IMPACT OF PROPOSED Wi-Fi OPERATIONS ON MICROWAVE LINKS AT 6 GHz

1/10/2020 **VER 1.0**

Prepared By: Roberson and Associates, LLC
Authors:
Mark Birchler
Paul Erickson
Alan Wilson
Ken Zdunek, PhD

Table of Contents

1 EXECUTIVE SUMMARY 4

2 BACKGROUND 5
2.1 POINT-POINT COMMUNICATIONS 5
2.2 NPRM 5

3 INTERFERENCE SCENARIO DESCRIPTION 6
3.1 SPECTRUM VIEW 6
3.1.1 UNLICENSED Wi-Fi 6
3.2 AGGREGATE INTERFERENCE SCENARIO 7

4 METRO AREA INTERFERENCE ANALYSIS APPROACH 7
4.1 OVERALL AGGREGATE INTERFERENCE APPROACH 7
4.1.1 METROPOLITAN HOUSTON AREA 7
4.1.2 POINT-POINT LINKS IN HOUSTON 8
4.2 POINT-POINT CHARACTERISTICS AND ANALYSIS PARAMETERS 9
4.2.1 MICROWAVE POINT-TO-POINT TECHNOLOGY 9
4.2.1.1 Antennas 10
4.2.1.2 Point-to-Point Links 10
4.2.2 POINT-TO-POINT PARAMETERS USED IN ANALYSIS 11
4.2.3 INTERFERENCE THRESHOLD 12
4.3 Wi-Fi CHARACTERISTICS AND ANALYSIS PARAMETERS 12
4.3.1 POWER LEVELS 12
4.3.2 DUTY CYCLE 13
4.3.2.1 Streaming Video 4K, 8K 13
4.3.3 Wi-Fi ACCESS POINT PARAMETERS FOR INTERFERENCE CALCULATION 14
4.3.3.1 Spectral characteristics 14
4.3.3.2 RLAN Deployment Density and Frequency of Operation 14
4.4 PROPAGATION MODEL 15
4.5 INTERFERENCE CALCULATION IN HOUSTON METROPOLITAN AREA 15
4.6 CALCULATION OF INTERFERENCE 15

5 RESULTS 16
5.1 CUMULATIVE I/N FOR 2325 POINT-POINT RECEIVERS IN METROPOLITAN HOUSTON 16
5.2 GEOGRAPHIC AREA WHERE RLANS CONTRIBUTE TO INTERFERENCE 18
5.2.1 METROPOLITAN HOUSTON 18
5.2.2 CENTRAL HOUSTON 19
5.2.3 IMPACT OF PARAMETERS ON RESULTS 19
5.3 EXTENSION OF RESULTS TO TOP 20 MSAS 20
5.4 RESULTS FOR VERY LOW POWER DEVICES 21

6 SUMMARY AND CONCLUSIONS 21
6.1 SUMMARY OF RESULTS 21
6.2 CONCLUSIONS 21
6.3 VERY LOW POWER DEVICES 22

7 APPENDICES 23
7.1 INTERFERENCE ANALYSIS PARAMETERS 23
7.1.1 LINK BUDGETS 23
7.1.2 PATH LOSS MODELS 24
7.1.3 BUILDING ENTRY LOSS 25
7.2 INTERFERENCE I/N DETAILED RESULTS 26
7.2.1 ADJACENT CHANNEL EMISSIONS 31

7.2.2 POLARIZATION EFFECTS 32
7.3 INTERFERENCE AVOIDANCE 33
7.3.1 INTERFERENCE AVOIDANCE AREA 35
7.4 DOWNTOWN HOUSTON ANALYSIS 36
7.4.1 MICROWAVE RECEIVER DOWNTOWN 36
7.4.1.1 Backscatter into the Close-in Sidelobe of the Receiver 36
7.4.1.2 Direct Radiation into a Far Sidelobe of the Receiver 39
7.4.1.3 Direct Radiation into the Back Lobes of the Receiver 40
7.4.2 MICROWAVE TRANSMITTER DOWNTOWN 41
7.4.2.1 All of Houston Visible 41
7.4.2.2 Limited RLAN Frequencies Available 42
7.4.3 DOWNTOWN HOUSTON LINKS 43
7.4.4 SUMMARY OF DOWNTOWN HOUSTON STUDY 46
7.5 INTERFERENCE SUSCEPTIBILITY PATTERNS 46
7.6 Wi-Fi ACCESS POINT INTERFERENCE CHARACTERISTICS 49
7.6.1 MULTIBAND ROUTERS 49
7.6.2 RESIDENTIAL MESH NETWORKS AND EXTENDERS 50
7.6.3 TEMPORAL CHARACTERISTICS 50
7.7 TOP 20 METROPOLITAN STATISTICAL AREAS 51
7.8 VERY LOWER POWER DEVICES 52
7.8.1 SUMMARY OF DEFICIENCIES OF RECENT VLP ANALYSIS 52
7.8.2 EFFECT OF VLP ANALYSIS DEFICIENCIES ON INTERFERENCE 53

8 COMPANY PROFILE: ROBERSON AND ASSOCIATES, LLC 54

1 EXECUTIVE SUMMARY

The 6GHz band is vital to the security of our nation's infrastructure. A broad cross-section of critical infrastructure industries (CII) and public safety providers depend on the 6 GHz band for essential and mission-critical communications. Continued, unimpeded access is paramount.

Electric, gas, and water utilities, oil and gas companies, railroads, wireless carriers, as well as public safety and law enforcement officials, all require interference free access on a continuous (24/7), low latency, uninterrupted basis to operate key facilities and equipment, and as their main source of communication during emergencies and disasters. A few key examples:

- Electric, gas, and water utilities operate thousands of microwave links to support mission -critical communications, including voice and data communications with personnel and critical assets such as substations and teleprotection systems, emergency response, storm restoration, and situational awareness.
- More than 300 offshore oil and gas production platforms in the Gulf of Mexico use a microwave network to provide highly reliable backhaul communications to support real-time analysis and situational awareness for public safety, critical communications, and emergency response.
- Railroads rely on thousands of microwave links to safely coordinate train movements, including relaying critical data regarding train signals, remote switching of tracks, and dispatch radio traffic.
- Public safety organizations use microwave links as their mission critical backhaul for 9-1-1 dispatch and first-responder radio communications.

On December 17, 2018, the Federal Communications Commission (FCC) issued a Notice of Proposed Rulemaking on Unlicensed Use of the 6 GHz Band (6 GHz NPRM)[1] that proposes to authorize the operation of unlicensed devices in the band alongside the CII incumbents. Given the CII's reliance on the 6 GHz band and the concern about interference from unlicensed users with critical communications from proposed unlicensed operations, CII incumbents commissioned this report to provide a robust technical analysis of the scope of risk presented by the FCC's proposal. This report also details where and how to mitigate harmful interference so that future unlicensed and broadband deployment is appropriately balanced with the essential need to maintain safe, reliable, secure, and resilient critical infrastructure.

This report analyzes the actual impact of indoor and outdoor Wi-Fi deployments on the 2325 point-to-point communication receivers in U-NII-5 and U-NII-7 in the nine-county Houston Metropolitan Statistical Area (MSA). The Houston MSA is used because its flat terrain provides a highly realistic indication of interference levels in a major market. Current applications of fixed point-to-point networks in the Houston MSA also include the entire host of CII users, including energy companies, transportation, telecommunication backhaul, and utility and municipal infrastructure.

The analysis considers interference from both indoor residential and outdoor Wi-Fi access points, and it also includes results for Wi-Fi adjacent channel emissions. The unlicensed devices in the analysis operate at the standard power (1W, 6 dBi antenna) in outdoor installations, or low power for ubiquitous indoor installations (0.25 W, 0 dBi antenna). Importantly, the analysis employs Wi-Fi parameters based on planned future uses of Wi-Fi such as streaming video, rather than parameters based on past use cases.

The analysis shows that for the -6 dB I/N criteria necessary for highly reliable critical infrastructure communications, ubiquitous deployment of either outdoor, or residential indoor Wi-Fi access points at the power levels proposed by the FCC will seriously degrade all point-to-point receivers in the Houston metro area. Analysis in the Appendices shows that very low power outdoor devices also pose a risk of interference to point-to-point receivers when realistic parameters (more than one device, power levels above the minimum) are used to analyze their impact. Additional, more comprehensive study is required to realistically assess the interference potential of VLP devices.

[1] FCC, *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295, October 23, 2018 (6 GHz NPRM).

The analysis further shows that in order to reduce the interference to all point-to-point receivers to the necessary level, it would be necessary to prohibit U-NII-5 and U-NII 7 operations in approximately 94% of the nine-county area. It can therefore be concluded that at a minimum an effective Automated Frequency Coordination (AFC) is necessary for indoor and outdoor Wi-Fi deployment.

However, there are numerous obstacles to devising an effective AFC to control aggregate interference from indoor as well as outdoor Wi-Fi in metropolitan areas. These include taking into account the effect of variations in radio-wave propagation due to building reflections, scattering (backscattering), and the location of Wi-Fi devices in high-rises. AFC would also need to exclude interference from adjacent channel emissions As the analysis found, there are no unused channels in the Houston area for AFC to operate on.

In sum, the analysis clearly demonstrates that allowing unlicensed devices to operate in the 6 GHz band will render fixed point-to-point communications receivers serving critical infrastructure in Houston MSA unreliable and unable to meet minimal performance objectives, specifically geographic coverage (i.e., long links), high bit rates, low latency, and high reliability. The study demonstrates that if the current proposal for increased use of the band nationwide is adopted, interference from unlicensed devices will compromise the operation and reliability of CII mission-critical communications.

2 BACKGROUND

2.1 Point-Point Communications

The 6 GHz band is uniquely suited for and therefore heavily used by CII and public safety providers for licensed point-to-point microwave systems. The entities have made significant investments in the 6 GHz band because it has key characteristics that make it indispensable for their essential and mission-critical communications.

The band is perfectly suited for CII and public safety use. CII entities operate approximately 97,000 fixed point-to-point microwave links in U-NII-5 (5925 MHz to 6425 MHz) and U-NII-7 (6525 MHz to 6875 MHz) because their short wavelength (about 4.6 cm) allows small parabolic dish antennas to direct them in narrow beams, which can be pointed directly at the receiving antenna. Parabolic dish antennas at both the receiver and transmitter permit high gain on the link path, to allows link paths to extend out to the radio horizon. This permits microwave networks with multiple links to cover large geographical distances of hundreds of km, with very low latency time delays, high bit rates, and high reliability. The band is also particularly resilient to rain fading making it ideal for use in foul weather.

Given the critical nature of the communications carried on the 6 GHz band, the public safety and CII networks operating in this band are built to extremely high standards of reliability – 99.999 percent or 99.9999 percent availability. These networks must also transmit with extremely low levels of latency – 20 milliseconds or less of roundtrip delay from one point to another over long distances. No other band has sufficient bandwidth with all key characteristics (large geographical distances, low latency time delays, high bit rates, high reliability) to permit reliable operations in large, dense metropolitan networks such as Houston.

2.2 NPRM

The NPRM on Unlicensed Use of the 6 GHz Band (6 GHz NPRM) proposes to permit unlicensed devices at standard power levels up to 1 W conducted power and +6 dBi antenna gain. It also proposes a low power level at 0.25 W for certain rules. The proposed rulemaking would authorize wide deployment of unlicensed devices, including potentially ubiquitous residential deployment, at EIRPs equivalent to +14 dBm/MHz for 160 MHz channels. The NPRM divides the 6 GHz band into 4 sub-bands designated as U-NII-5, U-NII-6,

U-NII-7, and U-NII-8. The NPRM includes a proposal to limit unwanted emissions to -27 dBm/MHz EIRP while permitting average adjacent channel emission to be -11 dBm/MHz EIRP.

3 Interference Scenario Description

3.1 Spectrum View

The 6 GHz NPRM proposes to permit unlicensed Wi-Fi 6 devices at standard power levels, up to 1 W conducted power and 6 dBi antenna gain. The proposed rulemaking would authorize wide deployment of unlicensed devices, including potentially ubiquitous residential deployment, at EIRPs equivalent to +14 dBm/MHz for 160 MHz channels. The NRPM divides the 6 GHz band into 4 sub-bands designated as U-NII-5, U-NII-6, U-NII-7, and U-NII-8.[2] These bands are depicted in Figure 1.

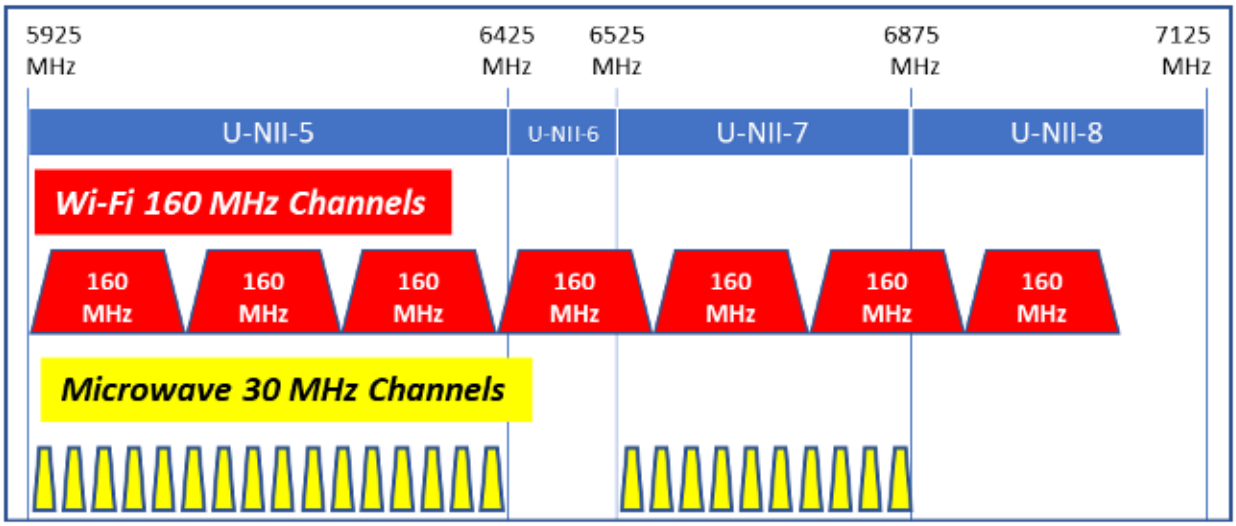


Figure 1 Radio Channels in 6 GHz

3.1.1 *Unlicensed Wi-Fi*

The Wi-Fi Alliance standardized generational numbering for Wi-Fi equipment in 2018. Equipment can indicate that it supports Wi-Fi 4, Wi-Fi 5, or Wi-Fi 6; if it operates in accordance with IEEE 802.11n, 802.11ac, or 802.11ax, respectively.[3] This report will use Wi-Fi 6 as a synonym for equipment following IEEE Std 802.11ax[4].

The IEEE 802.11 standards organization has proposed new Wi-Fi channels in the 6 GHz band in the IEEE Std 802.11ax. These channels can have bandwidths of 20, 40, 80, or 160 MHz.[5] There is also a specification for combining two 80 MHz channels into a synthetic 160 MHz channel.

---

[2] See 6 GHz NPRM, paragraph 21, table on pages 9 and 10.

[3] See: *Generational Wi-Fi® User Guide*, Wi-Fi Alliance, October, 2018.

[4] IEEE P802.11ax, *IEEE Draft Standard for Information Technology -- Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks -- Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment Enhancements for High Efficiency WLAN*, anticipated in late 2019, (IEEE Std 802.11ax).

[5] See Wi-Fi Alliance Ex Parte Comments, ET Docket No. 18-295, May 2, 2019, slides 8 and 9 for a depiction of U-NII frequency bands and Wi-Fi channels.

3.2 Aggregate Interference Scenario

Since the proposed Wi-Fi authorization is unlicensed, and low power (0.25 W conducted) indoor as well as outdoor devices, deployments will be distributed throughout the geographic area and the available spectrum. Any single victim point-to-point receiver will have an antenna that views a fairly large geographical area. In the analysis presented here, that area in view extends over a region averaging 37 km long and 6.5 km wide, or about 240 km^2, depending on the receiving antenna characteristics. Within that area the average population in the Houston nine county area is about 62,500 (based on the actual population density of 260 persons/km^2). If each person uses a Wi-Fi access point as envisioned for ubiquitous internet service in the NPRM, then there are about as many access points as the population with a view to the victim receiver antenna.[6] If only a small fraction of the access points are transmitting, they can contribute enough interference power to the victim receiver to exceed an interference threshold of -6 dB I/N, and thereby degrade performance. The overall aggregate set of access points contributing to interference is therefore many thousands of devices for each victim receiver. This is shown pictorially in Figure 2.

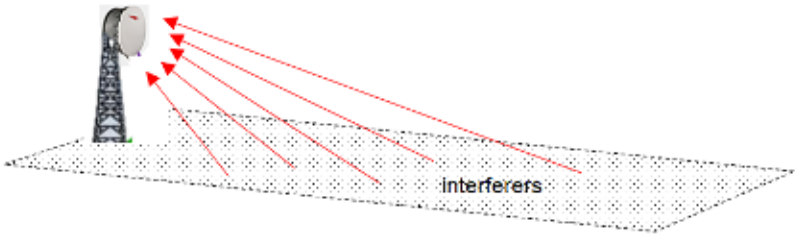


Figure 2 Pictorial Representation of Wi-Fi Aggregate Interference

The aggregate interference analyzed in this report uses a power spectral density instead of an absolute power figure. This is because the proposed unlicensed Wi-Fi transmitters and licensed microwave transmitters use different bandwidths, channels, modulations, antennas, and power levels. The analysis therefore relies on Shannon's information theory concepts of energy per bit and noise power spectral density figures of merit. Any undesired signal can then be considered as adding to the thermal noise. This allows aggregate interference to be taken into account as the sum of the interfering transmitter powers distributed across a representative spectrum segment.

4 Metro Area Interference Analysis Approach

4.1 Overall Aggregate Interference Approach

4.1.1 *Metropolitan Houston Area.*

The Houston Metropolitan Area encompasses 9 counties in Texas, centered on Harris County. Houston is the county seat for Harris County. Houston, the Woodlands, and Sugar Land is the fifth-most populous metropolitan statistical area in the United States.[7] The metropolitan area covers 26,060 km^2 and has an

[6] See *FCC 6 GHz NPRM*, Introduction: "Meanwhile, lower powered indoor operations – which we anticipate will be dominated by devices deployed ubiquitously inside homes and businesses – would be permitted to operate in two other sub-bands (totaling 350 MHz of spectrum)."

[7] See the Appendix section 7.7 for a tabulation of the top 20 MSAs.

estimated population of 6.77 million.[8] The average population density is 260 per km^2. The highest point in the metro area is 131 meters AMSL, so the terrain is fairly flat.

The FCC license database lists 520 microwave point-to-point sites in the 9-county Houston metro area, using microwave channels in the U-NII-5 and U-NII-7 bands.[9] The average antenna height is 57 meters.

Figure 3 Houston Metropolitan Area

4.1.2 *Point-Point Links in Houston*

The arrangement of the point-to-point links in the Houston metropolitan area is shown in the next figure. The picture shows links with at least one end point (receiver or transmitter) within the metro area.

[8] Census Bureau, 2016. AMSL abbreviates Above Mean Sea Level.
[9] FCC Universal License System, https://www.fcc.gov/wireless/systems-utilities/universal-licensing-system

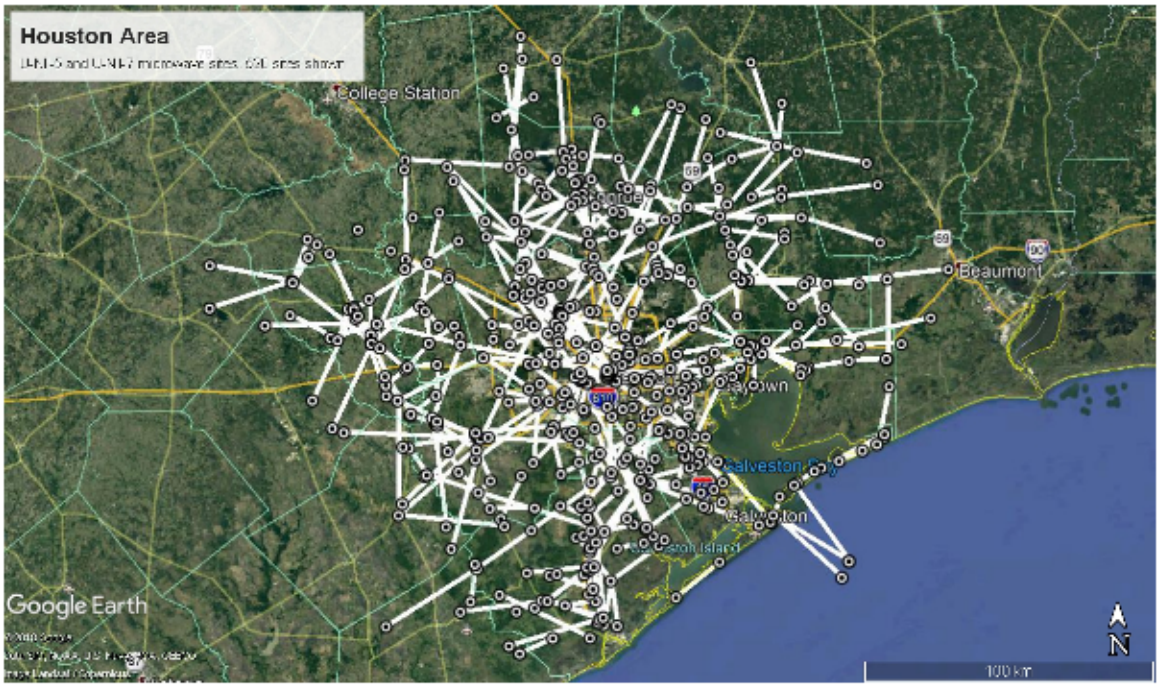


Figure 4 Houston Microwave Link Paths

4.2 Point-Point Characteristics and Analysis Parameters

4.2.1 *Microwave Point-to-Point Technology*

Point-to-point links are used in large scale high bit rate fixed networks. The Houston metropolitan area includes many microwave networks that service clients in the UTC as well as AWWA, APPA, and multiple railroads.[10] Among others, the FCC lists 50 licenses in the Houston metropolitan area for the City of Houston, 16 licenses for the Union Pacific railroad, 10 licenses for the BNSF railroad, and 13 licenses for the Texas New Mexico Power Company.

[10] UTC is an abbreviation of Utilities Technology Council; AWWA is an abbreviation of the American Water Works Association; APPA is an abbreviation of the American Public Power Association. Railroads that use microwave networks in Houston include BNSF and Union Pacific.

4.2.1.1 Antennas

Point-to-point links use high gain directional antennas. A common antenna listed in the FCC ULS database for the Houston Metro area is an Andrew HX6-6W, depicted at the right. The directional gain is listed as 39.1 dBi at 6.525 GHz. The gain function is plotted in Figure 5. The antenna meets the requirements for FCC Category A. A less stringent spec for FCC Category B also exists, and antennas meeting that spec would be several dB less selective at incident angles higher than 5 degrees.

4.2.1.2 Point-to-Point Links

Communication networks use fixed radio frequency point-to-point links to obtain low latency delay, high bandwidth, long distance propagation, and high reliability in a network. Electrical utilities, for example, use point-to-point radio links in their networks to respond to events in milliseconds instead of minutes.[11] The 6 GHz band is suitable for this application since it has the available bandwidth, propagation losses are low enough, and high reliability can be designed into the point-to-point links with suitable choices of radio and antenna equipment. Specifically, the bands shown in Figure 1 from 5925 MHz to 6425 MHz and 6525 MHz to 6875 MHz are now commonly used for fixed point-to-point networks. That is 850 MHz of bandwidth for point-to-point links that is not available in any other band below 9 GHz. Above 9 GHz the attenuation from water vapor and precipitation increases to the point that long distance links cannot be operated reliably. Therefore, no other band is currently available for point-to-point links with the characteristics of high bit rate, low latency, long distance coverage, and high reliability.

The Houston area networks shown in Figure 4 include 839 microwave links that average 19 km in length. A typical outage time is given in the sample link budget for one microwave link in the Appendix, section 7.1. The outage time is shown as 26 sec/month. This degrades by a factor of 2.5x for every dB of signal-to-noise degradation. Equivalently, this degrades by 2.5x for every dB of noise rise (N_{rise}) where $N_{rise} = 10 \log_{10}(1 + I/N)$. An I/N of -6 dB obtains 1 dB of N_{rise}. It is for this reason that the link fade margin cannot be reduced to accommodate Wi-Fi interference: the low outage time on which critical infrastructure communications relies would be jeopardized.

[11] See for example: UTC, Ex Parte Presentation, ET Docket No. 18-295, GN Docket No. 17-183, June 28, 2019.

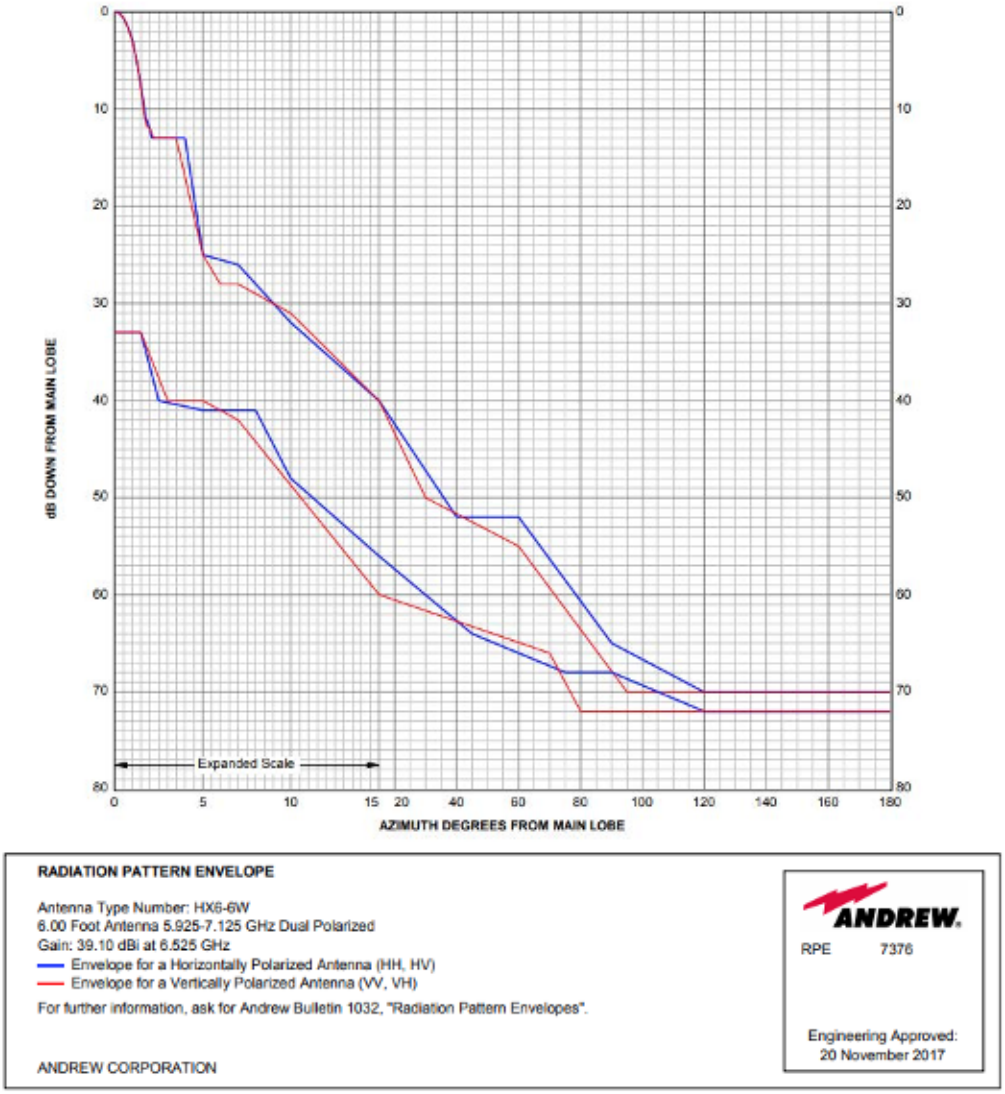


Figure 5 Typical Point-to-Point Antenna Gain Function

4.2.2 *Point-to-point Parameters Used in Analysis*

Specific characteristics of point-to-point radios are listed in the Appendix, section 7.1 The bandwidth is nominally 30 MHz. Digital modulation commonly varies with different QAM methods (2048 QAM is used in the sample link budget in section 7.1).[12] A noise figure of 4 dB is used for the receiver. The antenna gain and height is determined according to the FCC database (see section 7.2 for details). The link fade margin is used to obtain the necessary reliability for the network. According to Barnett and Vigants, the margin needs to exceed 20 dB, and can then be improved with a second diversity receiver.[13] This can bring the monthly outage times down to acceptable levels. In the sample link budget in the Appendix, section 7.1, the improvement from a second diversity receiver is a factor 48.53x for the outage time. This factor of 48.53x is

[12] Digital modulation commonly arranges points in a two-dimensional grid. The 2D grid geometry has varied with the number of points which is usually an exponential power of 2, such as 512, 1024, 2048, etc.

[13] BSTJ, Barnett, *Multipath Propagation at 4, 6, and 11 GHz*, February 1972. BSTJ, Vigants, *Space-Diversity Engineering*, January 1975.

also the degradation in outage time that occurs if the second receiver is degraded from interference, even if the primary receiver is still operational.

4.2.3 *Interference Threshold*

This study uses an interference protection criterion of -6 dB I/N.[14] TIA TSB 10-F is widely recognized in the US and is explicitly accepted by both the FCC and NTIA for fixed point-to-point frequency sharing.[15] The interference protection criteria specified in TSB 10-F are based on an increase in total noise of 1 dB or, equivalently, a reduction in fade margin of 1 dB. This equates to an I/N ratio of -6 dB.

4.3 Wi-Fi Characteristics and Analysis Parameters

4.3.1 *Power Levels*

The rules being proposed for the 6 GHz band allow for transmitter power levels up to 1 Watt and antenna gains up to 6 dBi in the U-NII-5 and U-NII-7 bands. Transmit power levels up to 250 mW along with antenna gains up to 6 dBi would be allowed in the U-NII-6 and U-NII-8 bands.

The typical indoor device is allowed to transmit 0.25 W. The NPRM advocates a ubiquitous national information infrastructure,[16] so this study will consider one indoor RLAN per person in the Houston area. RLAN devices are typically designed to operate in multiple bands (tri-band devices are commonly available today), so this study will assume that RLANs are able to transmit on any channel in the U-NII-1, U-NII-3, U-NII-5, U-NII-6, U-NII-7, or U-NII-8 bands, for a total of 1425 MHz of bandwidth. The available transmit Power Spectral Area Density (PSAD[17]) for Wi-Fi interference in the Houston metro area would then be 0.25 W x 1 RLAN/person x 260 person/km^2 / 1425 MHz or 45.6 mW/MHz-km^2. The PSAD will be used as a starting point in the analysis to calculate the average aggregate interference power and I/N ratio. Additional factors that will be considered in the analysis include a factor for Building Entry Loss (BEL)[18], and Wi-Fi access point Duty Cycle. An antenna gain factor is also included; this study will use 0 dBi for indoor RLANs.

Outdoor RLANs differ from indoor devices in that they can operate at a higher power (1 W in the NPRM), with antenna gain up to 6 dBi. The higher power is a factor of 4 for PSAD, or 182.4 mW/MHz-km^2. The outdoor RLAN area density is typically lower than the indoor density, and so the PSAD will be decreased later in the calculation to account for this factor. The antenna gain is a separate line item in the link budget. Outdoor RLANs do not have to overcome Building Entry Loss so the BEL loss will be zero.

Very low power (VLP) outdoor devices have been recently proposed and are discussed in Appendix Section 7.8.

---

[14] See for example: NTIA Report 05-432, *Interference Protection Criteria*, October 2005, page 4-4.

[15] TIA TSB-10, *Interference Criteria for Microwave Systems*, Revision F, June 1994. See for example, FCC CFR § 24.237 – Interference Protection, paragraph (a).

[16] See 6 GHz NPRM, Paragraph 5, "The worldwide installed base of Wi-Fi devices is 9.5 billion, and 76 percent of North America broadband households use Wi-Fi routers as their primary connected technology. Most areas where people gather—restaurants and bars, hotels and shopping centers, and even parks and stadiums— are now covered by multiple Wi-Fi hotspots."

[17] PSAD = Power Spectral Area Density. This parameter expresses the average power emitted from a square km geographical area and in a MHz of spectrum. This parameter is used as a variable function to integrate over a coverage area of a victim receiver antenna pattern in the Appendix, section 7.2, equation 10.

[18] See section 7.3 for more information about BEL.

4.3.2 *Duty Cycle*

4.3.2.1 Streaming Video 4K, 8K

In order to properly assess the effect of Wi-Fi on fixed wireless, the planned and emerging future uses of Wi-Fi must be taken into account. A typical consumer use case for Wi-Fi 6 will be for streaming video. A quick survey of televisions for sale to consumers from retailers shows that they are all 4K or UHDTV.[19] [20] The usual implication is that horizontal resolution is about 4,000 pixels. By November 2017, both Microsoft and Sony had released game devices that support 4K streaming and gaming.[21] [22] The industry has numerous other products with 4K displays for internet use.[23] [24] [25] [26] Some 8K video is becoming available and may be popular in the future.[27] [28]

Providers of 4K video recommend bit rates of 15 Mbps to 45 Mbps, depending on the provider, and their preferred video codec technology. The recommended data rates[29] [30] [31] are tabulated in Table 1. The Duty Cycle is then calculated with a ratio for the given bit rate.

Table 1 Video Duty Cycles

Provider	4K Recommended Rate (Mbps)	Duty Cycle at 250 Mbps	Duty Cycle at 1000 Mbps
You Tube	35-45	14-18%	3.5-4.5%
Amazon	At least 15	6%	1.5%
Netflix	25	10%	2.5%

The values in Table 1 show that the duty cycle for a 4K video streaming access point can range from 6% to 18% if the Wi-Fi channel and Wi-Fi router's capabilities can only support 250 Mbps. If the Wi-Fi channel can support 1000 Mbps and the Wi-Fi router is able to transmit at 1000 Mbps then the duty cycles will range from 1.5% to 4.5%. With four times the number of pixels compared to 4K video, 8K video will need even higher Duty Cycles.

---

[19] Costco, TVs, https://www.costco.com/televisions.html

[20] The UHDTV1 spec is for 3840 x 2160 pixels, and this is usually considered to be 4K. The UHDTV2 spec doubles the horizontal and vertical pixels so it would be considered 8K. Another term that is often used is 2160p which comes from the vertical resolution of the UHDTV1 spec.

[21] Microsoft, Xbox One X, https://www.xbox.com/en-US/xbox-one-x

[22] Sony, PS4 Pro, 4-K Gaming TV and More, https://www.playstation.com/en-us/explore/ps4-pro/

[23] Charles Cheevers, Arris, *The Quest to Send 4K Video Over Wi-Fi Networks*, 2014, https://www.arris.com/globalassets/resources/white-papers/arris_quest_4k_video_over_wi-fi_wp.pdf

[24] Best Buy, 4K Ultra HD Connected Home, https://www.bestbuy.com/site/4k-ultra-hd-ecosystem/4k-ultra-hd-connected-home/pcmcat748301862624.c

[25] Amazon, Fire TV Stick 4K with Alexa Voice Remote, streaming media player, https://www.amazon.com/Fire-TV-Stick-4K-with-Alexa-Voice-Remote/dp/B079QHML21/

[26] Apple, Apple TV 4K, https://www.apple.com/apple-tv-4k/.

[27] Stewart Wolpin, *What You Can Expect from 8K TVs in 2019*, January 2019, https://www.techlicious.com/blog/8k-tv-ces-2019/

[28] YouTube, How to Download 8K Video from YouTube, https://www.4kdownload.com/howto/howto-download-8k-video-from-youtube

[29] Internet Connection Speed Recommendations, https://help.netflix.com/en/node/306

[30] Watch Video in 4K Ultra HD on Your Fire TV, https://www.amazon.com/gp/help/customer/display.html?nodeId=201859000

[31] Recommended upload encoding settings, https://support.google.com/youtube/answer/1722171?hl=en

4.3.3 *Wi-Fi Access Point Parameters for Interference Calculation*

The Wi-Fi 6 RLANs are assumed to be able to support high data rates needed for streaming 4K or better video quality. A duty cycle of 4% is sufficient for a 1 Gbps RLAN channel to support 4K video. Higher duty cycles are possible, for example, if range extenders or residential mesh networks are used, since they would necessarily repeat transmissions on multiple hops through a network, and consequently multiply the active duty cycle.

4.3.3.1 Spectral characteristics

The interference calculations use the very conservative assumption that all video streaming takes place on 160 MHz channels having the highest data rates and therefore the shortest duty cycles. The use of narrower channels will necessarily increase the transmit duty cycle, and the consequent interference.

The interference calculation distributes the RLAN channels across an entire U-NII-1, 3, 5, 6, 7 and 8 bandwidth of 1425 MHz, which is much larger than a typical 30 MHz point-to-point victim receiver bandwidth and also much larger than any single Wi-Fi channel. The calculation uses a Power Spectral Density (PSD) to compute a ratio of I/N. As a consequence, the actual bandwidth used by an individual RLAN transmitter is unnecessary to consider for the PSAD. For example, an 80 MHz RLAN transmitter would transmit in half the bandwidth of a 160 MHz RLAN transmitter, and it would therefore have ½ the likelihood of overlapping a victim receiver channel, but it would transmit twice the power spectrum density. Thus, even though it would be ½ as likely to overlap a 30 MHz victim channel, this is compensated by twice the power spectral density so that the PSAD remains unchanged. While the PSD and PSAD is not affected by the RLAN channel bandwidth, the duty cycle used by the RLAN is affected by the bandwidth and so this is another variable in the calculation.

4.3.3.2 RLAN Deployment Density and Frequency of Operation

RLAN deployment is based on the population density. Details are tabulated in Table 4 in section 7.4. The RLAN area density in Houston is assumed to be proportional to the population density. For indoor devices, the analysis assumes a ratio of one Wi-Fi access point per person. The average population density in the Houston MSA is 260 persons/km^2. The RLANs transmit a conducted power of 0.25 W. This power is distributed across 6 possible U-NII frequency bands, or 1425 MHz, as tabulated in Table 4. The transmitted Power Spectral Area Density (PSAD) for indoor RLANs is therefore given by:

$$260 \text{ persons/km}^2 \times 1 \text{ RLAN/person} \times 0.25 \text{ W/RLAN} / 1425 \text{ MHz} = 45.6 \text{ mW/MHz-km}^2$$

The RLAN aggregate interference power calculation also includes the antenna gain of the RLAN (0 dBi for indoor devices, 6 dBi for outdoor devices), antenna gain of the victim receiver which varies according to the incident azimuth and elevation angles, RLAN transmitter duty cycle (4% is the basic assumption), Building Entry Loss (BEL), and path loss.

Outdoor RLAN devices transmit 1W, so the PSAD is four times higher than for indoor devices, or 182.4 mW/MHz-km^2. The deployment ratio per person will be lower, the calculation uses 1% outdoor deployment, which is a decrement of 20 dB in power spectral density relative to the indoor RLANs. The antenna gain is higher, +6 dBi. There is no BEL for outdoor deployments (E[BEL]=0). The duty cycle, path loss, and gain of the victim receiver antenna remain the same as for indoor deployments. This means that the aggregate interference from outdoor RLANs is calculated to be 3 dB higher than for indoor RLANs:

$$I[\text{outdoor RLANs}] = I[\text{indoor RLANS}] + 6 + 6 + 11 - 20 = I[\text{indoor RLANS}] + 3 \text{ dB}.$$

The calculation for RLAN adjacent channel aggregate interference uses the adjacent channel power ratio that is computed by averaging the power in the mask for undesired emissions. This comes to 24.69 dB below the power in the RLAN channel. The detailed adjacent channel emission mask is given in section 7.2.1. The aggregate interference power from adjacent channel emissions is therefore:

$$I[\text{indoor RLAN adjacent channel}] = I[\text{indoor RLANs}] - 24.69 \text{ dB}$$

$$I[\text{outdoor RLAN adjacent channel}] = I[\text{outdoor RLANs}] - 24.69 \text{ dB}$$

4.4 Propagation Model

The propagation of RF power on the path from the interfering transmitters to the victim receiver has building walls and windows, as well as terrestrial obstacles. Ultimately, the propagation path is cut off at the radio horizon. Propagation effects over the horizon are not included in this study, although in some specialized well-known conditions they may occur. For example, atmospheric ducting effects have been known to propagate RF for hundreds of km over water.

The distance to the radio horizon in this study is given by Equation 13 in section 7.2. The horizon distance is the sum of the horizon distances for each antenna, according to the height of each antenna:

$$D_{horizon} = (2\ h\ R_{effective})^{1/2}$$

where h is the antenna height and $R_{effective} = 4/3\ R_{earth}$, to account for atmospheric refraction of RF. For h_1=57m and h_2=2 m we obtain $D_{horizon} = 31 + 6 = 37$ km.

Building losses for indoor devices are estimated in ITU-R Rec. P.2109, as described in section 7.1.3. The median BEL for Traditional buildings is 16.3 dB in the 6 GHz band, and the average (E[BEL]) is calculated to be 11.0 dB. The E[BEL] calculation integrates building losses according to the probability distribution in the P.2109 standard, so it includes both high and low loss buildings. Outdoor devices do not have any building entry loss, so E[BEL] in those cases is 0 dB.

The propagation model calculates path loss according to a Free Space Path Loss (FSPL) definition for the first km of the path, and then a modified path loss model for distances beyond 1 km. The FSPL formula is $20 \log_{10}(4\ \pi\ D/\lambda)$ for wavelength λ. This loss increases at a rate of 20 dB/decade. Beyond 1 km the loss rate increases to 38 dB/decade to account for losses through and around obstacles in the path. Details of the path loss are given in section 7.1.2, Equations 6 and 7.

4.5 Interference Calculation in Houston Metropolitan Area

The RLAN interference sources can be either indoor or outdoor devices. This report will study indoor devices first, and then subsequently outdoor devices.

Step 1. Determine co-channel indoor interference sources and the power spectral area density.

$$PSAD_{indoor} = 45.6\ \text{mW/MHz-km}^2.$$

1.1 Extend calculation to outdoor RLANs.

$$PSAD_{outdoor} = 4 \times 45.6 = 182.4\ \text{mW/MHz-km}^2.$$

1.2 Extend calculation for adjacent channels.

$$PSAD_{adjacent} = PSAD_{co\text{-}channel} - 24.69\ \text{dB}$$

Step 2. Calculate I/N at victim receivers, compare with -6 dB criterion. See Equation 10 in Appendix section 7.2. Use standards-based propagation model and ITU-R Rec. P.2109 for Building Entry Loss (BEL).

2.1 Calculate Wi-Fi interference avoidance zones to avoid interference for victim receivers in Houston metro area.

2.2 Count licenses for RLANs to avoid interference in downtown Houston.

4.6 Calculation of Interference

The aggregate interference power is calculated by integrating the PSAD over the coverage area of a victim receiver antenna, with the victim antenna gain and antenna height used as variables to control the aggregate interference power from RLANs. The RLAN antenna gain, BEL and duty cycle are included in the calculation. The interference power spectral density is calculated from an integral as expressed in Equation 10 of section 7.2. The interference power spectral density (I) is then divided by the receiver noise spectral density to determine an I/N ratio. The noise power spectral density is given by:

N = k T B F
k = Boltzmann's constant
T = noise temperature
B = bandwidth = 1 MHz to obtain a power spectral density in 1 MHz
F = receiver noise figure = 4 dB
N = -110 dBm/MHz

The bandwidth of the victim receiver is not used in the I/N calculation since the I/N is computed from power spectral densities and not absolute powers. The victim receiver bandwidth could be used to compute an absolute power instead of a power spectral density, and in this case the interference power spectral density (I) would be multiplied by the receiver bandwidth, and the noise power spectral density (N) would also be multiplied by the same bandwidth, and the I/N ratio would then cancel out the effect of the receiver bandwidth. Nevertheless, the absolute power is of interest in an actual measurement since an absolute power is often reasonably easy to measure for comparison with calculations.

5 RESULTS

5.1 Cumulative I/N for 2325 Point-Point Receivers in Metropolitan Houston

The cumulative I/N distributions for the 2325 victim receivers in the Houston metro area are shown in Figure 6 for indoor RLANs, Figure 7 for outdoor RLANs, and Figure 8 for adjacent channel emissions for either indoor or outdoor RLANs.[32] These figures show the percentage of the victim receivers with I/N ratios below the value on the x-axis. For example, in Figure 6, 90% of the victim point-to-point receivers have I/N ratios less than +12.5 dB.

Figure 6 shows that the indoor I/N ratios vary from -0.5 dB to +19.2 dB, with a mean value of 8.3 dB. This shows that every victim receiver will be degraded in the Houston metro area from unlicensed indoor RLAN deployment. Figure 7 shows that the outdoor I/N ratios vary from +2.5 to +22.2 dB with a mean value of 11.3 dB. This shows that every victim receiver will be degraded in the Houston metro area from unlicensed outdoor RLAN deployment. The adjacent channel I/N ratios for outdoor RLANs shows a maximum I/N of -2.5 dB and 1.2% of the receivers exceed the -6 dB I/N limit. The adjacent channel I/N ratios for indoor RLANs shows a maximum of -5.5 dB, and about 0.1% of the receivers exceed the -6 dB limit. These results show that some victim receivers will be degraded from adjacent channel emissions originating from either indoor or outdoor RLANs.

A significant set of victims in Houston have higher I/N ratios and a relevant question is which antenna characteristics cause the higher I/N ratios. As explained in the Appendix after Figure 16, the higher I/N ratios typically correspond to the antennas with lower antenna height. The higher I/N ratios for those points is a direct consequence of lower height, and therefore smaller elevation angles to RLANs that are closer to the antenna. The RLANs closer to the antenna have less path loss, since they are closer. In the entire Houston area 10% of the antenna heights are less than 27 meters. However, in less densely populated areas, low antenna heights are more prevalent. In those cases, interference is expected to be more severe, corresponding to the extremely high I/N values at the right edge of the plots in Figures 6 and 7. The FCC ULS database reveals about 20% of all point-to-point antenna heights in the US are 18 meters or less. As shown by the analysis here, any interference assessment should consider a range of distances that include those distances at which the lowest combined path loss and receive antenna gain occurs.

[32] The FCC license database lists 525 microwave sites, 839 microwave links, and parameters for 2325 receivers. The differences between these numbers are from three factors. First, some sites have end points for two or more links. Second, many links have additional diversity antennas / receivers to improve reliability by decreasing the outage time figure of merit. Third, some links have an end point outside the 9-county area.

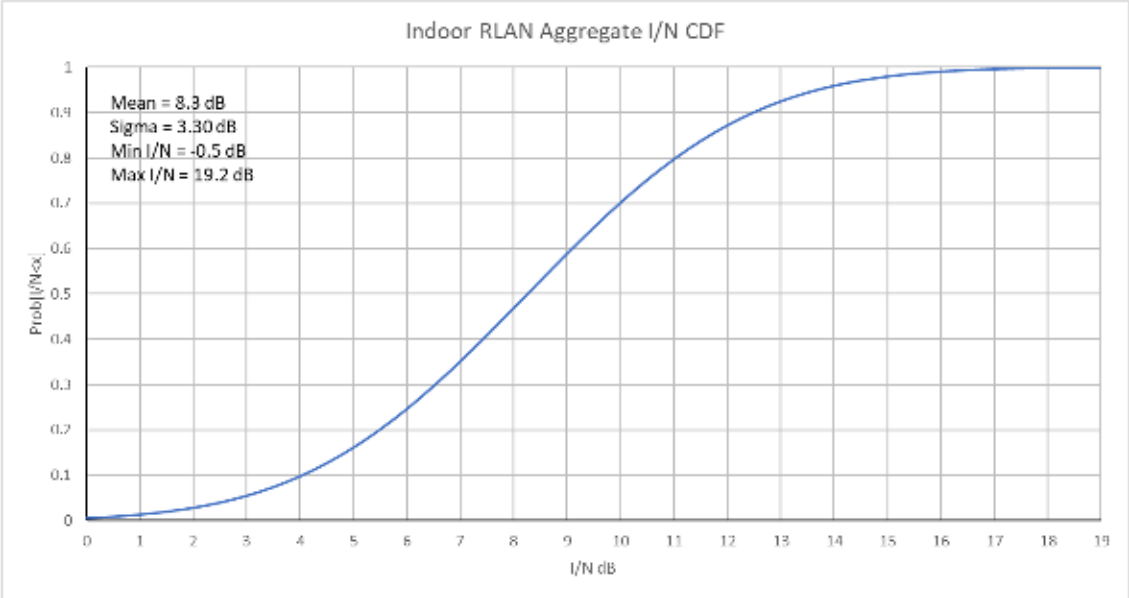


Figure 6 Indoor I/N Distribution

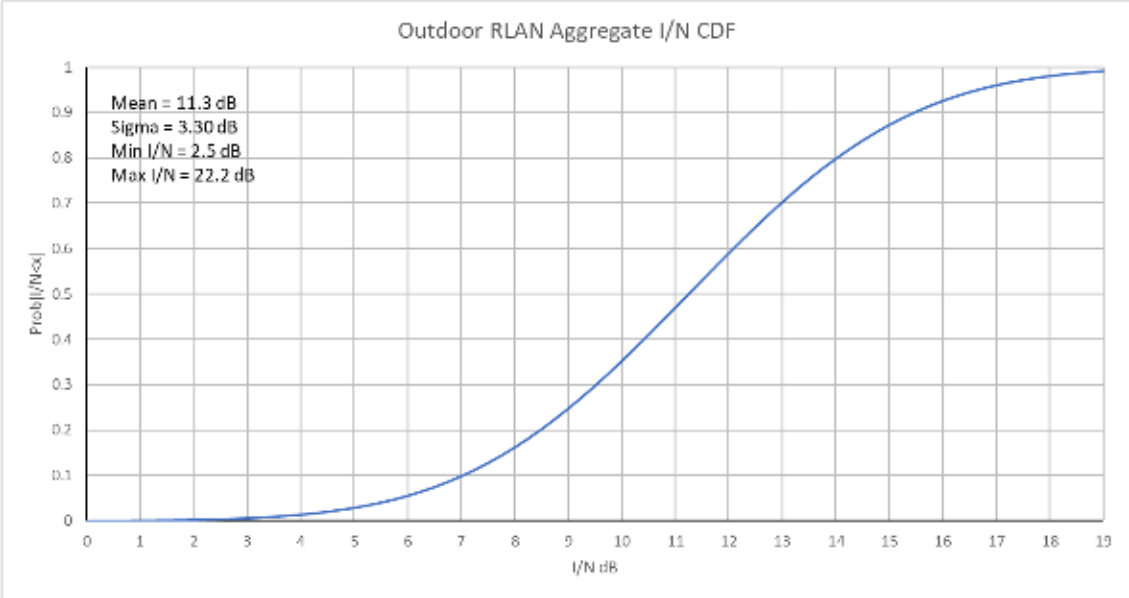


Figure 7 Outdoor RLAN I/N Distribution

Table 2 summarizes the main results for the I/N ratios for indoor and outdoor RLANs, for both co-channel and adjacent channel emissions. Indoor RLANs exceed the -6 dB I/N limit by an average of 14.26 dB or a power ratio of 27x. Outdoor RLANs exceed the -6 dB I/N limit by an average of 17.26 dB or a power ratio of 53x. The maximum interference occurs for outdoor RLANs exceeding the -6 dB limit by 28.24 dB or a power ratio of 667x. The adjacent channel emissions also cause some licensed microwave victim receivers to exceed the -6 dB limit by 0.55 dB for indoor RLANs and 3.55 dB for outdoor RLANs.

Table 2 Summary I/N Ratios for Indoor and Outdoor RLANs

Condition	Prob	I/N	Exceed Limit	Ratio
Indoor Co-Channel	Min	-0.54 dB	5.46 dB	3.5
	50%	8.26 dB	14.26 dB	27
	90%	12.50 dB	18.50 dB	71
	Max	19.24 dB	25.24 dB	334
Outdoor Co-Channel	Min	2.46 dB	8.46 dB	7.0
	50%	11.26 dB	17.26 dB	53
	90%	15.50 dB	21.50 dB	141
	Max	22.24 dB	28.24 dB	667
Indoor Adjacent Ch.	Max	-5.45 dB	0.55 dB	1.14
Outdoor Adjacent Ch.	99%	-5.55 dB	0.45 dB	1.11
	Max	-2.45 dB	3.55 dB	2.26

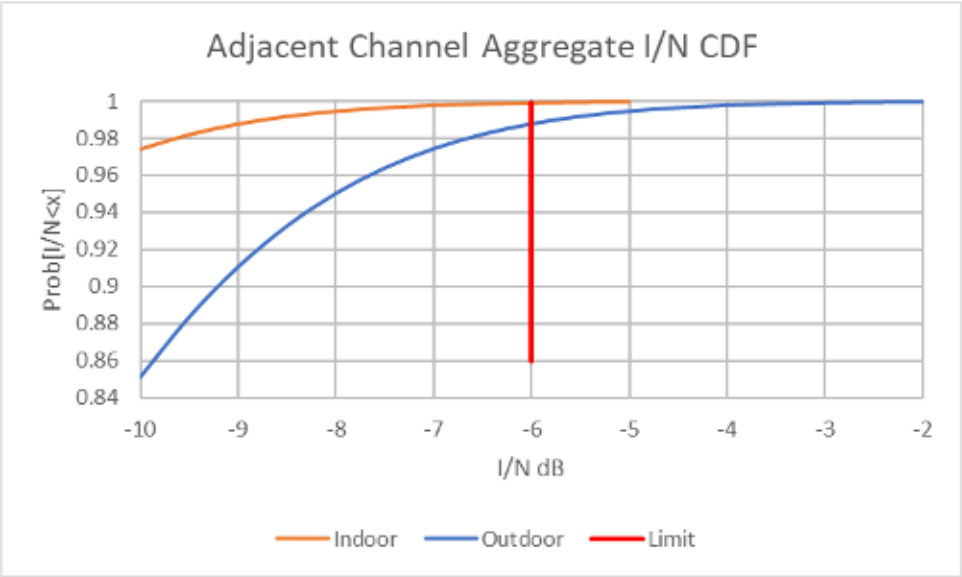


Figure 8 Adjacent Channel I/N Distributions

5.2 Geographic Area Where RLANs Contribute to Interference

5.2.1 *Metropolitan Houston*

The geographic area in metropolitan Houston where indoor RLANs contribute to point-to-point interference that exceeds the -6 dB I/N threshold is shown in Figure 9. It shows that 94% of the 9-county land area has at least 1 victim receiver from indoor or outdoor RLAN emissions. The central region in Harris county has multiple receiver interference regions that overlap up to a depth of 25 victim receivers. The number of microwave channels with interference in the central region is sufficient to exclude every Wi-Fi channel in the U-NII-5 and U-NII-7 bands if interference to licensees is to be avoided. To avoid interference from adjacent Wi-Fi channels, it is also necessary to exclude Wi-Fi channels in U-NII-6 and U-NII-8 that are within 1 channel spacing of U-NII-5 or U-NII-7.

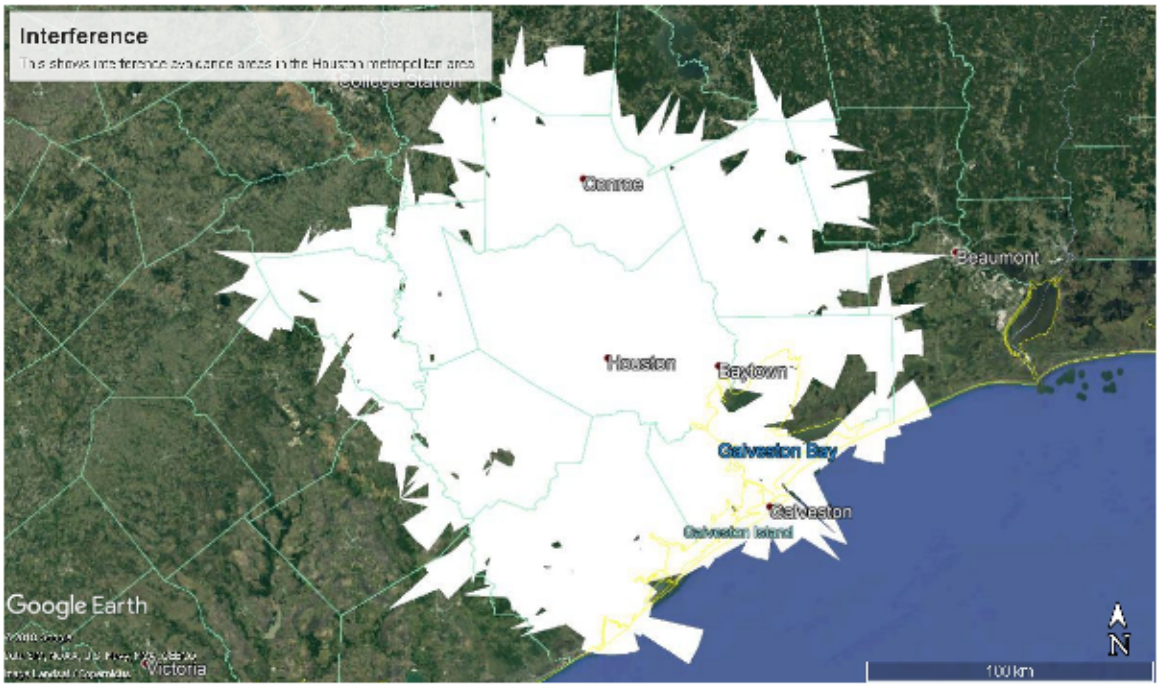


Figure 9 Interference Avoidance Areas in Houston MSA

5.2.2 *Central Houston*

There are multiple scenarios where both local and remote interference sources degrade microwave victim receivers in downtown Houston. These scenarios are selected to be representative but should not be considered exhaustive. In each case studied, the analysis shows that interference is likely if RLANs are allowed to operate in the general area of the receiver or along the main beam. Due to the gain of the receiving antenna and the height needed to provide Line of Sight (LOS) with clearance for the desired path, indoor RLANs in the main beam at distances within the microwave path length produce significant interference. These results are summarized in the following table for these scenarios: Backscatter, Side lobe, Back lobe, and Limited frequencies. Additional information is given in the Appendix in section 7.4.

Scenario	I/N (dB)	Exceed Spec (dB)	Ratio
Backscatter	3.48	9.48	8.9
Side lobe	8.91	14.91	31.0
Back lobe	0.43	6.43	4.4
Limited Frequencies	2.69	8.69	7.4

These interference sources, as well as the other general results in the previous section, indicate that all Wi-Fi channels in the U-NII-5 and U-NII-7 bands, and also those Wi-Fi channels adjacent to U-NII-5 and U-NII-7, will cause more than one licensed microwave receiver to be degraded by several dB (varying up to 22.2 dB I/N) and result in unacceptable performance degradation. The 6 GHz NPRM proposes consideration of AFC to avoid interference by assigning traffic to unused channels. In central Houston there are no unused channels available. For this reason, AFC would exclude all of 6 GHz.

5.2.3 *Impact of Parameters on Results*

These interference calculations do not include several conditions and parameters that can aggravate or increase interference beyond the levels reported above. Some of these conditions are listed as follows.

- Indoor RLANs are proposed in the 6 GHz NPRM to have conducted power levels up to 1 W, as opposed to 0.25 W in this analysis. They are also permitted up to 6 dBi of antenna gain. If these

limits were reached, the resulting interference could be 12 dB worse than is presented in this report. Population density can locally increase from multi-family apartment buildings and multi-story buildings. This can increase the local population density by 10x above the 260 person/km^2 in the calculations, and this can thereby increase interference by 10 dB.

- The choice of the Houston metropolitan area is not a worst-case geographic area. The Houston population density is 260 per km^2. For comparison, the population density on Manhattan Island in New York City is 25,800 per km^2. This is nearly 100x higher and it would result in 20 dB higher I/N ratios relative to those presented in this report. The top 20 MSAs in the US are listed in section 7.7 and they show that the PSAD for Houston is 0.99 dB below the average. The MSAs with above average PSAD are likely to have higher interference I/N ratios for microwave links.
- Backscatter and reflections from large buildings can redirect emissions in one direction to a different direction, and thereby create interference. The effect of unlicensed Wi-Fi in high rise buildings has not been included in this study.
- Propagation path loss variation can vary randomly with a sigma of 6 dB. This study does not include this random variation.
- Network reliability is dependent on the number of links, and the reliability of each link, for each path in the network. A large network, such as the City of Houston with 50 sites, would have a network span of about 7 links, so that the network reliability is 1/7x relative to the average link reliability. Systematic degradation of every link from RLAN interference throughout the metropolitan area would therefore degrade the entire network, instead of simply degrading individual links.
- Wi-Fi mesh networks and network extenders can effectively multiply channel activity and increase interference. For example, a network that relays a transmission from a user device in the U-NII-1 band could do so in the U-NII-5 band, and thereby create interference for a microwave victim receiver.
- This report identifies six different sources of interference: direct co-channel interference, adjacent channel interference, backscattering from nearby buildings, side-lobe interference, back-lobe interference, and increased interference from frequency limitations. A comprehensive management of these interference sources would analyze each one and allocate some part of an interference budget for each one. For example, if all six were of equal importance and the allowable interference budget was -6 dB I/N, then each one would be permitted an individual contribution of 1/6 (=-7.8 dB) or -13.8 dB I/N. This management interference analysis was not included in this report, but it would be necessary to manage interference down to acceptable levels. Obviously, none of the interference sources in this report is near the interference level of -13.8 dB I/N.
- Traffic concentration can occur when some frequencies or channels are not included in a design. This study has distributed RLAN traffic evenly across 1425 MHz of bandwidth as though all devices could access all the spectrum. Not all devices might do so. If some devices preferentially direct traffic to some channels or some bands, this can increase the PSAD for victim channels coincident with those preferred bands. For example, if U-NII-5 and U-NII-7 are excluded as suggested for downtown Houston, then traffic would be concentrated into U-NII-1, 3, 6, and 8, and this would increase the PSAD for adjacent channel emissions by 4 dB. The Adjacent Channel I/N CDF shown in Figure 8 would then degrade by 4 dB.

Design of an effective AFC must take all of the above considerations into account.

5.3 Extension of Results to Top 20 MSAs

The Appendix section 7.7 lists the top 20 MSAs in the US, with the corresponding population density and indoor PSAD. The Houston PSAD is 0.99 dB below the average PSAD of the top 20 MSAs. This suggests that the average I/N for indoor RLANs in the top 20 MSAs would then be about 1 dB worse than is shown here, or 9.25 dB I/N instead of 8.26 dB I/N as shown in Table 2. The highest PSAD is in New York City and it is 8.11 dB higher than Houston. This suggests that New York City microwave links would suffer about 8 dB more degradation or an average of 16.37 dB I/N instead of 8.26 dB I/N as shown in Table 2.

5.4 Results for Very Low Power Devices

A recent ex parte filing has proposed the authorization of very low power (VLP) devices in UNII-5 and UNII-7 and included an analysis of the impact of VLP devices on a hypothetical point-to-point communications link.[33] This proposal is considered in the Appendix in section 7.8. The analysis in this recent filing is deficient for reasons described in section 7.8, and cannot be used to provide evidence to support the authorization of VLP outdoor devices in the 6 GHz band.

6 SUMMARY AND CONCLUSIONS

6.1 Summary of Results

- Deployment of indoor low power (0.25 W) RLANs without Automated Frequency Coordination (AFC) would cause all point-to-point links in the Houston MSA to experience I/N ratios more than 5.46 dB and up to 25.24 dB greater than a -6 dB I/N threshold. This interference only considers direct, co-channel interference and does not consider additional interference mechanisms from adjacent channel, backscattering, antenna side-lobes, antenna back-lobes, or frequency limitations.
- Deployment of outdoor standard power (1 W) RLANs without AFC would cause all point-to-point links in the Houston MSA to experience I/N ratios more than 8.46 dB and up to 28.24 dB greater than a -6 dB I/N threshold. As above, this result is only from direct co-channel interference, and additional interference from other mechanisms is not included.
- RLANs within ±10 degrees of the boresight of fixed point-to-point receive antennas are the dominant contributors to interference exceeding -6 dB I/N. The analysis shows that RLAN emissions within ±10 degrees of the antenna boresight would have to be avoided to control interference. The avoidance zones for all the licensed link paths covers 94% the Houston metropolitan area. In central Houston, these avoidance zones include every Wi-Fi channel in the U-NII-5 and U-NII-7 bands.
- RLANS located anywhere within the radius of 1 mile of Houston center contribute to interference exceeding -6 dB I/N for all the fixed point-to-point links that terminate in Houston center.

6.2 Conclusions

- Indoor low-power RLANs without AFC cannot be deployed in the Houston MSA without degrading the performance of all point-to-point links in the Houston area. The degradation will cause immediate loss of network reliability. AFC cannot control interference from indoor RLANs in central Houston without degenerating to complete exclusion of the entire U-NII-5 and U-NII-7 bands.
- Outdoor standard-power RLANS without AFC cannot be deployed in the Houston MSA without rendering useless all of the point-to-point links in the Houston area. The analysis shows a degradation 3 dB more severe than for indoor low-power RLANs. AFC cannot control interference from outdoor RLANs in central Houston without degenerating to complete exclusion of the entire U-NII-5 and U-NII-7 bands.

[33] Ex parte filing, Harris, Wiltshire, and Grannis, December 9, 2019, Re: *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295; *Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz*, GN Docket No. 17-183. (*Harris, Wiltshire and Grannis ex parte*).

- RLANs located anywhere within Harris or Galveston counties or 94% of the nine-county Houston metropolitan area will contribute to the interference to licensed microwave links

6.3 Very Low Power Devices

A recent ex parte filing has proposed the authorization of very low power (VLP) devices in UNII-5 and UNII-7, and included an analysis of the impact of VLP devices on a hypothetical point-to-point communications link.[34] This proposal is considered in the Appendix in section 7.8. The analysis in this recent filing is deficient since it only considers the impact of one VLP device, applies a power level of 0.4 mW, 18 dB (63 times) less than the proposed authorized level of 14 dBm (25 mW), and analyzes a single separation distance from interferer to fixed receiver. Because of these and other deficiencies, the VLP analysis in this ex parte filing significantly understates the potential interference from VLP devices. Amending the analysis to take into account just the first two of these factors reveals that the desired interference threshold for fixed receivers is exceeded by nearly 10 dB. This recent ex parte filing cannot be relied on as evidence in support of permitting VLP outdoor devices in U-NII-5 and U-NII-7. Additional, more comprehensive study is required to realistically assess the interference potential of VLP devices.

[34] Ex parte filing, Harris, Wiltshire, and Grannis, December 9, 2019, Re: *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295; *Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz*, GN Docket No. 17-183. (*Harris, Wiltshire and Grannis ex parte*).

7 APPENDICES

7.1 Interference Analysis Parameters

7.1.1 Link Budgets

Table 3 contains representative link budgets for the desired (point-to-point) and interference (Wi-Fi) propagation paths.

Table 3 Desired and Interference Link Budgets

Desired		
TX.power	1.4	W
	31.46	dBm
BW	30	MHz
	16.69	dBm/MHz
G.tx	40.19	dBi
D	30.28	km
Fc	6152.75	MHz
λ	0.0487	m
L.path	137.85	dB
G.rx	41.90	dBi
RX	-39.07	dBm/MHz
k	1.38E-23	J/K
T	300	K
B	1.00E+06	Hz
NF	4	dB
N=kTBF	-109.83	dBm/MHz
SNR.rx	70.76	dB
QAM	2048	
Sensitivity	41.47	dB
Margin	29.28	dB
sigma	5.5	dB
p.lognorm	1.000000	
Tw	1275.00	sec
Separation	50	ft
	15.24	m
Io	48.53	
Tsd	26.27	sec

Interference		
PSAD	182.4	mW/MHz-km^2
Out ratio	0.0100	
Area	0.2	km^2
Duty Cycle	4%	
PSD	0.014592	mW/MHz
PSD	-18.36	dBm/MHz
G.tx	2	dBi
E[BEL]	0	dB
D	1.2	km
λ	0.0487	m
L.path	111.75	dB
G.rx	41.90	dBi
RX.I	-86.21	dBm/MHz
I/N	23.62	dB
I+N	-86.19	dBm/MHz
SINR.rx	47.12	dB
Sensitivity	41.47	dB
Margin	5.65	dB
sigma	5.5	dB
p.lognorm	0.847729	

TX Power – Conducted transmit power.

For the Desired signal this is transmitted in 30 MHz so that it results in a power spectral density of 56.88 dBm/MHz with the transmitter antenna gain.

PSAD – Power Spectral Area Density for the interfering transmitters. See Table 4 for the calculation. This is derived from the standard power outdoor devices in the 6 GHz NPRM.

E[BEL] – Expected Building Entry Loss. For outdoor devices this is zero.

G.tx Antenna Gain – Transmitter antenna gain relative to an isotropic antenna. Note that the TX antenna gain for the Desired transmitter and Interference transmitter are not necessarily the same.

D, fc, λ – Distance for the propagation path, center frequency for the desired and interfering transmitter / receiver, and the corresponding wavelength ($\lambda = c/fc$). The path distances for the Desired and Interference paths are not necessarily the same.

L.path – Path loss for the Desired signal is: $L = 20 \log_{10}(4 \pi D/\lambda)$. This is the Free Space Path Loss (FSPL) model for short distances, or for microwave links with high antennas designed to have a line-of-sight path.

G.rx Antenna Gain – Receiver antenna gain relative to an isotropic antenna. This is the antenna gain for the victim receiver. The victim receiver antenna gain has the same antenna pattern for both the desired and interference signals. However, the interference signals may be incident at different angles with a different gain values.

RX, RX.I– The received power spectral density. For RX this is the desired signal, while for RX.I it is the received interference power spectral density.

RX – Received average power spectral density:

RX = TX PSD + G.tx – L.path + G.rx.

RX.I Interference PSD – Received interference power spectral density:

RX.I = TX PSD + G.tx – E[BEL] – L.path + G.rx.

K, T, B, F – Receiver figures of merit for the noise floor. K is Boltzmann's constant. T is the noise temperature in Kelvin. B is the bandwidth for the power spectral density, which is 1 MHz in this calculation. F is a multiplicative noise factor for the receiver, often expressed in dB as an additive noise figure.

N – Receiver power spectral density noise floor. $N_0 = 10 \log_{10}(k\ T\ B\ F)$. This is the denominator in the E_b/N_0 ratio for customary BER curves according to Shannon's information theory. The N_0 value is also used as an interference threshold in the calculation.

Sensitivity – This is the sensitivity threshold to obtain acceptable receiver BER performance.

Margin – The Margin is the difference between the received PSD and the Sensitivity threshold. Positive margins permit the receiver to work, while negative margins cause the receiver to fail. A Margin exceeding 20 dB is necessary for a reliable microwave link. This is then improved with a second receiver and antenna for diversity to resist fades.

I/N – Interference to Noise ratio in the victim receiver. The distance parameter, D, for the Interference has been adjusted so that the I/N_0 ratio is near 0 dB, indicating that the interference power is equal to the noise floor in the receiver.

I + N – Sum of the power spectral density for the interference and noise floor. This is a sum of powers, so the I and N_0 parameters in units of dBm/MHz are converted to mW/MHz, then summed, and then converted back to dBm/MHz units.

SINR.rx – This is the ratio of the received PSD to the sum of the interference and noise powers, i.e. S/(I+N) ratio.

Tw, Tsd – Outage times without diversity (Tw) and with spatial diversity (Tsd).

7.1.2 *Path Loss Models*

Models for Path Loss (L_{path}) include Free Space Path Loss (FSPL), and Non-Line-of-Sight (NLOS) path loss for interfering devices more than 1 km from the victim receiver. The FSPL model is the basic formula given in textbooks as a function of the path distance, D, and the wavelength of the electromagnetic wave. The wavelength is determined by the speed of light and the frequency. If D and λ use the same units, their ratio will be dimensionless.

$$FSPL = 20 \log_{10}(4 \pi D/\lambda) \text{ in dB} \qquad \text{with } \lambda = c/f \qquad \text{Eq. 6}$$

The NLOS model for distances beyond 1 km follows a path loss model for given in ITU-R Report M.2135[35], Table A1-2 for Urban Macro Cell scenarios.

$$NLOS = (43.42 - 3.1 \log_{10}(hbs)) \log_{10}(D) + 20 \log10(4 \pi \, 1km/\lambda) \qquad \text{Eq. 7}$$

$$= 38 \log_{10}(D) + 108.7 \qquad \text{for hbs=57 m and } \lambda\text{=4.61 cm}$$

with D given in km and hbs in meters for the victim receiver antenna height

7.1.3 *Building Entry Loss*

Building Entry Loss (BEL) is predicted in Rec. P.2109. The recommendation gives a BEL Cumulative probability Distribution Function (CDF) that varies with frequency and elevation angle. In this application the elevation angle is zero, and the frequency is 6.5 GHz. The recommendation has two CDF functions, one for Traditional buildings and another for Thermally Efficient buildings. The Traditional CDF function is used here, as shown in Figure 10.

The entire BEL CDF distribution is used to compute an expectation of the path loss from building entry. An example calculation is given in Equation 9. The detailed definition of the BEL function is given in the P.2019 recommendation.

$$E[BEL] = -10 \, log_{10} \left(\int 10^{-0.1 \, BEL(p)} dp \right) = 11.0 \, dB \qquad \text{Eq. 9}$$

Figure 10 Cumulative Probability Distribution of Building Entry Loss

[35] ITU-R Report M.2135-1, *Guidelines for evaluation of radio interface technologies for IMT-Advanced*, December, 2009 (Rep. M.2135).

7.2 Interference I/N Detailed Results

The calculation of aggregate interference power spectral density (I) integrates a Power Spectral Area Density (PSAD) over a land area covered by the radiation pattern of a victim receiver antenna gain function (G_{victim}). The integrated power is then adjusted by factors for the duty cycle, BEL, and RLAN antenna gain. This is represented by the double integral given in Equation 10. This is then divided by the noise power spectral density, typically given by kTBF for Boltzmann's constant (k) and temperature (T) in Kelvin. The F variable is a noise figure for the receiver (=4 dB in this report). The unit of bandwidth used for the spectrum density is a MHz, so kT is multiplied by 1 megahertz to obtain kTB = -114 dBm/MHz. The noise spectral density, N, is represented in Equation 11.

$$I = G_{RLAN}\, E[BEL]\, DutyCycle \iint PSAD\, G_{victim}(\theta, \varphi)\, r\, dr\, d\theta \qquad \text{Eq. 10}$$

$$N = k\, T\, B\, F \qquad \text{Eq. 11}$$

The elevation angle, φ, for the victim antenna gain function is determined by the height of the antenna and the radius, r.

$$\varphi = \tan^{-1}\left({}^{h}/_{r}\right) \qquad \text{Eq. 12}$$

The elevation angle can be very steep, more than 45°, when the antenna height exceeds the radius. For example, an average antenna height in the Houston metro area is 57 m, so radii inside of 57 m will have elevation angles exceeding 45°. A quick review of the typical antenna pattern shown in Figure 5, indicates that the overall antenna gain is negative at such steep angles. The effect on the aggregate interference power spectral density, I, is negligible for the nearby radii less than the antenna height.

The integration upper limit of the radius, r, is the maximum value for the coverage area of the antenna. This calculation uses a simple calculation for the distance to the horizon, $D_{horizon}$.[36]

$$D_{horizon} = \sqrt{2\, h_1 R_e} + \sqrt{2\, h_2 R_e} \qquad \text{Eq. 13}$$

The variables h_1 and h_2 are the respective antenna heights for the victim receiver and interfering transmitter. The R_e variable represents the effective radius of the earth, accounting for atmospheric refraction of electromagnetic radio waves. The effective radius is 1.33 x R_{earth} = 1.33 x 6371 km = 8495 km. For example, with h_1 = 57 m and h_2 = 2 m the distance to the horizon is $D_{horizon}$ = 37 km.

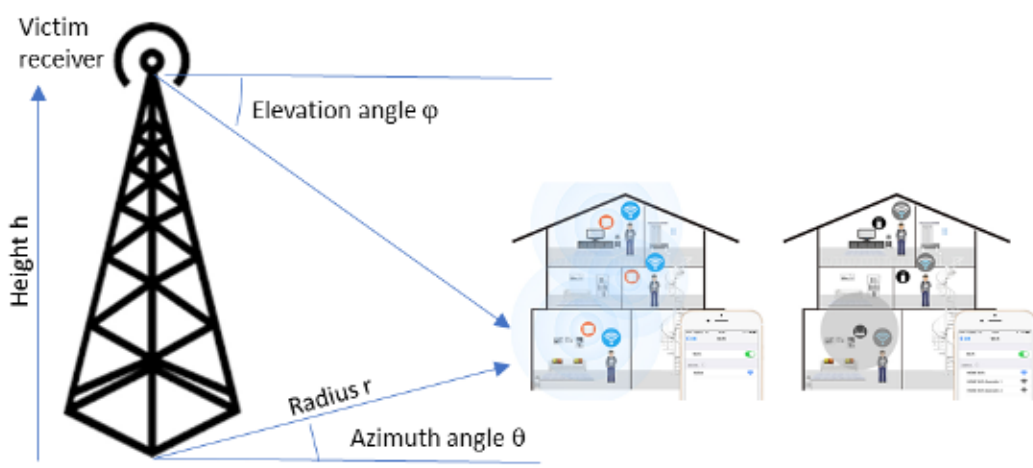


Figure 11 Radius, Azimuth, Elevation Geometry

[36] See for example: Busi, R., *High Altitude VHF and UHF Broadcasting Stations*, Technical Monograph 3108-1967, Brussels: European Broadcasting Union.

The integration variables for radius, r, azimuth angle, θ, antenna height, h, and elevation angle, φ, are shown in Figure 11. The (r, θ, h) coordinates correspond to customary cylindrical coordinates, with a supplementary elevation angle, φ.

Table 4 PSAD Calculation

Houston Parameter	Value	Band	Bandwidth
Metropolitan Area	26,060 km^2	**U-NII-1**	100 MHz
Population	6.77 million	**U-NII-3**	125 MHz
Density	259.79 person/km^2	**U-NII-5**	500 MHz
Indoor RLAN power	0.25 W	**U-NII-6**	100 MHz
RLAN ratio	1 RLAN/person	**U-NII-7**	350 MHz
Indoor PSAD	45.6 mW/MHz-km^2	**U-NII-8**	250 MHz
Outdoor RLAN power	1.0 W	**Total**	1425 MHz
Outdoor PSAD	182.4 mW/MHz-km^2		

The calculation of PSAD is given in Table 4. The geographical area and population of the Houston metropolitan area are given and their ratio yields a population density of 260 people/km^2. With one indoor RLAN per person at 250 mW, the product yields a power density in mW/km^2. This is then divided by the available RLAN bandwidth in the last column to obtain the Power Spectral Area Density of 45.6 mW/MHz-km^2 for indoor RLANs. Outdoor RLANs are permitted 1.0 W so their PSAD is four times higher.

The geographic coordinates, frequencies, antenna heights, antenna gains, and other parameters are given in the FCC Universal Licensing System (ULS) database.[37] The parameters in this analysis were derived from that database for licenses listed as Active, in the 9 counties (Harris, Galveston, Chambers, Liberty, Montgomery, Waller, Austin, Fort Bend, and Brazoria), and with frequencies in 5925-6425 MHz or 6525-6875 MHz.

The distribution of 520 point-to-point sites in the Houston metropolitan area in the U-NII-5 and U-NII-7 bands is shown in the next figure.

[37] FCC ULS, https://wireless2.fcc.gov .

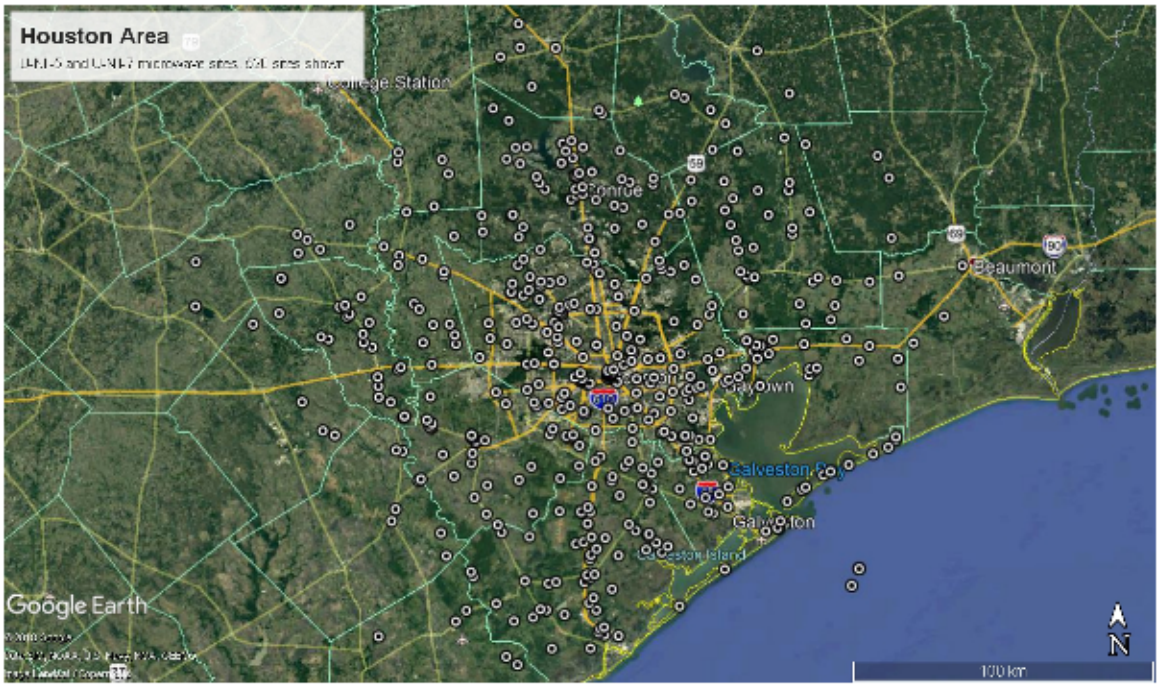


Figure 12 Houston Microwave Sites

The arrangement of the point-to-point links in the Houston metropolitan area is shown in the next figure. Note that this does not show the links that begin and end outside the metro area, but it does show links with at least one end point within the metro area.

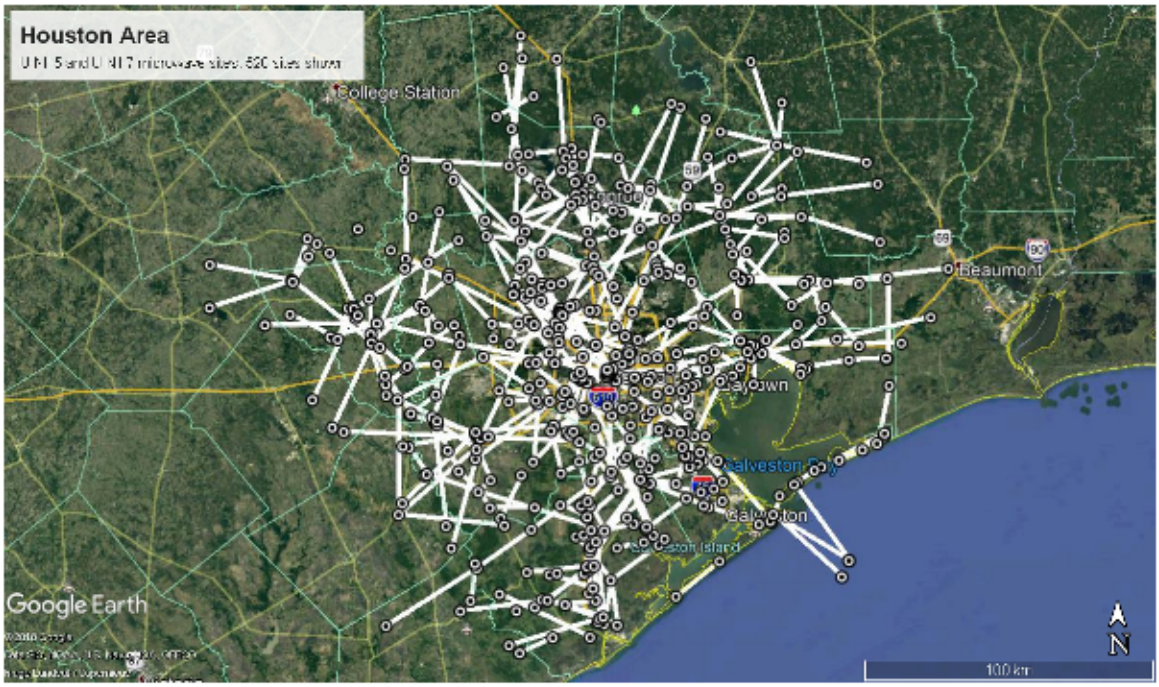


Figure 13 Houston Microwave Link Paths

The distribution of victim antenna heights and gains is shown in the next figures. The first figure shows the distribution of antenna heights. The distribution is nearly normal for 95% of the antennas, or those below 100 m in height. Above 100 m there is a long tail of a few percent of the antennas.

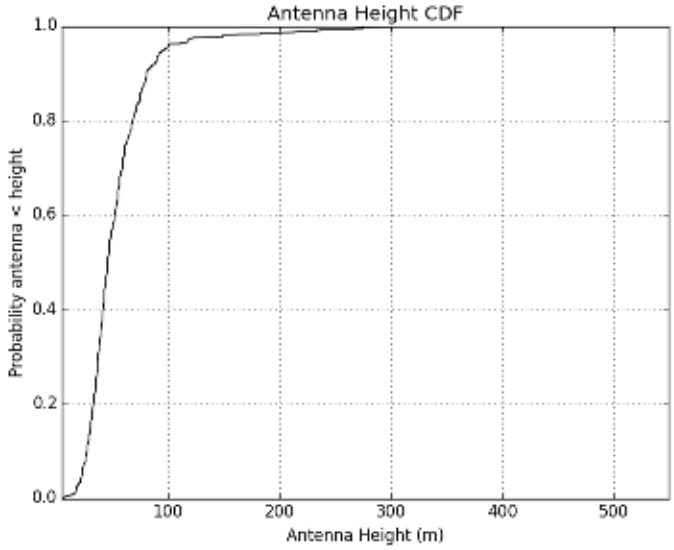


Figure 14 Microwave Antenna Height Distribution

The next figure shows the distribution of the antenna gains. This shows that the distribution is nearly normal, centered around 39 dB of gain. The antenna pattern shown in Figure 5 is representative of the average antenna gain function.

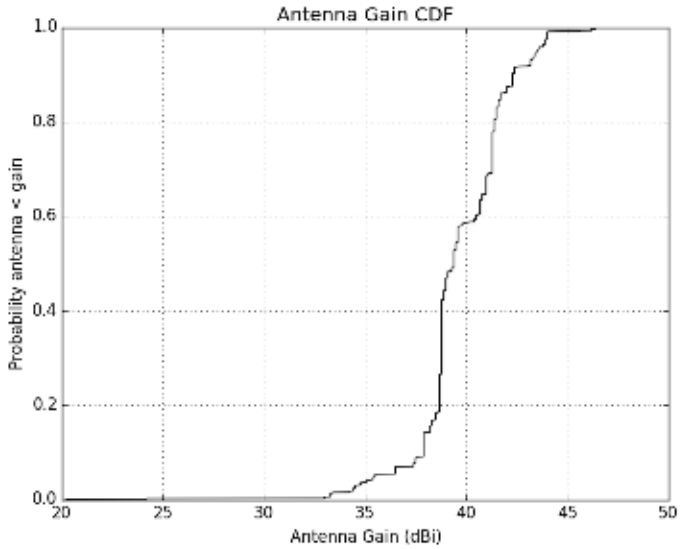


Figure 15 Microwave Antenna Gain Distribution

The next figure shows a scatter plot of the antenna gains and heights. The main cluster is a nearly normal 2-D distribution near 40 dBi gain and 50 m height. The scatter plot has 2325 points. There are some other antennas (about a dozen) with either higher heights, or lower gains. They are not numerous enough to significantly distort the central cluster that is normally distributed.

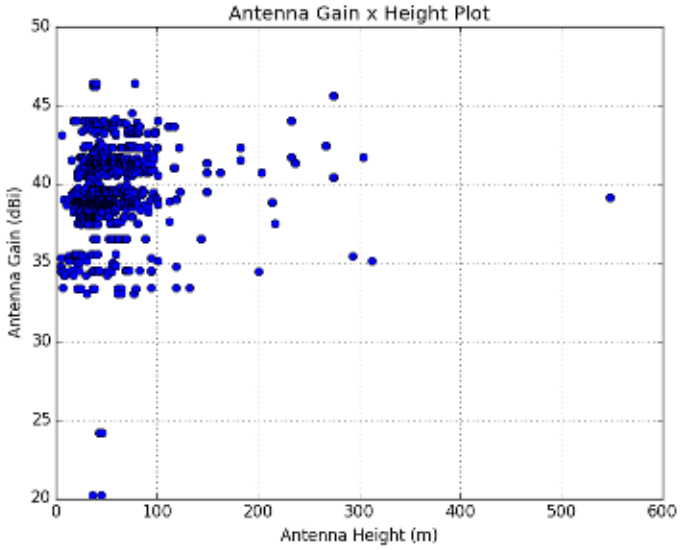


Figure 16 Microwave Antenna Gain x Height Scatter Diagram

A significant set of victims have higher I/N ratios (although still normally distributed), and a relevant question is which antenna characteristics cause the higher I/N ratios. From the calculations, the higher I/N ratios correspond to the antennas with lower antenna height, or essentially the dozens of points at the extreme left edge of the scatter plot. The higher I/N ratios for those points is a direct consequence of lower height, and therefore smaller elevation angles to RLANs that are closer to the antenna. The RLANs closer to the antenna have less path loss, since they are closer. In other words, the dozen or so points in the scatter plot in the right half or bottom half of the plot are not the victim receivers with the worst I/N ratios.

The next plot graphs the I/N ratios obtained from the integral in Equation 10, applied to each of the 2325 victim receivers represented by the previous graphs. This is for indoor deployment, so the PSAD was 45.6 mW/MHz-km^2. Each calculation used the antenna height and gain for the victim. The result is a nearly normal distribution with a mean value of 8.3 dB I/N and a sigma of 3.30 dB. The minimum / maximum I/N ratios are -0.5 / 19.2 dB, which are near the end points of the x-axis in the plot.

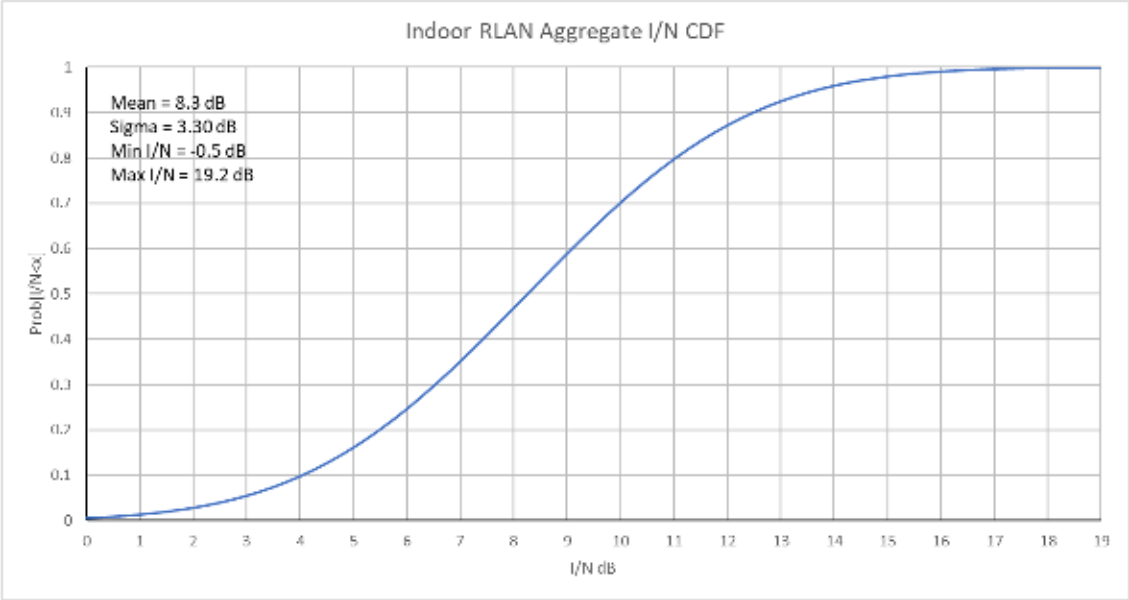


Figure 17 Indoor RLAN I/N Probability Distribution

7.2.1 *Adjacent Channel Emissions*

The emissions in the adjacent channel are controlled by an emission mask as described in ITU-R M.1450-5.[38] This is shown in Figure 18. The adjacent channel average power spectral density can be determined by integrating the curve from 0.5 to 1.5 and normalizing for the bandwidth. This comes to -24.69 dB relative to the co-channel power spectral density.

$$AdjacentChannelRatio = 10\log_{10}\left(\int_{0.5}^{1.5} 10^{0.1\,EmissionMask(f)}\,df\right)$$

[38] ITU-R Rec. M.1450-5, *Characteristics of broadband radio local area networks*, 2014.

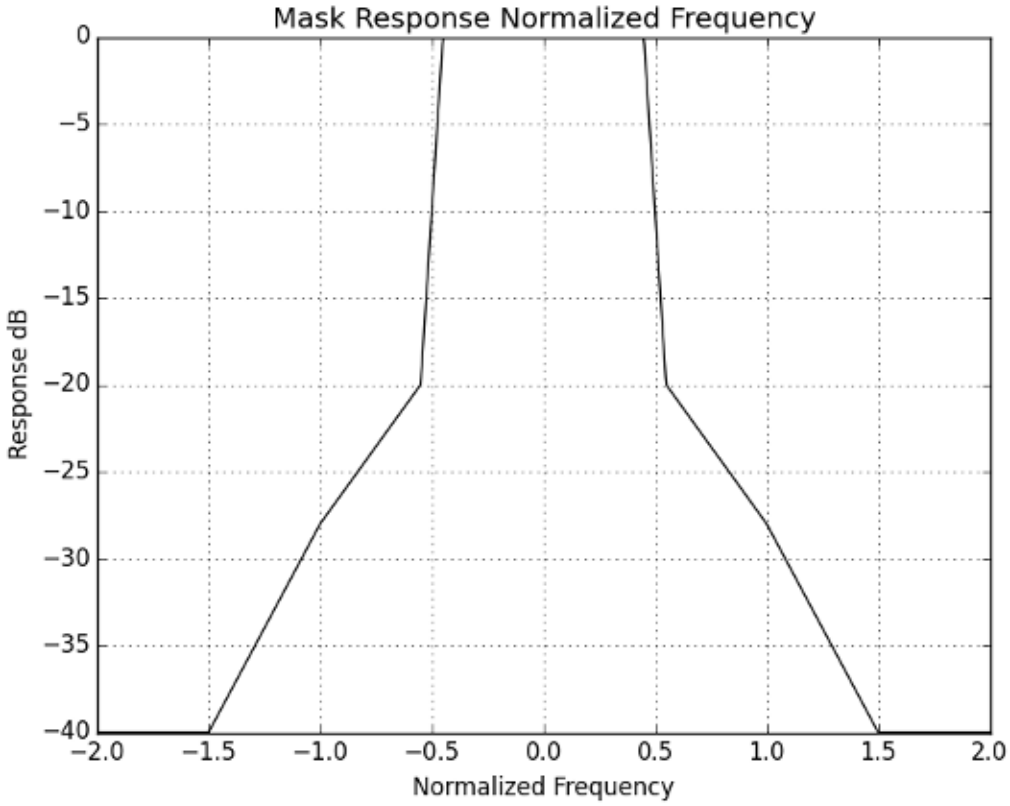


Figure 18 RLAN Adjacent Channel Emission Mask

7.2.2 *Polarization Effects*

Electromagnetic waves have a polarization that can be linear (horizontal or vertical), circular (left or right-handed), or some combination usually described as elliptical. Polarization can be used in a system design to discriminate between two different channels on the same frequency. Polarization is also randomized when electromagnetic waves are scattered, refracted, and reflected, so the application to system designs is limited to conditions that can control the propagation environment (e.g. LOS paths). The FCC database lists some licensees with horizontal polarization and some with vertical polarization. Wi-Fi emitters do not normally specify polarization for transmissions, since the orientation of portable consumer devices is often random, and multiple receive antennas permit reception in alternative polarizations. Since electromagnetic wave polarization is not controlled in Wi-Fi emitters, and both horizontal and vertical polarization is used in licensed microwave receivers, it cannot be used reliably for interference discrimination. Therefore, polarization discrimination is set to 0 dB in this study.

7.3 Interference Avoidance

The 6 GHz NPRM proposed using Automated Frequency Coordination (AFC).[39] The operational details of an AFC function are not explained to the level that AFC can be evaluated quantitatively. A straightforward extension of the previous analysis can evaluate the aggregate interference within a small "pie slice" represented by an azimuth angle to determine how large the azimuth angle must be to reduce the I/N to an acceptable value of – 6 dB. This is diagrammed in the next figure.

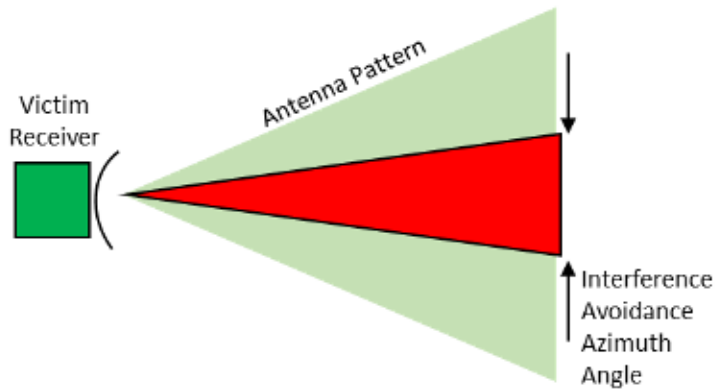


Figure 19 Interference Avoidance Azimuth Angle

The Interference Avoidance Azimuth Angle (IAAA) is evaluated by excluding the interference from devices with the IAAA and only integrating the aggregate interference in Equation 10 for θ outside the IAAA azimuth. This calculation is shown in Figure 20. The tabulated values for the distribution at I/N = -6 dB are given in the following table.

Table 5 Probability of I/N < -6 dB for IAAA Parameter

IAAA	Prob[I/N < -6 dB]	Prob[I/N > -6 dB]
0°	0%	100%
5°	17.2%	82.8%
10°	97.3%	2.7%
15°	99.9%	0.1%
20°	100%	0%

[39] See for example the 6 GHz NPRM, paragraph 17, page 7, "…a more nuanced position that would require automated frequency coordination (AFC) for all outdoor and some indoor devices."

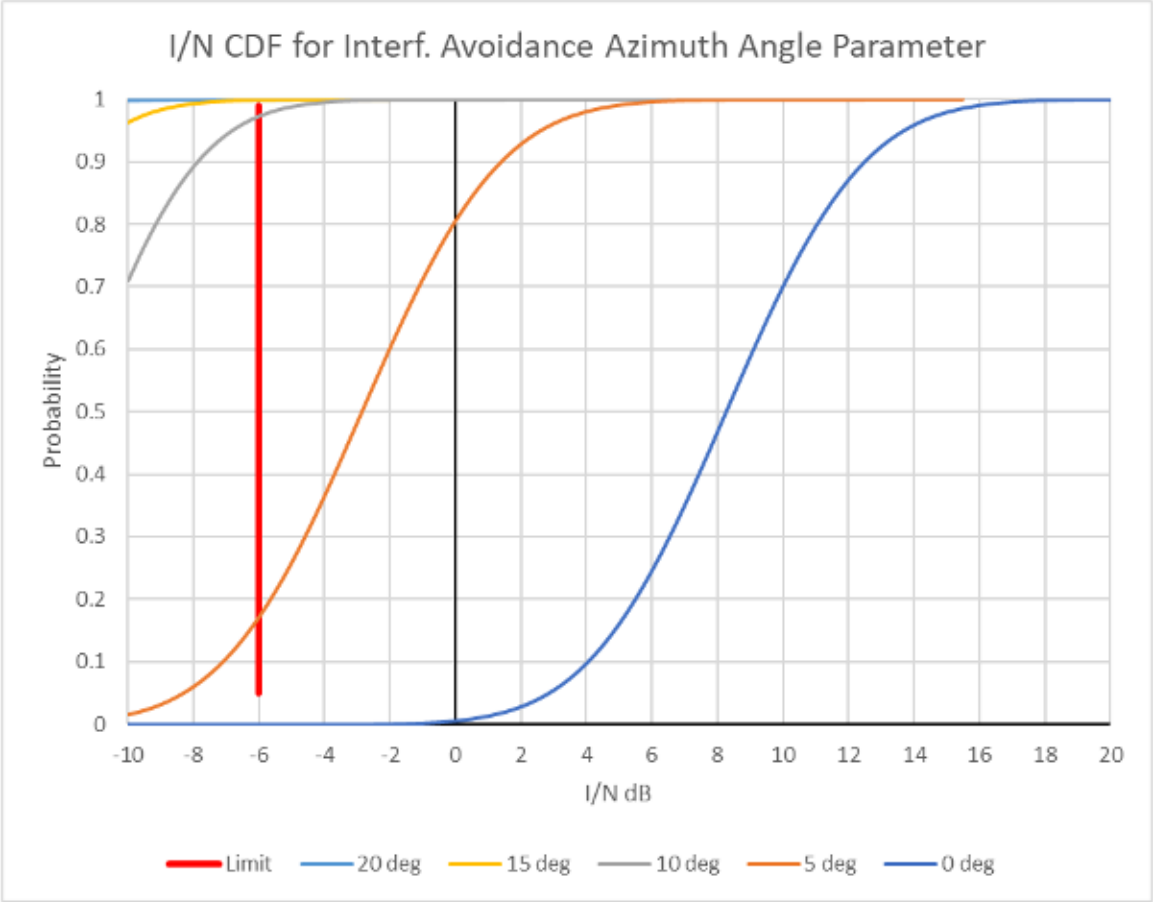


Figure 20 I/N with IAAA Parameter

7.3.1 *Interference Avoidance Area*

The interference avoidance area can be visualized by superimposing angular segments sized according to the IAAA. This is shown in Figure 21.

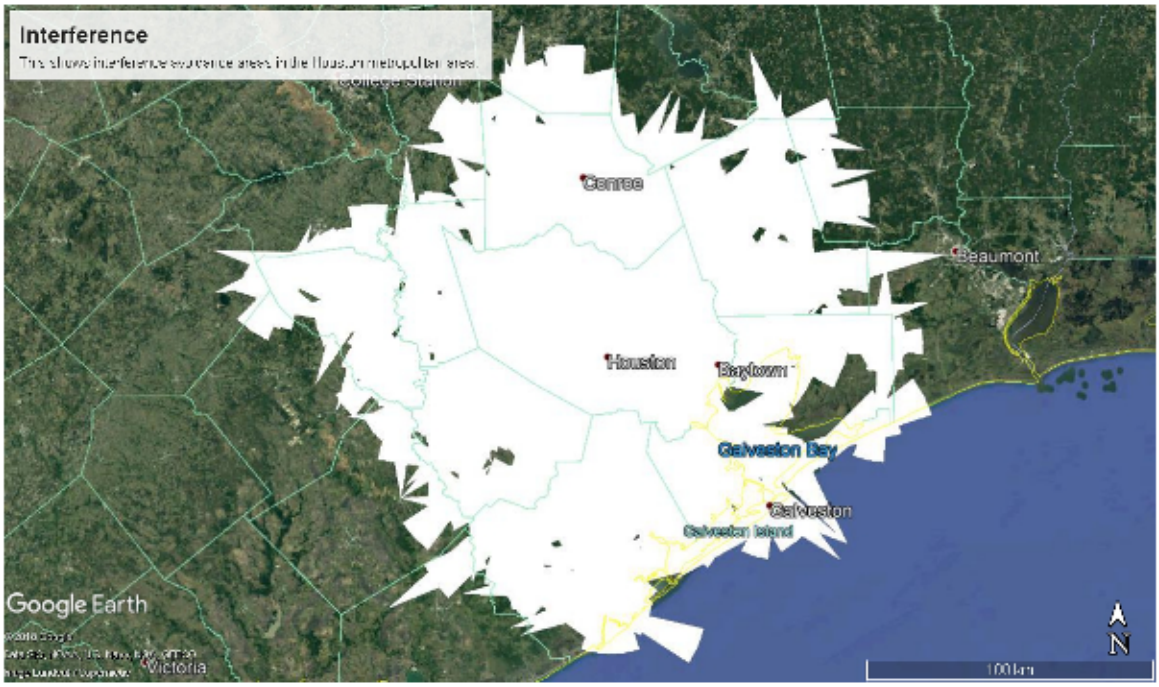


Figure 21 Interference Avoidance Areas in Houston

The interference avoidance areas in the figure show where indoor RLAN deployment would interfere with victim microwave receivers in the Houston metropolitan area. The figure can be compared with Figures 12 and 13 for the microwave sites and link paths. As can be seen, Harris county (Houston is the county seat) is completely covered for interference avoidance. Galveston county land area is also completely covered. Altogether, 94% of the land area of the 9-county Houston metropolitan area is covered by RLAN interference. The central region in Harris county is covered with multiple interference avoidance areas, to a depth up to 25. In other words, enough channels receive interference in central Houston to require elimination of all Wi-Fi channels in the U-NII-5 and U-NII-7 bands. This would result in an increase in traffic (and PSAD) in U-NII-6 and U-NII-8 channels. Adjacent channel interference is also a problem, however, so those would also have to be avoided to control interference in the central Houston area.

7.4 Downtown Houston Analysis

This section considers the microwave paths which terminate at one end (either receive or transmit) in the central downtown area. For the receivers located in the downtown area, this addresses the degree that local interference sources will significantly interfere via either direct or indirect paths. The primary indirect path considered will be backscatter into a near sidelobe of the antenna. For the transmitters downtown, the corresponding receiver by design has LOS to the transmitter and thus to all or part of the downtown area. The consideration is to what degree will the city aggregate noise impact the receiver at the other end. These results will then be applied to a frequency availability study where the active microwave links specific to Houston's downtown center is overlaid on a RLAN frequency plan to determine availability.

7.4.1 *Microwave Receiver Downtown*

7.4.1.1 Backscatter into the Close-in Sidelobe of the Receiver

The first consideration is of the noise energy produced by the city reflecting from the terrain or other clutter and reflecting into a near sidelobe, with its associated gain. As shown below, this section is an analysis of interference generated by the city surrounding the area of the microwave receiver and bouncing off the ground or other clutter in front of the microwave receiving dish. The paths here are relatively short – confined to a few km.

7.4.1.1.1 External RF Noise Power Spectral Density

The power from indoor RLANs is largely retained indoors, but not all. The amount escaping the building can be estimated. Referring to the following tables.

Noise Backscatter from Metropolitan Area

- The number of devices is derived from downtown office floor space (Wikipedia) and RLAN Access Point (AP) coverage, as suggested by Cisco and others. These recommend 10 m spacing for coverage or 100 m^2 per RLAN AP. This results in a RLAN Number of devices.
- The per RLAN AP average power is derived from the indoor power and estimated duty cycle (busy hour).
- That power is then spread over the RLAN spectrum (i.e., 7 channels of 160 MHz) to produce the expectation of the power spectral density (PSD) of a single RLAN.
- The aggregate power is then the product (sum of dBs) of the per device PSD times the number of devices.
- As mentioned before, only a small portion of the power is expected to escape the building. BEL[40] indicates an average loss of 11 or 22 dB depending on building type. Here a blend of about 50/50 is used for an average of 14dB BEL. This produces an exterior EIRP.
- Some of the exterior radiation will be blocked by other buildings and thus will not escape the central urban area. Google maps and city scape photos were reviewed in order to estimate the portion of the

[40] BEL Building Entry Loss, see section 7.1.3 for details.

building's sides which would be in clear view from outside the downtown area. That estimate of about half, which when applied to the previous, gives the EIRP PSD coming from the central downtown area.

7.4.1.1.2 Backscatter Path to the Microwave Receiver

Having established the radiation intensity from the background of the city, the microwave receiving antenna radiation pattern indicates a likely path for backscatter to impact the microwave receiver. Specifically, a reasonably close and yet high gain is likely the best path. The following presents one such possibility but is not intended to be the only or perhaps even the worst. Backscatter noise is a summation or integral over the pattern, therefore this method is very likely to under estimate the actual amount of backscatter.

- The previously discussed Andrews Radiation Pattern Envelope[41] provides antenna gain for a specific geometry and with an antenna height selected, the geometry of a reflected path may be determined. The total path in the table was selected with the intent of extending to a significant portion of the visible downtown area.
- The backscatter path distance needed to be traversed for about the average of the city front was estimated at 2 km.
- Although this particular link budget indicates a substantial issue, there are enough variables and estimates that various usage pattern, weather, and city conditions might land on either side of the threshold.

This then shows the possibility of a backscatter issue. The listed conditions are neither best nor worst case. The worst case would add ten's of dB's of interference, and the best could result in similar reductions in interference. From this, the assumption is that the frequencies of a microwave receiver operating downtown will necessitate avoidance of indoor RLANs on their frequencies for several km in any direction as well as many km in the direction of the gain antenna.

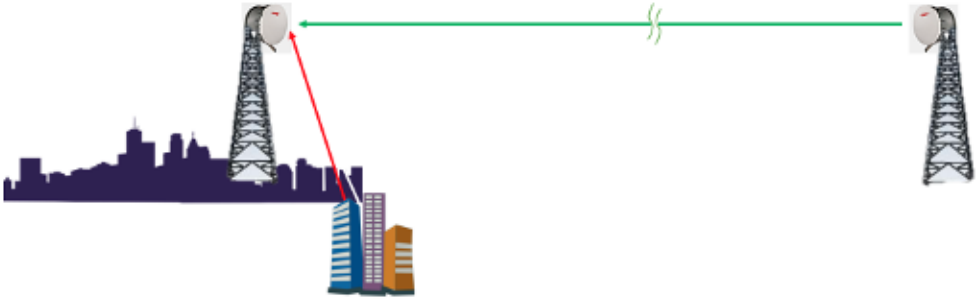
[41] Id., Andrews HX6-6W

Table 6 Interference from Backscatter Calculation

Backscatter Link Calculation		
City Noise		
Houston Texas Downtown office space (1)	4,000,000	sq m
AP coverage	100.00	sq m
Number of devices	40000.00	
Indoor device power	250.00	mW
Duty cycle	0.04	
Average power / device	10	mW
	10.00	dBm
Frequency covered (7x160)	1120.00	MHz
PSD	-20.49	dBm/MHz
Aggregate Power	25.53	dBm/MHz
Building Entry Loss (2)	14.00	dB
Exterior EIRP	11.53	dBm/MHz
Building Shadowing (3)	-3	dB
Downtown EIRP radiated from Houston	8.53	dBm/MHz
Antenna down elevation angle	4.00	deg
Antenna @-4 deg	26.00	dBi
Antenna height	50.00	m
Distance to spot on ground	716.78	m
Path length (from city to spot and back)	2000.00	m
Free Space Path Loss	114.03	dBi
Ground/Building reflection (4)	-5.00	dB
Received interference PSD	-110.50	dBm/MHz
Goal of I/N of -6dB (290degs)	-119.98	dBm/MHz
I/N	**3.48**	dB
Margin	**-9.48**	**dB**

1) All of Houston has 185Msq ft -> ~200k devices
2) ITU Building entry loss blend of building types Average
3) Visual estimate of portion of high rise building visible from a given direction
4) Building materials reflection vary widely with some approaching unity. Wet from rain will have a strong reflection.

7.4.1.2 Direct Radiation into a Far Sidelobe of the Receiver



Nearby noise source into Sidelobe of Antenna

Analysis of a direct path into the receiver is straightforward and has much less uncertainty. Since the close-in sidelobe contains a much smaller footprint, this analysis is presented as a single entity. Indeed, the threshold is maintained at the same level in the following table, but in a noise budget, any single contributor would be held to many dB (perhaps tens of dB) below threshold. Since this budget is more straightforward than the previous, instead of a step by step, only the highlights are outlined. First since it is a single device, peak power and its channel bandwidth are used. Since the moderately low probability BEL draw will occur, it is also assumed here. The antenna gain and geometry are determined from the radiation pattern of the antenna and assumed height. Friis transmission equation supplied the Free Space Path Loss (FSPL). The result is then compared to the I/N goal. Of course, here too, any one component should not be allowed to consume the entire noise budget – such that the rest of the world can contribute none. However, the situation is sufficiently bad to indicate that the near vicinity of the microwave system must be radio quiet for at least 200 m.

Table 7 Interference from Sidelobe Calculation

Sidelobe Link Calculation		
Single Device		
Indoor device power	250.00	mW
	23.98	dBm
Frequency covered (160)	160.00	MHz
PSD	1.94	dBm/MHz
Building Entry Loss (Bad draw)	0.00	dB
Exterior EIRP	1.94	dBm/MHz
Antenna down elevation angle	60.00	deg
Antenna @-60 deg	-13.00	dBi
Antenna height	50.00	m
Distance to spot on ground	57.74	m
Path length (from city to spot and back)	200.00	m
Free Space Path Loss	94.03	dBi
Received interference PSD	-105.09	dBm/MHz
Goal of I/N of -6dB (290degs)	-119.98	dBm/MHz
I/N	**8.91**	
Margin	**-14.89**	**dB**

Since, the single source needs to much less then threshold, it implies that the area slightly forward and far to the side has to be protected from RLANs on their frequencies for several km as well.

7.4.1.3 Direct Radiation into the Back Lobes of the Receiver

The nature of the receive microwave antenna may protect the back lobe (as would be expected from a building side mount) or may not as with a tower or rooftop antenna farm. A link budget for that scenario is below. Although in most practical antenna situations the -30dBi back lobe gain is likely not preserved in the environment it is used, it is used in the link analysis to demonstrate the significant issues with RLAN – even indoor devices - anywhere near the microwave receiver.

Nearby noise source into Backlobe of Antenna

Table 8 Interference from Backlobe Calculation

Backlobe Link Calculation		
Single Device		
Indoor device power	250.00	mW
	23.98	dBm
Frequency covered (160)	160.00	MHz
PSD	1.94	dBm/MHz
Building Entry Loss (Bad draw)	0.00	dB
Exterior EIRP	1.94	dBm/MHz
Antenna down elevation angle	120.00	deg
Antenna @-60 deg	-30.00	dBi
Antenna height	50.00	m
Distance to spot on ground	57.74	m
Path length (from city to spot and back)	75.00	m
Free Space Path Loss	85.51	dBi
Received interference PSD	-113.57	dBm/MHz
Goal of I/N of -6dB (290degs)	-119.98	dBm/MHz
I/N	**0.43**	
Margin	**-6.41**	**dB**

7.4.2 *Microwave Transmitter Downtown*

This examines a microwave link from downtown to a receiver many kilometers or tens of kilometers away. Specifically, will the city skyline noise be safely attenuated by the path loss to be well below the I/N goal? In the following two cases, an explicit budget item for the far end noise being a minority contributor to the overall goal. Specifically, the far end goal is being set here such that it contributes no more than ¼ of the overall noise which is in turn at a I/N of -6dB. This is done with the rationale that far distant noise cannot be allowed to command the majority (or all) of the noise budget as the local source are still present and difficult to control.

Noise source from Transmitter Area into Main Beam

Additionally, each of the two scenarios has one additional burden added to the link analysis to illustrate the various ways things might fail.

7.4.2.1 All of Houston Visible

The following includes the effect of the city of Houston (as opposed to the downtown scenarios which only address the limited town center). Since the city of Houston is large geographically, it is unlikely that most of remote ends of microwave systems will have the entirety of the city within the main beam and in that aspect the inclusion of those sources overestimates the noise. On the other hand, some of that urban spread will be in the direction of the receiver and have a significantly heavier impact on the aggregate noise. Thus, the purpose of this is limited to pointing out the need to carefully consider the far away receivers and establish positive measures to ensure their protection.

This follows the backscatter calculation closely, so the following highlights just the differences.

- All of Houston, so the office space is increased to capture. This leaves out the likely additional load of the population.
- The full main beam antenna gain is included.
- A specific allocation of far end noise being less than about ¼ of the total allowed interference.

Although this particular budget is in the red, the intended point is that obvious scenarios exist with a significant issue.

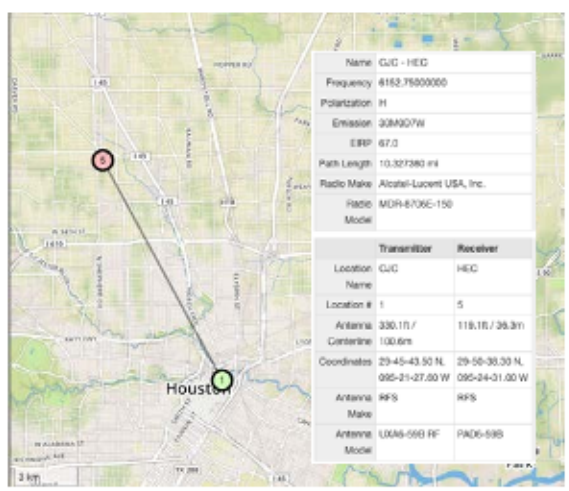
Table 9 Remote Receiver Calculation

Remote Receiver Link Calculation		
City Noise		
Houston Texas office space (1)	17,000,000	sq m
AP coverage	100.00	sq m
Number of devices	170000.00	
Indoor device power	250.00	mW
Duty cycle	0.04	
Average power / device	10	mW
	10.00	dBm
Frequency covered (7x160)	1120.00	MHz
PSD	-20.49	dBm/MHz
Aggregate Power	31.81	dBm/MHz
Building Entry Loss (2)	14.00	dB
Exterior EIRP	17.81	dBm/MHz
Building Shadowing (3)	-3	dB
Downtown EIRP radiated from Houston	14.81	dBm/MHz
Antenna down elevation angle	0.00	deg
Antenna @0 deg	39.10	dBi
Antenna height	100.00	m
Path length	20.00	km
Free Space Path Loss	134.03	dBi
Received interference PSD	-119.21	dBm/MHz
Goal of I/N of -6dB (290degs)	-119.98	dBm/MHz
Minority Contributor to Sum	-6.00	dB
Far Noise goal	-125.98	dBm/MHz
I/N	**-5.98**	
Margin	**-6.76**	**dB**

1) All of Houston has 185Msq ft -> ~200k devices
2) ITU Building entry loss blend of building types Average
3) Visual estimate of portion of high rise building visible from a given direction
4) Building materials reflection vary widely with some approaching unity. Wet from rain will have a strong reflection.

7.4.2.2 Limited RLAN Frequencies Available

In this section, the additional consideration is what might happen if there are limited RLAN frequencies and the mechanisms in place cause them to congest – in this case on a single RLAN channel on the far link. Of course this would also impact the local analysis by roughly 8 dB.



The same diagram as section 7.4.2 applies, so it is not repeated here. The path selected to analyze was WQMT627 Path 4. Specifically, the path length and antenna gain were used directly from the FCC database with that Call Sign and Path. Other details of the path were not brought into this analysis. This path is shown here.

The RLAN energy is only spread over a single 160MHz channel (not seven) and the resulting PSD increases in correspondence. Also, since it is a far receiver, there is a specific budget of ¼ for the far away

noise contribution. Several details of this example were taken from an actual path (i.e., the antenna gain, path length) but it is not a faithful analysis of that path.

This illustrates that there are many ways that a particular noise allocation can exceed an allowable limit of -6 dB I/N.

Table 10 Remote Receiver Link Calculation

WQMT627 Path 4 Remote Receiver Link Calculation City Noise - Single RLAN channel		
Houston Texas office space (1)	4,000,000	sq m
AP coverage	100.00	sq m
Number of devices	40000.00	
Indoor device power	250.00	mW
Duty cycle	0.04	
Average power / device	10	mW
	10.00	dBm
Frequency covered **(single channel available)**	160.00	MHz
PSD	-12.04	dBm/MHz
Aggregate Power	33.98	dBm/MHz
Building Entry Loss (2)	14.00	dB
Exterior EIRP	19.98	dBm/MHz
Building Shadowing (3)	-3	dB
Downtown EIRP radiated from Houston	16.98	dBm/MHz
Antenna down elevation angle	0.00	deg
Antenna @0 deg	38.70	dBi
Antenna height	100.00	m
Path length	10.33	km
Free Space Path Loss	128.28	dBi
Received interference PSD	-111.31	dBm/MHz
Goal of I/N of -6dB (290degs)	-119.98	dBm/MHz
Minority Contributor to Sum	-6.00	dB
Far Noise goal	-125.98	dBm/MHz
I/N	**2.69**	
Margin	**-14.67**	**dB**

1) All of Houston has 185Msq ft -> ~200k devices
2) ITU Building entry loss blend of building types Average
3) Visual estimate of portion of high rise building visible from a given direction
4) Building materials reflection vary widely with some approaching unity. Wet from rain will have a strong reflection.

7.4.3 *Downtown Houston Links*

This section studies a set of specific links to and from the downtown area and the impact on channel availability of the mechanisms needed for protection of these links.

Specifically, there are many links that one end or the other ends up in a fairly small downtown area. The question is if that concentration would limit the RLAN channel availability in central Houston.

Beginning with a microwave search for those links which has a receiver, a transmitter, or overflies the central downtown. A 5km radii produced the following. It's evident that there is a very localized concentration of microwave links in the town center and associated with the high-rise buildings.

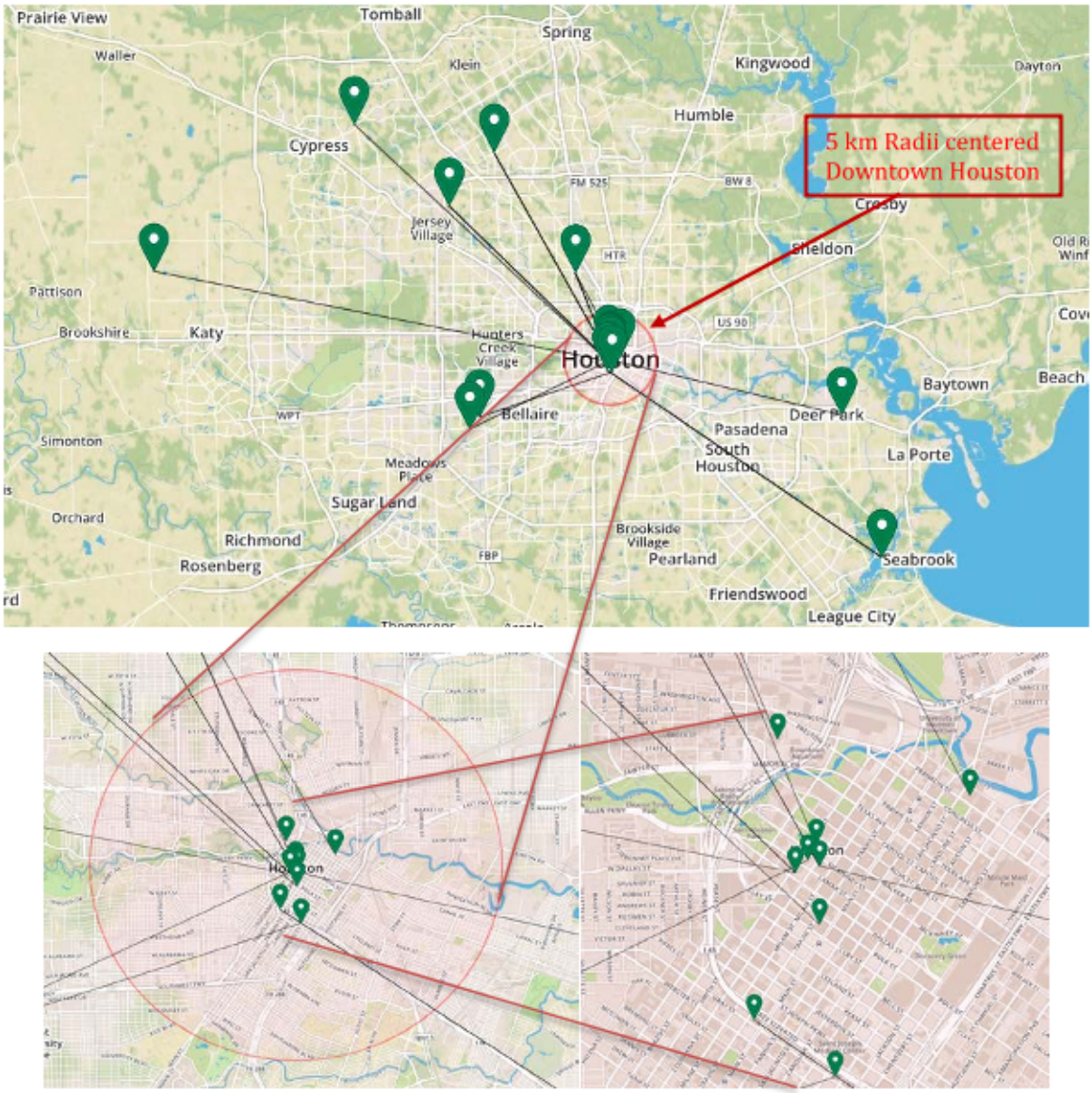


Figure 22 Downtown Houston Selected Sites

Zooming in at the bottom and lower right shows that there is some distribution, but still they are all within approximately 1 km of town center and therefore they very likely all overlap in the area needing protection.

The following table lists the links sorted by RX/TX and the center frequencies.

Call	DwnTwn Site	Rx/Tx	Opposing site	Fc	BW	Location	Azimuth	RLAN Chs
WQPT564	TS-HOU0002	Rx	TS-HOU0005	5945.200	25	29-44-57.40 N, 095-22-18.60 W	124.3	1
WQPT564	TS-HOU0002	Rx	TS-HOU0005	5974.850	25	29-44-57.40 N, 095-22-18.60 W	124.3	1
WRAE204	2000 Crawford St.	Rx	ARA	6019.325	60	29-44-45.70 N, 095-21-59.50 W	251.3	1
WPVV930	1001 Louisiana	Rx	NORTH HOUSTON	6197.240	30	29-45-28.90 N, 095-22-03.10 W	330.5	2
WQVL609	Wells Fargo	Rx	KPRC Studio	6212.065	56	29-45-30.20 N, 095-22-05.90 W	243.8	2
WPVV930	1001 Louisiana	Rx	NORTH HOUSTON	6226.890	30	29-45-28.90 N, 095-22-03.10 W	330.5	2
WPVV930	1001 Louisiana	Rx	NORTH HOUSTON	6256.540	30	29-45-28.90 N, 095-22-03.10 W	330.5	2 & 3
WPVV930	1001 Louisiana	Rx	NORTH HOUSTON	6286.190	30	29-45-28.90 N, 095-22-03.10 W	330.5	3
WQJK947	HPD	Rx	HEC	6315.840	30	29-45-55.00 N, 095-22-13.00 W	337.0	3
WQJK947	CJC	Rx	HEC	6315.840	30	29-45-43.50 N, 095-21-27.60 W	331.5	3
KKE59	CYPRESS, TX	Rx	FCC Loc #5: DOWN	6345.490	30	29-45-17.00 N, 095-22-03.10 W	312.9	3
WQJK947	HPD	Rx	HEC	6375.140	30	29-45-55.00 N, 095-22-13.00 W	337.0	3
WAQ680	Katy Tower	Rx	1100 LOUISIANA S	6404.790	30	29-50-44.70 N, 095-53-06.40 W	281.0	3 & 4
WQJK947	HFD	Rx	HEC	6404.790	30	29-45-33.40 N, 095-22-04.00 W	337.2	3 & 4
WQMX891	LOUISIANA ST	Rx	NEW DATA CNT	6725.000	30	29-45-27.70 N, 095-22-08.90 W	313.8	5 & 6
WQMX891	LOUISIANA ST	Rx	NEW DATA CNT	6815.000	30	29-45-27.70 N, 095-22-08.90 W	313.8	6
WQQK394	1001 Louisiana	Rx	Deer Park	6845.000	30	29-45-28.90 N, 095-22-03.10 W	103.1	6
WQQK393	1001 Louisiana	Tx	North Houston	5945.200	30	29-45-28.90 N, 095-22-03.10 W	330.6	1
WQVL614	Wells Fargo	Tx	KPRC Studio	5960.025	56	29-45-30.20 N, 095-22-05.90 W	243.9	1
WQQK393	1001 Louisiana	Tx	North Houston	5974.850	30	29-45-28.90 N, 095-22-03.10 W	330.6	1
WQQK393	1001 Louisiana	Tx	North Houston	6004.500	30	29-45-28.90 N, 095-22-03.10 W	330.6	1
WEH348	LOUISIANA ST	Tx	Katy Tower	6034.150	30	29-45-27.70 N, 095-22-08.90 W	281.2	1
WQQK393	1001 Louisiana	Tx	North Houston	6034.150	30	29-45-28.90 N, 095-22-03.10 W	330.6	1
WQJK946	HPD	Tx	HEC	6063.800	30	29-45-55.00 N, 095-22-13.00 W	337.0	1
WQRI951	DOWNTOWN, TX	Tx	CYPRESS, TX	6093.450	30	29-45-17.00 N, 095-22-03.10 W	313.0	1 & 2
WQJK945	HFD	Tx	HEC	6123.100	30	29-45-33.40 N, 095-22-04.00 W	337.2	2
WQMT627	CJC	Tx	HEC	6152.750	30	29-46-06.80 N, 095-22-07.10 W	331.5	2
WQMT627	CJC	Tx	HEC	6152.750	30	29-45-43.50 N, 095-21-27.60 W	331.5	2
WQIF898	TS-HOU0002	Tx	TS-HOU0005	6197.240	25	29-44-57.40 N, 095-22-18.60 W	124.2	2
WQIF898	TS-HOU0002	Tx	TS-HOU0005	6226.890	25	29-44-57.40 N, 095-22-18.60 W	124.2	2
WRCD870	2000 Crawford St.	Tx	Arena One	6271.365	60	29-44-45.70 N, 095-21-59.50 W	251.4	2 & 3
WEH348	LOUISIANA ST	Tx	NEW DATA CNT	6555.000	30	29-45-27.70 N, 095-22-08.90 W	313.9	4 & 5
WEH348	LOUISIANA ST	Tx	NEW DATA CNT	6555.000	30	29-45-27.70 N, 095-22-08.90 W	313.9	4 & 5
WQQK393	1001 Louisiana	Tx	Deer Park	6685.000	30	29-45-28.90 N, 095-22-03.10 W	103.0	5

We get a list of 34 victim receivers from what visually appears to be 11 links. The reason behind this is that a single path on the map often has multiple RF paths including diversity, polarization, multiple channels, duplex etc. From the previous, the most concerning are the receivers downtown shown in the top half of the table. Given their center frequency, fc, and bandwidth, BW, we can determine which of the RLAN channels presented before would be impacted by each of these link receivers. That is presented in the last column. Note that there are numerous instances where the microwave frequency overlaps two RLAN channels in which case both would need to be controlled in order to protect the microwave receivers.

The next step in this analysis is to tally the number to microwave links that would be impacted by each of the RLAN channels. That results in the following table that tallies the number of R/T microwave devices in downtown Houston:

RLAN Channel Number	Number of Microwave Receivers in this channel	Number of Microwave Transmistters in this channel	Number of Microwave Radios - Rx or Tx in this channel
1	3	8	11
2	4	7	11
3	8	1	9
4	2	2	4
5	1	3	4
6	3	0	3
7	0	0	0

Channel 7, due to it being entirely in the U-NII-8 band, is the only 160 MHz RLAN channel that might not impede downtown Houston links. Although the RLAN channel primarily in the U-NII-6 band has only one receive link downtown, but as noted earlier the three transmit paths would have to be diligently considered as well. Channel 7 might also be excluded despite this analysis, because of adjacent channel interference.

7.4.4 *Summary of Downtown Houston Study*

There were multiple scenarios for both local and remote interference sources degrading the microwave receiver. These scenarios were selected to be representative but should not be considered exhaustive. In each case studied, a plausible analysis showed that interference was likely if RLANs where allowed to operate in the general area of the receiver or along the main beam. Due to the gain of the receiving antenna and the height needed to provide Line of Sight (LOS) with clearance for the desired path, in-door RLANs in the main beam at distances on the order to the microwave path produce significant interference. These results are summarized in the following table.

Table 12 Summary of Interference Scenarios for Microwave links to & from Downtown Houston.

Scenario	I/N	Exceed Spec (dB)	Ratio
Backscatter	3.48	9.48	8.9
Side lobe	8.91	14.91	31.0
Back lobe	0.43	6.43	4.4
Far-Side[1]	-5.98	6.02	4.0
Limited Frequencies	2.69	8.69	7.4

1. For Far Side calculation, an additional 6 dB is included and the entire city office space was considered to be covered by RLANs, not just the central downtown high rise area.

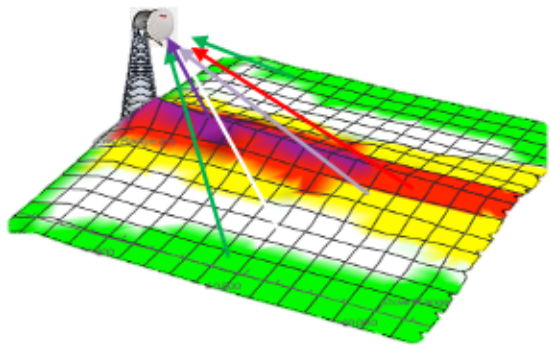
There appears to be no useable RLAN channels within the downtown Houston area that avoid interference. Only one of the RLAN channels will be generally available. Frequency coordination in order to get limited use of the other channels appears to take significantly more diligence in order to ensure coexistence and would result in limited utility of the lower 6 RLAN channels.

Further, the entire area network of microwave links coming into and leaving the downtown area would have to be analyzed beyond the common coverage analysis methods normally applied. Usually the information is obtained from a site survey to produce highly accurate analysis and if not the alternative estimate needs to be significantly conservative which would further limit the utility.

7.5 *Interference Susceptibility Patterns*

This section presents graphs of the areas around a few typical microwave receiver sites indicating the relative sensitivity to interference. Since RF paths are reciprocal, these graphs will be reminiscent of radiation contour maps. In this section, the graphs are not scaled in an absolute sense to determine precisely which areas must be excluded and which areas are ok. Such precise calibration is dependent on the distribution of the interference sources and other particulars. What can be done quite accurately is to show relative susceptibility. Some areas are so susceptible that the expectation is that the most normal assumption about interference source would cause that area to be excluded. On the other hand, there are areas that are very far less susceptible and seem likely to be safe. Therefore, a color coding accurately indicating relative susceptibility can be chosen such that it also gives a general feel for the area needing exclusion.

Interference is a power summation process and therefore determined at the receive antenna. A single source could all by itself be above the allowed interference level, but the normal situation when working is that all devices independently are very far below threshold such that the summation is as well at least below the threshold selected. This process is illustrated here with a susceptibility contour map colored from areas that are less susceptible in green and increasing through white, yellow, red, and peaking with purple. The colored arrows indicate a device sourcing an interference signal towards the microwave receive antenna (dish) which sums the interference signals together. The arrows are color coded to indicate the relative strength with which they respectively contribute to the total noise. In this example with purple, red etc. contributors, it is likely that the noise summation would be above threshold and the microwave link performance significantly affected. Assuming the more susceptible areas (i.e., purple, red, and likely yellow) were eliminated by some mechanism and their respective interference signals (represented by the arrows) was not present, the system would likely perform properly.



For the example above and figures below,

- the 0 dB reference (red – yellow boundary) is selected as the port to port attenuation needed to reduce a 50 mW/MHz source to 6 dB below kTB (i.e., I/N of -6 dB).
- The horizon is set by the limit of a 2 m high interference source and the receiving microwave antenna height.
- The antenna was the Andrews antenna discussed earlier.
- A very simplified path loss formula of similar nature to those in standard was selected. Specifically, if was free space (FSPL) with a smooth transition to double free space at a 3D distance of 10x the antenna mount height.
- Three different antenna heights are shown (100, 25, 300m) and each has one image of the full antenna range (radio horizon) and another zoomed in to show more detail.

A few observations are:

1. The multiple levels of purple (a 30 dB range) indicates there is the possibility of individual interference sources thousands of times the power level of threshold and likely many tens of thousands time stronger than that needed for the summed power to be below -6 dB I/N.
2. This tightly focused beam-width antenna pointed at the horizon leads to a very sharp response evident all the way to the horizon.
3. The response is so sharp that local clutter is expected to scatter the radiation and smooth and randomize the response in any actual deployment.
4. The lower elevation antenna mounts have smaller areas of significant susceptibility but much more intense. The areas are both shorter – due to the lower mount elevation having a shorter radio horizon and narrower since for a given off center beam angle will intersect the Earth surface at a location nearer to the antenna.
5. Even though the far side lobe and back lobe response is -70 dB, there remains significant area to the side and behind which likely needs a prohibition of interference sources.
6. The area likely needing to be avoided extends in the direction of the microwave main beam all the way to the horizon. In an actual physical deployment, it would extend as far as there is a small chance of LOS visibility and associated propagation.

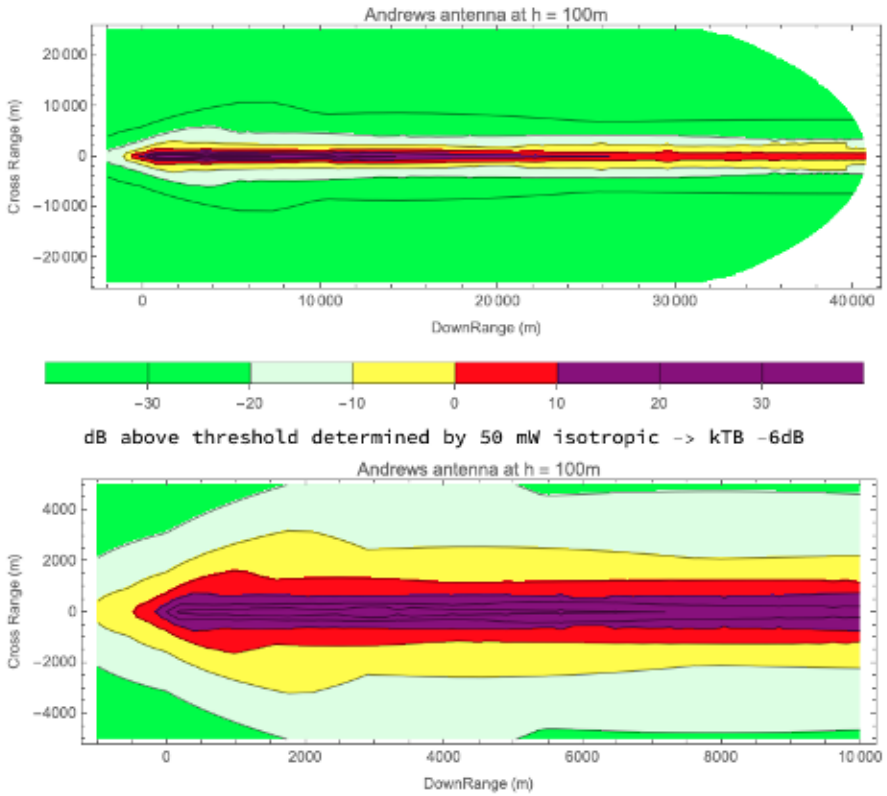


Figure 23 Radiation Pattern with Antenna at 100m

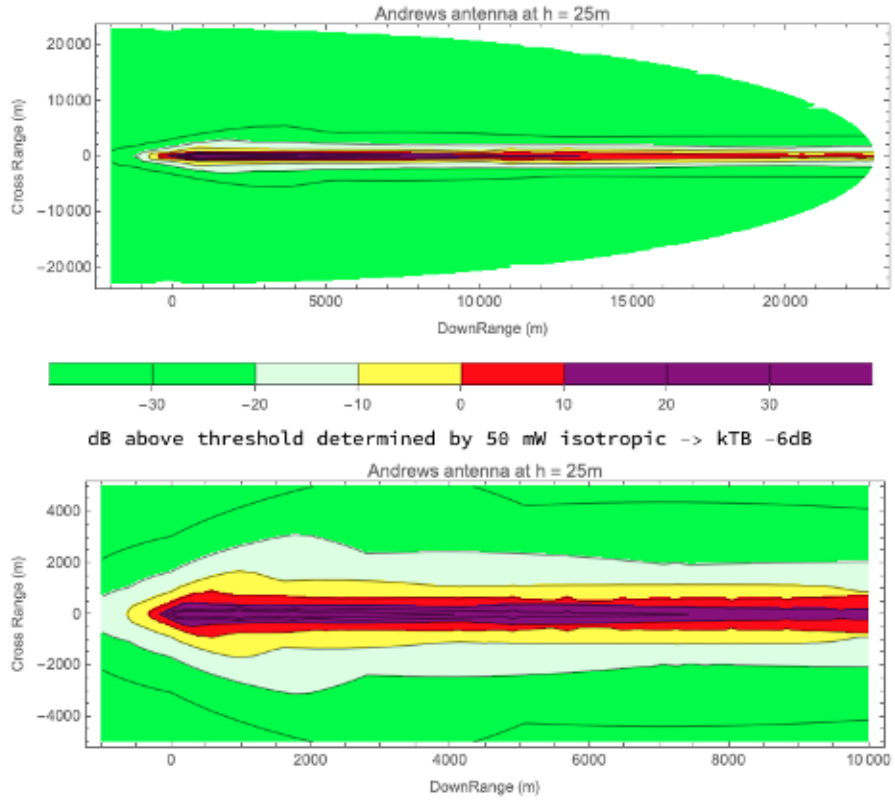


Figure 24 Radiation Pattern with Antenna at 25m

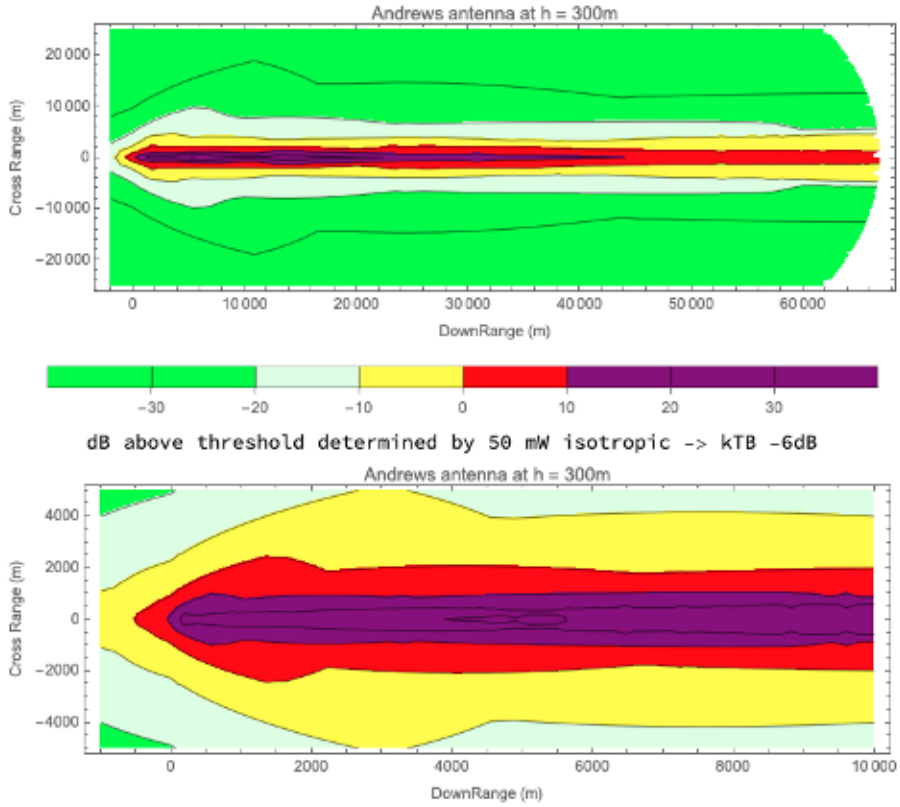


Figure 25 Radiation Pattern with Antenna at 300m

This section has presented imagery and example of relative susceptibility with various observations. Absolute levels of interference summation and its effect on the microwave system performance is discussed in various other sections.

7.6 Wi-Fi Access Point Interference Characteristics

Wi-Fi access points can be deployed indoors with multi-band routers, mesh networks, and network extenders, and these deployments can increase interference for microwave victim receivers. Most Wi-Fi access points for consumer use today are multi-band, typically the ISM, U-NII-1, and U-NII-3 bands. The selection of the channel can be default by the manufacturer or provided by conveniently providing separate IDs for a channel in each band. This multi-band concept is then applied to network extenders and mesh networks.

7.6.1 *Multiband Routers*

Some multiband routers will be able to use more than one band at the same time. One band may be used for mesh router-to-router hops while a second band will be used for the end device links. Besides supporting more devices and avoiding interference with other Wi-Fi devices on the same network, multiple bands allows for mesh-to-mesh backhaul without taking away channel capacity from end devices. Figure 26 diagrams a hypothetical residential multi-band mesh network.

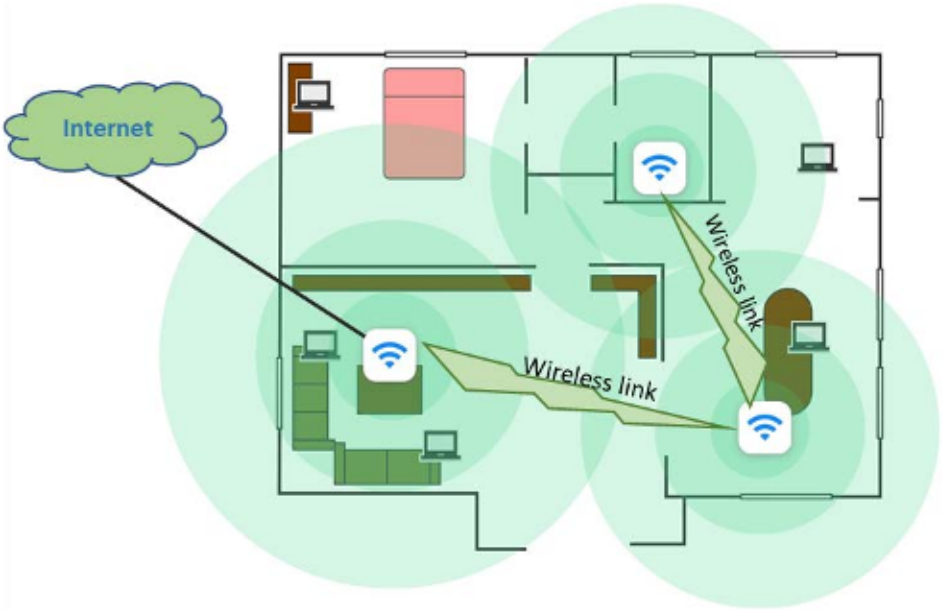


Figure 26 Mesh Wi-Fi Residential Network

Even though multi-band routers can minimize interference within the mesh RF Local Area Network (RLAN), they can have the opposite effect for victim receivers outside of the network. For example, if the end-point devices in Figure 26 used Wi-Fi channels in U-NII-1, the mesh network could relay the messages to (or from) the end-point devices through the mesh network on U-NII-5 channels. This avoids interference on U-NII-1, but it creates interference on U-NII-5. This interference mechanism is included here as a reminder that even if end-point devices do not use U-NII-5, the ubiquitous residential networks envisioned in the 6 GHz NPRM could still use the band and generate interference.

7.6.2 *Residential Mesh Networks and Extenders*

Mesh routers are a popular solution for providing coverage throughout a home. This will lead to situations where the same data is transmitted multiple times over successive hops between routers and finally to the end-point device. This will increase the apparent duty cycle generated by any single end-point device, such as a laptop or a tablet, since traffic for the end-point will be relayed through additional hops to reach the internet. An example residential mesh network is depicted in Figure 26.

A simpler device that is also provided by the industry is an extender for a Wi-Fi network. An extender also relays packets similar to a mesh router, and so it will also increase the apparent duty cycle on the network.

7.6.3 *Temporal Characteristics*

The 802.11ax standard increases the maximum data rates by adding 1024 QAM / OFDM and MU-MIMO to the standard.[42] This permits up to 1.2 Gbps in one spatial stream, and for 8 spatial streams this can multiply up to 9.8 Gbps. This rate is only achieved when the signal to noise ratio is sufficient and 8 antennas are used at both the transmitter and receiver. Very high data rates may lead to short transmitter duty cycles. Lower data rates correspond to longer transmissions and therefore higher duty cycles for the same information content.

[42] QAM abbreviates Quadrature Amplitude Modulation, OFDM abbreviates Orthogonal Frequency Division Multiplexing, and MU-MIMO abbreviates Multi-User Multiple Input Multiple Output technology. These permit Wi-Fi 6 devices to process simultaneous signals from multiple devices with multiple antennas.

Video streaming over the internet uses buffering at the viewer to prevent network congestion and other sources of error from causing incomplete or dropped video frames. RLAN packet traffic during sample video streaming sessions have been observed, and it was found that there were intervals of about a quarter of a second or more between bursts of large numbers of 1500-byte video data packets. The data rates peaked during these bursts.

Assuming that all potential interference transmissions used 160 MHz channels also implies that the shortest duty cycles will be observed. Transmitting the same data over 80 or 40 MHz channels will double or quadruple the duty cycle, and increase the average interference power proportionately.

7.7 Top 20 Metropolitan Statistical Areas

The top 20 MSAs ordered by population are listed in the following table. The indoor Power Spectral Area Density (PSAD) is also tabulated for ratios of 1 RLAN/pop and 250 mW of power per RLAN.

Table 11 PSAD for Top 20 Metropolitan Statistical Areas

	Name	Pop. Est.	Area km²	Pop/km²	PSAD mW/MHz-km²	PSAD dBm/MHz-km²
1	New York	19979477	11880	1681.8	295.0	24.70
2	Los Angeles	13291486	12562	1058.1	185.6	22.69
3	Chicago	9498716	10856	875.0	153.5	21.86
4	Dallas Fort Worth	7539711	24059	313.4	55.0	17.40
5	Houston	6770000	26060	259.8	45.6	16.59
6	Washington DC	6249950	14412	433.7	76.1	18.81
7	Miami	6198782	15890	390.1	68.4	18.35
8	Philadelphia	6096372	13256	459.9	80.7	19.07
9	Atlanta	5949951	21694	274.3	48.1	16.82
10	Boston	4875390	6500	750.1	131.6	21.19
11	Phoenix	4857962	37810	128.5	22.5	13.53
12	San Francisco	4729484	6410	737.8	129.4	21.12
13	Riverside San Bern.	4622361	70669	65.4	11.5	10.60
14	Detroit	4326442	10071	429.6	75.4	18.77
15	Seattle	3939363	15209	259.0	45.4	16.57
16	Minneapolis	3629190	21000	172.8	30.3	14.82
17	San Diego	3343364	11720	285.3	50.0	16.99
18	Tampa St Pete.	3142663	8630	364.2	63.9	18.05
19	Denver	2932415	21764	134.7	23.6	13.74
20	St Louis	2805465	21910	128.0	22.5	13.51
	Average	124778544	382362	326.3	57.3	17.58

The table shows that the PSAD for Houston is 0.99 dB lower than the average PSAD for the top 20 MSAs. In this respect the calculated I/N ratios in this report are below the expected average I/N across the top 20 MSAs, although still within 1 dB of average. The highest PSAD is for New York, and it is 8.11 dB higher than Houston, so the expected I/N ratios there could be 8 dB higher than those calculated in this report. The PSADs for the top 20 MSAs are diagrammed in Figure 27.

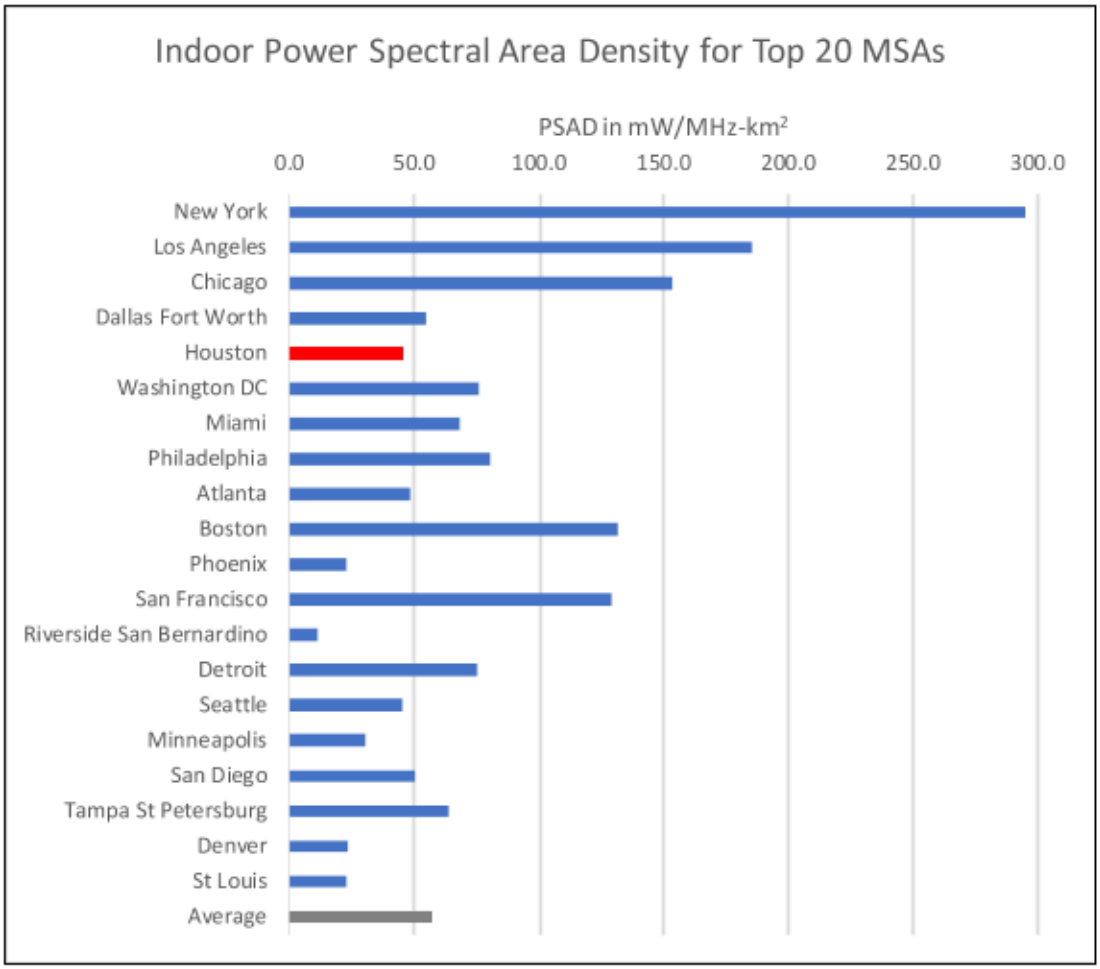


Figure 27 Indoor PSADs for Top 20 MSAs

7.8 Very Lower Power Devices

A recent ex parte filing has proposed the authorization of very low power (VLP) devices in UNII-5 and UNII-7 and included an analysis of the impact of VLP devices on a hypothetical point-to-point communications link.[43] The analysis claims to show that a single VLP device will not create interference greater than the -6 dB I/N level required to preserve the reliability of point-to-point links utilized for critical infrastructure. The analysis in this recent filing is deficient for reasons including but not limited to those that follow, and cannot be used to provide evidence to support the authorization of VLP outdoor devices in the 6 GHz band.

7.8.1 Summary of Deficiencies of Recent VLP Analysis

1. The analysis only considers the impact of a single VLP device, located at a single distance from a point-to-point receiver.

   This is a flawed assumption since the interference analysis in this report demonstrates the necessity of including the aggregate interference of multiple unlicensed devices with a view to the point-to-

[43] Ex parte filing, Harris, Wiltshire, and Grannis, December 9, 2019, Re: *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295; *Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz*, GN Docket No. 17-183. (*Harris, Wiltshire and Grannis ex parte*).

point receiving antenna at varying distances in order to assess interference. For an actual point-to-point antenna gain pattern,[44] increasing the distance from the interferer to the antenna results in a higher distance-based propagation loss which for certain distances is overcome by a higher receive antenna gain due to lower incidence angle, resulting in higher interference. Any analysis should consider a range of distances that include the distance at which the lowest combined path loss and receive antenna gain occurs.

2. The analysis only considers a single (low) effective transmit power level, based on the use of transmit power control and body loss.

   This assumption is flawed because a population of VLP enabled devices with a view to a point-to-point receiver and employing Transmit Power Control will exhibit a range of effective transmit power levels varying from low to high. Nominal and worst-case interference levels, not just best case from an interference standpoint, need to be considered.

3. The analysis only considers the parameters of a single, hypothetical point-to-point receiver, and asserts that the 18 meter antenna height analyzed is a very low height for a fixed station antenna.

   This approach is flawed because the analysis in this report demonstrates the necessity of analyzing the effect of aggregate interference on all the point-to-point receivers in a metropolitan area using their actual antenna characteristics and locations. The FCC ULS database reveals about 20% of all point-to-point antenna heights in the US are 18 meters or less. In the Houston area, 10% of the point-to-point antenna heights are less than 27 meters, 20% are less than 33 meters.

7.8.2 *Effect of VLP Analysis Deficiencies on Interference*

The effect of the VLP analysis deficiencies on the calculation of the interference power is illustrated in the table below.

Table 12 VLP Analysis and Revision

	Parameter	Previous Filing		Revised	Comment
A	RLAN Bandwidth	160	MHz	160	But I/N would increase 6 dB for 80 MHz BW (not shown in Total I/N)
B	Maximum RLAN EIRP	14	dBm	20	Revised for aggregate power of 4 devices
C	Body Loss /Transmit Power Control	-18	dB	-15, -12	Revised for +3, +6 dB above minimum power
D	Effective RLAN EIRP	-4	dBm	+5, +8	Revised EIRP is 9 dB or 12 dB greater
E	Feeder/System Loss	-2	dB	-2	No justification provided for this value
F	Polarization Mismatch	-3	dB	-2	No justification provided for this value
G	Antenna Mismatch	-3	dB	-3	No justification provided for this value
H	FS-RLAN Distance (horiz)	100	m.	100	Should use multiple actual distances
I	FS Gain (@9.37 degrees)	4.86	dB	4.86	Should use actual gains vs angle
J	Prop Loss (FSPL)	88	dB	88	Should calculate for multiple interferers
K	Total I/N	-8.2	dB	+0.8, +3.8	Revised interference exceeds -6 dB I/N by 6.8 or 9.8 dB

The parameters in the "Previous Filing" are from the ex parte filing cited previously[45], and those in the "Revised" column show the impact of revisions to the interference parameters based on the deficiencies described above.

- In Row A if 80 MHz bandwidth is allowed and used, then the power spectral density increases by 3 dB and the noise bandwidth decreases by 3 dB, increasing the I/N by 6 dB. The effect of this usage is not included in the Total I/N in the "Revised" column.

- Row B shows that if the aggregate impact of four VLP devices with a view to the point-to-point receiving antenna are considered rather than just one, the interference power is increased by 6 dB.

- Row C shows the effect of small changes of +3 dB and +6 dB in the if the Body Loss/Transmit Power Control parameter compared to the minimum. For this revision, the Body Loss/Transmit

[44] See Figure 5, Typical Point-to-Point Antenna Gain Function.
[45] Harris, Wiltshire and Grannis ex parte, VLP Coexistence Analysis, slide 3.

Power Control attenuation is reduced to -15 dB and -12 dB respectively, resulting in an equivalent -1 dBm (0.8 mW) or +2 dBm (1.6 mW) EIRP per VLP device. Compared to the proposed maximum transmit EIRP of 25 mW per device, these are still extremely low transmit power levels.

- Row D shows that the combined effect of the small revisions to the VLP parameters in rows B and C results in an increase in the Effective RLAN EIRP of 9 to 12 dB, an order of magnitude.
- Row K shows that for the small modifications to the VLP parameters, the resultant I/N levels are fully 6.8 or 9.8 dB above the -6 dB level required for point-to-point operations.

8 COMPANY PROFILE: ROBERSON AND ASSOCIATES, LLC

Roberson and Associates, LLC, is a technology and management consulting company serving government, commercial, and academic customers and provides services in the areas of radio frequency (RF) spectrum management, RF measurement and analysis, strategy development, and technology management. The organization was founded in 2008 and is composed of a select group of individuals with corporate and academic backgrounds from Motorola, ARRIS, Bell Labs (AT&T, Bellcore, Telcordia, Lucent, and Alcatel-Lucent), BroadView Communications, Cisco, Department of Defense (DARPA), DePaul University, Google, IBM, Illinois Institute of Technology (IIT), Illinois Institute of Technology Research Institute (IITRI), Illinois Tool Works (ITW), Massachusetts Institute of Technology (MIT), NCR, Nokia, S&C Electric, Vanu, Inc., and independent consulting firms. Together, the organization has over 1,000 years of high technology management and technical leadership experience with a strong telecommunications focus.