Before the
Federal Communications Commission
Washington DC 20554

In the Matter of	)	
	)	
Unlicensed Use of the 6 GHz Band	)	ET Docket No. 18-295
	)	
Expanding Flexible Use of the Mid-Band	)	GN Docket No. 17-183
Spectrum Between 3.17 and 24 GHz	)	

COMMENTS OF THE FIXED WIRELESS COMMUNICATIONS COALITION

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The Fixed Wireless Communications Coalition, Inc. (FWCC")[1] files these comments in response to the Notice of Proposed Rulemaking in the above-captioned proceeding.[2]

A. SUMMARY

These comments are directed solely to protecting the 96,604 fixed service (FS) links in the 6 GHz bands from interference due to unlicensed devices.[3]

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[1] The FWCC is a coalition of companies, associations, and individuals actively involved in the fixed services—*i.e.*, terrestrial fixed microwave communications. Our membership includes manufacturers of microwave equipment, fixed microwave engineering firms, licensees of terrestrial fixed microwave systems and their associations, and communications service providers and their associations. The membership also includes railroads, public utilities, petroleum and pipeline entities, public safety agencies, cable TV providers, backhaul providers, and/or their respective associations, communications carriers, and telecommunications attorneys and engineers. Our members build, install, and use both licensed and unlicensed point–to–point, point–to–multipoint, and other fixed wireless systems, in frequency bands from 900 MHz to 95 GHz. For more information, see www.fwcc.us.

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

[3] All link data are courtesy of Comsearch, current as of January 21, 2019, except as noted.

Terminology: A “link” is a licensed channel on a physical path. There may be multiple links on a single license. The term “fixed service” (FS) includes the Part 101 Common Carrier and Private Operational Fixed Services, but not the Part 74 Broadcast Auxiliary Service.

The bands at issue are:

Band Name	Frequencies (MHz)	FS Usage
U-NII-5	5925-6425	66,324 FS links
U-NII-6	6425-6525	no FS links
U-NII-7	6525-6875	30,280 FS links
U-NII-8	6875-7125	194 FS links

We use the term radio local area networks (RLANs) for 6 GHz unlicensed devices generally. The Commission contemplates two RLAN categories: access points that receive frequency permissions from a database system, and client devices that receive frequency permissions from a nearby access point.

We take no position on the NPRM proposal to allow indoor operation in the U-NII-6 and U-NII-8 bands without frequency coordination.

RLANs in the U-NII-5 and U-NII-7 bands, however, will have to protect FS links at their current levels of reliability. This is a demanding standard. Many FS systems at 6 GHz carry critical services: controlling pipelines, railroad trains, and the electric grid, and providing backhaul for public safety communications. Some links operate at reliability levels of 99.9999%: downtimes of one second out of every million, or thirty seconds per year. Most others operate at 99.999%, a limit of five minutes’ outage per year. A system served by a networked FS receiver—most receivers are networked—may need fifteen minutes to resynchronize after even a short interruption, thus magnifying the effects of a transitory interference event. To keep 96,000

FS systems operating at their present reliability, RLAN interference will have to be extremely improbable.

The needed degree of protection is feasible, but the measures to achieve it will have to go beyond the RLAN proponents' proposals, and in some respects, beyond the Commission's proposals as well.

A study in the record, submitted by RLAN proponents, underestimates interference into the FS by using the shortcut of statistical modeling. The approach uses a computer program that populates an area with virtual FS receivers. It scatters RLANs at random, under some assumed distribution of locations and powers. The program tests to see how much RLAN/FS interference occurs. It then re-scatters the RLANs and tests again. Running a large number of such cases yields an overall estimated average probability of RLANs causing interference to FS receivers. Those estimates, unsurprisingly, depend on the assumed numbers: likely locations of RLANs, distributions of RLAN power levels, expected propagation losses, and so forth.

The approach has important limitations: it can successfully predict the incidence of interference only from RLANs whose placements match the study designers' expectations, and only where signal losses along the RLAN-to-FS path match the study's assumptions. But FS interference rarely arises from the expected. Decades of experience show that interference is rare, but when it occurs, most often comes from a single source at an unlikely location and atypical path loss—precisely the cases that statistical modeling is most likely to miss.

Statistical studies typically use propagation models that assume ambient clutter and local terrain will attenuate interference by *X* dB along part of every interference path between an RLAN and an FS receiver. If the model is properly chosen, then indeed, some large fraction of interference paths will have that much attenuation or more. But these models represent average path loss. They fail to account properly for the fraction of RLANs in locations that provide much less attenuation, and some smaller fraction of RLANs that have clear line-of-sight with FS receivers. By its nature, average path loss overestimates the actual path loss 50% of the time. This kind of statistical approach is useful where the result sought is itself an average, such as the number of cell phones within reach of a tower. The approach fails where, as here, the result needed is not the average, but the exceptional cases that defy the average.

The same study in the record predicts almost a billion RLANs in operation. Even a very small fraction of these causing interference would be catastrophic to FS reliability.

Some RLAN proponents claim that indoor devices can never cause interference, on the (incorrect) assumption that building walls will never allow interfering signals to leak out. Actual calculations give a very different result: even through building walls, an inopportunely located RLAN at any useful power will cause FS interference from kilometers away.

We see only one method of reliably preventing RLANs from interfering with FS receivers:

> (1) map out the three-dimensional "exclusion zone" around each FS receive antenna within which an RLAN could cause interference;
>
> (2) determine whether each RLAN that seeks to transmit is within one or more of those zones;
>
> (3) if so, use local propagation data to assess whether the RLAN signal threatens interference to an FS receiver; and
>
> (4) if so, prohibit the RLAN from operating on interfering frequencies.

Rather than use statistical modelling, such a system must consider the individual three-dimensional interference path between each RLAN and each threatened FS receiver. The system will require a complete and accurate database of FS receivers that includes their individual locations, elevations, azimuths, elevation angles, antenna size, and frequencies received. Also helpful will be a mapping database that shows the elevations of terrain and natural obstructions, and the locations and heights of buildings and other manmade structures.

For each interference path, the system must evaluate several factors that can affect the interference risk:

- RLAN power;
- attenuation due to actual terrain and buildings along the particular path;
- degree of uncertainty in the RLAN location;
- RLAN elevation (and degree of uncertainty);
- maximum possible radius of RLAN client devices around a coordinated access point; and
- FS receiver sensitivity to RLANs outside but close to the FS channel being received.

Where any of these data come with uncertainty, the system must always assume the worst case. If there are no data on possible terrain or structures along a path, the system must assume there are none, and use free-space propagation. If an RLAN's possible locations include part or all of a building, and the RLAN's elevation is unknown, the system must evaluate the RLAN both outside and inside the building at the worst-case elevations. If the database indicates neither the presence nor the absence of a building within the RLAN's range of possible locations, the system must examine the worst case at all elevations up to the FS antenna height. This kind of analysis is the only way to catch the one-in-a-million interference cases that slip through the statistical methods. Catching those is important, because even one-in-a-million interference would unacceptably degrade FS reliability.

We acknowledge that this individualized, fact-based approach has potential downsides for RLAN operators. It will be complex, and correspondingly expensive (although far simpler than the Spectrum Access System planned for the Citizens Broadband Radio Service). And the need to analyze worst cases will sometimes lock out RLAN frequencies that, if allowed, might not have caused actual interference. The FS community has worked in good faith with RLAN proponents to minimize these costs and limitations, and will continue doing so. Inevitably, however, the need to protect critical applications against very large numbers of unlicensed devices may sometimes cause suboptimal outcomes for RLAN interests.

The 6 GHz FS band carries services that are critical both to the safety of life and property, and to smooth functioning of the Nation's infrastructure and commercial activities. FS facilities will need protection from RLAN interference that maintains their very high levels of reliability.

B. 6 GHZ FS BANDS AND THE PUBLIC INTEREST

The Commission allows unlicensed devices in occupied, licensed bands only on the condition that they not

> transmit energy in a way that has a significant detrimental effect on the operation or development of the nation's communications network.[4]

For the Commission to approve an unlicensed device that it knows may cause harmful interference to a licensed service would violate the Communications Act.[5]

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[4] *Ultra-Wideband Transmission Systems*, Second Report and Order and Second Memorandum Opinion and Order. 19 FCC Rcd 24558 at ¶ 69 (2004). See also 47 C.F.R. § 15.5(b) ("Operation of an [unlicensed device] is subject to the conditions that no harmful interference is caused … [to] the operation of an authorized radio station ….")

[5] Section 301 of the Act prohibits radio transmissions without a Commission license. 47 U.S.C. § 301. The U.S. Court of Appeals held that the Commission can overlook the Section 301 licensing requirement only where it has determined that an unlicensed device will not cause

The public interest in protecting incumbent licensed services is all the greater where the applications carry safety-critical communications. The Commission recognizes this need as to 6 GHz FS services:

> [W]e emphasize our commitment to preserve and protect the important base of incumbent users in these frequency bands.[6]

FS applications in the U-NII-5 and U-NII-7 bands include:

- remote control of railroad switches, and signals for the synchronization of train movement;
- control of pumps and valves in petroleum and natural gas pipelines;
- control of electric utility circuit breakers and switches to operate and maintain the national electric grid;
- backhaul to dispatch public safety and emergency vehicles (first responders, emergency repair crews, etc.)
- Internet and telephone carriage;
- backhaul for cellular systems, including voice and 3G/4G data;
- connecting commercial centers with real-time financial and market data; and
- vast amounts of business data.

Because many of these applications protect the safety of life and property, FS systems are typically designed for at least 99.999% (five nines) availability; some are designed for 99.9999% (six nines). These numbers correspond to total outages, from all causes, of just five minutes or thirty seconds per year, respectively. In practice, most FS systems operate flawlessly year after year, despite outdoor exposure under sometimes adverse conditions, as in Figure 1.

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harmful interference to licensed services. *American Radio Relay League, Inc. v. FCC*, 524 F.3d 227, 234-35 (D.C. Cir. 2008).

[6] Notice at ¶ 2.

Figure 1: FS site subject to extreme weather (all photos by George Kizer)

The 6 GHz licensees include users displaced from the former 2 GHz FS band, once a workhorse for intercity FS links, but repurposed twenty years ago for mobile services. The 6 GHz band also includes operators who have been unable to coordinate at 4 GHz. Formerly preferred for long paths, 4 GHz has become largely unavailable to the FS despite a co-primary allocation with the Fixed Satellite Service (FSS). The Commission has required the FS to protect every FSS earth station against interference across the entire 3.7-4.2 GHz band and the entire geostationary arc, even if the earth station communicates with only one transponder on one satellite.[7] The proliferation of earth stations, including many receive-only stations, has made it impossible to coordinate 4 GHz FS links across most of the country. Today only 914 links are in use.[8] The Commission has announced a proposal to "sunset" these licenses.[9]

All other FS bands are above 10 GHz, where rain fade limits the useful range. **The 6 GHz bands are the only remaining option for long links.**

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[7] *See Expanding Flexible Use of the 3.7 GHz to 4.2 GHz Band*, GN Docket Nos. 18-122, 17-183 (Inquiry Terminated as to 3.7-4.2 GHz), Order and Notice of Proposed Rulemaking, FCC 18-91 at ¶ 37 (released July 13, 2018) (4 GHz Order & NPRM).

[8] Data as of October 18, 2018.

[9] 4 GHz Order & NPRM at ¶¶ 47-48.

The importance of the FS services at 6 GHz, their extreme reliability, and the lack of suitable alternative spectrum all set a high level of public interest in the Commission's ensuring that RLAN implementation fully protects FS communications.

C. FALLACIES ON RLAN/FS INTERFERENCE

Several misconceptions have troubled this proceeding from the start. One is the mistaken notion that FS receivers being on high towers makes antenna boresights safe from ground-level RLANs. Another is that RLANs can safely operate indoors because building walls and indoor clutter will sufficiently attenuate RLAN signals. A third is that statistical analysis can reliably predict interference into FS receivers. Each of these points has intuitive appeal, but all prove to be factually incorrect.

1. High-off-the-ground FS antennas

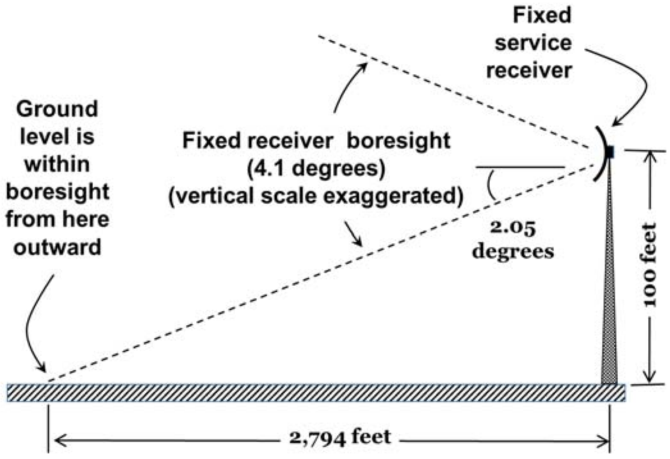

Figure 2: FS receiver boresight reaches ground level 0.53 miles from 100 foot tower

An FS antenna boresight takes the shape of a narrow cone with an approximately horizontal axis. In the case of the widest beam permitted at 6 GHz, a Category B2 antenna, the cone width cannot exceed 4.1 degrees.[10] With the antenna on a 100 foot tower, the boresight includes objects at level ground from half a mile on out. See Figure 2. An FS antenna with an RLAN in the boresight and no intervening blockages will receive interference from tens of miles away, limited only by the

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[10] 47 C.F.R. § 101.115(b)(2) (table). This width is at the half-power points.

curvature of the Earth. If the interfering source is close enough to the tower to be under the boresight, its proximity to the FS antenna may still result in interference.[11]

2. *Indoor operation*

RLANs used indoors even at low power can cause interference. We explain in Part F below why attenuation from building walls may be insufficient to block the signal. Taking into account the width of the antenna boresight (Part C.1. above), an RLAN just a few meters off the ground in a one- or two-story house can threaten interference.

Figure 3: FS antennas in Brooklyn, NY

Urban high-rise dwellers can likewise have line-of-sight with an FS antenna. Figure 3 shows an FS facility in New York City with tall residential and office buildings nearby. While high-rise construction offers better attenuation than some other structures, that can be offset by much shorter interference paths. Part F presents the details.

3. *Statistical interference prediction*

Some RLAN proponents seek to dismiss FS concerns by asserting, unsupported, non-quantitative claims: "minimal" interference risk, "very little" of an RLAN's emissions reaching the outdoors, "reduced risk" to FS facilities, "improbable" line-of-sight deployments,

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[11] For a sample calculation of this situation, *see* Comments of the FWCC in GN Docket No. 17-183 at 10 (filed Oct. 2, 2017).

"significantly higher than average" building attentuation …[12] The only backup for these particuar statements is a partial analysis of a single FS link, an anlysis that itself includes unsupported assumptions.[13] This is irrresponsible.

Parties that filed in the Notice of Inquiry phase of this proceeding offered sharply conflicting views on whether RLANs will cause FS interference, with detailed technical studies claiming to support both positions. The disagreement results from fundamentally different approaches to predicting interference.

RLAN proponents have used this method (which we argue below is unsuitable):

1. Assume appropriate ranges of values for RLAN powers, distances, propagation properties (clutter, etc.). Assign probabilities to each.

2. Determine (or assume) the locations, patterns, and sensitivities of FS receive antennas.

3. Repeatedly run a computer model that randomly assigns values for RLAN locations, powers, etc. according to the assumed probabilities. For each such case, calculate whether FS interference would occur.

4. Average the results over many runs to conclude that the overall probability of interference is low.

5. Argue that factors omitted from the analysis would make the probability of interference even lower.[14]

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[12] These examples come from a single paragraph: Letter from Alex Roytblat, Senior Director of Regulatory Affairs. Wi-Fi Alliance, to Marlene Dortch, Secretary, FCC, in GN Docket No. 17-183 at 3 (filed Sept. 18, 2018) (Wi-Fi Alliance September 18 Letter).

[13] *Id*. (attachment). Among other defects, the analysis relies on the FS link having "excess fade margin," which does not exist. See Part E below.

[14] This is a type of Monte Carlo simulation. For an example in the docket, *see Frequency Sharing for Radio Local Area Networks in the 6 GHz Band January 2018*, attached to Letter from Paul Margie, Counsel to Apple Inc., *et al.* to Marlene Dortch, Secretary, FCC, in GN Docket No. 17-183 (filed Jan. 26, 2018) (RKF Study). The FWCC noted shortcomings in this work. George Kizer, *Studies Regarding RKF's Frequency Sharing for Radio Local Area Networks in the 6 GHz Band Proposal*, attached to Letter from Cheng-yi Liu and Mitchell

This approach is inadequate to the present task. It is fine for studies whose goal is to acquire statistical results, such as predictions of cell phone coverage. But it has two fatal defects here.

First, using this approach to protect 96,000 FS receivers, each operating at 99.999% or 99.9999% reliability, would require the predicted average probability of interference to be a microscopically small number. The RKF Study, despite its flat claim that RLANs would "not cause harmful interference,"[15] found a probability of interference of 0.209%.[16] Multiplying 0.209% by 96,000 links gives a crude estimate of 200 links affected by interference—unacceptable under any standard.[17]

Second, although FS interference is extremely rare today, in the absence of RLANs, the few cases that do occur most often result from a single radio source at an unfortunate location. Each such case represents some combination of low probabilities, and hence is likely to be overlooked in a statistical analysis. But it takes only one misplaced source to disable an FS link.

The error of using average interference predictions, rather than predicting interference into specific receivers, has come up often in the proceeding. We will return to this point in the discussions below.

Lazarus to Marlene H. Dortch, Secretary, FCC, in FCC GN Docket No. 17-183 (filed March 13, 2018).

[15] RKF Study at 6.

[16] RKF Study at 45.

[17] In fairness, the RKF Study predated some RLAN proponents' suggesting a system of automatic frequency selection, at least for outdoor RLANs. The implementation of such a system, if applied to all RLANs and made consistent with the principles we outline below, would reduce the probability of FS interference to an acceptably low level.

D. AUTOMATIC FREQUENCY CONTROL USING EXCLUSION ZONES

A reliable technique for preventing interference must consider the individual paths from each RLAN to each possible victim FS receiver. Rather than averaging over multiple hypothetical cases, this approach evaluates whether actual interference will occur in each factual instance. One implementation of the approach is through a properly designed system of automatic frequency control (AFC):[18]

1. Obtain a database of all FS receivers that includes each receiver's location, elevation, azimuth, elevation angle (tilt), frequency usage, and antenna size.

2. Based on the antenna size, delineate the three-dimensional exclusion zone in front of and around each antenna within which RLAN operation would cause unacceptable interference. In the first instance, the sizes and shapes of these zones assume free-space propagation.

3. If an RLAN's location and elevation come within one or more FS exclusion zones, predict the impact of the RLAN on each FS receiver. The calculation can take into account any obstacles known to be in the path, such as buildings, terrain, and curvature of the Earth.

4. If the calculation predicts interference, authorize the RLAN to use only non-interfering frequencies.[19]

5. Require each RLAN to update its permissions at least once every 24 hours and to automatically shut down if it cannot obtain each new confirmation within 24 hours after the last one.[20] Rationale: an RLAN unable to obtain confirmation within 24 hours is likely to have lost contact with the database, and should not be permitted to operate until contact is restored.

6. Update the FS receiver database for new, modified, or cancelled FS links at least every 24 hours. The database should be centralized (not distributed

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[18] Notice at ¶ 23. Some RLAN proponents have agreed to some aspects of the proposal as to outdoor RLANs.

[19] We have no objection to the database allowing operation on some frequencies at reduced power, assuming the mechanism for power control is shown to be fully reliable. Notice at ¶ 26.

[20] Notice at ¶¶ 29-30.

into every standard-power access point) in order to facilitate prompt and accurate updates.[21]

This approach will catch the exceptional cases most likely to cause actual interference. It is subject to the following caveats:

- The propagation model used for each RLAN-to-FS path must incorporate the actual clutter, terrain, etc. physically present in that specific path. The use of "average" path characteristics risks causing interference if the particular path has lower losses than the average. Where the path details are not known, then the interference calculation must assume free-space propagation.

- The analysis must take into account the actual RLAN elevation. If the elevation is not known, the calculation must assume the worst-case elevation for that location. Again, average or typical cases are not acceptable. *See also* Part G.6, below.

- The analysis must evaluate potential interference into the channels adjacent to, and second-adjacent to, the channels used by the FS receiver. *See also* Part G.3 below.

- The database should require the registration of each device to which it assigns frequencies, so as to facilitate identifying and disabling an offending device that causes interference.[22]

Justification and detail for these elements follow in the sections below.

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[21] Notice at ¶ 25.

[22] Notice at ¶¶ 27-28.

E. MULTIPATH FADING AND FADE MARGIN

Some RLAN proponents misunderstand the purpose of an FS system's fade margin.

"Fading" is a reduction in received signal strength caused by changing conditions in the atmosphere. "Multipath" effects cause all 6 GHz fading in most parts of the United States.[23] Changes in temperature or humidity at different atmospheric elevations sometimes cause an upward-traveling component of the transmitted signal to refract (bend) back toward the receive antenna, just as a lens bends light rays. Because the refracted signal takes a longer path than the direct signal, it can arrive at the receiver out of phase with the direct signal, and partially cancel out the direct signal. This reduces the signal strength at the receiver by anywhere from a few dB to a few tens of dB. See Figure 4. Movement of the air at the refracting elevations causes the received signal to fluctuate unpredictably over this range.

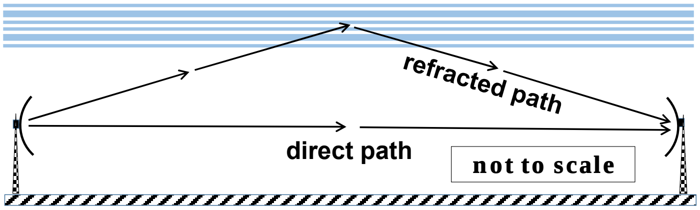

Figure 4: Multipath fading

Multipath is a nighttime phenomenon. During the day, solar heating of the land causes thermal updrafts that stir the air and prevent formation of the layers that produce refraction. At night the earth cools and the air forms the layers that cause fading. The Notice erroneously states that fading is most severe after midnight.[24] In fact, multipath occurs between sundown and

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[23] Some parts of the country also see significant fading from other causes. *See* Kizer, G., *Digital Microwave Communication* at 461-513 (Hoboken: Wiley and Sons, 2013).

[24] Notice at ¶ 46. The same error appears in the RKF Study at 28.

sunrise.[25] Variations occur, but on average the degree of fading is about the same throughout the night.

Without appropriate precautions, fades would cause frequent outages. System designers combat the problem by building in "fade margin"—extra reserves of signal power to compensate for the loss of received power caused by fades. Depending on the reliability needed, fade margins are typically in the range of 25-40 dB.[26]

An interfering signal that does not cause an immediate outage will nonetheless cut into the fade margin and leave the system more vulnerable to outage from fades it could otherwise withstand. If the system is already in a fade condition, even a small degree of interference may bring it down.

Multipath fading occurs only on links at least a few kilometers long. Most 6 GHz links are long enough for multipath to be a threat, while the link between an RLAN and a victim FS receiver is too short for multipath to provide any useful attenuation. Moreover, multipath fading occurs in bursts with no correlation among paths. There is no support for the suggestion in the Notice that fading on the interference path could reduce the risk of FS interference.[27]

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[25] Kizer, G., *Digital Microwave* Communication at 323, Fig. 9.5 (Hoboken: Wiley and Sons, 2013); J. A. Schiavone, *Microwave Radio Meteorology: Diurnal Fading Distributions*, Radio Science at 1306, Fig. 6 (Sept.-Oct. 1982); J. A. Schiavone, *Meteorological Effect on Diurnal and Seasonal Fading Variations*, IEEE International Conference on Communications (ICC 83), Conference Record, Volume 2 at C2.2.2 and C2.2.3, Figs. 3 and 4 (Boston, June 1983).

[26] Other techniques for combatting fades include automatic transmit power control, which temporarily boosts the transmitter power to compensate for a deep fade, and adaptive modulation, which downshifts to more robust but slower modulations when needed.

[27] Notice at ¶ 45.

National and international frequency coordination procedures, standards, and recommendations uniformly limit the acceptable long-term degradation of the fade margin to 1 dB.[28] One RLAN group implicitly accepted this criterion.[29]

Some RLAN proponents argue that interference to FS is harmless where "excess" fade margin is available to absorb the interference "dB for dB."[30] This is simply wrong. There is no excess fade margin, at least at night. For a system to maintain its reliability requires all of its fade margin from sundown till sunup. FS operators pay more for equipment that offers adequate fade margin because they need the added reliability—not to accommodate unlicensed devices.

The Commission asks whether interference protection criteria can be relaxed in regions where climate makes fading less severe.[31] The answer is no. Each system is designed specifically for the climate where it will be used. To over-engineer a system with unneeded fade margin would needlessly raise costs.

The Commission also asks whether interference mitigation strategies can exploit the diurnal and seasonal nature of multipath to minimize interference.[32] This is not practical for seasonal variations, which are uncertain and unreliable, and additionally are complicated by

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[28] TIA/EIA, *Interference Criteria for Microwave Systems*, Telecommunications Systems Bulletin TSB10-F at B-1, Annex B, Section B-2 (June 1994); ITU-R Recommendation F.758-6, *System Parameters and Considerations in the Development of Criteria for Sharing or Compatibility between Digital Fixed Wireless Systems in the Fixed Service and Systems in Other Services and Other Sources of Interference*, Geneva: International Telecommunication Union, Radiocommunication Sector at 9, Table 2 (Sept. 2015). These sources cite a criterion of I/N = -6, which is equivalent to a 1 dB reduction in fade margin.

[29] RKF Study at 11 (as comparison threshold, uses ratio of interference level to receiver front end noise of -6 dB, equivalent to 1 dB reduction in fade margin).

[30] *E.g.*, RKF Study at 28; Wi-Fi Alliance September 18 Letter (attachment) at 3.

[31] Notice at ¶ 46.

[32] Notice at ¶ 46.

ongoing climate change. Diurnal variations, however, are predictable and can be used to maximize RLAN transmission times, subject to wide variations with the time of year and the latitude.

1. Momentary interference

A source of interference strong enough to overcome all of a receiver's fade margin will produce errors. If the microwave link is part of a network, and most are, this causes the network to lose synchronization. The whole network stays down while it resynchronizes. Cellular and land mobile radio sites commonly take 15 minutes to resync after a short interruption.[33] One such incident can consume several years' worth of outage allowance.

In the absence of interference, loss of synchronization would only occur if there were multipath fading far in excess of the normal for that locale. Such outages are extremely rare—years apart, where they occur at all—because system designers carefully consider local conditions.

To avoid impairing FS reliability, outages due to RLAN interference must be kept to a small fraction of the outages due to extraordinary atmospheric conditions.

F. INDOOR OPERATION

The Commission proposes to require AFC-based coordination for both indoor and outdoor RLANs in the U-NII-5 and U-NII-7 bands.[34] It asks for comment on whether indoor RLANs need this coordination.[35]

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[33] Notice at ¶ 46.

[34] *See* Notice at ¶¶ 22-24.

[35] Notice at ¶ 73.

RLAN proponents have asked to operate low-power devices indoors without coordination, on the assumption that such devices will "operate at maximum powers sufficiently low that they pose no material risk of harmful interference to incumbent links."[36] These claims are guesswork—and wrong.[37] We show here that an indoor RLAN at any useful power in the U-NII-5 and U-NII-7 bands threatens interference to the FS, unless under AFC control.

We take no position on non-coordinated indoor operation in the U-NII-6 and U-NII-8 bands.[38]

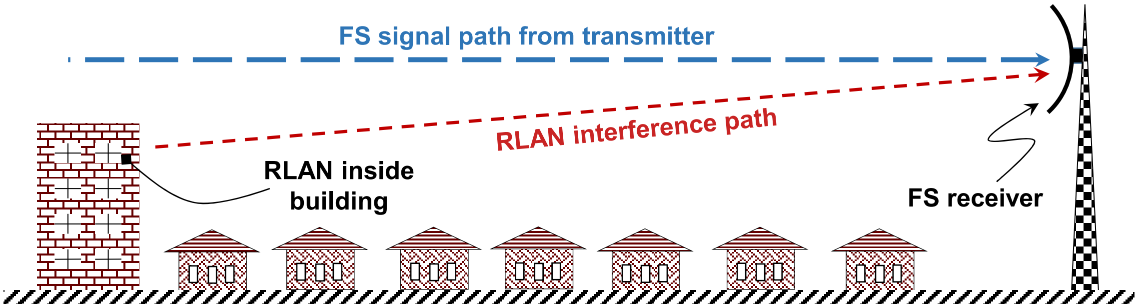

Figure 5: RLAN interference from indoor operation building (horizontal scale compressed)

The greatest risk of FS interference from indoor RLANs in the U-NII-5 and U-NII-7 bands comes from a unit, perhaps on an upper floor, located within the boresight of an FS receive antenna, with only the building wall between the RLAN and the FS antenna. See Figure 5. The RKF Study projected 469 million low-power indoor "clients" in urban and suburban areas.[39] In the presence of FS equipment receiving 96,000 links, most of which are likewise

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[36] *6 GHz: Additional FS Protection Discussion* (slide deck) at 7, attached to Letter from Paul Margie, Counsel to Apple et al., to Marlene H. Dortch, Secretary, FCC, in GN Docket No. 17-183 (filed Aug. 2, 2018).

[37] *See also* Wi-Fi Alliance September 18 Letter at 3 (undocumented, qualitative arguments).

[38] *See* Notice at ¶¶ 59-72.

[39] The RKF Study (at 13) assumes a total of 958 million RLANs, of which 98% are indoors, *id*. at 22, with 50% of those being low-power clients. *Id*. at 22, Table 3-5. Multiplying out gives

located in urban and suburban areas, some indoor RLANs are all but certain to appear in receiver boresights.

The study in Attachment A, *Determining the Impact of Non-Coordinated Indoor 6 GHz RLAN Interference on Fixed Service Receivers*, analyzes the interference from an indoor RLAN transmitter into a 6 foot FS receive antenna boresight. (An 8, 10, or 12 foot antenna would see more interference.) The analysis conservatively assumes 20 dB attenuation through the building wall. The results are in Table 1.

Distance from RLAN to FS Receiver (km)	Maximum Safe RLAN EIRP (dBm)
1	-1.7
3	7.8
6	13.9
10	18.3

Table 1
Maximum Non-Interfering Powers of Indoor RLANs at Various Distances from an FS Receiver

The data show that an uncontrolled indoor RLAN at any workable power poses an unacceptable interference threat to FS receivers. Some RLAN proponents have suggested 18.5 dBm for indoor client RLANs.[40] If one of these falls in an FS receiver boresight, even through a 20 dB wall, it will cause interference out to a distance of 10.2 km.[41]

The Wi-Fi Alliance (WFA) thinks that using 20 dB for building wall attenuation is overly conservative because, it says, that number combines many types of construction, rather than

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the number in text. The study expects most of these units to operate in the 5% of the country that is urban or suburban. RKF Study at 16 & Table 3-3.

[40] RKF Study at 18, Table 3-4.

[41] Attachment A at 6 (Table 4 and preceding equations).

focusing on high-rise buildings.[42] But we took that into account. Our authority on wall penetration averages four types of high-rise construction for an attenuation of 20.0 dB.[43]

WFA says a 30 dB wall attenuation would be more realistic, but in support, it offers only the surmise that all indoor RLANs that could threaten interference will be in steel high-rises.[44] That is obviously wrong. RLANs in countless residential city blocks of wood-frame homes will have line-of-sight with FS receivers.

Even the 30 dB wall that WFA prefers would not solve the problem. An RLAN at WFA's suggested power of 30 dBm EIRP[45] in the boresight of an FS receiver antenna—even behind a 30 dB wall—will cause interference out to 12 km from the antenna.[46]

No realistic estimate of wall attenuation can be a single number. Typically the value will vary over at least 10-20 dB according to the details of construction and the geometry of the emitter relative to columns, joists, windows, and the like. Even an accurate average for wall attenuation still underestimates the likelihood of interference from the 50% of emitters located in buildings that provide less shielding than the average.

WFA assumes tall buildings will give better interference protection from indoor RLANs because, it says, they are more likely to be made of "dense, energy-efficient materials" that will attenuate more of the signal.[47] This, again, is the kind of probabilistic "on average" argument we

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[42] Wi-Fi Alliance September 18 Letter at 3.

[43] Loew, L. H., Lo, Y., Laflin, M. G. and Pol, E. E., *Building Penetration Measurements from Low-height Base Stations At 912, 1920, and 5990 MHz*; NTIA Report 95-325 at 108, Table D-6 (Inst. for Telecom. Sciences, NTIA Sept. 1995) (measurements at 5.99 GHz).

[44] Wi-Fi Alliance September 18 Letter at 4.

[45] Wi-Fi Alliance September 18 Letter at 2.

[46] Attachment A at 5 (Table 3).

[47] Wi-Fi Alliance September 18 Letter at 4.

challenged in Part C.3, above. It is also factually unrealistic. Tall buildings are not only more likely to come within the boresight of an FS receiver, but also have more glass, which offers less attenuation. In our own law firm's 18-story high-rise, every outside wall is made of glass from waist height up to the ceiling—typical of the curtain wall construction used in high-rise commercial structures for the last fifty years. From an interference standpoint, an RLAN in a room on the building periphery might as well be outdoors.

The conclusion is inescapable: To avoid interference to the FS, every indoor RLAN in the U-NII-5 and U-NII-7 bands, at any useful power level, must operate under the control of an AFC system.

G. DETAILS OF AUTOMATIC FREQUENCY CONTROL

1. Protection Criterion

The Commission asks whether it should base protection criteria on I/N or C/I, and at what values.[48]

An I/N criterion is simpler to apply, and is appropriate for the digital systems used in FS facilities. The FWCC has agreed to accept I/N = -6 dB, which is equivalent to 1 dB fade margin degradation. A group of RLAN proponents have also agreed to this value.[49] As noted in Part E above, this value comports with national and international frequency coordination procedures, standards, and recommendations. We ask the Commission to adopt it.

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[48] Notice at ¶¶ 42-43. I/N is the ratio of interference to noise power; C/I is the ratio of carrier to interference power.

[49] RKF Study at 11.

2. Propagation models

A propagation model represents an assumed attenuation of a radio signal as it traverses from an RLAN user device to an FS tower. Typically the model sets a higher attenuation toward the RLAN's end of the path to represent the effects of buildings, ground clutter, and the like, and assumes free-space attenuation with no further obstacles for the rest of the way to the tower. Quantitative details—clutter loss per distance, and the allocation between clutter-limited and free-space propagation—depend on the kind of environment being modeled: urban, suburban, rural, etc. The RKF Study discussed above used this kind of model: Scenario C1 from WINNER II.[50]

The Notice supports this kind of model as well:

> We believe that in the first kilometer, an effective propagation model should include clutter loss in addition to both line-of-sight and non-line-of-sight conditions. Beyond the first kilometer, the propagation model should include a combination of a terrain-based path loss model and a clutter loss model appropriate for the environment.[51]

We respectfully disagree.

These models are well suited to statistical predictions that can safely rely on averages over multiple paths—*e.g.*, estimated areas of mobile coverage. They are inadequate for predicting interference over a specific path into a specific receiver. Where a particular model includes clutter loss for the first kilometer, this does not mean that every path—or any path—has exactly 1.00 km of clutter. Some paths will have more, possibly much more; some will have less,

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[50] Letter from Apple, Inc. *et al*. to Marlene Dortch, Secretary, FCC in GN Docket No. 17-183 at 12 (filed May 14, 2018). Documentation for the WINNER II model is at https://cept.org/files/8339/winner2%20-%20final%20report.pdf

[51] Notice at ¶ 49.

perhaps much less. In addition, the effects of actual clutter will vary from case to case, depending on the materials—anywhere from wooden signboards (little attenuation) to unbroken steel walls (complete blockage). Even the height of the RLAN-to-FS interference path can significantly affect the attenuation, especially if the path is short.[52]

The reference in a model to *X* dB of clutter over a first kilometer can only be an estimated average over a large number of paths. As we explained in Part C.3, above, such averages miss the most frequent cause of actual FS interference: an atypically sited emitter whose location has line-of-sight all the way to an FS receiver.

Protecting the high reliability of FS receivers requires evaluating the propagation along each individual three-dimensional path between an RLAN and a threatened FS facility, using a database that includes known terrain and other obstacles. A hill or an office building in the database can be included in the calculation. Where such data are not available, then the only way to avoid risk of interference is to assume free-space propagation. It would be foolhardy to rely on the existence of clutter just because a statistical model assumes it, without knowing whether the clutter in fact is there.

The Commission notes:

> A free space path loss model would effectively assume worst case conditions for every link and likely overestimate the potential interference in most cases and unnecessarily restrict access to the spectrum for unlicensed use.[53]

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[52] P. L. McQuate, J. M.Harman and M. E. McClanahan, *Tabulations of Propagation Data over Irregular Terrain in the 230-TO 9200-MHz Frequency Range Part 4: Receiver Site in Grove of Trees*, NTIA Technical Report OT/TRER 19 at 21-26, 95-100 (July 1971), available at https://www.its.bldrdoc.gov/publications/1949.aspx

[53] Notice at ¶ 49.

We agree that a free space model will overestimate potential interference in some cases. But we strongly disagree that a free space model will "unnecessarily" restrict spectrum access. To the contrary, in the absence of path-specific data, assuming free-space propagation is essential to protecting the FS. Although less than optimal from an RLAN provider's standpoint, the possibility of overprotection is an unavoidable downside of large-scale, unlicensed access to occupied spectrum that carries critical services.

3. Need for guard band

The Commission proposes to leave unprotected the channels adjacent to those used by an FS receiver, on the ground that RLAN out-of-band emissions limits will protect the channel being received.[54] This misapprehends the problem.

The AFC's function is to stop an RLAN inside an FS receiver exclusion zone from transmitting on interfering frequencies. Obviously included are cases where the RLAN channel overlaps the FS receive channel (Figure 6, top).

But the AFC must also block an RLAN whose transmit channel is close to an FS receive channel, even if there is no overlap (Figure 6, middle). An FS receiver, like all other radio receivers, is sensitive to frequencies outside but close to the channel it is tuned to. This does not indicate bad design. The fundamental properties of electronic circuitry make it effectively

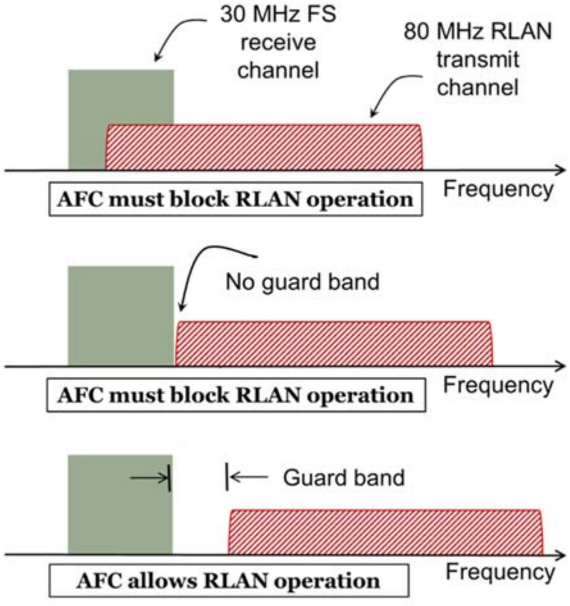

Figure 6: AFC and guard band

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[54] Notice at ¶ 44.

impossible to receive one channel unimpaired while completely blocking off the adjacent frequencies. Radio-frequency filters just can't do that. (This is why the Commission must geographically separate broadcast stations on adjacent and second-adjacent channels.[55])

Figure 7 shows a typical curve of FS receiver sensitivity as a function of frequency, for a 30 MHz FS channel bandwidth. The plot is adapted from a "Normalized Default Receiver Bandpass Characteristic" intended for use by frequency coordinators.[56] It represents the properties of a modern digital FS receiver. Efforts to achieve a "brick-wall" cutoff at the band edges inevitably cause distortions in the band being received,[57] and thereby raise the risk of transmission errors.

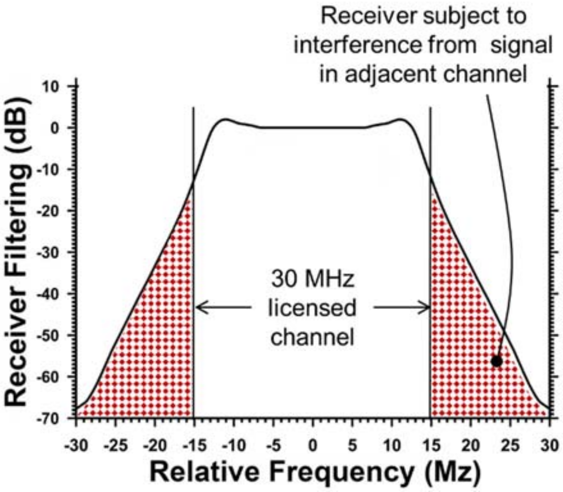

Figure 7: 30 MHz FS victim receiver passband response

The triangular shaded areas represent receiver sensitivity outside the nominal channel being received. These frequencies will see attenuation ranging down to about 12 dB, but RLAN signals there may still be strong enough to cause severe interference.

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[55] 47 C.F.R. §§ 73.37 (AM), 73.207 (FM), 73.623 (TV).

[56] TIA Committee TR-45 Working Group for Microwave Systems (George Kizer, Chairman), *Engineering Considerations for Fixed Point-to-Point Microwave Systems, Draft Standard ANSI/TIA-10*, Arlington: Telecommunications Industry Association, at 63, Figure 13 (C-6) (publication pending, expected May, 2019). The normalized plot is redrawn here for a 30 MHz FS channel.

[57] L. J. Giacoletto, *Electronics Designers' Handbook* at 6-45 (2d ed. 1977). The distortions are due to variations in signal delay caused by the steeper rise of the attenuation at the passband edges.

Note that the receiver will pick up interference from nearby frequencies even if the transmitter has no out-of-band emissions at all. Whether interference occurs will depend on both the FS receiver bandpass characteristic and the RLAN transmitter power spectrum, including its out-of-band emissions.

A large enough difference in frequencies between the RLAN and the FS receiver might allow operation within part of the exclusion zone. But the risk of interference remains even when there is no overlap of the channel bandwidths. Professional frequency coordinators routinely address interference that arises in adjoining channels from both FS and FSS sources, using complex, case-by-case calculations that may be too involved for an automatic AFC system. A practical alternative may be a guard band on either side of the FS channel receiver bandwidth (Figure 6, bottom). Figure 7 shows that frequencies separated by more than half the channel width would be attenuated by at least 70 dB.

Preliminary calculations suggest that a guard band equal to half the nominal FS channel should offer adequate interference protection in most cases.[58] This result is tentative, because the necessary guard band size is sensitive to the RLAN's distribution of energy across its bandwidth—a property on which we have no data. It appears likely that a wider guard band (or reduced RLAN power) will be needed for an RLAN within about a kilometer of the FS receiver and within a few degrees of its boresight. Conversely, though, a narrower guard band may suffice for an RLAN situated toward the outer edges of an exclusion zone. We are interested in working with RLAN proponents to determine whether the AFC can accommodate variable-width

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[58] *See* Attachment C.

guard bands, and if so, to derive the necessary size of the guard band from the RLAN's power and location so as to maximize the spectrum available for RLAN operations.[59]

For a more complete technical analysis, see Attachment B, "Need for Adjacent Channel Interference Protection," and Attachment C, "RLAN/FS Guard Band Analysis."

4. Choice of database

The Commission proposes to have the AFC system rely on the ULS database.[60] While ULS is reasonably accurate and complete as to transmitter information, its receiver data are not as good. A system that protects the wrong receiver types at the wrong locations will leave the actual receivers wide open to interference.

ULS being inadequate for this task, FS frequency coordinators use private databases that are far more accurate and up-to-date. We urge the Commission to explore how these could be made available to AFC system operators.

The alternative—having FS licensees check and update 96,000 sets of receiver data in ULS—would be costly in Commission filing fees. Probably most needed changes would qualify as minor modifications.[61] But a non-common-carrier FS licensee seeking to enter even a minor modification must pay a filing fee of $305 per call sign[62]—a serious burden for large-system operators. If the Commission insists on using ULS, we ask for a temporary amnesty on the filing

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[59] The Association of American Railroads is proposing an alternative solution that might also offer good protection to FS receivers. We think it merits close study.

[60] Notice at ¶¶ 38-39.

[61] *See* 47 C.F.R. § 1.929.

[62] *Wireless Telecommunications Bureau Fee Filing Guide* at 28 (effective Sept. 4, 2018). Common carrier FS licensees pay this fee only for major modifications. *Id*. at 27.

fees before AFC becomes operational. Application filing fees being statutory,[63] we understand the Commission would have to seek the necessary relief from Congress.

5. RLAN location accuracy

The Commission recognizes that RLAN geolocation accuracy may vary with the environment.[64] Rather than impose a one-size-fits-all requirement for location accuracy, the better approach is to ascertain the location accuracy for the particular environment, and coordinate the RLAN as though it were at the worst-case location within its region of uncertainty.

6. RLAN elevation

Acknowledging it is sometimes difficult to accurately ascertain a device's elevation,[65] the Commission suggests coordinating RLANs around a two-dimensional exclusion zone based on a typical RLAN installation height of perhaps 5 to 30 meters, coupled with an RLAN height limit of perhaps 30 meters.[66]

We strongly oppose this approach. Coordinating an RLAN without knowing its actual elevation will fail to block those cases most likely to cause actual interference: an RLAN below the height limit but nonetheless having line of sight with an FS receiver.

We urge the Commission to require a three-dimensional exclusion zone, coupled with an individual elevation determination for each RLAN. The elevation can be assessed either through GPS or by professional installation. Where the elevation has a range of uncertainty, perhaps due

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[63] 47 U.S.C. § 158.

[64] Notice at ¶ 50.

[65] Notice at ¶ 52.

[66] Notice at ¶ 51.

to GPS limitations or to installers' estimates—or where the elevation cannot be determined—the AFC system must assume the worst case among the possible elevations. Again, although not ideal for RLAN deployment, this is the only way to reliably protect FS critical services.

7. Client devices

A client device by definition does not incorporate its own AFC capability, but operates under control of an access point.[67]

We have no objection to the use of client devices so long as the coordination system properly accounts for them. Specifically: the AFC system must evaluate a sphere centered on the access point, with a radius equal to the maximum distance the client device can operate from the access point.[68] Frequency selection must then consider each FS exclusion zone that overlaps any part of the sphere. The evaluation can take into account the lower maximum power of the client device.

A client device cannot be permitted to send active probe requests to an access point, but instead must rely on passive probing.[69] At the time when a client device seeks to initiate a communication, it has no way of knowing whether it is safely within a coordinated sphere. To have client devices transmitting active probe requests from unknown and possibly non-coordinated locations should not be acceptable.

8. Initial request for frequencies

The Notice does not address how an RLAN access point will communicate its initial request for frequencies to the AFC database. This cannot occur in the 6 GHz band because, at the

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[67] Notice at ¶¶ 20-21, 53-54.

[68] Notice at ¶ 54.

[69] Notice at ¶ 53 n.123.

time of the initial request, the RLAN lacks information on what frequencies it can use to safely make the request. One solution is to require that every access point be connected to the Internet by a means other than 6 GHz.[70]

9. AFC security, reliability, and testing

FS interference protection is only as good as the underlying AFC technology. The Commission's rules should include provisions to ensure that the AFC database always remains up to date and secure against tampering. The rules should also include certification requirements to make certain that every RLAN device will always operate under strict AFC control. Any failure of RLAN frequency management, including failures in communication with the database, must automatically cause the RLAN to cease transmission until the problem has been fully resolved. We ask the Office of Engineering and Technology to develop detailed, mandatory guidelines on these issues using an open procedure in which FWCC members can participate.

Although the Notice asks about testing candidate AFC system operators, [71] it omits an important prior step: evaluating the AFC system itself for effectiveness in preventing interference. The system will need testing at least comparable to the Commission's program for white space devices.[72] Because radio-frequency signals can behave differently in the real world than on paper and in the lab, the studies will have to include field testing against representative 6 GHz FS receivers, with the participation of FS engineers.

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[70] Similarly, a fixed TV white space device must access its database over the Internet. 47 C.F.R. § 15.711(c)(2)(ii).

[71] Notice at ¶ 34.

[72] *The FCC's Office of Engineering and Technology Releases Peer Review Panel Report on Tests of Prototype TV White Space Devices*, Public Notice, 23 FCC Rcd 15592 (OET 2008).

10. Controlled AFC rollout

The RLAN industry predicts almost a billion units in operation.[73] After the AFC system has been developed and thoroughly tested, the rollout should initially be constrained to small areas and numbers of devices, with deployment increasing thereafter on a controlled schedule. The AFC and the devices it controls will constitute a novel and elaborate system having many moving parts that have to mesh in complex ways. It will be important to find any defects while the numbers are still small, and corrective action is still feasible—and before widespread FS interference can occur.

The TV White Space system began operation in just a few isolated locations,[74] and then expanded first to seven geographically small northeastern states and the District of Columbia.[75] Similarly, the Commission imposed a controlled rollout when it authorized Higher Ground to deploy handset-based mobile satellite uplink terminals in the 5925-6425 MHz band.[76] It should follow those precedents here.

11. Allocation of costs

All the costs of the AFC system— setting up, testing, operating, maintaining, and everything else—must be the RLAN industry's responsibility. The FWCC will encourage its

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[73] RKF Study at 13.

[74] *E.g.*, *Office of Engineering and Technology Announces the Approval of Spectrum Bridge, Inc.'s TV Bands Database System for Operation*, Public Notice, 26 FCC Rcd 16924 (Office of Engineering and Technology 2011) (Wilmington, NC and surrounding area).

[75] *Office of Engineering and Technology and Wireless Telecommunications Bureau Announce the Initial Launch of Unlicensed Wireless Microphone Registration System*, Public Notice, 27 FCC Rcd 11163 (Office of Engineering and Technology, Wireless Telecom. Bur. 2012).

[76] *Higher Ground LLC*, Order and Authorization, 32 FCC Rcd 728 at ¶ 40(a) (Internat'l Bur., Wireless Telecom. Bur., Office of Engineering and Technology 2017).

members to make available technical personnel to participate in developing and testing the system, without charge, but will expect the RLAN industry to cover reasonable out-of-pocket expenses.

H. OTHER ISSUES

1. Rural and underserved areas

The Commission asks whether higher RLAN power can be allowed in rural and underserved areas, perhaps limited to point-to-point operations with a minimum antenna gain, and possibly point-to-multipoint as well.[77]

There are many FS antenna sites in rural areas that relay signals traveling between metropolitan centers. See Figure 8. These require the same level of protection as urban antennas.

Point-to-point RLAN operation would greatly complicate AFC coordination. The AFC database would have to take into account not only an RLAN's location, elevation, and much higher EIRP, but also its antenna gain, azimuth and elevation angle.[78] We oppose point-to-point unlicensed operation in the initial roll-out, but are open to considering it after the AFC setup is running smoothly.

Figure 8: Rural FS operation

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[77] Notice at ¶ 79.

[78] The Wi-Fi Alliance requests unlimited EIRP. Letter from Alex Roytblat Senior Director of Regulatory Affairs. Wi-Fi Alliance, to Marlene Dortch, Secretary, FCC, in GN Docket No. 17-183 at 3 (filed Aug. 8, 2018) (seeking same power limits as 47 C.F.R. § 15.407(a)(3), which allows fixed point-to-point devices to have unlimited antenna gain with no power penalty, and hence unlimited EIRP).

We doubt that point-to-multipoint RLAN systems can be coordinated reliably. These would have the same problems as point-to-point RLANs, and in addition, are likely to add and change remote locations on a frequent basis. The Commission has proposed point-to-multipoint in the 4 GHz band.[79] The FWCC does not oppose this, so long as existing FS links in the bands remain protected.[80] We think the best solution is to move forward with point-to-multipoint at 4 GHz and exclude it from 6 GHz.

2. Moving vehicles and drones

We agree with the Commission that RLAN operation cannot be allowed in moving vehicles, due to the difficulty of updating frequency information rapidly enough to accommodate changing locations.[81] RLAN operation in aircraft, whether manned or unmanned, would add the further risk of traversing FS receiver boresights.[82]

3. Digital Identifying Information

The Commission asks whether RLANs should be required to transmit digital IDs.[83] This would not be helpful, for the reasons that the Commission notes: FS operators do not become aware of interference until after the link fails, and in any event, the FS receiver could not decode the RLAN ID.[84]

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[79] 4 GHz Order & NPRM at ¶¶ 116-32.

[80] *See* Comments of the Fixed Wireless Communications Coalition in GN Docket No, 18-122 (filed Oct. 29, 2018).

[81] Notice at ¶ 84.

[82] Notice at ¶ 85.

[83] Notice at ¶¶ 87-88.

[84] Notice at ¶ 87.

The Commission asks whether ID decoding capability should be added to FS receivers.[85] We oppose the suggestion. To preserve FS reliability, RLAN interference will have to be vanishingly rare, so the decoding capability would see little or no use. This makes it unreasonably expensive on a per-use basis. Some FS locations are difficult to reach, adding to the costs of retrofitting. See Figure 9.

Figure 9: Hard-to-access FS location

More useful would be a functionality within the AFC system that, on receiving an FS interference report, identifies the RLANs that might be responsible. To facilitate this, we support the proposal that each RLAN report back to the AFC database the particular frequencies it is using.[86]

4. Interference resolution

An AFC system operator that receives an interference report from an FS operator, and can narrow down the source to one or a few RLANs, should be required to immediately disable the offending RLAN(s), without prior notice, pending repair or replacement.

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[85] Notice at ¶ 88.

[86] Notice at ¶ 89.

CONCLUSION

This is the Commission's first attempt at introducing very large numbers of unlicensed devices into a band whose services maintain the safety of life and property. We urge the Commission to proceed cautiously, and to resolve reasonable doubts in favor of protecting fixed links.

Respectfully submitted,

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February 15, 2019

Attachment A

Determining the Impact of Non-Coordinated
Indoor 6 GHz RLAN Interference on Fixed Service Receivers

Attachment B

Need for Adjacent Channel Interference Protection

Attachment C

RLAN/FS Guard Band Analysis

ATTACHMENT A

Determining the Impact of Non-Coordinated Indoor 6 GHz RLAN Interference on Fixed Service Receivers

George Kizer

When sharing spectrum, the standard approach is to limit interference so that it increases the receiver front end noise by no more than a tolerable amount. We shall use the value adopted by the RLAN proponents[1] and the Wi-Fi Alliance[2] : I/N = - 6 dB.

[Allowable] Foreign System Interference = Radio Front End Noise – 6 dB (1)

Receiver front end noise N is given by the following:[3]

$$N(\text{dBm}) = -114 + NF + 10\,\text{Log}(B) \qquad (2)$$

NF = receiver noise figure (dB)
B = receiver bandwidth (MHz)

RKF took the typical receiver noise figure in this band to be about 5 dB,[4] and I/N = – 6 dB, so the allowable foreign system interference I would be the following.

$$I(\text{dBm}) = -115 + 10\,\text{Log}(B) \qquad (3)$$

The 6 GHz channel bandwidths having commercial significance are the following:

Channel Bandwidth (MHz)	Lower 6 GHz	Upper 6 GHz
60	X	----
30	X	X
10	X	X
5	X	X

Table 1 – Most Used FS Channel Bandwidths (MHz)

From the above equations, we can calculate receiver front end noise N and the allowable interference power I for these bandwidths:

Channel Bandwidth (MHz)	Receiver Noise N (dBm)	Allowable Interference I (dBm)
60	-91	-97
30	-94	-100
10	-99	-105
5	-102	-108

Table 2 – Receiver Front End Noise and Allowable Interference Power

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[1] *Frequency Sharing for Radio Local Area Networks in the 6 GHz Band January 2018* at 5, 6, 11, attached to Letter from Paul Margie, Counsel to Apple Inc., *et al*. to Marlene Dortch, Secretary, FCC (filed Jan. 26, 2018) ("RKF Study").

[2] Letter from Alex Roytblat, Senior Director of Regulatory Affairs, WI-FI ALLIANCE, in GN Docket No. 17-183 at 3 (filed Sept. 18, 2018) (WFA September 18 Letter).

[3] Kizer, G., *Digital Microwave Communication*, page 674, formula (A.54), Hoboken: Wiley and Sons, 2013.

[4] RKF Study at 29.

Receiver path performance is a direct function of path fade margin. Fade margin is limited by the combined power level of receiver front end noise and external interference, given by the following formula:

$$RFM = \{10 \log_{10} [10^{N/10} + 10^{I/10}] \} - N \tag{4}$$

RFM = Reduction in Fade Margin (dB)
N = Receiver Front End Noise (dBm)
I = External Interference (dBm)

If we relate I to power relative to N, we can set N = 0 and I as the dB level of power relative to N. Using this approach with equation (3), and the RLAN proponents' (I/N) of - 6 dB,[5] gives an equivalent reduction in fade margin of 1 dB.

Multipath effects cause all 6 GHz fading in most parts of the United States,[6] due to changing refractions from atmospheric layers that can interfere destructively with the direct signal. An FS receiver under stress from atmospheric fading may need all of its fade margin to maintain communication at an acceptable level of availability.

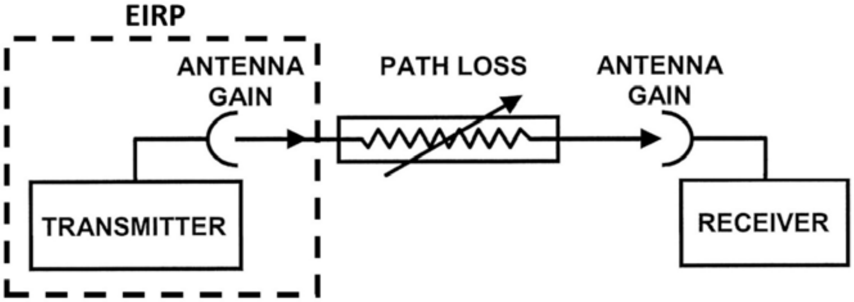

Figure 1 – Typical Radio Path

For the typical radio path, transmission line losses may be ignored. They are insignificant relative to the other losses in the path. If both antennas are operating in their far fields,[7] the propagated power appearing at the receiver is simply the sum of transmitter power (dBm) and transmit antenna gain (dBi) (in combination termed EIRP), minus the free space and atmospheric losses (dB), plus the receive antenna gain (dBi). Atmospheric losses for the frequencies under consideration are insignificant and may be ignored.

The main interference threat from indoor RLAN operation is a unit, perhaps on an upper floor, located within the boresight of an FS receive antenna under free-space conditions

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[5] RKF Study at 5, 6, 11.

[6] Some parts of the country also see significant fading from other causes. See Kizer, G., *Digital Microwave Communication* at 461-513 (Hoboken: Wiley and Sons, 2013).

[7] Kizer, G., *Digital Microwave Communication*, pages 265-274. Hoboken: Wiley and Sons, 2013 and Kizer, G., "Microwave Antenna Near Field Power Estimation," *4th European Conference on Antennas and Propagation (EuCAP) Proceedings,* April 2010.

with only the building wall between the RLAN and the FS antenna. RKF estimates there will be 469 million low-power indoor "clients."[8] Concentrated into urban and suburban areas, in the presence of 96,000+ FS receivers, some of these are virtually certain to fall into receiver boresights.[9]

Wi-Fi Alliance's Proposal

The Wi-Fi Alliance proposes to exempt from frequency coordination indoor RLAN systems below 30 dBm EIRP power level, on the incorrect assumption that low-power indoor devices pose no threat of interference to 6 GHz Fixed Service (FS) receivers.[10] We demonstrate below that indoor RLANs at any useful power will risk unacceptable levels of interference into FS receivers and so will require coordination.

A Wi-Fi Alliance estimate for signal loss through a building wall at 6 GHz is 30 dB.[11] Based upon this assumption, we may write an equation for FS receiver interference from an indoor RLAN:

Interference (dBm) = RLAN EIRP (dBm) – Path Loss (dB)
– Building Penetration Loss (dB) + Receive Antenna Gain (dBi)
– Antenna Side Lobe Rejection (dB) – Near Field Loss (dB)
– Bandwidth Mismatch Loss (dB) - Polarization Decoupling Loss (dB) (5)

Building Penetration Loss (dB) = 30 (per the Wi-Fi Alliance; see above)
Receive Antenna Gain (dBi) = 38.0 (boresight, 6 foot Cat. A or B1 parabolic antenna)[12]
Antenna Side Lobe Rejection (dB) = 0 (for boresight case)
Near Field Loss (dB) = negligible for the cases we are considering (beyond 0.5 km)
Bandwidth Mismatch Loss (dB) = 10 Log (94 MHz (RLAN weighted average) / 30 MHz) = 5
Polarization Decoupling Loss (dB) = 3

This gives:

Interference (dBm) = RLAN EIRP (dBm) – Path Loss (dB) - 30 + 38.0 - 5 - 3 (6)

Assume Path Loss is free space.

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[8] This number follows from a total of 958 million RLANs, RKF Study at 13, of which 98% are indoors, *id*. at 22, with 50% of those being low-power clients. *Id*. at 22, Table 3-5.

[9] The ITU-R suggests using free space loss when analyzing interference of ubiquitous RLANs into FS systems. ITU-R Recommendation F.1706, *Protection Criteria for Point-to-Point Fixed Wireless Systems Sharing the Same Frequency Band with Nomadic Wireless Access Systems in the 4 to 6 GHz Range*. Geneva: International Telecommunication Union, Radiocommunication Sector, January 2005.

[10] WFA September 18 Letter at 2.

[11] WFA September 18 Letter at 4.

[12] §101.115 (b) (table) (antenna standards).

Free Space Path Loss (dB) = 92.5 + 20 Log [Frequency (GHz)]
+ 20 Log [Path Distance (kilometers)] (7)
= 108.3 + 20 Log [Path Distance (kilometers)] (assumes lower 6 GHz mid-band frequency of 6.175 GHz)

The allowable interference for a 30 MHz FS channel is -100 dBm (from Table 2 above):

–100 = RLAN EIRP (dBm) – 108.3 - 20 Log [Path Distance (kilometers)]
- 30 + 38.0 - 5 - 3

RLAN EIRP (dBm) = -100 + 108.3 + 20 Log [Path Distance (kilometers)]
+ 30 - 38.0 + 5 + 3

= + 8.3 + 20 Log [Path Distance (kilometers)] (8)

From equation (8), Table 3 gives the maximum RLAN power that limits interference to the I/N = -6 dB criterion specified by RLAN Group, for various path lengths between the RLAN and the FS receiver:

Path Distance (km)	RLAN EIRP (dBM)
1	+ 8.3
3	+ 17.8
6	+ 23.9
10	+ 28.3
12.2	+ 30.0

Table 3 – Indoor Wi-Fi RLAN Power Limits for FS Boresight Antennas (30 dB Wall)

RLAN Proponent's Proposal

RLAN proponents have asked to operate low-power devices indoors without coordination, on the assumption that such devices will "operate at maximum powers sufficiently low that they pose no material risk of harmful interference to incumbent links."[13] They propose indoor RLAN systems with up to 18.5 dBm EIRP. A more realistic assumed building path loss is 20 dB.[14]

Based upon these assumptions, we may write an equation for FS receiver interference from an indoor RLAN:

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[13] *6 GHz: Additional FS Protection Discussion* (slide deck) at 7, attached to Letter from Paul Margie, Counsel to Apple et al., to Marlene H. Dortch, Secretary, FCC, in GN Docket No. 17-183 (filed Aug. 2, 2018).

[14] Loew, L. H., Lo, Y., Laflin, M. G. and Pol, E. E., *Building Penetration Measurements from Low-height Base Stations At 912, 1920, and 5990 MHz*; NTIA Report 95-325 at 108, Table D-6 (Inst. for Telecom. Sciences, NTIA Sept. 1995) (measurements at 5.99 GHz).

Interference (dBm) = RLAN EIRP (dBm) – Path Loss (dB)
– Building Penetration Loss (dB) + Receive Antenna Gain (dBi)
– Antenna Side Lobe Rejection (dB) – Near Field Loss (dB)
– Bandwidth Mismatch Loss (dB) - Polarization Decoupling Loss (dB) (9)

Building Penetration Loss (dB) = 20 (see above)
Receive Antenna Gain (dBi) = 38.0 (boresight, 6 foot Cat. A or B1 parabolic antenna)[15]
Antenna Side Lobe Rejection (dB) = 0 (for boresight case)
Near Field Loss (dB) = negligible for the cases we are considering (beyond 0.5 km)
Bandwidth Mismatch Loss (dB) = 10 Log (94 MHz (RLAN weighted average) / 30 MHz)
= 5
Polarization Decoupling Loss (dB) = 3

Interference (dBm) = RLAN EIRP (dBm) – Path Loss (dB) - 20 + 38.0 - 5 - 3 (10)

Assume Path Loss is free space.

Free Space Path Loss (dB) = 92.5 + 20 Log [Frequency (GHz)]
+ 20 Log [Path Distance (kilometers)] (11)
= 108.3 + 20 Log [Path Distance (kilometers)] (assumes lower 6 GHz mid-band frequency of 6.175 GHz)

The allowable interference for a 30 MHz FS channel is -100 dBm (from Table 2 above):

–100 = RLAN EIRP (dBm) – 108.3 - 20 Log [Path Distance (kilometers)]
- 20 + 38.0 - 5 - 3

RLAN EIRP (dBm) = -100 + 108.3 + 20 Log [Path Distance (kilometers)]
+ 20 - 38.0 + 5 + 3

= - 1.7 + 20 Log [Path Distance (kilometers)] (12)

From equation (12), Table 4 gives the maximum RLAN power that limits interference to the I/N = - 6 dB criterion specified by RLAN Group, for various path lengths between the RLAN and the FS receiver:

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[15] §101.115 (b) (table) (antenna standards).

Path Distance (km)	RLAN EIRP (dBM)
1	- 1.7
3	+ 7.8
6	+ 13.9
10	+18.3
10.2	+18.5

Table 4 – RLAN Proponent’s Indoor RLAN Power Limits for FS Boresight Antennas (20 dB Wall)

CONCLUSION

Even indoor RLANs at very low power pose an unacceptable interference threat to FS receivers unless they operate under control of a coordination system.

ATTACHMENT B

Need for Adjacent Channel Interference Protection

George Kizer

Introduction

A fixed service receiver, like all practical radio receivers, has a frequency passband wider than the band being received. Interference occurs when an interfering transmitter spectrum overlaps any part of the passband response of the victim receiver, even if outside the nominal channel being received.

If the transmitter interference center frequency occurs on the same center frequency as the victim receiver, the interference is designated "co-channel." If it occurs on the frequency one channel bandwidth away from the receiver center frequency, the interference is designated "adjacent channel." If it occurs two channel bandwidths away from the receiver center frequency, the interference is designated "second-adjacent channel."

If the interference bandwidth is similar to the victim receiver bandwidth, interference analysis over the adjacent and second-adjacent channel frequency range is generally adequate. If the interference bandwidth is larger than the bandwidth of the victim receiver, interference analysis over a larger frequency range is necessary. In cases where the interfering transmitter bandwidth is much wider than the receiver bandwidth, significant interference can occur from interfering transmitters operating on a center frequency far removed from the center frequency of the victim receiver. That will be demonstrated toward the end of this article.

This document is based upon principles established in TIA Bulletin 10-F.[1]

Digital Receiver Interference

Fixed point-to-point microwave radio systems use transmitters and receivers deployed miles apart to transport high speed digital signals. The reliability of the transmission is directly related to the path fade margin, namely, the difference between the normal received signal power and the lowest received signal power that still supports receiver operation. In the absence of external interference, the lowest operational received power (receiver threshold) is determined by the receiver's front end (Gaussian) noise. External interference causes the receiver threshold to occur at a larger (stronger) received power, thereby reducing the effective path fade margin, and in consequence, reducing path availability and reliability.

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[1] TIA/EIA Telecommunications Systems Bulletin 10-F, *Interference Criteria for Microwave Systems*, Washington, D.C.: Telecommunications Industry Association,1994, page B-1 through B-8.

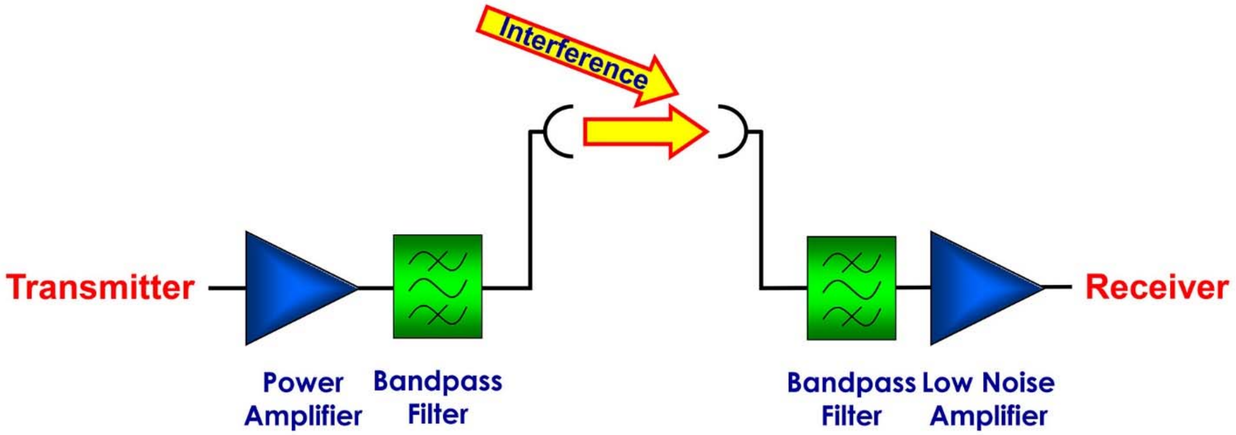

Figure 1 Interference into a Victim Receiver

Threshold to Interference (T/I) values[2] are used to estimate interference caused by an interfering signal into a victim digital receiver. T/I represents the maximum interfering signal power level where the victim receiver's 10^{-6} bit error ratio (BER) threshold has been degraded by 1 dB.

The interference objective defined by T/I is given by the following:

Icoord = coordinated interference objective (dBm) (1)

= RSLmin (dBm) – T/I (dB)

RSLmin = received signal level at radio 10^{-6} BER threshold (dBm) (2)

= receiver threshold specification (dBm)

= RSLnorm (dBm) – FM (dB)

RSLnorm = normal received signal level (dBm) (3)

FM = radio fade margin (dB) = RSLnorm - RSLmin (4)

The use of T/I simplifies analysis of the effect of interference into a receiver. Typically, T/I is specified by the manufacturer for similar signal interference which is co-channel, adjacent channel, or second-adjacent channel. Here, there is a need to estimate T/I data for cases where the victim receiver and interfering transmitter have very different bandwidths. In this case, measured data is seldom available and the T/I must be estimated.

Most fixed microwave receivers in the 6 GHz have a 30 MHz bandwidth, but bandwidths of 10 MHz and 60 MHz also occur. Most RLANs in the band are projected to have

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[2] TIA/EIA Telecommunications Systems Bulletin 10-F, *Interference Criteria for Microwave Systems*, Washington, D. C.: Telecommunications Industry Association,1994, page B-1.

operating bandwidths of 80 MHz or 160 MHz, with a minority at 20 MHz or 40 MHz.[3] The mismatch between microwave receiver and RLAN transmitter bandwidths complicates the interference calculations.

Defining "Adjacent Channel" Interference

Adjacent channel interference, as the term is used by frequency coordinators, is interference centered at a frequency equal to the receiver center frequency plus or minus the receiver bandwidth. For a 29.65 MHz (nominal 30 MHz) bandwidth receiver centered at 6034.15 MHz, adjacent channel interference could be centered at 6004.50 MHz or 6063.80 MHz. RLAN transmitters will have center frequencies and bandwidths be different from those of the Fixed Services (FS). This will lead to non-intuitive results such as "adjacent channel" 80 and 160 MHz wide RLAN transmitters producing interference in the FS channel being received. Because the RLAN center frequencies are unpredictable, we graph interference for a continuum of interference frequency offsets.

Estimating Interference T/I Using Default Parameters

No manufacturer can provide T/I curves for all possible combinations of interfering signal and desired signal. In the present case, the T/I values must be theoretically derived. By the Convolution Theorem, if two devices are cascaded (multiplicative) in the time domain, the frequency domain representation of the output is the convolution of the frequency domain representation of the two devices. We apply this theorem to derive the frequency domain representation of a digital signal passing through a linear receiver.

A normalized T/I curve $T/I_{\text{Normalized}}$ may be estimated using the following equation:

$$T/I_{\text{Normalized}} = 10\log\left\{\left[\int_{-\infty}^{+\infty} s(\tau - f)c(\tau)d\tau\right] / \left[\int_{-\infty}^{+\infty} s(\tau - f_0)c(\tau)d\tau\right]\right\} \qquad (5)$$

The term c(f) is the normalized power transfer function (bandpass characteristic) of the victim receiver expressed as a power ratio. C(f) is a normalized transfer function (bandpass characteristic) of the victim receiver with power ratio expressed in dB. Therefore $c(f) = 10^{C(f)/10}$. The term s(f) is the normalized spectral power density of the interfering signal being applied to the input of the receiver. For the interfering spectral density function S(f) with power expressed in dB, $s(f) = 10^{S(f)/10}$. The convolution integral in the denominator is referenced to the receiver center frequency f_0. That integral's function is to normalize the result of the convolution integral in the numerator.

We further define the following relationships:

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[3] Letter from Paul Margie, Counsel to Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene Dortch, Secretary, FCC (filed Jan. 26, 2018) (attachment) ("RKF Study"), table 3-9, page 24.

Bandwidth Ratio (BWR) = Interfering Spectrum Bandwidth / Desired Spectrum Bandwidth

(6)

Bandwidth Factor (dB) = 10 Log10 [Bandwidth Ratio (BWR)] if Bandwidth Ratio (BWR) > 1

= 0 if Bandwidth Ratio (BWR) ≤ 1 (7)

|Normalized Frequency| = Absolute Value [(Interfering Signal Center Frequency

– Desired Signal Center Frequency) / Desired Signal Channel Bandwidth] (8)

T/I (dB) = Normalized T/I (dB) + Receiver Co-Channel T/I (dB) - Bandwidth Factor (dB)

(9)

Sometimes the transmitter and/or receiver characteristics are not known. We will use the following "default" curves (developed by the TIA TR-45 Working Group for Microwave Systems based upon the average of several actual transmitters and receivers[4]). The default transmitter spectrum complies with the emission limitation provisions of §101.111 (a) (2) (i).

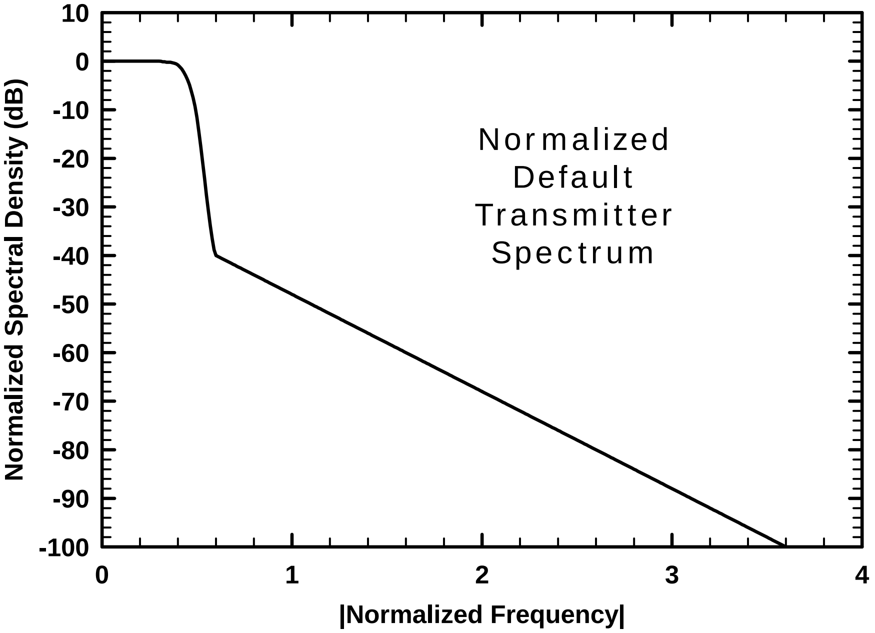

Figure 2 Default Transmitter Spectrum S(f)

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[4] Draft Standard ANSI/TIA-10, *Engineering Considerations for Fixed Point-to-Point Microwave Systems*, Arlington: Telecommunications Industry Association

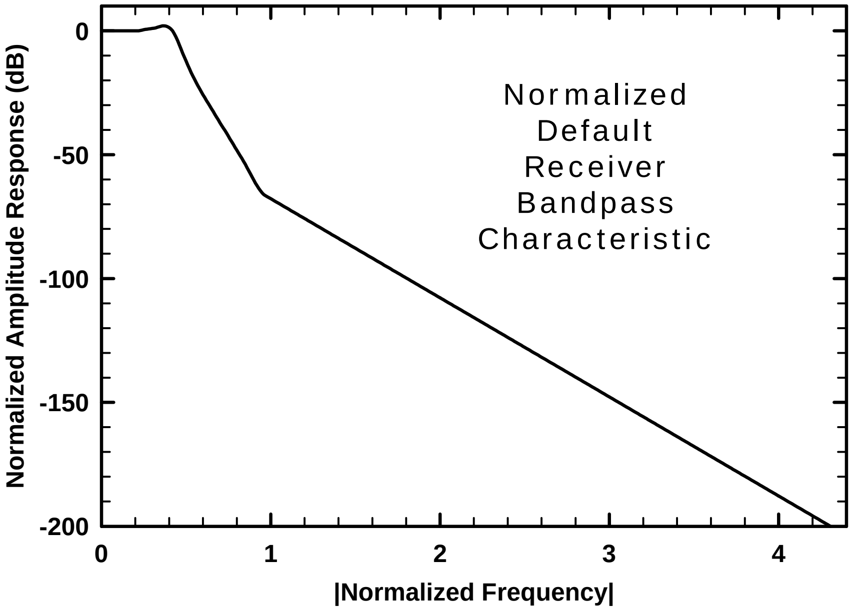

Figure 3 Default Receiver Bandpass Characteristic C(f)

Notice that the receiver bandpass curve shows significant sensitivity to signals outside the receiver's channel bandwidth (within about ± 0.5 normalized frequency). A "brick-wall" filter is not practical because of " … delay distortion which is due to the steeper rise of the attenuation at the passbands edges … ."[5]

Using the above default curves, normalized T/I values were calculated for dissimilar interference bandwidths.

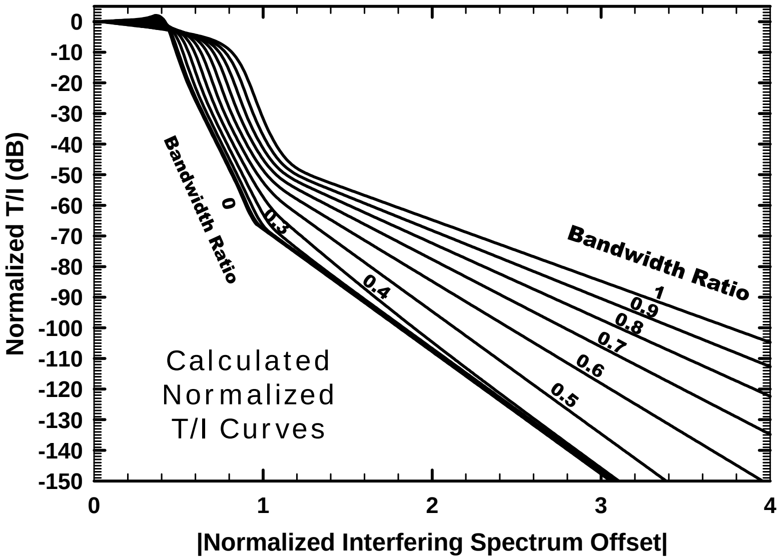

Figure 4 Small Bandwidth Ratio Interference T/I Curves

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[5] L. J. Giacoletto, *Electronics Designers' Handbook*, Second Edition, 1977, at 6-45.

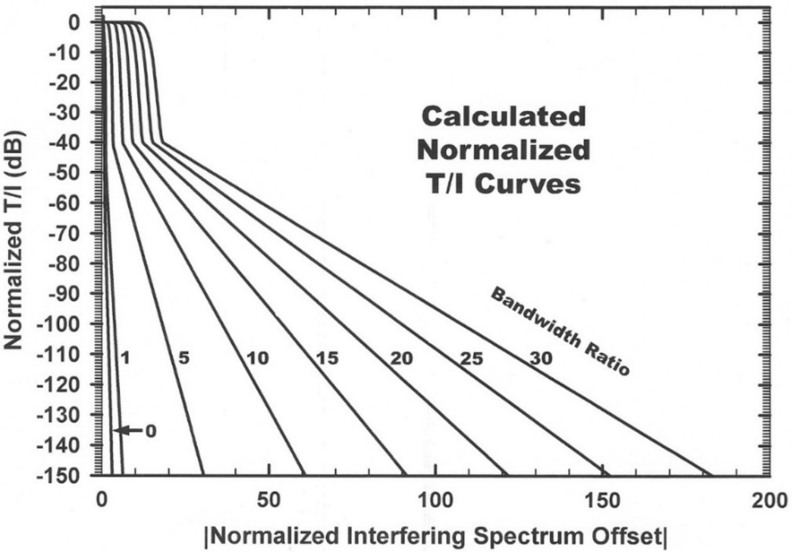

Figure 5 Large Bandwidth Ratio Interference T/I Curves

Converting a normalized T/I curve to an actual T/I curve requires knowledge of the victim receiver's co-channel T/I value.

Modulation	Average Measured T/I	Default T/I Value
4096 QAM		47.0 dB
2048 QAM		44.0 dB
1024 QAM	40.2	41.0 dB
512 QAM	38.2	38.0 dB
256 QAM	33.9	35.0 dB
128 QAM	31.4	32.0 dB
64 QAM	29.1	29.0 dB
32 QAM	25.5	26.0 dB
16 QAM	22.8	23.0 dB
QPSK / 4 QAM	15.5	17.0 dB

Table 1 - Typical Co-Channel Like Interference T/I Values

The above average measured values are based upon a major coordinator's T/I data base

The normalized T/I values assume a QAM victim receiver. However, the interfering signal need only be a broadband digital signal. A particular modulation format is not assumed.

It should be noted that the T/I curves are limited by the interfering transmitter's main spectral signal overlapping the victim receiver's bandpass response. The transmitter's roll-off spectrum outside the transmitter's main spectral signal (out-of-band emissions) has little influence on the T/I result.

Applying the Results to the Proposed Unlicensed Transmitter Interference Case

We shall assume the typical 30 MHz wide fixed (point to point) service (FS) receiver as the victim. The unlicensed transmitters will have bandwidths of 20 MHz, 40 MHz, 80 MHz, and 160 MHz bandwidth channels with 80% of the channels using 80 MHz and 160 MHz bandwidth channels[6]. Using the 80 MHz (BWR = 2.67) and 160 MHz (BWR = 5.33) channel transmitters as interference, we may compare the T/I requirements to those of a typical FS interfering transmitter (BWR = 1.00).

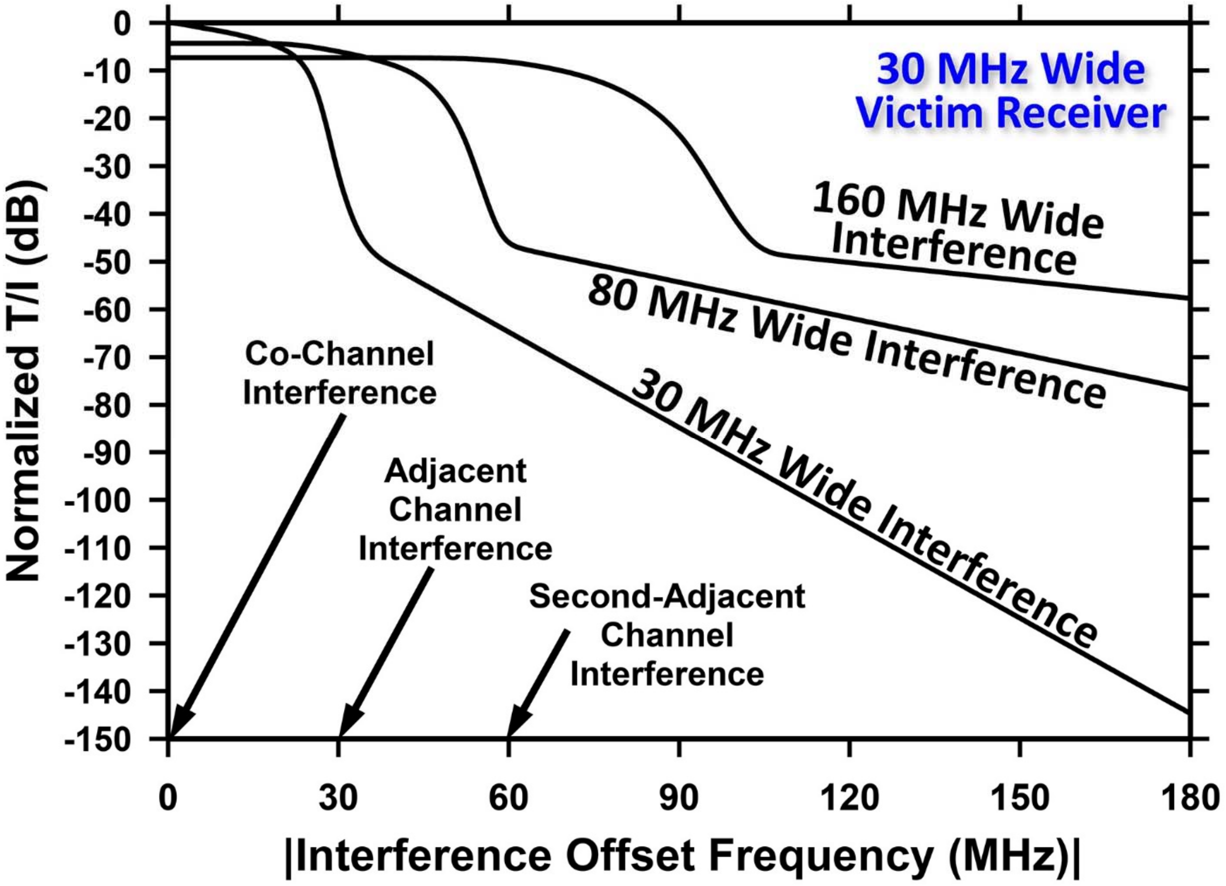

Figure 6 Normalized Receiver Interference (≈ T/I)

(The Interference Offset Frequency in Figure 6 is the absolute value of the difference between the center of the FS receiver channel and the center of the RLAN signal channel.)

Notice that the primary issue for adjacent channel interference is direct spectrum overlap of the wide bandwidth interfering signal into the victim receiver's pass band response. For the 80 MHz bandwidth interference, adjacent channel interference is nearly the same as co-channel interference. Second-adjacent channel 80 MHz wide interference is essentially as strong as adjacent channel interference from a 30 MHz wide FS transmitter. For a 160 MHz wide interfering signal, co-channel, adjacent channel and second-adjacent channel interference are essentially the same. Third-adjacent channel interference from 160 MHz wide interference is greater than adjacent channel interference from a FS 30 MHz interfering transmitter. Today frequency coordination among FS transmitters and

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[6] RKF Study, table 3-9, page 24.

receivers require co-channel and adjacent channel analysis.[7] If wider bandwidth interfering signals are introduced into the band, analysis beyond adjacent channel interference will be required.

Conclusion

Standard frequency coordination of conventional 30 MHz FS receivers require an analysis of co-channel, adjacent channel (30 MHz) and second-adjacent channel (60 MHz) interference frequency offset. Frequency coordination for a wide band RLAN interfering signal will require analysis well beyond adjacent channel and second-adjacent channel interfering frequency offsets.

Ignoring the N-adjacent channels specified above would open FS receivers to RLAN interference that reduces path fade margin sufficiently to impact receiver availability and reliability.

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[7] NSMA WG 5.92.008 Report, *Report and Tutorial Carrier-to-Interference Objectives*, Arlington: National Spectrum Management Association, January 1992, at 10. <https://nsma.org/recommendations/>

ATTACHMENT C

RLAN / FS Guard Band Analysis

George Kizer

One way to reduce interference from RLAN transmitters into victim Fixed Service (FS) receivers is to provide a guard band (frequency separation) between the operational channels of the fixed service receiver and the RLAN transmitter. We will investigate the impact of frequency offset on transmitter interference into Fixed Service receivers.

Interference as a Function of Interfering Transmitter Frequency Offset

The pass band frequency response of a typical FS receiver[1] is graphed in Figure 1.

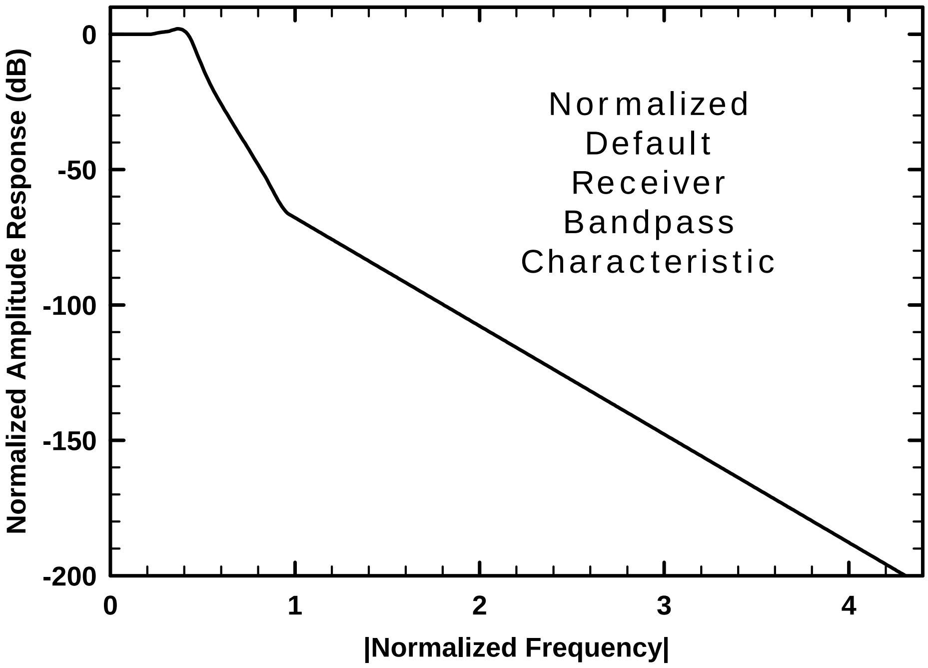

Figure 1 - Typical Fixed Service Receiver Bandpass Characteristic

Lacking data on the RLAN transmitter power spectral density (PSD) (spectrum limitation mask), we will assume it is similar to either that of a Fixed Service microwave transmitter[2] or a typical Wi-Fi transmitter,[3] in either case scaled to a nominal bandwidth of 80 or 160 MHz. See Figures 2 and 3.

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[1] TIA Committee TR-45 Working Group for Microwave Systems (George Kizer, Chairman), *Engineering Considerations for Fixed Point-to-Point Microwave Systems, Draft Standard ANSI/TIA-10*, Figure 13 (C-6) Default Receiver Bandpass Characteristic C(f), page 63. Arlington: Telecommunications Industry Association, publication pending (expected May 2019) ("Draft ANSI/TIA-10").

[2] CFR, Title 47, Chapter I, Subchapter D, Part 101, Subpart C, §101.111 (a) (2) (i), Emission Limitations

[3] IEEE Standard 802.11-2016 Part 11, Figures 21-31 and 21-32

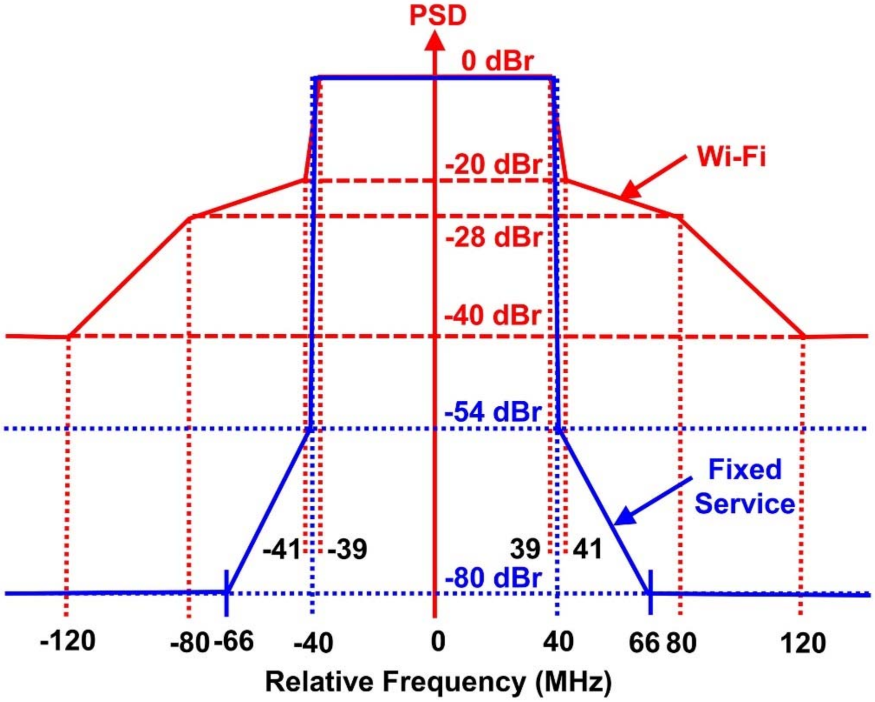

Figure 2 - Hypothetical Transmitter Spectral Power Densities for Nominal 80 MHz Bandwidth Based on Wi-Fi and FS PSDs

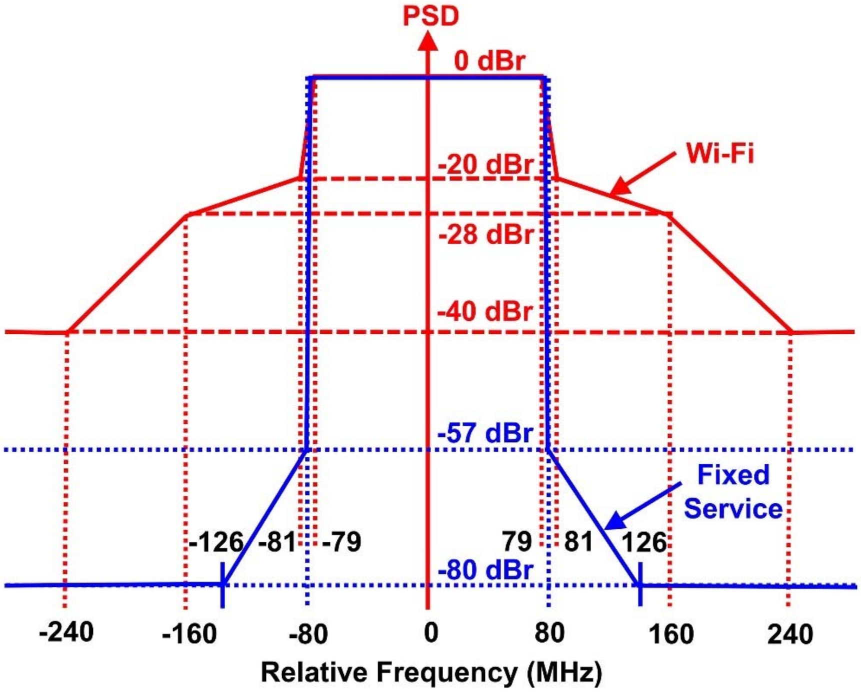

Figure 3 - Hypothetical Transmitter Spectral Power Densities for Nominal 160 MHz Bandwidth Based on Wi-Fi and FS PSDs

Using the methodology of draft ANSI/TIA draft standard 10[4], we calculated[5] normalized T/I values from 80 MHz and 160 MHz transmitters into a 30 MHz victim FS receiver with various relative frequency offsets between the interference channel center frequency and the victim receiver channel frequency.

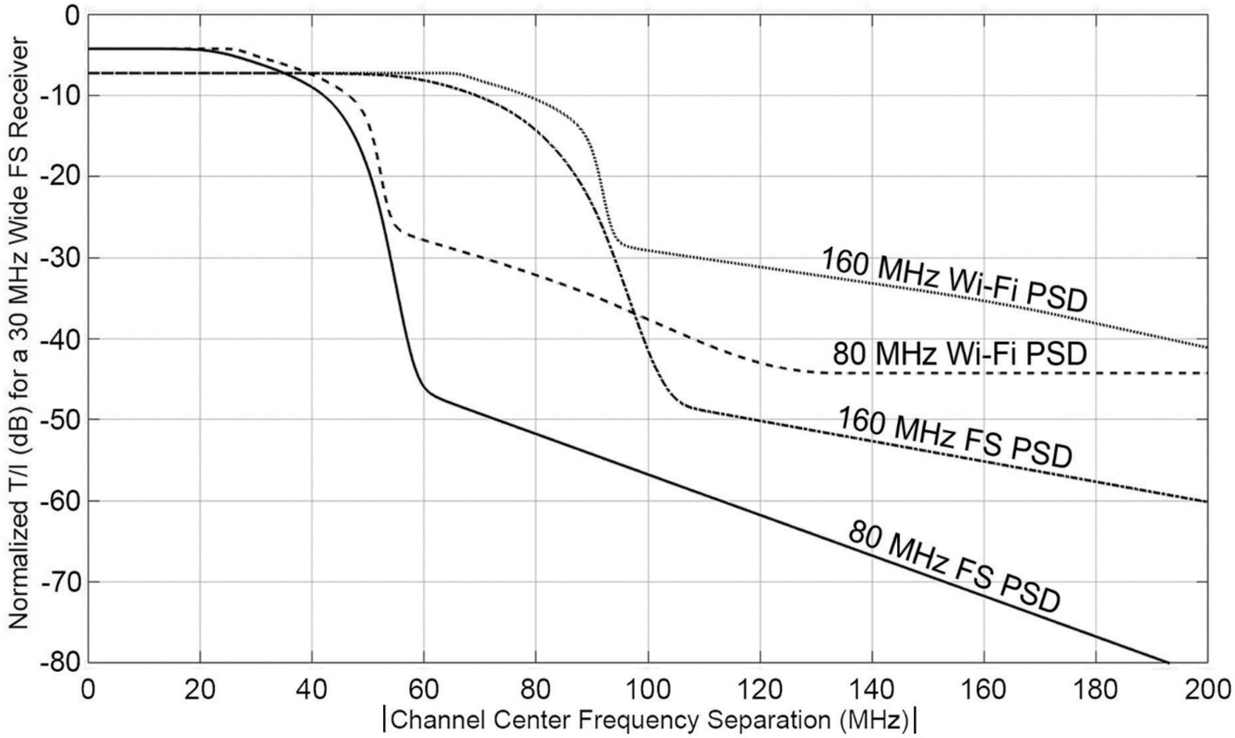

Figure 4: Normalized Interference T/I Values

Figure 4 graphs normalized T/I values for various interference bandwidths and frequency offsets. (The Center Chanel Frequency Separation is the difference between the center of the FS receiver channel and the center of the RLAN signal channel.)

T/I (normalized, for labeled interference case) = T/I (actual, for labeled interference case) - T/I (actual for 30 MHz interference into a 30 MHz FS receiver) or written alternatively

$T/I_{Nlic} = T/I_{Alic} - T/I_{A30}$ where (1)

T/I_{Alic} = T/I (actual, for labeled interference case)
T/I_{Nlic} = T/I (normalized, for labeled interference case) -
T/I_{A30} = T/I (actual for co-channel 30 MHz interference into a 30 MHz FS receiver)
T/I_{N30} = T/I (normalized for co-channel 30 MHz interference into a 30 MHz FS receiver)

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[4] Draft ANSI/TIA-10 at Chapter 5, Subsection 5-7, pages 62-65.

[5] Calculations provided by Will Perkins of Comsearch.

The general equation of interference limit[6] is the following:

$L_A = T_R - T/I$ (2)

T_R = receiver threshold
L_A = actual interference limit for a given case
T/I = actual T/I for a given case

We may determine the interference limit (strongest interference power for which the I/N = -6 criterion[7] is not exceeded) for a particular interference case as follows.

$T/I_{Nlic} = T/I_{Alic} - T/I_{A30} = (T_R - L_{Alic}) - (T_R - L_{A30}) = L_{A30} - L_{Alic}$ where (3)

T_R = receiver threshold
L_{Alic} = actual interference limit for labeled interference case
L_{A30} = actual interference limit for co-channel 30 MHz interference into a 30 MHz FS receiver

Therefore

$L_{Alic} = L_{A30} - T/I_{Nlic}$ or alternatively (4)

actual interference limit for labeled interference case = (actual interference limit for a co-channel 30 MHz FS transmitter into a 30 MHz FS receiver) - (normalized T/I for labeled interference case)

Figure 4 graphs the normalized T/I values for each labeled interference case.

Now we shall determine the actual interference limit for a co-channel 30 MHz FS transmitter into a 30 MHz FS receiver.

Interference Limit for a Fixed Service 30 MHz Receiver

We calculate the co-channel 30 MHz FS transmitter (i.e., “like” bandwidth) power into a 30 MHz receiver for various QAM modes of operation where the interference just degrades the receiver threshold 1 dB. This power is termed the co-channel Like Interference Limit.

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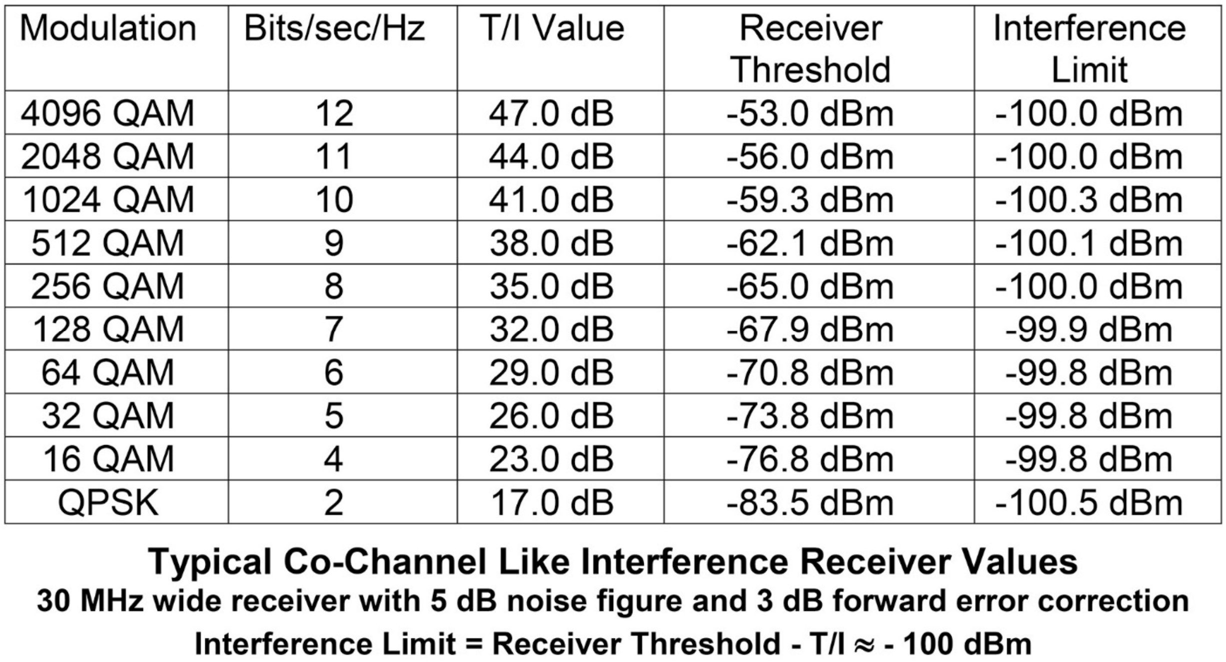
[6] Kizer, G., *Digital Microwave Communication*, page 562, formula (14.7), Hoboken: Wiley and Sons, 2013.
[7] Equivalent to the interference power which degrades a receiver threshold one dB.



Modulation	Bits/sec/Hz	T/I Value	Receiver Threshold	Interference Limit
4096 QAM	12	47.0 dB	-53.0 dBm	-100.0 dBm
2048 QAM	11	44.0 dB	-56.0 dBm	-100.0 dBm
1024 QAM	10	41.0 dB	-59.3 dBm	-100.3 dBm
512 QAM	9	38.0 dB	-62.1 dBm	-100.1 dBm
256 QAM	8	35.0 dB	-65.0 dBm	-100.0 dBm
128 QAM	7	32.0 dB	-67.9 dBm	-99.9 dBm
64 QAM	6	29.0 dB	-70.8 dBm	-99.8 dBm
32 QAM	5	26.0 dB	-73.8 dBm	-99.8 dBm
16 QAM	4	23.0 dB	-76.8 dBm	-99.8 dBm
QPSK	2	17.0 dB	-83.5 dBm	-100.5 dBm

Typical Co-Channel Like Interference Receiver Values

30 MHz wide receiver with 5 dB noise figure and 3 dB forward error correction

Interference Limit = Receiver Threshold - T/I ≈ - 100 dBm

Table 1: Co-channel Interference Receiver Values

The T/I values are from draft ANSI/TIA standard 10[8]. Receiver threshold was derived by calculating the receiver front end noise[9] for a 5 dB noise figure 30 MHz wide receiver, modifying that by required signal to noise (S/N)[10] for a 10^{-6} BER receiver threshold for a given modulation mode and finally subtracting 3 dB to account for 3 dB forward error correction. Interference limits were derived from the definition of T/I[11] [equation (2)].

The interference limit is the interference power in dBm which just degrades the receiver threshold by one dB (equivalent to I/N = - 6 dB where I is interference power and N is receiver front end noise).

The interference limit for 30 MHz like interference (L_{A30}) is -100 dBm. Using this we may use the equation $L_{Alic} = L_{A30} - T/I_{Nlic}$ and Figure 4 to determine interference limits for other forms of RLAN interference.

To honor the 1 dB receiver threshold degradation object, the interference will need to be less than the interference limit. In most cases antenna discrimination will be needed to meet or exceed the objective.

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[8] Draft ANSI/TIA-10 at Table 1 - (C-1) Typical Co-Channel Like Interference T/I Values, pages 57 and 58.

[9] Kizer, G., *Digital Microwave Communication*, page 52, formula (3-10), Hoboken: Wiley and Sons, 2013.

[10] *Id*. at page 64, Table 3.4.

[11] *Id*, at page 562, formula (14.7).

Interference Examples Assuming No Guard Band Between FS and RLAN Channels

First we will consider no guard band to protect FS receivers; the FS and RLAN transmission channels will just touch. For a 30 MHz fixed service receiver, that would impose a 15 MHz separation between the center of the FS receiver center frequency to the edge of the RLAN channel. For an 80 MHz wide RLAN channel, that would require the RLAN center frequency to be no closer than 40 + 15 = 55 MHz to the FS receiver center frequency. For an 160 MHz RLAN channel, the center to center frequency limit would be 80 + 15 = 95 MHz.

Using equation (4), Figure 4 and the above receiver interference limit, we have the following interference limits:

80 MHz Wide RLAN with FS PSD and 55 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 33.4 = -66.6$ dBm (5)

160 MHz Wide RLAN with FS PSD and 95 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 31.7 = -68.3$ dBm (6)

For purposes of FS PSD examples, we will use -67.5 dBm as the common interference limit.

80 MHz Wide RLAN with Wi-Fi PSD and 55 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 26.1 = -73.9$ dBm (7)

160 MHz Wide RLAN with Wi-Fi PSD and 95 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 28.1 = -71.9$ dBm (8)

For purposes of Wi-Fi PSD examples, we will use -72.9 dBm as the common interference limit.

We can calculate the expected received signal level at a FS 30 MHz receiver for various distances from a RLAN. We will assume the maximum RLAN EIRP of 35.4 dBm[12].

We also note that the boresight gain of a 6 foot antenna is 38.8 dBi and of a 10 foot antenna is 43.2 dB.

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[12] Letter from Paul Margie, Counsel to Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene Dortch, Secretary, FCC (filed Jan. 26, 2018) (attachment) Figure 3-10, page 24.

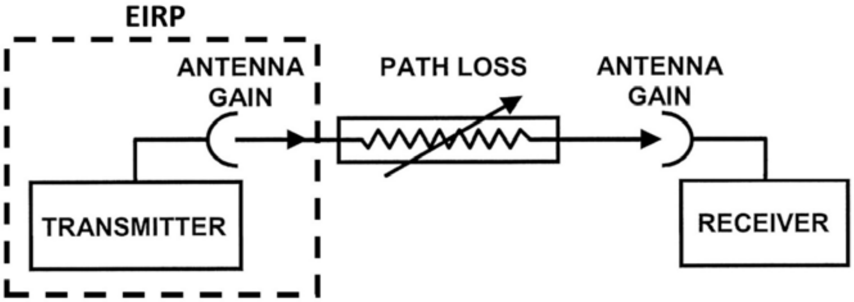

Figure 5 – Typical Radio Path

For the typical radio path, transmission line losses may be ignored. They are insignificant relative to the other losses in the path. If both antennas are operating in their far fields,[13] the propagated power appearing at the receiver is simply the sum of transmitter power (dBm) and transmit antenna gain (dBi) (in combination termed EIRP), minus the propagation and atmospheric losses (dB), plus the receive antenna gain (dBi). Atmospheric losses for the frequencies under consideration are insignificant and may be ignored. We will further assume the RLAN transmission is in the same polarization as the FS receive antenna, propagation loss is free space and transmission frequency is the center of the lower 6 GHz band (6.175 GHz).

Received Signal Power (dBm) = transmitter EIRP (dBm) - free space loss (dB)
+ receive boresight antenna gain (dBi) - receiver antenna off axis suppression

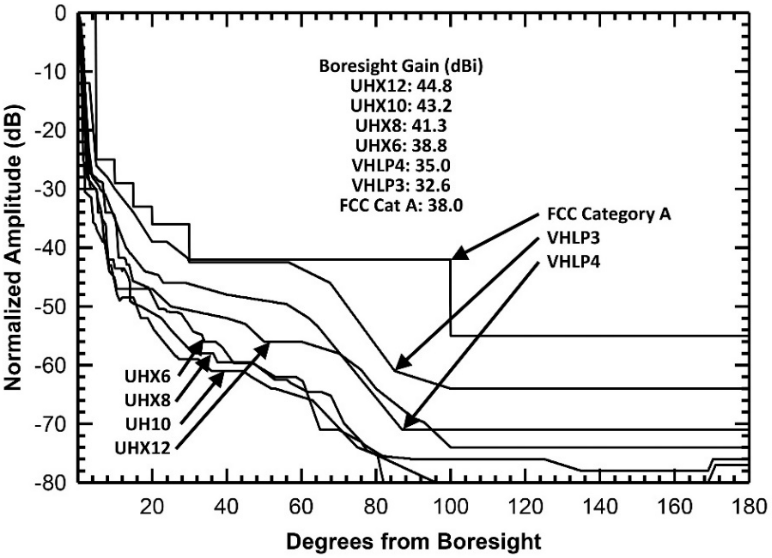

Figure 6: Typical Worst-Case Antenna Side Lobe Suppression and Average Boresight Gain

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[13] Kizer, G., *Digital Microwave Communication*, pages 265-274. Hoboken: Wiley and Sons, 2013 and Kizer, G., "Microwave Antenna Near Field Power Estimation," *4th European Conference on Antennas and Propagation (EuCAP) Proceedings,* April 2010.

$$\text{Free Space Loss (dB)} = 92.45 + 20 \log_{10} F \text{ (GHz)} + 20 \log_{10} d \text{ (kilometers)} \qquad (9)$$

F = Frequency of radio wave
d = Distance between antennas

6 foot antenna, 80 MHz Channels, no channel separation, FS PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-67.5	-14.4	2.2
1	-34.1	-67.5	-33.4	7.4
0.1	-14.1	-67.5	-54.4	31.3

6 foot antenna, 80 MHz Channels, no channel separation, Wi-Fi PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-72.9	-18.8	2.6
1	-34.1	-72.9	-38.8	10.7
0.1	-14.1	-72.9	-58.8	40.9

Interference in the table is the boresight interference. **Exclusion Angle Relative to Boresight** is the angle between the interference path and the receive antenna boresight path needed to bring the interference into compliance with the interference limit.

10 foot antenna, 160 MHz Channels, no channel separation, FS PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-67.5	-17.8	1.3
1	-29.7	-67.5	-37.8	5.8
0.1	-9.7	-67.5	-57.8	25.4

10 foot antenna, 160 MHz Channels, no channel separation, Wi-Fi PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-72.9	-23.2	1.5
1	-29.7	-72.9	-43.2	9.1
0.1	-9.7	-72.9	-63.2	49.8

Interference Examples Assuming Guard Band of One Half a FS 30 MHz Channel Bandwidth

Next we will consider a guard band of one half a FS receiver bandwidth. For a 30 MHz fixed service receiver, that would impose a 15 MHz separation between the edge of the FS receiver channel and the edge of the RLAN channel. For an 80 MHz wide RLAN channel, that would require the RLAN center frequency to be no closer than 40 + 15 + 15 = 70 MHz to the FS receiver center frequency. For a 160 MHz RLAN channel, the center to center frequency limit would be 80 + 15 + 15 = 110 MHz.

Using equation (4), Figure 4 and the above receiver interference limit, we have the following interference limits:

80 MHz Wide RLAN with FS PSD and 70 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 49.3 = -50.7$ dBm (10)

160 MHz Wide RLAN with FS PSD and 110 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 48.9 = -51.1$ dBm (11)

For purposes of FS PSD examples, we will use -51 dBm as the common interference limit.

80 MHz Wide RLAN with Wi-Fi PSD and 70 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 30.0 = -70.0$ dBm (12)

160 MHz Wide RLAN with Wi-Fi PSD and 110 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 30.1 = -69.9$ dBm (13)

For purposes of Wi-Fi PSD examples, we will use -70 dBm as the common interference limit.

6 foot antenna, 80 MHz Channels, half 30 MHz channel separation, FS PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-51	+3.1	0.0
1	-34.1	-51	-16.9	2.4
0.1	-14.1	-51	- 36.9	10.5

6 foot antenna, 80 MHz Channels, half 30 MHz channel separation, Wi-Fi PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-70	-15.9	2.3
1	-34.1	-70	-35.9	10.3
0.1	-14.1	-70	-55.9	34.0

10 foot antenna, 160 MHz Channels, half 30 MHz channel separation, FS PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-51	-1.3	0.3
1	-29.7	-51	-21.3	1.4
0.1	-9.7	-51	-41.3	8.2

10 foot antenna, 160 MHz Channels, half 30 MHz channel separation, Wi-Fi PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-70	-20.3	1.4
1	-29.7	-70	-40.3	8.1
0.1	-9.7	-70	-60.3	34.6

Interference Examples Assuming Guard Band of One FS 30 MHz Channel Bandwidth

Note that providing a guard band equal to one-half the FS receiver channel greatly reduces the exclusion angles needed to avoid interference.

We now consider a wider guard band of one full 30 MHz FS channel bandwidth. For a 30 MHz fixed service receiver, that would impose a 45 MHz separation from the center of the FS receiver center frequency to the edge of the RLAN channel. For a 80 MHz wide RLAN channel, that would require the RLAN center frequency to be no closer than 40 + 45 = 85 MHz to the FS receiver center frequency. For a 160 MHz RLAN channel, the center to center frequency limit would be 80 + 45 = 125 MHz.

Using equation (4) and Figure 4, we have the following interference limits:

80 MHz Wide RLAN with FS PSD and 85 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 53.1 = -46.9$ dBm (14)

160 MHz Wide RLAN with FS PSD and 125 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 50.8 = -49.2$ dBm (15)

For purposes of FS PSD examples, we will use -48 dBm as the common interference limit.

80 MHz Wide RLAN with Wi-Fi PSD and 85 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 33.4 = -66.6$ dBm (16)

160 MHz Wide RLAN with Wi-Fi PSD and 125 MHz Center to Center Offset:
Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 31.7 = -68.3$ dBm (17)

For purposes of Wi-Fi PSD examples, we will use -67.5 dBm as the common interference limit.

6 foot antenna, 80 MHz Channels, one 30 MHz channel separation, FS PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-48	+ 6.1	0.0
1	-34.1	-48	-13.9	2.2
0.1	-14.1	-48	-33.9	7.5

6 foot antenna, 80 MHz Channels, one 30 MHz channel separation, the Wi-Fi PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-67.5	-13.4	2.1
1	-34.1	-67.5	-33.4	7.4
0.1	-14.1	-67.5	-53.4	31.1

10 foot antenna, 160 MHz Channels, one 30 MHz channel separation, FS PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-48	+1.7	0.0
1	-29.7	-48	-18.3	1.4
0.1	-9.7	-48	-38.3	6.2

10 foot antenna, 160 MHz Channels, one 30 MHz channel separation, Wi-Fi PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-67.5	-17.8	1.3
1	-29.7	-67.5	-37.8	5.8
0.1	-9.7	-67.5	-57.8	25.4

Interference Examples Assuming Guard Band of Two FS 30 MHz Channel Bandwidths

Note that doubling the guard band from one-half of the FS receiver channel to the full width of the channel has relatively little effect on the exclusion angles.

Finally we will consider a still wider guard band of two 30 MHz FS channel bandwidths. For a 30 MHz fixed service receiver, that would impose a 60 MHz separation from the center of the FS receiver center frequency to the edge of the RLAN channel. For a 80 MHz wide RLAN channel, that would require the RLAN center frequency to be no closer than 40 + 60 = 100 MHz to the FS receiver center frequency. For a 160 MHz RLAN channel, the center to center frequency limit would be 80 + 60 = 150 MHz.

Using equation (4) and Figure 4, we have the following interference limits:

80 MHz Wide RLAN with FS PSD and 100 MHz Center to Center Offset:

Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 56.8 = -43.2$ dBm (18)

160 MHz Wide RLAN with FS PSD and 150 MHz Center to Center Offset:

Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 53.9 = -46.1$ dBm (19)

For purposes of FS PSD examples, we will use -45 dBm as the common interference limit.

80 MHz Wide RLAN with Wi-Fi PSD and 100 MHz Center to Center Offset:

Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 37.7 = -62.3$ dBm (20)

160 MHz Wide RLAN with Wi-Fi PSD and 150 MHz Center to Center Offset:

Interference Limit = $L_{Alic} = L_{A30} - T/I_{Nlic} = -100 + 34.2 = -65.8$ dBm (21)

For purposes of Wi-Fi PSD examples, we will use -64 dBm as the common interference limit.

6 foot antenna, 80 MHz Channels, two 30 MHz channels separation, FS PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-45	+9.1	0.0
1	-34.1	-45	-10.9	1.8
0.1	-14.1	-45	-30.9	7.1

6 foot antenna, 80 MHz Channels, two 30 MHz channel separation, the Wi-Fi PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-54.1	-64	-9.9	1.7
1	-34.1	-64	-29.9	6.9
0.1	-14.1	-64	-49.9	21.4

10 foot antenna, 160 MHz Channels, two 30 MHz channel separation, FS PSD.

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-45	+4.7	0.0
1	-29.7	-45	-15.3	1.3
0.1	-9.7	-45	-35.3	4.2

10 foot antenna, 160 MHz Channels, two 30 MHz channel separation, Wi-Fi PSD:

Distance (km)	Interference (dBm)	Interference Limit (dBm)	Interference Margin (dB)	Exclusion Angle Relative to Boresight (degrees)
10	-49.7	-64	-14.3	1.2
1	-29.7	-64	-34.3	4.1
0.1	-9.7	-64	-54.3	20.9

Increasing the guard band beyond one half a FS receiver bandwidth offers little improvement,

Conclusion

The 6 foot FS Receive antenna case:

Exclusion Angle (degrees) for an 80 MHz wide FS PSD channel:

Distance (km)	No Channel Separation	Half FS Channel Separation	One FS Channel Separation	Two FS Channel Separations
10	2.2	0.0	0.0	0.0
1	7.4	2.4	2.2	1.8
0.1	31.3	10.5	7.5	7.1

Exclusion Angle (degrees) for an 80 MHz wide Wi-Fi PSD channel:

Distance (km)	No Channel Separation	Half FS Channel Separation	One FS Channel Separation	Two FS Channel Separations
10	2.6	2.3	2.1	1.7
1	10.7	10.3	7.4	6.9
0.1	40.9	34.0	31.1	21.4

The 10 foot FS receive antenna case:

Exclusion Angle (degrees) for a 160 MHz wide FS PSD channel:

Distance (km)	No Channel Separation	Half FS Channel Separation	One FS Channel Separation	Two FS Channel Separations
10	1.3	0.3	0.0	0.0
1	5.8	1.4	1.4	1.3
0.1	25.4	8.2	6.2	4.2

Exclusion Angle (degrees) for a160 MHz wide Wi-Fi PSD channel:

Distance (km)	No Channel Separation	Half FS Channel Separation	One FS Channel Separation	Two FS Channel Separations
10	1.5	1.4	1.3	1.2
1	9.1	8.1	5.8	4.1
0.1	49.8	34.6	25.4	20.9

Area of interference (interference cone area) is significantly influenced by power spectrum density (emission limitations mask). The more restrictive FS PSD provides significantly smaller three-dimensional RLAN exclusion area for short interference paths.

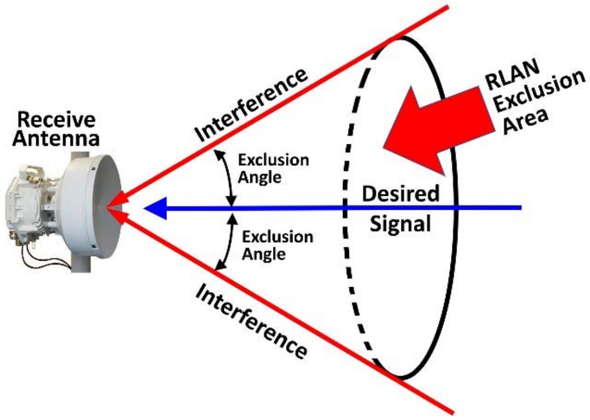

Figure 7: Interference Exclusion Angle

The difference between no guard band and one-half channel guard band is significant. A guard band of half a FS receiver bandwidth between the edge of the fixed service channel and the edge of the RLAN channel provides significant interference reduction. Increasing the guard band beyond that yields only moderate improvement.

For long interference paths (>> 1 km), a guard band equal to half the FS receiver bandwidth reduces the interference to moderate levels. For short interference paths (<< 1 km) the interference is significant even with the guard band. At these short distances, when the angle between the RLAN interference path and the FS boresight path is smaller than the exclusion angle, the RLAN transmitter may have to operate at reduced power.

In practice FS antennas exhibit twist and sway when subjected to wind. The exclusion angle must take this into account.

This analysis assumes free space propagation interference. Narrower guard bands may be feasible for very long interference paths, or for those known to have significant clutter or blockage.