HWG | HARRIS, WILTSHIRE & GRANNIS LLP

January 26, 2018

Ex Parte

Marlene Dortch, Secretary
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Re: Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz, GN Docket No. 17-183

Dear Ms. Dortch:

On January 25, representatives from Apple Inc., Broadcom Corporation, Cisco Systems, Inc., Hewlett Packard Enterprise, Facebook, Inc., Google LLC, Intel Corporation, MediaTek, Inc., Microsoft Corporation, and Qualcomm Incorporated met with representatives from the Office of Engineering and Technology, the Wireless Telecommunications Bureau, and the International Bureau. A complete list of the participants in these meetings is attached to this letter.

Demand for unlicensed spectrum is expected to grow enormously in the coming years. In fact, the Wi-Fi Alliance has concluded that between 500 MHz and 1 GHz of additional unlicensed spectrum may be needed by 2020 to support Wi-Fi's growth. The above companies, representing a broad-based coalition of mobile operating system providers, semiconductor manufacturers, content providers, and access point equipment manufacturers, all see the 6 GHz band as a unique opportunity to meet this need. We believe that it is critical for the FCC to open access to additional unlicensed spectrum as soon as possible and that the interests of incumbents—in some cases our customers and industry partners—must be protected. We have therefore worked collaboratively on a thorough engineering analysis that will aid the Commission in moving quickly to a Notice of Proposed Rulemaking on sharing in the 6 GHz band.

In these meetings, we presented that study, prepared by RKF Engineering Solutions. The study analyzed sharing between unlicensed operations in the 6 GHz band and existing services. RKF conducted a comprehensive independent analysis to determine the impact of a nationwide deployment of unlicensed services on satellite, microwave, and mobile incumbents. **RKF's findings are clear: unlicensed services can successfully coexist with the primary services present in the 6 GHz band.**

Unlicensed services will not cause harmful interference to Fixed Satellite Services (FSS) because the power levels of unlicensed devices at the satellite receivers are so low. Interference

from existing Fixed Service (FS) transmissions significantly exceeds any potential interference that might be caused by unlicensed operations. RKF's findings also demonstrate that unlicensed services can successfully coexist with the 6 GHz band's FS incumbents. RKF directly addressed concerns that individual unlicensed devices situated on high floors, at close range, through a window, or other corner-case geometries may pose an unacceptable risk to FS receivers, and it concluded that these corner cases are extremely rare. And even when they occurred in the study, their impact was exceedingly small: in no case did the interference cause any FS link to fall below its availability design criteria.

For mobile services, RKF's study showed that a small impact to incumbent links is possible. The study evaluated the introduction of unlicensed devices in a mobile services deployment scenario where the likelihood of interference impact was highest (i.e., in an urban environment with high population density, in the presence of Broadcast Auxiliary Service base stations and mobile, truck-mounted transmitters). Even in that worst-case scenario, unlicensed operations did not cause a degradation in service approximately 99 percent of the time, and in the remaining 1 percent of the time, the link margin could be maintained by the mobile operator in a manner consistent with the current operating and setup practices for these highly variable ad hoc deployments.

Unlicensed services like Wi-Fi have proven to be highly complementary to licensed wireless broadband services. RKF's study demonstrates that unlicensed services can similarly coexist successfully with the range of licensed services present in the 6 GHz band. We believe that the need for new unlicensed spectrum is urgent, and we hope that providing a detailed and thorough engineering analysis unusually early in the process, before the NPRM stage, will aid the Commission in working quickly to meet that need.

Pursuant to the FCC's rules, I have filed a copy of this notice electronically in the above-referenced docket. If you require any additional information, please contact the undersigned.

Sincerely,

Paul Margie
Counsel to Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation

Enclosures

cc: meeting participants

MEETING ATTENDEES

Donald Stockdale (WTB)
Chris Andes* (WTB)
Steven Buenzow* (WTB)
Peter Daronco* (WTB)
Thomas Derenge (WTB)
Ariel Diamond (WTB)
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Christopher Bair (IB)
Diane Garfield (IB)
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Chris Szymanski, Broadcom Corporation
Mary Brown, Cisco Systems, Inc.
Chris Hemmerlein, Facebook, Inc.
Michael Tseytlin, Facebook, Inc.
Austin Schlick, Google LLC
Chuck Lukaszewski, Hewlett Packard Enterprise
Peter Pitsch, Intel Corporation
James Wang, MediaTek Inc.
Paula Boyd, Microsoft Corporation
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Frequency Sharing for Radio Local Area Networks in the 6 GHz Band

January 2018

Prepared by:

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Prepared for:

Apple Inc., Broadcom Limited, Cisco Systems, Inc., Facebook Inc., Google LLC, Hewlett-Packard Enterprise, Intel Corporation, Microsoft Corporation, MediaTek Inc., and QUALCOMM Incorporated

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1.0 Executive Summary

In the United States, the 5.925 to 7.125 GHz band (6 GHz band) is shared primarily by two services: Fixed Satellite Service (FSS) uplinks[1] and fixed microwave (Fixed Service or FS) links. Portions of this band are also used by the Mobile Service (MS) for public safety and electronic news gathering applications such as TV Broadcast Auxiliary and Cable Relay Services. In light of recent regulatory developments,[2] RKF Engineering Services, LLC (RKF), analyzed the potential impact of unlicensed Radio Local Area Network (RLAN)[3] devices on existing 6 GHz FSS, FS, and MS operations in the 48 contiguous United States (CONUS).

The results of this analysis show that a national deployment of RLAN devices (RLANs) in the 6 GHz band, using established RLAN mitigation techniques and regulatory constraints similar to those applied in the neighboring 5 GHz band,[4] will be complementary in spectrum utilization to these primary services and will not cause harmful interference.

Fixed Satellite Service

In the 5.925-6.425 GHz uplink band, RKF analyzed the interference from all registered FS stations to establish an interference baseline for subsequent RLAN analysis. Our study shows that the worst-case scenario for potential aggregate FS-to-FSS interference occurs toward the horizon, and only on those satellites located well to the east and west of CONUS. We then modeled a national deployment of RLANs and found that the maximum interference to noise ratio (I/N) into FSS receivers was -21.9 dB, well below the applicable interference protection criteria (IPC) and significantly less than the interference FSS presently receives from existing FS microwave transmissions.

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[1] Paired with FSS downlinks in 3.4-4.2 GHz band.

[2] *In the Matter of Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Notice of Inquiry, 32 FCC Rcd. 6373 (2017) (NOI).

[3] RLAN is a generic term used to describe a device that provides local area network connections between various electronic devices. While Wi-Fi is one type of RLAN, this study applies to other RLANs with Unlicensed National Information Infrastructure (U-NII) operating characteristics.

[4] 47 C.F.R. § 15.407(a)(1).

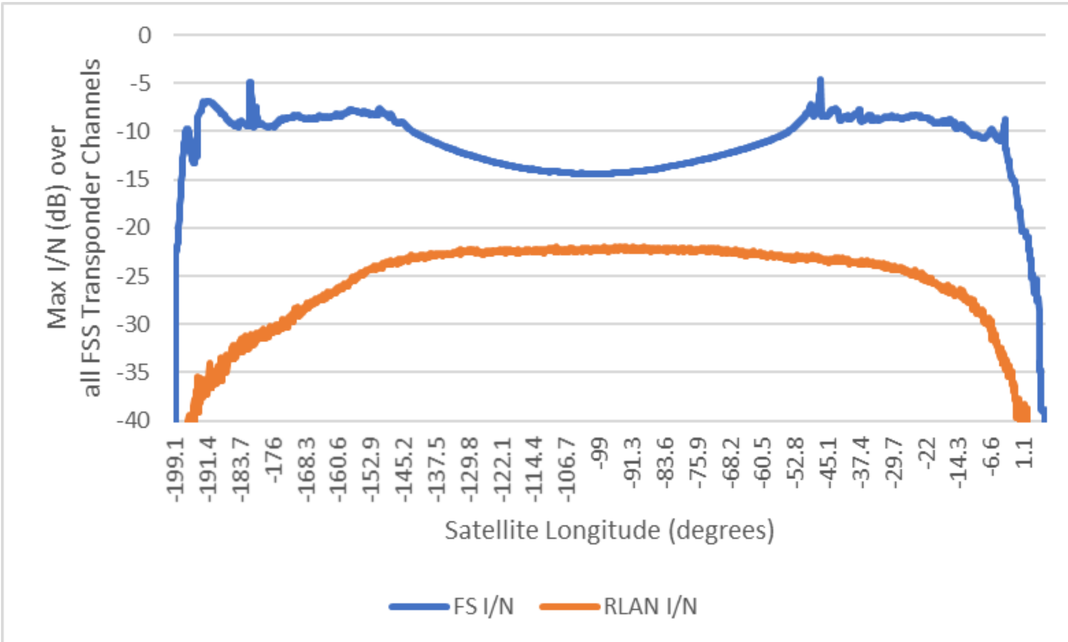

Figure 1-1 - I/N Due to FS and RLAN Transmitters in 5.925-6.425 GHz to FSS Satellites with Visibility to CONUS

We also noted a stark contrast when comparing the results of RLAN interference into FSS versus FS interference into FSS: the highest levels of RLAN interference into FSS were in the orbital locations with the lower levels of FS-to-FSS interference, and the orbital locations with the highest levels of FS-to-FSS interference had the lowest levels of interference from RLANs. This indicates that RLAN and FS interference are relatively independent of each other, which significantly reduces the overall RLAN interference potential to FSS. In light of these analyses, we conclude that a national deployment of RLAN devices in the 6 GHz band can share the spectrum without harmful interference to existing FSS services.

Fixed Service

To assess FS protection, we analyzed the potential impact a national RLAN deployment would have on the more than 91,000 FS links operating in CONUS. Because these links include critical infrastructure, public safety, and other important services, they are designed to maintain a high level of availability. As such, the key criterion we evaluated was the impact RLAN devices would have on the availability of FS links. The first step was to characterize aggregate potential interference into FS receivers from a nationwide deployment of RLANs. Ten CONUS-wide simulations were performed corresponding to more than 910,000 different RLAN-to-FS interference morphologies and time instances. These simulations demonstrated that approximately 99.8% of the FS stations within CONUS had aggregate interference levels from RLAN operations below the target interference-to-noise (I/N) criteria of -6 dB.[5] For the remaining 2/10ths of 1% (165 FS links), where the threshold was above the target, the results

[5] To avoid interference to FS receivers in the 6 GHz band, the I/N threshold should not exceed -6 dB. *See, e.g, In the Matter of Higher Ground LLC Application for Blanket Earth Station License*, Order and Authorization, 32 FCC Rcd. 728, ¶ 16 (2017).

showed the affected sites to be highly random and caused by a single or small number of dominant interferers proximate to, or operating in the main beam of, the FS receiver.

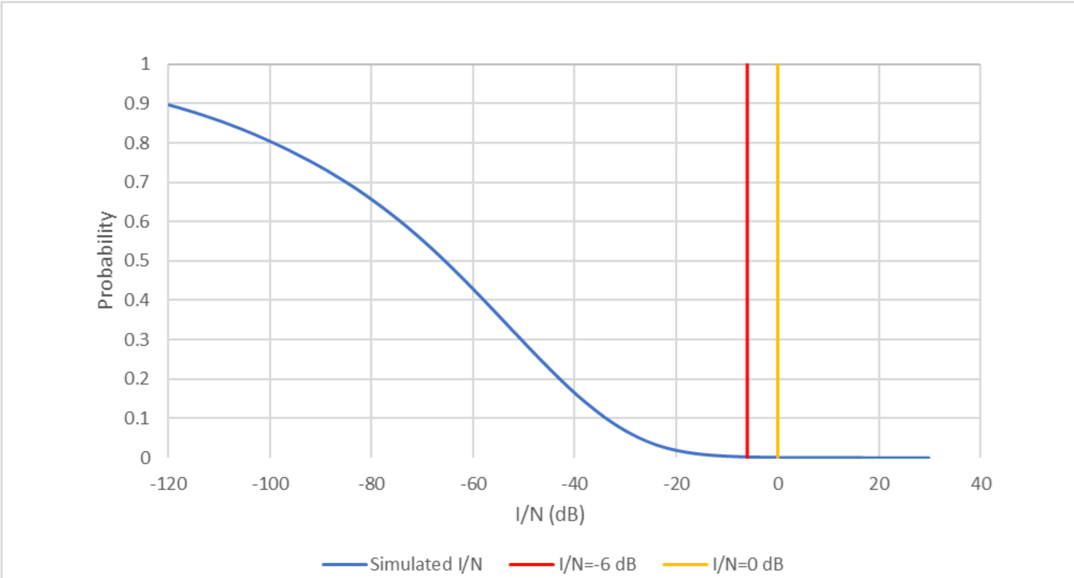

Figure 1-2 - Distribution of RLAN-to-FS Interference across 910,000 Morphologies & Time Instances

To account for the temporal variation of RLAN transmissions within the 165 FS links, we performed 1,000 additional RLAN interference simulations. Even for this set of worst-case geometry simulations, which corresponded to 165,000 RLAN-to-FS interference morphologies and time instances, an I/N greater than -6 dB occurred just 1,052 times (or 0.64%) with 1,025 of those instances caused by single entry interference. Thus, RLAN devices do not pose any substantial aggregate interference risk to FS receivers.

To evaluate the dominant single interferers and calculate their impact on FS link unavailability, a distribution was generated for each of the 165 FS links. Links designed to 99.999% availability (i.e., approximately 315 seconds of downtime per year), incurred approximately 8 seconds of additional downtime per year, and links designed to 99.9999% availability (i.e., approximately 31.6 seconds of downtime per year) incurred approximately 0.8 seconds of additional downtime per year. Even for these worst-case scenarios, the resulting impact on FS availability and quality of service delivered over these FS links from the introduction of RLAN devices falls within the existing availability design margin and does not cause harmful interference.

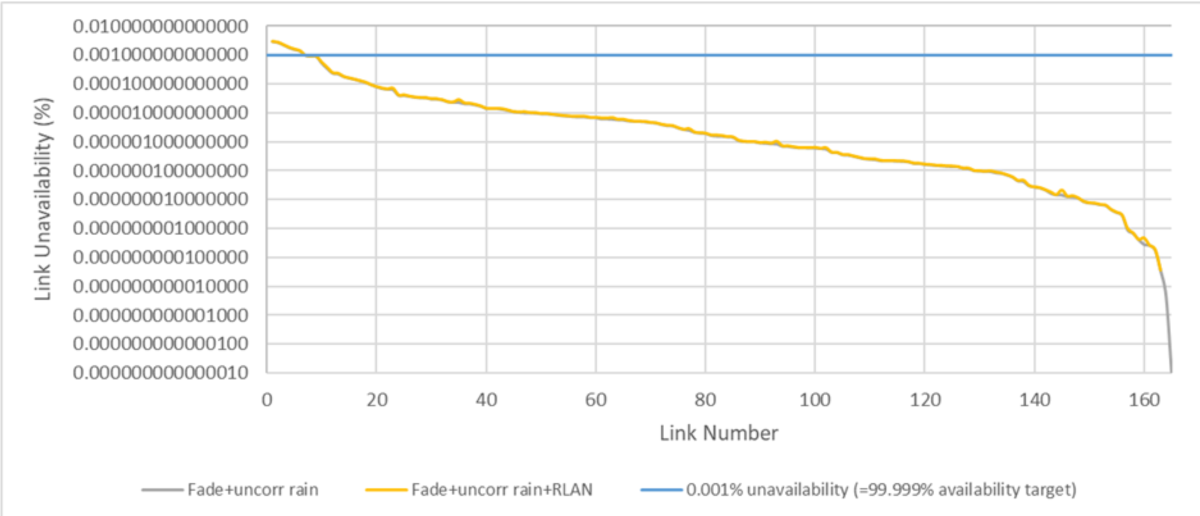

Figure 1-3 - Link Unavailability for Worst-case Links Without (Fade+Uncorr Rain) and With RLAN Interference (Fade+Uncorr Rain+RLAN)

This study also demonstrates that individual RLANs situated on high floors, at close range, through a window, or other corner case geometries do not pose a harmful interference risk to FS receivers. We find that the *rate of occurrence* of such geometries is extremely low—on the order of two-tenths of one percent. Further, we show that *the cumulative statistical effect of such occurrences* does not cause any FS links in CONUS to fall below its availability design target.

Mobile Service

Finally, RKF determined that the worst-case mobile links would involve trucks communicating to base stations located on towers, buildings, or mountains. In these scenarios, the base station is pointing toward the ground and it is possible for the RLANs to be in the base station main beam. For the simulation, several Broadcast Auxiliary Service (BAS) base stations were selected in San Francisco and Los Angeles to reflect this worst-case geometry.

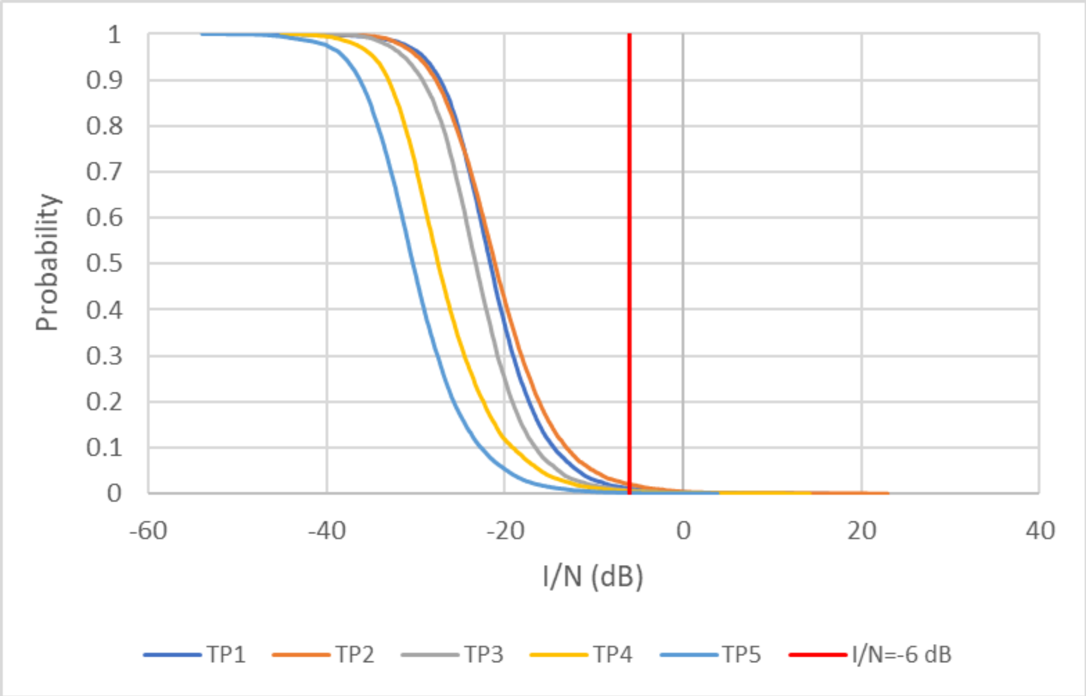

Figure 1-4 - Probability of Aggregate RLANs I/N Exceeding an I/N Level (x-axis) for TP1, TP2, TP3, TP4 and TP5

A simulation was performed 10,000 times to determine the aggregate interference from RLANs to the MS base station receivers. For each iteration of the simulation, RLANs were randomly deployed, with weighting according to population density. Then the simulation was run with the vehicular MS transmitter randomly deployed within the base station operating radius. The modeled RLAN operations did not cause a degradation in service approximately 99% of the time. In the remaining 1%, an improvement in fade margin could be achieved in a manner consistent with current operational practices (e.g., by optimizing the transmitter location, reducing the data rate, using adaptive coding, and modulation). Further, by its very nature, MS operating conditions within a desired coverage area are highly variable and additional RLAN interference does not cause a material impact on MS performance.

2.0 Introduction

2.1 Background

On August 3, 2017, the Federal Communications Commission (FCC or Commission) released an NOI to study mid-band frequencies for wireless broadband use.[6] The Commission believes that exploring options to expand spectrum access opportunities in mid-band frequencies could further its goal of establishing comprehensive, sound, and flexible policies that enable innovations and investment to keep pace with technological advances, and maintain U.S. leadership in deployment of next-generation wireless broadband services.

Over the next four years, U.S. wireless data services are expected to increase 500%, the number of connected devices is predicted to more than double to one billion, and demand for unlicensed spectrum is expected to grow significantly. As an example of unlicensed demand, more than half of all internet traffic is predicted to be carried over RLAN networks by 2021.[7] To address this critical need for expanded spectrum access, a broad-based coalition of mobile operating system providers, semiconductor manufacturers, content providers, and access point equipment manufacturers, including Apple, Broadcom, Cisco, Facebook, Google, Hewlett-Packard Enterprise, Intel, MediaTek, Microsoft, and Qualcomm, retained RKF to perform an independent assessment of a nationwide deployment of RLANs in the 6 GHz band.

RKF has a long history of performing these types of technical analyses in support of FCC initiatives, specifically in spectrum sharing studies that involve fixed and mobile wireless services delivered through terrestrial and satellite links, including in the 6 GHz band. Using publicly available FCC licensing data for terrestrial and satellite systems, including performance parameters for fixed and mobile wireless services, RKF simulated nationwide deployments of RLANs and analyzed the feasibility of RLAN sharing within the 6 GHz band with existing wireless services.

2.2 Objectives

This report evaluates sharing possibilities of RLANs with existing services in the 6 GHz band.

2.3 Approach

Current services and uses of the 6 GHz band are considered. Consistent with the FCC's Table of Frequency Allocations,[8] incumbent services with primary allocation within the 6 GHz band are indicated in Figure 2-1.

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[6] 32 FCC Rcd. 6373 (2017).

[7] ITI, *Broad-Based Coalition Applauds FCC for New Mid-Band Spectrum Notice of Inquiry*, Aug. 3, 2017, https://www.itic.org/news-events/news-releases/broad-based-coalition-applauds-fcc-for-new-mid-band-spectrum-notice-of-inquiry.

[8] *FCC Online Table of Frequency Allocations*, Dec. 13, 2017, https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

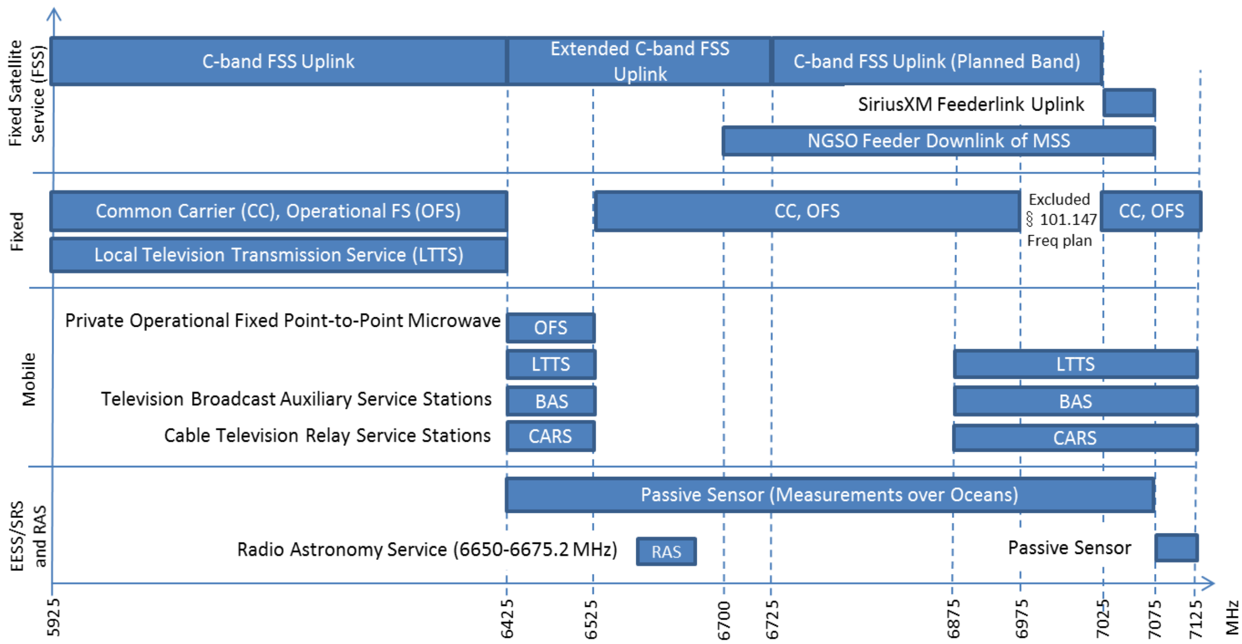


Figure 2-1 – Incumbent Services with Primary Allocation Within 5.925-7.125 GHz

Because most spectrum within CONUS in the 6 GHz band is allocated to FSS uplink, FS, and MS, this report focuses only on these sharing scenarios.[9]

A detailed CONUS-wide simulation of the interference environment was developed and RKF ensured its simulation was a conservative representation of the interference environment by:

1) Including the maximum number of incumbent stations listed in FCC databases and deriving all operating data from publicly available records. Such FCC databases include: the International Bureau Filing System (IBFS) and FSS filings as of May 31, 2017); the Universal Licensing System (ULS) and FS and certain MS terrestrial systems as of March 21, 2017;[10] and the Cable Operations and Licensing System (COALS) for mobile Cable Television Relay Service (CARS) terrestrial systems as of July 19, 2017. We note, however, that using all stations found in the FCC's IBFS, ULS, and COALS databases likely overstates actual incumbent operations because a number of registered facilities are out of service;

2) Using US Census Bureau (USCB) 2020 estimated population density maps and definitions of urban, suburban, and rural areas. As described in Section 3.1.2, urban and suburban areas comprise only 5% of CONUS land area but contain over 80% of the population, implying that interference will be concentrated predominately in these areas. Including rural areas, 90% of the population is in urban, suburban, or rural CONUS, occupying 10% of the geography. The remaining 10% of the population is widely spread

[9] Radio Astronomy and Earth Exploration Satellite Services (EESS)/Space Research Service (SRS) sharing scenarios are not considered in this report.
[10] For instances where records were incomplete, we used representative data based on the means within the FCC's ULS database.

out in “barren” areas that were excluded from the simulation for two main reasons: the extremely low population density and the continued use of legacy RLANs that do not operate at 6 GHz. The low population density implies a very low probability of congested spectrum and therefore users would not need to expand out of legacy bands;

3) Using realistic but conservative RLAN operating and deployment assumptions as described in Section 3.0. These were based on existing and projected market data, usage, and performance and include:

a) Full CONUS simulation of an RLAN deployment;

b) Approximately 1 billion 6 GHz capable RLAN devices;

c) A very high installed base of 6 GHz capable RLAN devices (45%) assumed in 2025, which is more likely to be a 2035 projection;

d) A higher average Equivalent Isotropic Radiated Power (EIRP) than ITU-R WP5A document (*see* Section 3.2.1);

e) Significantly higher EIRP above 30° elevation of 1 watt (30 dBm) as compared with U-NII-1 rules which limit maximum EIRP to 125 mW (21 dBm);

f) A conservative assumption of the number of thermally efficient buildings (affecting penetration loss) of 20% vs 30% used in WP5A;

g) Doubling published market research on outdoor RLAN equipment shipments to estimate more rapid growth scenarios; and

h) Conservative propagation and clutter models for various environments as described in Section 4;

4) Diversity and/or Multiple-Input-Multiple-Output (MIMO) processing gains were not considered for FS;

5) Using worst case scenarios to represent possible situations;

6) Executing numerous different scenarios with a wide variation of propagation paths and RLAN deployment configurations to ensure statistically significant results. USCB definitions are used to partition the CONUS into urban, suburban, and rural areas and a USCB 2020 projected CONUS population density was used to randomly deploy RLANs for each simulation iteration;

7) An I/N of -6 dB was used as a comparison threshold in this study with the understanding that the analysis in this report is very conservative and did not take into account many factors that would lower the aggregate I/N (*see* Section 3.2.5.2).

Simulation results are presented and analyzed in Section 5. FSS uplinks are reviewed in Section 5.1, FS links are covered in Section 5.2, and MS link results are described in Section 5.3.

3.0 RLAN Deployment and Operating Assumptions

This section describes the analysis and methodology for assigning source quantities to the proposed 6 GHz band RLANs and their operating parameters.

3.1 RLAN Deployment Assumptions

3.1.1 Number of Active RLANs and Deployment Distribution

Table 3-1 depicts the parameters and calculations used to develop the numbers of active RLANs. As noted above, this study applies to all RLANs that comply with U-NII operating characteristics, including but not limited to Wi-Fi Access Points (AP) and stations.
At a first level, the deployment of RLANs is assumed to be closely associated with population density, and therefore geographically allocated according to the population distribution in CONUS. The basis of the active device analysis is an estimated US population of 347 million in 2025. As described in Section 3.1.2, we used USCB population thresholds that define urban, suburban, and rural areas, to determine population density across CONUS.

	TOTAL	URBAN			SUBURBAN			RURAL		
Population (%)	**90%**	70%			10%			10%		
User Type	**All**	**Corp**	**Public**	**Home**	**Corp**	**Public**	**Home**	**Corp**	**Public**	**Home**
Type (%)	**All**	10%	5%	85%	5%	5%	90%	2%	1%	97%
Device Population	**958,062,017**	74,515,935	37,257,967	633,385,445	5,322,567	5,322,567	95,806,202	2,129,027	1,064,513	103,257,795
High Activity Device Population (% of Total)		10%	10%	10%	10%	10%	10%	10%	10%	10%
Data/device/hour, (MBytes)		1000	500	2000	1000	500	2000	1000	500	2000
Device Rate (Mbps)		2.22	1.11	4.44	2.22	1.11	4.44	2.22	1.11	4.44
Link Speed (Mbps)		1000	1000	1000	1000	1000	1000	1000	1000	1000
Duty Cycle per Device		0.22%	0.11%	0.44%	0.22%	0.11%	0.44%	0.22%	0.11%	0.44%
Instantaneous Number of Transmitting 6 GHz Devices (Subtotal, High Activity)	**393,042**	16,559	4,140	281,505	1,183	591	42,581	473	118	45,892
Low Activity Device Population (% of Total)		90%	90%	90%	90%	90%	90%	90%	90%	90%
Data/device/hour, (Mbytes)		1	1	1	1	1	1	1	1	1
Device Rate (Mbps)		0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022
Link Speed (Mbps)		1000	1000	1000	1000	1000	1000	1000	1000	1000
Duty Cycle per Device		0.00022%	0.00022%	0.00022%	0.00022%	0.00022%	0.00022%	0.00022%	0.00022%	0.00022%
Instantaneous Number of Transmitting 6 GHz Devices (Subtotal, Low Activity)	**1,916**	149	75	1,267	11	11	192	4	2	207
Instantaneous Number of Transmitting 6 GHz Devices (total)	**394,958**	**16,708**	**4,214**	**282,771**	**1,193**	**602**	**42,772**	**477**	**120**	**46,099**

Table 3-1 - RLAN Active Device Distribution

In Figure 3-1, the data show that 90% of the U.S. population is included in the rural, urban, and suburban demographic areas and the remaining 10% of the population in barren areas. While the interference potential in barren areas is very low, such areas were excluded from consideration in

this report since the people who live in these areas are likely to rely on legacy RLANs that provide sufficient capacity and speeds for their internet access, if they have access at all.

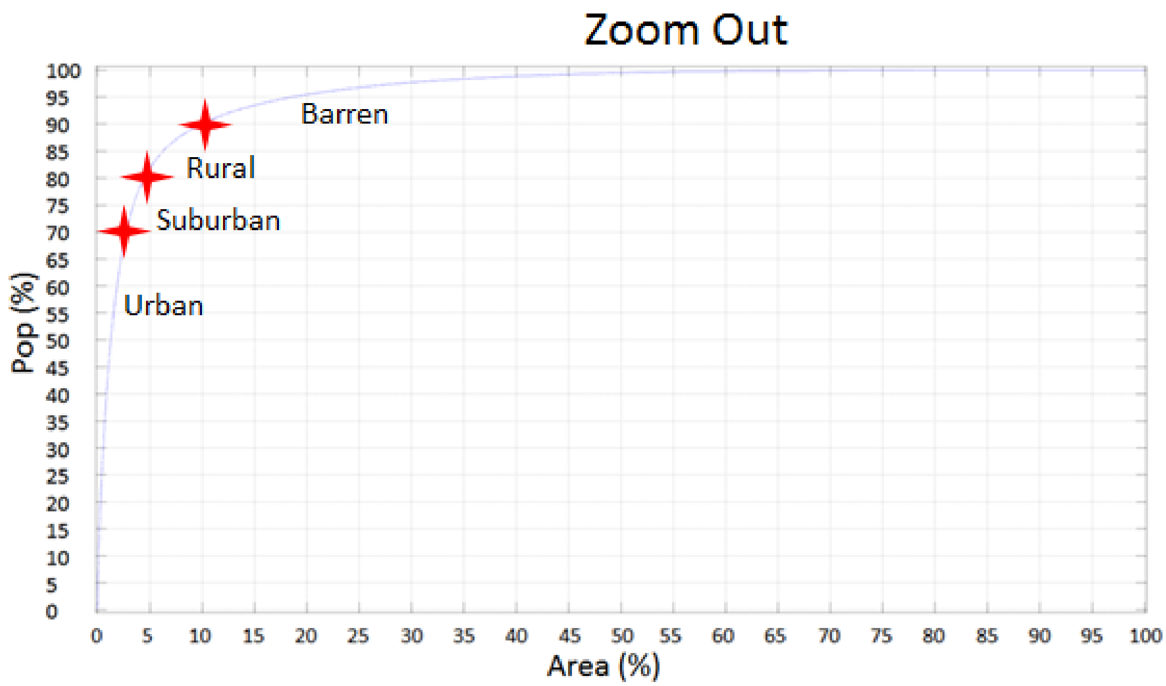


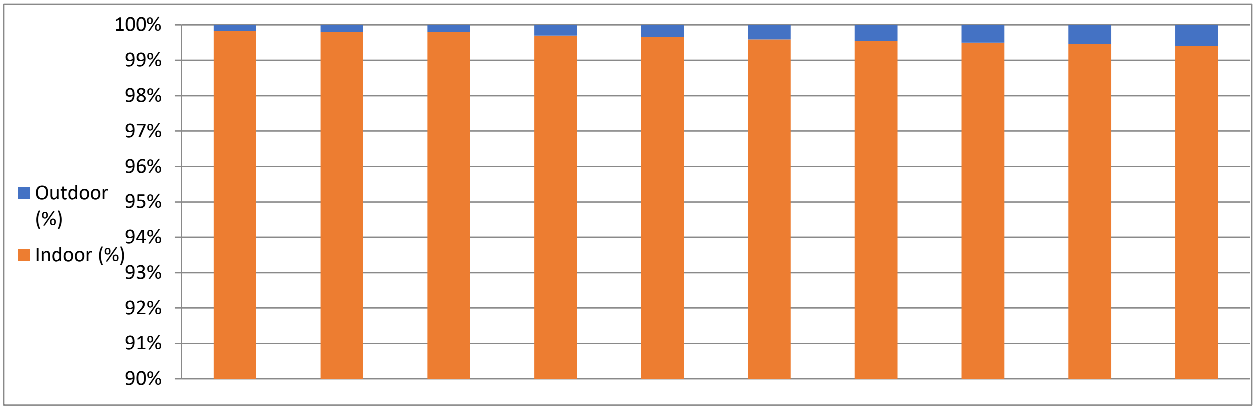
Figure 3-1 - Census Bureau 2020 Population Distribution

Assuming an average RLAN device count of 10 per person, the total RLANs in operation over CONUS is estimated to be 3.47 billion in 2025 and the market penetration of 6 GHz capable RLANs is assumed to be 45%. Because 6 GHz capable RLANs are expected to also operate in the 2.4 and 5 GHz bands, and assuming spectrum loading will be even across all the contemplated channels in the unlicensed bands, 68% of 6 GHz enabled RLANs are estimated to be using the 6 GHz band. As shown in the following equation, the resulting number of RLANs connected to a 6 GHz network, excluding barren areas, is 958 million:

Total 6 GHz Attached Devices = Total Population (people) x Devices per Person x Market Penetration x (target 6 GHz Spectrum) / (total 2.4 + 5 + 6 GHz Spectrum) x 90% (3-1)

Total 6 GHz Attached Devices = (346,953 x 10 x 0.45 x 1200/1760) x 0.9 = 958 Million (3-2)

To estimate indoor versus outdoor deployments, we used Figure 3-2 which depicts the ratio of indoor vs outdoor Wi-Fi AP shipments from 2011 to 2021, including both historical actual shipment figures for Wi-Fi APs through 2016 as well as a forecast for future years. Outdoor unit shipments in 2021 are estimated at 0.6% of all Wi-Fi APs.



Deployment Type	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Indoor APs	99,750.2	112,676.0	123,414.7	122,463.5	140,000.1	147,825.7	159,546.9	171,540.1	182,602.2	189,331.7
Outdoor APs	171.7	229.3	245.5	375	477.1	609	726.8	860.4	1,002.8	1,152.1
Total	99,921.9	112,905.3	123,660.2	122,838.5	140,477.2	148,434.7	160,273.7	172,400.5	183,605.0	190,483.8

Figure 3-2 – Worldwide Indoor vs Outdoor Wi-Fi Shipments.
Source: Dell'Oro Group July 2017 Wireless LAN report (thousands)

While this study considers RLANs generally, a conservative model for outdoor 6 GHz RLANs may consider both Wi-Fi and 3GPP based technologies such as Licensed Assisted Access (LAA) because many small cell deployments are expected to be outdoors. Table 3-2 depicts data from the Small Cell Forum and shows a forecast of 1.5 million outdoor small cells deployed in 2021.

Applying the same 45% market penetration for outdoor small cells that are LAA and 6 GHz-capable, yields figures slightly lower than the outdoor Wi-Fi AP market. The combined forecast of Wi-Fi and small cell outdoor shipments is approximately 1% of total units in 2021. Doubling this figure yields a conservative ratio for indoor vs. outdoor RLANs in all sub-markets of 98% and 2% respectively.[11]

	2014	2015	2016	2017	2018	2019	2020	2021	CAGR
Indoor	176	310	794	1,080	1,901	2,946	3,420	3,239	52%
Outdoor	47	78	251	441	937	1,387	1,466	1,596	66%
Total	**223**	**388**	**1,045**	**1,521**	**2,838**	**4,333**	**4,886**	**4,835**	**55%**

Table 3-2 – Small Cell Forum Forecast for Outdoor Small Cell Shipments (thousands)

For the peak usage analysis (busy hour), an activity level was assigned to represent the amount of data consumed wirelessly. For this analysis, the activity on these RLANs was distributed around two primary modes (i.e., bi-modal):

- "High activity" mode – Typical of RLANs in active use by a person. For this simulation we assumed one device per person, a more conservative model than typical assumptions.
- "Low activity" mode – Typical of RLANs making periodic or intermittent transfers of data, such as RLANs connected to the network but not in direct use (idle), or RLANs that make small data transfers typical of "Internet of Things" (IoT) connected devices.

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[11] 5G Americas and Small Cell Forum, *Multi-operator and Neutral Host Small Cells: Drivers, Architectures, Planning and Regulation*, Dec. 2016, http://www.5gamericas.org/files/4914/8193/1104/SCF191_Multi-operator_neutral_host_small_cells.pdf.

To determine the worst-case time of interference into incumbent systems, busy hours for corporate, public, and home usage were studied. Results showed that home usage was the heaviest and therefore busy hours were assumed to be 7:00 pm – 11:00 pm local time.[12] That resulted in a busy hour across CONUS of 7:00 pm – 8:00 pm Pacific Time. It was assumed that on average every person in the CONUS is actively using one RLAN during the busy hour while owning an average of nine other RLANs that were not being actively used. As a result, the percentage of devices in the High activity mode was assumed to be 10% and 90% were assumed to be in the Low activity mode. [13,14]

For devices in the High activity mode, usage was modeled to be 2.0 Gbytes/hour (4.44 Mbps) for the home user, 1 Gbytes/hour (2.22 Mbps) for the corporate user, and 500 Mbytes/hour (1.11 Mbps) for public (hotspot connected) users. For devices in the Low activity mode, usage was modeled to be 1 Mbyte/hour (2.2 kbps).

As a final step in this derivation, the efficiency of high bitrate modulation techniques offered by modern unlicensed wireless technologies is considered. It is expected that new, 6 GHz technology will deliver an average application layer throughput rate of 1 Gbps as achieved in current 5 GHz technology. It is also expected that this capability will be deployed for the types of 6 GHz devices in use during the busy hour for applications like video streaming. Based on the available over-the-air rate of the AP, the data required per device per hour and the required duty cycle can be assigned per device as follows:

$$\textit{Device Duty Cycle (\% of available airtime)} = \textit{Data per Device per Hour (Mbytes)} \times \textit{(8 bits / 3600 secs) / Average Rate (Mbps)} \qquad (3\text{-}3)$$

For example, for the Home Market active device model

$$\textit{Device Duty Cycle} = 2000 \textit{ MBytes} \times (8/3600) / 1000 \textit{ Mbps} = 0.44\ \% \qquad (3\text{-}4)$$

The number of instantaneously active devices included in the model over all of CONUS is the sum of the low and high activity mode devices for all markets (urban, suburban, rural) and environments (corporate, public, home) as follows:

$$\textit{Instantaneous Transmitting Devices} = \textit{Total Devices Using 6 GHz} \times \textit{Duty Cycle} \qquad (3\text{-}5)$$

Note that the device duty cycle is calculated and assigned for all RLANs in each of the above market types and environments and for both low and high activity mode devices. Table 3-1

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[12] Chitik, *Hour-by-Hour Examination: Smartphone, Tablet, and Desktop Usage Rates*, Mar. 26, 2013, https://chitika.com/browsing-activity-by-hour.

[13] ITU document Revision 1 to 5A/TEMP/236, Sharing and compatibility studies of WAS/RLAN in the 5 150-5 250 MHz frequency range, Section 5.1.1.4.2.5, stated busy hour demographic factor was 71%, 64%, and 47% for urban suburban, and rural populations. This simulation assumed 90%.

[14] While the ITU-R Working Party 5A concludes that busy hour participation is 62.7%, this simulation uses 90%. ITU-R, *Annex 22 to Working Party 5A Chairman's Report: Use of Aggregate RLAN Measurements from Airborne and Terrestrial Platforms to Support Studies Under WRC-19 Agenda Item 1.16* (Nov. 16, 2017) at 3, *available at* https://www.itu.int/md/R15-WP5A/new/en (ITU-R 5A/650 (Annex 22)-E).

shows the resulting input quantities of instantaneous transmitting devices for each of these markets and environments.

3.1.2 Population Density

The sharing analysis for this report used an estimated 2020 population density, based on USCB projections, to randomly distribute the active RLANs estimated in Section 3.1.1. [15]Population density thresholds, based on USCB 2010 definitions, were used to divide the country into urban, suburban, rural, and barren areas.

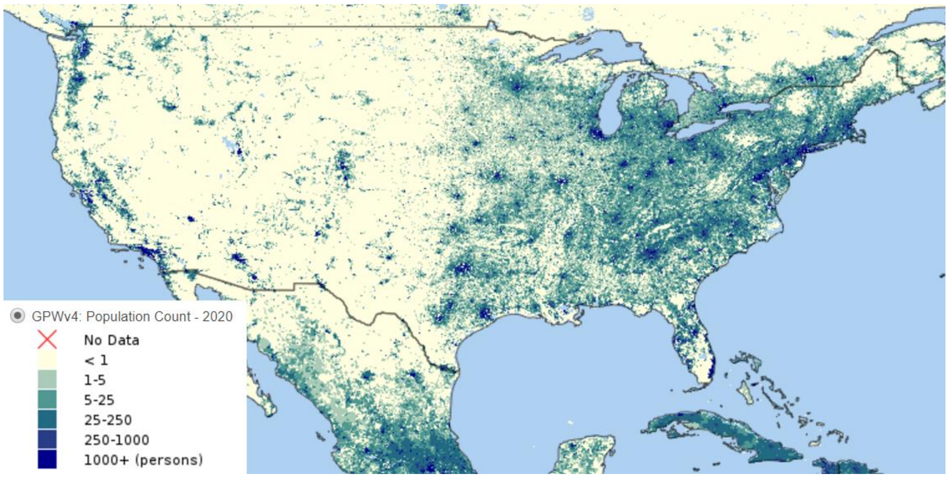

Figure 3-3 - 60 Arcsecond Resolution of Census Bureau Population Count Map

The resulting population and area percentages shown in Table 3-3 were used in the simulations to randomly distribute the number of RLANs estimated in Section 3.1.1 for sharing analysis with the existing FSS, FS, and MS services in the 6 GHz band.

As can be seen, approximately 95% of CONUS is either rural or barren, which implies that interference will be predominately concentrated in urban and suburban areas.

	Pop (%)	Area (%)
Urban	71.2%	2.8%
Suburban	9.5%	2.2%
Rural	9.3%	5%
Barren	10%	90%

Table 3-3 - Population Distribution

3.2 RLAN Operating Assumptions

To perform a thorough simulation of RLAN sharing of the 6 GHz band, reasonable statistical operating assumptions were developed to account for the myriad possibilities of RLAN use

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[15] Socioeconomic Data and Applications Center, *Gridded Population of the World (GPW), v4, available at* http://sedac.ciesin.columbia.edu/data/collection/gpw-v4/maps/gallery/search?facets=theme:population.

given the deployment models in Section 3.1. As described in that section, we are considering rural, suburban, and urban environments with corporate, public, and home submarkets. Within each of these nine submarkets, key operating parameters that affect the received interference level include RLAN source EIRP, bandwidth and channel usage, and installed height. Because these operating parameters can vary, statistical assumptions must be derived before they can be used in the simulations.

3.2.1 Distribution of Source RLAN Power Levels

To develop the statistical RLAN source power, or EIRP, we looked at typical use cases, RLAN peak power, and busy hour usage weights. Since RLAN locations and antenna orientations tend to be random and RLANs generally have a wide range of available output power and operating characteristics, randomization of the RLAN source EIRP values is a valid approach for the broad statistical analysis of this report.

As stated in Section 3.1, both indoor and outdoor RLAN installations were randomized based on population density and therefore can be installed anywhere relative to a victim receiving location. In each installation, the orientation of the RLAN antenna is in general not fixed. Therefore, in the analysis we assumed an equal weight assigned to all values in the E-plane pattern. Outdoor RLAN antennas most likely will be oriented such that the omnidirectional pattern is horizontal with respect to the ground at the installation site and, as shown in Figures 3-4 through 3-9, will be designed to limit maximum EIRP to 1 Watt above 30^{o} in elevation (9 dB higher than currently allowed in U-NII-1 rules). Even though indoor RLAN antennas have similar elevation patterns (E-plane) as outdoor RLANs, an isotropic radiating pattern for all indoor RLANs was used in the simulations to define a worst-case scenario.

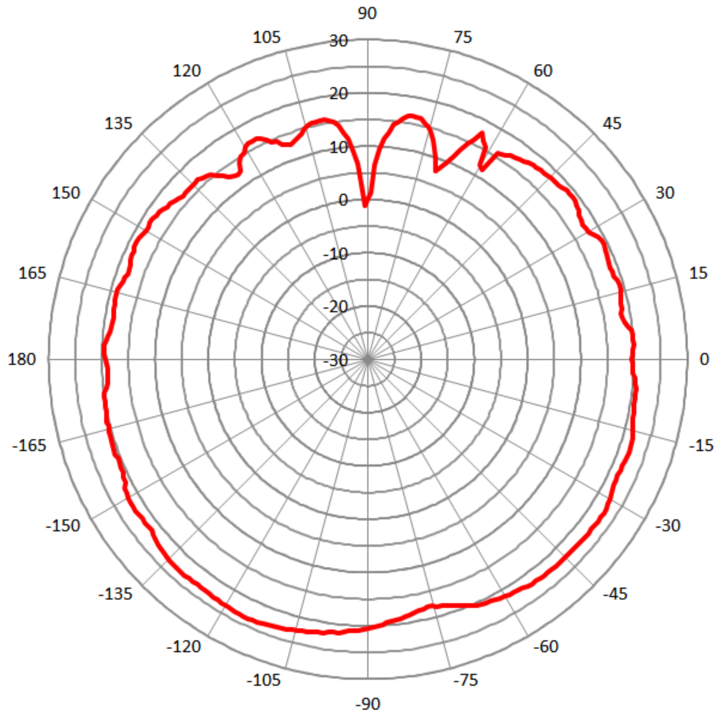
Given these basic assumptions, the expected RLAN power levels can be represented by a distribution of power levels typical of RLANs operating in frequency bands where the current regulatory limit is a conducted transmit power of 1 Watt plus a 6 dBi omnidirectional antenna gain. To derive the RLAN source EIRP in the submarkets described in Section 3.1.1, seven typical use cases were used.

- Indoor Enterprise AP, Indoor Consumer AP, and Indoor High-Performance AP
- Indoor/Outdoor Client
- Outdoor High-Power AP, Outdoor Low Power AP

Table 3-4 provides the peak power of these use cases in the elevation patterns (E-plane) depicted in Figure 3-4 through 3-9. For this analysis, the horizontal patterns (H-plane) were assumed to be omnidirectional.

	Indoor Enterprise AP	Indoor Consumer AP	Indoor High Performance Gaming Router	Indoor/Outdoor Client	Outdoor High Power AP	Outdoor Low Power AP
	Figure 3-4	*Figure 3-5*	*Figure 3-6*	*Figure 3-7*	*Figure 3-8*	*Figure 3-9*
Conducted Power (dBm)	13.5	12.5	24	12	27	14
Peak Antenna Gain (dBi)	4.1	5.3	5.3	3.5	5.3	5.3
MIMO Gain (dB)	6.0	6.0	6.0	3.0	3.0	4.8
Total Peak EIRP (dBm)	**23.6**	**23.8**	**35.3**	**18.5**	**35.3**	**24.1**

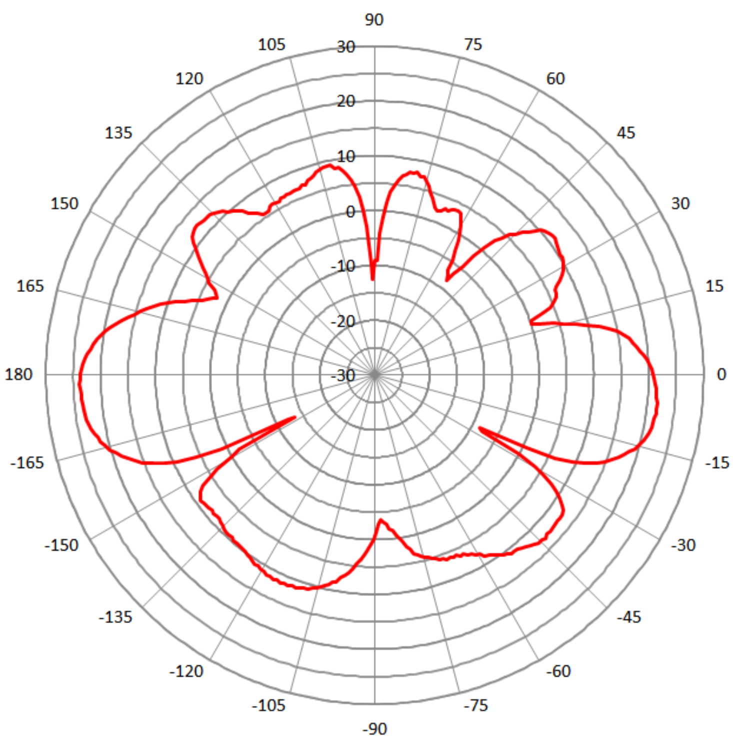
Table 3-4 - Peak Power (EIRP) of Typical RLAN Use Cases



Indoor Enterprise Access Point EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	0.00%
< 30 dBm ≤ 24 dBm	0.00%
< 24 dBm ≤ 20 dBm	40.17%
< 20 dBm ≤ 17 dBm	34.07%
< 17 dBm ≤ 11 dBm	22.16%
< 11 dBm ≤ 0 dBm	3.32%
< 0 dBm	0.28%
Total	**100.00%**

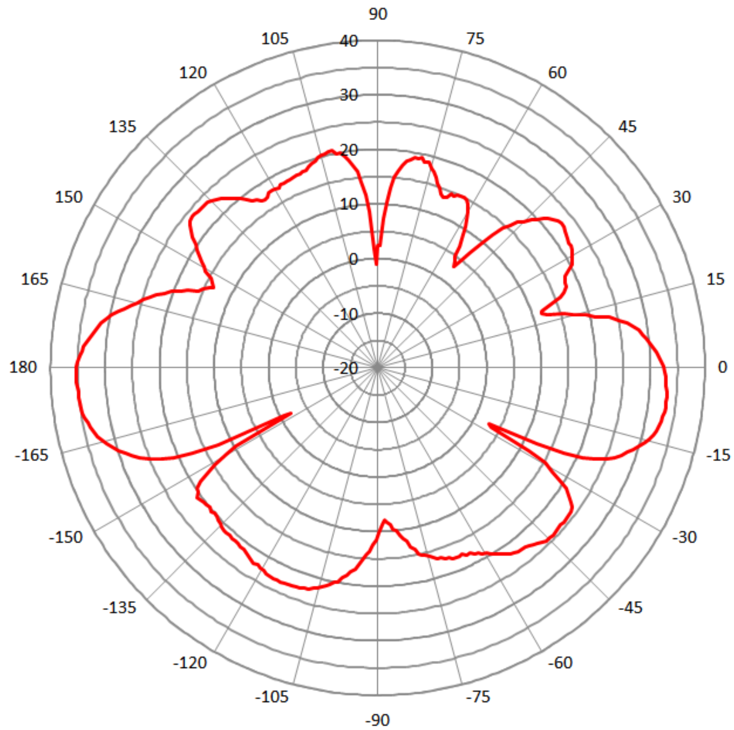
Figure 3-4 - Indoor Enterprise Access Point, Typical Pattern (EIRP)



Indoor Consumer Access Point EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	0.00%
< 30 dBm ≤ 24 dBm	0.00%
< 24 dBm ≤ 20 dBm	11.19%
< 20 dBm ≤ 17 dBm	4.16%
< 17 dBm ≤ 11 dBm	16.90%
< 11 dBm ≤ 0 dBm	58.73%
< 0 dBm	8.31%
Total	**100.00%**

Figure 3-5 - Indoor Consumer Access Point, Typical Pattern (EIRP)

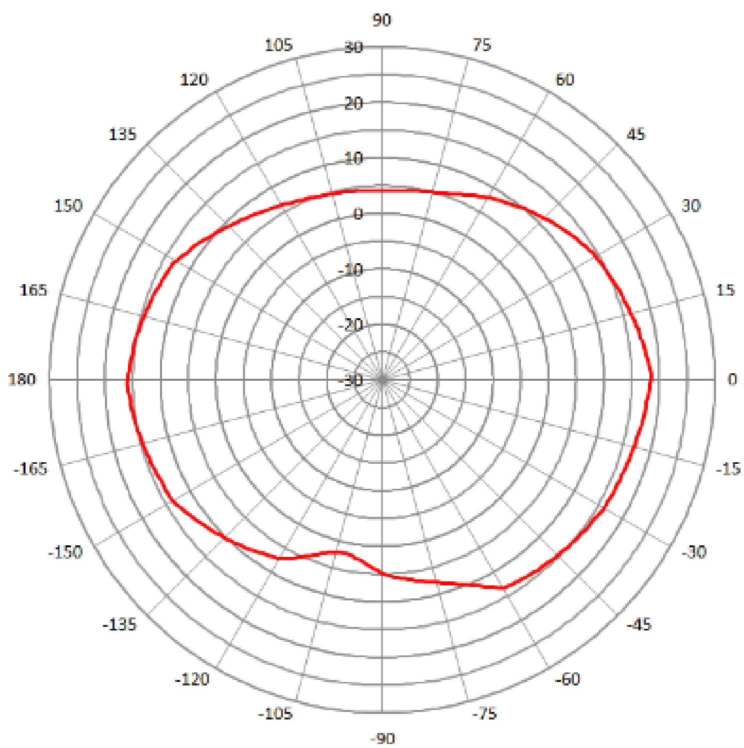


Indoor High-Performance Gaming Router Access Point

EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	14.13%
< 30 dBm ≤ 24 dBm	8.86%
< 24 dBm ≤ 20 dBm	30.19%
< 20 dBm ≤ 17 dBm	21.33%
< 17 dBm ≤ 11 dBm	17.45%
< 11 dBm ≤ 0 dBm	7.20%
< 0 dBm	0.83%
Total	**100.00%**

Figure 3-6 - Indoor High-Performance Gaming Router, Typical Pattern (EIRP)

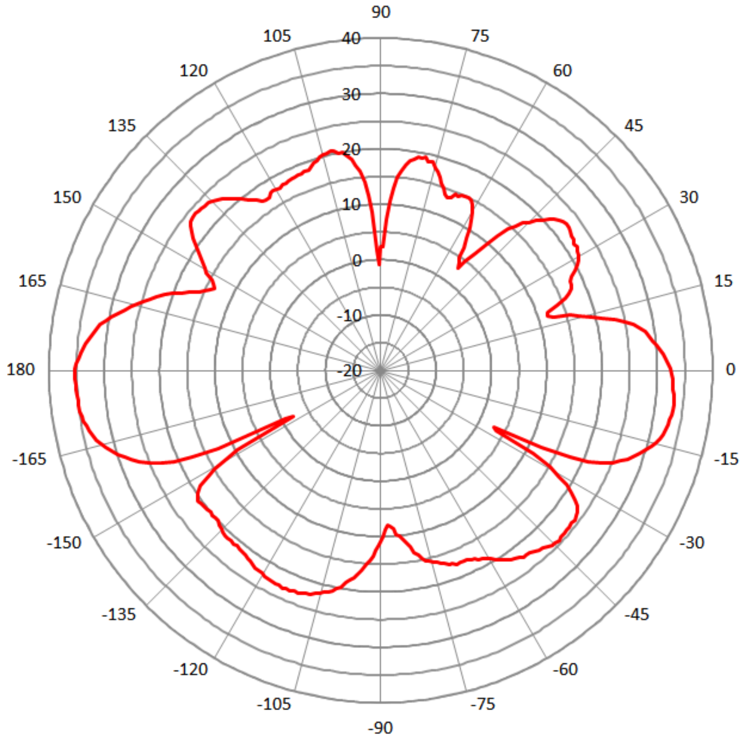


Indoor and Outdoor Client

EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	0.00%
< 30 dBm ≤ 24 dBm	0.00%
< 24 dBm ≤ 20 dBm	0.00%
< 20 dBm ≤ 17 dBm	6.93%
< 17 dBm ≤ 11 dBm	45.71%
< 11 dBm ≤ 0 dBm	47.37%
< 0 dBm	0.00%
Total	**100.00%**

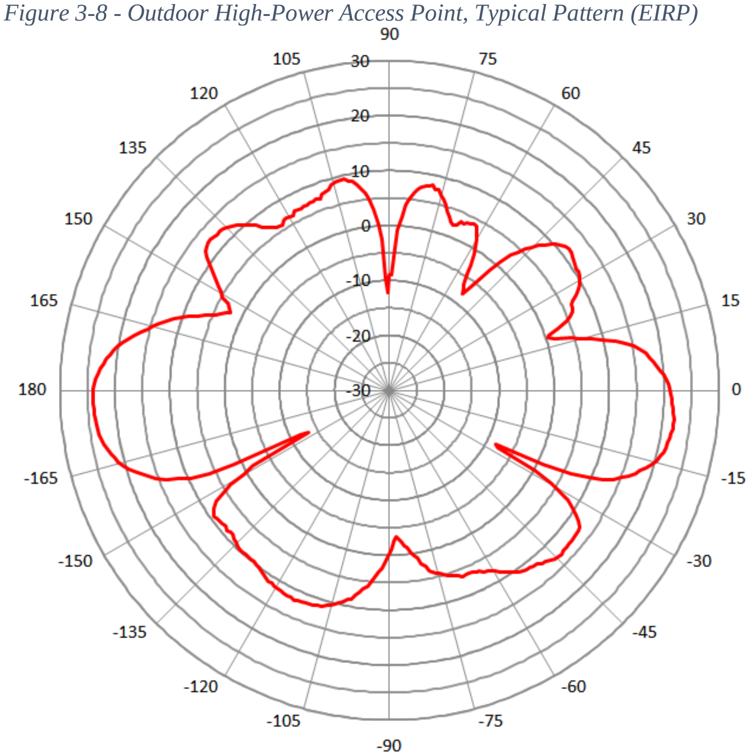
Figure 3-7 - Indoor and Outdoor Client, Typical Pattern (EIRP)



Outdoor High-Power Access Point EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	14.13%
< 30 dBm ≤ 24 dBm	8.86%
< 24 dBm ≤ 20 dBm	30.19%
< 20 dBm ≤ 17 dBm	21.05%
< 17 dBm ≤ 11 dBm	17.73%
< 11 dBm ≤ 0 dBm	7.20%
< 0 dBm	0.83%
Total	**100.00%**

Figure 3-8 - Outdoor High-Power Access Point, Typical Pattern (EIRP)



Outdoor Low Power Access Point EIRP Probability based on E-Plane Directivity

36 dBm ≤ 30 dBm	0.00%
< 30 dBm ≤ 24 dBm	0.83%
< 24 dBm ≤ 20 dBm	11.36%
< 20 dBm ≤ 17 dBm	4.43%
< 17 dBm ≤ 11 dBm	19.11%
< 11 dBm ≤ 0 dBm	56.23%
< 0 dBm	8.03%
Total	**100.00%**

Figure 3-9 - Outdoor Low-Power Access Point, Typical Pattern (EIRP)

The mix of indoor and outdoor RLANs is conservatively estimated at 98% and 2%, respectively (Section 3.1.1). Table 3-5 provides busy hour weights for indoor use cases. Note that device weights correspond to a 1:1 ratio of downlink to uplink traffic for corporate and public users, and a 2.3:1 ratio for home users.

User Type	URBAN			SUBURBAN			RURAL			BARREN		
Client	50%	50%	25%	50%	50%	25%	50%	50%	25%	50%	50%	25%
Enterprise AP	50%	50%	0%	50%	50%	0%	50%	50%	0%	50%	50%	0%
Consumer AP	0%	0%	70%	0%	0%	70%	0%	0%	70%	0%	0%	70%
High-Performance Gaming Router	0%	0%	5%	0%	0%	5%	0%	0%	5%	0%	0%	5%
Total (Indoor)	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 3-5 – Busy Hour Weights Assigned to Use Cases, Indoor Environments (by submarket)

Since outdoor RLAN usage is not expected to vary significantly by submarkets, all use cases were assigned the same weights in all submarkets (Table 3-6) and, for all outdoor scenarios, a 1:1 ratio of downlink to uplink traffic was used.

The combination of the use case busy hour weights of Tables 3-5 and 3-6, with the E-plane patterns shown in Figures 3-4 through 3-9, results in a power distribution for the source RLANs as shown in Table 3-7 for indoor RLANs and Table 3-8 for outdoor RLANs. This results in weighted average EIRPs for indoor RLANs of 19.167 dBm, outdoor RLANs of 22.73 dBm, and combined indoor/outdoor of 19.28 dBm are used in the simulations. It is noted that although these weighted average EIRP values were independently derived by the methods described above, the resulting values are consistent and slightly conservative compared to EIRP values used for previous RLAN sharing studies.[16,17,18]

	URBAN	SUBURBAN	RURAL
Outdoor High-Power AP (Figure 3-8)	20%	20%	20%
Outdoor Low Power AP (Figure 3-9)	30%	30%	30%
Outdoor Client (Figure 3-7)	50%	50%	50%
Total (Indoor)	**100%**	**100%**	**100%**

Table 3-6 - Busy Hour Weights Assigned to Use Cases, Outdoor Environment (all sub-markets)

The distributions in Tables 3-7 and 3-8 represent the probability of the specified EIRP occurring in any random direction from an active RLAN. For the purposes of simulation, the continuous

[16] ITU document Revision 1 to 5A/TEMP/236, Sharing and compatibility studies of WAS/RLAN in the 5 150-5 250 MHz frequency range, Section 5.1.1.4.2.1, average EIRP is 18.9 dBm for indoor RLANs, 21.2 dBm for outdoor RLANs, and 19 dBm for indoor and outdoor.
[17] ITU document Revision 1 to 5A/TEMP/236, Sharing and compatibility studies of WAS/RLAN in the 5 150-5 250 MHz frequency range, Appendix 2, Section 5.1.4.2.1, states average power used in the analysis was 19 dB with average.
[18] The ITU-R concludes that a mean EIRP of 19 dBm should be used for 5 GHz RLAN studies. ITU-R 5A/650 (Annex 22)-E at 3.

values in between each breakpoint shown in the tables are represented as the maximum value. For example, the probability of a 250 mW EIRP from Table 3-7 for indoor RLANs of 10.39% is inclusive of all continuous EIRP probabilities greater than 100 mW, up to and including 250 mW, and were then included in the simulation as 250 mW sources with a 10.39% probability of occurrence. Because the distributions of Tables 3-7 and 3-8 already assume the RLAN antenna orientation to the victim receive locations are random, no further adjustment is provided in the analysis for directivity effects of the RLAN sources. This is equivalent to stating that the above EIRP values are treated isotropically (radiate equally in all directions) once seeded into the model for a given source location. EIRP values above 1W up to and including 4W are modeled as isotropic for indoor use cases, but limited (truncated) to 1W at elevation angles above 30° for outdoor RLANs as described above.

		Weighted EIRP Distribution (mW)							
Indoor Use Case	**Weight**	**4000**	**1000**	**250**	**100**	**50**	**13**	**1**	**Total**
Client	26.32%	0.00%	0.00%	0.00%	1.82%	12.03%	12.47%	0.00%	26.32%
Enterprise AP	2.63%	0.00%	0.00%	1.06%	0.90%	0.58%	0.09%	0.01%	2.63%
Consumer AP	66.31%	0.00%	0.00%	7.90%	2.76%	11.20%	38.94%	5.51%	66.31%
High-Performance Gaming Router	4.74%	0.67%	0.42%	1.43%	1.01%	0.83%	0.34%	0.04%	4.74%
Sub-Total	**100.00%**	**0.67%**	**0.42%**	**10.39%**	**6.49%**	**24.64%**	**51.84%**	**5.56%**	**100.00%**

Table 3-7 - Indoor RLAN Source EIRP Distribution (mW)

The weights shown in Table 3-7 were obtained by combining the use cases of Table 3-5 with the active device populations shown in Table 3-1. For example, the indoor client weight of 26.32% is obtained as the weighted sum of the active devices inclusive of all submarkets as derived in the equation below.

> *Indoor Client Weight = {Table 3-5 [Urban (Corporate, Public, Home)] x Table 3-1 Device Population [Urban (Corporate, Public, Home)] + Table 3-5 [Suburban (Corporate, Public, Home)] x Table 3-1 Device Population [Suburban (Corporate, Public, Home)] + Table 3-5 [Rural (Corporate, Public, Home)] x Table 3-1 Device Population [Rural (Corporate, Public, Home)]} / {Table 3-1 [Total Active Devices]}* (3-6)

The weights shown in Table 3-8 are the same as Table 3-6 for all outdoor devices because there is no variation assumed in the proportion of active devices for each use case across the sub-markets.

		Weighted EIRP Distribution (mW)							
Outdoor Use Case	**Weight**	**4000**	**1000**	**250**	**100**	**50**	**13**	**1**	**Total**
High Power AP	20%	2.83%	1.77%	6.04%	4.21%	3.55%	1.44%	0.17%	20.00%
Low Power AP	30%	0.00%	0.25%	3.41%	1.33%	5.73%	16.87%	2.41%	30.00%
Client	50%	0.00%	0.00%	0.00%	3.46%	22.85%	23.68%	0.00%	50.00%
Sub-Total	**100.00%**	**2.83%**	**2.02%**	**9.45%**	**9.00%**	**32.13%**	**41.99%**	**2.58%**	**100%**

Table 3-8 - Outdoor RLAN Source EIRP Distribution (mW)

For the simulation, interference results are presented as the aggregate interference from a deployment of all RLAN device types.

3.2.2 Bandwidth and Channel Distribution

RLANs modeled in this report, such as those developed in compliance with IEEE 802.11, are assumed to operate in 20 MHz, 40 MHz, 80 MHz, and 160 MHz bandwidth channels. To determine the number of channels, and how those channels may overlap with FSS, FS, and MS receivers, the following channel plan outlined in Figure 3-10 was assumed.

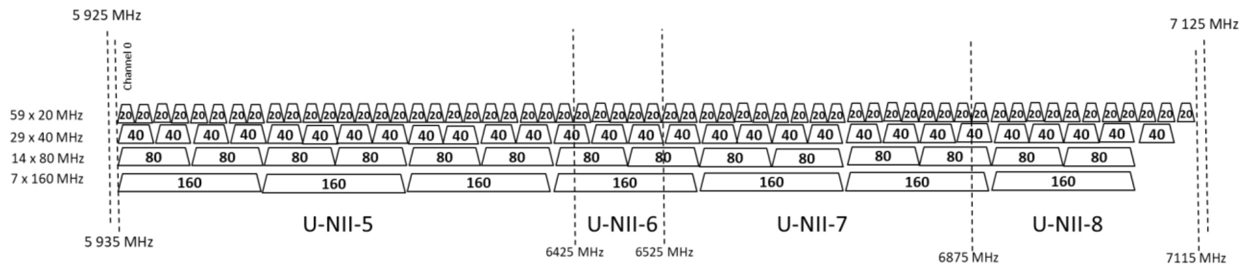


Figure 3-10 - Proposed RLAN Channel Plan

The bandwidth distribution in Table 3-9 is based on the assumption that RLAN systems will operate with larger channel sizes to maximize airtime efficiency, resulting in lower latency and higher throughput.

Bandwidth	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
Percentage	10%	10%	50%	30%

Table 3-9 - RLAN Bandwidth Distribution

3.2.3 Distribution of RLAN heights

To assign a RLAN transmit source height, a height distribution was separately prepared for each of the following indoor environments: urban, suburban, and rural. In addition, a common outdoor height distribution was used for all environments. The starting point of the height distribution is the building construction type probability for each environment, shown in Table 3-10. [19]

Within multi-story buildings, the distribution of RLANs is assumed to have an equal probability of occurring on any floor up to ten stories. A height of ten stories was selected as the maximum because the probability of RLANs on higher floors diminishes significantly even when taller buildings are considered. Stated differently, studying taller buildings does not impact the analysis in any significant way. This is due to the assumed equal spreading of RLANs on all floors of a tall building, which results in the combined distribution being heavily weighted toward lower floors.

For example, the 28.5m height assumed for RLANs on the 10th floor of a ten-story building comprises only 0.02% of all RLANs in the Urban environment. It is noted that the inclusion of the 10-story building in the analysis, while placing 0.02% of RLANs at this height, increases

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[19] U.S. Energy Info. Admin., *2012 Commercial Buildings Energy Consumption Survey: Building Questionnaire - Form EIA-871A*, https://www.eia.gov/consumption/commercial/data/2012/pdf/questionnaire.pdf; NAHB, *The Number of Stores in Single-Family Homes Varies Across the Country*, Aug. 5, 2016, http://eyeonhousing.org/2016/08/the-number-of-stories-in-single-family-homes-varies-across-the-country/.

		Urban Indoor			Suburban Indoor			Rural Indoor			Outdoor
Building Story	Height (m)	Corp	Public	Home	Corp*	Public	Home	Corp	Public	Home	
1	1.5	69.0%	69.0%	60.0%	69.0%	69.0%	60.0%	70%	70%	70%	95%
2	4.5	21.0%	21.0%	30.0%	21.0%	21.0%	30.0%	25%	25%	25%	2%
3	7.5	7.0%	7.0%	7.0%	7.0%	7.0%	5%	5%	5%	5%	2%
4	10.5	0.7%	0.7%	0.7%	0.7%	0.7%	5%	0%	0%	0%	0.5%
5	13.5	0.58%	0.6%	0.6%	0.58%	0.6%	0%	0%	0%	0%	0%
6	16.5	0.50%	0.5%	0.5%	0.50%	0.5%	0%	0%	0%	0%	0%
7	19.5	0.43%	0.4%	0.4%	0.43%	0.4%	0%	0%	0%	0%	0%
8	22.5	0.35%	0.4%	0.4%	0.35%	0.4%	0%	0%	0%	0%	0%
9	25.5	0.28%	0.3%	0.3%	0.28%	0.3%	0%	0%	0%	0%	0%
10	28.5	0.2%	0.2%	0.2%	0.2%	0.2%	0%	0%	0%	0%	0.5%
Total		**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 3-10 - Building Construction Type Probability by Environment

the probability of RLANs at heights on floors one through nine by 10% of the ten-story building type probability. For example, the likelihood that an RLAN will be on the first floor in an urban environment is the sum as follows:

RLAN on 1st Floor Probability = 1 Story Building Probability + 2 Story Building Probability/2 Floors … +10 Story Building Probability/10 Floors *(3-7)*

As such, including buildings of taller heights provides limited additional insight into the question of aggregated RLAN interference because each additional building height of n stories that is included provides only a $1/n$ contribution to the distribution of RLANs at that height, while the rest are distributed as $1/n$ to each of the lower floors.

Using the above described method based on the building construction type probability and equal assignment of RLANs to each floor of a multi-story building results in the distribution of source heights shown in Table 3-11.

		Urban Indoor			Suburban Indoor			Rural Indoor			Outdoor
Building Story	Height (m)	Corp	Public	Home	Corp*	Public	Home	Corp	Public	Home	
1	1.5	82.35%	82.35%	77.85%	82.35%	82.35%	77.92%	84.17%	84.17%	84.17%	95.00%
2	4.5	13.35%	13.35%	17.85%	13.35%	13.35%	17.92%	14.17%	14.17%	14.17%	2.00%
3	7.5	2.85%	2.85%	2.85%	2.85%	2.85%	2.92%	1.67%	1.67%	1.67%	2.00%
4	10.5	0.52%	0.52%	0.52%	0.52%	0.52%	1.25%	0.00%	0.00%	0.00%	0.50%
5	13.5	0.36%	0.36%	0.36%	0.36%	0.36%	0.00%	0.00%	0.00%	0.00%	0.00%
6	16.5	0.24%	0.24%	0.24%	0.24%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%
7	19.5	0.16%	0.16%	0.16%	0.16%	0.16%	0.00%	0.00%	0.00%	0.00%	0.00%
8	22.5	0.09%	0.09%	0.09%	0.09%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
9	25.5	0.05%	0.05%	0.05%	0.05%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
10	28.5	0.02%	0.02%	0.02%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%	0.50%
Total		**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 3-11 - RLAN Source Height Distributions

3.2.4 RLAN Operating Mitigations

Spectrum sharing is not new; the orderly sharing of spectrum has been the primary consideration of spectrum management since the beginning of the practical use of radio. From their inception, RLAN devices have been designed to operate in interference environments. As the standards evolve, systems are able to make better use of temporal and spatial variations in the environment to share with themselves and with other systems. The 5 GHz bands are an example of an advanced RLAN environment with billions of device-years of operating experience.[20] Major mitigation methods currently employed by various national spectrum regulators for controlling the interference level to co-channel systems (licensed or unlicensed) in the 5GHz band are given below.

Transmit power limit:

Limiting transmit power is the most common sharing method used not only in the 5 GHz band but across the whole RF spectrum. By limiting the transmit power for devices, interference can be reduced or prevented, and such limits can be defined as conducted and/or radiated powers, and on total power and/or power spectral density.

Antenna gain limit:

Limiting antenna gain helps reduce the transmitted energy concentrated in a given direction to reduce potential interference to incumbents located in that direction. Furthermore, antenna gain limits help prevent users from acquiring and using high-gain antennas to increase EIRP. 5 GHz band rules have different limits for point-to-multi-point and point-to-point systems.

[20] Wi-Fi Alliance, *Wi-Fi Alliance® Publishes 2018 Wi-Fi® Predictions: Advances in Home Wi-Fi, Enhanced Capabilities, and Next Generation Connectivity Coming Soon*, Jan. 5, 2018, https://globenewswire.com/news-release/2018/01/05/1284169/0/en/Wi-Fi-Alliance-publishes-2018-Wi-Fi-predictions.html.

Minimum bandwidth:

Setting minimum bandwidth requirements helps prevent interference by limiting power spectral density of narrowband signals. In the U-NII-3 band, for example, the minimum 6 dB bandwidth of digitally modulated signals is limited to 500 kHz.

Dynamic Frequency Selection (DFS):

In some parts of the 5 GHz band, DFS is needed to prevent interference to the incumbent radar systems. DFS dynamically detects signals from other systems and avoids co-channel operation with these systems. Since DFS is generally associated with radar systems, it can be considered as a special case of detect and avoid mechanisms.

Transmit Power Control (TPC):

TCP enables 5 GHz band devices to dynamically switch between several transmission power levels and is used to prevent unnecessarily high transmission power when not needed. Devices operating in the U-NII-2 band are required to have TPC capability.

Elevation mask:

An elevation mask limits the amount of radiated power above a certain elevation angle and is used to limit emissions toward satellites in U-NII-1 band where EIRP above 30° from horizon is reduced by 15 dB.

Indoor restriction:

In the initial U-NII-1 rules, the possibility of interference to satellite systems was addressed by limiting devices to indoor use only. However, later rule changes lifted this restriction. Other regulatory domains continue to employ this mitigation in the 5.15 – 5.35 GHz bands.

3.2.5 Interference Protection Criteria and Further Considerations

In the process of writing this report, we chose some parameters that were more conservative than what could have been used and noted that a number of typical parameters and effects that reduce interference were not included in this analysis.

3.2.5.1 Conservative Interference Threshold

In considering the interference threshold for this analysis, we noted that the performance of FS links is generally defined in terms of availability objectives. In the 6 GHz band, the typical per hop availability objective is set at 99.999%. Correspondingly, the FS link IPC is based on the overall degradation allowance. The ITU defines this degradation allowance in terms of I/N whereas the TIA TSB 10 criteria is based on a carrier-to-interference (C/I) ratio. The I/N criteria approach is more general and, therefore, is better suited for the purpose of this analysis. Further, for the FS links, the interference criteria are segregated into long-and short-term interfering signal criteria. According to ITU-R Recommendation F.758-6, long-term interference degrades the error performance and availability of a system by reducing the fade margin available to protect the FS system against fading.[21] In sharing and compatibility studies, long-term

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[21] ITU-R Recommendation F. 758-6, *System Parameters and Considerations in the Development of Criteria for Sharing or Compatibility Between Digital Fixed Wireless Systems in the Fixed Service and Systems in Other*

interference is usually characterized as the interference power that is exceeded 20% of the time, at the victim receiver input. Short-term interference requires separate consideration because the interference power may be high enough to produce degradation even when the desired signal is unfaded. Such interference must occur rarely enough and in events of short duration for the interference to be acceptable. A short-term interference criterion is based on the interference power necessary to cause a particular error performance defect (such as an errored second) when the desired signal is unfaded.

Since RLAN transmissions are low-duty cycle, it is appropriate to analyze the interference caused by RLANs to the FS receiver as short-term. In the case of FS in the 6 GHz band, ITU-R publications provide various short-term interference objectives such as I/N greater than +20 dB (*see*, *e.g.*, for example ITU-R SF.1650, ITU-R F.1108). Recognizing secondary status of the RLAN operations in the band, we have selected a much more conservative I/N value of 6dB.

3.2.5.2 Typical Parameters and Effects that Reduce Interference Not Included in this Analysis

FS link performance is dominated by multipath-related microwave fading. However, multipath fading generally occurs during the period midnight to 8:00 am, when RLAN activity is lowest and "some relaxation of the long-term IPC may be possible."[22] In analyzing the impact of RLAN interference to FS link availability, interference and multipath fading were assumed to be independent. Since the RLAN busy hour is before midnight, and multipath occurs primarily after midnight, there should be a relaxation of the IPC and a significant portion of the link fade margin can be used to relax, dB-for-dB, the IPC.

Although a large percentage of the FS links in the FCC's ULS database use antenna diversity to improve link availability, antenna diversity was not modeled. Instead, this report over estimates the unavailability impact of the RLAN interference for all FS links that use antenna diversity.

The established IPC for the FS are generally based on long-haul performance, whereas the 6 GHz band includes a large percentage of links that are short-haul (35% of ULS links are less than 20 km). Interfering signal levels 1-10 dB or more above accepted long-haul performance requirements are usually acceptable on shorter digital paths since long-term performance is not adversely affected.[23]

While other studies have assumed a polarization mismatch of 3dB, polarization mismatch was not included in this report.[24]

ITU-R Rec. F.1245 (F.1245) was used to model the FS antenna sidelobe performance. As shown in Figure 3-11, the newer commercial antennas, portrayed by the red line in the figure,

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Services and Other Sources of Interference (Sept. 2015), *available at* https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.758-6-201509-I!!PDF-E.pdf (ITU-R Rec. F.758-6).

[22] Nat'l Telecom. & Info. Admin., *Interference Protection Criteria Phase 1 - Compilation from Existing Sources*, NTIA 05-432, Oct. 1, 2005, https://www.ntia.doc.gov/files/ntia/publications/ipc_phase_1_report.pdf (NTIA 05-432).

[23] *Id.* at 4-8 and 4-9.

[24] ITU document Revision 1 to 5A/TEMP/236, Sharing and compatibility studies of WAS/RLAN in the 5 150-5 250 MHz frequency range, Appendix 2, Section 5.1.6.7, "Polarization mismatch, a value of 3 dB is considered according to what have been supported by France in during TG-5.1 (see Doc TG-5.1/104)."

significantly outperform F.1245, as described by FCC A and ETSI Class 4 antenna masks. Based on data provided by Comsearch,[25] as of 2011, over 83% of antennas deployed in 5.925-6.425 GHz band in the United States exceeded Category A requirements, and over 52% of the antennas were classified as high performance or ultra-high performance, which greatly exceed Category A requirements. These higher-performing antennas provide up to 27.5 dB more attenuation from the side lobes than what was modeled.

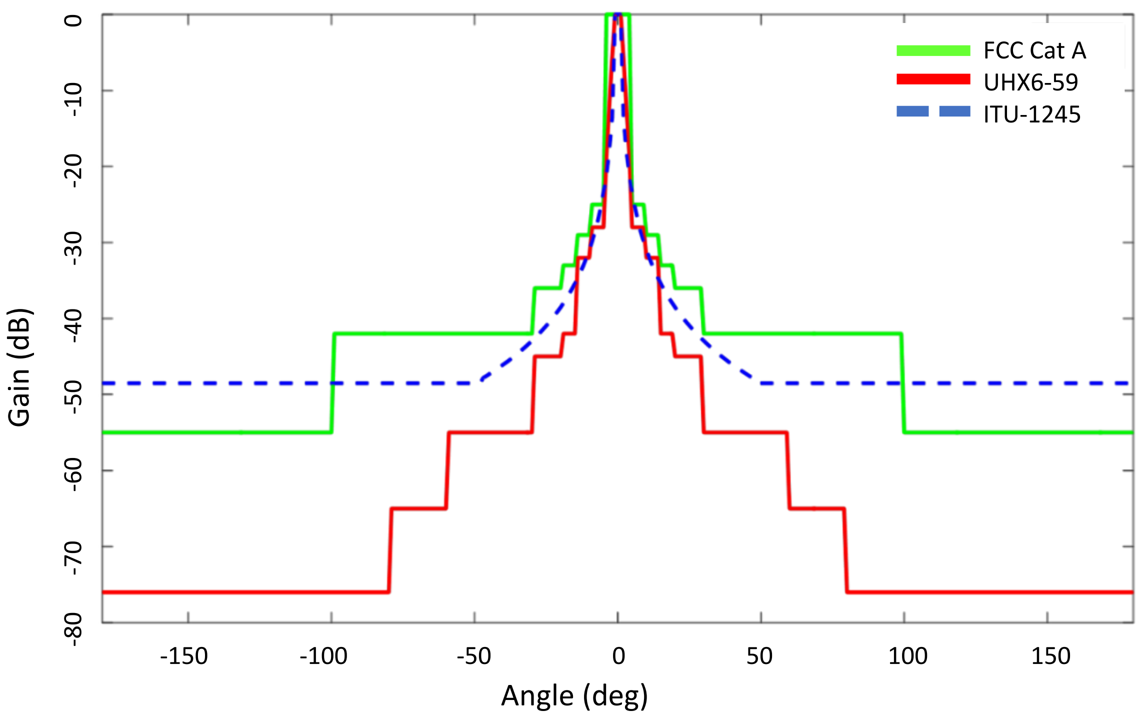

Figure 3-11 – Comparison of ITU-R 1245, FCC Category A, and Ultra High-Performance Antenna (UHX6-59) Radiation Patterns

The FS interference analyses in this report assumed the minimum Noise Figure[26] in ITU-R Rec. F.758-6 and represents a conservative assumption. Other analyses have used a Noise Figure of 5 dB, which would reduce the I/N values by 1 dB.

The factors that were not considered in this report are summarized in Table 3-12. They represent a significant reduction in aggregate interference from RLANs that can also be budgeted as a reduction in IPC.

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[25] *See* Letter from Christopher R. Hardy, Vice President, Comsearch, to Marlene H. Dortch, Secretary, FCC, in WT Docket Nos. 10-153, 09-106 and 07-121, (filed Apr. 4, 2011).

[26] The ITU-R recommends a maximum Noise Figure of 5 dB while TIA recommends a default FS Noise Figure of 5 dB. ITU-R Rec. F.758-6; *available at* https://global.ihs.com/doc_detail.cfm?document_name=TIA%20TSB-10.

Factor not considered	IPC Relaxation	Applicable Service
1. RLAN operation outside of Multi-path fading period	Majority of fade margin can be used dB-for-dB by RLANs from 8:00 am to midnight*	FS
2. FS links receive antenna diversity	Diversity significantly improves both link availability and resistance to interference*	FS
3. Relaxation for short haul links	1-10 dB	FS
4. FS polarization mismatch	3 dB (average)	FS and MS
5. Improved Antenna Sidelobe Performance	0-27.5 dB	FS
6. Noise Figure	1 dB	FS and MS

Table 3-12 – RLAN Interference Reduction Factors Not Considered in this Report

*Note that it is difficult to quantify the IPC improvement in dB for items 1 and 2. However, both factors will contribute to reductions in the received interference from RLANs into FS systems.

4.0 Propagation Models

The interference paths from a large deployment of RLANs to other services will vary considerably with terrain, local ground clutter, and the location of the RLAN installation (e.g., indoor or outdoor, building heights, building type, density of buildings, etc.). Interference estimates therefore require statistical propagation models that can account for this large variability and random nature of some of the propagation effects.

Section 4.1 describes propagation models used by RKF to calculate path loss for RLAN interference to the FSS. Section 4.2 describes propagation models used to calculate path loss for RLAN interference to terrestrial services.

4.1 RLAN to FSS Propagation Models (Earth to Space)

Figure 4-1 shows possible interference paths from terrestrial sources to satellites on the geosynchronous (GEO) arc. Paths from indoor devices will experience penetration losses through buildings. Some paths will then interact with terrain, while others will suffer from local end-point clutter (e.g., buildings), and still others will have line-of-site (LOS) visibility to the GEO arc.

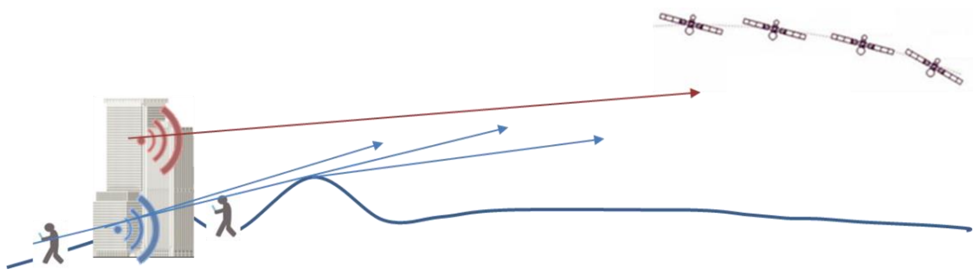

Figure 4-1 - Typical Interference Paths toward the GEO Arc

Figure 4-1 Key	
	Indoor RLAN
	Outdoor RLAN
	LOS Path
	Paths that interact with terrain and/or suffer from end-point-clutter

Paths from indoor RLANs to terrestrial systems experience penetration loss calculated using Recommendation ITU-R P.2109 (P.2109) as the path exits a building. P.2109 is a heuristic model based on many measurements with users located randomly within a building. It considers the elevation angle of the signal leaving the building to the affected receiver. Two types of buildings are defined: traditional and thermally efficient. Penetration losses through thermally

efficient buildings are higher than traditional buildings. The models assume a very conservative 80% of buildings are traditional and 20% of buildings are thermally efficient.[27]

The Irregular Terrain Model (ITM) model of radio propagation is a general-purpose model for frequencies between 20 MHz and 20 GHz that can be applied to a large variety of engineering problems. The model, which is based on electromagnetic theory and statistical analyses of both terrain features and radio measurements, predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in time and in space. The ITM, along with the Shuttle Radar Topography Model (SRTM) (3 sec) terrain database, is used to model terrain interactions. The ITM uses the SRTM terrain elevation data along with diffraction theory to calculate the path loss when there is terrain blockage.

Local end-point clutter is added using Recommendation ITU-R P.2108 (P.2108), Section 3.3 (for Earth-space paths). This is a statistical clutter model for urban and suburban areas. It accounts for the elevation angles from the transmitters to the satellites. According to guidance from ITU-R Study Group 3, the model is currently used only for frequencies above 10 GHz.[28] This is because building penetration is not taken into account. However, it is reasonable to assume that at 6 GHz, buildings will be mostly opaque (i.e., large losses will occur transmitting through buildings). This is verified using P.2109 for indoor users, where average penetration loss through traditional buildings at 6 GHz and at an elevation angle of 30° is about 20 dB. As is shown in Section 4.2, P.2108, Section 3.2 (for Terrestrial paths) underestimates clutter when compared to near-in clutter models such as P.1411 and Winner II.

To estimate rural clutter loss, Recommendation ITU-R P.452 (P.452) was used with RLANs deployed predominately in village centers. P.452 assumes that in village centers clutter height is 5 m and the distance to the clutter is 0.07 km which equals an angle of 4.1°. Therefore, in the simulations, when the rural RLAN height is 1.5 m, a clutter loss of 18.4 dB was added when the look angle to the FSS receiver was ≤ 4.1°. When rural RLAN heights are above 1.5m, the clutter loss is assumed to be negligible and is not calculated.

For LOS paths, the radio horizon is defined using 4/3 earth assumptions. Free space path loss is used when there is no blockage from the transmitter to the satellite. Conservatively, atmospheric loss, which is small, was ignored in this calculation.

4.2 RLAN to Terrestrial FS or MS Propagation Models

Possible interference paths from RLANs to terrestrial FS and MS systems are similar to those described in Section 4.1 for paths from terrestrial systems to satellites on the GEO arc. Like Section 4.1, paths from indoor RLANs to terrestrial systems experience penetration loss calculated using P.2109 as the path exits a building.

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[27] ITU-R Working Party 5A "agreed that, instead of using the model for 'traditional building' only, a mix of 70% (traditional building) and 30% (thermally efficient building) be used." ITU-R 5A/650 (Annex 22)-E at 6.
[28] 5A/337-E, 3 April 2017, Working Parties 3K and 3M, LIAISON STATEMENT TO WORKING PARTY 5A, PROPAGATION MODELS FOR COMPATIBILITY STUDIES REGARDING WRC-19 AGENDA ITEM 1.16.

4.2.1 Selection of Propagation Models up to 1 km

After building penetration loss is considered, the terrestrial propagation models pose some additional complexity compared to the earth-to-space models.

We first determined how close RLANs might be deployed to an FS station. Since most FS sites are surrounded by security fencing within urban and suburban areas on industrial and government facilities and antennas are installed on towers, we considered a 30-meter exclusion zone around a FS receiver to be reasonable and conservative.

From 30 m to 1 km we analyzed different model options. P.2108 Section 3.2 (for terrestrial paths) is defined for clutter distances greater than or equal to 250 m. The minimum distance applies only when one of the terminals is in the clutter field while a minimum distance of 1 km applies when both terminals are in the clutter field. When modeling near-in clutter for distances less than 1 km a propagation model that includes clutter is usually used. This includes Recommendation ITU-R P.1411 (P.1411) or Winner II.

Winner II is a propagation model used by cellular operators for coverage analyses that has been validated by measurement for frequencies between 2 and 6 GHz, however, it can reasonably be applied for the frequencies being considered here. The Winner II model has the advantage that it includes a probability of LOS term that is a function of distance. This term allows random assignment of LOS and Non-LOS (NLOS) paths in the simulation. Another advantage is the Winner II model differentiates between urban and suburban morphologies. When used for planning commercial deployments, it is believed that Winner II is more reliable than other models especially in dense urban environments. This is important relative to this study since dense urban environments will have the largest deployment of RLANs.

Figure 4-2 shows a comparison of several different propagation models up to 1 km. P.1411 site-general model, Section 4.2.1, describes propagation over-rooftops and is derived from measurements in urban and suburban environments over 0.8 to 73 GHz. Although the model is valid up to 5 km, P.1411 is intended for distances only up to 1 km and includes LOS and NLOS median path loss models as well as a random shadowing component (Table 4-1). The LOS component is defined for distances ≥ 55 m and the NLOS component is defined for distances greater than or equal to 260 m. As seen in Figure 4-2, one deficiency of P.1411 is that there is no clear definition on how to transition between the LOS and NLOS models.

Winner II combined urban/suburban models in Figure 4-2 include both LOS and NLOS components combined following the Winner II methodology. In fact, the Winner II suburban path at 250 m is reasonably close to the P.1411 NLOS model while P.1411 LOS significantly underestimates clutter loss. The Winner II urban model reflects the additional loss that would be expected in a densely populated area.

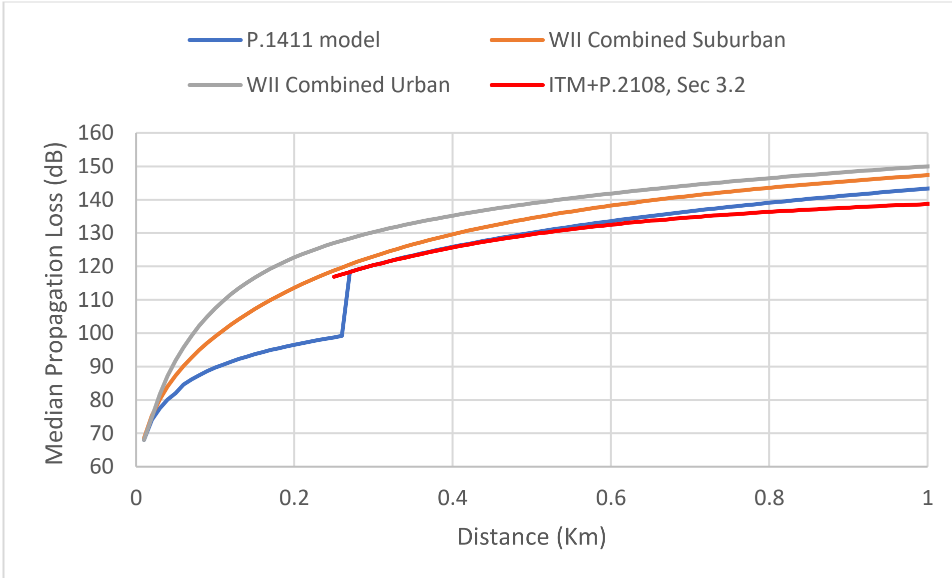

Figure 4-2 - Propagation Model Comparison

	LOS	NLOS
P.1411	3.48 dB	6.89 dB
Winner II	4 to 6 dB	8 dB

Table 4-1 - Lognormal Shadowing Standard Deviation for P.1411 and Winner II

Based on this comparison, the following model was used for propagation loss up to 1 km:

- 30-meter exclusion zone around receiver
- 30-1 km: Winner II

4.2.2 Selection of Propagation Models beyond 1 km

Figure 4-3 compares the P.1411, Winner II, and ITM/SRTM + P.2108 models between 1 and 5 km. At 1 km, the P.1411 prediction is between the Winner II suburban and ITM/STRM+P.2108 models, but at 5 km the P.1411 and Winner II urban models are in good agreement. The ITM/SRTM + P.2108 model levels off after about 1 km and at 5 km underestimates clutter loss by about 20 dB compared to the other models. An interpretation might be that on average the near-in clutter field ends after about 1 km. However, in denser urban environments the clutter fields can be expected to extend farther out with significantly more clutter loss.

The ITM/SRTM +P.2108, Section 3.2 model was selected for use beyond 1 km with the knowledge that this a very conservative model and will under-predict the clutter loss in the dense urban environments. To quantify the magnitude of understatement, simulations were performed using Winner II up to 5 km. Figure 4-3 demonstrates that P.2108 produces an immediate 10dB discontinuity at 1 km as compared to Winner II that is unfavorable to RLANs. This gap widens to 20dB at 5 km. This is a significant and intentional choice on our part in deference to the criticality of FS links and their long average path length.

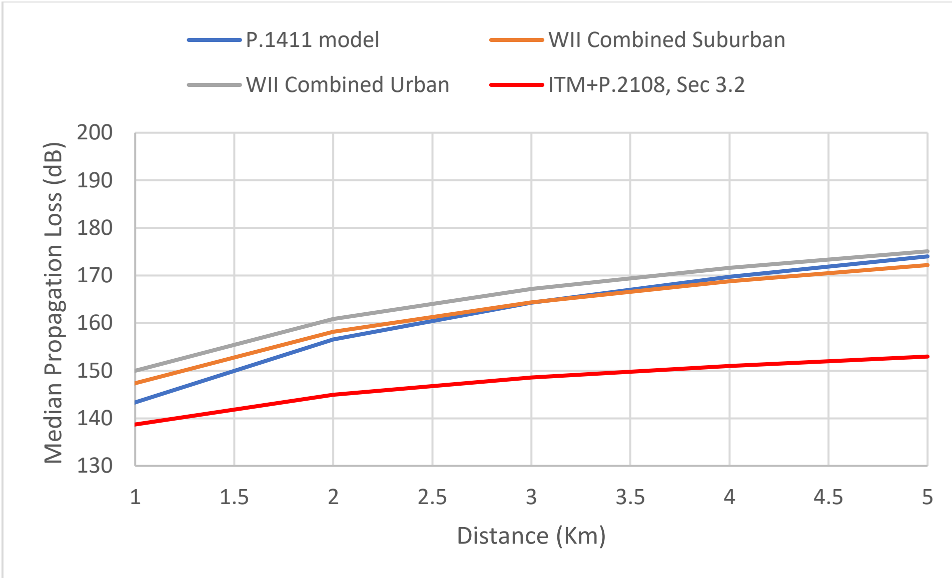

Figure 4-3 - Propagation Model Comparison

For rural area clutter, P.452 was used assuming RLANs will be predominately deployed in village centers. As discussed in Section 4.1, for any RLAN with a 1.5 m height and an elevation angle to the FS of less than or equal to 4.1º, a clutter loss of 18.4 dB was added. For any RLAN with a height greater than 1.5 m, no clutter loss is added.

5.0 Sharing Results

5.1 FSS Uplink Sharing

To determine the potential for FSS sharing, interference into the FSS space station receivers was estimated by:

Step 1: Reviewing the C-Band FSS uplinks to determine typical performance parameters (Section 5.1.1).
Step 2: Performing a simulation to baseline the I/N to the GEO arc from the existing CONUS FS stations to the Conventional C-Band satellites (Section 5.1.2).
Step 3: Performing a simulation to estimate I/N into the GEO arc from random RLAN deployments to determine what impact can be expected (Section 5.1.3).
Step 4: Performing a comparative analysis of the results of Step 2 and 3 to assess the impact of interference to the FSS space station receiver (Section 5.1.4).

Each of these steps is explained below.

5.1.1 FSS Uplink Typical Performance Parameters

Within the 6 GHz band, FSS uplink (Earth-to-space) has primary allocation within 5.925-7.075 GHz defined in four FSS uplink bands:

- Conventional C-band: 5.925-6.425 GHz
- Extended C-band: 6.425-6.725 GHz
- (Appendix 30B) Planned Band: 6.725-7.025 GHz [per ITU RR no. 5.441]
- Band used by SiriusXM feederlink: 7.025-7.075 GHz

As of May 31, 2017, there were 78 active unique satellites filed in these bands. Of these, 65 have partial or full uplink beam coverage over the US. Table 5-1 shows the number of filings within each uplink band.

FSS Uplink Frequency Band (GHz)	# of Satellite Filings (with any coverage over the US)
Conventional C-band 5.925 – 6.425	58
Extended C-band 6.425 – 6.725	9 (7x also use 5.925-6.425 GHz)
App 30b/Planned Band 6.725 – 7.025	2 (1x also uses 5.925-6.425 GHz)
DARS Radio Feeder Link 7.025 – 7.075	4

Table 5-1 - Number of Satellite Filings (IBFS Database) Within Each FSS Uplink Frequency Band

As supported by the filings,

- Conventional C-band is the most widely used band (89%) and an orbital separation of 2° between satellites is not unusual. This implies that adjacent satellite interference (ASI) is a key driver for system margin. To reduce ASI, Earth Stations (ES) must operate with high gain antennas (small beam width) and are therefore generally 2.4 meters or greater. The large gateway antenna installations require a level of complexity and effort such that the RF equipment would be carefully sized to ensure sufficient system margin.
- Extended C-band is less widely used than Conventional C-band and ASI is probably proportionally less.
- Planned band is used primarily for international coverage. These satellites only have partial coverage of CONUS and, therefore, see only a fraction of the RLAN population.

- The upper 50 MHz of the FSS band (7.025-7.075 GHz) is currently used by SiriusXM Satellite Radio feeder uplinks for Digital Audio Radio Service (DARS). The number of satellites in this band is not expected to increase significantly.

The RLAN-to-FSS interference analysis focused on the Conventional C band since this band has the highest density of satellites making it the most challenging sharing environment among the four FSS UL bands listed above.

The first task was to review the antenna gain-to-noise temperature (G/T) contours over CONUS to select a representative G/T for use in the FS and RLAN interference simulations.

Interference into the GEO arc from RLAN transmitters deployed throughout CONUS is a function of the satellite's G/T, CONUS coverage patterns, and orbital location. To bound the simulation results with a worst-case interference scenario, we reviewed G/T contours in the FSS filings of satellites with CONUS coverage. These filings included a variety of coverages that included CONUS coverage, larger global and regional beams that cover multiple countries, and smaller spot beams.

Figures 5-1 through 5-3 show beams that are representative of the CONUS coverage patterns. These particular beams were selected due to their high G/T relative to other filings with CONUS coverage. These figures show that:

- Regional and global beams have lower G/T over CONUS compared to beams just covering CONUS.
- CONUS beams have a more consistent G/T throughout the coverage area.
- Spot beams have higher G/T in a smaller coverage area and receive a small fraction of the interference from RLANS operating throughout CONUS.

In these examples:

- SatMex 8 Regional beam (Figure 5-1) has peak and average G/T over CONUS of 1.3 dB/K and 0 dB/K respectively.
- SES-2 CONUS beam (Figure 5-2) has peak and average G/T over CONUS of 3.39 dB/K and <2 dB/K respectively.
- Anik F1 Spot beam (Figure 5-3) has peak and average G/T over CONUS of 5.6 dB/K and <-1 dB/K respectively.

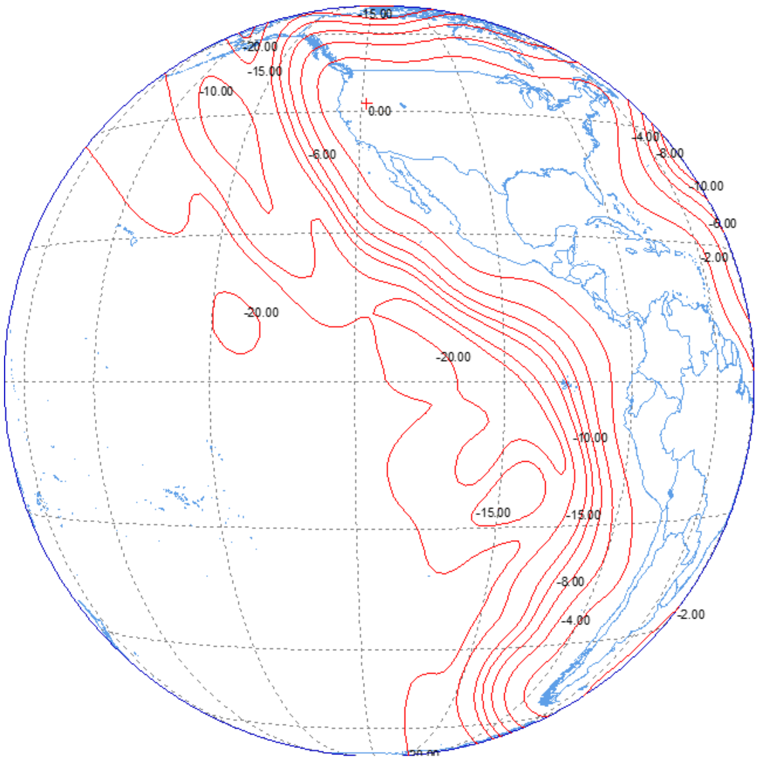

Figure 5-1 – Representative Regional G/T Contour (SatMex 8, 116W)

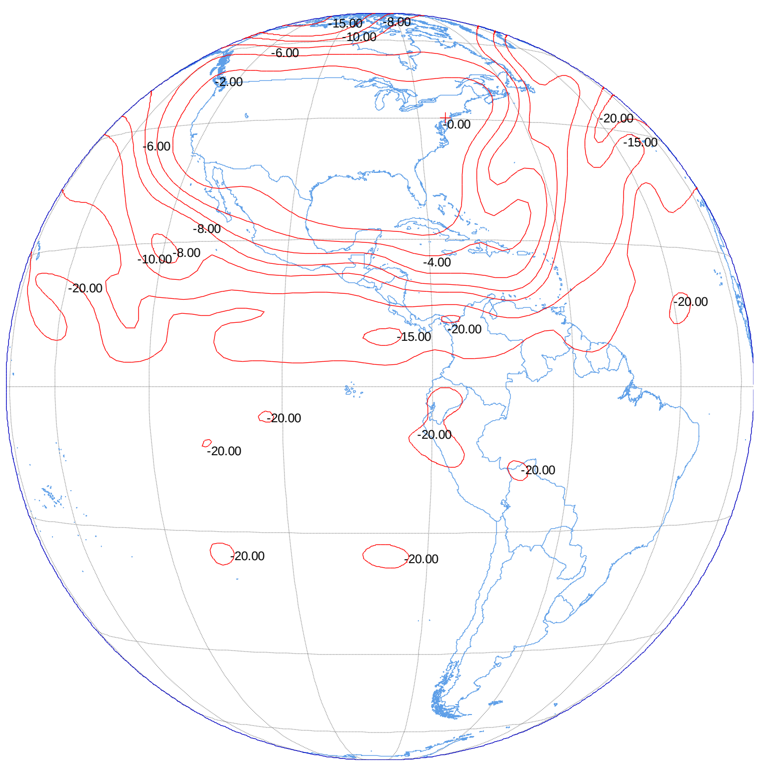

Figure 5-2 - Representative CONUS G/T Contour (SES-2, 87W)

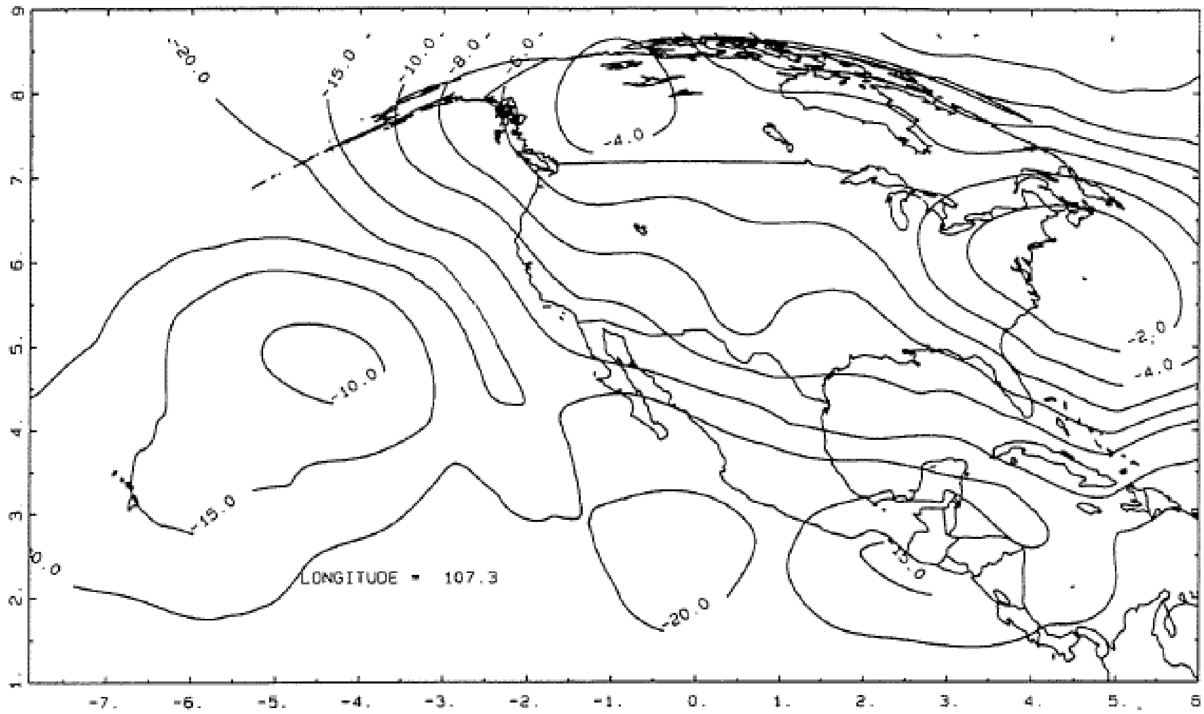

Figure 5-3 - Representative Spot Beam G/T Contour (Anik F1, 107.3W)

Using these representative beams, RKF determined that a G/T across all of CONUS of about 2 dB/K represents a bounding condition for FSS receiver sensitivity. Although there are some higher G/T spotbeams they cover small areas and see only a fraction of the total RLANs over CONUS. Thus, a G/T value of 2 dB/K was used in simulations to assess interference, across CONUS, to FSS systems. Results are discussed in the following sections.

5.1.2 Existing FS Interference to FSS Satellites

GEO satellites currently receive interference from FS stations operating in the 6 GHz band. To determine a baseline level for this interference, without an RLAN deployment, a simulation was performed using the FCC's ULS data as of March 21, 2017. For this analysis, interference levels were estimated every 0.1^{o} on the GEO arc to represent all possible locations on the GEO arc. All longitudes were analyzed with visibility to CONUS. As determined in Section 5.1.1, each satellite is assumed to have a G/T value of 2 dB/K across CONUS.

As indicated in Figure 5-4, the highest concentration of FS stations is between 5.925 and 6.425 GHz. As shown in Table 5-2, some of the ULS entries had data missing. Thus, to ensure as many FS stations as possible were included in this baseline interference assessment, estimates replaced missing data as described in Section 5.2.2. This resulted in 57,086 FS stations in the 5.925-6.425 GHz band used for the simulation of FS interference into the GEO arc. If pointing

direction was missing, the simulated direction was restricted to ensure links were off pointed at least 2° from the GEO arc consistent with FCC rules.[29]

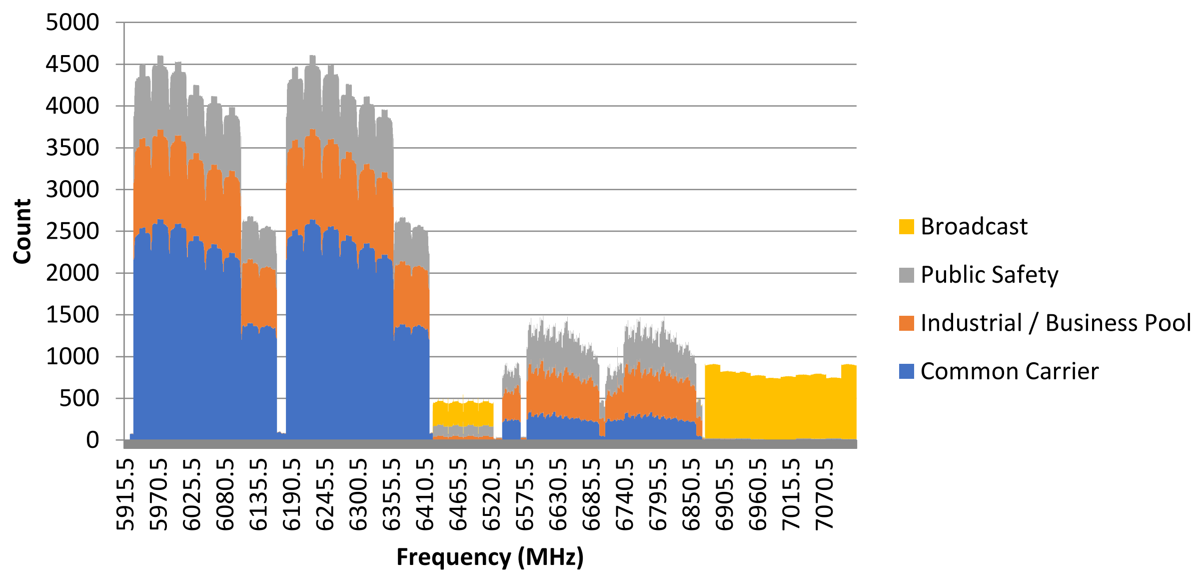

Figure 5-4 - Histogram of Count of Terrestrial Services[3] over Their Frequency Channels [ULS database (as of 03/21/2017)]. Broadcast Refers to BAS TI, TS, and TP services.

Total entries in ULS database	123,535
Total entries outside of CONUS	-3,592
Total entries out of band	-62,857
Total entries that were mobile	-0
Total entries with invalid data	-620
Total valid entries	56,526
Total number of entries with data fields corrected by RKF	+620
Total entries used in Simulations (Valid + Corrected data fields)	**57,086**

Table 5-2 – FS-to-FSS Simulation ULS Database Summary (5,925-6,425 MHz, (as of 03/21/2017))

The nominal FSS transponder plan between 5.925 to 6.425 GHz is shown in Table 5-3. Each transponder has a bandwidth of 36 MHz and is spaced 40 MHz apart. Over this 500 MHz band there are 24 transponders, 12 in each polarization. The channel center frequencies for each polarization are staggered by 20 MHz.

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[29] 47 C.F.R. § 101.145(b)

Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pol 1 (MHz)	5945		5985		6025		6065		6105		6145		6185		6225		6265		6305		6345		6385	
Pol 2 (MHz)		5965		6005		6045		6085		6125		6165		6205		6245		6285		6325		6365		6405

Table 5-3 - Representative FSS Transponder Frequency Plan (fc, Separation=40MHz)

The propagation model described in Section 4.1 was used to calculate the received power in each FSS channel at each orbital location. The simulation considers each FS transmitter in the CONUS region. Each transmitter has an associated bandwidth and EIRP in the direction of a specific orbital location, and thus contributes to the power received in each orbital location for any FSS channels that overlap the FS transmit spectrum. These power contributions are aggregated over all FS transmitters in CONUS to give the received power in each FSS channel at each orbital location. Figure 5-5 shows the results of these simulations where the x-axis is the satellite longitude, the y-axis is the aggregate I/N received at the satellite from all FS links across CONUS, and the 24 channels are shown on the depth-axis. The I/N due to all terrestrial transmitters across CONUS in the 5.925-6.425 GHz band on each of the FSS space station locations is less than -4.7 dB. The highest levels of interference occur towards satellites on the horizon as seen from the US coasts due to the low elevation angles of most FS links.

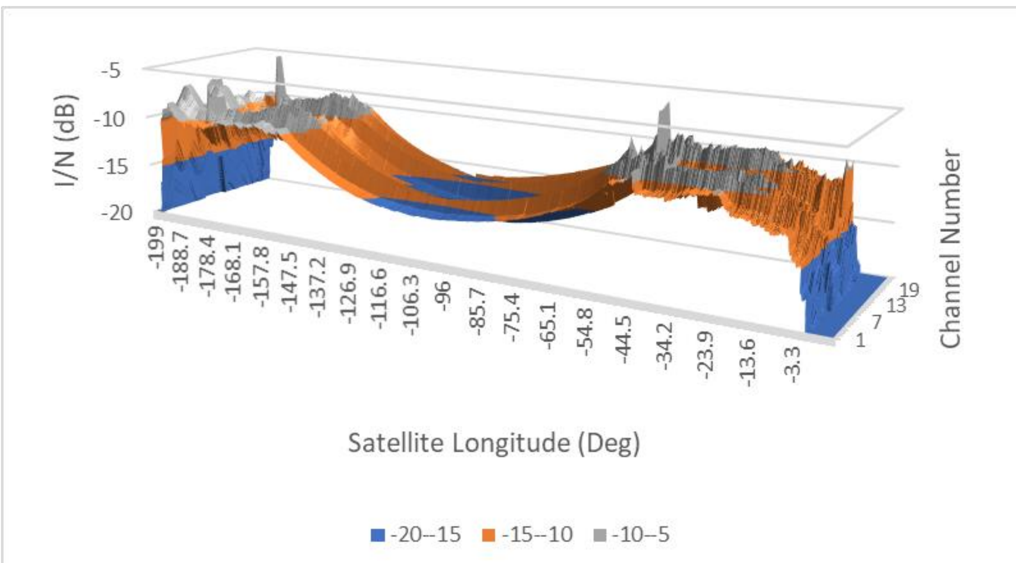

Figure 5-5 - I/N Due to Terrestrial Transmitters (in ULS Database) in 5.925-6.425 GHz to Satellites Across the Visible GEO Arc

5.1.3 RLAN Interference to the FSS Satellite

Finally, the interference from a national deployment of RLANs was simulated. The simulation included these assumptions:

- RLANs were distributed as described in Section 3.1.
- Operating assumptions are described in Section 3.2.
- For a worst-case analysis, the simulation assumed both East and West Coasts were operating at busy hour levels of 7:00-8:00 pm Pacific Time and that every person was not only awake, but actively using an RLAN device. We note, however, that because a large

percentage of the East Coast population is sleeping after 10:00 pm Eastern Time, interference levels could have been further reduced.[30]

- No time of day traffic variation was applied.
- The propagation models used are described in Section 4.

Figure 5-6 shows the simulation results indicating that the aggregate I/N due to indoor and outdoor RLAN transmitters deployed throughout CONUS does not exceed -21.9 dB.[31] With the omni-directional RLAN transmission, interference is distributed uniformly across the GEO arc.

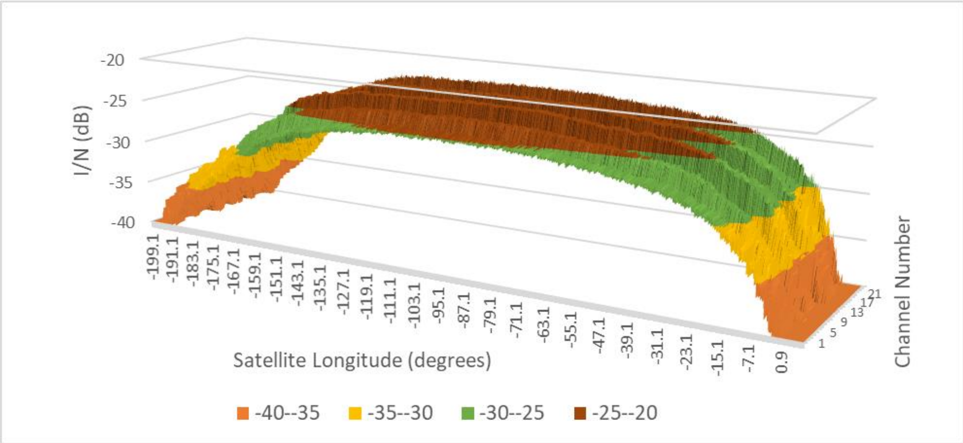

Figure 5-6 - I/N due to RLAN Transmitters in 5.925-6.425 GHz to Satellites Across the Visible GEO Arc

5.1.4 RLAN FSS Sharing Results

The results show that a national deployment of RLANs in the 6 GHz band can share the spectrum without harmful interference to existing FSS services.

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[30] Even in New York City, the "City that Never Sleeps", a significant percentage of the population (as high as 47%) is asleep before 10:30 pm. Jawbone, *In the City We Love*, Aug. 15, 2014, https://jawbone.com/blog/jawbone-up-data-by-city/#newyork.

[31] ITU-R recommends that "error performance degradation due to interference at frequencies below 30 GHz should be allotted portions of the aggregate interference budget of 32% or 27% of the clear-sky satellite system noise in the following way: . . . 1% for all other sources of interference." ITU-R Recommendation S.1432, *Apportionment of the Allowable Error Performance Degradations to Fixed-Satellite Service (FSS) Hypothetical Reference Digital Paths Arising from Time Invariant Interference for Systems Operating Below 30 GHz* (2006), *available at* https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1432-1-200604-I!!PDF-E.pdf (ITU-R Rec. S.1432).

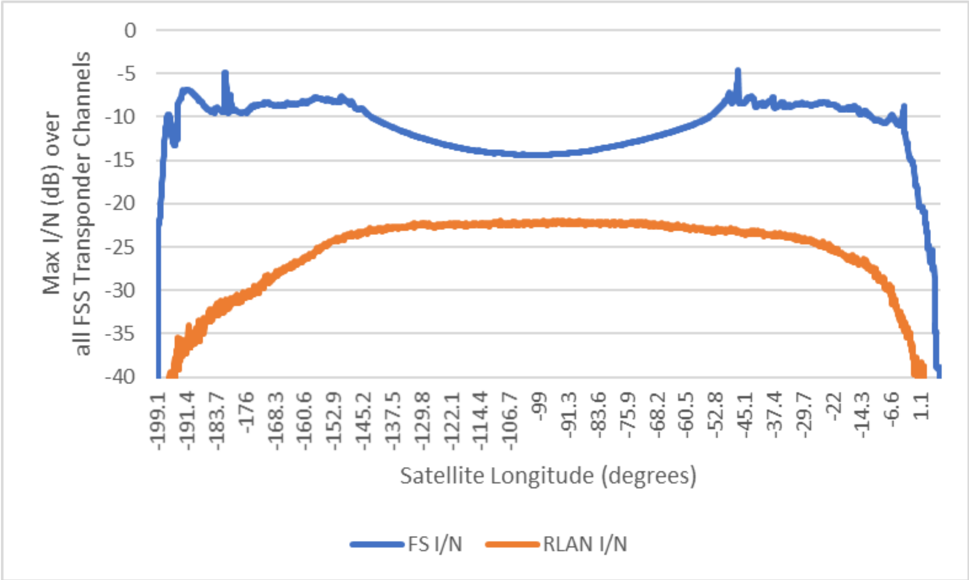


Figure 5-7 –Max I/N (over FSS Transponder Channels) due to RLAN and FS Transmitters in 5.925-6.425 GHz to Satellites across the Visible GEO Arc

In Figure 5-7 above we show the FS and RLAN max I/N over FSS transponder channels in one graph. The simulation results indicate that RLAN I/N is less than -20 dB to the GEO arc and therefore has a minimal impact on FSS performance. Figure 5-8 below shows the aggregate FS and RLAN I/N at the FSS space station receiver. Because the RLAN interference is negligible compared to the FS interference, it won't be detectable.

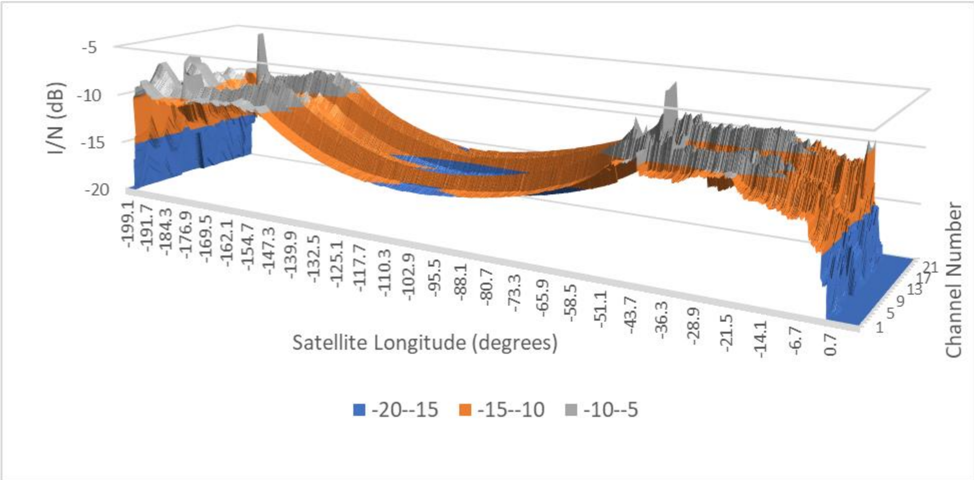


Figure 5-8 - Aggregate I/N due to FS and RLAN Transmitters in 5.925-6.425 MHz to Satellites across the Visible GEO Arc

Today, the demand for C-band spectrum is mostly stable. However, NSR forecasts an annual decline in C-band capacity usage of around 2% per year to 2024.[32] If this reduction were to

[32] Northern Sky Research, *C-Band: Still Suitable for Satellite?* Oct. 7, 2015, http://www nsr.com/news-resources/the-bottom-line/c-band-still-suitable-for-satellite.

occur, there would be a corresponding reduction in ASI. As stated above, ASI is a key driver in system link margin. Any reduction in ASI would lead to further improvements in FSS performance that are not reflected in our analysis.

5.2 FS Sharing

Having shown that a national deployment of RLANs can successfully share the 6 GHz band with FSS satellite uplinks, we now look at the FS sharing possibilities.

To determine the impact of interference on FS links, the following analyses and simulations were performed:

Step 1: ULS database review (Section 5.2.1) – The FCC's ULS database was used to identify FS stations in the 6 GHz band.

Step 2: CONUS-wide aggregate interference simulations (Section 5.2.2) – As described in Section 3.1, RLANs were randomly distributed throughout CONUS based on population density to determine interference levels at each FS station. Since the interference levels are statistical, the following sections examine how the simulated statistical link performance impacts FS operation.

Step 3: FS Link availability without RLAN interference (Section 5.2.3) – For each FS link in ULS, link budgets were generated and the link margin was calculated. Using the link margins and procedures in Recommendation ITU-R Rec. P.530 (P.530), the link availability for each link was calculated to characterize FS link performance before RLAN interference.

Step 4: FS link Availability with single entry RLAN Interference (Section 5.2.4). From the CONUS simulations in Step 2, FS stations with high levels of RLAN interference were identified. A detailed analysis was performed to determine the impact on FS link availability, on these worst-case links, due to the RLAN interference.

Step 4: FS overload and RLAN Out-of-Band Emission (OOBE) requirements (Section 5.2.5): As a last step, we reviewed RLAN requirements to protect FS systems from overload and OOBE emissions.

5.2.1 ULS Database Review

The FCC's ULS database was reviewed to determine the number of unique FS station locations and radio service types in CONUS.

As shown in Table 5-4, there were 123,534 FS stations in the ULS database as of March 31, 2017. Seventy-two percent of those links had valid receiver data within CONUS, are fixed, have spectral overlap with the RLAN spectrum, and are not duplicate counts of the same FS transmitter-receiver link corresponding to a different frequency channel.

To be conservative in the CONUS simulations, we included as many FS links as possible. This meant making assumptions for the 2,076 entries with invalid data. Assumptions were based on careful analysis of each radio service and missing parameters, such as receive gain, antenna height, and bandwidth, were set to average values for the corresponding radio service. When the transmitter location was missing, the receive antenna was pointed in a random azimuth direction uniformly distributed over 360° and a random elevation angle uniformly distributed over +/- 5°. With these changes, an additional 1,923 corrected links were included, resulting in total of 91,187 FS links in the CONUS simulations.

Total entries in ULS database	123,534
Total entries outside of CONUS	-5,403
Total entries out of band	-22,896
Total entries that were mobile	-3,895
Total entries with invalid data	-2,076
Total valid entries	89,264
Total number of entries with data fields that were updated with assumptions based on representative criteria by RKF	+1,923
Total entries used in Simulations (Valid + assumed data fields)	**91,187**

Table 5-4 – Fixed Service Simulation ULS Database Summary (as of 03/21/2017)

Table 5-5 shows the mix of radio services represented by the valid and corrected links with the corresponding FCC rule parts (47 C.F.R.). According to the Fixed Wireless Communications Coalition, these links are designed with an availability of 99.999% (outages < 5.3 minutes/year) or 99.9999% (outages < 0.32 seconds/year).[33]

Radio Service Type	**# of links**
CF: Common Carrier Fixed p2p Microwave (Part 101)	35,623
MG: Microwave Industrial/Business Pool (Part 101)	27,118
MW: Microwave Public Safety Pool (Part 101)	23,752
TB: TV Microwave Booster (Part 74) TI: TV Intercity Relay (Part 74) TS: TV Studio Transmitter Link (Part 74) TT: TV Translator Relay (Part 74)	4,694
Total entries used in Simulations (Valid + Corrected data fields)	**91,187**

Table 5-5 - Mix of Radio Services in the valid ULS entries (as of 03/21/2017)

5.2.2 CONUS Wide FS Aggregate Interference Simulation

Ten CONUS-wide simulations were performed to determine the aggregate I/N at each of 91,187 FS receive locations. For each simulation, the active RLANs (Section 3.1) were deployed randomly according to population. Together these simulations represent 911,870 different RLAN-to-FS interference morphologies in CONUS, which represent an excellent statistical model of expected interference. To ensure inclusion of every RLAN that could affect a receiver, while avoiding the unnecessary complexity of modeling every RLAN in CONUS for every receiver, all RLANs operating within 150 km of the receiver were considered in the calculation.

Figure 5-9, Figure 5-10, and Table 5-6 show the probability of I/N (aggregated over the aforementioned morphologies) exceeding an I/N level (x-axis) due to the deployed active RLANs. Of the 911,870 different RLAN-FS morphologies simulated, there were 1,904 instances where the aggregate I/N for an FS receiver exceeded -6 dB, giving a probability of 0.209%. Further investigation into these 1,904 instances revealed that 99.1 % (1887 instances) were caused by a single RLAN. Further, over half of these single-entry threshold exceedance cases are due to an RLAN in the main bean of the FS receiver antenna. There are 1,073 instances

[33] Application for Review of the Fixed Wireless Communications Coalition in File No. SES-LIC-20150616-00357, at 10 (filed Feb. 10, 2017).

where a single RLAN device at an angle less than or equal to 2º off boresight from the FS receiver caused an I/N value greater than -6 dB. There were 461 instances where the angle off boresight was greater than 2º and the distance from the FS receiver to the RLAN device was less than 1 km resulting in an I/N value greater than -6 dB. Furthermore, there are additional topologies that resulted in a single RLAN device causing an I/N value greater than -6 dB such as: outdoor RLAN devices, indoor RLAN devices with very small building penetration loss, and RLAN devices having small path loss values that are statistically in the tail of the path loss probability distribution function. For all the threshold exceedance instances analyzed, none had a significant impact on FS link availability (*see* section 5.2.4).

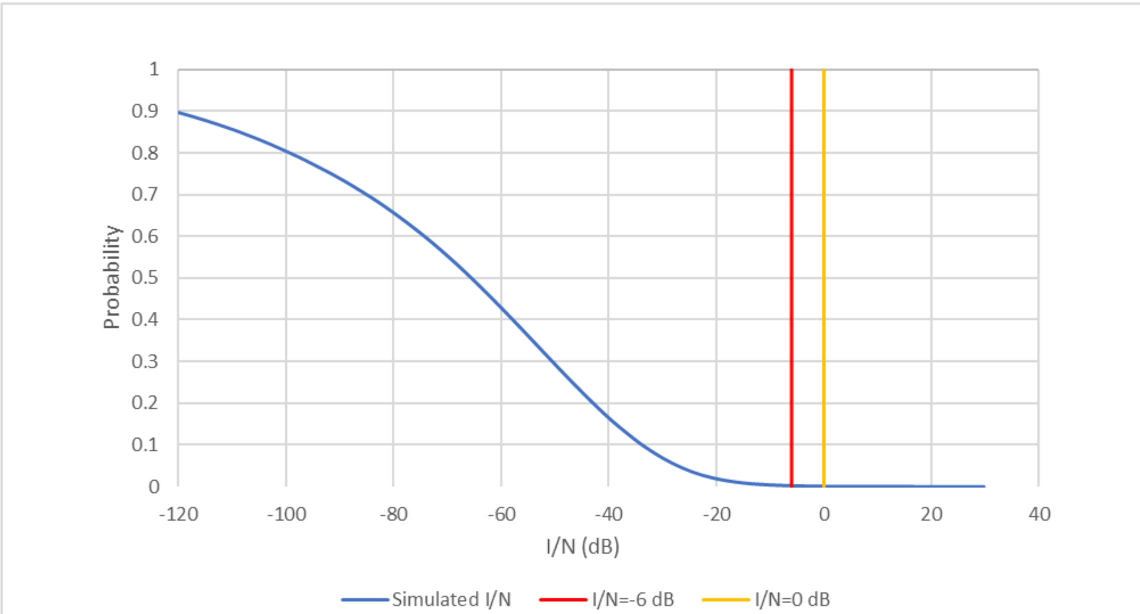


Figure 5 9 – Probability of Aggregate RLANs I/N Exceeding I/N Values on X-axis for 911,870 FS Links (91,187 FS/run x 10 Runs)

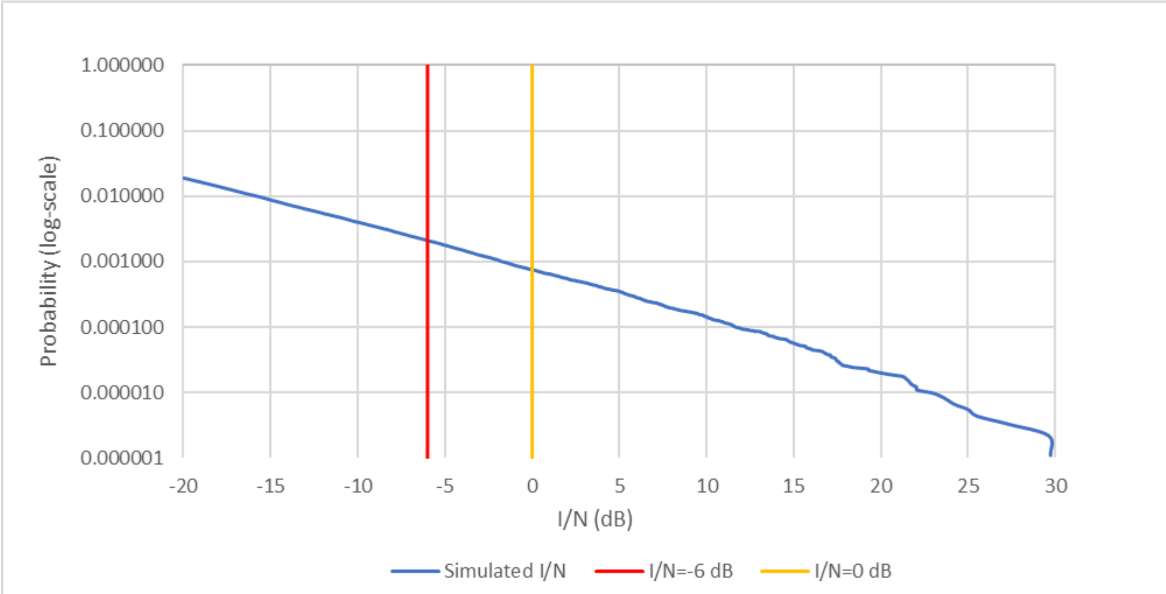


Figure 5-10 – Probability of Aggregate RLANs I/N Exceeding I/N values on X-axis for 911,870 FS Links (91,187 FS/run x 10 runs) Zoomed In

I/N Threshold (dB)	Aggregate
-6	0.209%
0	0.075%

Table 5-6 – Interference Statistics from Ten Independent Simulations of a CONUS Wide RLAN Deployment

As described in Section 3.1, the population of RLANs will be very large with only a small fraction transmitting at a time. Given also that the duty cycle of each RLAN is low, the statistical variation of the interference will be high. For this reason, it is worthwhile to look more closely at the statistical impact of RLAN interference.

5.2.3 FS Link Availability Without RLAN Interference

The calculation of link availability (100-unavailability (%)) is described in P.530 for multipath and rain fade. This calculation requires links budgets for each FS link and an estimate of fade margin. The calculation assumes that multipath and rain fade are independent events.

The FS link margin is calculated using Equation (5-1):

$$Margin = EIRP + PL + Gr - 10 \times \log (K\ T\ B) - S/Nreq\ (dB) \qquad (5\text{-}1)$$

Where

EIRP	Effective isotropic radiated power(dBW) = Transmit power(dBW) + Transmit gain(dBi)
PL	Path loss (dB)
Gr	FS receiver gain (dBi)
K	Boltzmann's constant = $1.38064852 \times 10^{-23}$ m^2 kg s^{-2} K^{-}
T	System temperature (estimate) = 579 K (Noise Figure = 4 dB; Antenna Temperature =290 K)
B	Signal bandwidth (Hz)
S/Nreq	Required signal-to-noise ratio (dB)

EIRP, receiver gain (Gr), and signal bandwidth (B) in Equation (5-1) were taken from the FCC's ULS database. All 91,187 entries in the database, as derived in Table 5-5, were used in the analyses in this section. Consistent with ITU-R Rec. F.758-6, an FS Noise Figure of 4 dB was assumed and, as mentioned in Section 3.2.5.2, this represents a conservative assumption.

To determine if each link was LOS, the transmit and receive locations were used and a Fresnel Zone plus earth bulge calculation was performed. All but a handful were LOS (terrain was not included in this calculation) and as a result Path Loss (PL) was calculated using the free space path loss equation.

The minimum gain of an FS antenna for Category A and B antennas is 38 dBi, but our review of ULS data shows the median is 40 dBi.

The required signal-to-noise ratio (S/Nreq) parameter in Equation (5-1) had to be derived using ULS data. Since the ULS database includes the modulation, ranging from trellis code to QAM, but not the code rate, we calculated the spectral efficiency (bits/sec/Hz) by dividing the channel data rate by the bandwidth assuming a 20% filter roll-off. These results are shown in Figure 5-11 and reflect a median efficiency of about 5.3 bits/sec/Hz. To further be conservative, for the 12,651 links that were missing modulation and data rate information an efficiency of 6 bits/sec/Hz was assumed.

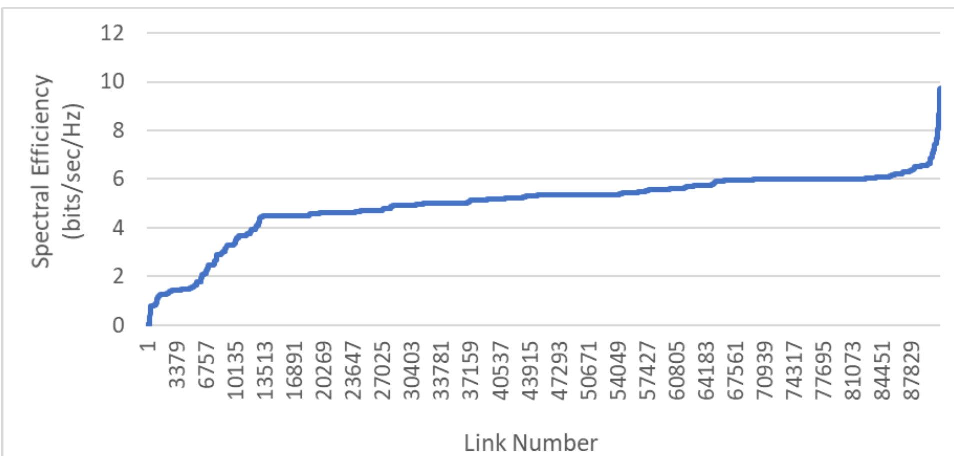


Figure 5-11 – Calculated Spectral Efficiency for 91,187 FS ULS Links

The S/Nreq for each of the 91,187 links was determined using the spectral efficiency shown in Figure 5-11 and the QAM versus capacity curve, shown in Figure 5-12. The S/Nreq varied from approximately 5 to 25 dB. For example, for a link with a spectral efficiency of 6 bits/sec/Hz the S/Nreq is 19 dB.

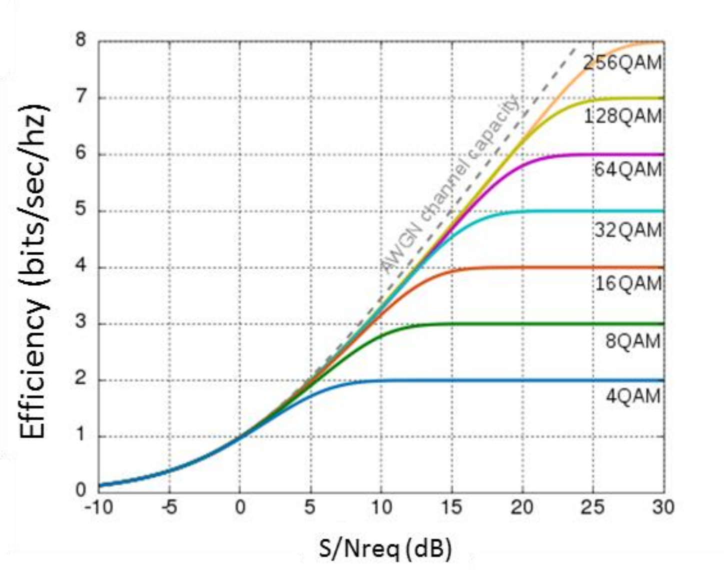


Figure 5-12- Spectral Efficiency vs. SNR for 4QAM up to 256QAM[34]

These values were entered into Equation (5-1), with the resulting calculated fade margins shown in Figure 5-13. Virtually all links from ULS were included in this calculation. A small percentage (0.8%) of links were eliminated based on clear errors or omissions in the ULS data. These included links missing parameters such as the EIRP, bandwidth, where transmit and receive locations are the same, or where the link margin was negative. Within the remaining 99.2%, Figure 5-13 includes a small percentage of the links with very low and very high fade margins. Links with very high link margin (> 80 dB, 0.7%) are not shown in Figure 5-13. As stated above, we assume these links have database errors. The resulting calculated FS median link margin is 50.8 dB, which is reasonable for the high availability targets associated with these links. We note that 30% of the FS links in Figure 5-13 have receive diversity, implying that these links have higher link margin, as a result of diversity gain, than is shown.

[34] Wikipedia, *Quadrature Amplitude Modulation*, https://en.wikipedia.org/wiki/Quadrature_amplitude_modulation (last visited Jan. 19, 2018).

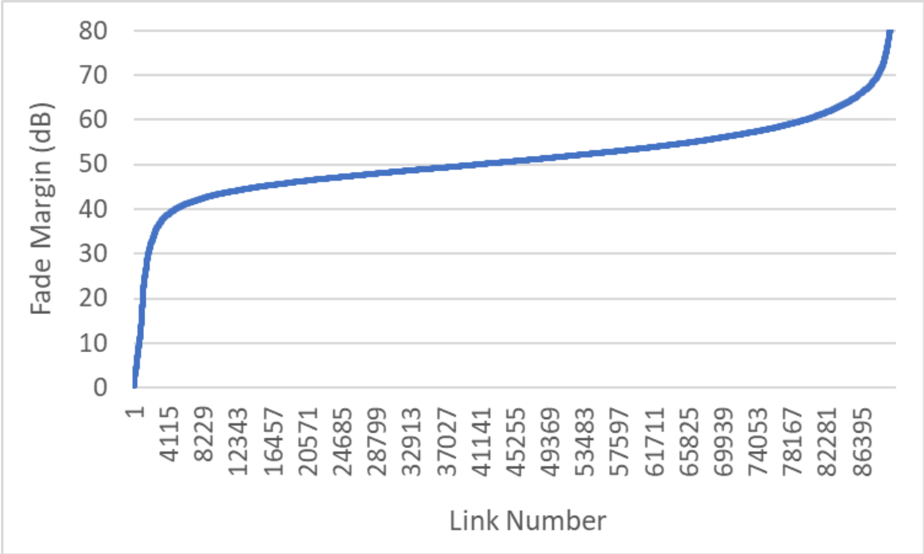


Figure 5-13 - FS ULS Station Calculated Link Margins

The link unavailability for the FS links due to multipath and rain fade is shown in Figure 5-14. The calculation used P.530 and assumed that multipath and rain fade are independent. The rain fade distribution is only defined for availabilities up to 99.999%. However, rain fade is not the dominant contributor. 748 FS links (out of 90,486 links with calculated fade margins) were removed due to missing or erroneous data required for availability calculation. All but 3.9% of the remaining 89,738 links meet the 99.999% minimum availability (.001% unavailability). FS links that don't meet this requirement are assumed to have errors or rely on diversity that was not analyzed in this report.

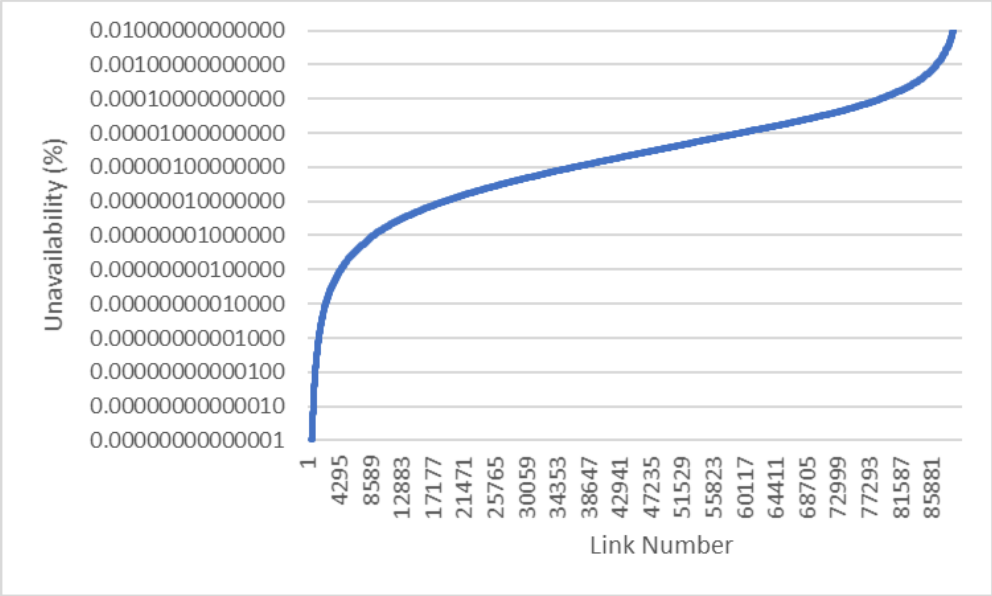


Figure 5-14 – Unavailability for FS ULS Links

Figure 5-15 shows the calculated unavailability for the ULS links as a function of service type. From the figure it is clear that all the services generally purchase the same equipment and have similar target availability. One service is not more sensitive than another.

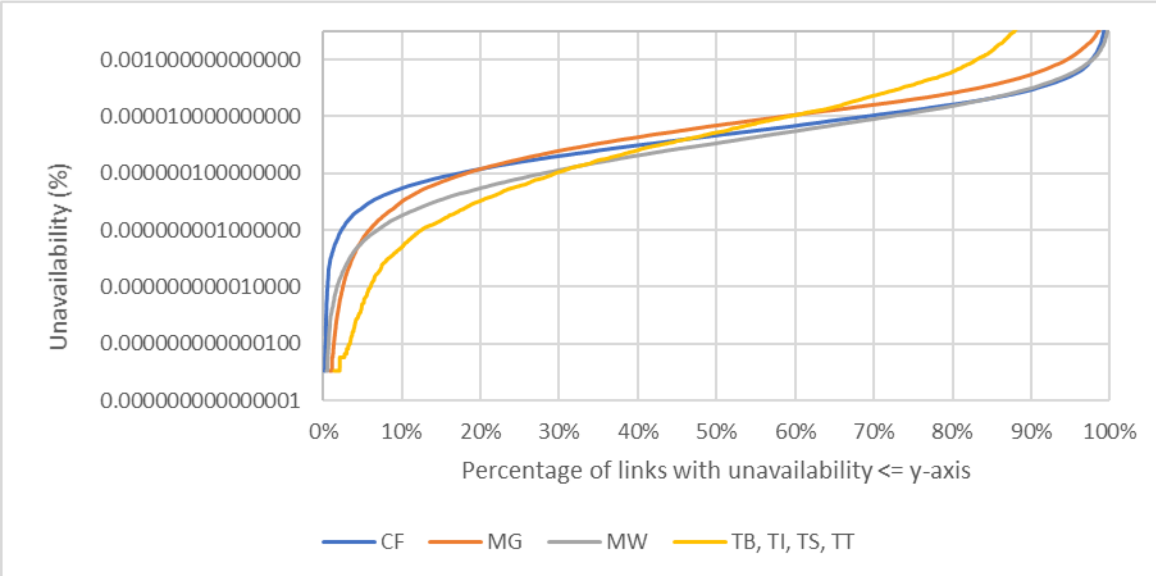


Figure 5-15- Unavailability of ULS Links as a Function of Service Application

5.2.4 FS Link Availability with RLAN Interference

This section examines the impact of interference on FS link availability of a national RLAN deployment. Over the ten CONUS simulations, a total of 1,904 unique FS receivers exceeded the I/N>-6 dB. In 99.1%, of the cases (1,887), a single RLAN device caused the exceedance. As shown in Table 5-7, the affected FS receivers were strongly random in nature. This is a key finding that demonstrates that no specific RLAN-FS geometry is more likely to occur with higher frequency.

Number of FS with I/N > -6 dB	Number of Runs (among 10 Runs)
1832 (96.2%)	1
70 (3.7%)	2
2 (0.1%)	3

Table 5-7 - Number of FS Links Repeated in Each Simulation

We then arbitrarily selected one CONUS simulation and identified the 165 worst-case links that exceeded the I/N>-6 dB threshold. For these worst-case affected links, we performed 1,000 additional simulations, each with random RLAN deployments, to calculate a statistically significant I/N distribution. This distribution was then used in calculating the increase in FS link unavailability.

As described in Section 3.1, the population of RLANs will be very large with only a small fraction transmitting at a time. Given that the duty cycle of each RLAN is low, the statistical variation of the interference, over time, to the FS receivers will be high. The calculation of the link availability used P.530 and added the calculated RLAN interference distribution with the assumption that RLAN interference, multipath and rain fade are all independent. Thus, the link availability calculation involves a convolution of the probability density functions of each of the impairments.

Figures 5-16 and 5-17 show that the impact of RLAN interference on the link unavailability is negligible. All links still meet the unavailability target of 0.001% (99.999% availability). Thus, even though interference can exceed an I/N value of -6 dB, the overall impact on FS availability is negligible.

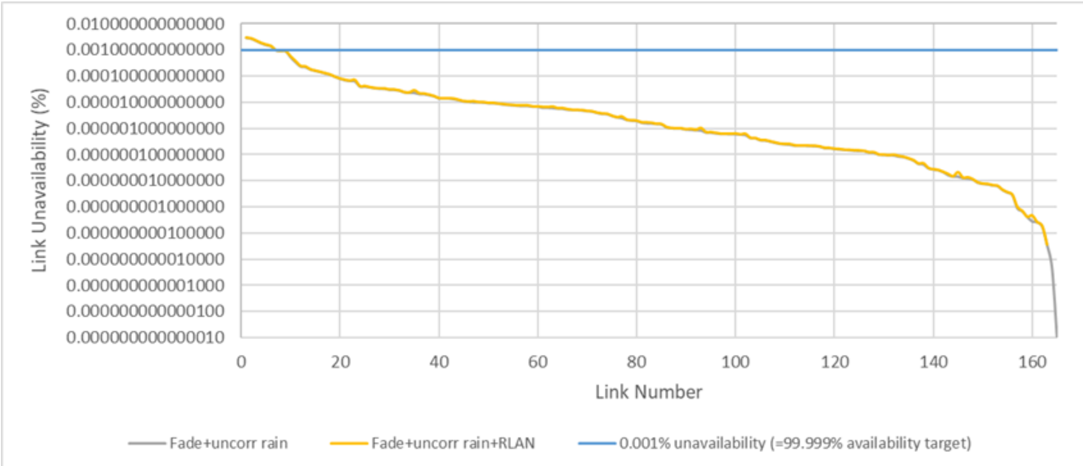


Figure 5-16 - Link Unavailability for 165 Worst-case Links Without (Fade+uncorr rain) and With RLAN Interference (Fade+uncorr rain+RLAN)

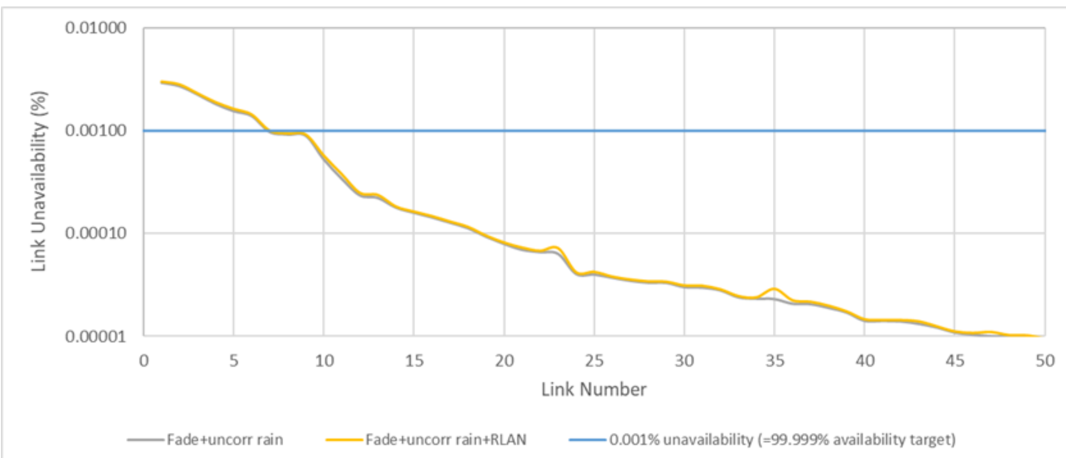


Figure 5-17 – Link Unavailability Zoomed-in for 1.0 E-05 to 1.0 E-03.

5.2.5 Overload and RLAN Out of Band Emissions Requirements

Based on ETSI documentation,[35] overload levels range from -26 dBm to -21 dBm for FS receivers in the 6 GHz band. The FS stations have diplexers with a receive bandwidth of 250 MHz. If the receiver Noise Figure is 4 dB, per ITU-R Rec. F.758-6, with an antenna temperature of 290K, then an I/N = -6 dB, over the full 250 MHz, corresponds to a receive interference

[35] European Telecom. Standards Inst., *Fixed Radio Systems; Characteristics and Requirements for Point-to-Point Equipment and Antennas; Part 2-1: System-Dependent Requirements for Digital Systems Operating in Frequency Bands Where Frequency Co-ordination Is Applied*, ETSI EN 302 217-2-1 V2.1.1 (2014-12) at 19, http://www.etsi.org/deliver/etsi_en/302200_302299/3022170201/02.01.01_60/en_3022170201v020101p.pdf.

power equal to only -92 dBm. From the simulations, this scenario is unlikely. Even if it did occur, there would be 66 dB of margin before there is a risk of overload.

The OOBE level from RLANs into an FS receiver with a 30-MHz channel was analyzed. From Figure 5-18, OOBE was calculated to an FS station assigned the diplexer center channel. The RLAN bandwidths were 20 MHz and the OOBE power calculation included the out-of-band contribution of all in-band RLANs. This analysis should provide a worst-case estimate of OOBE. Applying the RLAN transmit mask in Figure 5-19, it was found that the maximum I/N from RLAN OOBE would be attenuated 24.9 dB below the in-band I/N. This corresponds to a 0.01 dB increase to the in-band noise.

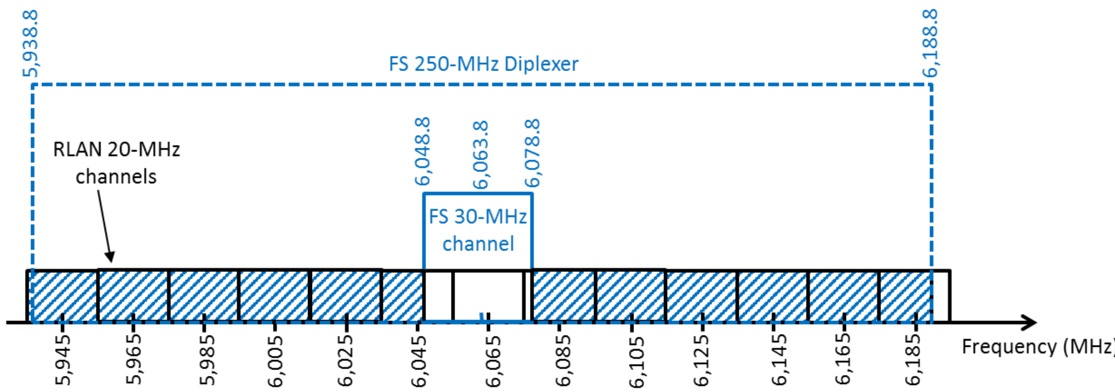


Figure 5-18 - Alignment of 13 20-MHz RLAN Channels Within FS Receiver's 250-MHz Diplexer. RLAN Power Within Hashed Frequencies Were Used to Calculate OOBE from RLANS into an FS 30-MHz Channel Centered at 6.0638 GHz.

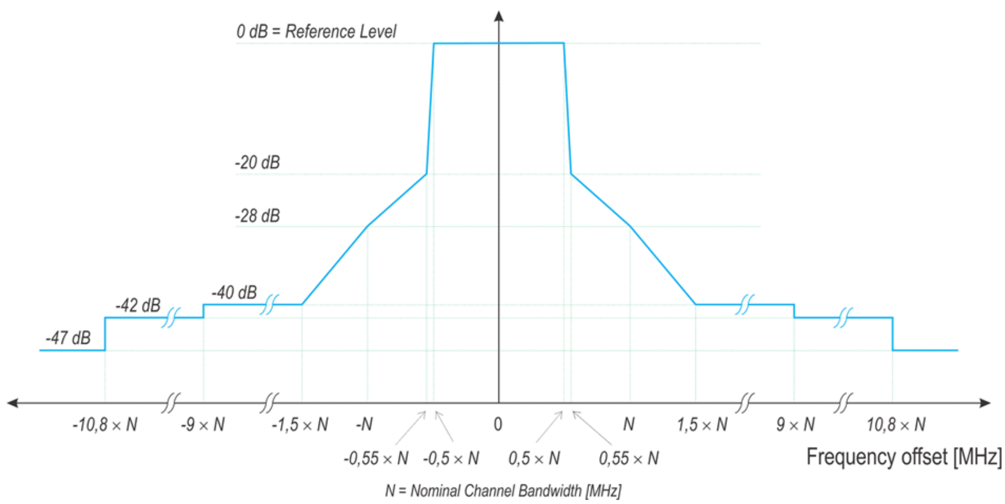


Figure 5-19 - RLAN Transmit Mask

5.2.6 FS Sharing Conclusions

The simulation results show that a large national underlay deployment of RLANs in the 6 GHz band will have negligible impact on FS availability and, therefore, will not present risk of harmful interference at either an aggregate or a single-entry level. The study found that across all runs, approximately 99.8% of the FS stations within CONUS had aggregate interference levels from RLAN operations below -6 dB I/N. For the 0.2% of remaining FS stations, the study found that FS links designed to 99.999% availability (i.e., approximately 315 seconds of downtime per year) incurred approximately an additional 8 seconds per year of outage, and links

designed to 99.9999% availability (i.e., approximately 31.6 seconds of downtime per year) incurred approximately an additional 0.8 seconds per year of outage. This study quantitatively addresses the concern that individual RLAN devices situated on high floors, at close range, through a window, or other corner case geometries pose an unacceptable interference risk to FS receivers. We find that the *rate of occurrence* of such geometries is extremely low – on the order of two-tenths of one percent and that the few instances of interference over -6 dB I/N were dominated by a single RLAN in the mainbeam of the FS station or near the FS receiver. Further, we demonstrate that *the cumulative effect* of such occurrences statistically does not cause any FS links in CONUS to fall below its availability design target.

We conclude that the resulting impact on FS availability and quality of service delivered over these links from the introduction of RLANs will fall within the existing availability design margin even for these worst-case scenarios, and does not cause harmful interference.

5.3 MS Sharing

5.3.1 MS Usage Studied

6 GHz band MS links consist of BAS, CARS, public safety, microwave industrial/business pool, and local television transmission links. As shown in Figure 5-20, only those links directly connected to a mobile asset are considered. These include:

- A helicopter transmitting to a receiver on a tower;
- A vehicle transmitting to a receiver on a tower; and
- A tower transmitting to a receiver on a vehicle.

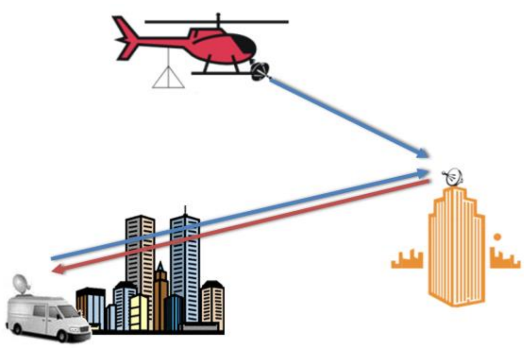


Figure 5-20 – Mobile Service Links

Because the mobile bands are primarily used for news or emergency events, such deployments are generally unpredictable and intermittent.

5.3.2 MS Simulation

Recommendation ITU-R Rec M.1824 (M.1824), the FCC's ULS database, as well as other available references, were studied to understand the characteristics of these mobile systems. This analysis revealed that the different applications had similar link characteristics.

MS is allocated to the 6.425-6.525 GHz and 6.875-7.125 GHz bands. Tables 5-8 and 5-9 summarize ULS information as of March 31, 2017, for the 1,566 entries in these bands. Some of these entries are for the same link with different channel frequencies, leaving 659 unique links. The tables below indicate both the total number of links and the number of unique links representing a limited number of base stations, indicating site-specific coordination is possible.

Most links are 25 MHz, although some smaller bandwidths also occur. Antennas with gains above 30 dBi are most prevalent. The dominant receiver height is 6.1 m, indicating they are most likely vehicle-mounted.

Radio Service Type	Total # of ULS (unique)	RX Gain (dBi)	RX Height to Center RAAT (m)
TP (BAS TV Pickup, Part 74F)	490 (257 unique)	Range: 8-42 dBi 28%: 35 dBi or 36 dBi M.1824: 35 dBi	Range: 6.1-553 m 37%: 6.1 m <2%: remaining
MW (Microwave Public Safety Pool, Part 101)	396 (61 unique)	Range: 2-39 dBi 13%: 6 dBi 11.5%: 15 dBi 34%: 30 dBi 7%: 34 dBi	Range: 6.1-106.7 m 85%: 6.1 m <2%: remaining
MG (Microwave Industrial/Business Pool, Part 101)	220 (30 unique)	Range: 2-34 dBi 23%: 3 dBi	6.1m (all, except one at 91.1m)
CT (Local Television Transmission, Part 101)	18 (4 unique)	13, 20, 30, and 35 dBi	6.1 m (all)

Table 5-8 - ULS Data for MS Links in the 6.425 – 6.525 GHz Band

Radio Service Type	Total # of ULS (unique)	RX Gain (dBi)	RX Height to center RAAT (m)
TP	440 (305 unique)	Range: 8-44 dBi 3%: 15 dBi 8%: 20 dBi 21%: 25-29 dBi 9.5%: 30 dBi 34%: 35-36 dBi	Range: 6.1-553 m 31.5%: 6.1 m <3%: remaining
CT	2 unique	10 and 20 dBi	6.1 m (all)

Table 5-9 - ULS Data for MS Links in the 6.875-7.125 MHz Band

As of July 19, 2017, there are 26 and 20 active CARS licenses in COALS in 6.425-6.525 GHz and 6.875-7.125 GHz respectively. Each license corresponds to a single transmitter with one or more receiver sites. Hence, the above licenses correspond to 29 and 20 receivers in 6.425-6.525 GHz and 6.875-7.125 GHz respectively. However, the COALS database does not provide the receiver gain required for interference analysis. The mobile link that is most susceptible to RLAN interference is the vehicle-mounted transmitter to a receiver mounted on a tower. In this scenario, the receive antenna points to the ground location of the MS transmitter mounted on a vehicle. This is a worst-case geometry with RLANs within the main beam of the receive antenna.

To analyze the impact of RLAN interference in this worst-case scenario, five exemplars were selected from the ULS database. These are all BAS TV Pickup links with the receiver located on tall buildings or on top of mountains. Of the five base stations selected for worst-case analysis, three are in Los Angeles and two are in San Francisco. These base stations were selected because they use high gain receive antennas (25 dBi to 36 dBi) and point to high population density areas resulting in worst-case interference geometries. These areas also had worst-case interference in the FS simulations. Their receiver locations are shown in Figure 5-21 with ULS parameters summarized in Table 5-10. Consistent with ITU-R Rec. F.758-6, an MS receiver

Noise Figure of 4 dB was assumed and, as mentioned in Section 3.2.5.2, this represents a conservative assumption.

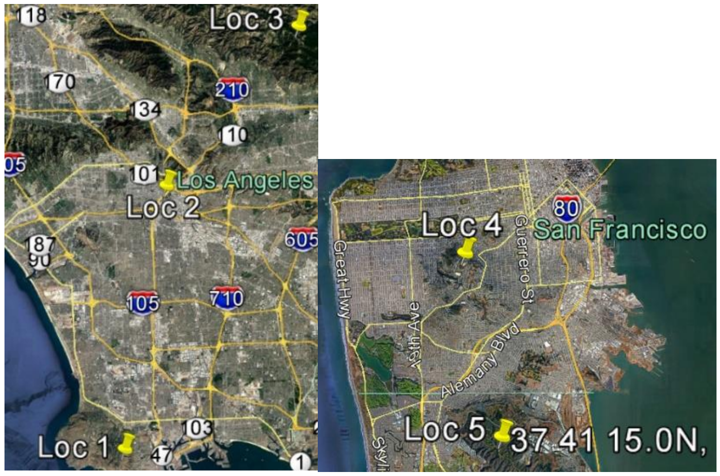


Figure 5-21 - MS Exemplars in Los Angeles (left) and San Francisco (right)

TP Site ID	Call Sign	Rx Latitude	Rx Longitude	Rx Ground Elevation (m)	Rx Height to Center RAAT (m)	Rx Gain (dBi)	Operating Radius (km) from Tx Lat/Long
TP1	KA88959	33-44-46.0N	118-20-10.0W	442	16	35	100
TP2	KA88959	34-3-1.0N	118-15-46.0W	104.2	121.9	35	100
TP3	WQGK889	34-13-35.0N	118-4-1.2W	1739.8	6.1	36	80.4
TP4	KA35181	37-45-19.0N	122-27-10.0W	254.2	195.7	25	160
TP5	KA35181	37-41-15.0N	122-26-8.0W	395	4.4	25	160

Table 5-10 – BA (TP) Example Links (ULS Parameters)

Simulations were performed to determine the aggregate interference from RLANs to the MS base station receivers. For each of the 10,000 iterations of the simulation, RLANs were randomly deployed, with weighting according to population density. Then the simulation was run with the vehicular mounted MS transmitter randomly deployed within its operating radius listed in Table 5-10. Even without RLAN interference, there was a high probability that the MS link wouldn't close.[36] This is indicative of a highly cluttered environment where the transmit locations are chosen randomly by the Monte Carlo (MC) simulator. In reality, truck operators mitigate these outages by using a number of techniques to achieve better margin including, moving the truck, increasing the antenna height, pointing to an alternate base station, switching frequencies, or even setting up a relay station. To account for this in the simulation, as each mobile transmitter site was randomly selected, we first calculated the link margin *without* RLAN interference. In cases where the link margin was insufficient to close the link, we discarded that location and selected another. The simulation was repeated until 10,000 MS locations with

[36] The receiver sensitivities are taken to be -120 dBW, and the propagation model including clutter is used to determine if the RX level exceeds the sensitivity in which case the link is considered to be closed.

closed links (in the absence of RLANs) were generated. The simulation containing the 10,000 MS locations was then run in the presence of RLANs.

For each simulated location, the interference impacts were evaluated including the impact of changes to the Modulation and Coding Scheme (MCS) or loss of the link. It is assumed that the MS operator will take steps such as choosing a more robust MCS to improve link quality if required.

5.3.3 MS Sharing Results

Aggregate interference analysis results are shown in Figures 5-22 and 5-23 and are summarized in Table 5-11. With 10,000 iterations, the results are not considered accurate within about 0.1% probability. The interference shown in Table 5-11 will be intermittent with a low duty cycle, and therefore may have a minimal effect on the MS link.

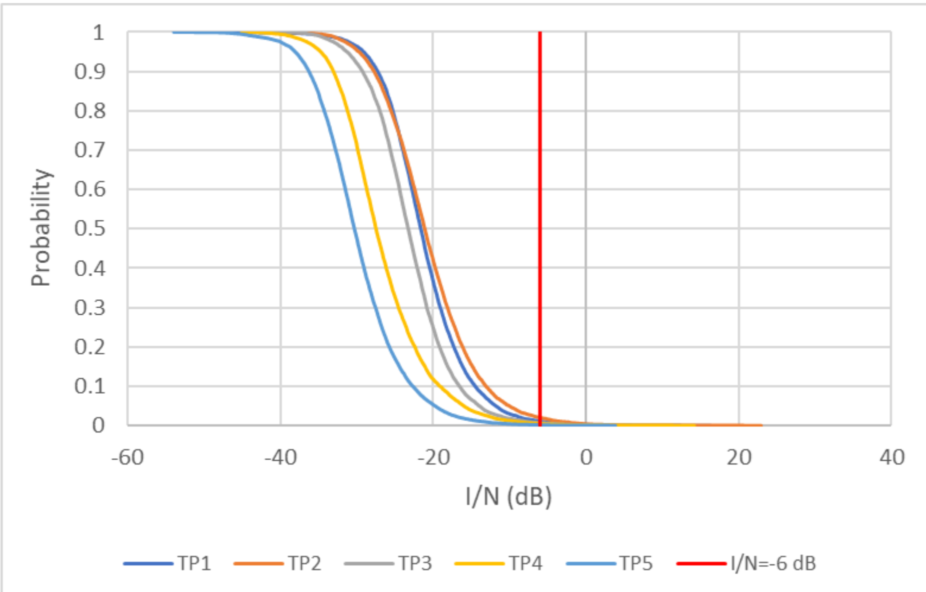


Figure 5-22 - Probability of Aggregate RLANs I/N Exceeding an I/N Level (x-axis) for TP1, TP2, TP3, TP4 and TP5

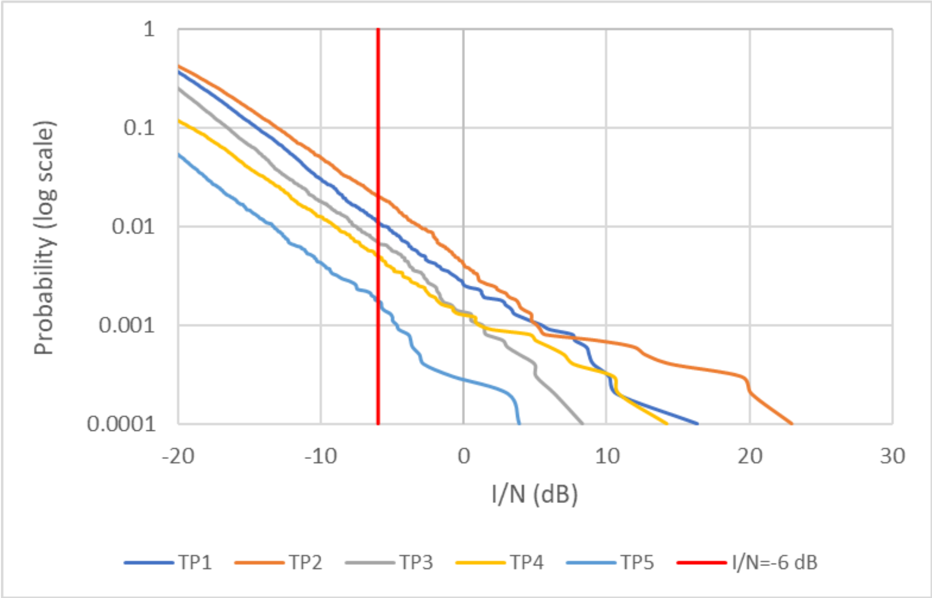


Figure 5-23 - Probability of Aggregate RLANs I/N Exceeding an I/N Level (x-axis) for TP1, TP2, TP3, TP4 and TP5, Zoomed in

	TP1	TP2	TP3	TP4	TP5
I/N Total > -6 dB	1.1%	2%	0.69%	0.5%	0.17%

Table 5-11 - MS Interference Simulation Results

To better quantify the impact of the interference, we determined that any assessment of the impact from the RLAN interference should consider the additional effort an MS operator may have to take to improve the fade margin of a desired operating location within the defined service radius. It was assumed that there will seldom be a case where the MS operator cannot mitigate these affects (e.g., by moving the vehicle). To define this effort, we tabulated the following:

1. The percentage of randomly selected links that do not close even without the introduction of RLAN devices;
2. The MCS change resulting from the interference; and
3. The percentage of links that couldn't close with the minimum MCS because of the interference.

The performance of the MS link was measured against the code points in Table 5-12 from M.1824. The MS link carrier-to-noise (C/N) and carrier-to-noise plus RLAN aggregate interference (C/(N+I)) was calculated for each iteration of the simulation. The C/N and C/(N+I) values were then converted into achievable data rates using the code points shown in Table 5-12 from M.1824. This calculation does not consider the temporal variation of the RLAN interference or detailed characterization of the MS receiver.

Occupied Bandwidth (MHz)	Modulation	Rx Sensitivity (dBW)	C/N required (dB)
9	QPSK-OFDM	-120	10.43
18	QPSK-OFDM	-116.9	10.52
18	16QAM-OFDM	-109.9	17.52
18	32QAM-OFDM	-107.6	19.82
18	64QAM-OFDM	-105.1	22.32

Table 5-12 - Code Points

Table 5-13 shows that in this simulation, a very large percentage of randomly selected MC locations the MS links don't close even without RLAN interference. This example highlights the effort required by the MS operator under normal conditions without RLANs to ensure that their links close with a reasonable margin. As a worst case, RLAN interference causes a reduction in link margin that can result in the requirement to apply routine mitigation in approximately 1% of interferences instances. Since MS system data rates vary due to changes in geometry and condition, the change in performance due to RLAN interference would be difficult to observe. Finally, in the worst-case example, less than 0.17% of the total links did not close when the RLAN interference was added. This was largely because these links were already marginal prior to adding the RLAN interference. As a result of RLAN interference, the increase in MS Monte Carlo percentage of links requiring routine mitigation is captured in the last column of the table below. An improvement in the link margin achieved, for example, by moving the truck and/or antenna, consistent with routine practice today, could mitigate these effects.

TP Site ID	MS Monte Carlo Percentage of links failing without RLAN interference	MS Monte Carlo Percentage of links that may have to apply routine mitigation	Increase in MS Monte Carlo Percentage of links requiring routine mitigation
TP 1	53.00%	1.06%	0.07%
TP 2	44.11%	0.93%	0.00%
TP 3	69.35%	0.81%	0.05%
TP 4	29.27%	0.75%	0.17%
TP 5	27.85%	0.44%	0.07%

Table 5-13 - Percentage of MS Links Potentially Affected by RLAN Interference

5.3.4 MS Sharing Conclusions

Since by its very nature the MS operating conditions within the desired coverage area are highly variable and often challenging, additional RLAN interference causes an impact on the MS performance that would be unnoticeable or at most barely noticeable.

Simulations were performed on three MS ULS database base stations in Los Angeles and two MS ULS database base stations in San Francisco, representative of worst-case MS scenarios. 10,000 simulated trials of randomly placed MS transmitters and RLANs were used to approximate the environment. RLAN interference caused less than 0.2% of the links to fail. In the worst case, a code point change occurred in less than 1.1% of the simulated cases due to RLAN interference.

As is standard practice among MS operations, the MS transmitter operating parameters are optimized on a location-by-location basis (e.g., slightly closer, clearer path to MS receiver). We would expect the introduction of RLANs to require no change to these current practices by MS operators.

Appendix A – ITU, FCC CFR, and IBFS Information

The table shows the filed frequency of each satellite, indicated by x if over the entire band, or by actual frequency band as shown in the FCC's IBFS database.

Satellite Designation	Orbital Location	Conventional C- 5.925-6.425 GHz	Extended C-band 6.425-6.725 GHz	Planned Band 6.725-7.025 GHz	7.025-7.075 GHz
NSS-9	177W	x			
AMC-10	135W	x			
AMC-7	135W	x			
Galaxy 15	133W	x	6.629- 6.650 6.680- 6.701 [RPS payload]		
AMC-11	131W	x			
Galaxy 12	129W	x			
Galaxy 13	127W	x			
Galaxy 14	125W	x			
Galaxy 18	123W	x			
Galaxy 23	121W	x			
Anik F3	118.7W	x			
SATMEX 8	116.8W	x			
FM-6	116.15W				7.052- 7.053 7.056- 7.057 7.060- 7.073
XM-4	115.25W				x
Eutelsat 115 West B	114.9W	x			
SATMEX 6	113 W	x			
Anik F2	111.1W	x			
Anik F1R	107.3W	x	6.625- 6.725 [RPS payload]		
Anik F1	107.3W	x			
SES-11	104.95W	x			
AMC-18	104.95W	x			
SES-3	103W	x			
SES-1	101W	x			
Galaxy 16	99W	x			
Galaxy 19	97W	x			
Galaxy 3C	95.05W	x	6.425- 6.675		
Intelsat 30	95.05W		x		
Intelsat 31	95.05W		x		
ICO G1 [MSS]	92.85W	5.925- 5.930 6.420- 6.425			
Galaxy 17	91W	x			
Galaxy 28	89W	x			
SES-2	87W	x			
XM-5	85.2W				x

Satellite Designation	Orbital Location	Conventional C-5.925-6.425 GHz	Extended C-band 6.425-6.725 GHz	Planned Band 6.725-7.025 GHz	7.025-7.075 GHz
XM-3	85.15W				x
AMC-2	84.85W	x			
AMC-9	83W	x			
Arsat-2	81W	x			
EchoStar-1	77.25W	5926-5927	6.423-6.424		
StarOneC1	65W	x			
Amazonas-3	61W	x			
Intelsat 21	58W	x			
Intelsat 34	55.5W	x			
Intelsat 23	53W	x			
NSS-806	47.5W	x	6.491- 6.650		
SES-14	47.5W	x			
Intelsat 14	45W	x			
Intelsat 9	43.1W	x			
Intelsat 11	43W	x			
SES-6	40.5W	x		x	
AMC-12	37.45W	x			
Intelsat 35e	34.5W	x			
Intelsat 903	34.5W	x			
Intelsat 25	31.5W	x	6.425-6.645		
HISPASAT 30W-6	30W			x	
Intelsat 907	27.5W	x			
Intelsat 905	24.5W	x			
SES-4	22W	x			
GNSS-7	20W	x			
Intelsat 901	18W	x			
Intelsat 1R	50.1E	x			
MEASAT 2	148E	x			
Intelsat 19	166E	x			
Intelsat 805	169E	x	6.425- 6.650		
AMC-23	172E	x			
Intelsat 18	180E	x			

More detail on incumbent services including the ITU radio regulations (RR) or FCC CFR (Code of Federal Regulations), referenced inside brackets where applicable, are provided below.

1. Fixed Satellite Service
    a. Uplink
        i. 5.925-6.425 GHz: Conventional C Band, includes ESV (Earth Stations on Vessels) [ITU RR NG181]
        ii. 6.425-6.725 GHz: Extended C Band
        iii. 6.725-7.025 GHz: Planned Band (Appendix 30B) [ITU RR no. 5.441]
        iv. 7.025-7.075 GHz: Band used by SiriusXM for Feeder uplink of DARS (Digital Audio Radio Service)

b. Downlink
    i. 6.700-7.075 GHz: limited to Feeder links for NGSO of MSS [ITU RR no. 5.458B]
    ii. 7.025-7.075 GHz: Use limited to two grandfathered satellite systems and their earth stations [ITU RR NG172]

2. Fixed Service
    a. 5.925-6.425 GHz
        i. Fixed Microwave (Part 101): Common Carrier (CC), Operational Fixed Service (OFS) and Local Television Transmission Service (LTTS)
    b. 6.525-6.875 GHz
        i. Fixed Microwave (Part 101): CC and OFS
    c. 6.875-7.125 GHz
        i. Fixed Microwave (Part 101): CC and OFS
            1. Links shall not intersect with service areas of TV Pickup stations [47 C.F.R. §101.147(a) (34)]
            2. 6.975-7.025 GHz: Channel not used per frequency plans [47 C.F.R. §101.147]
        ii. Television Broadcast Auxiliary Service Station, BAS (Part 74F)
3. Mobile Service
    a. 6.425-6.525 GHz
        i. Fixed Microwave (Part 101): OFS and LTTS
            1. LTTS: Television pickup and television non-broadcast pickup stations [47 C.F.R. §101.147(a) (24)]
        ii. BAS (Part 74F)
        iii. Cable Television Relay Service, CARS (Part 78)
    b. 6.875-7.125 GHz
        i. Fixed Microwave (Part 101): LTTS [47 C.F.R. §74.602(e)]
        ii. BAS (Part 74F)
        iii. CARS (Part 78)
4. Earth Exploration Satellite Service and Space Research Service
    a. 6.425-7.075 GHz: Passive Sensors (measurements over Oceans) [ITU RR no. 5.458]
    b. 7.075-7.125 GHz: Passive sensors (includes over land) [ITU RR no. 5.458]
5. Radio Astronomy
    a. 6.650-6.675.2 GHz: Spectral line observations [ITU RR US342]

Coexistence Study for Radio Local Area Networks in the 6 GHz Band in the Continental United States

Presentation of Apple, Broadcom, Cisco, Facebook, Google, Hewlett-Packard Enterprise, Intel, MediaTek, Microsoft and Qualcomm from a study prepared by RKF Engineering Solutions, LLC

January 25, 2018

Executive Summary

*A national deployment of RLANs in the 6 GHz Band, using established RLAN mitigation techniques and regulatory constraints similar to those applied in the neighboring 5 GHz band, **will not cause harmful interference to primary services**.*

– Simulated impact of nearly 1 billion 6 GHz RLAN devices in the continental US on existing terrestrial, satellite & mobile operations using existing U-NII rules

– Finding #1: Maximum RLAN interference into FSS receivers is below -21.9 dB I/N

– Finding #2: nearly all (approximately 99.8%) of the FS receivers within CONUS had aggregate interference levels from RLAN operations below -6 dB I/N ***and*** no instance of interference ≥ - 6 dB caused a link to fall below its availability design target

  – Links designed to 99.999% availability (or 315.6 seconds of downtime per year) incurred 8 additional seconds of outage per year

  – Links designed to 99.9999% availability (or 31.6 seconds of downtime per year) incurred 0.8 additional seconds of outage per year

– Finding #3: RLAN operations did not degrade MS 99% of the time

  – For the remaining 1%, routine operational practices (e.g. optimizing the transmitter location, or using adaptive modulation) could overcome any interference

– The addition of this study to the extensive record developed in the NOI provides the foundation needed for the Commission to proceed expeditiously to an NPRM

Primary User Protection Is Our Starting & Ending Point

- 6 GHz fixed, mobile & space-borne infrastructure is critical for public safety, common carrier, broadcast, satellite, science and other primary users
- Our companies are significant technology suppliers to these industries at all levels
- As requested by incumbents, we are presenting a detailed engineering study that quantifies the impact to incumbent operations to facilitate evaluation by the Commission.
- We used realistic and conservative assumptions in our simulations
- Our technical analysis suggests that sharing is uniquely feasible in 6 GHz for several reasons:
  - The positions and operating parameters of all incumbent receivers are fixed and available in ULS
  - Vast majority of unlicensed devices operate indoors; only ~2% of fixed infrastructure is deployed outside
  - Fixed Service links typically utilize extremely high quality antennas and have median fade margins over 50dB
  - Differences in signal geometry and elevation of FS vs. unlicensed systems
  - The dominant component of FS link performance (multipath fading > 40dB) occurs well after the RLAN busy hour

Overview of Key Study Inputs & Methodology

RLAN Device Population Model

- 347 million people in CONUS in 2025
- 10 devices per person
- 45% are 6 GHz capable
- 68% of devices are assigned channels in 6 GHz
- 98% indoor and 2% outdoor

958 million RLAN devices (APs and clients)

RLAN Airtime Consumption Model

- Busy hour 7-8PM PT
- 1 of 10 devices in "high" activity mode
- "High" activity mode
  - Home – 2GB/hr
  - Corporate – 1GB/hr
  - Hotspot – 500MB/hr
- "Low" activity mode
  - 1MB/hr

394,958 instantaneous active transmitters

Geographic Population Density Model

- US Census Bureau 2020 population density maps
  - 70% urban
  - 10% suburban
  - 10% rural
- Exclusion for "barren" areas

90% of US population concentrated in 10% of CONUS area

Device Power & Directivity Model

- Obtain typical E-plane antenna patterns per device type
- Assign typical peak EIRP per device
- Anchor E-plane patterns on peak EIRP
- Build E-plane EIRP histogram
- Create weighted EIRP model using DL:UL ratios and device subpopulations

RLAN EIRP up to 4W

Transmitter Height Model

- Use actual US building height distributions for commercial & residential property[1][2]
- Program simulation to distribute RLAN devices uniformly over actual height data

78% - 83% of RLANs on first floor in Urban/Suburban; 84% in Rural

[1] https://www.eia.gov/consumption/commercial/data/2012/;
[2] http://eyeonhousing.org/2016/08/the-number-of-stories-in-single-family-homes-varies-across-the-country/

Airtime Consumption Model by Use Case & Device Type

– 1:1 ratio of Downlink-to-Uplink traffic for Corporate and Public, and a 2.3:1 ratio for Home devices

User Type		Urban			Suburban			Rural	
Client	50%	50%	25%	50%	50%	25%	50%	50%	25%
Enterprise AP	50%	50%	-	50%	50%	-	50%	50%	-
Consumer AP	-	-	70%	-	-	70%	-	-	70%
High-Performance Gaming Router	-	-	5%	-	-	5%	-	-	5%
Total (Indoor)	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

– 1:1 ratio of Downlink-to-Uplink traffic for all outdoor devices

	Urban	Suburban	Rural
Outdoor High-Power AP (Figure 3-8)	20%	20%	20%
Outdoor Low Power AP (Figure 3-9)	30%	30%	30%
Outdoor Client (Figure 3-7)	50%	50%	50%
Total (Indoor)	**100%**	**100%**	**100%**

Propagation & Clutter Models

– 0-30m:	Exclusion zone around FS receiver
– Urban/Suburban	
– Terrain + Clutter losses 30m-1km:	Winner-II
– Local End-point Clutter > 1km:	ITU-R P.2108
– Terrain >1 km:	ITM/SRTM
– Building Penetration Loss:	ITU-R P.2109
– Rural	
– Terrain losses > 30m:	ITM/SRTM
– Clutter losses > 30m:	ITU-R P.452
– P.452 Village Center Clutter Loss	18.4 dB

Summary of Realistic & Conservative Assumptions

– Full CONUS simulation of approximately 1 billion 6 GHz capable RLAN devices

– Higher average EIRP than ITU-R WP5A

– Employed significantly higher EIRP above 30° elevation of 1 watt (30 dBm) as compared with U-NII-1 rules which limit maximum EIRP to 125 mW (21 dBm)

– A conservative assumption of the number of thermally efficient buildings (affecting penetration loss) of 20% vs 30% used in WP5A

– Diversity and/or Multiple-Input-Multiple-Output (MIMO) processing gains were not considered for FS

– Incorporated published market research on outdoor RLAN equipment shipments, were then doubled to estimate more rapid growth scenarios

– Selecting conservative, internationally accepted propagation, terrain and clutter models

– Including the maximum possible number of incumbent stations listed in the FCC databases

– Using US Census Bureau 2020 estimated population density maps and definitions of urban, suburban, and rural areas.

– Executing numerous different scenarios with a wide variation of propagation paths and RLAN deployment configurations to ensure statistically significant results.

FIXED SATELLITE SERVICE SHARING ANALYSIS

Methodology – FSS

Assess Impact of RLAN to Fixed Satellite Service (FSS) Uplink

IBFS Database Review and Analysis

↓

Monte Carlo Run for
Existing FS Interference Analysis

↓

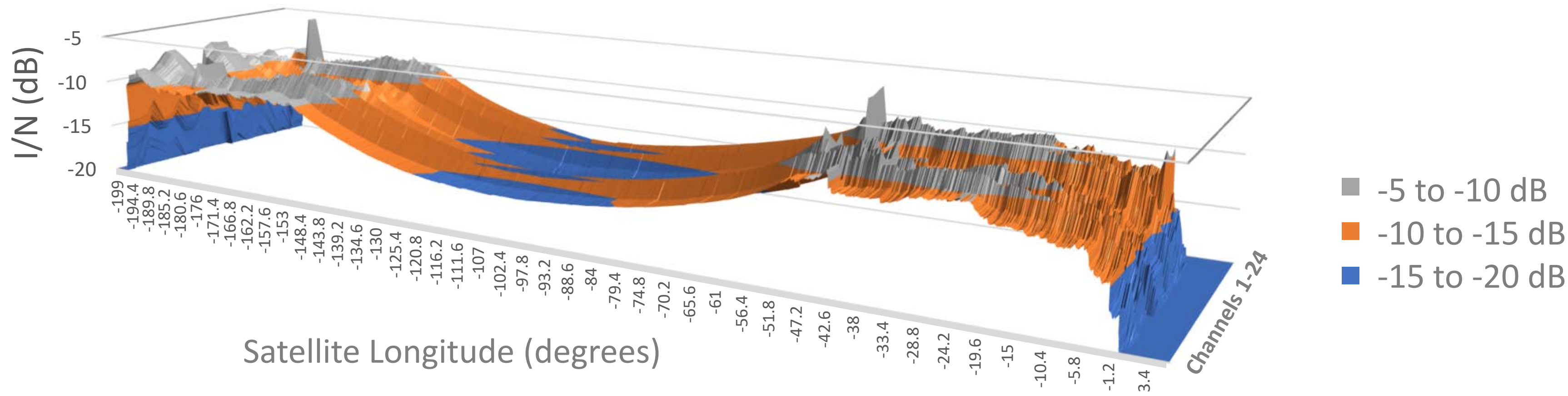
Monte-Carlo Run for
RLAN Interference Analysis

IBFS Database Review & Analysis

FSS UL Simulation Assumptions

- 5,925-6,425 MHz (Standard C-band) contains most satellites
  - 58 satellites covering Continental US (CONUS)
- Using satellite filings' representative beams, a G/T across all of CONUS of about 2 dB/K represented a bounding condition for FSS receiver sensitivity
- Study assumptions
  - Satellites distributed every 2° along GEO arc
  - Interference measured every 0.1°
  - 36 MHz most typical bandwidth

Monte Carlo for Existing FS Interference Analysis

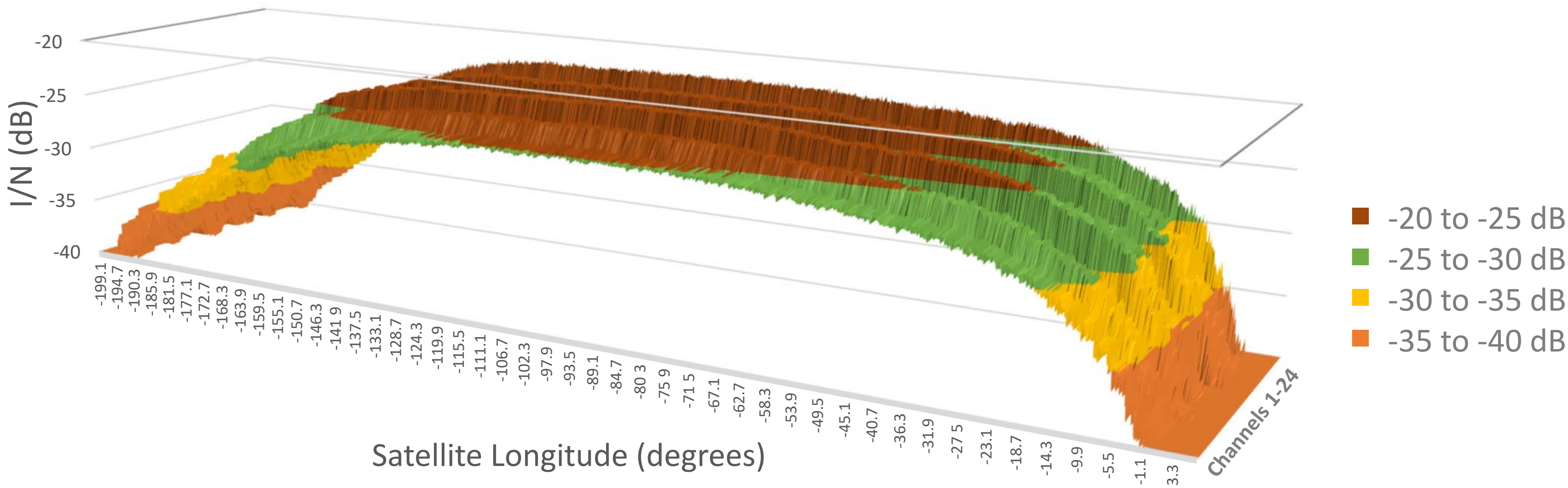


Channel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pol 1 (MHz)	5945		5985		6025		6065		6105		6145		6185		6225		6265		6305		6345		6385	
Pol 2 (MHz)		5965		6005		6045		6085		6125		6165		6205		6245		6285		6325		6365		6405

- Modeled aggregate interference into all FSS operating over CONUS from all FS links in 5925-6425 MHz
  - IBFS used as source for 58 satellites covering CONUS
  - 24 channels, alternating polarization, 36 MHz bandwidth, and 20 MHz spacing
- Assumed satellite G/T=2 dBK
  - Based on filings that over-bound CONUS coverage
- Model predicted max I/N of -4.68 dB
  - Greatest interference to satellites off Pacific and Atlantic coasts well outside of CONUS
  - FS links elevation angle similar to GEO Look angles

RKF Report at 39

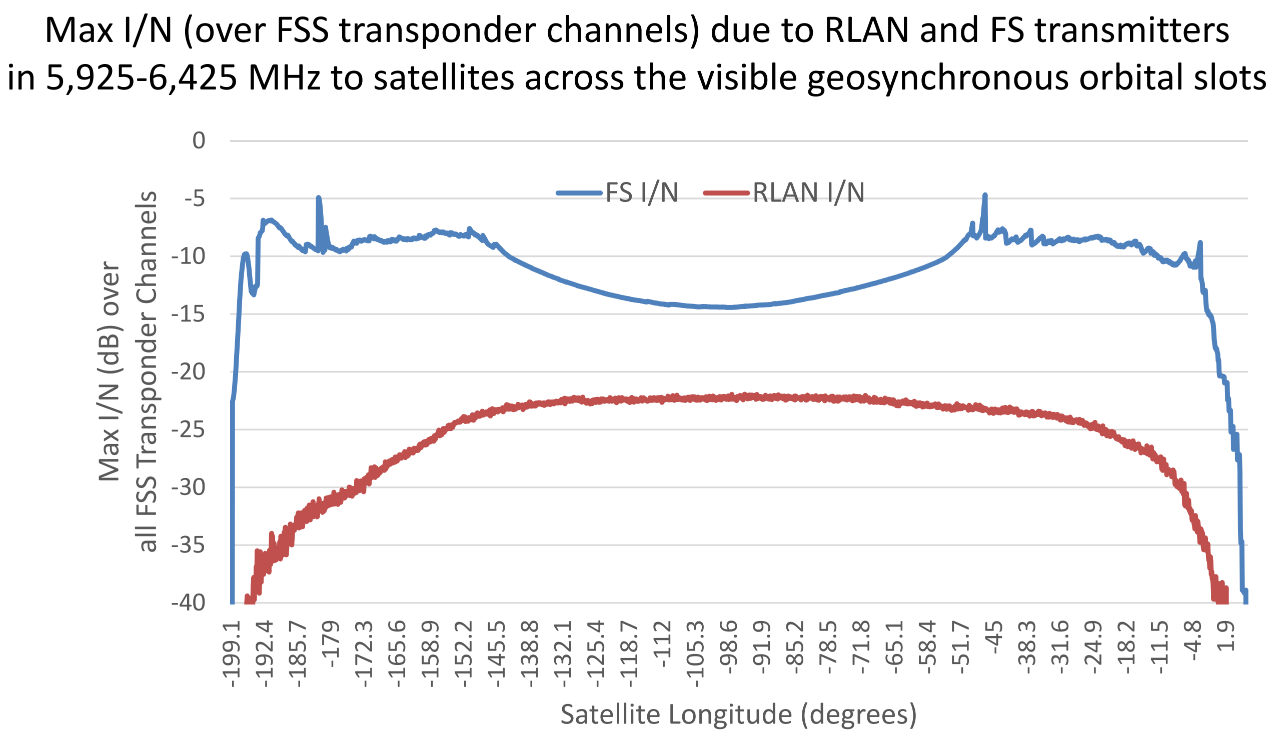
Monte Carlo for RLAN Interference Analysis



- Assumes RLAN usage across Continental United States (CONUS) in the 5925-6425 MHz range
- Predicted aggregate max I/N interference below -20 dB for aggregate RLAN operations
- Minimal impact, with lower interference to satellites that are most impacted by FS
- RLAN transmit gain doesn't have a strong elevation angle dependence
    - Therefore, aggregate interference is not a function of elevation angle to the satellite

RKF Report at 40

Comparison of FS & RLAN Interference into FSS



Results:
A national deployment of RLANs in the 6 GHz Band can share the spectrum without harmful interference to existing FSS services

RKF Report at 41

FIXED MICROWAVE SERVICES SHARING ANALYSIS

Methodology – FS

Assess Impact of RLAN to Fixed Service (FS)

ULS Database Review and Analysis

↓

Monte-Carlo Runs for
Aggregate RLAN Interference Analysis

↓

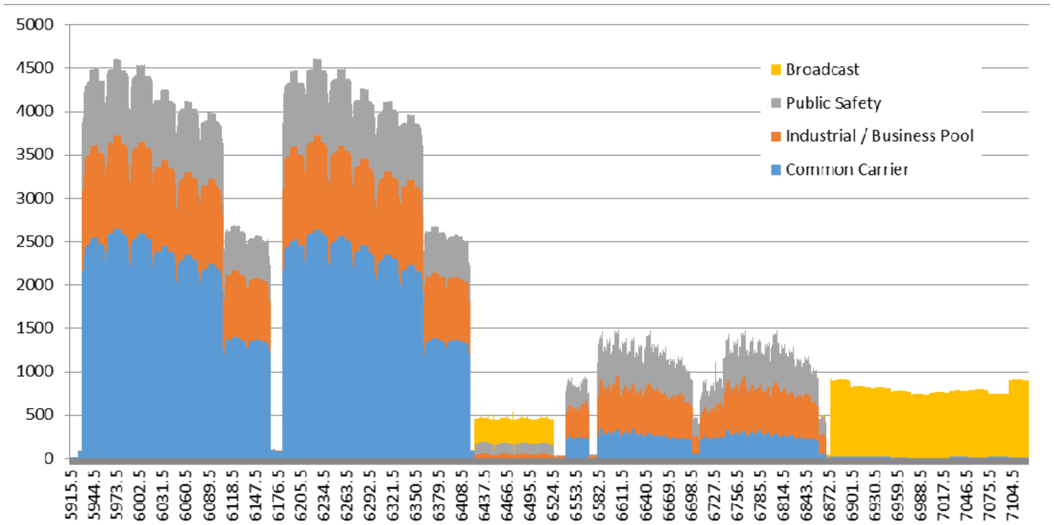
FS-Only Availability Analysis
(per P.530)

↓

Monte-Carlo Runs for
Focused FS+RLAN Availability Analysis

ULS Database Review and Analysis for FS

Number of FS Links per MHz in ULS by Incumbent Category



Link Total Used for RKF Simulation

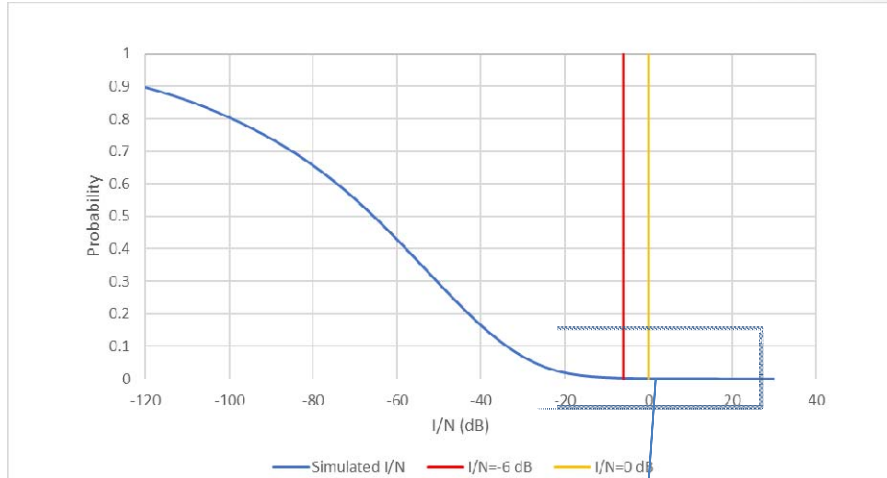
	All ULS
Total entries in ULS database	123,534
Total entries outside of CONUS	-5,403
Total entries out of band	-22,896
Total entries that were mobile	-3,895
Total entries with invalid data	-2,076
Total valid entries	89,264
Total number of entries with data fields that were updated with assumptions based on representative criteria by RKF	+1,923
Total entries used in simulations (valid + assumed data fields)	**91,187**

RKF Report at 43

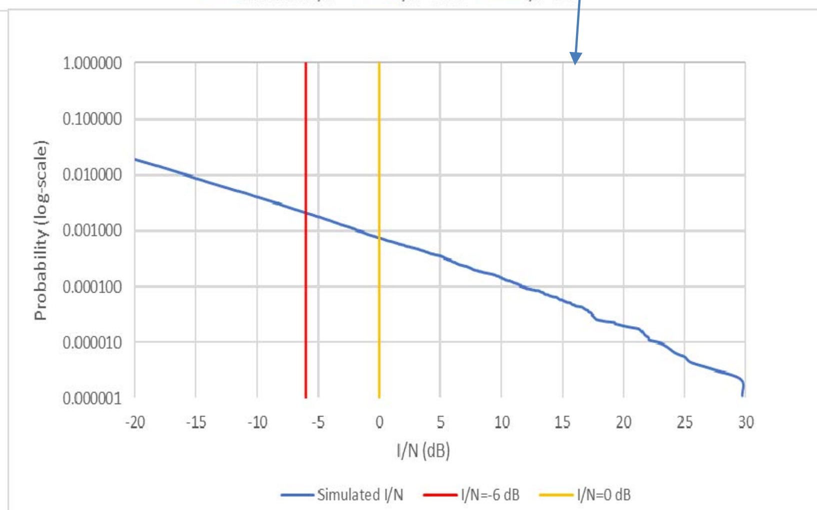
Monte Carlo Runs for Aggregate RLAN Interference Analysis

- Figures show probability of aggregate I/N exceeding an I/N level (x-axis)
- All ULS FS: I/N over 911,870 RLAN to FS interference morphologies

I/N threshold (dB)	Exceedance Probability (all ULS FS)
-6	0.209%
0	0.075%



Log-scale



RKF Report at 44-45

Monte Carlo Runs for Aggregate RLAN Interference Analysis

- FS sites with I/N > -6 dB
  - 0.2% or ~190 out of 91,187 per run
  - Single RLAN caused over 188 of 190 exceedances
- Very small % of recurring sites within each run

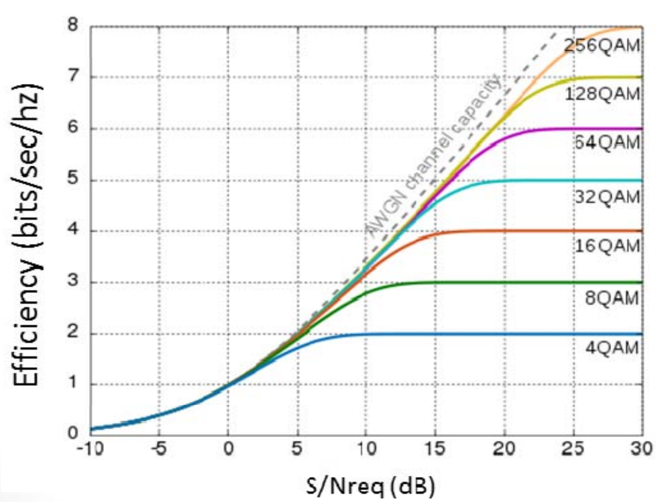
Number of FS with I/N > -6 dB	Number of runs (among 10 runs)
1832	1
70	2
2	3

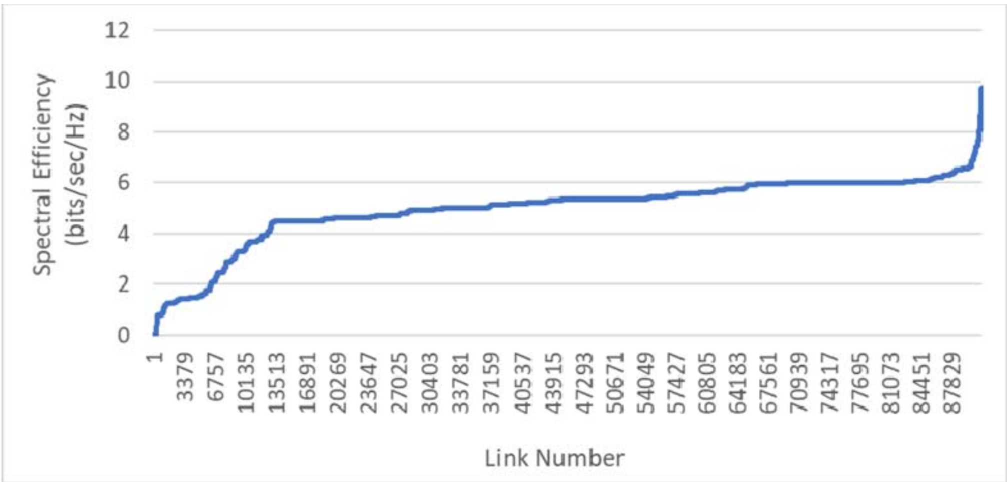
Key Finding:
No specific RLAN-FS geometry is more likely to occur with higher frequency

FS-Only Availability Analysis

Required S/N Calculation

- S/Nreq:
  - ULS database does not include code rate being used (or S/Nreq)
  - Used QAM efficiency vs S/N curve
  - Spectral efficiency (bits/sec/Hz) derivation
    - Channel data rate [ULS] ÷ Nominal bandwidth (reduced by 20% filter roll-off)

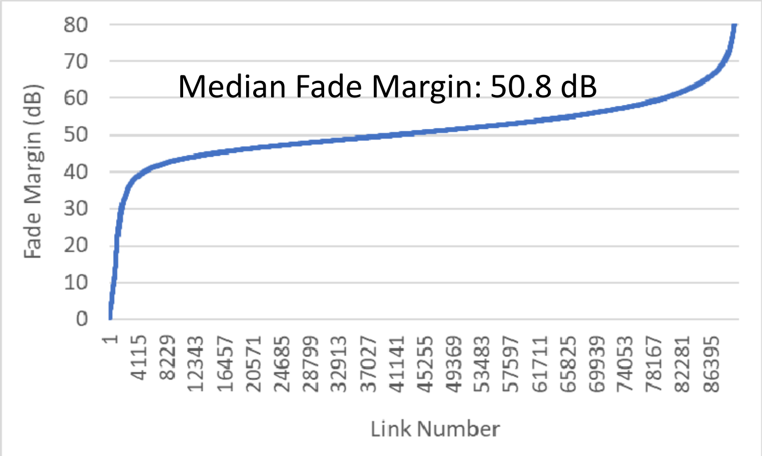




FS-Only Availability Analysis

Fade Margin Calculation

- Resulting calculated fade margin for each FS link
  - Includes 90,486 of 91,187 FS
  - Small % with very low fade margins
    - Database error assumed
  - Small % with very high fade margins
    - Not Shown



- Receive diversity in 30% of sites
  - 3% with low fade margin (< 30 dB)
  - Margin improvement not included in analysis
  - On average, dramatic improvement in service availability and interference resistance

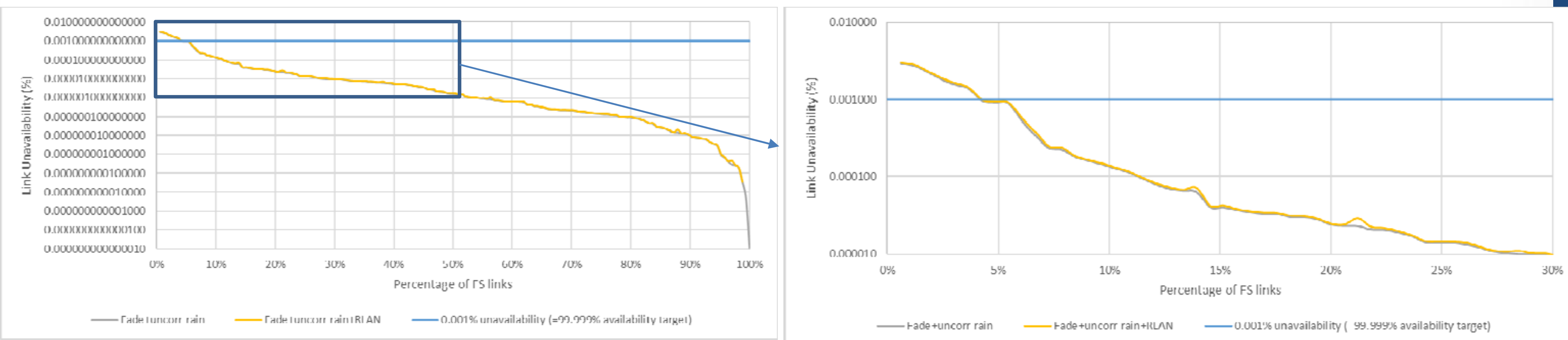
RKF Report at 48

Monte-Carlo Runs for Focused FS+RLAN Availability Analysis

- Focused Monte Carlo simulations on worst case affected links
  - 165 unique FS sites with I/N > -6 dB
    - All dominated by a single-entry interferer
    - Performed 1,000 additional Monte Carlo simulations
    - Each with random RLAN deployments
- I/N > -6 dB occurred just 1,052 times (0.64%) with 1,025 caused by single entry interference
- Results used to calculate FS link unavailability with RLAN interference
  - Convolved probability density functions
    - Multipath
    - Rain fade
    - RLAN (per interference distribution from above simulation)
    - Assumed RLAN interference independent of multipath and rain fade

Monte-Carlo Runs for Focused FS+RLAN Availability Analysis

- Figure shows FS link unavailability with and without RLAN interference
  - 165 ULS links (FS with I/N > -6 dB, determined from the first CONUS run of 91,187 FS)
- All links still meet the unavailability target of 0.001% (99.999% availability) or 0.0001% (99.9999%)



Results:
Overall impact on FS availability by RLAN Interference is negligible

RKF Report at 49-50

MOBILE SERVICES SHARING ANALYSIS

Methodology – MS

Assess Impact of RLAN to Mobile Service (MS)

MS ULS Database Review and Analysis

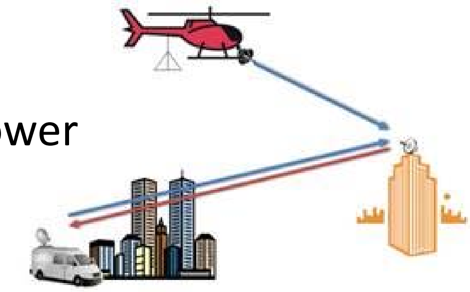
↓

Worst-Case MS Site Selection

↓

Monte Carlo Runs of Mobile Vehicle to Fixed BAS Receiver

Worst-Case MS Site Selection

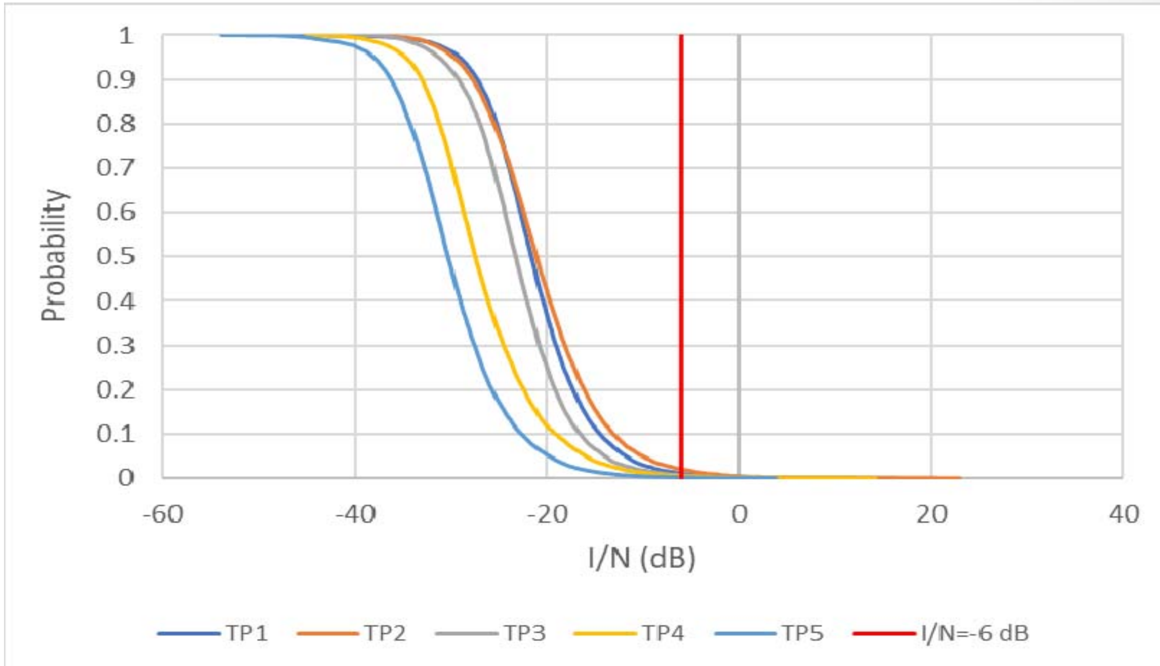


- MS link: vehicle-mounted transmitter to receiver mounted on tower
  - Worst-case geometry
  - RLANs within main beam of the receive antenna
- Selected 5 BAS TV-Pickup (TP) links
  - Receiver on tall buildings or on top of mountains
  - Receivers serve high population density areas: 3 in Los Angeles, 2 in San Francisco
  - High gain receive antennas (25 to 36 dBi)

TP Site ID	Call Sign	Rx Latitude	Rx Longitude	Rx Ground Elevation (m)	Rx Height to Center RAAT (m)	Rx Gain (dBi)	Operating Radius (km) from Tx Lat/Long
TP1	KA88959	33-44-46.0N	118-20-10.0W	442	16	35	100
TP2	KA88959	34-3-1.0N	118-15-46.0W	104.2	121.9	35	100
TP3	WQGK889	34-13-35.0N	118-4-1.2W	1739.8	6.1	36	80.4
TP4	KA35181	37-45-19.0N	122-27-10.0W	254.2	195.7	25	160
TP5	KA35181	37-41-15.0N	122-26-8.0W	395	4.4	25	160

Monte Carlo Runs of Mobile Vehicle to Fixed BAS Receiver

- In simulated cases, without any RLAN operations, the mobile vehicle link failed for 28 to 53% of locations
- In simulated cases with RLAN indoor and outdoor operations, the mobile vehicle:
  - Applied routine mitigation in only < 1.1% of simulated cases
  - Required vehicle movement in only < 0.17% of simulated cases
  - This is before the use of new mitigation requirements



Results: Since by its very nature MS operating conditions within the desired coverage area are highly variable, additional RLAN interference causes a barely noticeable impact on MS performance.

RKF Report at 56-57

Executive Summary

A national deployment of RLANs in the 6 GHz Band, using established RLAN mitigation techniques and regulatory constraints similar to those applied in the neighboring 5 GHz band, ***will not cause harmful interference to primary services****.*

– Simulated impact of nearly 1 billion 6 GHz RLAN devices in the continental US on existing terrestrial, satellite & mobile operations using existing U-NII rules

– Finding #1: Maximum RLAN interference into FSS receivers is below -21.9 dB I/N

– Finding #2: nearly all (approximately 99.8%) of the FS receivers within CONUS had aggregate interference levels from RLAN operations below -6 dB I/N ***and*** no instance of interference ≥ - 6 dB caused a link to fall below its availability design target

  – Links designed to 99.999% availability (or 315.6 seconds of downtime per year) incurred 8 additional seconds of outage per year

  – Links designed to 99.9999% availability (or 31.6 seconds of downtime per year) incurred 0.8 additional seconds of outage per year

– Finding #3: RLAN operations did not degrade MS 99% of the time

  – For the remaining 1%, routine operational practices (e.g. optimizing the transmitter location, or using adaptive modulation) could overcome any interference

– The addition of this study to the extensive record developed in the NOI provides the foundation needed for the Commission to proceed expeditiously to an NPRM