Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

COMMENTS OF APPLE INC., BROADCOM INC., CISCO SYSTEMS, INC., FACEBOOK, INC., GOOGLE LLC, HEWLETT PACKARD ENTERPRISE, INTEL CORPORATION, MARVELL SEMICONDUCTOR, INC., MICROSOFT CORPORATION, QUALCOMM INCORPORATED, AND RUCKUS NETWORKS, AN ARRIS COMPANY

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INTRODUCTION AND SUMMARY

The Commission's proposal to open the entire 6 GHz band for unlicensed technologies will expand access to broadband, promote innovation, and spur economic growth—while protecting existing users.[1] The NPRM is a crucial step in making more unlicensed spectrum available to address exploding consumer demand for wireless technologies. The Commission has wisely proposed to make spectrum available under a regulatory structure based on the successful and time-tested Unlicensed National Information Infrastructure (U-NII) rules, while adding an additional set of conservative restrictions that will protect incumbent operations. These proposed rules accomplish this goal by creating different categories of unlicensed devices in four unlicensed 6 GHz sub-bands: 5.925–6.425 GHz (U-NII-5); 6.425–6.525 GHz (U-NII-6); 6.525–6.875 GHz (U-NII-7); and 6.875–7.125 GHz (U-NII-8). In these comments, we explain how the Commission can adopt final rules for the band that promote efficient spectrum use, facilitate rapid deployment, and protect incumbent services from interference. Because access to this spectrum is so critical, both to meet growing consumer demand for Wi-Fi and to support other 5G investments, we ask that the Commission move quickly to resolve this proceeding and adopt rules that allow for rapid product deployment to maximize the value of the 6 GHz band for the country.

Achieving this balance is important because demand for unlicensed spectrum is projected to continue increasing rapidly. This growth is driven by the forthcoming deployment of 5G networks, greater access to gigabit-speed home Internet connections, the proliferation of Internet

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1 *See Unlicensed Use of the 6 GHz Band, Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*, Notice of Proposed Rulemaking, FCC No. 18-147, ET Docket No. 18-295, GN Docket No. 17-183 (rel. Oct. 24, 2018) ("6 GHz NPRM").

of Things (IoT) devices, and the ever-expanding importance of Wi-Fi networks for consumer and business broadband. The Commission's action on 6 GHz comes at a critical time. Multiple studies have demonstrated that the country requires a substantial increase in unlicensed spectrum resources just to keep pace with demand and deliver the important new capabilities of today's wireless technologies to consumers. We will need even more spectrum to support new innovations.[2]

Allowing unlicensed RLAN devices in the entire 6 GHz band, as the Commission has proposed, is the perfect way to achieve this goal. Due to the complementary operational characteristics of RLAN devices and existing 6 GHz licensees, unlicensed RLAN operations are the only realistic option for increasing use of the band without wholesale relocation of licensed users. Conversely, introducing a new licensed mobile service would force incumbents to relocate. Furthermore, the Commission can adopt rules that ensure unlicensed RLANs protect incumbents from harmful interference, as explained below.

Unlicensed operations in the 6 GHz band are particularly valuable because device makers, operators, and users can take advantage of similarities in propagation characteristics and technical rules with the neighboring U-NII bands, which are the nation's most important unlicensed frequencies. Commission action in mid-band spectrum would therefore improve and expand the existing unlicensed ecosystem, for the benefit of all users.

The Commission can facilitate the most effective use of the 6 GHz band by adopting rules as summarized in the following table:

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2 *See infra* notes 8–16.

Device Class	Bands	Location Restrictions	AFC Control	Power Limits	PSD Limits
Standard-Power AP	U-NII-5 U-NII-7 Bottom 100 MHz of U NII-8	Indoor/ Outdoor	Yes	30 dBm (1 Watt) conducted; 36 dBm (4 Watts) radiated	27 dBm/MHz
Low-Power Indoor AP	U-NII-5 U-NII-6 U-NII-7 U-NII-8	Indoor	No	24 dBm (250 milliwatt) conducted; 30 dBm (1 Watt) radiated	21 dBm/MHz
Very-Low-Power AP	U-NII-5 U-NII-7 Bottom 100 MHz of U-NII-8	Indoor/ Outdoor	No	14 dBm (24 milliwatts) radiated	1 dBm/MHz
Client Devices	Same as associated AP	Same as associated AP	N/A	Same as associated AP	Same as associated AP

<u>*Low-power indoor devices*</u>. Enabling low-power indoor (LPI) devices to operate across the entire 6 GHz band is fundamental to the success of the 6 GHz proceeding. Because of their low power and their indoor operation, these devices do not require Automated Frequency Coordination (AFC) and can operate in all four sub-bands while protecting licensed operations. The NPRM's fragmented approach to spectrum access, in which standard-power devices under AFC control and LPI devices would be permitted in alternating 6 GHz sub-bands, would significantly hinder investment and efficient utilization throughout the band. Critically, it greatly reduces the potential for LPI devices to access wider, 160-megahertz channel sizes that facilitate the higher speeds needed for next-generation broadband infrastructures (e.g., ISPs delivering multiple gigabits per second service to the home) and could also reduce the potential for global harmonization.

There is no technical justification to restrict LPI use to only U-NII-6 and U-NII-8. Incumbent Fixed Service (FS) operations in U-NII-5 and U-NII-7 are not vulnerable to

interference for the same reasons that existing operations are protected in the sub-bands where the NPRM would allow LPI (U-NII-6 and U-NII-8). In fact, the types of licensees present in U-NII-5 and U-NII-7 are a subset of those present where the Commission has proposed to allow LPI. LPI rules will likewise protect fixed and mobile broadcast auxiliary services (BAS), Low Power Auxiliary Service (LPAS), and public safety licensees. Furthermore, the Commission can adopt technical restrictions and consumer guidance that effectively preclude the outdoor use of devices certified only for LPI operation.

14 dBm indoor and outdoor operations. The Commission can permit very-low-power operations, at radiated power levels of 14 dBm, in U-NII-5, U-NII-7, and the bottom 100 megahertz of U-NII-8, on a portable basis both indoors and outdoors, without causing harmful interference to licensed services. The interference analysis for these operations draws from the LPI operations that the Commission has already proposed, but with significantly decreased radiated emissions—and *dramatically* lower power spectral density—compensating for the lack of building loss in certain interference geometries.

The AFC framework. The Commission is also correct that standard-power access points (APs) can protect licensees using AFC. The AFC framework can ensure that RLAN devices will not operate in a way that exceeds a specified interference threshold at the FS receiver. There is already significant record support for the use of a -6 dB I/N threshold for this purpose, although FS links could also tolerate the higher interference level of 0 dB I/N that the Commission references in the NPRM, and even much higher interference levels so long as they occur only very briefly. The AFC system can perform these calculations using the specific information for each FS receiver in the Commission's ULS database combined with a reliable propagation model. An appropriate propagation model for this task is a combination of the WINNER II,

Irregular Terrain Model (plus Shuttle Radar Topography Model (SRTM), when available), and applicable ITU clutter models, depending on the distance from the FS receiver, as described in detail by the attached declaration by Dr. Vinko Erceg, a recognized expert on radiofrequency propagation.[3]

Importantly, the AFC framework can also enable portable RLAN devices to operate at standard power levels without risking harmful interference to incumbents by reusing existing rules for portable operations in other shared bands. These rules would leverage devices' abilities to pre-load channel availability data for multiple locations for greater efficiency.

Protecting BAS and LPAS operations. Although the potential for interference to BAS and LPAS licensees is already low, we propose to provide even greater protections by limiting outdoor operations to U-NII-5, U-NII-7, and the bottom 100 megahertz of U-NII-8, where, according to the FCC's database of licensees, there has been little documented investment in BAS infrastructure.

Protecting Fixed Satellite. Due to the characteristics of Fixed Satellite Service (FSS) uplinks, RLAN operations pose no risk of harmful interference to these operations, especially when compared to the high-power FS links that already operate in the band. The AFC system also can easily protect the locations and frequencies of the very small number of satellite earth stations with downlink operations in the 6 GHz band.

Pro-investment AFC rules. The Commission should promote innovation and investment by avoiding over-regulatory, command-and-control rules that unnecessarily dictate the details of AFC system implementation. Instead, AFC rules should focus on results—the Commission should adopt rigorous protection thresholds for incumbent services rather than prescribing

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3 Declaration of Dr. Vinko Erceg, attached hereto as Appendix A ("Erceg Declaration").

specific operational characteristics for an AFC. Similarly, the Commission should not require professional installation of AFC-controlled APs. Automated geolocation technologies make this highly burdensome requirement unnecessary.

Further, the Commission should allow AFC systems to apply the applicable interference protection criteria in a way that takes the height of RLAN transmitters and FS receivers into account. This will result in the efficient use of spectrum in locations and geometries where FS links will not be affected. Adopting flexible rules that permit a variety of careful AFC system implementations will provide device manufacturers with room to innovate and meet the demands of specific market segments in a targeted way—the same limited regulatory approach that has made other unlicensed bands so successful. In the same vein, AP registration, identification, and tracking requirements are unnecessary. As FS licensees themselves have pointed out, these requirements would likely offer little benefit for interference protection,[4] and they would impose significant burdens, compromise user privacy, and restrict AFC design.

U-NII-3 compatible technical rules. The Commission should adjust the power spectral density (PSD) limits to 27 dBm/MHz for standard-power AFC-controlled devices, and 21 dBm/MHz for LPI devices—still lower than U-NII-3 rules, but sufficient to allow modern modulation techniques. Additionally, the Commission should allow greater directional gain for AFC-controlled devices and facilitate point-to-point (P2P) and point-to-multipoint (P2MP) operations. Such rules have been instrumental in the U-NII-3 band for promoting use by WISPs, bringing high-speed connectivity to millions of rural Americans.

Client devices. Finally, all client devices should be allowed to operate at the same transmitted power level and power spectral density as the AP with which they are associated. The

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[4] 6 GHz NPRM ¶ 87.

current proposal of 18 dBm for client devices would create unbalanced links where APs can communicate with client devices but not the other way around, reducing the utility of the associated APs. Moreover, the Commission's proposed power spectral density limits will cripple devices' ability to use some of the most important features of new standards such as 802.11ax.

I. The Commission Should Affirm Its Decision to Enable Unlicensed Broadband Operations Throughout the Entire 6 GHz Band.

The Commission has correctly concluded both that unlicensed technologies are indispensable for American consumers and businesses and that the country's unlicensed spectrum resources are inadequate to keep up with demand.[5] Opening the 6 GHz band for unlicensed use would directly address this challenge. It would serve the public interest by expanding broadband availability, fostering innovation in next-generation technologies, and strengthening new 5G deployments. The Commission's leadership in establishing rules for the existing 2.4 GHz and 5 GHz bands initiated the world's first unlicensed technologies, provided space for extraordinary innovation and invention, and led to standards such as Wi-Fi and Bluetooth that today provide nearly ubiquitous connectivity.[6] We sit at a similar inflection point now, with the emergence of 5G technologies that use unlicensed spectrum, and a new version of the Wi-Fi standard that will allow far greater speeds, better performance in crowded areas such

5 *See id.* ¶ 4 (explaining that an "insatiable" appetite for wireless broadband connections places high demands on systems that use unlicensed spectrum and noting that the Commission has initiated several proceedings to make more unlicensed spectrum available); *id.*, Statement of Commissioner O'Rielly ("[I]t is undisputed that the exponential growth of wireless data . . . has led to severe congestion in our highly-prized unlicensed spectrum bands."); *id.*, Statement of Commissioner Carr ("Your neighbors, your family, and nearby businesses are all competing for a relatively limited amount of unlicensed spectrum."); *id.*, Statement of Commissioner Rosenworcel ("[O]ur current Wi-Fi bands are congested because they are used by more than 9 billion devices.").

6 *Id.* ¶ 3.

as stadiums and other public venues, greater battery life, and improved support for beamforming and other advanced features. Building on this success with the NPRM's proposal to make 1,200 megahertz of spectrum available for unlicensed use in the 6 GHz band would be another historic step in unleashing this next wave of unlicensed innovation.[7]

The Commission's action on the 6 GHz band comes at a critical time. The continued growth in demand for unlicensed spectrum shows no signs of slowing, but the country has not opened new frequencies to unlicensed technologies in the mid-bands for more than a decade. More consumers than ever before have access to gigabit home connections. But the nation's unlicensed spectrum inventory is typically not sufficient for gigabit wireless speeds, even though most consumers access their home broadband connections wirelessly using unlicensed spectrum. The rollout of 5G networks, the proliferation of IoT devices, and the consumer and business need for ubiquitous broadband connectivity continue to drive demand for unlicensed spectrum. Furthermore, each generation of cellular service (2G, 3G, and 4G) has offloaded more and more traffic onto Wi-Fi. 5G is projected to continue this trend, likely requiring "significant Wi-Fi capacity supportive of carrier-grade voice and video services."[8] 3GPP has also released the New Radio (NR) standard, with 5G NR being designed to operate in both unlicensed spectrum and licensed spectrum, including in the 6 GHz bands.[9] The new 802.11ax Wi-Fi standard will also allow higher speeds and, therefore, more intensive use through innovative new modulation techniques, wide channels, and other features to meet exploding consumer demand.

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7 *See id.* ¶¶ 2, 22, 59.

8 Cisco, *IEEE 802.11ax: The Sixth Generation of Wi-Fi* 2 (June 2018) ("The Sixth Generation of Wi-Fi"), https://www.cisco.com/c/dam/en/us/products/collateral/wireless/white-paper-c11-740788.pdf.

9 Yongbin Wei, *What can we do with 5G NR Spectrum Sharing that isn't possible today?*, Qualcomm (Jan. 3, 2018), https://www.qualcomm.com/news/onq/2018/01/03/what-can-we-do-5g-nr-spectrum-sharing-isnt-possible-today.

The projected growth of IoT devices and applications will likewise increase the demand for unlicensed spectrum. The Ericsson Mobility Report predicts that the number of short-range IoT devices (a category comprising devices connected by unlicensed technologies) will reach 15.7 billion by 2023.[10] 4.2 billion Bluetooth devices are projected to ship by the end of this year, with that number expected to grow to 5.2 billion annually in 2022.[11] Five hundred million Zigbee chipsets, which use IEEE 802.15.4, shipped as of mid-2018, and the Zigbee Alliance projects that 4.5 billion cumulative IEEE 802.15.4 mesh devices will be sold worldwide by 2023.[12] IoT technologies are fueled by unlicensed frequencies, and spectrum supply must keep pace with user demand for connected devices for the United States to maintain its technological leadership.

Wi-Fi's popularity and advanced capabilities also continue to increase the demand for unlicensed spectrum. Around the world, Wi-Fi speeds for mobile devices are projected to double by 2022.[13] The Cisco Visual Networking Index projects that the number of Wi-Fi deployments will continue increasing each day, with the fastest projected increase occurring in hospitals and healthcare facilities, where Wi-Fi is improving the delivery of healthcare services and increasing staff productivity.[14]

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10 Ericsson, *Ericsson Mobility Report* 16 (June 2018), https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-june-2018.pdf.

11 Bluetooth, *2018 Bluetooth Market Update* 11 (2018), *available at* https://www.bluetooth.com/markets/market-report#.

12 Zigbee Alliance, *Zigbee Alliance, Analysts Confirm Half a Billion Zigbee Chipsets Sold, Igniting IoT Innovation; Figures to Reach 3.8 Billion by 2023* (Aug. 7, 2018), https://www.zigbee.org/analysts-confirm-half-a-billion-zigbee-chipsets-sold-igniting-iot-innovation-figures-to-reach-3-8-billion-by-2023-2/.

13 Cisco, *Cisco Visual Networking Index: Forecast and Trends, 2017-2022* 20 (Nov. 2018) ("2018 VNI"), https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html.

14 *Id.* at 21.

Providing additional frequencies to allow Wi-Fi to thrive will strengthen the American economy. A recent study by Dr. Raul Katz of Columbia University estimates that in 2018, Wi-Fi generated a total of $499.09 billion of economic value in the United States. That number is expected to grow to nearly $1 trillion by 2023.[15] Unlike many other technological sectors, the unlicensed-technology industry—including chipmakers, device manufacturers, and integrators—is centered in the United States, increasing the nation's global economic competitiveness. Supporting Wi-Fi directly supports U.S. technological leadership.

Making the 6 GHz band available for unlicensed use will also allow Wi-Fi 6 to reach its full potential. Wi-Fi 6 employs new technologies to increase Wi-Fi's "ability to support high traffic loads, hyperdense deployments, and latency-sensitive services with increased spectrum efficiency, range, reliability, and security."[16] Wi-Fi 6 will be capable of operating in the 2.4, 5, and 6 GHz bands, meaning that devices can use 6 GHz quickly.[17] The availability of the 6 GHz band for unlicensed access in the U.S., as well as in Europe and other jurisdictions, will enable a "major expansion for Wi-Fi performance and capacity."[18] Wi-Fi 6 will allow APs to "support more clients in dense environments and provide a better experience for typical wireless LAN networks."[19] Wi-Fi 6 APs will control the downlink and uplink resource-unit allocation on a per-packet basis, which, combined with advanced queuing and QoS techniques, could achieve

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15 Raul Katz & Fernando Callorda, *The Economic Value of Wi-Fi: A Global View (2018 and 2023)* 33–34, Telecom Advisory Services (Oct. 2018), *available at* https://www.Wi-Fi.org/downloads-registered-guest/Economic%2BValue%2Bof%2BWi-Fi%2B2018.pdf/35675.

16 Wi-Fi Alliance, *Next Generation Wi-Fi: The Future of Connectivity* 4, (Dec. 2018) ("Next Generation Wi-Fi"), *available at* https://www.Wi-Fi.org/downloads-registered-guest/Next_generation_Wi-Fi_White_Paper_20181218.pdf/35810.

17 *Id.*

18 *Id.* at 6.

19 The Sixth Generation of Wi-Fi at 1.

similar results as licensed spectrum technologies, giving the Wi-Fi 6 network excellent multiplexing and densification capabilities.[20] ABI Research estimates that Wi-Fi 6 global annual chipset shipments will exceed 1 billion by 2022, driven by numerous factors, including growth in Wi-Fi-enabled devices, increased per-user traffic demand, greater number of users per AP, increased cellular offloading, and higher-density Wi-Fi deployments.[21] Opening 6 GHz will allow the United States to enjoy the full benefits of this new Wi-Fi standard while setting an example for other administrations around the world.

Importantly, opening the band to unlicensed use—with carefully designed rules to protect licensees—is the only way to improve intensity of use without displacing incumbents, including FS, FSS, BAS, and Cable Television Relay Service. These operations require high levels of reliability to support important public safety and critical infrastructure functions.[22] Unlicensed services operating pursuant to the Part 15 rules have a lengthy and successful track record of sharing with existing users, including highly sensitive government users. The proven Part 15 rules contain substantial measures and recourse options to protect existing licensees from interference with their current and future operations and, when combined with the additional band-specific protection mechanisms the Commission has proposed, allow coexistence with robust protections for licensees.[23] Unlicensed users must avoid causing harmful interference to licensees' operations, and unlicensed operations must accept harmful interference from new licensees,

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20 The Sixth Generation of Wi-Fi at 10.

21 Next Generation Wi-Fi at 8 (citing ABI Research, *Wi-Fi to Retain Connectivity Crown in 5G Era as Wi-Fi 6 Chipset Shipments Break 1 Billion Unit Barrier by 2022* (Nov. 20, 2018), https://www.abiresearch.com/press/Wi-Fi-retain-connectivity-crown-5g-era-Wi-Fi-6-chipset-shipments-break-1-billion-unit-barrier-2022/).

22 *See* 6 GHz NPRM ¶¶ 8–13.

23 *See* 47 C.F.R. § 15.5.

regardless of whether those licensed operations are deployed before or after the unlicensed deployment.[24] Despite these limits on unlicensed operations, this framework has supported extraordinary innovation, investment, and economic growth for more than twenty years, while protecting licensees from harmful interference.

Opening the entire 6 GHz band to new unlicensed use, rather than radically disrupting the band by introducing new licensed mobile broadband services, is prudent.[25] Because of the large number of incumbent operations, a new licensed mobile service would require the Commission to relocate incumbents. This would require the FCC to identify a suitable destination band, as well as a viable plan for compensating relocation costs and service disruption. But most incumbents in the band have stated in the record that they cannot realistically be relocated. Thus, any new operations at 6 GHz must share with existing services.[26] Unlicensed services will be able to share under a combination of proven Part 15 rules and new interference protections, avoiding the threat to 6 GHz licensees that would result from trying to squeeze new licensed services into the band. Unlicensed devices will operate in a manner that avoids harmful interference to licensed services *and* allows incumbent systems to grow organically over time. Unlicensed operators will have neither a legal basis for, nor interest in, attempting to evict licensed services.[27]

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[24] Each licensee must coordinate with other licensees before new operations are permitted. *See* 47 C.F.R. § 101.103.

[25] 6 GHz NPRM ¶¶ 14, 19–20.

[26] Comments of the Fixed Wireless Communications Coalition at 14, GN Docket No. 17-183 (filed Oct. 2, 2017); *see also* Reply Comments of Southern Company Services at 4–5, GN Docket No. 17-183 (filed Nov. 15, 2017) (explaining that "licensed mobile operations would require a plan to relocate the tens of thousands of microwave paths from this band," and there are no available bands for that purpose).

[27] *Cf.* Comments of the State of Maryland at 5, GN Docket No. 17-183 (filed Oct. 2, 2017) (reasoning that incumbent services such as FS should be considered "primary users" of the 6 GHz band and that "any new transceiver technology employed to expand wireless

Further, highly refined sharing abilities make use by unlicensed technologies the best option for safely improving spectral efficiency in the 6 GHz band. Wi-Fi, for example, has an exceptionally high spectrum use and reuse rate, because it can accommodate many concurrent users on multiple networks in the same location. Although Wi-Fi currently only has access to 600 megahertz of spectrum in the 2.4 GHz and 5 GHz bands, it carries 83% of global wireless traffic, even as it shares these bands with other technologies.[28] Unlicensed technologies therefore will maximize the economic potential of the 6 GHz band while protecting incumbent operations from interference.

Opening the 6 GHz band to unlicensed technologies also allows the Commission to comply with the Congressional requirement to expand unlicensed spectrum resources. Congress has recognized that securing additional unlicensed spectrum for wireless broadband is integral to expanded wireless broadband access. In the MOBILE NOW Act, Congress directed the Commission and NTIA to "identify a total of at least 255 megahertz of Federal and non-Federal spectrum for mobile and fixed wireless broadband use."[29] Of that amount, Congress directed that at least "100 megahertz below the frequency of 8000 megahertz . . . be identified for use on an unlicensed basis."[30] Making the 6 GHz band available for unlicensed use allows the Commission to fulfill this directive.

broadband in rural and underserved areas should operate on a secondary basis meaning that wireless broadband may not cause interference to public safety microwave paths and if interference is received by a wireless broadband station, it must accept it without remedy from the Commission").

28 Next Generation Wi-Fi at 5 (citing 2018 VNI).

29 *See* MOBILE NOW Act, Pub. L. No. 115-141, § 603(a)(1), 132 Stat. 348, 1098 (2018) (codified as amended at 47 U.S.C. § 1502).

30 *Id.* § 603(a)(2)(A).

Furthermore, the proposed rules advance the Commission's goal of improving spectral efficiency. A 6 GHz unlicensed band will allow companies to leverage existing technologies and standards. Because the band has propagation characteristics similar to the workhorse U-NII-3 band at 5.725–5.850 GHz, device makers will be well positioned to rapidly adapt existing technology for use in 6 GHz. Our companies and organizations are committed to rapidly bringing products to market to allow consumers and businesses to realize the full potential of 6 GHz. The Commission can facilitate this by promulgating rules for unlicensed use that enable low-cost, mass-market devices. Specifically, we recommend that the Commission permit LPI operations throughout the band, require standard-power devices—including portable devices—to operate using an AFC system, and permit very-low-power operations indoors and outdoors.

II. The Proposed 6 GHz RLAN Device Categories, with an Additional Category for 14 dBm Very-Low-Power Devices, Would Help Meet Urgent Demand for Unlicensed Spectrum.

Permitting RLAN operations using a variety of device classes throughout the 6 GHz band is the right approach to meeting the urgent demand for unlicensed spectrum. The Commission is correct that LPI devices will protect licensees from interference in U-NII-6 and U-NII-8. It can also safely expand these devices throughout the 6 GHz band. In U-NII-5 and U-NII-7, the Commission has correctly concluded that standard-power devices can operate without causing harmful interference under the control of an AFC system.

The proposed rules are based on sound technical analysis. In fact, both the Commission's analysis and the RKF Study submitted in this proceeding[31] are overly conservative, because they

31 RKF Engineering Services, *Frequency Sharing for Radio Local Area Networks in the 6 GHz Band* 31–32 (Jan. 2018) ("RKF Study"), *as attached to* Letter from Paul Margie, Counsel, Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and

do not account for various real-world sources of attenuation and overestimate the likelihood of an RLAN device transmitting in or near the main beam of an FS link.

In keeping with our prior analyses, we assume a very low -6 dB I/N interference protection threshold for FS receivers. That level of interference protection, which requires an interfering RLAN signal to be four times fainter than *background noise* at the FS receiver, will be more than adequate to protect FS links, even under worst-case conditions. This level of protection does not account for the significant excess margin built into FS links to compensate for weather and other sources of periodic fading, and other robustness features that will, in the vast majority of cases, render a -6 dB I/N protection threshold significantly overconservative. For example, ITU and NTIA recommended FS design criteria recommend at least 37 dB of available fade margin for an FS link.[32] Even a vulnerable link will typically have tens of dB of margin.[33] Thus, in the real world, a higher interference protection threshold of 0 dB I/N would be more than sufficient to protect FS links. Interference at a level of 0 dB I/N would only increase noise by 3 dB, which is a small fraction of the available margin of the typical link. And even in the very unlikely event that this interference were to occur at the same time as another significant fading event that consumed all available fade margin, the result would typically be only a slight reduction in link throughput.[34] This is why the RKF analysis found that RLAN operations would have no impact on FS link availability. A link designed for 99.999% reliability would virtually

Microsoft Corporation to Marlene H. Dortch, Secretary, Federal Communication Commission, GN Docket No. 17-183 (filed Jan. 26, 2018).

32 *See e.g.*, NTIA Report 05-432, *Interference Protection Criteria* tbl.4-1 (Oct. 2005).

33 Declaration of Fred Goldstein Regarding Fixed Service Operations ¶¶ 26–29, attached hereto as Appendix B ("Goldstein FS Declaration").

34 *Id.* ¶¶ 2, 29.

always continue to operate at 99.999% reliability even in the face of unconstrained RLAN interference at levels up to 36 dBm EIRP.[35]

Moreover, accounting for sources of attenuation that RKF's analysis did not consider, such as feeder and polarization losses, RKF's analysis overstated interference potential by at least 5 dB. This means that the very small interference probabilities we highlighted for a -6 dB I/N protection threshold would be even lower in the real world. The even lower probabilities for interference at the 0 dB I/N that the NPRM references would likely have been more illustrative in this respect as well. Nonetheless, we continue to assume an interference protection threshold of -6 dB I/N to be very conservative.

To effectively stimulate investment and maximize the band's potential, however, minor modifications to the proposed rules are necessary. Critically, in addition to the bands already proposed for LPI use, U-NII-5 and U-NII-7 should be opened to LPI. Without the availability of a large, contiguous band shared by at least one category of APs, maximum channel width will be unnecessarily restricted for all devices, international harmonization will be far more challenging, and valuable spectrum will go to waste.

The Commission also should adopt its proposals to authorize standard-power operations under AFC control in U-NII-5 and U-NII-7. In addition, the Commission should allow standard-power operations under AFC control in one additional frequency range not proposed in the NPRM: the bottom 100 megahertz of U-NII-8, which will allow for the formation of wider standard-power channels.

The Commission should also authorize a class of 14 dBm very-low-power APs in U-NII-5, U-NII-7, and the bottom 100 megahertz of U-NII-8, indoors and outdoors. At such low

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[35] RKF Study at 53–54.

power, there is no meaningful risk of harmful interference to high-power FS links, which will virtually always be located high above where any RLAN devices, especially outdoor devices, are used.

Finally, the Commission should adjust its proposed power and PSD rules. For client devices, it should adopt power levels that allow them to make full use of the power levels proposed for APs. The proposed across-the-board power limit of only 18 dBm would result in unbalanced links, with significantly reduced range and throughput. For APs, the highly restrictive power spectral density limits that the Commission has proposed will cripple devices' ability to take advantage of some of the most important features of 802.11ax and, in all likelihood, other future wireless standards.

A. The Commission Should Allow LPI Operations Throughout the 6 GHz Band.

As the NPRM correctly concludes, unlicensed operations at sharply limited power levels "would protect incumbent licensed services, while creating new unlicensed use opportunities."[36] The Commission proposes to permit such operations without AFC because this restrictive mechanism is justified only for standard-power devices. As the NPRM observes, LPI devices will play an important role in supporting the country's connectivity needs. They will "support high throughput and low latency applications for residences and businesses" which "could include augmented or virtual reality, in-home video distribution at 4K/8K levels, and IoT applications."[37] Despite these conclusions, the Commission proposed to permit LPI only in the U-NII-6 and U-NII-8 sub-bands, which make up only 350 megahertz of the total 1,200 megahertz available, while asking whether to allow such operations in U-NII-5 and U-NII-7.

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[36] 6 GHz NPRM ¶ 59.

[37] *Id.*

LPI devices should be permitted in U-NII-5 and U-NII-7. These devices will protect incumbent operations in these sub-bands for the same reasons that they will protect incumbents in U-NII-6 and U-NII-8. In fact, each type of licensed user that LPI would have to protect in U-NII-5 and U-NII-7 is also present in U-NII-6 and U-NII-8, making the conclusion that LPI devices can protect incumbents equally applicable to U-NII-5 and U-NII-7. There is therefore no technical reason to drastically limit LPI operations.

Band-wide operation of LPI devices is crucial to our companies' abilities to make the 6 GHz band a success. In addition to important use cases that the Commission identified in the NPRM, allowing LPI operations throughout 6 GHz is of fundamental importance to the band's utility. First, a checkerboard approach where LPI operation is only permitted in every other 6 GHz U-NII band will severely limit the efficient use of spectrum by limiting channel sizes and barring the use of channels that only partially overlap with one of the proposed 6 GHz U-NII sub-bands. Second, other jurisdictions may take a more limited approach to improving intensity of use of the 6 GHz band and allow *only* LPI operations—due to, e.g., the lack of a centralized database of licensees to support AFC capabilities—potentially forcing U.S. manufacturers to face a challenging patchwork of international spectrum availability. Finally, LPI operations throughout the band would put this spectrum into consumers' hands much sooner, allowing marketing and sale of devices that take advantage of the full 6 GHz band while AFC systems are in development to support standard-power operations.

1. LPI operations can protect licensed services in U-NII-5 and U-NII-7 for the same reasons they can do so in U-NII-6 and U-NII-8.

U-NII-5 and U-NII-7—the bands where the Commission has not yet proposed to permit LPI operations—are primarily used by terrestrial FS P2P links and FSS uplink transmissions. Notably, these operations are also present in the U-NII-6 and U-NII-8 bands where the

Commission has proposed to allow LPI operations and has concluded that the combination of low-power and indoor-only operational restrictions will protect incumbents from harmful interference. LPI operations will protect FS and FSS incumbents and can do so throughout the 6 GHz band—in addition to the other classes of incumbents found in U-NII-6 and U-NII-8.

2. *LPI operations will protect FS links.*

The RKF Study demonstrated that the nationwide operation of standard-power RLAN devices operating indoors and outdoors, without any additional sharing mechanisms, would result in less than 0.2% of FS links receiving sufficient energy to even conceivably cause measurable interference to a receiver—i.e., exceeding a conservative -6 dB I/N interference threshold. At a threshold of 0 dB I/N, RKF found a still lower rate of 0.1%. In the real world, the probability of a link's receiving even this minimal level of energy would be lower still. Moreover, even these results exaggerate the likelihood of real-world interference because RKF did not account for important sources of attenuation such as polarization mismatch and feeder loss or common robustness features routinely included in FS link designs such as spatial diversity, cross-polarization, adaptive modulation, and forward error correction.[38] The analysis also assumed not only indoor but also outdoor operations and included outdoor transmissions up to 35.3 dBm (approximately 4 Watts)—which would not be present when considering LPI.

LPI operations would result in far less interference impact on FS than even the small impact shown by RKF because LPI devices would be subject to substantial building loss (i.e., they operate only indoors) and sharply limited radiated power (i.e., they would operate at a maximum of only one Watt (30 dBm) radiated power).

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38 *See, e.g.*, Goldstein FS Declaration ¶¶ 32, 35–36.

Another significant factor leading to the small impact caused by RLANs to FS links is the protective impact of the complementary geometries of FS links and RLAN operations. LPI devices will overwhelmingly be used either near ground level or within a structure that will shield outside receivers from potential interference. Fixed links, on the other hand, are mounted on towers or other structures and pointed away from buildings, which would obstruct transmissions between transmitter and receiver.[39] According to registration data in the Commission's ULS database, the average FS receiver height is 43 meters above ground level, approximately the height of a fourteen-story building. Eighty percent are higher than 18 meters, approximately the height of a six-story building. The most commonly used six-foot FS antennas exhibit off-axis gain at least 35 dB below peak at ten degrees from the center of the main beam and more than 10 dB below peak at only two degrees from the center, meaning that off-axis interfering RLAN signals will be received at much lower power levels than the desired FS signal, transmitted directly towards the boresight of the FS receiver.[40] (Many perform much better. A twelve-foot UHX antenna, for example, exhibits approximately 30 dB less than peak gain at only *two* degrees from the center).[41]

These factors—elevation mismatch and building attenuation—combine to make the risk of harmful interference from LPI devices exceedingly remote. Near the FS receiver, the narrow beamwidth combined with significant height means that any RLAN transmitter on or near the ground will be tens of degrees from the center of the FS receiver main beam. To be within two

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[39] *Id.* ¶ 7.

[40] Letter from Apple Inc., Broadcom, Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183, at 9 (filed May 14, 2018) ("FS Response").

[41] *Id*.

degrees of the center, assuming the average FS height of 43 meters, for example, an RLAN operating in a typical two-story home (i.e., a height of 4.5 meters) would have to be more than 1.2 kilometers away from the receiver. At this distance, the receiver would experience propagation loss of 121 dB even assuming WINNER II *line-of-sight* conditions. Real world loss, taking into account building loss, clutter, terrain, and other factors, would be far greater still. A device at the same height twenty degrees from the center of the main beam would be significantly closer—113 meters—but would be received with 47 dB less gain compared to the desired FS signal as a result of the directionality of the typical FS antenna. It would also be subject to approximately 95 dB propagation loss in addition to the other sources of very significant real-world attenuation described above. In either case, there is extremely little chance of harmful interference, especially when the RLAN device is indoors and operating at low power. Additionally, links over 10 kilometers—links where the risk of harmful interference could be increased due to the potentially faint FS signal—require that antennas be raised even higher to account for the curvature of the earth. Therefore, the longer the link, the greater the elevation difference between FS and most RLAN systems.

The only situation in which this geometric analysis might not apply would be when a building is located within the main beam of an FS receiver, unshielded by terrain or other buildings between the FS transmitter and receiver. This would be a highly unusual case because the presence of such a building could itself seriously disrupt performance of the link, making such configuration rare within the universe of properly engineered FS paths.[42]

Notably, RKF's analysis did not take this tendency of FS link designers to avoid buildings into account and instead assumed that that the locations of RLAN transmitters and FS

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42 Goldstein FS Declaration ¶¶ 7, 11–12.

links were independent. In other words, the odds of an RLAN device transmitting at a given location were considered the same regardless of whether that location happened to be within the main beam of an FS link. This simplifying assumption means that the very small impact reported by the RKF analysis significantly overstates the potential for harmful interference from indoor devices. In the real world, RLAN devices are less likely to transmit in a building within the main beam of an FS link because FS link designers avoid designing links that pass near buildings.[43]

This is a notable factor in link design because, in addition to blocking FS signal directly, an obstacle such as a high-rise building within the main beam of an FS link could significantly reduce performance even if it does not directly obstruct it. Engineers designing FS links must also avoid obstructions within the link's Fresnel Zone, an ellipsoidal area around the centerline of the link.[44] Within the Fresnel Zone, a portion of the transmitted signal may reflect off an obstruction, causing it to be received at the receiver antenna when it otherwise would not have been, but with a delay relative to the desired signal. This delay causes that stray portion of the signal to be out of phase with transmissions that were not reflected, meaning that the "peaks" of that component of the signal may arrive at the same time as the "troughs" of the non-reflected signal. This can cause the reflected signal to partially cancel out energy in the non-reflected signal, weakening the net received signal—a phenomenon called destructive interference.[45] Moreover, FS engineers clear an area even wider than the Fresnel Zone as a best practice. This is in part because areas with existing tall structures are more likely to experience further such

43 *Id*.

44 *Id.* ¶ 11.

45 Engineers distinguish between multiple Fresnel zones, which are differentiated by their distance from the center line of a FS link—i.e., the first Fresnel zone, second Fresnel zone, third Fresnel zone, etc. Obstructions within these different Fresnel zones hold distinct risks of weakening the received signal.

construction in the future, and because there is a chance of destructive interference even beyond the Fresnel Zone due to high amplitude reflections anywhere inside the main beam.

In the rare situation where, despite all of the factors described above, an LPI device operates within a tall building located in or near the main beam of an FS link, a number of other factors will still prevent any harmful interference to the licensee. First, RLAN devices operating in a building are rarely installed in ways that cause them to radiate significant energy towards windows. Consumer APs are typically placed on tables or in unobtrusive locations next to or under furniture, with energy directed upwards and outwards from integrated antennas. In enterprise deployments, APs are often professionally installed in ceilings, with antennas that radiate energy down towards the floor, not horizontally out a window. Thus, even in this scenario, the only RLAN devices of concern will generally be those installed in highly unusual ways that waste energy by radiating it out a window.

A second factor that reduces the possibility of harmful interference is building loss. Buildings generally exhibit a range of values for building entry loss. But, importantly, high-rise buildings that would be involved in the unusual corner case of an RLAN operating near the same elevation as an FS link are generally energy-efficient constructions characterized by at least 30 dB of building loss.[46]

High-rise construction requires the use of dense, radio-opaque structural materials such as steel and concrete, and energy efficiency standards have long required the use of metal-coated, low-emissivity (low-E) glass and thick layers of insulation, which are nearly opaque to 6 GHz signals.[47] Moreover, regulations are constantly updated to require ever greater degrees of thermal

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46 Building and Vehicle Attenuation at E-2–E-4, attached hereto as Appendix E ("BEL Analysis").

47 BEL Analysis at E-1–E-4.

efficiency, further increasing building loss.[48] Even in buildings that were built before these energy efficiency standards went into effect, local regulations or consumer demand typically have long since driven building owners to retrofit their properties with new thermally efficient windows, additional insulation, and other materials.[49] Therefore, even transmissions from a device positioned immediately next to a window in a high-rise building are subject to significant attenuation.[50] Builders are keenly aware of this issue, which has driven significant new work to include distributed antenna systems, small cells, and other technologies within high-rise buildings to facilitate in-building reception of mobile wireless service by licensed carriers.[51]

Because RKF studied the potential for interference from *any* RLAN device, not just those operating in the kind of building that could place them at the elevation of an FS link, it assumed that only 20% of buildings would be thermally efficient.[52] RKF noted that this was a conservative assumption even as applied to all RLAN devices.[53] But it is simply unrealistic as applied to the restricted LPI use case, where the only devices operating in or near the main beam of an FS link in any reasonable proximity to the FS receiver will be located within high-rise buildings. For these buildings, the percentage that use thermally efficient materials is closer to 100%,[54] greatly reducing the already low risk of harmful interference. In addition, in the event that a high-rise is

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[48] *Id*. at 3.

[49] *Id.*

[50] *Id.* at 3–4. Extremely few high-rise buildings have balconies. In the rare case that a building does have a balcony, there is no reason to expect that consumers will operate an LPI AP outside, where it would be exposed to the elements, be challenging to plug into mains power, and be on the opposite side of a panel of low-E glass from the living areas where RLAN devices are most commonly used.

[51] BEL Analysis at E-5.

[52] RKF Study at 31–32.

[53] *Id*.

[54] BEL Analysis at E-4.

constructed after a microwave path has been cleared, that new building will have been constructed in compliance with current building codes that require use of thermally efficient materials.[55]

In addition to their building materials, approximately half of high-rise buildings are commercial, rather than residential buildings.[56] This means that, in addition to the significant building-entry loss caused by thermally efficient construction or retrofitting, the 6 GHz RLAN APs deployed in these structures will generally be enterprise-grade, and professionally installed. They will therefore typically be ceiling-mounted, with downward pointing antennas, resulting in even less energy radiated towards walls and windows.[57] In fact, for a typical down-tilted enterprise AP, antenna gain at zero degrees elevation—i.e., directly to the sides of the downward-pointing AP—is between zero and -5 dBi.[58] In addition, when considering all possible angles of incidence at an FS receiver from an LPI AP, it is important to note that the vast majority also exhibit pattern mismatch. This RLAN antenna pattern mismatch loss is an independent variable in the interference link budget, and averages 6 dB.[59]

Finally, RKF's analysis did not consider other factors that would reduce the risk of harmful interference even further. For example, it did not include polarization mismatch loss, which would contribute an additional 3 dB attenuation, antenna pattern mismatch loss, which would contribute another 5 dB attenuation, or feeder and other system loss of at least 3 dB. In

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55 *Id*.

56 *Id*.

57 Characteristics of Enterprise Deployments Using IEEE 802.11 Equipment: Joint Declaration of Matt MacPherson, Chuck Lucaszewski, and Sundar Sankaran ¶¶ 11, 14–15, attached hereto as Appendix D.

58 *Id*.

59 *Id*. ¶ 14.

addition, because it was designed to quantify the baseline risk for standard-power operations without AFC, not to examine the specific case of LPI operations, the RKF study included devices operating at higher power levels and included devices operating outdoors with the simulated population.

In addition, in the real world there is only a small probability that a given LPI transmission will overlap perfectly with an FS signal, meaning that the received power level would be reduced still further in the typical case to account for only partial overlap between the two signals. In total, therefore, the additional sources of loss present in the unusual situation where an LPI device would be at a similar elevation as an FS link dramatically reduce the risk of harmful interference far below the already very low risk described in the RKF Study.[60]

To further confirm these results, we have performed an analysis of the interference levels that an LPI device would cause at an FS receiver, assuming that the RLAN device is *directly in front of the FS receiver* at ground level at distances up to 4 kilometers. This analysis assumes a conducted power of 24 dBm and an average antenna gain of 0 dBi, consistent with typical real-world antenna patterns.[61] It also assumes that the FS receiver is at the average height of 43 meters in addition to a typical RLAN transmitter height of 4.5 meters—the typical height of a device on the second floor of a single family home—a conservative 20 dB building loss, 3 dB feeder and other system loss, 2 dB loss to account for the typical combined efficiency of RLAN

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60 *See* RKF Study at 48.

61 It is important to emphasize that this does not mean that RLAN LPI radiated power limits may be reduced from the proposed 30 dBm to 24 dBm without adverse effects. The 0 dB antenna gain figure assumes, consistent with the discussion above, peak gain of greater than 0 dB in particular directions, but with an average of 0 dB in any single directions. Thus, if the radiated power limit of an LPI device were reduced to 24 dB, the average radiated power in all directions would be lower still.

antennas,[62] and 3 dB polarization mismatch loss. It also accounts for the fact that the typical RLAN channel is substantially wider than the typical FS bandwidth, meaning that only a fraction of the energy emitted by the RLAN device would be received as interference in the FS receiver's band of operation. Specifically, this analysis conservatively assumes an FS bandwidth of 30 MHz and an RLAN bandwidth of 160 MHz.

Using the WINNER II non-line-of-sight (NLOS) model that is most appropriate for this situation,[63] and accounting for a variety of standard antenna patterns, worst-case interference was less than -35 dB I/N. This is far below the levels that could cause harmful interference. The complete results of this analysis are depicted below, and clearly illustrate the complementary roles of geometry and FS antenna patterns in preventing harmful interference in this use case. Notably, beyond distances of 2.5 km, the main beam of these simulated receivers will have reached the ground. In the real world, however, it is unlikely for the FS main beam to reach buildings at ground level without obstructions, making this a worst-case analysis in this respect as well.

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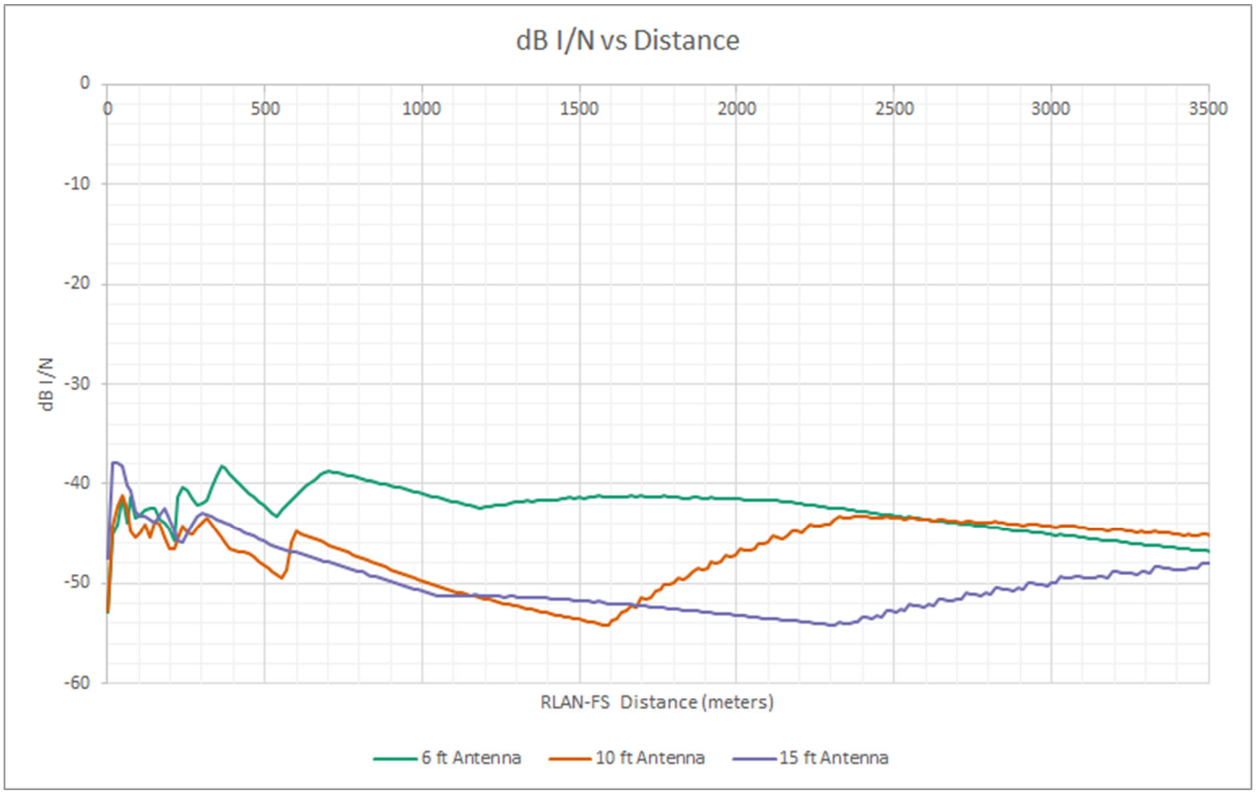
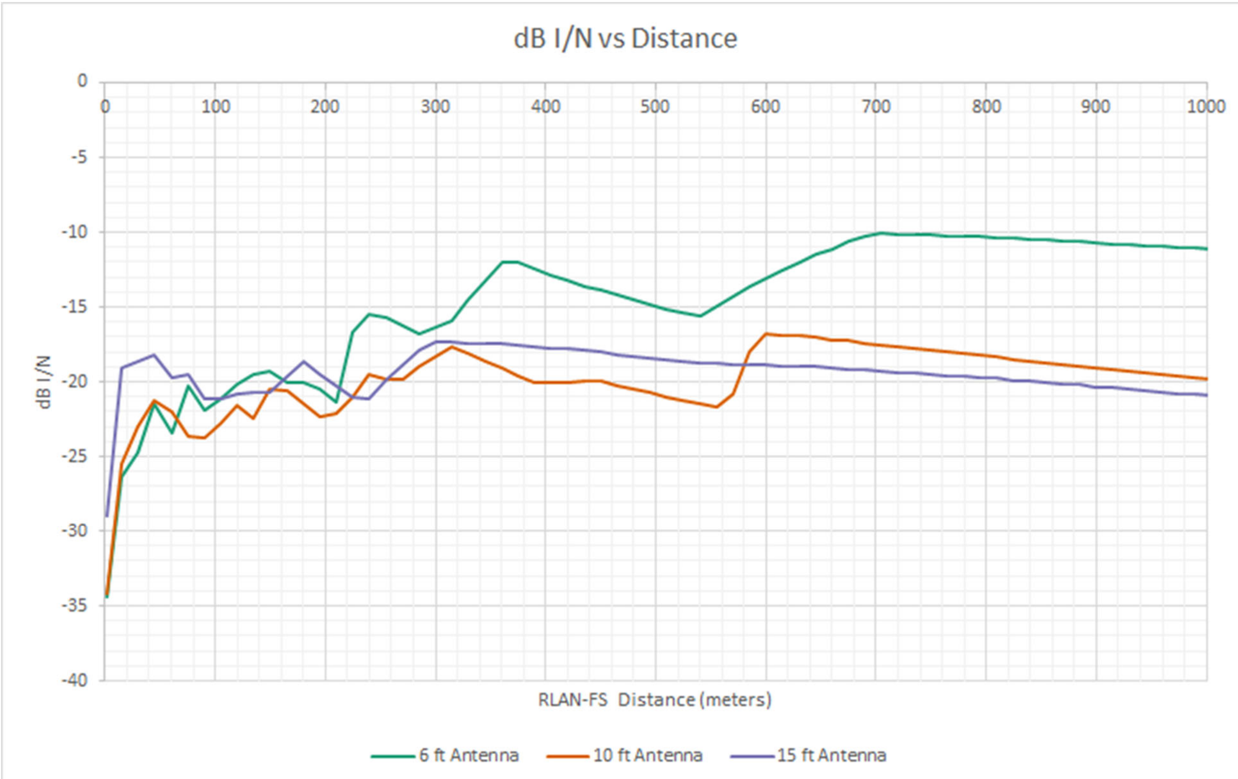
62 *See* Comments of Broadcom Inc. at 14–15, ET Docket No. 18-295, GN Docket No. 17-183 (filed Feb. 15, 2019).

63 Erceg Declaration.



We also considered shorter-range interference morphologies between at distances of up to 1 kilometer where the WINNER II's line-of-sight (LOS) model would be more likely to apply in the worst case. However, even assuming LOS conditions, absolute worst-case interference reached only -10 dB I/N—and, again, only at one specific distance for only certain antennas. Therefore, for both of these cases—LOS and NLOS—even assuming the rare situation of an RLAN device perfectly aligned in azimuth with the FS receiver, interference will always be well below both -6 dB I/N and 0 dB I/N. This means that none of these cases would result in harmful interference to incumbents even setting aside the role of excess fade margin and other robustness features built into FS links.



3. *LPI restrictions will also protect other existing 6 GHz operations including mobile BAS and indoor LPAS.*

Mobile BAS and indoor LPAS licensees operate in U-NII-6 and U-NII-8. The Commission correctly concluded that LPI devices can share these bands with BAS and LPAS as well as FS, as described above, without causing harmful interference.

The LPI/BAS sharing situation is similar to LPI/FS sharing. Although BAS operations may be classified as mobile, they typically take the form of a temporary one-way P2P link between a remote user, such as a news truck, and a central receive site located on a broadcast tower or a tall building rooftop. Accordingly, many of the same factors that cause a low risk of harmful interference to FS links also apply to BAS. The primary, limited difference is that one end of the BAS link is typically less elevated than the average FS radio, because it is often mounted on a truck or other vehicle. In order to quantify the effect of this difference in

morphologies, RKF undertook a separate study to assess the risk of harmful interference between BAS links and RLAN transmitters—not only LPI devices, but *all* classes of RLANs, including outdoor standard-power operations. Even then, it found that RLAN operations would present a risk of harmful interference only in rare circumstances. In these few cases, it concluded that the BAS operator could mitigate any interference that it experienced in the same way that such operators resolve occasional reception issues today—simply by slightly adjusting the location of the mobile BAS truck.[64] In the real world, this would have no material effect on BAS operations because BAS operators already locate their mobile stations to maximize the quality of their links. The theoretical potential for RLAN interference in rare cases would, in fact, never mature into actual harmful interference because BAS operators would not operate their trucks in locations where such interference is possible when alternatives are so readily available.[65]

Finally, LPAS is typically used in closed venues and at specific events where the radiofrequency environment can be centrally managed. The venue owner can choose to operate LPAS devices on different frequencies than those being used by RLAN devices. This is especially true with respect to LPI devices because they will only operate indoors, giving property owners even greater control.

4. *Commission rules can effectively prohibit outdoor use of devices certified only for LPI operation.*

The Commission has a number of tools at its disposal to ensure that LPI devices are not used outdoors in contravention of FCC rules. Initially, it is important to recognize that historical

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64 *See, e.g.*, National Spectrum Management Association, Recommendation WG 03.17.001, *Fixed Service Frequency Coordination in the Broadcast Auxiliary Service and Cable Television Relay Service Bands of 6875-7125 MHz and 12700-131500 MHz*, Appendix 4, https://nsma.org/wp-content/uploads/2015/04/nsma-recommendation-wg0317001-fixed-service-frequency-coordination.pdf.

65 *See* RKF Study at 8.

concerns involving users placing indoor devices in aftermarket outdoor enclosures are unlikely to be relevant today. The current cost difference between an indoor and an outdoor AP is much lower than in the early days of the RLAN industry. This trend will continue in the 6 GHz band. The cost of suitable enclosures to weatherproof a device intended for indoor use—called "NEMA enclosures"—is now more than the marginal cost of an outdoor RLAN device versus an indoor device. A high-quality NEMA enclosure suitable for protecting an RLAN AP can easily cost more than $100. But the NEMA enclosure cost pales in comparison to the labor and materials necessary to install it. Enclosures require power and network backhaul through weather protected conduit. Many enclosures include fans or heaters for temperature control, necessitating separate conduits for AC and low-voltage data cable. Also, NEMA enclosures virtually always require external antennas to be mounted outside the box, with specialized low-loss coaxial cable "pigtails" that must be specially weatherproofed.

In addition, lower-cost indoor devices will often lack important features designed to facilitate outdoor deployment. For example, they may not support power-over-Ethernet, requiring them to somehow be connected to AC power despite being exposed to rain and other elements. Moreover, while the initial purchasing cost for outdoor devices may be somewhat higher than for indoor, buyers typically focus on total lifecycle cost, and outdoor devices have been engineered to reduce lifecycle cost in that environment.

Given the ready availability of all-weather RLAN APs intended for outdoor use, the lower lifecycle cost of these devices, and the shrinking difference between the initial purchase prices of indoor and outdoor devices (especially considering the cost of purchasing and installing a NEMA enclosure), there will be little or no reason for a consumer to intentionally circumvent the Commission's indoor-only restriction. If, however, the Commission determines that

additional steps to prevent such behavior are necessary, it could prohibit the use of connectorized antennas on LPI devices. Outdoor deployments typically rely on directional antennas to cover specific areas, such as loading docks, parking lots, and public gathering areas. By prohibiting connectorized antennas on LPI devices, for which there would rarely be any legitimate need, the Commission would further limit the already small risk of LPI devices being used outdoors.

The Commission could further address this possibility by issuing device-certification guidance to prevent equipment from being marketed for improper uses and to deter misuse by end users. For example, it could require that LPI APs operate only when connected to mains power, preventing use in a battery-powered mode that would facilitate unauthorized outdoor operations. In so doing, the Commission must take care not to prohibit legitimate use of DC power-over-ethernet by bona fide indoor devices, which is common for indoor enterprise deployments. This restriction, if the Commission adopts it, should generally require the use of mains power, and not specifically require connection to an AC wall outlet.

The Commission could also prohibit inappropriate marketing of LPI devices as suitable for outdoor use, or require "indoor use only" labeling—in either physical or electronic form—to ensure that consumers are aware of this restriction. Provided consumers are suitably warned, the Commission also could consider penalties for inappropriate outdoor use of a device certified only for indoor use.

A professional installation requirement for LPI devices would not be an appropriate way to ensure that these devices remain indoors. As the Commission has recognized, a number of the key applications for 6 GHz LPI devices would be for consumer electronics. A requirement to hire a professional installer to set up a next-generation game console, 8K television, or Wi-Fi 6

AP would be radically inconsistent with consumers' expectations for these types of devices. Such over-regulation would be costly, unnecessary, and inefficient and should be avoided.

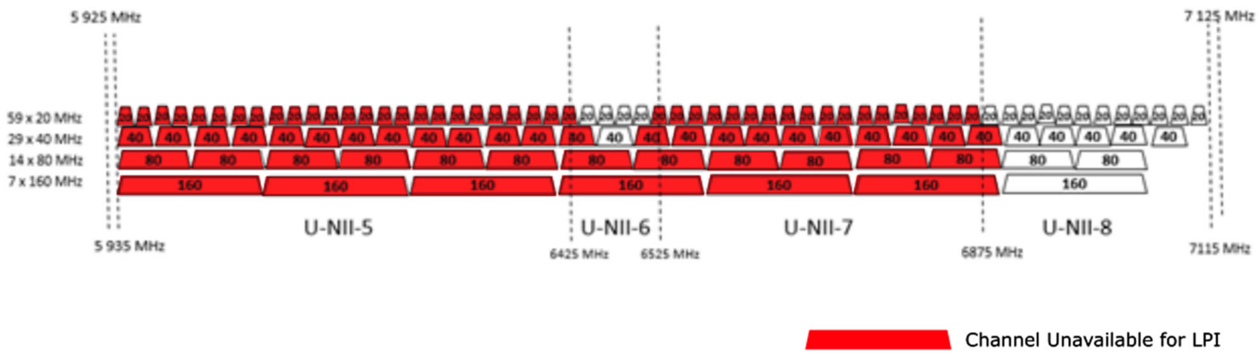
5. *Allowing LPI throughout the band will produce significant public interest benefits.*

Some parties have called for requiring the use of AFC in U-NII-5 and U-NII-7 for *all* devices, even for LPI devices for which it is unnecessary. The Commission should reject this proposal, which would delay or reduce investment in the entire 6 GHz band, sharply diminish the amount of usable spectrum, and risk creating a fractured international regulatory regime that undermines economies of scale.

Development of an AFC will take time. A simple, straightforward AFC will allow commercialization of AFC-controlled devices on a shorter timescale and at lower cost than previous database-controlled spectrum sharing systems in other bands. Nevertheless, the technical development and regulatory validation of an AFC system will likely require a significant period of time before consumers can begin enjoying the benefits of AFC-controlled devices. LPI devices that are not subject to AFC, however, could be ready for consumers on a much faster timeline, potentially coming to market within a few months of the Commission's finalizing the applicable rules, potentially in time for the second "wave" of Wi-Fi 6 devices expected in 2020.

A checkerboard approach to the 6 GHz band, in which LPI devices can only operate on a fraction of those frequencies, will greatly reduce the total amount of usable spectrum for LPI operations to a level that will substantially undermine the overall value of the band. First, standards-based RLAN operations will generally follow channel plans set by international standards bodies for global use. The Wi-Fi standard, for example, includes channels ranging in size from 20 to 160 megahertz wide, with wider channels facilitating higher speeds. But with a checkerboard band plan, LPI devices may not have access to channels that cross regulatory

boundaries, meaning that the amount of usable spectrum available for devices operating under the LPI rules will be even less than the limited range contained in U-NII-6 and U-NII-8. Although industry has not yet selected a final 6 GHz band plan, the potential band plan below illustrates the risks of a checkerboard approach—only a single 160-megahertz channel would be available for LPI devices, and two others would straddle sub-bands.



Moreover, this problem disproportionately affects the very devices and applications that the Commission most hopes to promote: next-generation technologies that require access to wider channels, because wider channels have a higher probability of falling across one of the band edges. Under the Commission's proposed band plan, with AFC required in U-NII-5 and U-NII-7 and operations restricted to LPI in U-NII-6 and U-NII-8, there will likely be only one 160-megahertz channel available for LPI, band-wide. This inefficient result would fall far short of the transformative potential of broadband RLAN use in 6 GHz that the NPRM envisions.

Finally, the Commission's rules should allow U.S. companies to take advantage of worldwide economies of scale through globally harmonized rules. Although standard-power capabilities under AFC control will ultimately be critical in the U.S. market, other international markets may not approve use of these devices initially, largely because they do not have detailed databases like ULS upon which AFC protections can be based. Some jurisdictions, for example,

are considering authorizing only LPI operations in U-NII-5 in the near term. If this occurs, and the Commission retains its proposed checkerboard approach, manufacturers seeking to market an AP globally before an AFC implementation is certified will face complex design and marketing challenges in order to reach a worldwide market, raising costs through diminished economies of scale or an increased bill of materials.

Complicating matters further, standards bodies may adopt separate band plans if the FCC adopts the checkerboard approach: one for the U.S. and a second for global markets that offer more flexibility for LPI. This would confine the costs and limitations of a checkerboard band plan in the U.S., but would increase costs for consumers.

B. The Commission Should Permit 14 dBm Very-Low-Power Operations in the 6 GHz Band Without AFC Control, Both Indoors and Outdoors, for Short-Range Services.

Operation of LPI devices without AFC control will present no significant risk of harmful interference to licensees. These devices are sufficiently low power that a combination of building attenuation, losses associated with usage and propagation conditions, and the sidelobe rejection of FS receivers makes the risk of harmful interference negligible. Similar characteristics would allow devices operating indoors or outdoors at even lower power levels to operate in the 6 GHz band without a real-world risk of harmful interference to incumbents. Operation of extremely faint 14 dBm EIRP unlicensed devices in the 6 GHz band, indoors or outdoors, without AFC should therefore be permitted. This is a tenth of the radiated power that the Commission itself proposed for client devices.

This forward-looking action would spur innovation and produce important benefits for consumers. Innovators would gain access to flexible new use cases in the 6 GHz band at even lower cost and with even greater flexibility than standard-power AFC-controlled devices or LPI devices. A 14-dBm EIRP very-low-power device class would provide an important complement

to the two device classes proposed in the NPRM by fully replicating the flexibility available in the 5 GHz U-NII-3 band—but at far lower allowed-power levels to account for incumbent operations. A 14 dBm device will allow specialized, but important, applications. While a single such device could not provide whole-home Wi-Fi coverage, it would fill a gap for short-range connectivity between devices such as game console controllers, hearing aids, headphones, or keyboards. It would also allow AR/VR applications to go mobile, by allowing headsets to connect to portable devices.

With a power limit of 14 dBm, the harmful interference risk to licensees is vanishingly small. For a common six-foot UHX antenna, at the average FS receiver height of 43 meters, a device would only appear within this narrow zone if it were 1.2 kilometers away. In this case, propagation loss will exceed 151 dB which, after accounting for other real-world sources of attenuation such as feeder loss and polarization mismatch loss, this means that the RLAN signal for a typical portable device would be received at the FS receiver at a mere -133 dBm, 38 dB below the noise floor of the FS receiver—or -38 dB I/N.[66]

At longer distances, an RLAN device could theoretically be closer to the boresight of the FS receiver, but this would be offset by the increase in propagation loss. At a range of 3.5 kilometers, for example, an RLAN device could be only 0.7 degrees from the center of the main beam of an FS receiver (assuming that it is similarly aligned to the receiver in azimuth). But at this range, propagation loss will exceed 167 dB. The result is that, despite being near the

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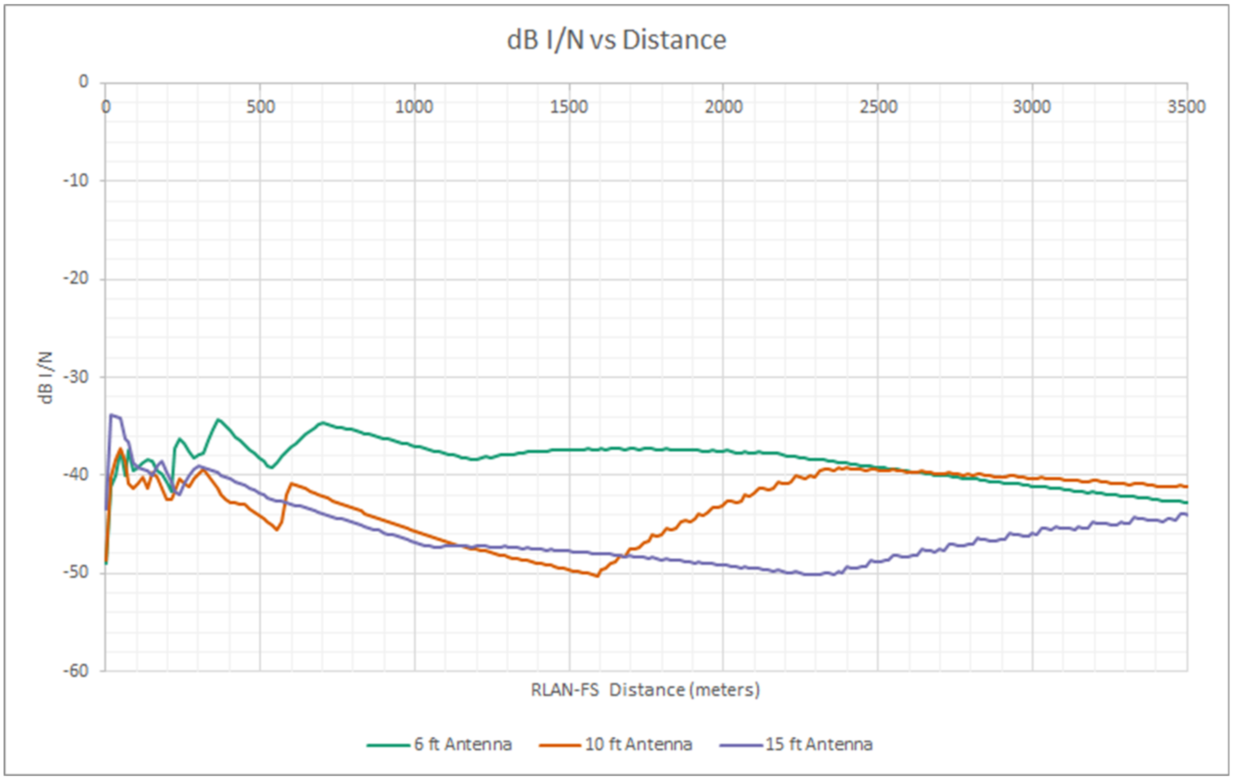
66 This also assumes a 160-megahertz RLAN signal which fully overlaps a 30-megahertz FS channel, an average FS height of 43 meters, an FS receiver using a very common six-foot UHX antenna, an RLAN device height of 1.5 meters, 3 dB feeder and other system loss, 4 dB body loss, 3 dB polarization mismatch loss, and *zero* building entry loss. Ranges less than 1 kilometer conservatively assume WINNER II line-of-sight propagation conditions. For longer distances, NLOS conditions apply.

boresight, such an RLAN device would only produce -137 dBm of interference at the FS receiver, 43 dB below the noise floor of the FS receiver—or -43 dB I/N.

At much shorter distances, the opposite situation occurs. At a distance of 200 m, for example, line-of-sight propagation loss would be only 101 dB, but the signal would also be subject to 3 dB *rejection* (i.e., negative gain) at the FS receiver's antenna (more than 40 dB less gain than the desired FS signal). Otherwise using the same assumptions as above, this results in an interfering RLAN signal of only -111 dBm, 17 dB below the noise floor of the FS receiver—or -17 dB I/N.

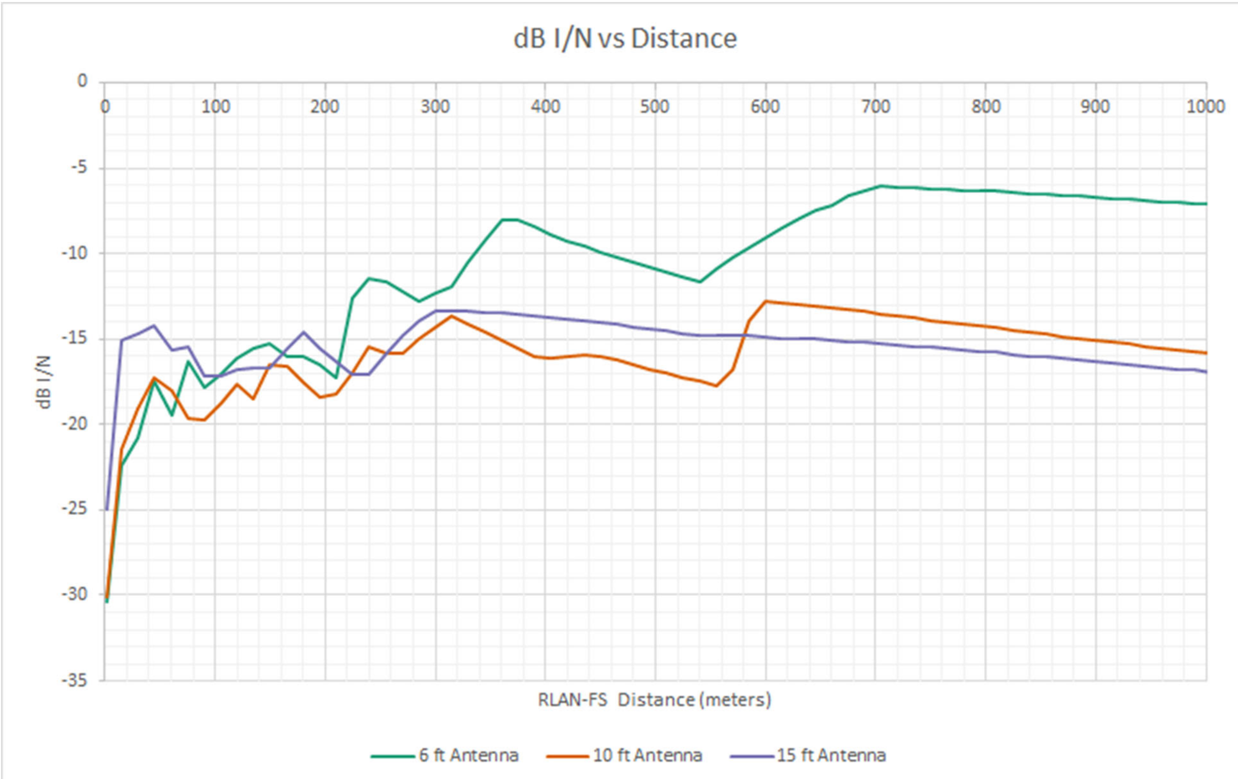
These scenarios are unusual in that they make the absolute worst-case assumption that an RLAN device is directly aligned in azimuth with the FS receiver boresight. Moreover, this analysis omits all building loss. Nonetheless, although it represents only a small corner case, we have performed a comprehensive analysis of the interference risk to an FS receiver of a 14-dBm very-low-power RLAN device operating outdoors by repeating the analyses across the full range of angles with respect to the FS receiver, otherwise using the same assumptions as those described above.[67] Under these conditions, the maximum interference at the FS receiver would be less than -30 dB I/N, far below any reasonable threshold for harmful interference. The full results of this analysis are illustrated below:

67 *See supra* p. 36.



In fact, even assuming worst-case WINNER II *line of sight* propagation model conditions yields, using the same assumptions as those described above,[68] a maximum interference level of -6.1 dB I/N, below any reasonable harmful interference threshold, and only for a tiny range of distances. As in the LPI analysis above, even assuming the rare situation of an RLAN device perfectly aligned in azimuth with the FS receiver, interference will always be below both -6 dB I/N and 0 dB I/N in both LOS and NLOS cases. This means that none of these cases would result in cause harmful interference to incumbents even without considering fade margin, diversity, and other robustness features built into FS links.

68 *Id.*



C. The Commission Should Authorize a Robust but Flexible AFC System to Govern Standard-Power APs.

The Commission has proposed to implement an AFC system to protect FS incumbents operating in the 6 GHz bands from harmful interference from standard-power APs. AFC would be analogous to the existing process of manual coordination for new operations in the band.[69] Automation, however, would allow far more efficient use of the band and new levels of sophistication to facilitate sharing with RLAN transmitters under a wide range of conditions. The Commission correctly concluded that AFC will protect FS operations in the U-NII-5 and U-NII-7 bands. However, the Commission should also permit AFC-controlled devices in the lowest 100 megahertz of U-NII-8—allowing the formation of an additional 160-megahertz channel with

[69] 6 GHz NPRM ¶ 23.

spectrum in U-NII-7 while providing belt-and-suspenders protection for BAS and other mobile licensees. The Commission should also affirm its determination that AFC is not needed to protect FSS uplink operations from harmful interference. For the tiny number of earth stations with 6 GHz downlinks, the AFC framework can readily provide the needed interference protection.

Furthermore, FCC rules should allow flexibility in the design of AFC implementations. The Commission should establish rigorous protection thresholds and performance criteria, but should avoid prescriptive regulations about, for example, the specific type of geolocation data the AFC should receive, whether protection calculations may take into account RLAN device height, whether the AFC will specify RLAN operation on a channel-by-channel basis or by identifying specific frequencies, or other implementation details. Similarly, the Commission should not regulate details of AFC system architectures or intervene in private negotiations between AFC operators and device manufacturers by, for example, requiring that every AFC be able to work with every device. These aspects of the AFC do not affect interference protection and are decisions best left to individual companies and market forces.

Finally, the Commission should affirm its conclusion that it can best promote investment by adopting technical rules for AFC-controlled devices that align with rules applicable to 5 GHz U-NII devices that facilitate unlicensed P2P deployment and P2MP operations. The AFC can prevent harmful interference by these types of operations just as it does for RLAN devices with less directional gain, while facilitating far more agile deployment than the highly regulatory rules governing licensed FS service.

1. AFC will prevent harmful interference to FS links.

As described above, the RKF Study demonstrated that it is very unlikely that a standard-power RLAN operating under today's U-NII-3 rules would cause harmful interference to an FS receiver, even without AFC. RKF reached these conclusions despite making a series of worst-

case assumptions, and despite ignoring several factors that would reduce the risk of interference still further.[70] Importantly, no party appears to disagree with the conclusion that is most significant to enabling standard-power devices under AFC control: any measurable interference to an FS receiver, if it occurs, will be caused by a single RLAN transmitter, not aggregate interference from multiple devices. Therefore, even if an FS receiver could potentially receive interference from an individual standard-power RLAN device in unlikely scenarios without AFC control, the AFC system the Commission has proposed would prevent those situations from occurring.

Despite the fact that standard power RLANs with no AFC control present little chance of harmful interference, we agree with the Commission that it would be appropriate to require AFC control for standard-power RLAN devices, with conducted power levels up to 30 dBm. This rule will provide even greater assurance for operators of FS systems. In fact, the proposed AFC framework closely resembles the process that FS links rely on today. Every new FS link that comes online is coordinated with every other link using a manual process that is analogous—but far less efficient than—the automated process the Commission has proposed.

The AFC system will take advantage of data in the Commission's ULS database, which is generally the same data used by private frequency coordinators in siting a new FS link. For every licensed FS receiver, and every FS receiver for which a license application has been filed, the rules require that the applicant provide critical information such as the frequency of operation, geolocation coordinates, antenna height, and antenna model, gain, and azimuth (i.e., the precise direction in which the antenna is pointing).[71] This information, in conjunction with a suitable

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70 *See supra* pp. 19–25.

71 47 C.F.R.§ 101.21.

propagation model and, potentially, terrain, building, and clutter information, is sufficient to determine the strength with which an FS receiver will pick up a potentially interfering RLAN signal. That is because the received power level will be a function primarily of the RLAN transmitter power in the direction of the FS receiver, gain of the FS receiver antenna in the direction of the RLAN transmitter, distance, and the propagation conditions between them.

According to a review of ULS data, an FS link almost never enters operation less than 30 days after Commission receipt and posting of the corresponding application to ULS. Therefore, AFC will protect FS links as long as AFC implementations obtain up-to-date information at least once every 30 days and protect links that have been applied for, but not yet granted.[72] This will result in some nonexistent or inoperative links being protected unnecessarily, because the filing of an application creates no real-world interference protection needs. But this minor inefficiency is justified because it will ensure robust protection for FS licensees and flexibility in the design of the AFC system, avoiding the limitations and costs of a requirement to obtain updated ULS data more often than necessary.

Although there are cases where ULS data may be incomplete or inaccurate, a number of common-sense strategies are available to ensure that noncompliant FS links do not hinder more effective use of the entire band, while protecting licensees that have failed to provide complete and accurate registration data. As explained in detail in the attached declaration by Fred

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72 Even in the very rare case where a link goes into operation less than 30 days from the initial application, the odds that it will be exposed to harmful interference by a standard-power RLAN device that has not received updated information are vanishingly small. Although it is possible that some RLANs might not have received updated information before the FS link goes into operation, the large majority will have. Thus, the small probability that *any* RLAN device will be configured in a way to make harmful interference possible will be reduced even further by the slim probability that this device also will not have received updated licensee data.

Goldstein, an expert in the design of FS links, the Commission may use certain default values to fill in missing data.[73] We also support a generous amnesty window in which 6 GHz FS licensees could correct erroneous or incomplete FS link registration data without penalty or fee, and without being required to comply with any otherwise applicable coordination requirement,[74] provided that they certify that the changed information represents a correction, not a modification to the licensed facilities. After the conclusion of the amnesty window, however, the Commission should make clear that, in investigating any potential interference complaint, it would consider the extent to which the claimed interference was due to that licensee's own failure to provide correct registration information. These steps would serve the public interest, because requiring licensees to comply with Commission registration rules and ensuring the accuracy of FS registration data is important to facilitate RLAN sharing, and to ease future coordination of licensed FS links. These measures will also protect FS licensees while preserving incentives for licensees to bring registration information into compliance with the FCC's rules.

As explained in the attached declaration of Dr. Vinko Erceg, a recognized expert in the field of propagation modeling, currently the most appropriate approach to AFC propagation modeling would involve a combination of WINNER II, the Irregular Terrain Model (combined with site-specific terrain data, where available, such as the SRTM), and applicable ITU clutter models.[75] As the Commission correctly concluded, use of free-space propagation assumptions

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73 *See* Declaration of Fred Goldstein Regarding Automated Frequency Coordination and The Universal Licensing Database ¶¶ 15–17, attached hereto as Appendix C.

74 *See* 47 C.F.R. § 101.103(d)(1) (requiring coordination prior to "filing an application for regular authorization, or a major amendment to a pending application, or any major modification to a license"). Modifications would continue to be administered under the Commission's normal rules.

75 Although this model represents the state of the art today, the Commission should provide sufficient flexibility for improved models to be used in the future, provided it can be shown that they will offer the necessary protection to incumbents.

for every link and RLAN device would "overestimate the potential interference in most cases and unnecessarily restrict access to the spectrum for unlicensed use."[76] True free-space propagation conditions would be extremely rare between RLAN transmitters and FS receivers, making free-space assumptions especially inappropriate. Real-world RLAN transmissions will be shielded by walls, foliage, terrain, the user's body, and other features.

A far better approach is to select the propagation model that best captures real-world propagation conditions at a given distance, and that can be expected to be valid in the 6 GHz band. Although the use of a single, all-encompassing model may appear preferable in theory, no such model exists to capture these various conditions accurately. Moreover, most models are only a "single model" in name only, and actually rely on a variety of tuning parameters, the values of which may be manipulated by the user to effectively apply different models at different distances or for other variations.

For distances up to one kilometer in urban and suburban areas, the most appropriate model is the WINNER II model. This model includes both line-of-sight and non-line-of-sight components, consistent with the Commission's finding that an appropriate model should account for both of these scenarios.[77] WINNER II also incorporates the effects of clutter, and accounts for differences between urban and suburban morphologies, improving accuracy.[78] Unlike other models that only account for the differences between line-of-sight and non-line-of-sight conditions in a general, average way, WINNER II provides separate models for these situations.[79]

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[76] 6 GHz NPRM ¶ 49.

[77] *Id.*

[78] Erceg Declaration ¶ 6.

[79] *Id.* ¶ 5.

In rural areas, and other areas at distances longer than one kilometer, the Irregular Terrain Model (ITM) is most accurate, in conjunction with location-specific terrain data such as that provided by the SRTM, when available. In areas where this data is not available, it could be replaced with estimated height-variation values.[80] ITM should also be supplemented with a clutter model, drawn from applicable ITU-R models of urban, suburban, and rural areas.[81]

Finally, even in the extraordinarily unlikely event that interference at an RLAN receiver does exceed the chosen protection threshold, the effect on the FS link will typically be unnoticeable, as described in detail in the attached declaration of Fred Goldstein.[82] This is because, first, unlike an FS link that transmits continuously, an RLAN device transmits in extremely short bursts. A one millisecond burst of energy in excess of a specified interference threshold at the FS receiver is very unlikely to have any material effect. Second, even a more sustained signal is unlikely to cause a material degradation in service because high-reliability FS links are designed with sufficient fade margin. Hence, transient increases in noise level will still leave a sufficiently high signal-to-noise ratio for communications to continue with no change in quality.[83] Finally, in the event that even *this* margin is somehow exceeded, FS links often employ additional robustness features such as forward error correction and adaptive modulation to avoid an outage.[84]

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80 *Id.* ¶ 14.

81 *Id.* ¶ 17.

82 Goldstein FS Declaration ¶¶ 2, 29–33.

83 *Id.* ¶ 31.

84 *Id.* ¶¶ 34-40.

2. *Standard-power devices will protect mobile operations such as BAS in U-NII-8.*

In addition to the U-NII-5 and U-NII-7 bands, AFC can enable standard-power RLAN operations in U-NII-8 without risking harmful interference to BAS and LPAS licensees. The AFC-enabled sharing approach described above would be equally protective of U-NII-8 operations similar to how the FCC enabled FS operations to share this band. BAS and associated LPAS licenses are granted for a specified operational area—typically 100 to 150 kilometers from the central receive tower for BAS operations. Standard power RLANs could be authorized to operate in any frequencies where BAS/LPAS are not authorized to operate. In addition to FS, the U-NII-8 band also includes low-power mobile operations, such as camera back transmitters and wireless microphones, as well as higher-power operations, such as truck-mounted BAS. These operations also take place in the BAS operating zone and would be adequately protected by an AFC.

As explained above, for higher-power BAS operations, the RKF Study analyzed potential interference morphologies between an RLAN transmitter and a BAS receiver. It found that RLAN transmissions would cause no material impact to BAS operations in 99% of cases even without AFC coordination. In the remaining 1% of cases, the impact, if any, would be so minor and localized that a BAS operator could easily remedy any interference by simply adjusting its location to increase signal-to-noise ratio, just as these operators do today to address reception issues.

In the case of LPAS operations, which typically occur either within a closed venue or at a specific site, usually with on-site engineers, the LPAS operator or venue owner could prevent harmful interference by choosing not to install 6 GHz RLAN equipment, selecting LPAS channels that do not overlap with nearby RLAN operations (or vice versa), or physically changing the location of RLAN and LPAS transmitters.

Nonetheless, to provide an additional layer of protection, we recommend that the Commission permit standard-power RLAN operations in only the lower 100 megahertz of U-NII-8. The bottom portion of the band is most critical to the success of the band because it is needed, in conjunction with U-NII-7, to form large channel sizes, facilitating gigabit speeds. At the same time, this portion of the U-NII-8 band has seen especially little investment in licensed mobile infrastructure.

3. *Because RLANs will not cause harmful interference to FSS uplinks there is no need for aggregate or other special protections for these facilities.*

There is no need for special protections for satellite uplink operations in the 6 GHz band. Using a number of highly conservative assumptions regarding both RLAN utilization and FSS operations (e.g., satellite receivers with full-CONUS coverage and high G/T specifications), RKF showed that the peak energy that an FSS receiver might receive from 6 GHz RLAN operations would be a small fraction of what it already receives today from licensed FS links. RKF reported this result despite including the excessively conservative assumption that all RLAN traffic would be concentrated on a *single channel* co-channel with a satellite operator. Real-world operations would reflect a different pattern of usage, with RLAN operations spread across all available channels in 6 GHz and beyond, further reducing the likelihood of harmful interference to levels far below the extremely small risk that RKF identified. Several undersigned companies have submitted detailed analyses confirming these conclusions and have responded at length to concerns from FSS incumbents.[85]

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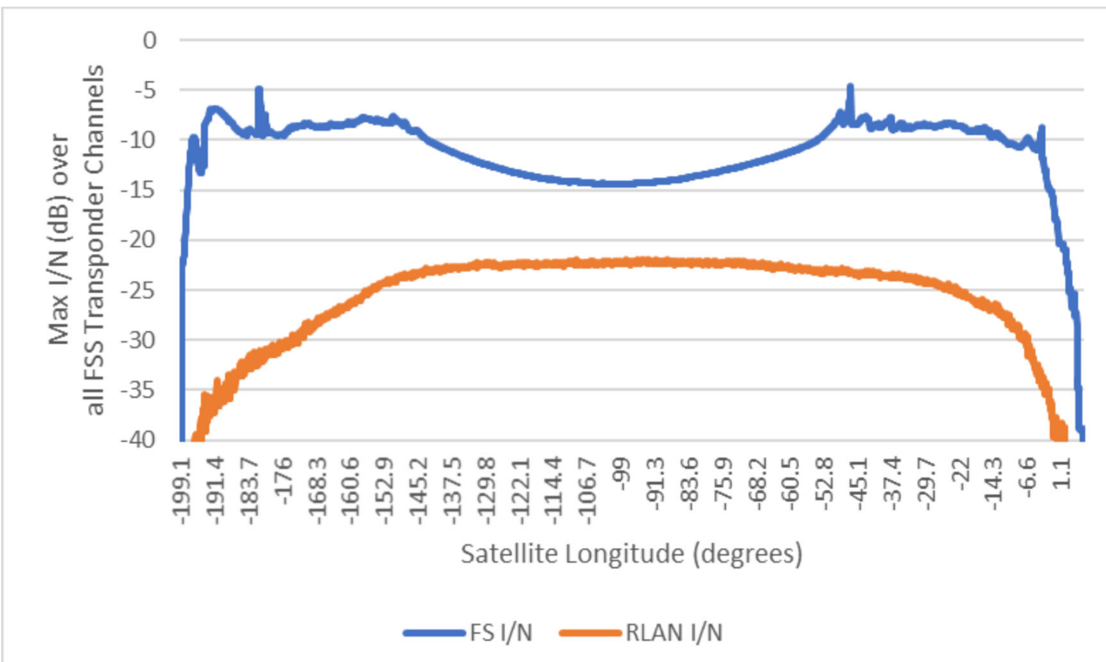
[85] *See* RKF Study; *see also* Letter from Paul Margie, Counsel, Apple Inc., Broadcom Inc., Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Apr. 10, 2018); Letter from Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Technology Group,

These simulations confirm that FS and RLAN transmitters exhibit roughly complementary interference characteristics as a function of elevation. FSS receivers experience peak energy from FS transmitters when they are close to the horizon, but peak RLAN energy when they are high overhead. Thus, as depicted below, not only is the total RLAN energy far lower than interference from FS, this complementarity ensures that the two sources combined will not meaningfully increase peak energy beyond what FSS systems already experience. Note that the vertical axis of this graph is logarithmic, meaning that the blue line representing interference from FS indicates approximately 40-times more energy than the orange line representing energy from RLAN devices.



A small handful of satellite earth stations in the United States also receive satellite *downlink* transmissions in the 6 GHz band. The locations and frequencies of operation of these sites are well known and documented in IBFS, meaning that the AFC can readily provide

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Microsoft Corporation, and Qualcomm Incorporated to Marlene H. Dortch Secretary, Federal Communications Commission, GN Docket No. 17-183 (filed Aug. 16, 2018).

protection. These operations are also far less dynamic than FS operations in the band. Thus, a one-month maximum AFC recheck time should be more than sufficient to protect FSS earth station downlinks.

D. Power Levels for Client Devices Should Allow for Effective Use of APs at the Proposed Power Levels.

The Commission should allow client devices to operate, in all cases, at the same transmitted power level of the AP with which they are associated. Limiting all client devices to a conducted power of 18 dBm as the Commission has proposed will significantly reduce the utility of the power limits permitted for APs. The far lower power levels for client devices will result in unbalanced links, with client devices able to receive signals from an AP at a much longer range than they can send. In addition, even setting aside issues with total conducted power, client device power spectral density is much too low to support emerging RLAN modulation technologies such as OFDMA.

Increased client-device power will not affect the harmful interference potential of either standard power AFC-controlled devices or LPI devices. The AFC will readily account for the interference potential of an AP's client devices regardless of power level. The interference protection methodology will work in exactly the same way to protect FS receivers with 30 dBm client devices as it would with 18 dBm devices. The former will simply be subject to greater geographic restrictions than the latter, all else being equal. Similarly, the analysis relating to the negligible interference risk of LPI APs pertains equally to LPI client devices.

III. Commission Rules Should Allow a Wide Variety of AFC Implementations to Enable Innovation, Diversity, and Cost Flexibility.

Promising and innovative new ideas can be stymied by the unforeseen consequences of excessive regulation. The Commission should remain vigilant and ensure that this does not

happen in the 6 GHz band. Although rules are needed to protect incumbents, these rules should not go beyond verifying that the system will protect these licensees. The Commission should avoid mandating a specific, one-size-fits-all approach to AFC design and operation and adopt a flexible set of rules that will allow different AFC implementations to accommodate a wide range of use cases and deployment scenarios including consumer, service provider, enterprise, IoT, and rural access. This will accommodate different business models and cost constraints as well as their distinct spectrum needs and operational requirements.

AFC rules should be animated by a single principle: an AFC implementation must correctly determine whether a device operating at a given location, on a given range of frequencies, and at a given power level would exceed the chosen interference protection criterion for any FS receiver. If so, the AFC must notify the device that those frequencies are not available, given its operational parameters. There are many ways that this fundamental capability can be implemented and enhanced to allow more efficient operations, reduce device costs, and support important use cases such as portable devices and higher power P2P and P2MP connectivity, etc. But in each of these permutations, the core AFC functionality remains unchanged: protecting licensees from harmful interference.

A. The Rules Should Permit Portable AFC-Controlled Devices, Including Devices in Vehicles.

Portable APs, including those operating in vehicles, represent one of the most prevalent use cases today and are central to making the 6 GHz band a success. A portable device in this context is a battery-powered device—for example, a tablet or smartphone—used in ways that consumers are already familiar with: it may operate at a fixed location, or may be in motion such as in the user's hand while walking, or it may be stationary within a moving platform (such as within a vehicle). Further, it may operate indoors or outdoors. Because the portable use case is

already prevalent, a restriction on portable devices would substantially undermine the overall value of the band for consumers. It is also unnecessary. As described below, an AFC system, combined with location capabilities that are already commonplace in portable devices such as smartphones, can account for the location and velocity variations of the portable device in its channel availability calculation, thereby protecting incumbent operations in an analogous manner as stationary RLAN APs and their associated tethered clients.[86]

The Commission can enable portable devices in the 6 GHz band by building on the extensive comment record and rules already in place for other bands.[87] In the 600 MHz band, for example, the Commission enabled portable operations while a device was in motion by allowing devices to pre-load channel availability data for multiple locations, and to use that data to define a region in which it could operate on a given frequency without performing an additional database check.[88] As long as devices correctly take into account their speed and location accuracy in determining whether they are still in one of these geofenced areas—which can be accomplished through the certification process—portable devices using this approach pose no greater an interference risk than stationary devices.

Depending on implementation, a recheck distance could be chosen by the device in its initial operating area request to the AFC, or could be calculated by the AFC based on parameters provided by the device. An AP that is aware it is in motion may intentionally choose a large operating area at the potential cost of reduced spectrum availability. For example, a device that knows it is moving at 30 meters per second (approximately 65 miles per hour) may request the AFC to provide spectrum availability for a 6 kilometer radius from its position. In this case, the

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86 *See* 6 GHz NPRM ¶ 76.

87 47 C.F.R. §§ 15.711(d)(5); 96.39(a)(3).

88 47 C.F.R. § 15.711(d)(5).

device would determine its location no less than once every 200 seconds in order to continue to operate—the time it would take to cover 6 kilometers at that speed. In addition, the AFC could impose an additional protection buffer around the RLAN device by adding to the device's reported uncertainty level the distance it could possibly travel before its next AFC contact, or accounting for the time required to complete AFC transactions. Another common enterprise scenario involves portable RLAN devices within a large facility that is several square kilometers but is nonetheless private property. Examples include railyards and container terminals, oil fields, refineries, manufacturing plants, airfields, mines, quarries, power plants, and other industrial facilities. In this case, a simple geofence that fully encloses the property is all that is required, and RLAN devices in motion within the facility need never approach a recheck boundary.

It should also be pointed out that different business models for enabling AFC-controlled portable devices are feasible and should not be foreclosed via rules that are overly prescriptive. For example, a separate entity may offer a service of pre-calculating the available channels list for portable devices over a large metropolitan area, such as on a 50 meter grid. The table would be updated periodically to reflect any changes to incumbent links within the relevant geographic scope.

Under this framework, there is no reason for the Commission's rules to distinguish between different portable device use cases (e.g., a handheld portable device versus a portable device in various types of vehicles). This is because the AFC's availability calculations use a common set of location and velocity parameters for all use cases, and the result automatically scales based on those parameters. Thus, the straightforward approach described above will automatically adjust the necessary degree of protection relative to the RLAN device's speed.

Importantly, operations in many types of vehicles presents a lower baseline risk of harmful interference than other outdoor operations, as they are typically subject to at least 10 dB of loss due to the shell of the vehicle. Additional protection margin is also available due to other vehicle-specific factors. In the case of automobiles, for example, with an embedded AFC device for use by portable devices of passengers, the communications links are at very short distances and the power level can be reduced while still maintaining reliable communications.[89] In the case of passenger trains with embedded AFC devices for use by portable devices of passengers, the fixed track routes allow for pre-calculated channel availability and a more stable and predictable radio environment. In the case of commercial passenger aircraft with ceiling-mounted AFC devices for use by portable devices of passengers, the maximum recheck distance may be impractical given the air speed, and the AFC system could simply prohibit 6 GHz operations when the aircraft is below a specified altitude, and could limit which channels are available based on local or flight path conditions. Other use cases for AFC-controlled portable devices include nearly all aspects of the nation's transportation system: commercial freight and delivery trucks, subways, freight trains, and farming equipment, to name a few. Therefore, we encourage the Commission to enable the AFC-controlled portable use case with as much flexibility as is feasible while protecting incumbent operations.

B. Professional Installation of AFC-Controlled Devices Is Unnecessary.

The widespread availability of highly accurate, automated geolocation technologies negates any reason to require that AFC-controlled devices be professionally installed. For

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[89] Note that there is a logical reason for AFC-controlled in-car communications to minimize their transmit power to the lowest level that will maintain reliable communications: at lower power levels, the channel availability calculated by the AFC will generally be higher because the RLAN emission footprint is smaller.

example, GPS could provide location information for AFC-controlled devices to allow effective operation of the protection mechanism. Furthermore, where automated geolocation technologies such as GPS may include a significant degree of uncertainty, the AFC can provide worst-case frequency availability information within the area of uncertainty. The GPS system makes the degree of uncertainty readily ascertainable because GPS receivers commonly report this accuracy information with the geolocation data.[90] This allows the AFC to perform interference protection calculations that are at least as protective as professional installation. Moreover, a professional installation requirement for all AFC-controlled devices would eliminate any meaningful consumer market for these devices. This would badly harm the eventual market for 6 GHz RLAN devices because only AFC-controlled devices could replicate the power levels of 5 GHz APs currently on the market. The enormous costs of requiring professional installation are not justified given the equally effective alternative of automatic geolocation.

Nonetheless, the Commission should *permit*, but not require, professional installation as a permissible geolocation approach. This would allow more efficient operation in situations where professional installation would offer significant improvements over the accuracy of automated geolocation technologies. Portable use of professionally installed devices should not be permitted, but no special rules are needed. The rules described above would automatically require a device to ascertain its location after moving a certain distance, or cease operating at standard power.

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[90] *See, e.g.*, u-blox, *u-blox 6: Receiver Description* 172 (2013) (describing the communications protocol used by a popular line of GPS receivers, which includes horizontal and vertical position accuracy estimates), https://www.u-blox.com/sites/default/files/products/documents/u-blox6_ReceiverDescrProtSpec_%28GPS.G6-SW-10018%29_Public.pdf.

C. The Rules Should Permit Multiple Geolocation Strategies so Companies Can Meet Diverse Customer Demand in the RLAN Market.

6 GHz RLAN devices should be allowed to use a variety of geolocation strategies, depending on use case and device type. Some devices may employ more accurate geolocation capabilities and be permitted in areas where an AFC would prohibit other devices with less accurate geolocation capabilities. But the impact to incumbent licensees would be the same: the RLAN device would comply with AFC-determined operational limitations to avoid harmful interference.

Therefore, it is sufficient that the Commission's rules require AFC to take geolocation uncertainty into account, and that the certification process verifies that devices report the correct accuracy to the AFC. This would permit the use of lower-cost, less-accurate GPS receivers for cost-sensitive applications rather than setting a single accuracy level that all devices must achieve. Because these devices will be limited to fewer 6 GHz frequencies due to the effect of location uncertainty on interference protection calculations, competitive pressures could drive the use of more accurate receivers. But the Commission should not substitute its own judgment for market forces. The same is true of other characteristics of geolocation technology, such as the speed with which a receiver can acquire a high-quality GPS fix. Indeed, mandating the use of GPS, or any other specific geolocation technology, is also not needed. As illustrated above, for example, professional installation may prove to be a valuable geolocation option in some circumstances.

Another example relates to automated height determination. Although GPS can provide height information outdoors, device manufacturers and service providers have developed other height sensing techniques for indoor use cases, such as sensing of barometric pressure and the use of other types of sensors. Ultimately, a combination of approaches will likely be most

successful in the market. The Commission should not limit such innovation—and their resulting efficiency improvements—through unnecessarily prescriptive rulemaking.

As in other aspects of the AFC, the Commission's approach to geolocation technologies should be performance based. Geolocation technologies should only be required to reliably determine a device's position and the uncertainty associated with that determination, and the AFC should use that information to correctly apply relevant protection thresholds. Although some novel approaches may require collaboration between industry and OET to develop certification processes, as has been the case frequently in other bands, the Commission need not limit future innovation by pre-selecting specific favored technologies.

D. Three-Dimensional Interference Protection Calculations Will Ensure Accurate and Efficient AFC Operation.

The Commission should maintain flexibility and technological neutrality in determining how an AFC implementation must perform interference protection calculations. The NPRM asks whether these protection criteria should account for RLAN device height and, if not, asks whether AFC systems should assume a typical installation height and impose a height restriction on AFC-controlled devices.[91] The question highlights the significant problems inherent in a two-dimensional approach to interference protection calculations. Use of a typical antenna height would create uncertainty and a predetermined height limitation would prohibit operation in tall buildings. The flaws in the two-dimensional approach far outweigh the very modest additional complexity associated with accounting for RLAN device height in these calculations.

Allowing AFC implementations to take both FS and RLAN device height into account would permit RLAN devices to make far more efficient and intensive use of spectrum. If these

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[91] 6 GHz NPRM ¶ 51.

calculations were performed in only two dimensions, the Commission would need to artificially select an arbitrary device height, instead of relying on a conservative value for the *actual* device height. This would unnecessarily eliminate one significant benefit of the 6 GHz band for RLAN sharing: the useful elevation mismatch created by the fact that FS links are typically directed well above ground-level, safely permitting RLAN operations beneath. Exaggerating RLAN heights to create an artificial two-dimensional system would lead the AFC to block sharing even where there is no risk of harmful interference, leaving valuable spectrum unused. Shadowing effects due to the curvature of the Earth will also play an important role in promoting sharing and efficient use of spectrum, by allowing RLAN operations over the horizon from an FS receiver. However, it is unclear how an AFC system could take this phenomenon into account if it is not permitted to take RLAN and FS heights into account, unnecessarily reducing the spectrum available for RLAN devices.

While perfect height information will not always be available to the AFC, height information should not be ignored altogether. The AFC can account for height uncertainty just as it can account for uncertainty in longitude and latitude. RLANs with especially poor height accuracy could have less access to spectrum if they are operating near protected links. This would not undermine incumbent protection, however, and would create another opportunity for market forces to dictate the degree of height-location accuracy most appropriate for various classes of devices. On one extreme, a manufacturer of wireless sensors for precision agriculture could prioritize low cost over height accuracy, if the sensor requires little spectrum and is intended to operate in flat, rural areas where height information would be of little incremental value. On the other extreme, high-end commercial offices in dense urban cores could rely on enterprise-grade, professionally installed 6 GHz APs for maximum height accuracy and,

accordingly, the greatest possible access to bandwidth at a given site. Allowing these and other approaches to flourish will maximize efficiency without increasing the risk of harmful interference.

Three-dimensional calculations will not be significantly more complex for AFC operators to implement. The additional mathematical complexity associated with accounting for device height in interference protection calculations is very limited and will make little material difference to the overall burdens associated with AFC operations—burdens that will be borne by RLAN and AFC operators rather than incumbent licensees. Similarly, while propagation calculations may be simpler in two dimensions, they are also much less accurate. Furthermore, three-dimensional models are readily available. This aspect of the AFC calculations also will not need to be performed in real-time, due to how infrequently a new FS transmitter will require protection in a given location and can easily be pre-computed.

The fact that applying interference protection criteria in three dimensions may be more complex for an AFC operator is not a reason to forbid it. The performance-based approach to AFC regulation and certification proposed herein would allow operators to optionally implement simplified three-dimensional approaches,[92] or even a two-dimensional approach, provided doing so does not allow RLAN operations to cause harmful interference.[93]

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[92] This could include a so-called 2.5-dimensional approach, where protection contours are defined in terms of a series of two-dimensional slices, each of which applies to RLAN devices of different heights.

[93] One two-dimensional approach could, for example, be equivalent to a three-dimensional approach as applied to devices with very large height uncertainty.

E. Rules Should Permit Maximum Flexibility in AFC Internal Implementations While Still Verifying Their Effectiveness.

The Commission should ensure that key AFC functions may be performed in a variety of ways, as long as the result is verifiably correct. To highlight the significance of flexible implementation, this section illustrates three possible approaches to implementing an AFC system, each of which would protect incumbents and should be permissible under the Commission's rules.

Figure 1 below illustrates the possible architecture of an AFC implementation using a third-party database provider. In this example, a third party provides stored licensee data—obtained from FCC databases and potentially pre-processed to facilitate rapid calculations—and includes frequency availability calculation features. Channel selection, however, is performed by the AFC device from the available frequencies provided by the third-party AFC system. In this arrangement, the third party could provide these AFC services under a contract with an AP vendor or service provider for that vendor or provider's devices. The third-party provider could service AFC devices produced or deployed by multiple parties, and the interface between the AFC device and AFC system could be based on either an open standard or proprietary/closed standards.

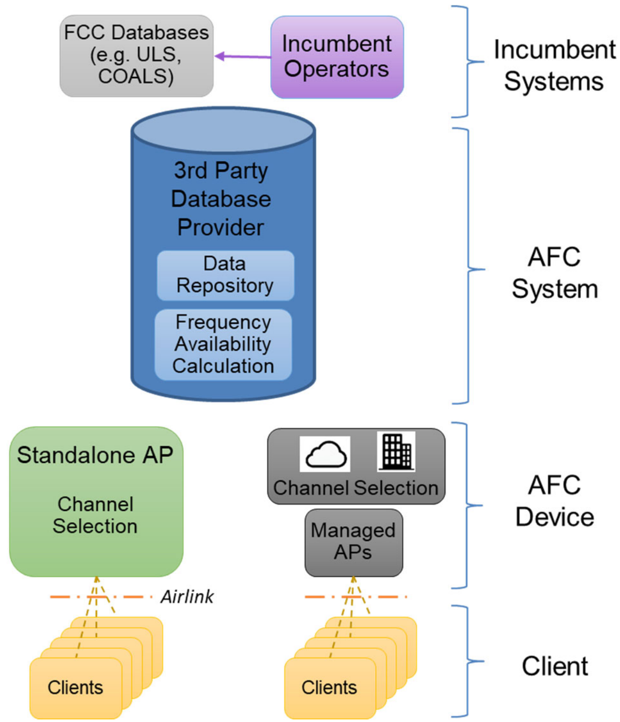

Figure 1—AFC Implementation with Third Party Database.

Figure 2 shows a different implementation, where the AP essentially provides its own AFC services using incumbent registration data downloaded periodically from a central repository. Under this physical implementation scenario, the AFC system and the AFC device that it controls are integrated into the same physical system on a user's premises (and perhaps even into the same device). As shown in Figure 2, there may be physical implementations where aspects of the AFC system, such as a mirrored copy of the FCC database, are cloud-based and other aspects are integrated within the same hardware as the stand-alone AP.

Under this integrated AFC model, once incumbent link information is retrieved from a central repository into a local data repository, the AP becomes a self-contained, indoor or outdoor solution for determining frequencies on which the AFC device can operate, until it is necessary to obtain updated licensee information. Associated clients will operate in accordance with the direction of the AP, as they would under any other AFC implementation.

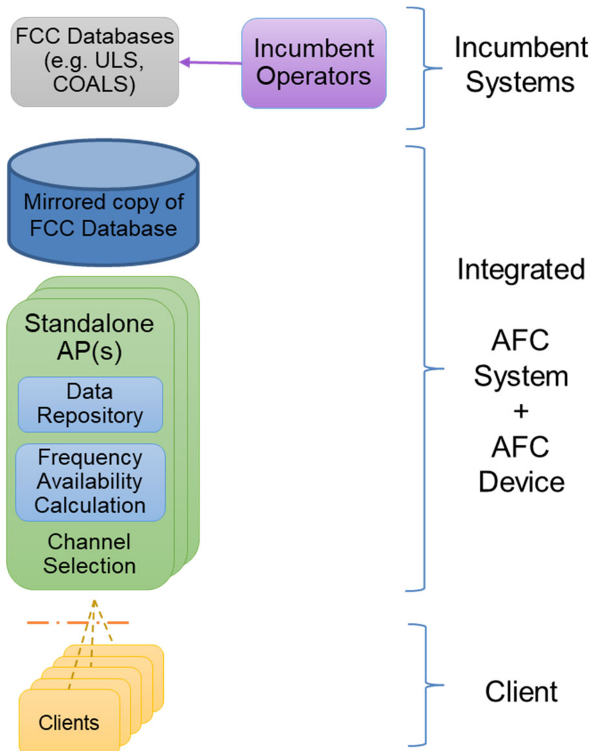

Figure 2—Fully Integrated AFC Implementation to Support Standalone Devices.

Finally, as depicted in Figure 3, a service provider, such as a large ISP operating many RLAN devices, could deploy and certify its own AFC system within its private cloud. A proprietary interface and protocol for communication between the AFC system and AFC-controlled devices could be developed, depending on network management needs. These AFC devices would be deployed at each subscriber location and could be unique to, and managed by, the provider's network.

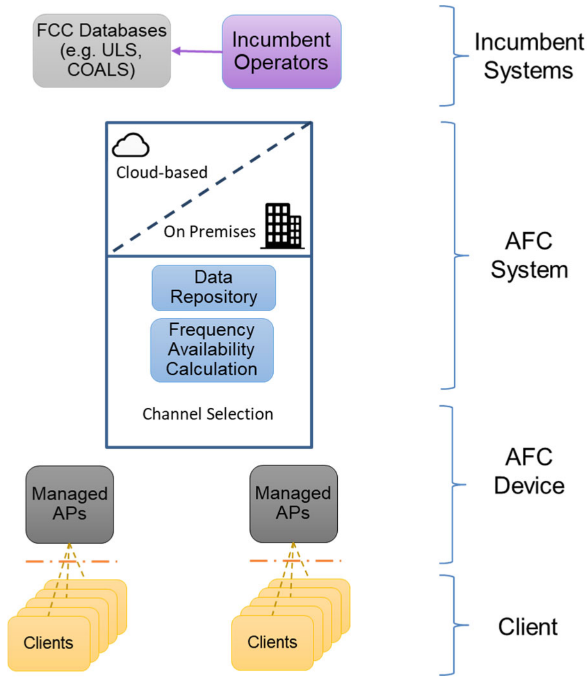

Figure 3—AFC Implementation Using Operator's Private Cloud.

Although the internal architectures of these systems would differ, they could be tested and certified using a common set of tools and procedures. The Commission should evaluate the AFC's performance at the point where it provides the results of its frequency availability calculations using a suite of input test vectors (horizontal location, vertical location, horizontal uncertainty, vertical uncertainty, client operating parameters) for which AFC performance would be compared to permitted frequencies of operation. These tests could be performed against representative test data or against "live" FCC data as necessary for reliability. Figure 4, below, illustrates the applicable, common test point in each sample AFC implementation described above. A uniform test point would facilitate testing of both AFC implementations and AFC-controlled devices. AFC systems could be tested to ensure that they provide the correct results (i.e., identifying the correct frequencies as available) for each three-dimensional location supplied at the specified test point. AFC-controlled devices could likewise be tested to ensure

that they correctly respond to a simulated AFC system response provided at this same test point (i.e., only operating on permitted frequencies).

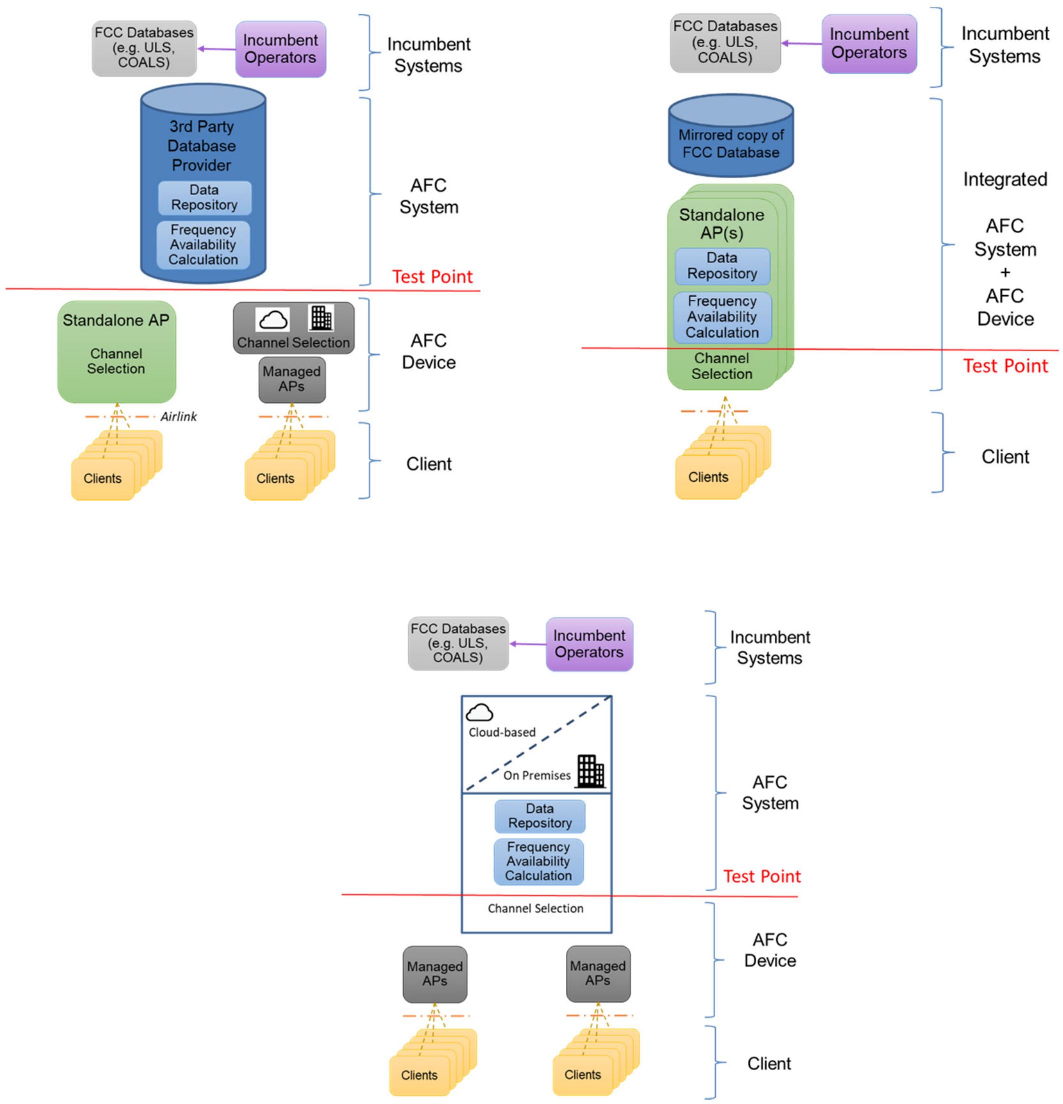

Figure 4—Implementation of a Common Test Point Across Diverse AFC Implementations.

Substantial multi-stakeholder collaboration has already occurred relating to 6 GHz RLAN operations. Thus, there is no need for the Commission to mandate a specific group to administer AFC system requirements or set standards for AFC system interactions. Unlike in database approaches in other bands, AFC-to-AFC communications are not needed. Without complex

device registration requirements, these systems would need to exchange data. While multi-stakeholder groups could adopt *voluntary* standards for AFC operation (e.g., communication between AFC systems and AFC devices), regulations *mandating* the creation of such standards are unnecessary.

F. Burdensome and Unhelpful Device Registration, Identification, and Tracking Requirements Would Compromise User Privacy and Greatly Restrict AFC Design.

The NPRM asks about the appropriateness of (1) requiring registration of AFC-controlled devices, (2) directing these devices to periodically transmit a unique identifier, and (3) mandating that AFC systems log the frequencies used by AFC-controlled RLAN devices. Such rules are unnecessary, would be ineffective in mitigating interference, would greatly reduce consumer use of the 6 GHz band, would limit AFC implementation choices to one or two existing models similar to the TV White Spaces database, and would present consumer privacy threats.

The transmitter identification requirement central to these proposals would require RLAN devices to transmit a unique identifier that, in theory, could be used by licensees to identify RLAN devices. However, merely requiring RLAN devices to transmit such a signal does not provide licensees with the tools to *receive* it. The Commission would need to mandate the use of a specific technology to modulate this information, stimulate the creation of devices that a licensee could use to identify the source of any interference, and then hope that licensees purchase these devices. Moreover, the technology would have to allow the identifier to be transmitted in a way that licensees could easily receive and successfully decode despite

significant background noise. In fact, FS incumbents agree that these issues would likely render a transmitter identification requirement ineffective.[94]

The periodic transmission of a unique identifier would also allow every affected 6 GHz RLAN device to be tracked anywhere in the world. This is clearly unacceptable from a user privacy perspective. Malicious actors could surreptitiously monitor 6 GHz identifier transmissions on a large scale, gathering sensitive data about where an individual consumer is at a particular time. For example, a motivated adversary could readily associate these data with real-world identities by recording identifiers transmitted in residential areas at night. Furthermore, in order to be usable, identifiers would need to be aggregated from all of the AFC operators and stored in a central repository that could be vulnerable to penetration. This would require additional synchronization systems to be developed, increasing the cost and complexity of the AFC system.

These privacy risks, combined with a cumbersome registration process before a user can use the device, would greatly reduce the appeal of 6 GHz RLAN devices, a result completely at odds with existing consumer expectations. Complicating matters further, it is unclear how access to the device registration database could be controlled. To perform its envisioned function, it must be accessible to licensees, but not to the public at large. It is unknown whether a robust way exists to restrict access to this registration database to *only* licensees, much less to just those licensees that may be experiencing interference.

Finally, recording the frequencies used by each RLAN device, which would require both a transmitter identifier and a database of registered devices, adds additional difficulties. Radio

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94 *See* Letter from Mitchell Lazarus, Counsel for the Fixed Wireless Communications Coalition to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 17-183, Attachment at 16 (filed July 17, 2018).

resource management subsystems in APs routinely change channels in response to changing RF conditions. Recording the current state of every one of millions of RLAN devices (and possibly its channel history for some period of time) creates a significant and costly burden with no utility. In addition, maintaining such a log would likely prevent certain AFC architectures, such as the fully integrated standalone AP, eliminating important use cases and product categories. Finally, in order to be even potentially useful in addressing interference, the log would have to include both frequencies and locations of devices. The frequencies used by RLAN devices in Cleveland will be useless to a licensee in San Diego seeking to troubleshoot a link. But, by recording both, this requirement may effectively mandate the maintenance of a complete log of the movements of any person with an AFC-controlled AP—adding to the privacy risk.

G. The Commission Should Reject Unnecessary and Highly Limiting Interoperability Requirements.

The Commission should not regulate business decisions such as whether to centralize the AFC under a single entity's management or to open all AFC implementations to any 6 GHz client device. No need for such regulations has been identified. Maintaining flexibility would allow the market to identify the most advantageous business arrangements and technical implementations. For example, it is unclear today whether the "best" approach will be for manufacturers to provide AFC functionality for their own devices, or whether large numbers of RLAN devices will use third-party AFCs. Although the use of third-party AFC operators may have advantages, future trends such as whether AFC operation will prove to be sufficiently profitable as a standalone service cannot be predicted. The marketplace may reveal that certain options are superior for different types of devices, highlighting the importance of regulatory flexibility.

In particular, the Commission should not require all AFC implementations to synchronize with one another. Because there is no need for aggregate interference protection or any other need for data to be synchronized between operators, such a requirement would impose substantial burdens on AFC systems with no corresponding benefit. Moreover, these burdens would grow exponentially as additional AFC implementations are certified, essentially creating an artificial limit on how many can be authorized before the synchronization burden becomes untenable for AFC operators.

H. The Rules Should Permit Flexibility in How AFCs Communicate Available Frequencies.

The NPRM asks how the AFC will communicate to APs which frequencies are available, and whether to make these protections specific to the actual RLAN power level.[95] Here as well, prescriptive regulation is unnecessary, provided that the performance of the AFC and AFC-controlled devices can be verified during the certification process to confirm that they will not authorize operations that would cause harmful interference.

There are multiple ways that the AFC might communicate which frequencies are available, including lists of permitted channels, lists of forbidden channels, or specific frequency ranges, any of which should be permissible. Requiring the AFC to report available channels would be especially problematic, because it would require a rigid ex-post channel plan. There would be no benefit to this approach, which is bound to be incompatible with some future application, imposing unnecessary regulatory burdens.

Likewise, the AFC should be permitted to take into account actual device power levels, rather than assuming that all devices operate at the maximum allowed power. This would

[95] 6 GHz NPRM ¶ 26.

facilitate much greater use of spectrum. AFC-controlled devices could reduce power and operate in many places where operations would have been prohibited if the AFC had to assume maximum power at all times. Indeed, this would create incentives for RLAN devices to voluntarily reduce operating power in exchange for spectrum availability, benefitting incumbents and unlicensed users alike. Ensuring that the AFC properly calculates available frequencies based on device power level and that AFC-controlled devices adhere to identified power limitations could be part of the certification process for AFCs and AFC-controlled devices. This testing would involve verification, presumably through an automated process, that the AFC would identify correct available frequencies at FCC-selected locations and device operating parameters.

IV. THE 6 GHZ PSD AND ANTENNA GAIN RULES SHOULD BE CLOSELY ALIGNED WITH THE SUCCESSFUL 5 GHZ U-NII-3 BAND RULES.

Although we generally agree with the Commission's proposals regarding AP power levels, its proposals regarding limits on power spectral density and directional gain raise concerns.

Manufacturers and chipmakers will need higher PSD limits for 6 GHz RLAN devices to allow devices using the next-generation modulation scheme, OFDMA, to operate at the Commission's power limits. As explained above, OFDMA will bring important new spectrum-sharing efficiency and increased quality of service to 6 GHz RLAN technologies. Technologies like OFDMA will be important to many technological improvements for licensed and unlicensed operations to unlock the full potential of 5G.

The Commission's proposed power spectral density limit of 17 dBm/MHz would align 6 GHz RLAN devices with U-NII-1 technical rules, not the far more heavily used U-NII-3 band,

which is spectrally much closer to 6 GHz. Although complete alignment with U-NII-3 PSD rules would be ideal, the Commission need not allow the full 30 dBm/500 kHz currently allowed in U-NII-3 to facilitate OFDMA deployments. The Commission need only adjust its proposed power spectral density limits to allow 27 dBm/MHz for standard-power AFC-controlled devices, and 21 dBm/MHz for LPI devices. A PSD limit of only 1 dBm/MHz would suffice for-very-low power APs, further minimizing the interference potential of these devices.

For standard-power devices, this change in power spectral density would not change the risk of harmful interference because it would be accounted for in the AFC's frequency availability calculations. Similarly, for LPI and 14-dBm very-low-power devices, this minor change in PSD is unlikely to alter the risk of harmful interference, given the interference analyses above,[96] and the numerous sources of attenuation.

The Commission's proposed rules also deviate significantly from the U-NII-3 antenna gain rules in their treatment of higher-gain antennas and unlicensed P2P and P2MP operations. U-NII-3 rules permit the use of higher-gain antennas with the limitation that, for non-P2P operations, conducted power must be reduced by 1 dB to compensate for antenna gain in excess of 6 dBi. For P2P operation, U-NII-3 rules do not limit the gain of transmitting antennas and do not require such a reduction in conducted power to compensate for high gain.

However, the NPRM's treatment of this issue for 6 GHz RLAN devices is ambiguous. On the one hand, it says that "[i]f a transmitting antenna with directional gain greater than 6 dBi is used, the maximum power and power spectral density shall be reduced by the amount in dBi that the directional gain is greater than 6 dBi."[97] But on the other it cautions that "we are

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96 *See supra* Section II.A.2–3.

97 6 GHz NPRM ¶ 78.

proposing no provisions for high gain antennas for unlicensed devices."[98] We take the former, more specific statement to control, meaning that the Commission intended to propose rules similar to the existing U-NII-3 rules for non-P2P devices. Indeed, the ability to use higher-gain antennas under such an approach is critical. Prohibiting antenna gain in excess of 6 dBi would be unnecessary and would greatly reduce the value of the band for key enterprise and WISP use cases. In addition, we urge the Commission to adopt a version of the U-NII-3 P2P rule to allow highly directional, steerable P2P beam systems that provide non-simultaneous P2MP operation.

As observed above, the use of connectorized Wi-Fi APs in enterprise use cases has declined over the last ten years. This is true both indoors and outdoors. However, there are specific and vital use cases that call for sectorized or narrow beam antennas, as well as higher-gain omnidirectional antennas. All enterprise WLAN vendors certify and market their equipment with a limited family of such antennas for this reason. Outdoors, it is common to see sectorized coverage for loading docks, railyards, container terminals, or airport tarmacs, to name just a small number of examples. Indoors, one can find them in distribution centers with long aisles, inside aircraft hangars, and inside freezers. Two common antenna configurations used in these applications are an 8 dBi panel with a 60° x 60° beam, or a 12 to 14 dBi sector with a roughly 55° x 13° beam. Operators also deploy higher-gain antennas in stadiums, arenas, and airport concourses, with many vendors offering specially designed 14 dBi models with patterns as tight as 20° x 20°. These venues are some of the most important use cases because they are the most spectrum limited today in the 5 GHz band. And the U.S. Army, Air Force, Navy, and Marines make extensive use of higher-gain antennas to provide secure connectivity on bases, flight lines, ordnance depots, and more. To forbid such operations, prohibiting gain greater than 6 dBi even if

98 *Id.* ¶ 79.

conducted power is reduced to compensate, would not serve the public interest and would significantly constrain the market.

Mesh applications have been another vital unlicensed use case for over fifteen years. Municipal Wi-Fi deployments continue to occur, leveraging P2MP mesh networks to backhaul traffic to a nearby uplink node. Smart city IoT traffic is now routinely carried on such networks, such as video feeds from traffic or police cameras. These networks routinely employ high-gain, omnidirectional antennas of 8 or even 10 dBi to maximize range because they do not serve client devices. Large industrial facilities, such as petroleum fields, oil refineries, shipyards, and manufacturing plants of all kinds use mesh links to connect buildings, well heads, cranes, cameras, and more. School districts commonly use Wi-Fi mesh networks to connect temporary classrooms in trailers to a nearby school building. Somewhat higher gain antennas are also used for shorter length (by FS standards) backhaul links of 5 to 10 miles; some vendors offer antennas up to about 23 dBi for this purpose. All such use cases should be fully permitted—subject to AFC—in the Commission's decision.

Beyond "enterprise" applications, the U-NII-3 gain rule has been instrumental in promoting the use of U-NII-3 for WISPs, providing an important high-speed connectivity option for rural areas. Unlicensed P2P operations, alongside P2P fixed links licensed under Part 101, are especially critical for enabling residential high-speed wireless connections. The ability to use high-throughput directional links for these last-mile connections increases both aggregate network capacity through frequency reuse and the capacity of individual links due to the potentially very high signal-to-noise ratio. Part 101 license procedures, however, are a poor fit for this use case. Although the months-long coordination and licensing process is reasonable for high-power common carrier or other similar links installed on towers within controlled sites, that

process is not appropriate for links that terminate at residences. Most significantly, the licensing and coordination process introduces delays that could block a WISP from timely activating service to a home, a result inconsistent with subscribers' expectations. The licensing and coordination process could also present a problem if a user wanted to change the location of their consumer premises equipment, or if the radio needed to be replaced to support upgraded service.

Allowing 6 GHz P2MP operations with gain rules similar to U-NII-3 P2P would take these benefits a step further, allowing tremendous flexibility and reducing the number of radios that must be installed for each link. In a P2MP configuration, a WISP, for example, could provision service for many homes, in many different directions, all using the same steerable P2MP phased array antenna.

In each of these cases, an AFC implementation could provide robust protection for incumbents. Every significant aspect of the AFC system would remain the same as an AFC system designed to serve more conventional RLAN users, except an AFC optimized for P2P or P2MP devices could take into account the narrow beamwidth of each RLAN link in determining channel availability. Given the significant benefits of promoting these use cases, and the lack of any additional interference risk under AFC control, there is no reason to block manufacturers and operators from deploying these devices and services in the 6 GHz band.

CONCLUSION

This proceeding presents an unprecedented opportunity for the Commission to address the pressing need for additional unlicensed spectrum and to usher in the next wave of wireless innovation. The overall framework proposed by the Commission is conservative and well-constructed. It will protect incumbent users from harmful interference while advancing the

Commission's core goals of supporting innovation, expanding broadband, and improving spectral efficiency.

The Commission should adopt this framework, with a set of important adjustments that will make the 6 GHz band a success. We recommend that the Commission:

- Improve efficiency and intensity of use by permitting unlicensed operations to share the entire 5975–7125 MHz frequency range with incumbents—and reject introducing a new licensed mobile service in any portion of the band, which would displace incumbents.

- Permit standard-power AFC-controlled devices and LPI devices without AFC—while (1) allowing LPI devices to operate in all four sub-bands, (2) adding a 14-dBm very-low-power device class that can operate indoors or outdoors in U-NII-5, U-NII-7, and the bottom 100 megahertz of U-NII-8, (3) authorizing standard-power operations in U-NII-8 on a limited basis, and (4) revising proposed client-device power levels to permit symmetric operation.

- Adopt rigorous but flexible AFC rules that require careful protection of incumbents, while rejecting calls to over-regulate or dictate specific elements of AFC implementation, by permitting (1) portable and in-vehicle operation, (2) flexible geolocation strategies, (3) interference protection calculations that take FS and RLAN device height into account, and (4) operation without professional installation, device registration, ID transmission, or tracking of consumer devices or APs.

- Adopt technical rules based on the successful U-NII band, while also (1) adjusting power spectral density and client-device power levels to permit manufacturers to bring the latest wireless innovations to American consumers and (2) supporting WISPs' efforts in rural communities by permitting greater directional gain for AFC-controlled devices and facilitating P2P and P2MP operations.

This approach will produce the investment and innovation needed for our companies and others to make the 6 GHz band a tremendous success to the benefit of the country. We therefore encourage the Commission to move expeditiously and adopt a final order in this proceeding.

Respectfully submitted:

Apple Inc.
Broadcom Inc.
Cisco Systems, Inc.
Facebook, Inc.
Google LLC
Hewlett Packard Enterprise
Intel Corporation
Marvell Semiconductor, Inc.
Microsoft Corporation
Qualcomm Incorporated
Ruckus Networks, an ARRIS Company

Appendix A

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

DECLARATION OF DR. VINKO ERCEG

1. My name is Dr. Vinko Erceg. I am a Fellow in the Wireless Connectivity – WLAN Group at Broadcom Corporation. I have worked for Broadcom for 14 years, where I served as a standards lead in the Broadcom WLAN group and became a Broadcom Fellow in 2014. In 2007, I became an Institute of Electrical and Electronics Engineers (IEEE) Fellow for my work on wireless channel propagation modeling and signal processing. I also serve as the 11ax Technical Task Group Chair in the Wi-Fi Alliance. I hold a Ph.D. and a B.S. in Electrical Engineering. In my current positions, I often use wireless propagation and path loss models to predict and improve network performance. My Ph.D. thesis was related to propagation; thus, I have done extensive work and research in this area and have published numerous propagation-related works including the widely used Erceg-Greenstein propagation model. I hold about 250 patents and I have authored more than 50 papers for journals, magazines, and conferences.
2. I have reviewed the Notice of Proposed Rulemaking (NPRM) in the above-captioned proceedings, specifically, the Commission's proposal and questions regarding the appropriate

propagation models for the 6 GHz band. As a starting point, the Commission is correct that a free space path loss model would severely overestimate potential interference.[1] The use of a free space model would thus unnecessarily restrict access to the 6 GHz band and reduce the efficient use of these frequencies.

3. For distances within the first kilometer and beyond a 30 meter exclusion zone around FS receivers,[2] my analysis of multiple alternative models reveals that the models that best account for clutter loss and include both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions[3] are the WINNER II model for urban and suburban environments, and the Irregular Terrain Model (Shuttle Radar Topography Model) (ITM(SRTM)) combined with the ITU-R P.452 clutter model for rural environments. Figure 1a shows comparisons of the various models.

4. The WINNER II model[4] is an appropriate propagation model for Urban (WINNER II Scenario C2) and Suburban (WINNER II Scenario C1) environments for predicting interference from RLANs within one kilometer of an FS receiver. WINNER II is a propagation model used by cellular operators for coverage analyses that has been validated by measurement for frequencies between 2 GHz and 6 GHz. However, it can reasonably be applied for the frequencies being considered here.

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1 *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, FCC 18-147, ET Docket No. 18-295, GN Docket No. 17-183, ¶ 49 (rel. Oct. 24, 2018) ("NPRM").

2 An exclusion zone is a separation of a certain distance between devices as a function of their susceptibility to the energy of other devices.

3 *See* NPRM ¶ 49.

4 Pekka Kyösti et al., *WINNER II Channel Models*, IST-4-027756 WINNER II, D1.1.2 V1.2 (last updated Feb. 4, 2008), https://www.cept.org/files/8339/winner2%20-%20final%20report.pdf.

5. One key advantage of the WINNER II model is that it includes a probability of LOS term that is a function of distance. This term allows random assignment of LOS and NLOS paths in the simulation. For Automated Frequency Coordination (AFC) purposes, the LOS and NLOS conditions may be determined using site-specific information (including building and terrain information), if available. If site-specific information is not available, the path loss model averaged over LOS and NLOS conditions may be used (see Figure 1b). The formula for averaged path loss is: Combined Path Loss = Pathloss_LOS x Prob_LOS + Pathloss_NLOS x Prob_NLOS.

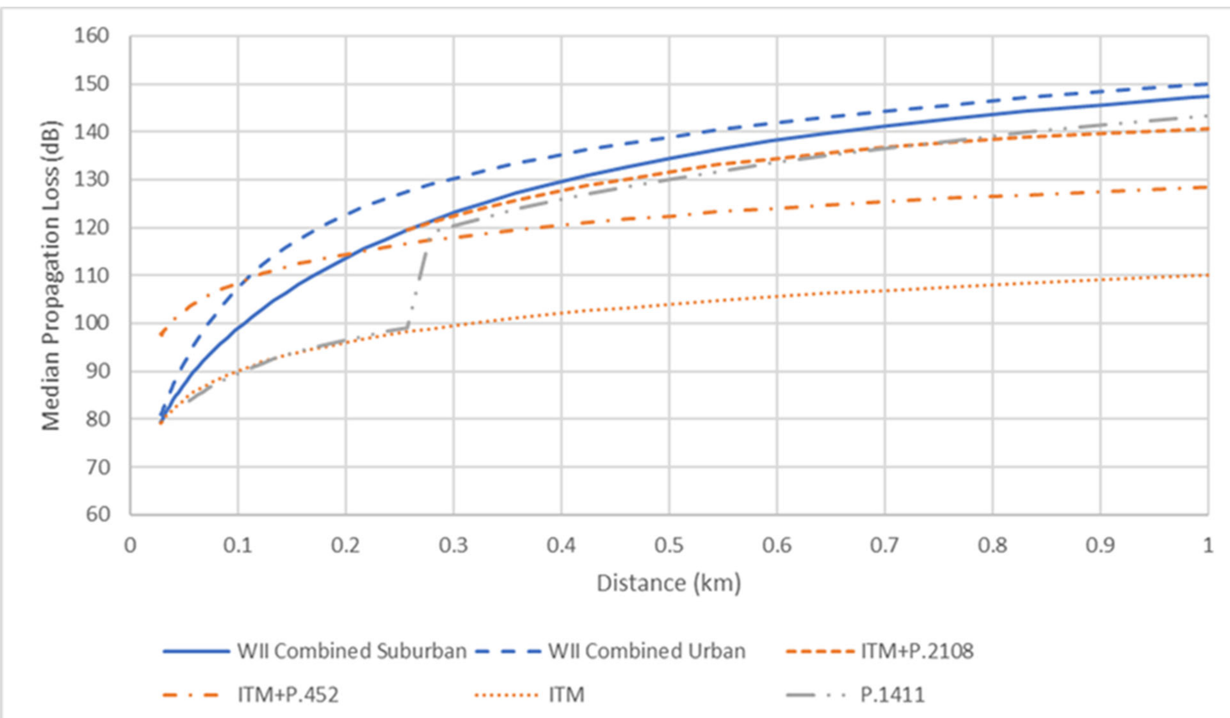

Figure 1a: WINNER II, ITU-R P.1411, ITM (flat earth), ITM (flat earth) plus ITU-R P.2108 (21-31 dB variable clutter loss vs. distance), and ITM (flat earth) plus ITU-R P.452 (18.4 dB clutter loss) models

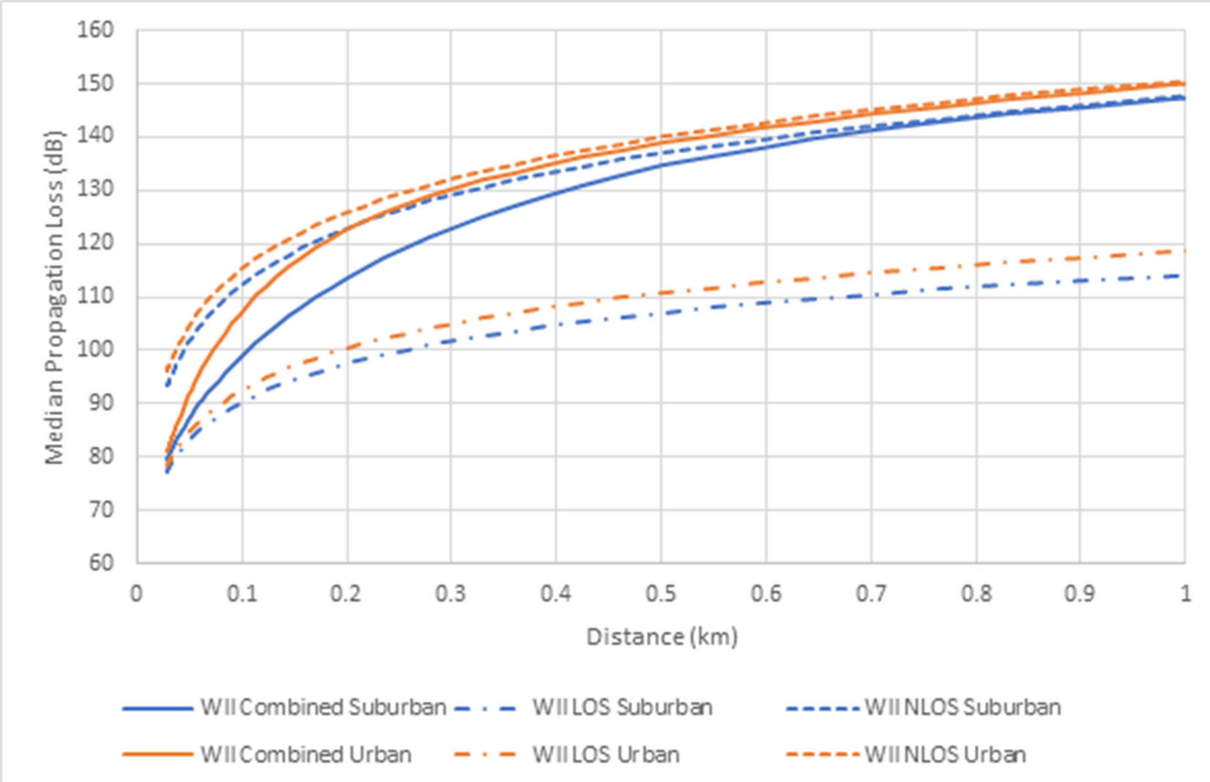

Figure 1b: Winner II Suburban and Urban LOS, NLOS, and combined (average) models

6. Another advantage of the WINNER II model is that it differentiates between urban and suburban morphologies, and also reflects clutter attenuation. When used for planning commercial deployments, especially in dense urban environments, WINNER II is more reliable than other models. This is important because dense urban environments will likely contain the majority of RLAN deployments in the 6 GHz band.

7. Although the WINNER II model is applicable up to distances of five kilometers, a conservative approach is to use it for distances up to one kilometer. Additionally, the WINNER II NLOS Urban and Suburban models match the Extended Hata (Cost-Hata or eHata) model at 2 GHz where their frequencies overlap. The eHata model, based on Okumura's extensive measurements, is widely accepted in the frequency range from 1500 to 2000 MHz.

8. In sum, the WINNER II model: reflects clutter attenuation and distinguishes between LOS and NLOS conditions; is based on a broad set of measurements conducted in cities; accounts for variable building height typical of major cities; was designed to represent a realistic propagation model and was peer-reviewed by experts in the field; and has been the model of choice in many studies and cellular coverage analyses.

9. In contrast, the ITU-R P.1411 (see Figure 1a) model is not as effective since it is defined for limited propagation situations such as street canyons and over-rooftops, for example.

10. For distances beyond one kilometer, and for distances under one kilometer in rural areas, the most appropriate and effective model would be a combination of Irregular Terrain Model (Shuttle Radar Topography Model) and a clutter loss prediction depending on the environment. Such a model would include "a combination of a terrain-based path loss model and a clutter loss model appropriate for the environment."[5]

11. The Irregular Terrain Model (ITM) 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 scenarios.[6] The model, which is based on electromagnetic theory and statistical analyses of both terrain features and radio measurements, predicts the attenuation of a radio signal as a function of distance and the variability of the signal in time and in space.

12. The ITM, along with the Shuttle Radar Topography Model (SRTM), for example, the one or three arc-second SRTM terrain database, can be used to model terrain interactions.[7] The ITM

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5 *See* NPRM ¶ 49.

6 *See* Institute for Telecommunication Sciences, *Irregular Terrain Model (ITM) (Longley-Rice) (20 MHz – 20 GHz)*, https://www.its.bldrdoc.gov/resources/radio-propagation-software/itm/itm.aspx (last visited Feb. 13, 2018).

7 Alternatively, one could use terrain databases such as National Elevation Dataset (NAD) or ones that also include building databases such as LIDAR.

uses the SRTM terrain elevation data along with diffraction theory to calculate the path loss when terrain blockage exists.

13. If the ITM alone (i.e., over flat earth) is used, it estimates approximately 50 dB less path loss than the WINNER II and ITU-R P.1411 models at a five-kilometer distance, for example, significantly overestimating received signal strength. There are two main reasons for this large discrepancy: first, the lack of terrain effects may result in tens of dBs of path loss underestimation, and second, the ITM model lacks clutter loss, which may also result in in tens of dBs path loss underestimation. This underestimation of path loss significantly overestimates harmful interference and would create an unnecessarily conservative model.

14. There are several effective ways to compensate for this underestimation:

- Use the ITM together with the SRTM when available.
- If the SRTM option is not available (and in rural areas for distances less than one kilometer), then use the ITM in a statistical (area) prediction mode, with a terrain variation parameter (Δh) set to appropriate values. Depending on the environment, Δh would equal: 0 meters (flat earth), 30 meters, 90 meters, 200 meters, or 500 meters. A Δh of 90 meters (for hills) is defined in the model as "average terrain" and it seems that it should be used in most cases.
- For urban and suburban environments, add clutter loss to the model according to the widely accepted ITU-R P.2108 recommendation.[8]
- For rural environments, add clutter loss according to the widely accepted ITU-R P.452 recommendation.[9] By default, the rural clutter morphology is assumed to be in the village

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[8] *See* International Telecommunications Union, Recommendation ITU-R P.2108-0: Prediction of clutter loss (June 2017), *available at* https://www.itu.int/rec/R-REC-P.2108/en.

center, since RLANs are generally used inside buildings. Rural locations dominated by trees can be determined by using the National Land Cover Database (NLCD)[10] in which case the village center classification would not be used (since it underestimates clutter loss in the presence of trees).

15. The ITU-R P.2108 model is valid only for urban and suburban areas. Thus, it is more accurate to model rural clutter using the ITU-R P.452 model.

16. When the ITM terrain variation parameter of Δh is set in the 30-meter to 90-meter range, the ITM path loss combined with the clutter loss prediction is consistent with the WINNER II and ITU-R P.1411 models.[11] This is illustrated in Figure 2 below.

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9 *See* International Telecommunications Union, Recommendation ITU-R P.452-16: Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz (July 2015), *available at* https://www.itu.int/rec/R-REC-P.452/en.

10 In the U.S., NLCD provides land cover data. *See* U.S. Geological Survey, Department of the Interior, *National Land Cover Database (NLCD) Land Cover Collection*, Data.gov (last updated Aug. 2, 2018), *available at* https://catalog.data.gov/dataset/national-land-cover-database-nlcd-land-cover-collection.

11 It is assumed that the ITM with the terrain variation parameter of "Δh" set to a particular value would match the ITM(SRTM) path loss prediction using terrain database information reflecting the same "Δh" value.

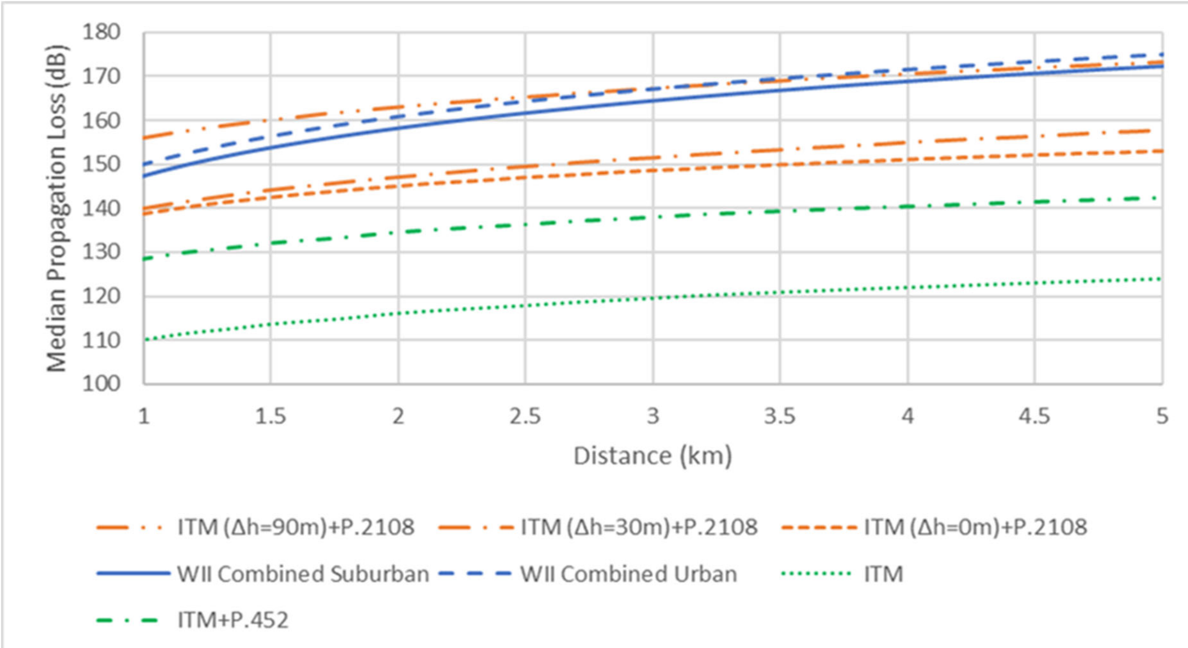

Figure 2: WINNER II, ITM (flat earth), ITM (Δh) plus ITU-R P.2108 (31 dB clutter loss), and ITM (flat earth) plus ITU-R P.452 (18.4 dB clutter loss) models

17. Based on the comparisons in Figure 2, for distances greater than one kilometer, the most effective path loss model for the 6 GHz band is the ITM(SRTM) combined with the ITU-R P.2108 or ITU-R P.452 clutter models, depending on the environment.[12]

18. The NPRM further asks whether the propagation models for different conditions could be combined into a single model.[13] If no LOS and NLOS determination can be made using the AFC on a per-site basis, then it is possible to average the path loss corresponding to LOS and NLOS conditions (see the WINNER II models in Figures 1a and 1b). The NPRM also explains that one party submitted a study that used curve fitting to combine propagation models with different ranges of applicability into a single model and asks whether such an

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[12] This combination of models—ITM(SRTM) combined with ITU-R P.2108 or ITU-R P.452—could also be investigated to potentially serve as an alternative path loss model for distances less than one kilometer, which could provide a consistent path loss model for all distances. ITU-R P.2108 only defines clutter loss beyond 250 meters; thus, for distances less than 250 meters, clutter loss extrapolation or other approaches may need to be considered.

[13] NPRM ¶ 49.

approach is appropriate in this context.[14] Such an approach is suitable when no single model applies for a wide range of frequencies, antenna heights, or distances. In that scenario, it is appropriate to use combined models.

19. In summary, the most appropriate and effective propagation models for the 6 GHz band analysis are: (1) an exclusion zone for distances between 0 and 30 meters from an FS receiver; (2) for distances between 30 meters and one kilometer from an FS receiver, the WINNER II model for urban and suburban areas, and ITM(SRTM) combined with ITU-R P.452 clutter model for rural areas; (3) for distances greater than one kilometer from an FS receiver, the ITM(SRTM) combined with the ITU-R P.2108 for suburban and urban environments, and ITU-R P.452 for rural environment clutter models. If the SRTM option is not available, ITM can be used in a statistical (area) prediction mode with a terrain variation parameter (Δh) set to appropriate values.

I, Vinko Erceg, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

Vinko Erceg, Ph.D.

[14] *Id.*

Appendix B

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of Unlicensed Use of the 6 GHz Band Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	 ET Docket No. 18-295 GN Docket No. 17-183

DECLARATION OF FRED GOLDSTEIN REGARDING FIXED SERVICE OPERATIONS

1. My name is Fred Goldstein. I have been working with the telecommunications industry for over four decades. I am currently a Principal of Interisle Consulting Group. Previously I have been with Arthur D. Little, BBN Corp., and Digital Equipment Corp. I am a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) and also serve as FCC Technical Consultant to the Wireless Internet Service Providers Association (WISPA). In my consulting practice, I have worked with a range of clients, many of whom, particularly in the public safety sphere, make use of both licensed microwave systems and unlicensed 5 GHz radio systems to perform mission-critical functions.
2. This declaration relates to the ability of unlicensed devices to operate on the same frequencies as 6 GHz Fixed Service (FS) microwave devices without causing significant harmful interference. With increasing usage of Wi-Fi (RLAN) and other unlicensed applications, including 5 GHz unlicensed radios used by Wireless ISPs, security cameras, and public safety, there is a need for additional unlicensed spectrum. At the same time, the 6 GHz band carries mission-critical FS traffic that must be protected. Thus, a sharing arrangement

must respect the primary status of FS even while allowing an unlicensed underlay. Because of the way FS links are designed, sited, and coordinated, they are generally unlikely to experience any significant level of interference from RLAN devices operating, as proposed, at low and standard power levels. For those that do receive some appreciable amount of RLAN energy, FS links generally have sufficient margin and other reliability features that they should not be adversely affected. So long as FS links are protected to a level of 0 dB I/N, the worst that should happen even in rare cases is slight reduction in speed. And, of course, the AFC will protect FS links at whatever interference protection threshold the FCC chooses for standard power devices

3. The NPRM defines two levels of underlay operation, consistent with industry recommendations: standard-power and low-power indoors. Standard-power devices, allowed up to one watt (+30 dBm) conducted power and four watts (+36 dBm) EIRP, would be required to operate under control of an Automated Frequency Coordination (AFC) system. The AFC would maintain a copy of the FCC's Universal Licensing System (ULS) database of FS operations in the 6 GHz band, and would use methodologies similar to traditional frequency coordination, such as path loss and antenna pattern analysis, to ensure that the RLAN device would not cause unacceptable interference to an FS receiver.

4. Interference protection methodologies for frequency coordination are well established, though there are different ways to perform some of the computations and arrive at satisfactory results. Most coordination makes use of C/I (carrier to interference) ratios. The NPRM also raises the option of using I/N (interference to noise) ratios. The C/I ratio compares potential interference with the predicted level of the received signal, while the I/N ratio compares it with the background noise level of the receiver itself. As the NPRM notes,

"[t]he I/N ratio is a simpler metric than the C/I."[1] It then suggests an I/N ratio of 0 dB, meaning that the interfering signal from an AFC-controlled device would be at the noise level of the FS receiver. This level is unlikely to cause significant degradation in performance. Most FS links are received at much higher signal levels, accommodating severe fade. They are required to meet the 4.4 bps/Hz efficiency requirement at least 99.95% of the time. That requires a fairly high signal to noise ratio, generally more than 20 dB, so only the deepest fades result in a reduction in performance. At worst, a 0 dB I/N ratio could result in a slight reduction in modulation for a few minutes a year, primarily in the rare instances where it coincides with fade events. And even then it would be unlikely to cause a loss in connectivity.

5. An I/N ratio would not take into account the strength of the desired FS signal and therefore may overprotect most links. But using a C/I protection threshold would also have significant practical disadvantages. It would require the AFC to perform a more detailed computation, taking into account FS antenna patterns (at both the transmitter and receiver), EIRP, and predicted receive signal levels. I/N, by contrast, requires knowledge of the receive antenna, but does not need to take the corresponding transmitter into account. Studies of sample data using C/I could help demonstrate the ratios of unlicensed to licensed signal that could, for instance, be produced by some number of non-AFC low-power indoor devices, but computational overkill could increase the cost and thus the acceptance of AFC for standard-power and outdoor devices.

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[1] *Unlicensed Use of the 6 GHz Band*, Notice of Proposed Rulemaking, FCC 18-147, ET Docket No. 18-295, GN Docket No. 17-183, ¶ 42 (rel. Oct. 24, 2018).

6. In determining that overall level of interference, one needs to take into account the fact that unlicensed devices, particularly Wi-Fi, do not transmit all the time. While FS links on 6 GHz are primarily Frequency Division Duplex (FDD) and can transmit constantly, almost all unlicensed links, including Wi-Fi, are Time Division Duplex (TDD), and thus only transmit when they have something to send, plus some modest amount of protocol overhead such as beacons. This is required by Rule 15.407(c), which states, "The device shall automatically discontinue transmission in case of either absence of information to transmit or operational failure." Most high-bandwidth data streams are bursty. This general technical requirement would remain in effect for the U-NII-5 through U-NII-8 bands as proposed.

7. Computing RLAN to FS interference has another notable difference from evaluating the links used in FS coordination. An FS link is virtually always "line of sight." Antennas are installed such that they are unobstructed by terrain or clutter (buildings, foliage, etc.). They are typically on towers, mountains, or atop tall buildings. RLAN links, however, rarely have line of sight to an FS antenna. The vast majority of RLANs are indoors. Most outdoor RLANs are at lower elevations, where clutter would be likely to impact the path to an FS antenna, and they are usually lower to the ground than FS links. There are a number of possible approaches that the AFC might use to evaluate these additional path losses, but they are undeniably significant. Low-power indoor operation, as proposed without requiring AFC, has the same path losses to any FS antennas, plus those that result from being indoors, again reducing the risk of interference.

<u>There is only a very low probability that an RLAN device will transmit directly within the main beam of an FS link without significant attenuation.</u>

8. FS antennas are highly directional. Part 101 defines two levels of performance, Category A, which is required in congested areas, and Category B, which is allowed elsewhere. The RKF

Study notes that over 83% of antennas deployed in the 5.925-6.425 GHz band exceed Category A requirements.[2] A Category A antenna has a 3-dB beamwidth of only 2.2 degrees, and a minimum boresight gain of 38 dB. The signal 5 degrees off of the boresight must be at least 25 dB lower. The front to back ratio must be at least 55 degrees. Such antennas are thus primarily susceptible to interference coming from very close to the boresight.

9. Indoor devices are generally at low elevations, well out of the direct path of most FS links. FS antenna elevation is maintained well above ground in order to minimize path losses and maintain line of sight. Hence the angle from the FS antenna to nearby indoor devices is usually well out of the main beam. Given this degree of focus, and the requirement for AFC for outdoor and higher-power indoor RLANs which keeps them out of the path the same way other coordination does, it is quite unlikely that an RLAN would cause interference to an FS link. In an urban rooftop setting, the FS antenna would generally be above the nearest potential RLAN interferers, and the attenuation of the antenna in a downward direction, as well as the attenuation from the roof itself, would minimize the amount of RLAN signal actually picked up. In other settings, the height of the tower or hilltop would have a similar effect. RLANs at close proximity to the antenna would thus not be in or near the main beam. Any potential interference would be mitigated by the directionality of the receiving antenna and in most cases by local clutter.

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2 RKF Engineering Services, *Frequency Sharing for Radio Local Area Networks in the 6 GHz Band* 29 (Jan. 2018) ("RKF Study") (citing Letter from Christopher R. Hardy, Vice President, Comsearch, to Marlene H. Dortch, Secretary, FCC, WT Docket Nos. 10-153, 09-106 & 07-121 (filed Apr. 4, 2011)), *as attached to* Letter from Paul Margie, Counsel, Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation, to Marlene H. Dortch, Secretary, Federal Communication Commission, GN Docket No. 17-183 (filed Jan. 26, 2018).

10. RLANs at a considerable distance from the FS receive antenna, such as those close to the FS transmitter, could theoretically be in the beam path. Their distance alone would reduce their impact—the inverse square law dictates that the received power decreases by three-fourths (6 dB) every time the distance doubles, and RLANs begin with much lower power than FS links. Indoor low-power devices are proposed to have a maximum EIRP of only +30 dBm, far lower than FS EIRP and lower than AFC-coordinated RLAN EIRP, and building penetration losses would further lessen their signal strength outdoors, at FS antennas. That combination of low power, angle, distance, and clutter should generally render RLANs harmless to FS receivers.

11. The so-called line-of-sight path that is designed to remain unobstructed for an FS link is wider than just the optical straight line between the two end points. A radio signal's path is characterized by Fresnel zones, which essentially form a cone-shaped area emanating from the antenna, effectively widest in the middle of the path. The first Fresnel zone is the most important one. If it is obstructed, the signal is attenuated. On a 30 kilometer path at 6.2 GHz, the first Fresnel zone has a maximum radius of 19 meters. The elevations of the two ends of the link are thus generally designed to keep the first Fresnel zone, or at least over 60% of it, above obstructions. This may require more elevation than what is simply required to overcome the curvature of the earth. A building-mounted antenna must also be high enough to keep the first Fresnel zone away from any part of the building, such as roof structures, and away from where people might walk. FS links are also generally located in such a manner as to keep all obstructions, including other buildings, out of the main beam.

12. Thus, an RLAN device is unlikely to be in the main beam of an FS path unless it is quite far from the receiver, in which case the path loss from distance reduces its potential impact on

the FS signal. Based upon evaluating almost 200,000 entries in ULS, the average 6 GHz FS signal is transmitted with an EIRP of over 66 dBm. A distant unlicensed signal with a power of no more than 30 dBm, coupled with building penetration losses, would likely have a C/I ratio well above 50 dB, and thus be harmless to an FS link. Rain fade may weaken the desired FS signal on a long link, but it would also weaken distant interferers.

<u>An unlicensed transmission within the main beam of the FS receiver is still unlikely to cause material interference.</u>

13. For indoor low-power devices not controlled by an AFC system, a number of factors lessen the risk of harm from such operations.

14. Power spectral density is one such systemic parameter. The proposed low-power indoor operations have a maximum EIRP of +30 dBm and a maximum conducted power of +24 dBm. This limits the total power, not the power *per* 20 megahertz. Because 6 GHz RLAN operations will typically use channels *at least* as wide as 20 megahertz—and often wider—power *per* 20 megahertz will usually be significantly below the total radiated limit. The primary purpose of allowing underlay operation in the 6 GHz band is to facilitate high-bandwidth RLAN operation on channels wider than allowable today in the U-NII-3 band. For example, 802.11ac, widely used in U-NII-3, has a maximum channel bandwidth of 80 megahertz, which is generally contiguous. (Some devices can operate on two non-contiguous channels, and thus up to 160 megahertz.) The pending 802.11ax standard, on the other hand, allows for wider and more flexible frequency selections and these wider channels with the same total power limit creates a lower power spectral density within each MHz of the channel. Thus a 160-megahertz channel has half the PSD of an 80-megahertz channel.

15. An FS link in the proposed U-NII-5 (lower 6 GHz) band has a maximum channel bandwidth of 60 megahertz. The upper 6 GHz FS band, proposed as U-NII-7, has a maximum channel

bandwidth of 30 megahertz. If a 160-megahertz underlay signal overlaps a 60-megahertz FS signal, only about 37% of the underlay signal's power will be within the FS channel. This alone will result in about 4 dB of reduction in interference potential from the underlay signal. For a 30-megahertz FS channel, the reduction would be about 7 dB.

16. The nature of the different systems' antennas and their signal patterns also lessens potential interference. FS is characterized by high-gain antennas with very high rejection of out-of-beam signals. Most RLANs, especially indoors, are the opposite; they are designed to spread the power rather broadly. No antenna is truly isotropic (emits power equally in all directions, like a perfect sphere) but many types of unlicensed device seek to approximate it. Mobile phones, for instance, need to be as close to isotropic as possible, as they are held in all sorts of angles and move around. Home access points seek to fill the home in all directions, including up and down, since homes are not all flat. In these cases the EIRP is close to the conducted power limit; the allowable 6 dB of gain, before power reduction occurs, is rarely reached. In fact, because RLAN conducted power levels are limited by the radiated power at the point in their antenna radiation pattern with the greatest gain, the energy radiated in most directions will be lower still. Some home access points can be mounted horizontally or vertically; if they had significant antenna gain in the horizontal direction, then angling the device by 90 degrees would dramatically impair performance. Enterprise APs are more likely to exhibit some degree of gain based upon not sending signals upwards or downwards. These are "omnidirectional" but not isotropic, as they are not omnidirectional in the elevation plane.

17. Many higher-end APs, which are more likely to have higher EIRP, make use of beam forming. This is done by having multiple antennas fed with phase relationships that create gain in some directions and losses in others. A beam forming system generally adapts to the

location of the target client, so its power is not uniformly transmitted in all directions, or even consistently towards one direction, as in a sectoral antenna. Because an FS antenna is often not in the same direction as a Wi-Fi client, beam forming antennas are even less likely to pose a risk to FS than conventional omnidirectional antennas of the same power level.

18. In the case of AFC *coordinated* access points using beam forming, another property of beam forming antennas can be taken into account. Antennas can create nulls in their pattern. On a receive antenna, that reduces the impact of interference. In the case of RLANs or wireless ISPs protecting FS, though, a null in the direction of an FS receiver, if coordinated by the AFC, could allow greater EIRP in other directions. Beam forming is becoming less expensive and more common; it can play a greater role in future band sharing in order to make more efficient use of scarce spectrum.

19. Building penetration loss, of course, is a major factor in why indoor devices pose less of a risk to FS operation than outdoor devices. The lowest penetration losses are in wooden houses, but home access points are less likely than enterprise units to operate at or near full legal power. Homes are also more likely to be far from FS antennas, or much lower. Commercial buildings are more often made of concrete, steel, and the type of coated glass that itself impedes RF transmission. In the 3.5 GHz CBRS band, indoor devices are currently managed with a nominal building penetration loss assumed to be 15 dB. That is an unnecessarily conservative value for the 6 GHz band, as it is used for protecting, among other things, military radar and satellite earth stations, with different interference protection needs. Losses are greater at higher frequencies; the 20 dB value used for the RKF Study is likewise quite conservative.

20. Besides building penetration losses, other obstructions in the path contribute to path loss from typical RLAN installations. Many client devices are hand-held; these may be blocked by the wearer's body. Laptop computers and tablets, even when on a desk, may be shielded by the user or by furniture in the direction of the potentially-impacted FS receiver. In many areas, especially around homes, trees are near the building. A useful guideline in the 5 GHz band is that a typical tree directly in the path of the signal near the antenna may add about 12 dB to the path loss. (Of course a deciduous tree in winter has less path loss than in the summer, as it is the moisture in the leaves that have the most impact. Evergreens are lossy year-round.) FS links are always above the trees; RLANs are more often below the tree canopy.

21. Polarization loss also reduces the risk from Wi-Fi devices. Most FS links are coordinated with a single polarization. Wi-Fi, in contrast, most often uses MIMO with both vertical and horizontal polarization. Hence half the access point's power is likely to be in the wrong polarization, which can create attenuation of more than 10 dB for that chain.

22. Indoor RLANs are thus likely to be isolated from FS paths by some or all of these mitigating factors, compared to the desired signal, even without AFC coordination: low power spectral density within the FS passband, polarization mismatch, outdoor clutter such as buildings and foliage, building penetration loss, antenna pattern attenuation, and in some cases beam forming away from the FS receiver.

<u>FS users can tolerate some amount of RLAN interference without major impact</u>

23. It is critical to note that even in the rare event that an FS receiver received sufficient energy from an RLAN transmitter to exceed the applicable interference protection threshold, this will not typically be harmful. Competing demands for spectrum require a more nuanced real-world protection approach which recognizes both that FS links must be protected from

harmful interference, but also that FS receivers can tolerate sporadic instances of slightly increased noise levels without material harm.

24. No radio link is 100% reliable. There are many failure modes that can impact a microwave link which, if it is to be reliable, the link must be able to tolerate without significant degradation. Interference is just one of them.

25. Rain fade is another. The 6 GHz band is widely used for long paths precisely because it is the least susceptible to rain fade. ITU-R Recommendation P.838-3 indicates that a rain rate of 50 mm/hr, typical of temperate zones, has a loss of 0.229 dB/km at 6 GHz. On a 50 km path, that adds up to 11.45 dB. Heavier rains cause disproportionately heavy loss, though. Doubling the rain rate to 100 mm/hr raises the loss to 0.682 dB/km. Microwave links thus are designed with a fade margin intended to accommodate the rainfall expected in their area, typically for 99.999% or even higher reliability, albeit with the possibility of reduced data rates for a fraction of a percent of the time. A few minutes per year of loss due to weather, however, is not uncommon. This fade margin, however, also serves as protection against interference. Unless the rain is falling at a rate that occurs infrequently, the extra power used for the rain fade margin also works to limit the impact of interference, improving the C/I ratio. Because rainfall is not correlated with heavy RLAN use—in fact, it would most likely be *anti*correlated with outdoor use—the overwhelming likelihood is that, in the rare case that an RLAN device materially increases the noise received by an FS receiver this would not occur during an extreme rain event, and therefore *would* occur during a period when additional excess fade margin is available.

26. To give an example of how large fade margins can be and how infrequently they are fully utilized, I used a path calculator (AviatCloud) to show the typical reliability and impact of

rain and multipath fade, and thus how much fade margin is typically designed into FS links. The two ends of the model link are 26.4 miles apart, from an urban high rise roof to a hilltop tower (not an actual tower, but assumed for this test), too great a distance to reliably reach on higher-frequency bands and thus best suited to 6 GHz. They are elevated well above any Fresnel zone or clutter incursion. The modeled rain rate for that region (Boston) is 39 mm/hr. Antenna gain was modeled as 39 dB at each end, using a six-foot dish meeting FCC Category A requirements. For the purpose of the model, this is an *unprotected* link, a raw path between two dishes.

27. With a 60-megahertz channel (the maximum allowable bandwidth in the lower 6 GHz band), 1024QAM modulation (10 bits/symbol), and a modeled transmitter power of 28 dBm, the usual received signal strength is predicted to be -35.2 dBm. The receiver threshold for 1024QAM is -61 dBm, and the fade margin is 25.7 dB. Net of forward error correction, the link capacity is 462 Mbps (7.7 bps/Hz). At these parameters, the rain fade probability is essentially zero. With the city rooftop antenna 320 feet above ground and the remote antenna 120 feet above ground (typical of a tower sized to reach safely above the tree canopy), the primary cause of impairment is multipath. The model link is only able to sustain 1024QAM performance 98.34% of the time even with its 25.7 dB fade margin.

28. One might expect that such a link, not being very robust in the absence of RLAN interference, would be the most effected by RLAN operations. But in practice several factors minimize that risk, even for this type of link. For any appreciable interference to occur, an interfering RLAN signal would have to coincide with significant multipath fading, Both of these events are rare on their own, and their combination is rarer still, especially considering that multipath fading primarily occurs at night, when indoor Wi-Fi usage at business

locations, which are likely to be higher and closer to FS paths than homes, is at a minimum. Home Wi-Fi access points are also generally lower-powered than enterprise models used in office buildings and hotels.

29. Furthermore, even in these rare cases, the effect on link performance is very limited. Multipath interference is particularly problematic at very high modulation rates, where receivers need the strongest signals. If 1024QAM is not sustainable, an FS radio will typically shift to a lower modulation rate. At 256QAM, netting a 357 Mbps link speed, the same path's reliability improves to 99.77%. Part of that improvement is a 1.5 dB increase in transmitter power output, because transmitters are more efficient at lower modulation schemes. Most of the gain, however, is due to improved receiver sensitivity, a threshold of -68 dBm. The resulting 34 dB fade margin leaves much more room for multipath and other losses. However, some multipath loss still occurs at high power since multipath is essentially a form of self-interference.

30. Again, loss mitigation occurs within the fixed system itself. During that 0.23% of the time when 256QAM is not usable due to multipath loss, the link down-shifts again. At 64QAM, a data rate of 265 Mbps still carries 4.41 bits/Hz, almost exactly the FCC minimum that a link must be engineered to provide 99.95% of the time. And indeed this model link has 99.95% reliability at 64QAM. It is 99.998% reliable at the lowest rate, QPSK, but still passes 77 Mbps at that speed. Actual loss of connectivity due to multipath interference would occur only 8 minutes out of an average year.

31. That very small percentage of the time when the path margin is being consumed by multipath, rain, or the combination of the two is the only time the link is likely to be vulnerable to RLAN interference. But even then, coordination by the AFC based on an I/N

ratio would limit interference to the same level as the background noise. Because links are engineered to handle fade, most of the time the C/I ratio will be much greater than actually required, resulting in no degradation to the performance of the link.

32. A link that required extreme reliability, however, might be engineered a bit differently. One common method would be to use space diversity—two antennas on the same tower[3]. Multipath is especially well overcome by space diversity, as these out-of-phase reflections vary over centimeter distances. Using the same vendor's model radio with space diversity antennas, two antennas on the same towers ten meters apart, to provide path protection, 1024QAM reliability improves from its non-protected level of 98.35% to 99.87%. That is a 92% reduction in time when the link is degraded. At 256QAM, the diversity-protected link reliability is already up to 99.95%, and 64QAM works 99.9997% of the time. That is less than two minutes per year of outage. Predicted loss at QPSK is three seconds per year.

33. The point of these numbers is that the typical FS path operates with considerably more power than usually is necessary, in order to handle those very-high-rain or multipath conditions when signals are most impaired. Thus the impact of unlicensed interference is likely to be noticed much less than 1% of the time—and this is only in the unlikely event that any measurable interference exists in the first place.

34. Another factor favoring the graceful degradation of links, rather than sudden and complete outage, is the fact that most microwave transmitters are more efficient, and thus produce higher power output, at lower modulation rates. As an example, a typical FS transmitter (Aviat WTM4500-HP) is specified as having a transmitter power output, in 6 GHz, of +28

[3] *See* RKF Study at 28 ("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.").

dBm when using 1024QAM, rising to +29.5 dBm at 256QAM and +32 dBm at QPSK. This contributes to links' ability to stay up, if not at full speed, under difficult conditions. The same effect is true for Wi-Fi and most other unlicensed transmitters. Even if they have a rated power output of +30 dBm, the maximum allowed for unlicensed use, that generally applies only at very low modulation indices. For example, the MikroTik RB951G-2HnD indoor access point is specified as being able to generate +30 dBm at MCS0 (BPSK, 7.2 Mbps in 20 megahertz) but only +23 dBm at MCS7 (64QAM, 144 Mbps in 20 megahertz). Thus most Wi-Fi is likely to operate at much lower power levels than the equipment is nominally approved for. Rate adaptation, in response to variations in path conditions, include both modulation type, Forward Error Correction level (in Wi-Fi, it ranges from 1/2 to 5/6), and power level.

<u>System reliability may exceed link reliability</u>

35. But even then, microwave systems that require very high reliability do not depend on the fade margin of a single receiver. There are two approaches to improving overall system reliability via redundancy. One, noted above, is to apply it, referred to in this context as diversity, to the microwave link itself. The other is to make the link part of a network that has multiple ways to reach the same destination.

36. Diversity is a well-established practice in microwave systems. The deep fades, from both multipath and rain, that most seriously impact links tend to very widely over small distances. Systems that require high reliability thus often employ space diversity. The microwave receiver chooses the better of the two signals. Frequency diversity—simultaneously transmitting on two channels in the same band—also works, but is now discouraged as an inefficient use of spectrum.

37. The network approach has become more common in the internet age. Large networks generally make use of some kind(s) of routing protocol to maintain connectivity via links that are up and running, even when others fail. Standards for this exist in the IEEE 802 domain, where Ethernet and related LAN protocols are standardized. Rapid Spanning Tree Protocol (RSTP), for instance, is a widely implemented protocol for finding a working path across a network that has multiple links. While it began for enterprise Ethernet LANs, "Ethernet" currently refers to a family of metropolitan and wide-area protocols (e.g., the "Carrier Ethernet" family specified by Metro Ethernet Forum) and these are often configured with complex graphs. RSTP allows rerouting across such a network within about one second. Microwave radios connected to Ethernet switches, which are very common, thus gain the benefit of the Ethernet switching.

38. IP networks, of course, are themselves typically able to reroute traffic. Microwave links are often deployed as part of modern enterprise or carrier IP networks. IP itself, which operates above the Ethernet layer that most modern radios operate at, has several routing protocols. Among them are OSPF, IS-IS, BGP, and EIGRP. Again, a loss of connectivity in one link in such networks does not necessarily mean a loss of connectivity between the applications using the network; rerouting takes place automatically.

39. Any of these network approaches can be deployed in a multi-medium network, one with a mix of microwave, fiber, and other media. Some networks use a hybrid fiber-microwave design. Fiber optics generally have a higher bandwidth capacity than microwave, but if they fail, restoration can take days; microwave tends to be faster to restore. And they may fail at different time; microwave is more sensitive to rain, for instance, while winter icing can bring down trees that in turn bring down aerial fiber.

40. Resilient network design thus does not count on making any one link bulletproof, but on making the overall network design reasonably redundant. Although the Commission can expect that 6 GHz RLAN devices will protect FS links from harmful interference for the reasons described above, it is important to bear in mind that even if such interference *were* to occur, critical systems would likely remain unaffected due to these other system resiliency features.

I, Fred Goldstein, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

Fred R. Goldstein

Fred Goldstein

Appendix C

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

DECLARATION OF FRED GOLDSTEIN REGARDING AUTOMATIC FREQUENCY COORDINATION AND THE UNIVERSAL LICENSING SYSTEM DATABASE

1. My name is Fred Goldstein. I have been working with the telecommunications industry for over four decades. I am currently a Principal of Interisle Consulting Group. Previously I have worked with Arthur D. Little, BBN Corp., and Digital Equipment Corp. I am a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) and also serve as FCC Technical Consultant to the Wireless Internet Service Providers Association (WISPA). In my consulting practice, I have worked with a range of clients, many of whom, particularly in the public safety sphere, make use of both licensed microwave systems and unlicensed 5 GHz radio systems to perform mission-critical functions.

2. This declaration relates to the ability of an Automatic Frequency Coordination (AFC) system to protect Fixed Service operations from unlicensed operations in the upper C-band, the 5925-6425 MHz (U-NII-5) and 6525-6875 MHz (U-NII-7) bands that are currently shared between Fixed Satellite Service (FSS) uplinks and Fixed Service (FS). The FCC's Universal Licensing System (ULS) database includes enough information for the AFC to perform the calculations needed to protect FS links. In cases where data is inaccurate, the FCC could

easily create a process for licensees to correct/complete it, and use protective default values for those that do not comply.

<u>Frequency coordination is a well-established practice:</u>

3. FS use under Part 101 requires frequency coordination.[1] This has been standard practice for decades, essentially since commercial private microwave operations began. Numerous entities operate as frequency coordinators, following the same practices, to ensure that users do not have conflicts. Part 101 operation is characterized by its careful coordination, designed for very high reliability of service and negligible chance of conflict. It is important to avoid disruption to this important service.
4. Frequency coordination involves careful analysis of location, antenna patterns, and terrain. It was historically performed manually, but nowadays computers play a key role in the analysis. Coordination is fundamentally about protecting receivers from undesired signals that would impair reception of desired signals. This includes both the signals that arrive under ordinary circumstances and those which have a significant likelihood of arriving when propagation conditions are outside of the norm.
5. FS on 6 GHz operates in a Frequency Division Duplex (FDD) mode, with each FS antenna generally performing both a transmit and receive function on different frequencies. Each side of the link is analyzed separately to avoid conflict. Unwanted transmissions near an antenna on the transmitting frequency are unlikely to be problematic; the receive frequency requires the most protection. An unwanted signal can come from a large area in front of, near, or

[1] *See, e.g.*, 47 C.F.R. § 101.103 (describing frequency coordination procedures for FS licensees).

behind the transmitter that the receiver is listening to. Hence, a so-called "keyhole" area needs to be protected.

6. Because there are many coordinators, they all need access to the same, up-to-date information about what licenses exist and what frequencies are in use. The FCC's ULS database contains this information. Every FS license should have entries in ULS specifying its transmitter location, its receiver location(s), site elevation above mean sea level, antenna elevation above ground level, transmitting frequency, frequency tolerance, emission designator (which specifies signal bandwidth), and effective isotropic radiated power (EIRP). Most entries also specify the transmitter manufacturer and type. Most, but not all, specify the antenna type, including its forward gain and half-power (3 dB) beamwidth. Antenna beamwidth is, however, strictly regulated, as Part 101 establishes minimum performance requirements for FS antennas.[2] For the 6 GHz band, minimum gain is usually 38 dB, with a 2.2-degree 3 dB beamwidth. In non-congested areas, a 32 dB gain antenna with 4.1-degree beamwidth is allowed.[3] Even this is well above what is typically seen in the unlicensed arena. These could provide worst-case default values where accurate antenna information has not been provided.

7. Once a coordinator selects an apparently-clear frequency for a new proposed path, prior coordination notice (PCN) is sent to existing licensees in the subject area. This enables incumbent licensees to request further study, or that a proposed license not be granted, if the proposed path seems to create a possible conflict. The PCN response period is generally 30

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2 *See* 47 C.F.R. § 101.115.

3 Some pre-1997 installations may be grandfathered in with lower-performance antennas. However, current requirements are more suitable as defaults; grandfathered low-performance installations can protect themselves by ensuring the accuracy of their ULS entries.

days, though an expedited PCN allows 15 days. The license application is then generally filed immediately upon expiration of the PCN period. Applications for pending licenses, which have already been coordinated, are listed in ULS, prior to the grant of a license. The Commission then undertakes a review of the application before it is granted. While it is theoretically possible for a license to be granted within one month of application, actual deployment of the FS link usually takes significantly longer.

8. Thus, ULS provides essentially all of the data necessary for an AFC system to operate. The AFC will need to maintain updated ULS records for all licenses in the 6 GHz band, as well as for pending applications already coordinated. For any unlicensed operation subject to AFC, it will need to locate all FS users, including pending applications, within potential interference range, evaluate the path between the unlicensed user and the FS user, and evaluate the FS user's receiver antenna gain in the direction of the unlicensed user. If the path and alignment are such that the receive antenna is likely to pick up a harmful level of interference from the unlicensed user, then its frequency should be deemed unavailable by the AFC. This is essentially the same process now performed by manual frequency coordination, but automated and on a more local scale, given the much lower EIRP of an unlicensed system. Essentially, the "keyhole" of the AFC will be smaller than that used by Part 101 coordinators, and it will need to take into account the different usage patterns of unlicensed operation, such as less-directional antennas and paths that are not line-of-sight. For the sake of simplicity, AFC can also make use of an interference to noise (I/N) ratio, which protects receivers based upon the anticipated baseline noise level of the receiver. This does not take into full account the typical fade margins of actual links. Thus, the AFC is likely to provide generous protection to most FS links and adequate protection to all.

9. The AFC needed to protect 6 GHz FS operation is far simpler than the SAS specified for the 3.55-3.7 GHz CBRS band. Several requirements of the SAS are inapplicable here. One is the very rapid time scale on which the SAS operates. The SAS must be able to clear a frequency within five minutes or less, because it must protect naval radar systems that come and go. The AFC, in contrast, would deal with changes that occur slowly. Thus the AFC does not need to be queried often. Given the time it takes for an application to be processed and for a microwave link to be installed, monthly queries should typically suffice. Even the most urgent installations, with an expedited 15-day PCN period, generally take at least a month to process start to finish.

ULS location information is generally accurate but corrections should be encouraged:

10. Protected device license information in ULS requires site information to be entered in three-dimensional coordinates (latitude, longitude, elevation). No evidence exists of widespread error in these coordinates. The required accuracy of Part 101 licenses is one arc second in the horizontal direction and one meter in the vertical direction. One arc second is generally less than forty meters accuracy in the horizontal direction, though one arc second of longitude is longer near the equator than near the poles.

11. Latitude and longitude are, by rule, referenced to the "National Spatial Reference System." Some confusion may result from the fact that there is more than one latitude and longitude coordinate for a given location, depending on which datum is being used. Older maps made use of the NAD27 (North American Datum of 1927) coordinates. A more accurate survey, using satellites, resulted in the newer NAD83 (North American Datum of 1983) coordinates, which is specified for new license applications. That is very close to the WGS84 (World Geodetic System 1984) datum, which applies worldwide. WGS84 and NAD83 started almost

the same and differ primarily due to tectonic drift, which has been much less than one arc second. Thus, an antenna located using WGS84 coordinates (which are used, for example, by Google Earth) would be well within NAD83 tolerances. The FCC has online tools to convert between NAD27 and NAD83. Hand-held GPS devices are also generally accurate enough to determine latitude and longitude, though civilian GPS is not very precise with regard to altitude.

12. Nonetheless, it is possible that errors have crept in. Prior to widespread computer mapping, coordinates were often determined by using paper maps, interpolating between parallel and meridian lines. The Commission should encourage licensees to clean up any erroneous entries that they find. The Commission can facilitate this by providing clear notice to licensees and opening an amnesty window for geolocation corrections. During this period, fees should be waived, and coordination requirements should be relaxed, so long as licensees certify that the change is a correction and does not reflect a physical change in location. This way, future coordination with unlicensed devices by the AFC, and between Part 101 licensees using the legacy coordination process, can be performed with more confidence.

<u>Incomplete entries in ULS should be flagged for correction:</u>

13. Some entries in ULS, especially older ones, may lack some information normally supplied. This should be easy to spot. ULS is a large relational database, and it should be possible to check all currently-active entries for 6 GHz licenses to ensure that all the required information is present.

14. A cursory examination of records shows that the most common omission is probably detailed antenna information. Section 101.21(e) states that license applications should specify "[r]eceiving antenna(s), model, gain, and, if required, a radiation pattern provided or certified

by the manufacturer."[4] Some ULS entries specify the gain but not the model. Radiation pattern is a characteristic of the antenna model, so individual applicants who use a known antenna should not need to enter the pattern, but the model itself should be specified. Licensees have an incentive to do this so that they can be protected most accurately against interference, whether from other Part 101 licensees or from other users, such as the proposed Part 15 users.

Default values are generally adequate:

15. While specific details of Part 101 receiver locations are ideal, AFC can operate without them. Antenna performance requirements are specified in Part 101. If an antenna is in a congested area, then it must meet performance Category A, as specified in section 101.115(b)(2). Otherwise it may use either Category B1 or B2. Performance categories specify minimum antenna gain, maximum 3 dB beamwidth, and suppression below peak gain in seven different ranges of angles off the centerline (from 5-10° to 140-180°).[5]

16. In the event that a ULS entry lacks its elevation data, but does indicate the height of the tower, then an interim answer could be to use a value based upon the height of the tower or the location of other FS devices on the tower. The FS licensee should also be required to correct such omissions.

17. Tower height itself is not necessarily a useful value, as there are many very tall broadcast towers with FS antennas mounted quite low (i.e., well below the midpoint). If the elevation is not provided, using the full height of the tower could prove counterproductive and, in most cases, significantly overprotective. The default should thus be high enough to provide

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4 *See* 47 C.F.R. § 101.21(e).

5 *See* 47 C.F.R. § 101.115(b).

reasonable protection but not so high as to discourage prompt correction. Too high a default could also under-protect against interference from sites very close to the tower, because antenna gain at angles well below the boresight is very low, and vertical spacing is generally more important than horizontal spacing. Thus, nearby interferers could appear to be weaker than they actually are.

18. In any case, all licensees are subject to a plenary obligation to provide truthful information on license applications. Protection against harmful interference is predicated on accurate information. Both incumbent FS licensees and potential AFC users have such obligations. Unlicensed operations using the AFC are not protected against interference, and must protect FS licensees against interference, but still have an incentive to provide accurate information.

I, Fred Goldstein, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

Fred R. Goldstein

Fred Goldstein

Appendix D

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

CHARACTERISTICS OF ENTERPRISE DEPLOYMENTS USING IEEE 802.11 EQUIPMENT:

JOINT DECLARATION OF MATT MACPHERSON, CHUCK LUCASZEWSKI, AND SUNDAR SANKARAN

1. I, Matthew MacPherson, Chief Technology Officer, Wireless, Cisco Systems, Inc. work in the Enterprise Networking Busness Unit of Cisco's engineering organization. My group has world-wide responsibility for Cisco's Wireless thought leadership through analyzing technology and industry trends and providing direction to product and engineering teams. The Wireless CTO team manages the innovation pipeline from idea to proof-of-concept and, eventually, to execution decisions. Domains include driving strategy for both Service Provider and Enterprise markets for a broad range of wireless solutions across licensed, unlicensed and shared spectrum. Through boards of directors and workgroups, my team takes a strong leadership role in defining industry standards. I sit on the Board of Directors for the Wireless Broadband Alliance (WBA) and the CBRS Alliance, and my team participates in standards groups for Wi-Fi Alliance (WFA), GSMA, Internet Engineering Task Force (IETF) and Institute of Electrical and Electronics Engineers (IEEE). I joined Cisco in 1995 and have

driven multiple service provider collaborations and strategic alliances. Prior to Cisco, I spent eleven years developing communication and control systems at Fermi National Accelerator Laboratory—the high-energy physics particle research facility. I hold a master's degree from Illinois Institute of Technology (IIT) and a Bachelor of Science in Computer Engineering and Systems from Taylor University.

2. My name is Chuck Lukaszewski. I am Vice President, Wireless Strategy and Standards for Aruba, a Hewlett Packard Enterprise company and report to the Chief Technology Officer of the company. Aruba is the second largest manufacturer of managed WLAN systems in the United States. Previously, I served on and then led the company's global Customer Engineering team where I was personally responsible for engineering RF coverage and deploying large-scale 802.11 networks in hospitals, universities, warehouses, seaports, rail yards, manufacturing plants, and large stadiums, including for two Super Bowls. I am the author of six books and design guides including *Very High Density 802.11ac Networks* and *Outdoor MIMO Wireless Networks*.

3. My name is Sundar Sankaran and I am Vice President of Engineering at Ruckus Networks, an ARRIS Company, where I lead the Access Point Hardware and Software team. I have been involved in design and development of wireless systems for nearly two decades. I joined Ruckus from Atheros/Qualcomm, where I was Senior Director of Technology and served as overall engineering lead, with the responsibility to deliver silicon along with reference hardware and software, on multiple Wi-Fi chip programs. Prior to Qualcomm/Atheros, I have been employed at Intel, ArrayComm, and Infosys. I have also served as an Adjunct Faculty in the Electrical Engineering Department at Santa Clara University. I am a co-inventor on eighteen U.S. patents as well as several pending patents, all

in the area of wireless communication. I earned my bachelor's degree in Electronics and Communication Engineering from Anna University, and master's and Ph.D. degrees in Electrical Engineering from Virginia Tech.

4. The purpose of this declaration is to explain the deployment of Wi-Fi networks in enterprise networks, with particular reference to RF design and utilization, including typical antenna types and placements, and also to show that these deployments are non-disruptive to incumbent outdoor use of this spectrum. For the purpose of this declaration, we use the term "enterprise networks" to mean wireless networks set up in for-profit, non-profit, governmental, education, healthcare, and other similar settings <u>inside</u> of buildings, typically by an information technology installation company or the IT department of the enterprise itself. We are not addressing a single Wi-Fi router that would be offered as a desktop unit directed to the small business market, and typically self-installed. In addition, we are not addressing outdoor enterprise networks.

5. Enterprise Wi-Fi networks typically consist of several parts: client devices, access points (APs) including antennas, and centralized services/functions that may provide network management and control (including power and policy enforcement), as well as other capabilities that are not relevant to the radio frequency characteristics of the network and its use.

6. Client devices (such as smartphones, laptops, and tablets, as well as IoT devices) both associate to APs and authenticate to the enterprise network. This means that not only has a radio link formed between the client device and an AP, but also that the enterprise network has agreed to trust the client device and allow it to use its network for data exchange. Prior to authentication and association, the client device probes for nearby APs to find an AP that

can, for example, support connectivity to the enterprise network and establish a link to the public internet. Sending probes does not constitute association. Access points, meanwhile, transmit beacon frames, enabling the client to generate a list of the Wi-Fi networks in range. Information gained from client probing will allow the client device to rank order the available Wi-Fi networks within range. When a user seeks to connect with a specific AP identified from the probing and beaconing processes, the user must first authenticate to the specific AP, and once authenticated, the client device and AP become associated. Probing is accomplished with extremely minimal upstream traffic from the client to the APs. In enterprise networks consisting of multiple APs that are managed, previously associated clients that are losing signal with an AP (e.g., when the client device is being carried around an office) can be directed by network management tools to listen for beacons from a different AP that will create a stronger radio link, a standards-based feature known as a reduced neighbor report. This reduces the need for clients to probe.

7. Access points are typically mounted on, or in, ceilings in order to minimize the cost of horizontal Ethernet cabling. This ensures that the APs are difficult to unplug or tamper with, even unintentionally, while permitting reasonable access to the IT department or installer once the device has reached the end of its useful life and needs to be upgraded. As a general rule, the AP is connected by Ethernet cabling to an equipment/wiring closet, and receives power from that Ethernet cable. Particularly in high rise structures, the use of Ethernet cabling means that the APs cannot reside in the floor—as the floor is generally poured concrete.

8. The number of APs used to deploy signals within a building depends upon the capability of the AP technology being installed, characteristics of interior construction that may inhibit a

radio signal from reaching portions of the physical space where signal is desired, the number of connections (e.g., users, IoT devices) that the network needs to serve at peak capacity, and whether the network will also support location-based services.

9. Most installations for mid- to large-sized enterprises (and including smaller branch offices of these entities) will initially be planned with a site survey to ensure that the strength of the radio signal is sufficiently strong wherever coverage is needed (such as work stations, open office environments, private offices, and meeting rooms), and to ensure that multiple APs are located in a way that will make the most efficient use of the unlicensed spectrum and limit interference between stations, thereby maximizing throughput. In sum, the planning process enables installation of a Wi-Fi system that has the coverage and capacity to support business processes, with the minimum number of APs necessary to achieve these goals. In the United States, with some variance due to differing business goals, the site plan typically results in a three-channel (for the 2.4 GHz frequency-range) or 12-channel reuse pattern (in 5 GHz) of APs enabling seamless coverage and handoff as workers or things move about inside the physical space, along with sufficient capacity to meet the business requirements.

10. Importantly, indoor enterprise Wi-Fi networks are not intended to provide access to client devices outdoors. Indeed, newer highly energy efficient buildings (e.g., LEED certified buildings and buildings constructed in cities under modern building codes) utilize exterior construction materials and metalized glass windows that effectively isolate the indoor Wi-Fi networks from the outdoor environment. Accidental outside-to-inside connections due to particular signal geometries result in poor user experience for both outdoor users (due to low Signal-to-Noise Ratio and low connection speed) and indoor users (due to less available channel airtime), and are therefore considered to be a problem by RF architects. RF architects

will reduce power or make other configuration changes on the indoor network to minimize such occurences, and may deploy dedicated outdoor coverage if the site requires it.

11. Antennas used in ceiling mounted APs are taken into account in the planning process, as different antennas may radiate emissions in somewhat different patterns. Since at least 2010, most enterprise APs have employed a "squint" or "downtilt" pattern to improve coverage directly below the AP. A squint antenna will radiate energy down toward the work environment below it, with the direction of maximum gain generally at an angle of 30 to 45 degrees below the ceiling line.[1] If present, antenna gain, which is usually a low value below 6 dBi, acts to adjust the usable footprint of the AP by shaping the emissions across the work surface where signal is needed. Representative antenna patterns from each of our three companies are below:

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[1] *See* B. Montenegro et al., *Characterization of the RF emission patterns of IEEE 802.11ac Wireless LAN consumer and enterprise devices* 3, 26 (Mar. 27, 2015), *as attached to* European Commission – Joint Research Centre, Project Team Spectrum Engineering 45 (SE-45), Doc. SE24(15)042RO, *WI52: Results of 5GHz RLAN (802.11ac) AP emission pattern measurements of consumer and enterprise devices* (Apr. 9, 2015), *available at* https://cept.org/ecc/groups/ecc/wg-se/se-24/client/meeting-documents/?flid=4116 (measuring four enterprise antenna emission patterns, the study found "[e]nterprise APs present higher directivities than the consumer ones. Consequently, the emission pattern depends strongly on how the AP is positioned. . . . For ceiling mounted APs, maximum EIRP values are found downwards. E1 and E4 APs produce maximum EIRP for elevations between -10° to -60°. From -10° to upper elevation angles, EIRP decreases substantially until -9 dB at 90° elevation. On the contrary, E3 AP produces constant $EIRP/EIRP_{max}$ values with variations up to -1 dB for elevations. from -80° to 20° elevation, from 20° to 70° $EIRP/EIRP_{max}$ reduces to -3 dB. At 90 ° and -90° the $EIRP/EIRP_{max}$ is -6 dB and -4 dB respectively. E2 AP presents its maximum EIRP value at -90°, for negative elevation angles $EIRP/EIRP_{max}$ varies between -2 to -4 dB and for positive elevation angles the EIRP decreases until -8 dB at 80°.").

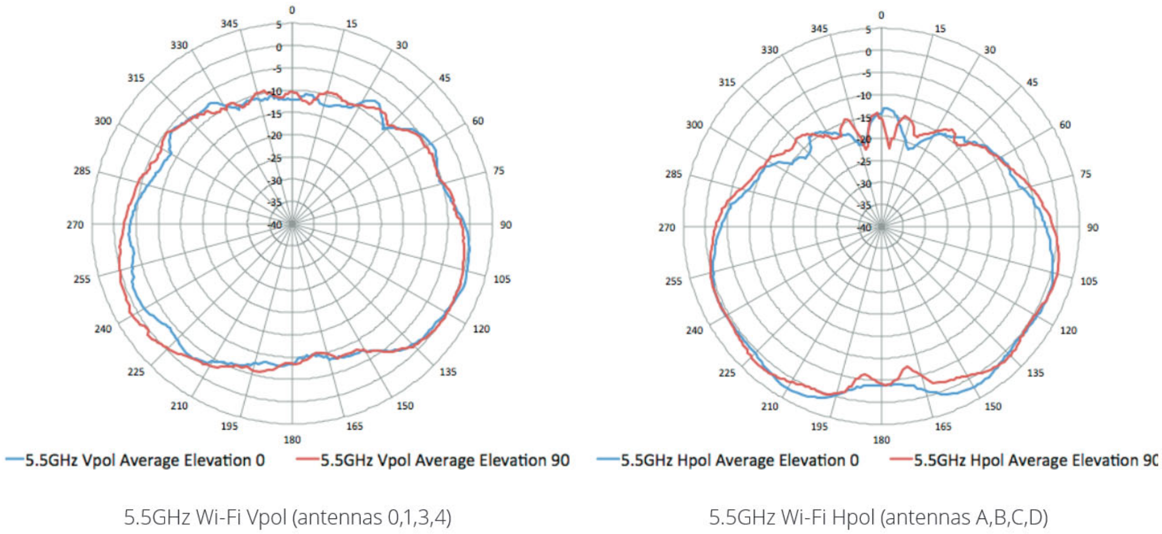

Figure 1: Aruba AP-335 802.11ac Wave 2 Enterprise AP E-Plane Antenna Pattern

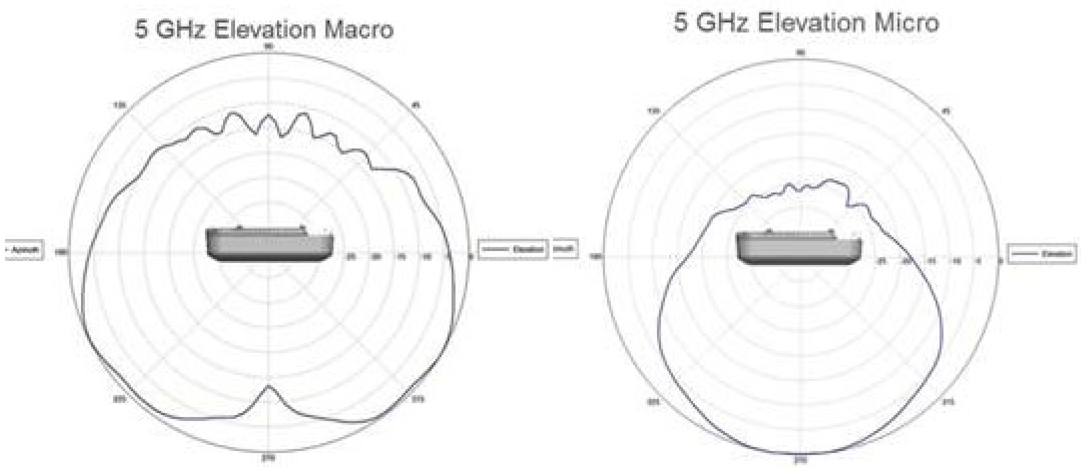

Figure 2: Cisco 3800 802.11ac Wave 2 Enterprise Access Point E-Plane Antenna Pattern

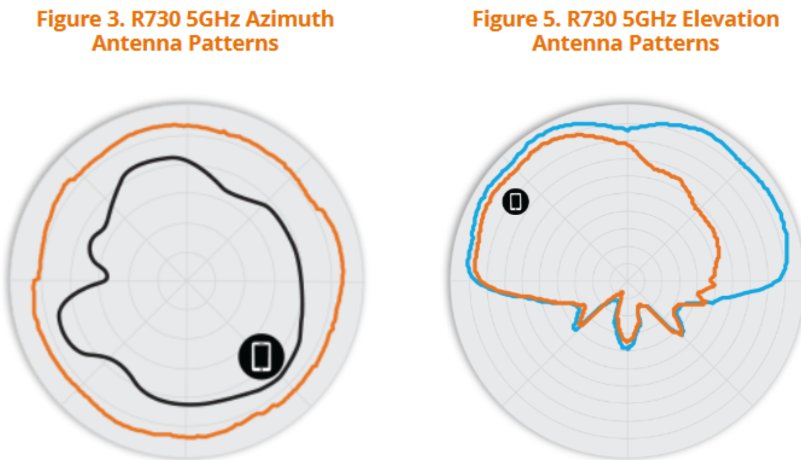

Figure 3: Ruckus R730 802.11ax Wave 2 Enterprise AP E-Plane Antenna Pattern

12. The impact of new radio technologies, such as IEEE 802.11ax, on the overall efficiency of enterprise Wi-Fi networks is expected to be significant when viewed through the lens of how the new technology will utilize radio spectrum. By combining high-order modulations, large channel bandwidths, highly efficient channel access mechanisms, and various other techniques, next generation Wi-Fi systems such as those based on emerging IEEE 802.11ax technology are expected to achieve very high data rates while maintaining a low duty cycle. As a result, there is less energy in the air than would otherwise be the case, resulting in lower observed power spectral density.
13. One of the many technology innovations that results in such low duty cycles is beamforming (i.e., multi-user MIMO), which has already been introduced into 802.11ac APs, but is being further developed and refined in 802.11ax. Beamforming calculates the effect of radio signal reflections so that the signal will arrive at the receiver in phase. The chief value of beamforming is higher received signal strength, which in turn raises the achievable modulation rate and link layer speed between the AP and the associated client, enabling faster transmissions which require less "air time".

14. APs do not radiate isotropically (uniformly in all directions) by design. APs can be ceiling mounted or wall mounted with enhanced receive sensitivity and more radiated power directed away from the mount. In general, APs are deployed for receive coverage/capacity and employ transmit power to match communications from client stations. In general, APs in the 5-6 GHz bands supporting multiple spatial streams show an average antenna efficiency loss of 6 dB when compared to an isotropic radiator (integrated spherically).
15. Polarization of received energy is also important. For an antenna to receive the maximum power transmitted from a corresponding transmitting antenna, both antennas must have the same spatial orientation, the same polarization sense, and the same axial ratio. Polarization losses will on average amount to 3 dB due to physical misalignment of the antennas and multipath distortions. In enterprise networks, energy would rarely reach a nearby fixed microwave receiver with equivalent polarization, because AP energy is directed from the ceiling down to the workspace. The AP energy will reflect off interior surfaces, so the little energy that does leave the building would not be aligned to the microwave receiving antenna.
16. Enterprise APs in mid-to large-sized offices are often connected via Ethernet to some form of data aggregating/forwarding function, which aggregates wireless traffic within the network, and/or to a wireless control function. These functions can be separate or combined, and can either be provided via physical devices, virtual instances, cloud services, or some combination thereof. Wireless controllers are relevant to the RF environment in at least one important sense: among their many responsibilities, controllers may be used to set policy for transmit power control on all of their subordinate APs, enabling these APs to operate only up to the specified power limits, thus avoiding unwanted intercell interference and

unneeded/unwanted emissions. As a result, enterprise APs generally operate below statutory emission limits most of the time.

17. In summary, managed indoor WLAN deployments typical of multi-floor buildings have multiple characteristics that inherently minimize or eliminate unintentional outdoor emissions. In the first instance, such networks employ hardware that intentionally directs radiation downward, and are carefully planned to distribute load across all the available spectrum. Second, radio management algorithms typically converge to the lowest usable EIRP to minimize intra-system co-channel interference. Third, technologies including but not limited to wide channels (80 or 160 megahertz) and beamforming maximize data rate while reducing transmission duration. Finally, where outdoor coverage is required it is provided via dedicated outdoor-rated equipment to maximize user experience and avoid interfering with indoor users. In a 6 GHz system, such outdoor APs would be subject to Automatic Frequency Coordination and so would pose no risk to incumbent systems.

I, Matt MacPherson, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

Matt MacPherson

I, Chuck Lukaszewski, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

Chuck Lukaszewski

I, Sundar Sankaran, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 15, 2019.

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Sundar Sankaran

Appendix E

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	
Unlicensed Use of the 6 GHz Band	ET Docket No. 18-295
Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz	GN Docket No. 17-183

BUILDING AND VEHICLE ATTENUATION

Building Loss:

Building entry (or exit) loss (BEL) is additional signal loss caused by the terminal of a radio system being inside a building.[1] Buildings fall into two distinct groups in terms of BEL: (1) buildings that use modern, thermally-efficient building methods such as metallized glass and foil-backed building panels and (2) "traditional" buildings constructed without such materials.[2] The "U-value" indicates the thermal transmittance of a material and provides a quantifiable description of its thermal efficiency. Low U-values represent high thermal efficiency factors, and the presence of metallized glass windows, insulated cavity walls, thick reinforced concrete, and metal foil-backed cladding are typically indicators of a thermally-efficient building.[3] For

[1] International Telecommunication Union, Recommendation ITU-R P.2040-1: Effects of building materials and structures on radiowave propagation above about 100 MHz, at 26 (July 2015), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2040-1-201507-I!!PDF-E.pdf.

[2] International Telecommunication Union, Recommendation ITU-R P.2109: Prediction of Building Entry Loss, at 2 (June 2017), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-0-201706-I!!PDF-E.pdf.

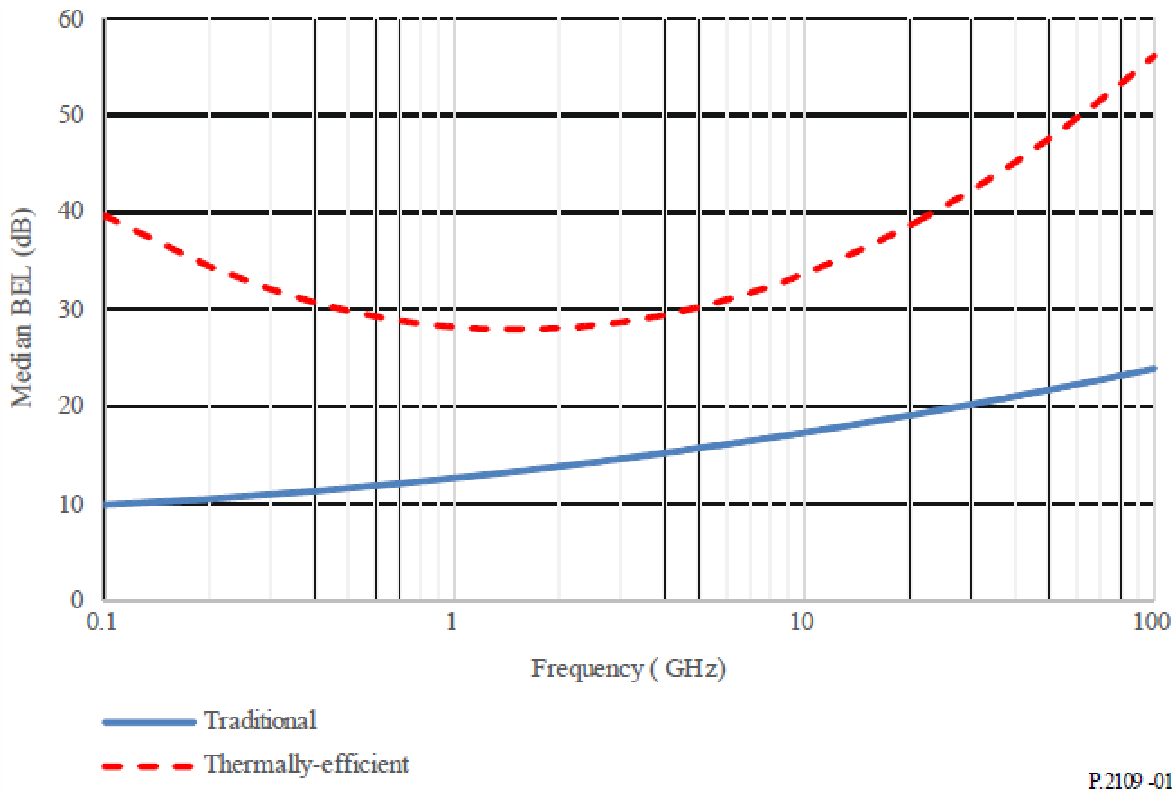
[3] *Id.* at 2–3.

example, U-values of < 0.3 and < 0.9 represent a thermally-efficient main structure and metallized glass, respectively.[4]

ITU models show that, for thermally-efficient buildings, the median predicted BEL at 6 GHz is approximately 30 dB, and for traditionally constructed buildings, the median predicted BEL is 18 dB:[5]

FIGURE 1

Median building entry loss predicted at horizontal incidence



4 *Id.* at 3 n.1.

5 *Id.* at 4 fig.1.

Buildings across the U.S. increasingly fall into the thermally-efficient category due to the increased use of energy-efficient building materials. The use of such building materials is now required by many state and local building codes, and the number of jurisdictions that have adopted such codes has grown dramatically over the past decade.[6] The U.S. Department of Energy estimates that by 2035 75% of buildings in the U.S. will be new or renovated to comply with energy efficiency standards.[7]

Windows are one category of building materials that have undergone substantial changes to improve energy efficiency in recent decades and now contribute significantly to signal attenuation associated with buildings.[8] Energy-efficient glass commonly used in new construction or renovation of older buildings is "typically metal-coated for better thermal insulation" and its "coating introduces additional losses that can be as high as 40 dB even at lower frequencies."[9] Models for BEL predict that losses increase as a function of frequency for a

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6 *See* Building Codes Assistance Project, *Code Status: Commercial Energy Code Adoption & Residential Energy Code Adoption* (Nov. 2018), http://bcapcodes.org/code-status/commercial/; *see also* U.S. Department of Energy, *Building Energy Codes Program: Status of State Energy Code Adoption* (Dec. 2018) ("*Status of State Energy Code Adoption*"), https://www.energycodes.gov/status-state-energy-code-adoption.

7 United States Department of Energy, *Building Energy Codes Program* (last visited Feb. 14, 2019), https://www.energy.gov/eere/buildings/building-energy-codes-program.

8 *See* Per Angskog et al., *Measurement of Radio Signal Propagation through Window Panes and Energy Saving Windows*, *in* 2015 IEEE International Symposium on Electromagnetic Compatibility 74–99; *see also* Association of Professional Wireless Production Technologies, Electronic Communications Committee, Working Group Frequency Management Project Team FM 51, Doc. FM51(15)(164), *Building Absorption and the RF Loss through Glass* (Oct. 2, 2015), https://cept.org/Documents/fm-51/27483/fm51-15-164_building-absorption-and-the-rf-loss-through-glass.

9 Aalto University et al., *5G Channel Model for bands up to 100 GHz* 12, 4th International Workshop on 5G/5G+ Communications in Higher Frequency Bands (v.2.3 rev. Oct. 2016) ("5G Channel Model White Paper"), http://www.5gworkshops.com/5GCMSIG_White%20Paper_r2dot3.pdf.

specified building material—for example, losses for glass and concrete increase as a function of frequency.[10]

High-rise buildings are likely to use energy-efficient materials, including windows. The majority of skyscrapers in the U.S. were either constructed or have been renovated since energy-efficiency regulations first went into effect requiring the use of these materials.[11] Additionally, high-rise buildings are likely to exhibit the ITU-R P.2109 30 dB BEL value typical of thermally-efficient buildings because of the building materials required for such a structure (i.e., steel frameworks, reinforced concrete walls, and for recently-constructed buildings, energy efficient windows). Concrete building materials exhibit losses that increase rapidly with frequency, and produce approximately 40 dB of loss at 6 GHz.[12] Approximately half of high-rise buildings are non-residential and occupied by commercial tenants.[13] In these buildings, in addition to the BEL factors described above, signals will be attenuated even further by the use of standard enterprise network deployment techniques, such as the use of ceiling mounted access points with down-tilted antennas.[14]

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10 *Id.* at 48 tbl.8.

11 Energy efficient building codes were first enacted in large states such as California, Florida, and New York in the late 1970s. *See Status of State Energy Code Adoption*, *supra*, for California, New York, and Florida. Of the 100 tallest buildings in the U.S., for example, publicly-available data shows that the vast majority have been constructed or renovated since energy efficient building codes have been adopted. *See* The Skyscraper Center, *United States Buildings* ("Skyscraper Center Building Data"), http://www.skyscrapercenter.com/country/united-states (last visited Feb. 14, 2019).

12 *5G Channel Model White Paper* at 12–13 & fig.6.

13 *See* Skyscraper Center Building Data (data analyzed in February 2019 showed that, out of 4,967 total buildings in the U.S. measuring 118 feet high or taller, 2,815 were non-residential).

14 *See* Comments of Apple Inc., Broadcom Limited, Cisco Systems, Inc., Facebook, Inc. Google LLC, Hewlett-Packard Enterprise, Intel Corporation, Marvell Semiconductor, Inc., Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company, ET Docket No. 18-295, GN Docket No. 17-183, Characteristics of Enterprise

The real estate industry is aware of the continued progression in energy efficiency standards, and one emerging best practice is to ensure tenants can receive mobile wireless signals, including through the use of distributed antennas and small cells within buildings.[15]

Vehicle Loss:

Automobiles similarly cause signal attenuation, known as vehicle penetration loss (VPL). The metal frame and other structural components of a vehicle not only directly shield receivers outside the car, but they can also cause reflections that destructively interfere with signals that are not directly blocked, causing fading.[16] Additionally, automotive window films widely used for insulation, UV protection, and glare control are usually metallized, which adversely affects the propagation of radio signals through the windows.[17] VPL measurements are dependent on window coating, type of vehicle, and placement of the device within the vehicle.[18] Across

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Deployments Using IEEE 802.11 Equipment: Joint Declaration of Matt MacPherson, Chuck Lucaszewski, and Sundar Sankaran ¶¶ 11, 14–15 (filed Feb. 15, 2019).

[15] Aaron Friedman, *3 Ways Distributed Antenna Systems Can Contribute to LEED*, Connected: Wireless for the Commercial Real Estate Professional (Apr. 21, 2017), https://www.connectedremag.com/das-in-building/3-ways-distributed-antenna-systems-can-contribute-to-leed/.

[16] *See* Emmeric Tanghe et al., *Evaluation of Vehicle Penetration Loss at Wireless Communication Frequencies*, 57 IEEE Transactions on Vehicular Technology 2037, 2037–38 (July 2008), *available at* https://ieeexplore.ieee.org/document/4382920.

[17] Usman Tahir Virk et al., *Characterization of Vehicle Penetration Loss at wireless communication frequencies*, The 8th European Conference on Antennas and Propagation (EuCAP 2014), 234–38 (Apr. 2014) ("*Vehicle Penetration Loss*"), *available at* https://ieeexplore.ieee.org/document/6901733.

[18] *See id.* at 234, 238; LS telcom UK, *In-car Mobile Signal Attenuation Measurements* (Nov. 8, 2017), *available at* https://www.ofcom.org.uk/__data/assets/pdf_file/0019/108127/in-car-mobile-signal-attenuation-report.pdf.

different vehicles, types of windows, and device locations, an average of 10 dB of VPL is a conservative value.[19]

Operations inside commercial aircraft experience even greater VPL than operations inside motor vehicles. For example, one study analyzing the potential impact of wireless transmissions from electronic devices inside commercial aircraft on exterior fuselage-mounted antennas predicted a minimum of 66 dB of path loss from the inside of the aircraft to a dorsal-mounted antenna system operating at 5060 MHz, depending on passenger load.[20] Increasing the passenger load from 0 percent to 50 percent increased the predicted path loss by 7 dB, and a fully-loaded aircraft increased the predicted path loss to 10 dB.[21] In addition, an ETSI technical paper summarizing real-world aircraft fuselage attenuation testing in the 5 GHz band reported average attenuation in excess of 17 dB even when measured at a distance of only 3 meters outside of the cabin windows.[22] As the ETSI technical report notes, the ITU and regulators around the world consider this path loss to be comparable to an indoor environment. Thus, ETSI has concluded that 5 GHz "radiated power levels impinging the ground from an aircraft in flight are so low as to assure no harmful interference to terrestrial systems."[23]

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19 *See Vehicle Penetration Loss* at 236.

20 *See* Kathy Wei Hurst & Steven W. Ellingson, *Path Loss From a Transmitter Inside an Aircraft Cabin to an Exterior Fuselage-Mounted Antenna*, 50 IEEE Transactions on Electromagnetic Compatibility 504, 511 (Aug. 2008), *available at* https://www.faculty.ece.vt.edu/swe/mypubs/0710_TEC.pdf.

21 *Id.*

22 ETSI, *Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Technical Characteristics for Airborne In-Flight Entertainment Systems operating in the frequency range 5 150 MHz to 5 875 MHz*, Technical Report No. ETSI TR 102 631, at 19–21 (v.1.1.1 Sept. 2008), https://www.etsi.org/deliver/etsi_tr/102600_102699/102631/01.01.01_60/tr_102631v010101p.pdf.

23 *Id.* at 11.