ¶ 2; *2002 MVDDS Order* ¶ 11.

[6] MVDs are identical to Designated Market Areas or DMAs as they existed in 2002. The term DMA was abandoned after Nielsen Media Research, Inc. identified its trademark rights to that term. *See WTB Announces Changes in the Universal Licensing System to Revise the Names of Market Designators for Multichannel Video Distribution and Data Service Licenses*, Public Notice, 19 FCC Rcd 10679 (WTB 2004).

[7] Within 35 miles of the Canadian and Mexican borders, MVDDS stations must observe certain operational limitations. 47 C.F.R. § 101.1423. Within five miles of the Canadian or Mexican borders, no MVDDS stations are allowed. *Id*.

[8] The Coalition includes Braunston Spectrum LLC; Cass Cable TV, Inc.; DISH Network L.L.C.; GO LONG WIRELESS, LTD.; MDS Operations, Inc.; MVD Number 53 Partners; Satellite Receivers, Ltd.; SOUTH.COM LLC; Story Communications, LLC; Vision Broadband, LLC; and WCS Communications, Inc. Members of the Coalition hold 212 of the 213 MVDDS licenses in the United States.

[9] *Consumer & Governmental Affairs Bureau Reference Information Center Petition for Rulemakings Filed,* Public Notice, Report No. 3042 (May 9, 2016), http://bit.ly/1qPL2Oa.

[10] The Coalition also asked the FCC to revise the U.S. table of allocations table to add a mobile (except aeronautical mobile) allocation to the 12.2-12.7 GHz band, consistent with the mobile allocation of the band globally. MVDDS 5G coalition, *Petition for Rulemaking to Permit MVDDS Use of the 12.2-12.7 GHz Band for Two-Way Mobile Broadband Service*, RM-11768 16 (filed Apr. 26, 2016) ("*Coalition Petition*"). The addition of a mobile allocation to the 12.2-12.7 GHz band would be a prerequisite to the operating rule changes the Coalition has proposed.

carrier or non-common carrier service to operate in the band.[11] Second, the Coalition asked for a series of rule changes that would consider relaxing operational constraints on MVDDS, including:

- Restrictions that limit MVDDS effective isotropic radiated power (EIRP) to no more than 14 dBm per 24 MHz;[12]
- Requirements that MVDDS licensees meet a schedule of stringent equivalent power flux density level (EPFD) levels, which vary by region of the United States;[13] and
- Requirements that the MVDDS operator establish that the EPFD from its transmitting antenna will not exceed the applicable limit at all DBS customer-of-record locations prior to commencing MVDDS operations.[14]

Third, the Coalition sought the elimination of the current primary allocation for NGSO FSS in the 12.2-12.7 GHz band while continuing to allow NGSO FSS operations in the adjacent 11.7-12.2 GHz band.[15]

Although this study analyzes two-way communications and higher EIRP levels in the 12.2-12.7 GHz, the study emphatically does not envision any change to the framework for how DBS is protected: MVDDS would continue to have an absolute obligation to protect DBS to a scheduled EPFD level, just as it does today. No change in the EPFD protection framework is proposed or contemplated in this study. The analysis that follows demonstrates that two-way mobile broadband operations in the 12.2-12.7 GHz band can protect DBS receivers consistent with the currently prescribed EPFD limits, even if MVDDS power limits are increased. Further, given that the DBS protection mechanism continues to be EPFD limits at actual DBS antenna locations, power limits are, in effect, not required. In other words, if the EPFD level is met at all DBS antenna locations, then the EIRP of the MVDDS transmitter is irrelevant. For purposes of NGSO FSS operations, however, the analysis shows that coexistence between mobile broadband operations and NGSO FSS operations in the 12.2-12.7 GHz band is not possible even under the currently authorized MVDDS power levels without additional constraints, such as geographic or frequency separation, on MVDDS, NGSO FSS or both services.[16]

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[11] *Coalition Petition* at 18.

[12] 47 C.F.R. § 101.113(a).

[13] 47 C.F.R. § 101.147(b); 47 C.F.R. § 101.105(a)(4)(ii).

[14] 47 C.F.R. § 101.1440(a).

[15] *Coalition Petition* at 22.

[16] This study is limited to the technical feasibility of two-way mobile broadband operations in the 12.2-12.7 GHz band consistent with the services that are operating or are authorized to operate in the band. The study does not make any normative recommendations as to whether or how to permit coexistence between MVDDS and NGSO FSS operations in 12.2-12.7 GHz band.

III. Review of Current MVDDS Operational Constraints

MVDDS today can operate one-way digital fixed non-broadcast services.[17] Two-way transmissions, mobile services and aeronautical services are prohibited. Special technical rules apply to MVDDS for the benefit of DBS operations, which require a reasonably quiet operating environment to receive signals from geostationary satellites.[18] The FCC also adopted a set of equivalent power flux density level (EPFD) limits that MVDDS operators must meet.[19] The precise EPFD values vary by geography because rain and other atmospheric conditions can materially affect radiofrequency propagation in these frequencies.[20] MVDDS operations can commence operations only after ensuring that the EPFD limit from the MVDDS transmitting antenna does not exceed the applicable safeguard for DBS end users for that area at nearby DBS receive antennas.[21]

MVDDS licensees must conduct a survey of their proposed deployment area and calculate whether proposed MVDDS transmissions would exceed the EPFD for that area, after taking into account terrain, building structure characteristics, and actual DBS subscriber locations.[22] If proposed MVDDS operations exceed applicable EPFD limits, then the MVDDS licensee must either obtain written consent from affected DBS customers or take whichever steps are necessary to meet the EPFD limit.[23] If the proposed MVDDS operations do not exceed the applicable EPFD limits, then MVDDS deployment may commence.

In addition to EPFD limits, MVDDS operations are subject to strict EIRP limits of 14 dBm per 24 MHz.[24] To put this value in perspective, this MVDDS EIRP limit is roughly equivalent to *one tenth of the maximum power that a smartphone transmits*,[25] and roughly *half of the out-of-band power* allowed for unlicensed devices under part 15.[26] Using the

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[17] 47 C.F.R. § 101.1407.

[18] 47 C.F.R. § 101.1440.

[19] 47 C.F.R. § 101.1440(b); 47 C.F.R. § 101.105(a)(4)(ii).

[20] *See, e.g., Comprehensive Review of Licensing and Operating Rules for Satellite Services*, Notice of Proposed Rulemaking, 27 FCC Rcd 11619 ¶ 36 (2012) (defining "rain fade" as the "attenuation of transmitted signals due to the scattering effect of precipitation in the atmosphere").

[21] 47 C.F.R. § 101.1440(a).

[22] 47 C.F.R. § 101.1440(b).

[23] 47 C.F.R. § 101.1440(a).

[24] 47 C.F.R. § 101.113, n.11.

[25] A smartphone has a maximum EIRP of 23 dBm. Assuming a 20 MHz channel bandwidth, this maximum level is roughly equivalent to 24 dBm per 24 MHz. The MVDDS base station power level is 10 dB below this threshold, or about one tenth of the power available to a handheld smartphone. This conversion also represents the best-case comparison because it assumes the smartphone will utilize the widest possible LTE channel bandwidth. If one were to assume 23 dBm per 10 MHz, the converted value of smartphone signal strength would scale to 27 dBm per 24 MHz, or 13 dB more than the current MVDDS base station power limit.

[26] *See* 47 C.F.R. § 15.247(d). A 20 MHz channel in the 2.4 GHz band, for example, can transmit at 36 dBm EIRP (30 dBm conducted plus 6 dBi antenna gain). According to section

scaling factor proposed in the *Spectrum Frontiers NPRM*, this value equates to 20 dBm per 100 MHz.[27] In contrast, the power limits proposed for the 28, 39 and 37 MHz bands in the *Spectrum Frontiers NPRM* are 62 dBm per 100 MHz for base stations in non-rural counties and 65 dBm per 100 MHz for base stations in rural counties of less than 100 persons per square mile.[28]

IV. Discussion of Interference Effects on Co-Primary Services 12.2-12.7 GHz

MVDDS shares the 12.2-12.7 GHz band on a co-primary, non-harmful interference basis with DBS and on a purely co-primary basis with NGSO FSS.[29] The FCC adopted this regime in 2000 when it authorized MVDDS and NGSO FSS to operate in the band.[30] In doing so, the FCC rejected arguments that the regime would allow MVDSS to cause harmful interference to the incumbent DBS or the newly created NGSO FSS.[31] Instead, the FCC concluded that technical rules could ensure that MVDDS did not cause harmful interference to either service.[32] The FCC also found that the legislative history of the Rural Local Broadcast Signal Act demonstrated that Congress "fully anticipated" that terrestrial services could share spectrum with NGSO FSS operations.[33]

Limited deployment of MVDDS and NGSO FSS has occurred in the 12.2-12.7 GHz band since the FCC adopted this regime 16 years ago. The FCC has twice extended the buildout deadlines for MVDDS licensees on grounds that "the record demonstrates that there is a lack of viable, affordable equipment for MVDDS that can be deployed in the

15.247(d) of the Commission's rules, the out-of-band emissions in any 100 kHz segment must be 20 dB below the highest in-band power in a 100 kHz segment. *Id*. At 36 dBm/20 MHz, the average in-band power will be about 13 dBm/100 kHz and, thus, the out-of-band emissions must be −7 dBm/100 kHz. Scaling this to 24 MHz gives a total out-of-band power of 17 dBm/24 MHz. The MVDDS in-band base station power limit is 3 dB *below* this level, which means MVDDS in-band power is about half the out-of-band power permitted under part 15 of the FCC's rules. Technically, the Commission's rules allow more out-of-band power from unlicensed devices in the 12.2-12.7 GHz band than in-band power from licensed MVDDS services.

[27] The conversion is as follows: 14 dBm/24 MHz + 10*log(100/24) = 20 dBm/100 MHz.

[28] *Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Notice of Proposed Rulemaking, 30 FCC Rcd 11878 ¶ 275 (2015) ("*Spectrum Frontiers NPRM*").

[29] *See, e.g.*, *2003 MVDDS Order* ¶ 26.

[30] *See generally 2000 MVDDS Order*.

[31] *See id.* ¶¶ 21, 205-28; *see also 2002 MVDDS Order* ¶¶ 18-19, 27, 68.

[32] *See, e.g.*, *2000 MVDDS Order* ¶¶ 205-28. For example, the FCC's rules prohibit an MVDDS licensee from beginning operation until it can ensure that the EPFD from a proposed transmitting antenna does not exceed the applicable EPFD limit at any DBS subscriber location. MVDS licensees must also satisfy all complaints of interference to DBS customers of record during a one year period after commencement of operation of the transmitting facility. See *MDS Operations, Inc. et al*., Order, 25 FCC Rcd 7963 ¶ 3 (WTB 2010) ("*2010 MVDSS Extension Order*"); 47 C.F.R. §§ 101.105(a)(4)(ii), 101.144(g).

[33] *See 2002 MVDDS Order* ¶ 20.

12.2-12.7 GHz band."[34] DBS satellite receivers are widely deployed in the band.[35] But while the 12.2-12.7 GHz band is allocated on a co-primary for NGSO FSS, NGSO FSS operations have yet to be authorized for use or deployed in the United States.[36]

A. DBS/MVDDS Interference Analysis

DBS operations use high-powered geostationary satellite orbit (GSO) satellites to broadcast video content and other programming from space to satellite-receive antennas. These satellite-receive antennas or "dishes" are typically located on rooftops, balconies and other areas with a clear line of sight to the equatorial sky. DBS operations are allocated spectrum in the 12.2-12.7 GHz band in Regions 1 and 2 and support numerous satellite television operators, including DISH and DirecTV in the United States. More than 33 million Americans subscribe to satellite television.[37]

Analyzing the interference effects of mobile broadband communications on such an extensive set of receivers is complex. The number and variety of possible 5G wireless broadband deployment configurations, antenna orientations and incoming signal vectors means that, without more detailed analysis, a standard EIRP limit for 5G operations in the 12.2-12.7 GHz band cannot definitely prevent harmful interference to DBS receivers in all instances. That said, a modeling methodology that takes into account the deployment characteristics of DBS and MVDDS operations can greatly increase confidence that context-sensitive EPFD limits will prevent harmful interference from occurring for known use cases and deployment configurations.

We consider three likely 5G use cases for the 12.2-12.7 GHz band: (1) point-to-point (PtP) fixed links; (2) small cells in urban corridors with substantial pedestrian and vehicular traffic, which are also known as urban canyons; and (3) small cells to provide indoor coverage in various locations throughout the country. Each use case we analyzed started from the assumption that DBS antennas are ubiquitous. For the PtP use case, we modeled one DBS receive antenna in every two square meters of the study area. For the higher-resolution, outdoor and indoor small-cell use cases, we modeled one DBS receive antenna in every one square meter of the study area. These assumptions obviously overestimate the number of DBS receive antennas in the study area, but they allow for a conservative, worst-case prediction about the potential for 5G MVDDS operations to generate excess EPFD.

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[34] *2010 MVDDS Extension Order* ¶ 10; *see also* South.com L.L.C. and DISH Network L.L.C., Request for Extension of Time, ULS File No. 0006310688 (granted Jan. 26, 2015).

[35] *See, e.g.*, *Annual Assessment of the Status of Competition in the Market for the Delivery of Video Programming*, Seventeenth Report, DA 16-510 ¶ 19 (WTB 2016) (estimating that most Americans currently have access to DBS services), http://bit.ly/1PFfHtx.

[36] *See Coalition Petition* at 7.

[37] Press Release, Leichtman Research, Major Pay-TV Providers Added About 10,000 Subscribers in 1Q 2015 (May 14, 2015), http://bit.ly/1P9I9TR.

To accurately analyze the potential for excess EPFD in each of the three scenarios, we used detailed survey data generated by the United States Geological Service (USGS) using Light Detection and Ranging or LIDAR. LIDAR offers the ability to create high-resolution, three-dimensional digital models of both terrain and constructed features. This powerful mapping tool, which did not exist when the MVDDS rules were adopted in 2000, is now available in various resolutions, including detailed one-meter horizontal resolution and a ten-centimeter root mean square error standard for vertical accuracy.[38] The new spatial resolutions provide much more granular data than has been historically available to the public.[39] Whereas prior network planning tools had to rely upon very low resolution, wide-terrain data that did not allow any meaningful evaluation of spatial reuse by radiofrequency signals, the newly available LIDAR and digital elevation modeling information allows analysts and policymakers to account for actual obstructions and geometric orientations that will provide additional margin between satellite receivers and mobile broadband operations in the 12.2-12.7 GHz band.[40]

Scenario one, the PtP use case, was modeled approximately 20 miles outside Indianapolis, Indiana using LIDAR data with a resolution of two meters; and scenarios two and three, the small-cell use cases, were modeled in downtown Indianapolis using LIDAR data with a resolution of one meter. For scenario three, we modeled operations inside an existing physical structure, the Circle Centre Mall in Indianapolis, Indiana. Opened in downtown Indianapolis in 1995, the Circle Centre Mall has nearly 800,000 square feet of retail and office space located inside four, multi-story buildings that are joined together in the center by a glass dome.

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[38] Samantha T. Arundel et al., *1-Meter Digital Elevation Model Specification*, U.S. GEOLOGICAL SURVEY (2015), http://on.doi.gov/1TR4rtW. The USGS has noted that the "target non-vegetated vertical accuracy of the 1-meter [digital elevation model] shall be 19.6 cm accuracy at the 95-percent confidence level," which is "equivalent to the 10-cm root mean square error in the z dimension." *Id*. at 4.

[39] *Id*.

[40] Before the inception of the USGS 1-meter Three-Dimensional Elevation Program in 2015, the highest-resolution standard dimensional elevation information available in the United States was for 1/9 arc-seconds or about 3 meters. *Id*.

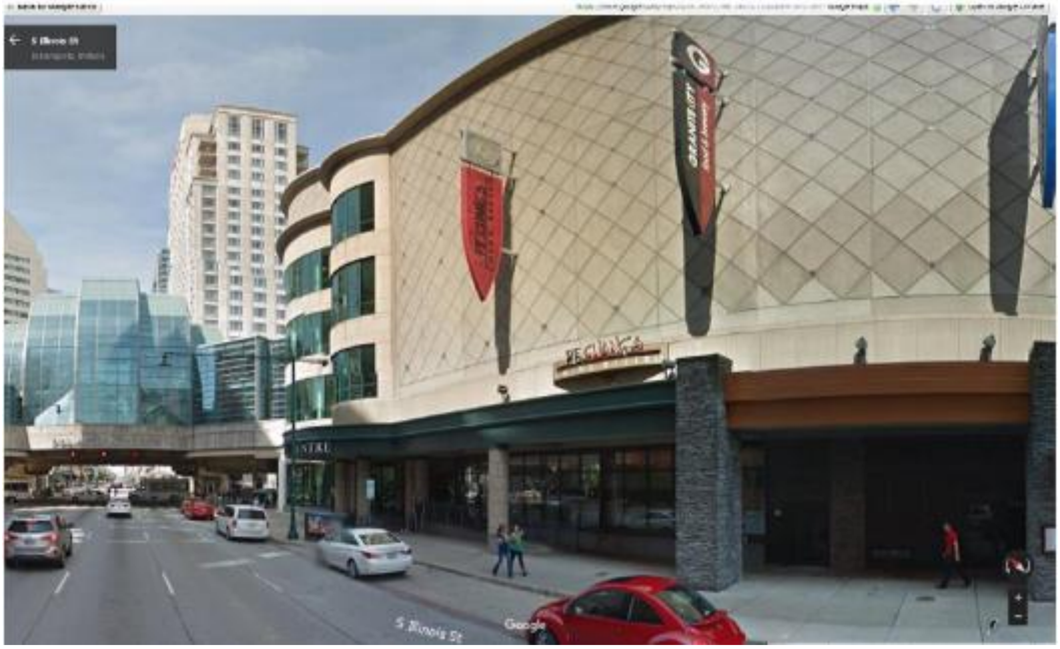

Figure 1: the Circle Centre Mall in Indianapolis, Indiana. *Image: Google Streetview (July 2015).*

To simulate a realistic deployment, our model placed four transmitter locations on each of the mall's four floors. We separated the 5G access points 60 meters apart and used an EIRP for the 5G base units of 36 dBm/100 MHz (i.e., 30 dBm/24 MHz for comparison with the current rule). As explained in greater detail below, to analyze interference from mobile devices, both our outdoor and indoor small cell models assumed five active 5G devices per cell operating simultaneously at maximum power at any given point in time.

For scenarios two and three we employed a stochastic path-loss model known as the Close In (CI) model, as studied and validated for 5G frequencies by Theodore Rappaport, among others. This model is defined by the following formula:

$$\mathrm{PL}^{\mathrm{CI}}(f,d)[\mathrm{dB}] = \mathrm{FSPL}(f,d_0)[\mathrm{dB}] + 10n\log_{10}\left(\frac{d}{d_0}\right) + \chi_\sigma^{\mathrm{CI}},\ \text{where } d \geq d_0$$

In this formula, the CI path loss, PL^{CI} is a function of frequency, *f*, where *f* is also in gigahertz, and distance, *d*. The parameter d_0 is the close-in free space path loss (FSPL) [41] reference distance, *n* is the path-loss exponent (PLE), and $\chi^{CI}{}_{\sigma}$ is a zero-mean Gaussian random

[41] Free space path loss is the loss in signal strength of an electromagnetic wave in the absence of obstacles. FSPL is a function of frequency and distance only, and in logarithmic form, the equation is 20*log(*f*) + 20*log(*d*) – 27.55 where the frequency, *f*, is in megahertz and the distance, *d*, is in meters.

variable with a standard deviation, σ , expressed in decibels.[42] Measurements taken at 10 GHz in Aalborg, Denmark show that this model with values of n=2.0 and $\chi^{CI}{}_{\sigma}$=3.1 closely approximates actual path loss in an urban setting at distances of 60 to 564 meters.[43] We extrapolated this result to the 12.2-12.7 GHz band and assumed that propagation losses for scenarios two and three are equal to FSPL + 3 dB. To remain conservative and to ensure the results were consistent with 5G applications for which a device is not held in a human hand or near a human body, we did not assume any hand or body losses when analyzing the EPFD impact due to mobile station transmissions.

For all scenarios, our analysis calculated signal strengths using a propagation modeling tool developed by Cellular Expert Company[44] with the high resolution LIDAR data. The output of this tool was then post-processed to calculate EPFD levels in accordance with Appendix J of the FCC's *2002 MVDDS Order*,[45] and this determined where the EPFD limits may be exceeded from all MVDDS sites at each pixel across the study area.[46] The actual loss factor for each pixel was calculated based on the DBS receiver's three-dimensional antenna pattern, which also included angle-dependent polarization mismatch losses,[47] and the MVDDS signal vector's angle of arrival to the hypothetical DBS receiver. This angle would vary by Θ (*theta*)*,* which is used to denote the angle of arrival on the horizontal plane, and Φ (*phi*)*,* which is used to denote the angle of arrival on the vertical plane, as shown in the diagram below.

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[42] Shu Sun, et al., *Investigation of Prediction Accuracy, Sensitivity, and Parameter Stability of Large-Scale Propagation Path Loss Models for 5G Wireless Communications*, 65 IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY 5 (May 2016).

[43] The transmit antennas used in the Aarlborg measurements were 20-25 meters high and the environment tested was Urban Macrocell (UMa), not Urban Microcell (UMi) as we are simulating here. However, lowering antennas will typically increase the path loss exponent "n", and this will have the effect of increasing path loss. Therefore, using the coefficients determined by the 10 GHz Aarlborg UMa measurements very likely underestimates MVDDS path loss in a UMi environment.

[44] Cellular Expert Company has developed wireless network performance and planning tools for more than 100 clients in 37 countries, including Vodafone, Telenor, Siemens, Softbank, and Motorola. *About Cellular Expert Company*, CELLULAR EXPERT, http://bit.ly/1sl4Fiq (last visited May 27, 2016).

[45] *2002 MVDDS Order* at App. J.

[46] In other words, power in each pixel from each interfering channel was linearly summed.

[47] The vertically polarized interfering MVDDS signal cannot be received by the circularly polarized DBS antenna without experiencing some loss, but this loss varies with the angle of arrival of the interfering signal. Therefore the polarization mismatch loss was accounted for in gain values included in the antenna pattern for the DBS antenna.

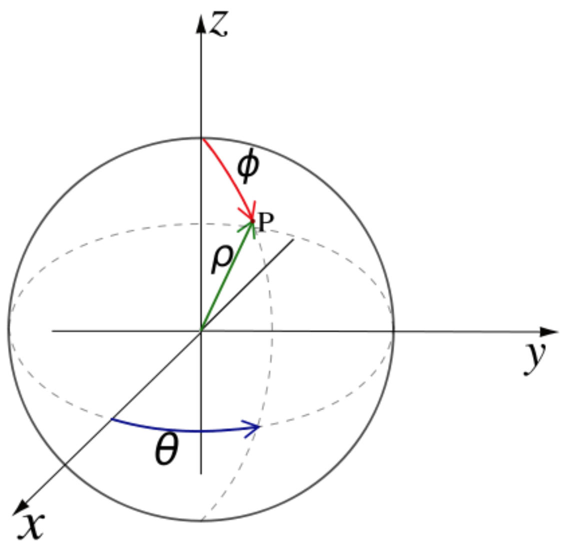

Figure 2: Spherical Coordinate Reference Criteria for DBS Angles of Arrival[48]

DBS satellites serving the United States in the 12.2-12.7 GHz band may be located in various geostationary orbital slots.[49] The orientation of the DBS antenna pattern will be different relative to the angle of arrival of the interfering signal depending on the desired satellite and the longitude and latitude of the DBS receive antenna. The orientation of the pattern relative to the interfering signal affects the antenna's gain and polarization mismatch loss, which, in turn, affects the calculation of EPFD. Therefore, the analysis considered each of the possible visible DBS antenna orientations separately in addition to the DBS receive antenna's geospatial location on Earth, and assumed a hypothetical DBS antenna was located at each pixel of the analysis. The pixel size was two square meters for scenario one and one square meter for scenarios two and three.

A DBS antenna must have a line-of-sight view to the DBS satellite, but due to the density of buildings in urban areas, that view is blocked at many rooftop locations to one or more of the otherwise visible satellites in the geostationary arc. Our analysis also took these types of physical limitations into account. Given that the current EPFD framework requires satisfying the required levels only where a DBS antenna is present, those locations where a DBS antenna cannot possibly be positioned need not be considered. For each of the DBS satellites visible to Indianapolis, Indiana, therefore, our analysis excluded any pixels for which the view to an otherwise visible DBS satellite was obstructed by terrestrial obstacles. We then combined the satellite-specific analyses into a composite, worst-case map by using the highest EPFD value calculated in each of the DBS antenna layers at each pixel. In effect, this methodology excluded only those areas in which the view to all

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[48] *SphericalCoordinates.png*, CONSERVAPEDIA, http://bit.ly/1Wtd8gb (last visited May 27, 2016).

[49] *See, e.g., Spectrum Five, LLC Petition for Declaratory Ruling to Serve the U.S. Market Using Broadcast Satellite Service (BSS) Spectrum*, Order, 21 FCC Rcd 14023, 14024, ¶ 2 (2006)(discussing eight U.S. orbital slots for DBS operations).

otherwise visible DBS satellites serving the United States was blocked by terrestrial clutter.

Figure 3 below shows how we performed the line-of-sight analysis for one of the GSO satellites used to support DBS in the United States. The blue areas represent rooftop pixels in the Indianapolis study area from which the southern view to the satellite operating at -110° West Longitude is obstructed and therefore incapable of supporting a DBS receive antenna from that location in the geostationary orbital arc. As explained above, we repeated this type of analysis

Figure 3: Locations for Which a Southern View to 110° West is Obstructed

for each of the visible DBS satellites and developed a composite view of the areas in which a DBS receive antenna is incapable of being placed while still receiving a signal from a visible DBS satellite serving the United States.[50]

Our analysis also filtered sharply pitched roofs, including gabled structures, domes, spires and other rooftop architectures that may have line-of-sight to MVDDS base stations or mobile device locations, but that feature such a steep pitch that the surface does not offer a suitable location for DBS satellite receive-antenna installations. The steep dome of the Indiana Statehouse, for example, represents a very unlikely location for a DBS antenna and the slope filter eliminated it from consideration. To account for this practical limitation on DBS receive-antenna placement in scenarios two and three, we conservatively

[50] The filter we applied to exclude certain geographic areas as locations of potential interference was conservative. The analysis excluded pixels from consideration only if the view to *all* otherwise visible DBS satellites authorized to provide service in the United States was obscured.

excluded pixels within the footprint of a building that had a pitch of 35 degrees or more.[51] In urbanized areas, such as the region of downtown Indianapolis in our study, we would expect installers to insist on a roof slope of much less than 35 degrees because the rooftops of urban buildings are typically much taller than those of single-family residential homes and the additional height above ground level of urban rooftops and the wind conditions there decrease installers' tolerance for a steeper slope. There are also typically many more easily accessible locations on the roof of a commercial or apartment building that do not require venturing onto a steeply sloped portion of the rooftop. Further, standard satellite antenna installations on urban rooftops use a non-penetrating ballast mount, which consists of a large steel frame that holds several cinder blocks as ballast to spread the anchoring weight over a large area.[52] This type of installation is only possible on the flat part of a roof. Regardless, to remain conservative, our slope filter only eliminated roof pitches in excess of 35 degrees for scenarios two and three. For scenario one, practical limits on installation also militate against the installation of DBS receive antennas on steeply pitched roofs, especially those with a pitch of greater than 35 degrees, but in an effort to remain conservative, all pixels were considered regardless of pitch. [53]

Finally, our analysis does not seek to replicate current-generation use cases of MVDDS, which cannot be linearly translated to a two-way 12 GHz operating environment. The current one-way operational limitation on MVDDS requires MVDDS licenses to use a different band for the uplink. Some MVDDS licensees, for example, use the 12.2-12.7 GHz MVDDS band for downlink and 5 GHz unlicensed spectrum for uplink. The part 15 rules that govern unlicensed operations in the 5 GHz band allow up to 4 watts EIRP from the user equipment back to the MVDDS base station. If the power levels of 5 GHz were mechanically carried over to the 12 GHz band, the resulting emissions would almost certainly create harmful interference into any DBS receivers in the vicinity. Thus, although the EPFD for a 5 GHz uplink associated with MVDDS operations today may be very high, this type of deployment cannot be replicated at 12 GHz due to the propagation and power differences between the two bands of spectrum. Instead, 12 GHz two-way deployment scenarios must support a balanced link budget with both links at 12 GHz.[54] Therefore, the

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[51] A flat roof is "[a] horizontal roof either having no slope, or a slope sufficient only to effect drain-age, its pitch being usually less than 10 degrees; it may be surrounded by a parapet or it may extend beyond the exterior walls." *The Dictionary of Architecture Construction* (4th Ed., 2006), http://bit.ly/1RRpVBh.

[52] *See, e.g.,* TRYLON, *Roof Top Structures,* http://bit.ly/1UxDO9p.

[53] DBS guidelines for residential installations express a preference for installations on roof slopes of less than 35 degrees to protect the occupational safety of the antenna installer; however, the guidelines permit residential installations of DBS antennas on roof slopes of up to 53 degrees if safety conditions permit. *See* DIRECTV, *Standard Professional Installation Guidelines*, 3.4 (Mar. 30 2006), http://bit.ly/1P4WI5R.

[54] DISH Network L.L.C. and South.com L.L.C., Public Interest Statement, File No. 0006310796 (June 3, 2014), http://bit.ly/1sl6hc1 (requesting a four-year extension of "substantial service" milestones for each of their respective MVDDS licenses). In its request for an extension of the MVDDS substantial service showing, DISH provided a detailed explanation for its conclusion that point-to-multipoint fixed services could not adequately protect DBS operations from harmful interference. *Id.*

use cases proposed and analyzed in this report are not intended to be equivalent to the current-generation use case of MVDDS and no relationship between them can or should be drawn.

While some simplifying assumptions are used to conclude the analysis, we have generally adopted the more conservative set of assumptions or modeling techniques to provide a worst-case analysis of the potential for interference between various types of 5G MVDDS deployments and DBS satellite receivers. As explained in greater detail below, our analysis has employed conservative assumptions for values ranging from mobile device transmitter power to device activity levels to satellite look angles and visibility. These conservative assumptions should provide an additional level of confidence that real-world 5G MVDDS deployment conditions are compatible with DBS satellite receive antennas so long as the 5G operators employ sound engineering practices in the design and operation of their systems.

1. DBS Coexistence with Point-to-Point MVDDS 5G Operations

Point-to-point 5G operations are intended to provide short-range communications pathways between fixed locations. For example, these links could be used to provide a backhaul connection from an operational cell site to a service-oriented hub or to support mesh networking. In general, the design of these links relies on the interdependency between the link's distance, the required bit rate and the allowed power. Under section 101.147(p), the FCC stopped accepting applications for new licenses for PtP private operational fixed stations in the 12.2-12.7 GHz band as of May 23, 2002.[55] The analysis that follows shows that PtP 5G communications links in the 12.2-12.7 GHz frequency range can be engineered and sited such that they will not cause harmful interference to DBS receivers. Attentive installation of the PtP units will allow the location, directionality and power of PtP transmissions to satisfy the EPFD limits that protect DBS receivers from harmful interference.

In analyzing PtP connections, we used hypothetical tower locations for flexibility in illustrating the potential for interference between PtP broadband connections and DBS receivers. Our analysis occurred at ground level in two-meter pixels. For purposes of the analysis, "ground level" included rooftop-level elevations in those areas where a building is present. In other words, each pixel of the analysis incorporated a height above mean sea level (AMSL). For pixels that fell on buildings, the pixel's height AMSL was the building's rooftop at that location because LIDAR data does not distinguish between natural and man-made objects – obstacles are obstacles whether they occur naturally or are man-made.

[55] 47 C.F.R. § 101.147(p).

Our analysis studied numerous configurations of a hypothetical four-mile PtP link that was located about 20 miles outside of central Indianapolis.[56] The Indianapolis study area has relatively flat terrain, which produced a worst-case result from the standpoint of potential interference. In an effort to replicate a model PtP deployment, we adjusted antenna tilts and the azimuth for the optimal PtP connection. We oriented the link in an East-West direction to maximize antenna discrimination to south-facing DBS antennas because this configuration would likely be the preferred one for deployment in areas with DBS operations in the vicinity. The bidirectional PtP links assumed a 1.8-meter, high-performance parabolic, shielded antenna with dual-polarization that we modeled on the CommScope HPX6-122/F antenna.[57] Typical to a residential installation, the DBS antennas used in our analysis were assumed to be only 18 inches in diameter and were located 0.8 meters above the LIDAR-generated "ground" (*i.e.*, rooftop) to simulate likely DBS antenna locations in the surrounding morphology. The azimuthal and elevation radiation patterns for the DBS receive antennas in our study were modeled on those documented in the MITRE Report as being used by DirecTV.[58] We assumed a vertically polarized terrestrial transmission to a circularly polarized DBS receive antenna. As for configuration the terrestrial PtP link, Figure 4 below shows a Google Earth image of the hypothetical link that was analyzed.

[56] For shorter-distance or lower-capacity links, EIRP could be reduced, but a four-mile PtP connection was studied to offer additional opportunities to introduce noise into the environment.

[57] Product specifications for the HPX6-122/F are attached as Appendix A.

[58] *See* THE MITRE CORPORATION, ANALYSIS OF POTENTIAL MVDDS INTERFERENCE TO DBS IN THE 12.2-12.7 GHZ BAND, Figs. 4-8/9 (filed April 18, 2001) ("MITRE Report"), http://bit.ly/1qXfBlh.

Figure 4: Four Mile Point-to-Point Link

Based on these modeling assumptions, we analyzed the likelihood for potential interference to DBS receivers from 5G PtP links in the 12.2-12.7 GHz band using the regional EPFD limit for Indiana of −169.8 dBW/m^2/4kHz, which applies to Midwestern states under the current MVDDS rules. The area of study was a rectangle 27 kilometers from east to west and 22 kilometers from north to south, centered at the center of the link. The analysis assumed a maximum EIRP for the PtP link of 55 dBm per channel, which is less power than the 62 dBm per 100 MHz limit for 5G operations the FCC has proposed in its *Spectrum Frontiers NPRM* for 5G operations in the 28 GHz, 39 GHz and 37 GHz bands.[59] However, for shorter links such as the one we analyzed, 55 dBm is not required to close the PtP communications link and the analysis assumed lower power levels, as described in more detail below.

To approximate an operational PtP link as closely as possible, we adjusted power to account for the link distance and minimum margin, including the rain-fade margin that applies to these frequencies, as needed to achieve 256QAM, which is the highest capacity modulation available. We also assumed a reliability level of 99.99 percent. We further

[59] *See Spectrum Frontiers NPRM* ¶ 274. DISH and others have requested waivers in the past to use an EIRP of 55 dBm to support PtP links. *See* DISH Network L.L.C. and South.com L.L.C., Public Interest Statement, File No. 0006310796 14 (June 3, 2014), http://bit.ly/1sl6hc1 ("*DISH Public Interest Statement*").

assumed free-space path loss and used a line-of-sight configuration for the PtP link. The PtP antennas were analyzed in two configurations: one with both end-points located 50 meters above ground level (AGL) and another with both end-points located 30 meters AGL. We then studied the potential interference effects on rooftops within line of sight for the PtP links where DBS receive antennas may be located. As described above, the study used actual three-dimensional DBS antenna patterns to accurately calculate the EPFD at each pixel according to the angle of arrival of the potential interfering signals.

The link budget for our hypothetical link is shown below in Table 1:[60]

Reliability	99.990%
Rain Zone For Indiana	E
dB/km Rain Fade Margin	0.72
Length of Link (mi)	4.30
Length of Link (km)	6.92
Total Rain Fade Margin (dB)	4.98
Free Space Path Loss (dB)	131.16
Rx Antenna Gain (dBi)	44.60
Rx Sensitivity, 256 QAM, 50 MHz Channel (dBm) (Dragonwave)	-61
Engineering margin (dB)	3
Minimum EIRP Needed (including rain fade at 99.99%) in 50 MHz channel	**33.54**
Minimum EIRP Needed (including rain fade at 99.99%) in 24 MHz channel	**30.35**

Table 1: Point-to-Point Link Budget for Hypothetical Link

Based on these assumptions, an EIRP of 30 dBm/24 MHz is required to close the link per our assumed requirements. Figure 5 below shows the areas in which the worst case EPFD is exceeded with antennas mounted 50 meters above ground level:

[60] Drawing from ITU Recommendation PN.837-1 *Characteristics of Precipitation for Propagation Modeling*, Raycom, a leading producer of wireless data-transfer equipment, has developed a practical digest of rain-fade zones and attenuation. *See* RAYCOM, *Implementation Notes*, http://bit.ly/1WthJ23 (last visited May 29, 2016). This analysis used the Raycom data shown for 11 GHz as proxy rain fade values associated with 12.2-12.7 GHz band in the United States.

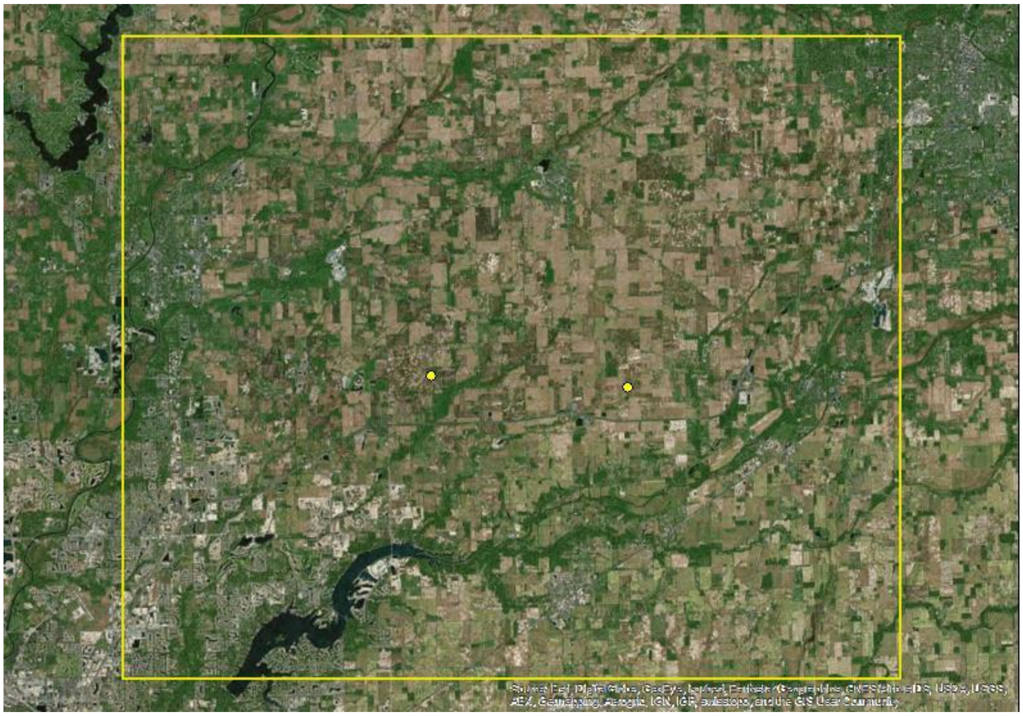

Figure 5: Areas of Exceeded EPFD for a Point-to-Point Link (50 meter antenna heights)

As seen in Figure 5 there are very few visible areas where the EPFD is exceeded, but this view shows the entire study area; therefore, Figure 6 shows a closer view in which areas of exceeded EPFD are highlighted in red.

Figure 6: Zoom of Areas of Exceeded EPFD for a Point-to-Point Link (50 meter antenna heights)

As shown in Figure 6, the areas where EPFD is exceeded are extremely few, are found only in line with the link, and do not fall on existing rooftops where DBS antennas may be located. This finding demonstrates that PtP links can be engineered to protect DBS, even in areas a mere 20 miles outside major urban centers. Given that the population density of much of the country is even lower than shown in this example, this analysis shows that PtP links in the 12.2-12.7 GHz band can be deployed in many locations without causing interference to DBS.

Since the PtP antenna height could affect areas of high EPFD, we also analyzed lower heights of 30 meters, and the results are shown in Figure 7 below.

Figure 7: Areas of Exceeded EPFD for a Point-to-Point Link (30 meter antenna heights)

Due to the lower antenna height, there are slightly more pixels that exceed the EPFD threshold, but the areas are still quite small. This analysis suggests that longer links requiring more power may also be possible in this area, which is located only 20 miles outside a major metropolitan area. In more rural areas of this same rain region, a 55 dBm power limit could possibly support links of up to 16 miles if engineered carefully to avoid large areas where the EPFD threshold is exceeded.

One possible exception to this outcome is the possibility of DBS receivers installed after the deployment of 5G PtP links in the area. A PtP 5G operation that travels between two points could cause harmful interference to after-deployed DBS receivers located in the path of the PtP link. The current rules adopt a first-in-time policy. But even if that policy were changed to afford additional protection to DBS, the diversity of terrain and morphology are such that MVDDS operators wishing to deploy PtP 5G operations can likely engineer solutions that rely on natural or man-made obstructions to reduce the actual EPFD at the DBS antenna and allow reliable DBS reception.

As DISH Networks and South.com said in an extension request of the MVDDS substantial-service showing in June 2014, "DISH believes that MVDDS can play an important role in providing broadband access to, among others, rural and underserved communities by providing PtP backhaul for mobile broadband."[61] Further, testing demonstrates that MVDDS can support PtP links with EIRP up to 55 dBm, "albeit with careful engineering to ensure interference avoidance and mitigation."[62] The simulations presented in this report support this conclusion.

2. DBS Coexistence with MVDDS 5G Outdoor Small Cells

Urban canyons are streets with sets of largely continuous building structures on either side. The wall-like topology of urban canyons poses a serious challenge to traditional cellular architectures, especially at higher frequencies where the bands' relatively feeble propagation characteristics mean that shadowing and multi-path effects typically result in poor to non-existent coverage for devices inside the canyon seeking to communicate with transmitters located outside of it. This frequency-isolating feature of the urban-canyon topology – combined with the current deployment configuration of DBS receivers and the anticipated deployment configurations of 5G operations – prove helpful in mitigating potential adverse interference effects between the two services. DBS is typically deployed on the rooftop of a dwelling, a chimney, a balcony or some other location that has a clear view toward the equator where the geostationary DBS satellites are located. 5G services, by contrast, are generally intended to operate in congested or resource-intensive areas of activity, principally on the floor of the urban canyon where pedestrian and vehicular traffic create immense streams of data and information. The separation between these two services allows for urban clutter and simple geometry to attenuate 5G MVDDS before they can reach any location where DBS receivers may be located. The analysis in the following section will illustrate this for MVDDS transmissions from both base stations and mobile devices.

a) MVDDS 5G Base Stations

To simulate an outdoor, small-cell urban configuration in the 12.2-12.7 GHz band, we modeled the deployment of 21 omnidirectional small cells in downtown Indianapolis, Indiana. The hypothetical small-cell base-station sites were located about 150 meters apart at or near street intersections for maximum visibility to potential end-users at street level, as shown in Figure 8. The inter-site distance indicates an ultra-dense small cell deployment, again our attempt to use a very conservative assumption in our analysis. We assumed 5G small cell base units would be deployed four meters, or roughly 13 feet, above ground level (AGL); however, standard engineering would suggest that the heights of actual 5G base station antennas could be changed if the proposed deployment would

[61] *DISH Public Interest Statement* at 11.

[62] *Id.* at 12.

exceed the applicable EPFD level at roof level of any of the adjacent buildings. The 5G small cell base units were assumed to operate at 48 dBm per 100 MHz (42 dBm per 24 MHz), which is 28 dB higher than the power currently allowed under the FCC's part 101 rules.[63] We modeled the 5G small cell base units based on a CommScope multi-band, quasi-omni Metro Cell antenna. CommScope's antenna has 8.6 dBi of gain in the PCS and AWS downlink bands, an elevation beamwidth of 13.3 degrees and up to 16 degrees of electrical downtilt.[64] The full specifications for the CommScope antenna used in our analysis are available in Appendix B. For 5G mobile units, we assumed User Equipment (UE) devices would operate at 23 dBm, using a 0 dBi omnidirectional antenna pattern at an operating height AGL of 1.5 meters, or somewhat less than five feet. We then assumed the 5G links would rely on 125 MHz channels with a reuse of four to separate antennas transmitting the same carrier frequency. Our analysis used Rappaport's CI model[65] and employed a common outdoor propagation tool developed by Cellular Expert Company[66] to consider EPFD from all co-channel sites at each pixel across the 3.6-square kilometer-study area.[67]

[63] *See* 47 C.F.R. § 101.147(p) (stating that EIRP shall not exceed 14 dBm per 24 MHz). The power we used was 42 dBm per 24 MHz which is 28 dB greater than this (42-14=28). 42 dBm per 24 MHz + 10*log(100/24) = 48 dBm per 100 MHz.

[64] Use of the 2.5 GHz antenna models is quite conservative because higher-frequency, 12 GHz antennas can likely be engineered to produce much smaller interference-causing, side-lobe emissions.

[65] As explained above, the CI model reduces to FSPL + 3 dB.

[66] Cellular Expert Company has developed wireless network performance and planning tools for more than 100 clients in 37 countries, including Vodafone, Telenor, Siemens, Softbank, and Motorola. *About Cellular Expert Company*, CELLULAR EXPERT, http://bit.ly/1sl4Fiq (last visited May 27, 2016).

[67] Although the power in each pixel from each interfering channel was not linearly summed, the nature of the analysis is equivalent to aggregate EPFD at each pixel. The reason is that line-of-site free space propagation produces signal levels that are much greater than the EPFD limit, and non-line-of-site produces infinitely low EPFD. Thus, aggregation of signals from multiple base stations will have no discernible effect.

Figure 8: Small Cell Model – Hypothetical 5G Sites in Indianapolis, IN

In Figure 9 below, all MVDDS 5G small cells are assumed to operate four meters AGL, the MVDDS 5G small cell EIRP is 48 dBm/100 MHz, electrical downtilt is 15 degrees, and DBS antennas are 0.5 meters high. The worst case rooftop areas in which the regional EPFD limit is exceeded from any of the 21 base stations for any of the satellite look angles are shown in red. Most of the red pixels are on the building parapets, which are the low protective walls that are typically installed on apartments, condominiums and other multi-story dwelling structures, not the actual building roofs where DBS dishes would be situated. Overall, there are few areas where the worst case EPFD limit is exceeded, and any problems can likely be addressed by attentive placement and radiofrequency design of the 5G MVDDS small cell.

Figure 9: 48 dBm / 100 MHz MVDDS Base Stations with Protection of DBS Antennas – Worst Case of Satellite Look Angles

Figure 10 shows the same view without the underlying image for better clarity. Although some rooftops show small areas of red where the EPFD would be exceeded, those areas are relatively minor with respect to the overall area and are mostly concentrated at the edges of the buildings. Moreover, the pixels shown in red only indicate the potential for harmful interference to DBS. Actual harmful interference could only occur if a DBS receive antenna were present in that location, which, given the building configurations and the likely DBS receive antenna look angles in this environment, is unlikely.[68] In sum, the areas in which 5G MVDDS small cells would cause EPFD to be exceed in the urban-canyon environment are quite limited and generally not among the more likely or desirable locations for DBS receive antennas in any case.

[68] If the analysis were to show a red pixel at an existing DBS antenna location, then additional site engineering would be required to eliminate that pixel. If it is not possible to remedy the exceeded EPFD using operational modifications to the offending site(s), then the analysis would conclude that MVDDS could not be deployed in such a configuration.

Figure 10: 48 dBm / 100 MHz MVDDS Base Stations with Protection of DBS Antennas – Worst-Case of Satellite Look Angles (without Underlying Image)

One structure consistently exhibited excessive EPFD measurements in our study. The building circled in Figure 10 located in the southeastern portion of the study area was under construction during the time the LIDAR measurements were taken. The skeleton frame of the building offered little attenuation for emissions in the 12.2-12.7 GHz band. Construction of the building has since been completed, and the building now incorporates interior and exterior walls and windows. In addition, another similar building has been built just to the west, between the building and the area where we placed 5G base stations. While LIDAR measurements for the finished structure were unavailable at the time of our analysis, we anticipate that the building's post-construction performance, and that of the new building on the adjacent parcel of land, closely resembles that of surrounding structures, which exhibit little or no excess EPFD.

b) MVDDS 5G Mobile Stations

Although mobile devices will transmit at lower power than base stations, they can be located in a variety of locations. Our analysis considered five mobile locations per base station and assumed that each was at the edge of coverage where the mobile devices would transmit at their maximum power. We assumed this fairly extreme level of the power and intensity of 5G MVDDS devices not to reproduce a realistic or likely operating environment, but rather to identify and model a worst-case scenario for assessing the likelihood of interference between 5G MVDDS operations and DBS satellite receive antennas in the 12.2-12.7 GHz band.

Modeling the interference effects of mobile-device operation must take into account numerous practical limitations on mobile-device density, including (1) the relatively small cell size of 12 GHz operations compared to lower-frequency services; (2) the likely market share of the licensee compared to other 5G service providers; (3) the variability in the use by the 5G devices at different times of day; and (4) the likelihood of an in-cell device operating in an active state at any given moment of time. We used data from New York City, which has the highest population density in the United States, to identify how these factors would affect mobile-device operational density in a 5G network operating in the 12.2-12.7 GHz band. As shown in the table below, New York City has a population density of approximately 27,013 people per square mile resulting in approximately 0.01043 people per square meter.[69]

New York City 2010 Population	8,175,133
New York City Land Area (sq mi)	302.64
New York City Population Density (POPs/sq mi)	27,013
Square Meters per Square Mile (m^2)	2,589,988
New York City Population density (POPs/m^2)	0.01043
Small Cell (75 m) Footprint (m^2)	17671.5
POP coverage per cell	184.3
Market share	20%
Busy-hour Activity Factor	12.5%[70]
Simultaneous Connections	4.6

Table 2: User Equipment Operational Density

[69] Based on 2010 Census data for the five boroughs of New York City and their land area. *See Quick Facts: New York City, New York*, U.S. CENSUS BUREAU, http://1.usa.gov/25KEhx4 (last visited June 7, 2016).

[70] NOKIA, WHAT IS GOING ON IN MOBILE BROADBAND NETWORKS? SMARTPHONE TRAFFIC ANALYSIS AND SOLUTIONS 3 (2014). Since Nokia estimates "10-15%" we used 12.5% as a compromise. This number is conservative since it represents the percentage of users that will be connected to the network, not the percentage that will be simultaneously transmitting on the uplink.

Assuming an average 5G cell radius of 75 meters, a single cell could cover somewhat more than 184 people.[71] If the service provider in this geographic area were to hold a 20 percent market share and if we assume an activity factor of 12.5% (that is, the 5G device is assumed to be actively operating 12.5% of the time) during the busy hour, the number of simultaneous connections within a cell at any given moment in time would be less than 3.5. For purposes of our model, we assumed as many as five simultaneous mobile devices per cell instead of 3.5 simultaneous connections in the interest of generating a conservative estimate of interference potential. Each of these units was assumed to be simultaneously transmitting from cell edge at a maximum power of 23 dBm.

For our analysis of 5G MVDDS mobile units, we again assumed deployment of the same 21 omnidirectional 5G MVDDS small cells at the same locations and elevations in downtown Indianapolis, Indiana, and then, consistent with our activity assumptions, associated five simultaneous mobile devices operating at maximum power at cell edge of each of the 21 small cells. Figure 11 below shows the areas in which each of the assumed total of 105 mobile devices operating at worst-case conditions would exceed the worst-case EPFD limit on rooftop locations in downtown Indianapolis:

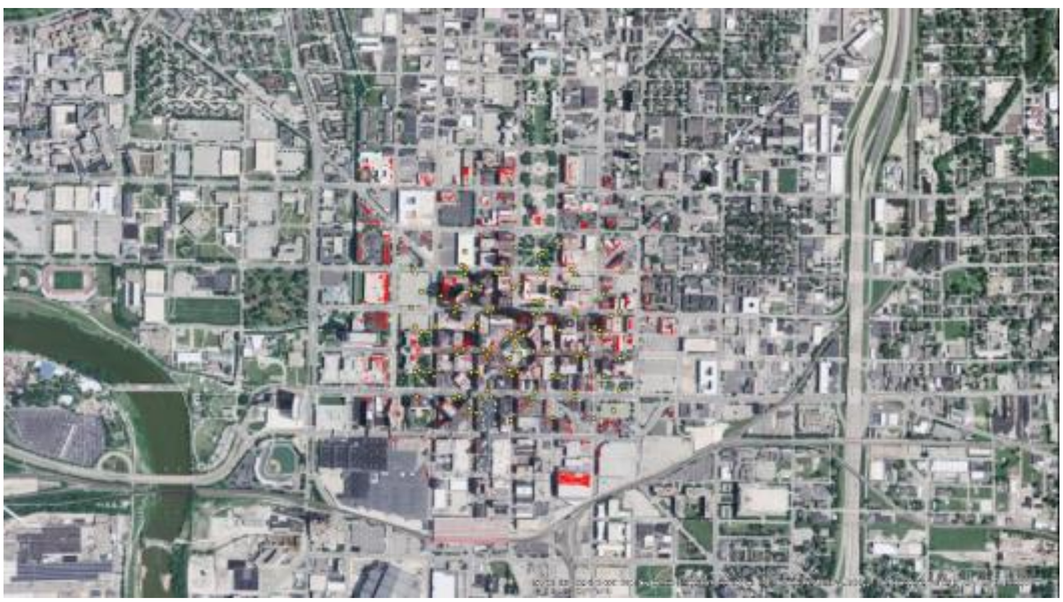

Figure 11: Excess EPFD from 105 Mobile Devices

As can be seen in Figure 11, the areas where the EPFD is exceed as a result of mobile devices transmitting at their maximum power is greater than that from the 21 base stations but is still minimal and concentrated on building parapets. We also have presented a worst case environment for device operation. In reality, the majority of mobile devices in an MVDDS 5G network would transmit at much lower power due to power control, which

[71] A circular cell with a radius of 75 square meters has a coverage area of roughly 17,640 square meters ($A = \pi r^2 = \pi 75^2 \approx 17671.45868$ m²).

would substantially reduce the potential for interference into DBS receivers from the already limited possibilities modeled here.

3. DBS Coexistence with 5G MVDDS Indoor Small Cells

Small cells allow for greater capacity, especially at indoor venues where macrocell networks often have difficulty penetrating interior spaces or accommodating periods of peak traffic demand.[72] The benefits of small-cell architecture are today especially evident in hotspots such as stadiums and airports. At these locations, the demand is irregular and can be many hundreds of times greater than the demand an operator would see from a typical suburban deployment.[73] Wireless use has also begun to shift indoors. Cisco, for example, estimates that the majority of mobile data usage – close to 80 percent – now occurs indoors.[74] Traditional macro networks were built for "voice on the go" and are ill-suited to meet this demand, especially when numerous walls and other physical obstacles weaken indoor coverage.[75] Recent tests also demonstrate that outdoor cells often cannot provide the capacity required to meet indoor demand.[76] Indoor small cells thus promise to play a key role in supporting the next generation of 5G wireless broadband services.

Developing an attenuation model for indoor obstacles is challenging. Building environments can vary considerably from structure to structure, and the attenuation losses attributable to indoor obstacles and the building envelope can vary markedly, too. Building materials, door sizes, ceiling height, window surfaces and orientation, and other factors create reflections, scattering and diffraction that can attenuate the signal strength of indoor transmitters as observed from outside of the envelope of a building. Research performed on radiofrequency transmissions at 9.6 GHz, 28.8 GHz and 57.6 GHz, for example, showed virtually no loss through glass walls, but losses increased by 25 dB to 50 dB when the glass surface was coated with metal.[77] Calculating precise attenuation losses for indoor transmitters as observed from outside of the building thus requires a fairly detailed understanding of the number of obstructions, the physical characteristics of those obstructions and precise system configurations for the transmitters and receivers involved. That said, numerous studies have analyzed the indoor propagation characteristics of 5G

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[72] *See, e.g.*, *Five Trends to Small Cell 2010*, HUAWEI, at 3 (2016), http://bit.ly/1TO3dBl ("*Five Trends to Small Cell*").

[73] *See id*.

[74] *Cisco Universal Small Cell Solution: A Platform for Service Innovation*, CISCO, at 2 (2015), http://bit.ly/24fzLnq.

[75] *See id.*; *Five Trends to Small Cell* at 5.

[76] *See, e.g.,* NOKIA, TEN KEY RULES OF 5G DEPLOYMENT 13 (2015), http://nokia.ly/1NXw6ZJ.

[77] Hung Zhao et al., *28 GHz Millimeter Wave Cellular Communication Measurements for Reflection and Penetration Loss in and around Buildings in New York City*, IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS (2013), http://bit.ly/20Qaakb (citing E. J. Violette, R. H. Espeland, R. O. DeBolt, and F. K. Schwering, *Millimeter-wave Propagation at Street Level in an Urban Environment*, IEEE Transactions on Geoscience and Remote Sensing, vol. 26, no. 3, pp. 368–380, May 1988.

networks, especially at higher frequencies,[78] and much of the work performed to date indicates that 50 dB is a typical value for the losses attributable to one internal wall and one external wall for frequencies in the 12 GHz range.[79]

For purposes of calculating the interference potential of 5G MVDDS small cells, we assumed that 5G MVDDS base stations would be positioned inside buildings on the ceiling behind one interior wall. Base stations would therefore experience 50 dB of penetration loss as the 12 GHz signals traversed the interior and exterior walls. For mobile devices, we assumed these units would operate anywhere within the building's interior. These types of operations would limit attenuation to only the building's exterior wall, which, consistent with well-established models, were assumed to offer 30 dB of penetration loss. Figure 12 below shows some of the possible attenuation levels for different transmission paths outside of a representative building based on the location of the 5G MVDDS transmitter relative to the location of the DBS satellite receiver.

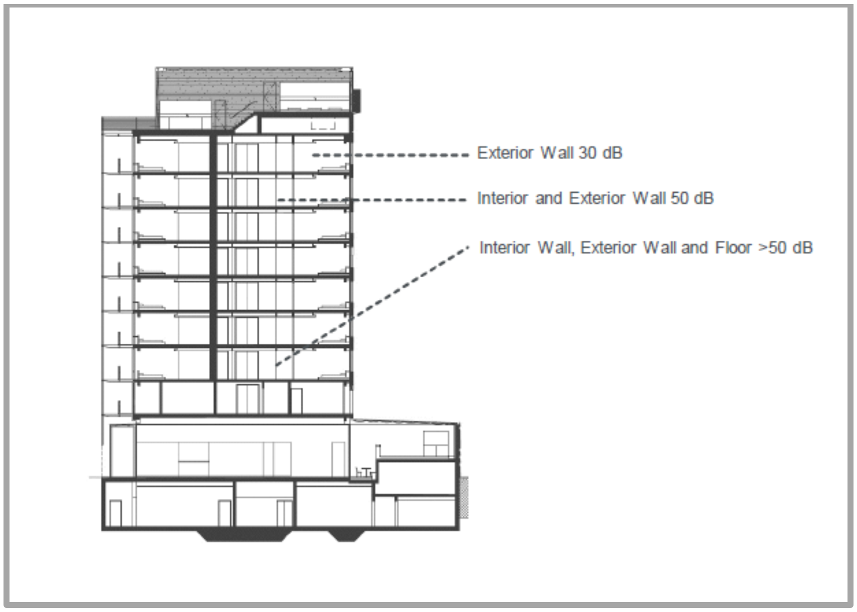

Figure 12: Building Attenuation For Representative Transmission Paths[80]

Of course, actual attenuation losses could vary: attenuation might exceed 50 dB if the signal were traversing an interior wall, a floor and an exterior wall, or could fall below 30 dB if the exterior wall were comprised of high-emissivity glass. To the extent a given in-

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[78] George R. MacCartney Jr. et al., *Indoor Office Wideband Millimeter-Wave Propagation Measurements and Channel Models at 28 GHz and 73 GHz for Ultra-Dense 5G Wireless Networks*, IEEE ACCESS (2015), http://bit.ly/25rVKtX (surveying some of the available analysis on high-capacity transmission performance in various indoor environments).

[79] Ignacio Rodriguez et al., *Radio Propagation into Modern Buildings: Attenuation Measurements in the Range from 800 MHz to 18 GHz*, 2014 IEEE 80TH VEHICULAR TECHNOLOGY CONFERENCE (VTC2014-Fall).

[80] *Hotel Americano*, *Building of the Week*, AMERICAN-ARCHITECTS, http://bit.ly/1sMTIX5 (last visited June 1, 2016).

building deployment configuration might achieve less than 30 dB of attenuation, however, operators could increase attenuation through careful selection of base station sites and orientation of user cells. Unlike prior-generation networks, moreover, 5G network operators would have the added capability to cost-effectively manage the transmission location of 5G mobile devices through "geofencing," which involves the use of location information from the device to assign unit geographical boundaries to the permitted area of operation. These mitigation techniques would allow the broadband operator to prevent 5G MVDDS mobile devices from venturing into areas that might offer insufficient attenuation to one or more DBS receivers outside of the building exterior. These techniques also offer some measure of confidence that the building penetration losses applied to 5G base station transmitters and 5G mobile devices under consideration in this study reasonably approximate real-world deployment conditions that would either exist or be capable of replication in the field. After accounting for building attenuation, we used the Rappaport CI model, which for our purposes equates to free space path loss plus 3 dB, and, consistent with our outdoor analysis, relied on one-meter resolution LIDAR profiles of the surrounding terrain, structures and other obstacles over a study area in Indianapolis measuring 2 kilometers by 1.8 kilometers. We then evaluated the effects of indoor 5G operations on DBS receiver configurations to the point where indoor 5G operations would exceed the required EPFD at locations where a DBS receive antenna may be placed. As in the earlier analysis, we applied two filters to identify relevant pixels for additional analysis. First, we filtered out those pixels from which terrestrial obstacles obstructed all of the otherwise visible GSO satellites authorized to provide DBS in the United States because DBS receive antennas cannot operate in these locations. Second, we filtered out those pixels in which the roof slope exceeded 35 degrees because, as explained previously, these steeply sloped conditions offer an unusually challenging environment for DBS installation, especially in an urban area where building heights, wind conditions and available alternatives would strongly discourage DBS receive-antenna installation.

Based on these modeling assumptions, we analyzed the likelihood that 5G indoor base stations and 5G indoor mobile units operating in the 12.2-12.7 GHz band might create excessive EPFD in locations where DBS receivers might be located. We once again applied an EPFD limit −169.8 dBW/m^2/4kHz, which is the EPFD limit that applies to Midwestern states under the current MVDDS rules. As described in greater detail below, we found that losses as signals in the 12.2-12.7 GHz band travel through one or more building walls generally provide sufficient attenuation to ensure EPFD limits remain below current limits. Where building attenuation alone might prove insufficient, careful placement and power control can prevent the maximum EPFD levels from being exceeded outside of the building envelope to ensure protection of DBS receive antennas.

a) MVDDS Indoor 5G Access Points

We began our study of indoor 5G small cell deployments by examining indoor base stations. Consistent with existing deployment practices, 5G small cell indoor base stations would likely operate from an installation point on the ceiling and use an omnidirectional antenna pattern. We identified a radiation pattern for a hypothetical 5G MVDDS antenna based on the Ruckus ZoneFlex 7762 Access Point that is used in the 5 GHz band.[81] We assumed transmit power for the MVDDS antenna of 36 dBm per 100 megahertz EIRP, which equates to 30 dBm per 24 megahertz. The assumptions about DBS deployment configurations were maintained from the prior PtP and outdoor small-cell models.

Figure 13 below shows areas where the EPFD limits are exceeded outside the building from four co-channel access points located inside the Circle Centre Mall, transmitting at 36 dBm per 100 MHz (i.e., 30 dBm per 24 MHz) and assuming 50 dB of building penetration loss between the 5G MVDDS base station and the building exterior. The four access points were located as indicated by the yellow dots with one on each of the four floors of the building at heights of six meters, 12 meters, 18 meters and 23 meters.

Figure 13: Areas of Excess EPFD from Access Points Inside the Building

For clarity, the same data is shown in Figure 14 below without the underlying image.

[81] While typically used outdoors, the Ruckus ZoneFlex 7200 uses the same wireless controller as the indoor access point. Operating parameters for the ZoneFlex 7200 are featured on the Cellular Expert Company modeling platform and its performance is consistent with indoor access point base stations.

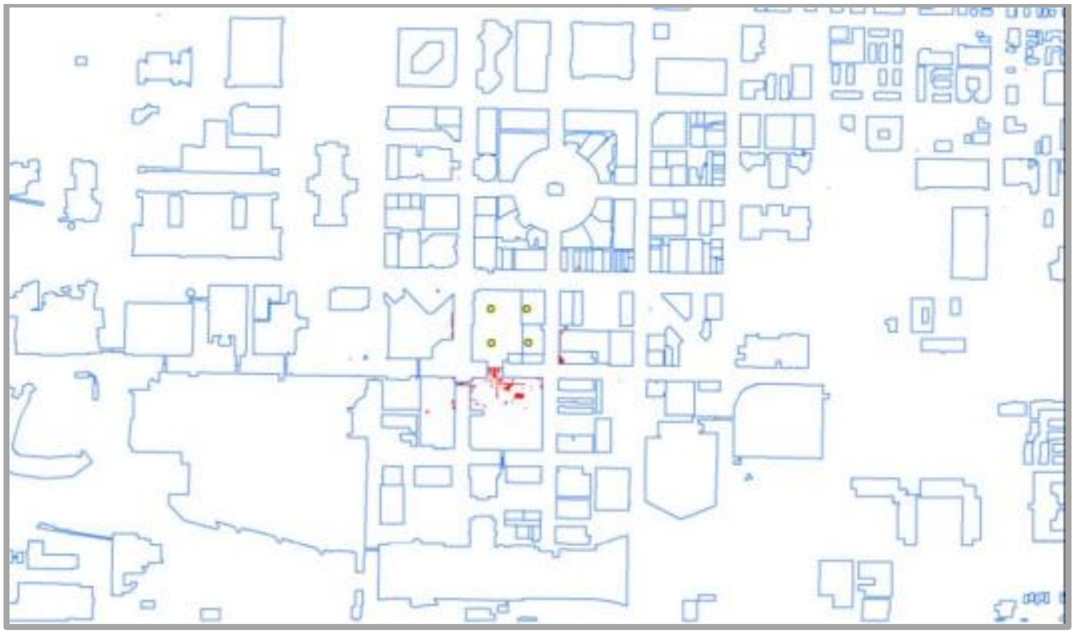

Figure 14: Areas of Excess EPFD from Access Points Inside the Building without Underlying Image

As shown in Figure 14, the significant attenuation of the exterior wall of the building limits the areas where the EPFD might be exceeded close to the building and does not affect any nearby rooftops, except again at the parapets. Indeed, the buildings that exhibit excessive EPFD in this model are those immediately south and south of the building in which the four 5G MVDDS base stations were installed for purpose of this model. Those two buildings, however, are actually part of the same Circle Centre Mall complex and are connected to the installation area of the 5G MVDDS indoor base stations by a large, elevated pedestrian walkway. A close-up view of the mall complex is provided in Figure 15 below. Arrows identify the walkways and mall buildings. If the areas integrated into and under common control of the mall were excluded, virtually no excess EPFD emissions would be visible.

Figure 15: Satellite View of Circle Centre Mall

b) MVDDS Indoor 5G Mobile Devices

Emissions from base stations as opposed to mobile units should pose a worst-case interference scenario for DBS receivers, especially in an indoor environment. 5G devices are not expected to communicate continuously with 5G base stations, and the known use cases suggest simultaneous operation of multiple devices at cell edge using the highest possible power would be highly unlikely. We assumed five 5G MVDDS mobile devices on each floor of the four-story mall for a total of twenty mobile devices operating simultaneously. We assumed that each 5G MVDDS mobile devices would transmit at 23 dBm using an omni-directional antenna pattern. We further assumed each 5G MVDDS mobile device would operate 1.5 meters above the floor. We then developed EPFD calculations just as we did for the base stations from the indoor model, subject to the premise that 5G MVDDS mobile devices would experience a minimum 30 dB of penetration loss if the signals traversed only the outside wall of the building.

The study of the 5G MVDDS mobile devices we modeled, again, showed remarkably few areas in which EPFD limits exceeded applicable limits. As with the indoor base stations the two southern buildings that are integrated into the mall complex showed some excessive EPFD levels. Aside from these areas, however, the pixels with EPFD levels in excess of applicable standards were limited and, indeed, confined to discrete buildings as identified in Figures 16 and 17 below.

Figure 16: Areas of Excess EPFD from Mobile Stations Inside the Building

For clarity, the same data is shown in Figure 17 below without the underlying image.

Figure 17: Areas of Excess EPFD from Mobile Stations Inside the Building without Underlying Image

B. NGSO FSS

Non-geostationary satellites in the Fixed Satellite Service provide communications from satellites that are not operating in synchronous orbit with the Earth to end-user terminals that are at fixed points or at fixed points within specified geographic areas.[82] Because the satellites are moving relative to the ground, NGSO FSS earth stations rely on steerable antennas that track the path of the satellites to close the communications link. In the United States, the NGSO FSS is allocated 2 gigahertz of downlink spectrum from 10.7-12.7 GHz and is co-primary with MVDDS in the 12.2-12.7 GHz band.

Internationally, the 12.2-12.7 GHz band is allocated to a number of services. The 12.2-12.5 GHz band in ITU Regions 1 and 3 is allocated for terrestrial fixed, mobile (except aeronautical), and broadcasting services. For those frequencies, there is also a BSS allocation in region 1 and an FSS (space-to-Earth) allocation in region 3. The 12.5-12.7 GHz band in ITU Regions 1 and 3 is allocated for FSS (space-to-Earth). In ITU Region 3 for the 12.5-12.7 GHz band, there are also additional allocations for terrestrial fixed and mobile (except aeronautical) services and BSS. In all the ITU Regions, NGSO FSS operations in the 12.2-12.7 GHz bands must protect GSO FSS and/or BSS operations in the same frequencies.[83] An excerpt from the U.S. Table of Frequency of Allocations is attached as Appendix C.

As a practical matter, the 12.2-12.7 GHz band is widely used for GSO FSS or BSS services by satellite operators in all ITU Regions.[84] Although there have been reported MVDDS-type terrestrial uses in other countries, there do not appear to be more than a handful of these types of deployments and there is no indication that such uses are growing.[85]

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[82] An NGSO FSS satellite constellation can theoretically maintain a highly elliptical orbit and time its active operations to align with the perigee of its orbit in a manner intended to simulate the operation of a geostationary satellite orbit (GSO) system. *See* Virtual Geosat LLC, SAT-LOA-19990108-00007, SAT-MOD-20070118-00018, et al. Call Sign S2366 (Dec. 21, 2006). From an interference standpoint, operation of this type of an NGSO constellation would more closely resemble a geostationary broadcast-satellite services (DBS) system than it would a standard NGSO FSS constellation, which would presumably result in a more manageable interference environment than a standard NGSO FSS system. But the only known GSO-like NGSO constellation surrendered its authorization in 2007. *See* Public Notice, DA 07-617 (Feb. 5, 2007), http://bit.ly/22tmKaK. No other GSO-like NGSO constellations planned. Therefore, this analysis does not address GSO-like NGSO FSS systems.

[83] *See* 47 C.F.R. § 2.106 nn. 5.484A, 5.487, and 5.487A.

[84] *See, e.g.*, Application of Intelsat License LLC, File No. SAT-LOA-20110929-00193, Narrative at 6 (proposing to use the 12250-12750 MHz frequencies at the 72°E.L. orbital location) (granted March 15, 2012); Application of Intelsat North America LLC, File No. SAT-LOA-20101014-00219, Engineering Statement at 1 (proposing to use the 12250-12750 MHz frequencies at the 180°E.L. orbital location).

[85] *See Case Studies*, MDS AMERICA, http://bit.ly/1Zke98o (discussing the provision of provision terrestrial services using MVDDS equipment by Etisalat in the United Arab Emirates and South

OneWeb has filed a letter of intent seeking market access to provide satellite service in the U.S. OneWeb proposes to operate an NGSO FSS system registered in the United Kingdom that would use 16 different downlink channels in the 10.7-12.7 GHz band; each of the 16 space-to-Earth downlink channels would have a nominal channel bandwidth of 250 megahertz with two times frequency reuse.[86] The proposed system would achieve at least two-times spatial frequency re-use by employing the same Ku-band frequencies among geographically separated beams of the same satellite. According to OneWeb, the EIRP density of its proposed system is -13.4 dBW/4kHz. This value equates to an EIRP of 40.6 dBm per megahertz or 64.6 dBm over a 250 megahertz channel. OneWeb satellites will operate at a nominal altitude 1200 kilometers above the Earth. At this altitude, the minimum path loss from the satellite to the Earth's surface is 175.9 dB. The EIRP density and level of path loss imply that the maximum signal strength on the Earth will be -135.4 dBm per megahertz (40.6 dB – 175.9 = -135.4 dBm/MHz).

Using worst-case assumptions that a 5G mobile device would transmit at its maximum power spectral density of 23 dBm per 24 MHz and the EIRP density would be 9.2 dBm per megahertz. For the power of the MVDDS 5G mobile device to be equal to or less than the maximum power of the NGSO downlink,[87] the 5G mobile device path loss would need to be at least 144.6 dB (9.2 dBm/MHz – (-135.4 dBm/MHz) =144.6 dB). Using free space loss, a 5G mobile device operating at 23 dBm per 24 MHz would need to be located approximately 32 kilometers from the NGSO terrestrial mobile receiver to avoid generating an MVDDS signal that is equal to or greater than the power the NGSO equipment would receive from the space station. While the NGSO receiver may have a directional, upward-facing antenna that provides some protection from the emissions of the 5G mobile UE, even 30 dB of antenna discrimination by the NGSO receiver would still require more than a kilometer of separation distance between the 5G mobile device and the NGSO receiver when the 5G mobile device was operating with an EIRP of 23 dBm per 24 MHz.

Coast TV in the southern region of Ireland); *compare South Coast TV*, WIKIPEDIA (service fully shut down in 2010), http://bit.ly/24mVkm9.

[86] *See* WorldVu Satellites Limited, SAT-LOI-2016-428-00041, Call Sign S2963 (Apr. 28, 2016), http://bit.ly/1WDK1a1.

[87] The interfering power from MVDDS does not need to be this high to cause interference to the NGSO terminal, but equal power was chosen for convenience to illustrate the high level of interference that NGSO terminal will experience in the 12.2-12.7 GHz band from MVDDS operations.

Satellite EIRP Density	-13.4	dBW/4kHz
Satellite EIRP Density	40.6	dBm/MHz
Channel Bandwidth	250	MHz
Total Power	64.6	dBm
Satellite Altitude	1200	km
Free Space Path Loss	175.9	dB
Receive (Rx) Power Maximum	-135.4	dBm/MHz
Max MVDDS Power	23	dBm/24 MHz
Max MVDDS Power Density	9.2	dBm/MHz
Path Loss for Equal Power	144.6	dB
Free Space Path Loss Distance	31996.7	meters
Minimum MVDDS Power	-40	dBm/24 MHz
Minimum MVDDS Power Density	-53.8	dBm/MHz
Path Loss for Equal Power	81.6	dB
Free Space Path Loss Distance	22.7	meters

Table 3: Assumed Parameters for Mobile Device Interference Analysis

Using best-case assumptions, the 5G mobile device might conceivably employ power control to operate with power similar to that of LTE, or approximately -40 dBm per 24 MHz. This value equates to -53.8 dBm per megahertz and the path loss required for the MVDDS 5G mobile device to be equal to or less than the maximum power of the NGSO downlink would be 81.6 dB (-53.8 dBm – (-135.4) = 81.6 dB). Using free space loss, achieving this level of power would require at least 22 meters of separation between the mobile device and the NGSO receiver. As a result, even with the best case assumption of a mobile device transmitting at the lowest power level possible, NGSO devices will still receive interference when they are located within 22 meters of a 5G mobile device.

Turning to base stations, the results are worse. The MVDDS Coalition has requested an increase in power under part 101 of the FCC's rules beyond the current limit of 14 dBm per 24 megahertz to support two-way operations in the 12.2-12.7 GHz band. But simply taking into account the *existing* power limits of 14 dBm per 24 megahertz under the current part 101 rules and free space loss indicates that NGSO receivers cannot operate within 11 kilometers of a current-generation MVDDS base station.[88] A separation distance this large between ostensibly co-primary services in the band suggests that coexistence

[88] Section 101.105(a)(4) of the Commission's rules requires that MVDDS protect NGSO FSS earth stations in the 12.2-12.7 GHz band by not exceeding -135 dBW/m^2/4 kHz at a distance of three kilometers; however, assuming a dipole antenna, this level is about 12 dB stronger than the maximum signal the NGSO FSS earth station can receive from the satellite. 47 C.F.R. § 101.105(a)(4). Thus, even the currently authorized MVDDS operational levels would appear to create a high likelihood of interference between MVDDS and NGSO FSS operations.

between MVDDS and NGSO FSS systems on coterminous frequencies in the same geographic areas is already impractical, if not infeasible. The introduction of additional power would increase the requisite sharing distance or require other constraints on operations of one or both services.

V. Conclusion

New, more detailed information about the feasibility of coexistence among the services authorized for co-primary use of the 12.2-12.7 GHz band has emerged since the FCC last commissioned a technical study of the issue more than a decade ago. First, policymakers now have a much better understanding about the architecture of the wireless broadband deployment models operators may deploy in the band. Second, analysts can now rely on much more accurate profiles of the nation's topographical, morphological and constructed features than previously existed. Taken together, these developments allow for a much more realistic and granular analysis of the potential for coexistence among the three primary services in the band than could be previously performed.

In this analysis, we considered three likely 5G deployment scenarios: PtP wireless fixed links; urban canyon small cells; and indoor small cells. We then employed ultra-high-resolution imagery of buildings and terrain to analyze the degree of attenuation that potential 5G operations would receive from a variety of obstacles to signal propagation.

Our updated analysis led to two basic conclusions. First, we found that coexistence between MVDDS 5G operations and DBS receivers is possible with modest adjustments to MVDDS site locations and radiofrequency design parameters. Second, we found that coexistence between MVDDS 5G operations and NGSO FSS operations is not possible without severe operational constraints on MVDDS, NGSO FSS or both services.

In light of these findings, the FCC will likely want to engage all interested stakeholders to resolve the various policy and licensing issues associated with any new service offerings in the 12.2-12.7 GHz band.

Appendix A

DBS Model Antenna Specifications

Product Specifications

COMMSCOPE®

HPX6-122/F

1.8 m | 6 ft High Performance Parabolic Shielded Antenna, dual-polarized, 12.200–12.700 GHz

General Specifications

Antenna Type	HPX - High Performance Parabolic Shielded Antenna, dual-polarized
Diameter, nominal	1.8 m | 6 ft
Polarization	Dual

Electrical Specifications

Beamwidth, Horizontal	0.9 °
Beamwidth, Vertical	0.9 °
Cross Polarization Discrimination (XPD)	30 dB
Electrical Compliance	ETSI Class 2 | US FCC Part 101A | US FCC Part 78A
Front-to-Back Ratio	68 dB
Gain, Low Band	44.6 dBi
Gain, Mid Band	44.8 dBi
Gain, Top Band	45.0 dBi
Operating Frequency Band	12.200 – 12.700 GHz
Radiation Pattern Envelope Reference (RPE)	3285E
Return Loss	26.4 dB
VSWR	1.10

Mechanical Specifications

Fine Azimuth Adjustment	±15°
Fine Elevation Adjustment	±20°
Mounting Pipe Diameter	115 mm | 4.5 in
Net Weight	115 kg | 254 lb
Side Struts, Included	1 inboard
Side Struts, Optional	1 inboard
Wind Velocity Operational	110 km/h | 68 mph
Wind Velocity Survival Rating	200 km/h | 124 mph

Wind Forces At Wind Velocity Survival Rating

Angle a for MT Max	-130 °
Axial Force (FA)	7744 N | 1741 lbf
Side Force (FS)	3836 N | 862 lbf
Twisting Moment (MT)	2955 N•m

Product Specifications

COMMSCOPE®

HPX6-122/F

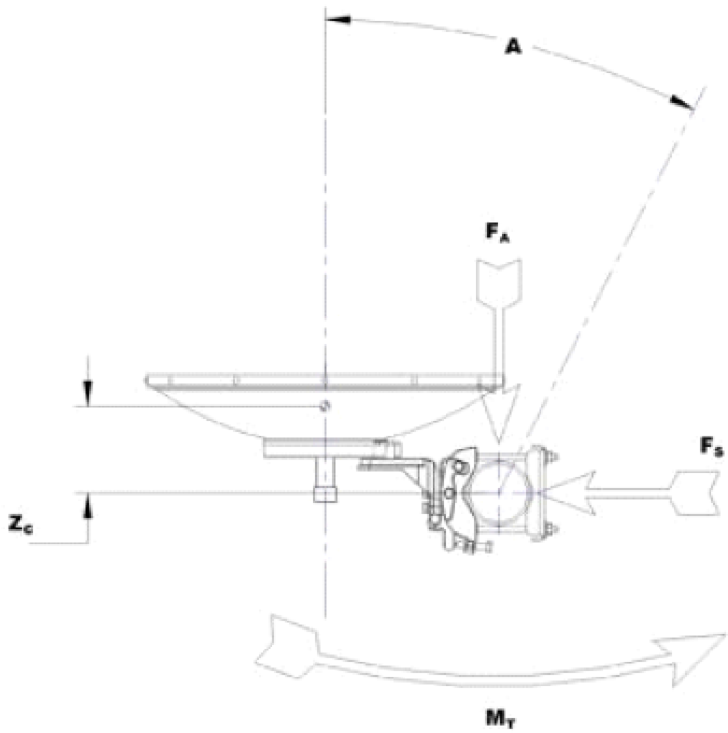
Weight with 1/2 in (12 mm) Radial Ice	235 kg | 518 lb
Zcg with 1/2 in (12 mm) Radial Ice	660 mm | 26 in
Zcg without Ice	466 mm | 18 in

Product Specifications

COMMSCOPE®

HPX6-122/F

Wind Forces At Wind Velocity Survival Rating Image

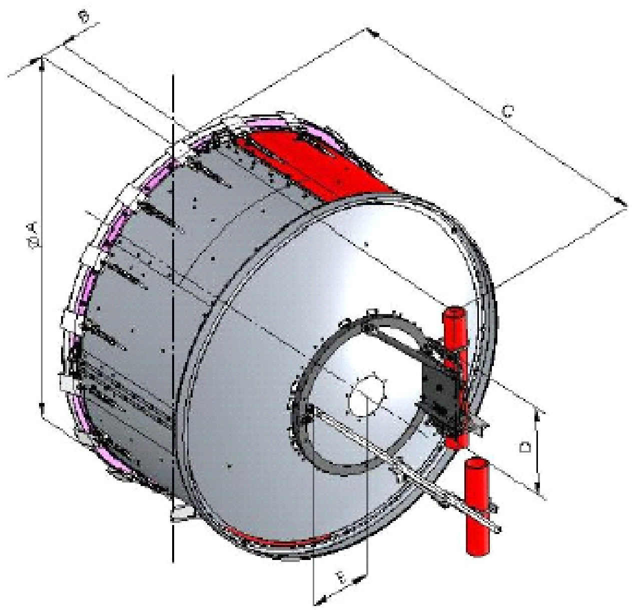


Product Specifications

COMMSCOPE®

HPX6-122/F

Antenna Dimensions And Mounting Information



Dimensions in Inches (mm)					
Antenna Size, ft (m)	A	B	C	D	E
6 (1.8)	77.5 (1970)	17.1 (435)	53.3 (1356)	19.3 (490)	11.7 (296)

* Footnotes

Axial Force (FA)	Maximum forces exerted on a supporting structure as a result of wind from the most critical direction for this parameter. The individual maximums specified may not occur simultaneously. All forces are referenced to the mounting pipe.
Cross Polarization Discrimination (XPD)	The difference between the peak of the co-polarized main beam and the maximum cross-polarized signal over an angle twice the 3 dB beamwidth of the co-polarized main beam.
Front-to-Back Ratio	Denotes highest radiation relative to the main beam, at 180° ±40°, across the band. Production antennas do not exceed rated values by more than 2 dB unless stated otherwise.
Gain, Mid Band	For a given frequency band, gain is primarily a function of antenna size. The gain of Andrew antennas is determined by either gain by comparison or by computer integration of the measured antenna patterns.
Operating Frequency Band	Bands correspond with CCIR recommendations or common allocations used throughout the world. Other ranges can be accommodated on special order.
Radiation Pattern Envelope Reference (RPE)	Radiation patterns determine an antenna's ability to discriminate against unwanted signals under conditions of radio congestion. Radiation patterns

Product Specifications

COMMSCOPE®

HPX6-122/F

	are dependent on antenna series, size, and frequency.
Return Loss	The figure that indicates the proportion of radio waves incident upon the antenna that are rejected as a ratio of those that are accepted.
Side Force (FS)	Maximum side force exerted on the mounting pipe as a result of wind from the most critical direction for this parameter. The individual maximums specified may not occur simultaneously. All forces are referenced to the mounting pipe.
Twisting Moment (MT)	Maximum forces exerted on a supporting structure as a result of wind from the most critical direction for this parameter. The individual maximums specified may not occur simultaneously. All forces are referenced to the mounting pipe.
VSWR	Maximum; is the guaranteed Peak Voltage-Standing-Wave-Ratio within the operating band.
Wind Velocity Operational	The wind speed where the antenna deflection is equal to or less than 0.1 degrees. In the case of ValuLine antennas, it is defined as a maximum deflection of 0.3 x the 3 dB beam width of the antenna.
Wind Velocity Survival Rating	The maximum wind speed the antenna, including mounts and radomes, where applicable, will withstand without permanent deformation. Realignment may be required. This wind speed is applicable to antenna with the specified amount of radial ice.

Appendix B

5G MVDDS Model Antenna Specifications

Product Specifications

COMMSCOPE®

NH360QS-DG-F0M

Andrew® Dualband Quasi Omni Metro Cell Antenna, 698-896 and 1710–2170 MHz with fixed tilt in the low band and manual tilt in the high band. Contains internal diplexer and active GPS L1 band antenna

Electrical Specifications

<table>
<tr><th>Frequency Band, MHz</th><th>698–806</th><th>806–896</th><th>1710–1880</th><th>1850–1990</th><th>1920–2180</th></tr>
<tr><td>Gain, dBi</td><td>5.2</td><td>5.5</td><td>8.2</td><td>8.3</td><td>8.6</td></tr>
<tr><td>Beamwidth, Horizontal, degrees</td><td>360</td><td>360</td><td>360</td><td>360</td><td>360</td></tr>
<tr><td>Beamwidth, Vertical, degrees</td><td>35.4</td><td>35.6</td><td>15.1</td><td>14.0</td><td>13.3</td></tr>
<tr><td>Beam Tilt, degrees</td><td>0</td><td>0</td><td>0–16</td><td>0–16</td><td>0–16</td></tr>
<tr><td>USLS (First Lobe), dB</td><td>13</td><td>13</td><td>10</td><td>13</td><td>10</td></tr>
<tr><td>Isolation, dB</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td></tr>
<tr><td>VSWR | Return Loss, dB</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td></tr>
<tr><td>PIM, 3rd Order, 2 x 20 W, dBc</td><td>-153</td><td>-153</td><td>-153</td><td>-153</td><td>-153</td></tr>
<tr><td>Input Power per Port, maximum, watts</td><td>125</td><td>125</td><td>125</td><td>125</td><td>125</td></tr>
<tr><td>Polarization</td><td>±45°</td><td>±45°</td><td>±45°</td><td>±45°</td><td>±45°</td></tr>
<tr><td>Impedance</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td></tr>
</table>

Electrical Specifications, BASTA*

<table>
<tr><th>Frequency Band, MHz</th><th>698–806</th><th>806–896</th><th>1710–1880</th><th>1850–1990</th><th>1920–2180</th></tr>
<tr><td>Gain by all Beam Tilts, average, dBi</td><td>4.2</td><td>4.8</td><td>7.6</td><td>7.8</td><td>7.9</td></tr>
<tr><td>Gain by all Beam Tilts Tolerance, dB</td><td>±1</td><td>±0.7</td><td>±0.6</td><td>±0.7</td><td>±0.8</td></tr>
<tr><td>Gain by Beam Tilt, average, dBi</td><td></td><td></td><td>0 ° | 7.9
8 ° | 7.7
16 ° | 7.2</td><td>0 ° | 8.0
8 ° | 7.9
16 ° | 7.3</td><td>0 ° | 8.3
8 ° | 8.0
16 ° | 7.5</td></tr>
<tr><td>Beamwidth, Vertical Tolerance, degrees</td><td>±4.2</td><td>±5.8</td><td>±1.3</td><td>±1</td><td>±1.2</td></tr>
<tr><td>USLS, beampeak to 20° above beampeak, dB</td><td>14</td><td>13</td><td>14</td><td>14</td><td>12</td></tr>
</table>

* CommScope® supports NGMN recommendations on Base Station Antenna Standards (BASTA). To learn more about the benefits of BASTA, download the whitepaper Time to Raise the Bar on BSAs.

General Specifications

<table>
<tr><td>Antenna Brand</td><td>Andrew®</td></tr>
<tr><td>Antenna Type</td><td>Metro Cell</td></tr>
<tr><td>Band</td><td>Multiband</td></tr>
<tr><td>Brand</td><td>DualPol®</td></tr>
<tr><td>Operating Frequency Band</td><td>1710 – 2170 MHz | 698 – 896 MHz</td></tr>
<tr><td>Internal GPS frequency band</td><td>1575.42 MHz</td></tr>
<tr><td>Internal GPS VSWR</td><td>2.0</td></tr>
<tr><td>Performance Note</td><td>Outdoor usage</td></tr>
</table>

Mechanical Specifications

Product Specifications

COMMSCOPE®

NH360QS-DG-F0M

Color	Light gray
GPS Connector Interface	4.1-9.5 DIN Female
GPS Connector Quantity	1
Lightning Protection	dc Ground
Radiator Material	Aluminum | Low loss circuit board
Radome Material	ASA
Reflector Material	Aluminum
RF Connector Interface	7-16 DIN Female
RF Connector Location	Bottom
RF Connector Quantity, total	2
Wind Loading, maximum	167.0 N @ 150 km/h 37.5 lbf @ 150 km/h
Wind Speed, maximum	241 km/h | 150 mph

Dimensions

Length	728.0 mm | 28.7 in
Outer Diameter	305.0 mm | 12.0 in
Net Weight	12.1 kg | 26.7 lb

Packed Dimensions

Depth	407.0 mm | 16.0 in
Length	998.0 mm | 39.3 in
Width	427.0 mm | 16.8 in
Shipping Weight	16.8 kg | 37.0 lb

Regulatory Compliance/Certifications

Agency	Classification
RoHS 2011/65/EU	Compliant by Exemption
China RoHS SJ/T 11364-2006	Above Maximum Concentration Value (MCV)
ISO 9001:2008	Designed, manufactured and/or distributed under this quality management system

* Footnotes

Performance Note	Severe environmental conditions may degrade optimum performance

Appendix C

Table of Frequency Allocations

International Table		
Region 1	**Region 2**	**Region 3**
11.7-12.5 FIXED MOBILE except aeronautical mobile BROADCASTING BROADCASTING-SATELLITE 5.492 5.487 5.487A	12.2-12.7 FIXED MOBILE except aeronautical mobile BROADCASTING BROADCASTING-SATELLITE 5.492 5.487A 5.488 5.490	12.2-12.5 FIXED FIXED-SATELLITE (space-to-Earth) MOBILE except aeronautical mobile BROADCASTING 5.484A 5.487
12.5-12.75 FIXED-SATELLITE (space-to-Earth) 5.484A (Earth-to-Space) 5.494 5.495 5.496		12.5-12.75 FIXED FIXED-SATELLITE (space-to-Earth) 5.484A MOBILE except aeronautical mobile BROADCASTING-SATELLITE 5.493

5.484A The use of the bands 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) in Region 2, 12.2-12.75 GHz (space-to-Earth) in Region 3, 12.5-12.75 GHz (space-to-Earth) in Region 1, 13.75-14.5 GHz (Earth-to-space), 17.8-18.6 GHz (space-to-Earth), 19.7-20.2 GHz (space-to-Earth), 27.5-28.6 GHz (Earth-to-space), 29.5-30 GHz (Earth-to-space) by a non-geostationary-satellite system in the fixed-satellite service is subject to application of the provisions of No. 9.12 for coordination with other non-geostationary-satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the fixed-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed-satellite service and of the complete coordination or notification information, as appropriate, for the geostationary-satellite networks, and No. 5.43A does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated.

5.487 In the band 11.7-12.5 GHz in Regions 1 and 3, the fixed, fixed-satellite, mobile, except aeronautical mobile, and broadcasting services, in accordance with their respective allocations, shall not cause harmful interference to, or claim protection from, broadcasting-satellite stations operating in accordance with the Regions 1 and 3 Plan in Appendix 30.

5.487A *Additional allocation:* in Region 1, the band 11.7-12.5 GHz, in Region 2, the band 12.2-12.7 GHz and, in Region 3, the band 11.7-12.2 GHz, are also allocated to the fixed-satellite service (space-to-Earth) on a primary basis, limited to non-geostationary systems and subject to application of the provisions of No. 9.12 for coordination with other non-geostationary-satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the broadcasting-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed-satellite service and of the complete coordination or notification information, as appropriate, for the geostationary-satellite networks, and No. 5.43A does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated.

5.488 The use of the band 11.7-12.2 GHz by geostationary-satellite networks in the fixed-satellite service in Region 2 is subject to application of the provisions of No. 9.14 for coordination with stations of terrestrial services in Regions 1, 2 and 3. For the use of the band 12.2-12.7 GHz by the broadcasting-satellite service in Region 2, see Appendix 30.

5.490 In Region 2, in the band 12.2-12.7 GHz, existing and future terrestrial radiocommunication services shall not cause harmful interference to the space services operating in conformity with the broadcasting-satellite Plan for Region 2 contained in Appendix 30.

5.492 Assignments to stations of the broadcasting-satellite service which are in conformity with the appropriate regional Plan or included in the Regions 1 and 3 List in Appendix 30 may also be used for transmissions in the fixed-satellite service (space-to-Earth), provided that such transmissions do not cause more interference, or require more protection from interference, than the broadcasting-satellite service transmissions operating in conformity with the Plan or the List, as appropriate.

5.493 The broadcasting-satellite service in the band 12.5-12.75 GHz in Region 3 is limited to a power flux-density not exceeding −111 dB(W/(m2 · 27 MHz)) for all conditions and for all methods of modulation at the edge of the service area.

5.494 *Additional allocation:* In Algeria, Angola, Saudi Arabia, Bahrain, Cameroon, the Central African Rep., Congo (Rep. of the), Côte d'Ivoire, Djibouti, Egypt, the United Arab Emirates, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Madagascar, Mali, Morocco, Mongolia, Nigeria, Oman, Qatar, the Syrian Arab Republic, the Dem. Rep. of the Congo, Somalia, Sudan, South Sudan, Chad, Togo and Yemen, the band 12.5-12.75 GHz is also allocated to the fixed and mobile, except aeronautical mobile, services on a primary basis. (WRC-12)

5.495 *Additional allocation:* In France, Greece, Monaco, Montenegro, Uganda, Romania, Tanzania and Tunisia, the band 12.5-12.75 GHz is also allocated to the fixed and mobile, except aeronautical mobile, services on a secondary basis. (WRC-12)

5.496 *Additional allocation:* in Austria, Azerbaijan, Kyrgyzstan and Turkmenistan, the band 12.5-12.75 GHz is also allocated to the fixed service and the mobile, except aeronautical mobile, service on a primary basis. However, stations in these services shall not cause harmful interference to fixed-satellite service earth stations of countries in Region 1 other than those listed in this footnote. Coordination of these earth stations is not required with stations of the fixed and mobile services of the countries listed in this footnote. The power flux-density limit at the Earth's surface given in Table 21-4 of Article 21, for the fixed-satellite service shall apply on the territory of the countries listed in this footnote.