NEXTNAV

February 27, 2025

VIA ECFS

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
45 L Street NE
Washington, DC 20554

Re: NextNav Petition for Rulemaking, Enabling Next-Generation Terrestrial Positioning, Navigation, and Timing and 5G: A Plan for the Lower 900 MHz Band (902-928 MHz), Public Notice (WT Docket No. 24-240)

Dear Ms. Dortch,

NextNav Inc. respectfully submits the attached engineering study, *5G NR and Unlicensed Part 15 Technologies in the Lower 900 MHz Band*, in response to stakeholder requests for additional technical analysis of NextNav's proposal for a next-generation, terrestrial positioning, navigation, and timing (PNT) system as a complement and backup to the Global Positioning System (GPS).

NextNav undertook this study in response to claims in the record that allowing 5G deployment in the 902-928 MHz band could cause unacceptable levels of interference to unlicensed Part 15 devices. Dr. John Kim and his co-authors examine whether replacing authorized M-LMS operations with 5G is likely to cause unacceptable interference to unlicensed operations that already thrive in noisy environments. Using a real-life scenario in the San Francisco downtown area and analyzing a broad range of unlicensed technologies, the study finds that 5G operations would have lower emissions levels than M-LMS, and any additional emissions are marginal compared to the emissions already present. Based on the analysis in the study, the conclusion is that 5G can coexist with unlicensed Part 15 devices in the 902-928 MHz band.

The study explores some of the features intrinsic to 5G that promote coexistence with unlicensed operations and analyzes scenarios involving 5G, M-LMS, and Part 15 devices. The 902-928 MHz band is a complex environment, with high levels of pre-existing emissions from unlicensed Part 15 devices, and licensed M-LMS and non-M-LMS operations, amateur radio, and ISM applications. The introduction of 5G operations will not materially alter this emissions landscape. Any additional emissions 5G deployments might generate will be marginal in comparison to the emissions already present and, based on the operational parameters of the San Francisco M-LMS deployment, would have no greater effect on unlicensed users than authorized, licensed M-LMS operations. Finally, the features and operations of unlicensed technologies, such as the five examined in this report, namely LoRaWAN, RAIN RFID, Wi-Fi HaLow, Wi-SUN, and Z-Wave, include capabilities that enable coexistence with licensed and unlicensed operations.

NextNav remains committed to a fact-based discussion about how to update the decades-old M-LMS service rules to enable a terrestrial backup and complement to GPS. The study filed today focuses only on unlicensed users of the band. NextNav also takes this opportunity to briefly update the record on the status of technical analyses with respect to commercial licensees and Federal operations in the band. NextNav has retained a global leader in rail research and testing to conduct joint testing with the Lower 900 MHz railroad licensees. NextNav also is in discussions with toll operators regarding joint testing to evaluate coexistence scenarios. Finally, NextNav has retained multiple vendors to conduct engineering studies to identify coordination tasks and to ensure that all primary Federal systems in the band remain protected from harmful interference.

This proceeding offers an opportunity to address a pressing national security and public safety issue: the need for a terrestrial back up and complement to GPS. NextNav remains committed to working with all stakeholders on the issues around the proposal to reconfigure the Lower 900 MHz band. As you review the attached submission, please feel free to contact me with any questions.

Sincerely,

/s/ Renee Gregory

Renee Gregory
NextNav Inc.
11911 Freedom Drive, Suite 200
Reston, VA 20190
rgregory@nextnav.com

NextNav Inc.

5G NR and Unlicensed Part 15 Technologies in the Lower 900 MHz Band

A Coexistence Analysis

Dr. John Kim, JongHak Jung, MS, Dr. Arun Raghupathy,
Dr. Tolis Papathanassiou, and David Gell, MS

February 27, 2025

Executive Summary

This report presents NextNav's comprehensive technical analysis demonstrating that the proposed 5G operations in the lower 900 MHz band will coexist with unlicensed Part 15 technologies. Detailed analysis, real-world deployment comparisons, and in-depth technical assessments support one consistent finding: the introduction of 5G operations with the technical parameters that NextNav has proposed will not cause unacceptable levels of interference to unlicensed Part 15 devices.

NextNav undertook this analysis in response to claims in the record that allowing 5G deployment in the 902-928 MHz band could cause unacceptable levels of interference to unlicensed Part 15 devices. The report examines whether replacing authorized Multilateration Location and Monitoring Services (M-LMS) operations with 5G is likely to cause unacceptable interference to unlicensed operations that already thrive in noisy environments. Using real-life scenarios and analyzing a broad range of unlicensed technologies, the study finds that 5G operations would have lower power density levels than M-LMS, that any additional emissions 5G deployments might generate will be marginal compared to the emissions already present, and that 5G can therefore coexist with unlicensed Part 15 devices in the 902-928 MHz band.

The lower 900 MHz band is a complex environment, with high levels of pre-existing emissions from unlicensed Part 15 devices, licensed M-LMS and non-M-LMS operations, amateur radio, and industrial, scientific, and medical (ISM) applications. The introduction of 5G operations will not materially alter this emissions landscape.

A detailed examination of emissions shows that the proposed 5G downlink operations will not exceed those of the currently authorized M-LMS deployments. Indeed, a real-world analysis of NextNav's San Francisco M-LMS network, which operated for more than a decade in compliance with FCC regulations without complaints of Part 15 interference, reinforces confidence that 5G will not cause unacceptable levels of interference to Part 15 devices. Furthermore, the characteristics of 5G transmissions—sporadic, brief, and dynamically power-controlled—ensure minimal interference potential. User equipment (UE) activity in a 5G network is also extremely limited, and base stations generally operate far below permissible power levels. In addition, low base station loading factors and power levels that adjust in response to real-time demand are designed to facilitate coexistence with other users.

A 5G deployment would produce emissions not only functionally similar to those already present, but also considerably *lower* than those generated by the deployment of the M-LMS system the FCC has already authorized NextNav to construct, according to the operational parameters of a fully deployed San Francisco M-LMS PNT network. In the context of the active radiofrequency environment in which Part 15 devices have been designed to operate, the incremental effect of a 5G deployment will be minimal and, in any case, well within the capacity of unlicensed devices to manage. Additional analysis of indoor signal strength confirms that Part 15 signals are significantly stronger than 5G in nearly all locations, which helps establish that the 5G operations NextNav has proposed will not cause unacceptable levels of interference to unlicensed Part 15 devices now and into the future.

To validate the lack of impact of a 5G deployment on Part 15 devices, NextNav performed extensive radiofrequency analysis on five unlicensed technologies supporting key existing and up-and-coming use cases that operate in the lower 900 MHz band, namely LoRaWAN; RAIN RFID; Wi-Fi HaLow; Wi-SUN; and Z-Wave. The results show how each of these technologies can successfully coexist with 5G. LoRaWAN's frequency agility and dynamic spreading factors enable it to mitigate interference risks. RAIN RFID's frequency hopping and robust signal processing make it highly resilient. Wi-Fi HaLow adapts through channel selection, carrier sensing, and relay-based architectures. Wi-SUN's mesh networking and frequency hopping provide stability. And Z-Wave employs retransmission protocols, clear channel assessment, and robust link budgets to sustain functionality even in noisy spectrum. These unlicensed technologies are designed for an active radiofrequency environment and can readily operate in the challenging conditions other Part 15 devices create. 5G will, in practice, present no greater emissions conditions than Part 15 devices and, in most cases, will prove considerably less challenging for Part 15 devices to overcome than existing Part 15 operations.

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Introduction

This report provides a detailed analysis reaffirming that unlicensed technologies which already coexist with licensed services in the lower 900 MHz band can continue to coexist if the FCC adopts the NextNav 5G positioning, navigation, and timing (PNT) proposal.[1] The report demonstrates that the band is already characterized by significant interference levels and permitting 5G operations in a portion of the band would not materially alter this noise environment. Additionally, replacing present-generation M-LMS operations with next-generation 5G operations would not result in an emissions increase beyond what is already permissible under current M-LMS rules and, unlike present-day M-LMS technologies, 5G has numerous intrinsic and dynamic features that mitigate its interference potential.

NextNav has previously discussed the bursty and intermittent nature of 5G transmissions that are driven primarily by user demand.[2] Unlike continuous transmissions, 5G signal levels fluctuate at both the base station and user equipment based on real-time network activity. Moreover, the system operation changes that NextNav has proposed will either maintain or reduce interference levels compared to those allowed under the existing Part 90 framework.[3] For both base stations and end-user equipment, moreover, NextNav has explained that various mechanisms typically reduce transmission levels far below regulatory limits.[4] Consequently, the probability of unacceptable levels of interference remains extremely low.

NextNav has also discussed the resilience of Part 15 technologies operating in the lower 900 MHz band.[5] These technologies are designed to withstand interference from other unlicensed devices as well as from licensed LMS, amateur radio, and ISM operations. Their robust coexistence mechanisms include flexible channel allocation, frequency agility, adaptive modulation and coding, retransmission, and clear channel assessment. These features not only enable compatibility among different Part 15 devices and technologies but also support coexistence with non-Part 15 operations. Indeed, managing coexistence has always been an integral consideration for the Part 15 community.[6]

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[1] Petition for Rulemaking of NextNav Inc., WT Docket No. 24-240 (Apr. 16, 2024) ("Petition").

[2] *See, e.g.*, Reply Comments of NextNav Inc. at 25, WT Docket No. 24-240 (Sept. 20, 2024) ("NextNav Reply Comments").

[3] 47 C.F.R. § 90.

[4] *See, e.g.*, Comments of NextNav Inc. at 12–14, WT Docket No. 24-240 (Sept. 5, 2024) ("NextNav Comments").

[5] *See, e.g.*, NextNav Reply Comments at 26–29.

[6] IEEE, IEEE Std 802.19.3™-2021, *IEEE Recommended Practice for Local and Metropolitan Area Networks—Part 19: Coexistence Methods for IEEE 802.11 and IEEE 802.15.4 Based Systems Operating in the Sub-1 GHz Frequency Bands* (Apr. 26, 2021), https://ieeexplore.ieee.org/document/9416944.

NextNav conducted a radiofrequency analysis, which confirms that unlicensed signals in the band will remain significantly stronger than 5G transmissions in most cases. As a result, it is highly unlikely that 5G operations will cause unacceptable levels of interference to unlicensed Part 15 devices. Further, this report applies the general analysis to specific unlicensed technologies in the band and demonstrates that each technology possesses the necessary capabilities to function effectively in a shared environment, including one with 5G deployments.

This report is structured as follows:

- **Section 1** describes the operational characteristics of 5G user equipment and base stations, including activity factors and loading factors for those network elements. It also explains how NextNav's proposed effective radiated power limits will result in significantly lower uplink power levels than the power levels currently permitted in the band. Additionally, this section provides an analysis of an actual M-LMS deployment in San Francisco, California that for many years emitted more power density in the lower 900 MHz band than 5G would, without a single confirmed complaint of unacceptable levels of interference to Part 15 devices. The interference-mitigation techniques intrinsic to 5G systems required to ensure their optimal operations combined with a lengthy track record of coexistence demonstrate that the proposed 5G downlink emissions can operate without causing unacceptable levels of interference to unlicensed users.

- **Section 2** presents a simulation analysis evaluating the band's emissions levels due to Part 15 operations and the additional contributions from either M-LMS or 5G. The findings confirm that introducing 5G would have no appreciable impact on overall emissions levels and, in fact, would produce less incremental noise than deployment of the currently authorized M-LMS system would. This section also details an RF prediction tool analysis, which shows that, for most buildings studied, indoor Part 15 signal strength significantly exceeds 5G signals.

- **Section 3** examines five distinct unlicensed technology families—LoRaWAN, RAIN RFID, Wi-Fi HaLow, Wi-SUN, and Z-Wave—and confirms that each is well-equipped to continue operating in the presence of a 5G network. Each technology employs a unique combination of techniques to manage interference and coexist effectively with other unlicensed and licensed operations, especially in light of the very low probability of unacceptable levels of interference to Part 15 devices.

Through this analysis, the report establishes that the NextNav petition for reform of the lower 900 MHz band is consistent with continued robust unlicensed operations in the lower 900 MHz band with minimal impact on existing uses while enabling a widescale 5G-based PNT deployment. The noise floor in the lower 900 MHz band is dominated by intra- and inter-Part 15 contention, and 5G's contribution is negligible in comparison. NextNav's findings strongly support the FCC's adoption of its Petition, which will enable a wide-scale, terrestrial back-up and complement system to GPS while maintaining the reliability of unlicensed technologies.

1. 5G Operations and Underlying Technical Assumptions

NextNav's planned 5G operations will not cause unacceptable levels of interference and, in fact, will result in material reductions to the permissible power compared to the current rules in most of the band.[7] Realistic user assumptions also indicate that the uplink power will fall well below unlicensed device operating power. And while the maximum theoretical operating power of 5G base stations will exceed the maximum permissible M-LMS emissions level per emission, the combination of practical limitations on network design and years of real-world field experience with 5G base station deployments will result in base stations causing no appreciable change to the unlicensed emissions environment.

Real-world deployment and operating practices result in user equipment (UE) emissions and base transceiver station (base station or BTS) emissions levels that are generally much lower than the maximum permissible emissions standards allowed under FCC rules.[8] While regulatory limits define the absolute maximum power levels for emissions, real-world use scenarios rarely approach such limits because of how networks and devices function in practice.

UE emissions, for instance, are influenced by activity factors. Devices only transmit when there is an active data demand, meaning emissions fluctuate with usage patterns. Even while in use, devices are power controlled by the network to ensure they only transmit the minimum power necessary to maintain a stable connection. This approach not only reduces interference but also conserves battery life, further ensuring emissions are significantly lower than the regulatory ceiling.

Similarly, BTS emissions are affected by loading factors, which depend on the number of active users and the demand for downlink data at any given time. Modern networks rely on the loading factor to adjust power levels to meet real-time demand, operating at a lower power when traffic is light or when coverage is dense.[9] Advanced technologies like

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[7] The current rule for the band requires M-LMS licensees to "demonstrate through actual field tests that their systems do not cause unacceptable levels of interference to 47 CFR part 15 devices." 47 C.F.R. § 90.353(d). The rules for unlicensed devices in the lower 900 MHz band should be the same as rules for unlicensed operations in other bands. *See* Petition at 29-30. For purposes of the present analysis, however, NextNav has used the current standard and demonstrated that there will be no unacceptable levels of interference to Part 15 devices.

[8] *See* NextNav Comments at 13-14.

[9] *See* NextNav Reply Comments at 6, 25.

beamforming and multiple-input, multiple-output (MIMO) enhance this efficiency by directing energy precisely where it is needed, rather than transmitting power indiscriminately. The use of MIMO, for example, increases resource usage efficiency by enabling resource sharing by multiple users. In other words, MIMO leads to reduction of the network loading factor. This targeted approach reduces overall emissions while improving performance for individual users.

The design philosophy of 5G further emphasizes energy and spectrum efficiency and the avoidance of self-interference, which encourages networks and devices to operate at power levels far below maximum regulatory limits. These practices are designed to accommodate extreme conditions, such as serving users at the farthest edge of a coverage area or during periods of unusually high-traffic congestion. In most scenarios, these types of conditions are rare, and actual emissions remain well below these thresholds.

In summary, 5G emissions generally remain well below the FCC's maximum permissible levels due to the practical realities of network operation, advanced technologies that enhance efficiency, and regulatory policies designed to ensure coexistence and minimize interference. This standard operating practice ensures that 5G networks not only meet performance requirements but also operate sustainably and responsibly within the broader spectrum ecosystem.

1.1. UE Activity Factor

UE transmits intermittently, which significantly reduces the potential for interference. To quantify this effect, this report estimates the UE activity factor by integrating publicly available projections of UE data transmission volumes through 2030 with transmission duration estimates based on current network speeds.

The UE activity factor differs from the base station uplink loading factor, though the two are related. Base station uplink loading factors typically range from 10% to 20%. Historical data on subscriber and site counts indicates that a typical base station serves approximately 1,000 subscribers, with each site typically divided into three sectors.[10] This distribution results in roughly 333 subscribers per sector. Each individual subscriber's contribution to the 10% to 20% BTS uplink loading factor is 0.03% to 0.06%.[11] This relationship between the BTS uplink loading factor and the UE activity factor demonstrates that the UE activity factor is inherently low due to the large number of subscribers per

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[10] For example, compare the subscriber and site counts in the CTIA Annualized Wireless Industry Survey Results, where the ratios, when calculated, range from 975 to 1,285 and average about 1,100 subscribers per site. CTIA, *Summary of CTIA's Annual Wireless Industry Survey* at 6 (Jul. 27, 2021), https://api.ctia.org/wp-content/uploads/2021/07/2021_SurveyResults-v8.pdf.

[11] To calculate the contribution, the 10% and 20% BTS uplink is divided among the subscribers in the sector: 10% / 333 = 0.03% and 20% / 333 = 0.06%.

sector and the well-known downlink/uplink traffic asymmetry. Stated simply, even under peak conditions, only a small subset of users actively transmit data at any given moment.

Examination of publicly available data allows us to refine this estimate of UE activity further and shows that the average UE activity factor on a 5G system in the 902-928 MHz band will be approximately 0.045%, or roughly in the middle of the baseline estimate above. The following paragraphs detail the calculation of this value, with accompanying tables illustrating the underlying assumptions and computations.

1.1.1. UE Busy Hour Traffic

Ericsson predicts that the monthly average data traffic per active smartphone will reach 52.2 GB per month in 2030.[12] With an average of 30 days per month, this is 1.74 GB per day. Traffic is not evenly distributed over the day, but rather concentrated in the busier hours. Instead of dividing this number by 24 hours per day, it is divided by eight to obtain the typical traffic per user in the busy hour — 0.218 GB. Ericsson further reports that 8% of mobile traffic is uplink traffic, by which Ericsson means periods when the UE is transmitting to the network base station.[13] Therefore, the average UE will transmit 8% of 0.218 GB over the busy hour in 2030. This equals 0.0174 GB, or 17.4 MB.

1.1.2. UE Frequency Diversity

Under NextNav's proposal, the 902-928 MHz spectrum used for 5G will be integrated with a partner's network that uses various bands of sub-6 GHz spectrum.[14] The FCC Communications Marketplace Report shows that Mobile Network Operators (MNOs) AT&T, EchoStar, T-Mobile, and Verizon respectively hold 264.3, 124.1, 375.6, and 278.9 MHz of spectrum useful and available for mobile broadband.[15] Considering that the Frequency Division Duplexing (FDD) bands are evenly split between the uplink and downlink with a few exceptions noted below, and assuming that the Time Division Duplexing (TDD) bands (EBS/BRS, 3.45 GHz, and 3.7 GHz) are configured as 80% downlink and 20% uplink, these four MNOs have respectively 92.6, 32.0, 123.5, and 91.2 MHz of uplink spectrum, or an average of 84.8 MHz uplink for a typical MNO. **Table 1** shows the input assumptions and

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[12] *See* Ericsson, *Mobile Data Traffic Outlook* (Nov. 2024), https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/mobile-traffic-forecast (last visited Feb. 24, 2025).

[13] *See* Ericsson, *Analysis of Traffic Profiles*, https://www.ericsson.com/en/reports-and-papers/mobility-report/dataforecasts/analysis-traffic-profiles#:~:text=Traffic%20measurements%20in%20a%20sample,and%2046%20percent%20in%20downlink (last visited Feb. 24, 2025).

[14] *See* Petition at 21–22.

[15] *See In re Communications Marketplace Report*, 2024 Communications Marketplace Report, GN Docket No. 24-119, FCC 24-136 at 61, figure II.B.14 (rel. Dec. 31, 2024), https://docs.fcc.gov/public/attachments/FCC-24-136A1.pdf.

calculations used to arrive at the UE activity factor in the lower 900 MHz band, while **Table 2** offers more detail on the spectrum inputs. These calculations show that when the five megahertz of uplink in the 902-907 MHz band is added to an MNO network, it is expected to carry traffic in proportion to the spectrum: 5 MHz / (84.8 MHz + 5 MHz) = 5.57%. This fraction of the 17.4 MB equals 0.969 MB.

1.1.3. Uplink Data Speeds and Channel Sizes

Ookla reports that the median 5G uplink data speed is 18.93 Mbps.[16] Typical 5G New Radio (NR) carrier sizes are 100 megahertz wide in large TDD bands, such as C-Band or BRS/EBS, or 20+20 megahertz wide in FDD bands, such as PCS or AWS or similar bands in other countries. Assuming again that TDD bands are configured 80% downlink and 20% uplink, the typical uplink bandwidth underlying the Ookla data is 20 megahertz.[17] Because the 902-907 MHz band segment that is slated for uplink use is a quarter of that value (5 MHz/20 MHz), the uplink speed will be a quarter of the Ookla rate, or 4.73 Mbps.

1.1.4. Calculating the UE Activity Factor

As explained above, the average UE will transmit 0.969 MB over the busy hour. Since each byte is eight bits, the transmission of 0.969 MB must be multiplied by eight, equaling 7.75 Mb.[18] At the calculated uplink rate of 4.73 Mbps, it will take 1.64 seconds to transmit this data. That is, the UE will transmit a total of 1.64 seconds over the busy hour. The resulting activity factor is 0.045%, which is calculated by dividing 1.64 seconds by 3,600 seconds (total seconds in one hour).

Table 1 summarizes the activity factor calculation:

Quantity	Value	Units
Per subscriber monthly traffic	52.2	GB/month
Per subscriber monthly traffic	5.22×10^{10}	bytes/month
Active days per month	30	days
Active hours per day	8	hours
Per subscriber in busy hour	2.18×10^{8}	bytes/subscriber
Uplink fraction	8.0%	

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[16] *See* Sylwia Kechiche, *Worldwide Connectivity: Mobile & Fixed Networks and the Digital Divide 2023*, Ookla (Dec. 19, 2023), https://www.ookla.com/articles/worldwide-connectivity-mobile-fixed-networks-digital-divide-2023.

[17] This assumes no uplink carrier aggregation, as such is rarely deployed.

[18] Mb means megabit, 1,000,000 bits, while MB means megabyte, where 1,000,000 bytes = 8,000,000 bits.

Quantity	**Value**	**Units**
Uplink traffic per subscriber	1.74×10^{7}	bytes/subscriber
Lower 900 MHz fraction	5.57%	
Uplink traffic lower 900 MHz	9.69×10^{5}	bytes/subscriber
Uplink traffic bits	7.75×10^{6}	bits/subscriber
Uplink rate	18.9	Mbps
Typical uplink bandwidth	20	MHz
900 MHz uplink bandwidth	5	MHz
900 MHz uplink rate	4.73	Mbps
Uplink rate	4.73×10^{6}	bps
Time transmitting	1.64	seconds
Fraction of hour	0.045%	

Table 2 summarizes the calculation of 84.8 MHz uplink spectrum on average. All values are expressed in megahertz.

		AT&T		**EchoStar**		**TMO**		**VZW**	
Band	**UL fraction**	**Total**	**UL**	**Total**	**UL**	**Total**	**UL**	**Total**	**UL**
600	50%	0.0	0.0	17.8	8.9	30.4	15.2	0.0	0.0
700	Note 1	29.6	11.1	4.6	0.0	10.5	5.3	21.7	10.9
Cellular	50%	23.5	11.8	0.0	0.0	0.0	0.0	25.3	12.7
SMR	50%	0.0	0.0	0.0	0.0	13.8	6.9	0.0	0.0
PCS	50%	37.6	18.8	0.0	0.0	66.3	33.2	22.3	11.2
H Block	0%	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0
AWS-1	50%	14.1	7.1	0.0	0.0	37.1	18.6	36.6	18.3
AWS-3	Note 2	20.4	10.2	21.1	16.9	3.3	1.7	12.0	6.0
AWS-4	0%	0.0	0.0	39.9	0.0	0.0	0.0	0.0	0.0
WCS	50%	19.6	9.8	0.0	0.0	0.0	0.0	0.0	0.0
BRS	20%	0.0	0.0	0.0	0.0	65.0	13.0	0.0	0.0
EBS	20%	0.0	0.0	0.0	0.0	110.0	22.0	0.9	0.2
3.45	20%	39.9	8.0	30.8	6.2	11.9	2.4	0.0	0.0
3.7	20%	79.6	15.9	0.0	0.0	27.2	5.4	160.1	32.0
Totals		264.3	92.6	124.1	32.0	375.6	123.5	278.9	91.2
Average Uplink		84.8							

Note 1: The 700 MHz band uplink fraction varies by carrier. The following uplink fractions were used for the major wireless operators: 38% for AT&T and 50% for Verizon and T-Mobile. A 0% value was used for EchoStar's 700 MHz band spectrum holdings, which are downlink only.

Note 2: In the AWS-3 band, an 80% uplink fraction was used for EchoStar because it holds a combination of uplink only and paired AWS-3 spectrum, and a 50% uplink factor was used for the other major operators, Verizon, T-Mobile, and AT&T because they hold only paired AWS-3 spectrum. The 80% value used for EchoStar was calculated from FCC ULS data.

1.1.5. Validating the Calculated UE Activity Factor

The average UE transmits for less than two seconds per hour, which may seem counterintuitive given that users spend significantly more time engaged in activities such as voice calls, web browsing, and app usage. However, the vast majority of mobile traffic consists of downlink transmissions, while uplink transmissions occur in short bursts, often lasting only a few milliseconds per instance.

As discussed at the start of this section, one can compare the UE activity factor during the busy hour used here to a corresponding base station loading factor during the busy hour. As noted earlier, MNOs generally maintain approximately 1,000 subscribers per site. Since most sites consist of three sectors, a typical sector will have roughly 333 subscribers in its service area, meaning the total transmission time of those subscribers is 333×1.64 seconds, equaling 546 seconds in total. This time equals approximately 15% of an hour, consistent with typical base station uplink utilization.[19]

1.2. Base Station Loading Factor

The loading factor of the 5G base station downlink is estimated at 20%, meaning that when looking at both the frequency and time domains, the base station loading factor will, on average, fill approximately 20% of the available resource elements.

The 20% loading factor is consistent with other expert reports and is commonly used for coexistence analyses. Notably, the NTIA has found a 20% BTS loading factor to be a reasonable parameter to use when calculating the protection of sensitive Federal operations, including sensitive Department of Defense operations.[20] Similarly, the International Telecommunication Union (ITU) found that "20% would normally represent a typical/average value for the loading of base stations across a network."[21] The Commerce Spectrum Management Advisory Committee (CSMAC) has also used similar values in its AWS-3 analysis, where it used 16% and 26% network loading factors.[22]

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[19] A GSMA Report by Coleago Consulting, Ltd used an activity factor ranging from 10% to 25%. Coleago Consulting Ltd, *Estimating the Mid-band Spectrum Needs in the 2025-2030 Time Frame*, at 7 (July 2021), https://www.gsma.com/spectrum/wp-content/uploads/2021/07/Estimating-Mid-Band-Spectrum-Needs.pdf.

[20] *See* Letter from Charles Cooper, Associate Administrator, Office of Spectrum Management, NTIA, to Ronald T. Repasi, Chief, Office of Engineering and Technology, FCC and Joel Taubenblatt, Chief, Wireless Telecommunications Bureau, FCC, GN Docket Nos. 15-319 & 17-258, at 2-3 (June 11, 2024), https://www.fcc.gov/ecfs/document/1061155768162/1.

[21] International Telecommunication Union, *Sharing and compatibility studies of HAPS systems in the fixed service in the 24.25-27.5 GHz frequency range in Region 2*, ITU-R Rep. F.2472-0, at 8 n.3 (Sept. 2019), https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-F.2472-2019-PDF-E.pdf.

[22] *See* Anthony Rennier et al., *SSTD Findings on AWS-3 Spectrum Sharing Assessments*, at 3, https://its.ntia.gov/media/tx0mmgue/rennier_isart22_sstd-findings-on-aws-3-spectrum-sharing-assessments.pdf ("CSMAC Report").

Relying on a 20% loading factor ensures that coexistence analyses remain consistent with commonly used values and, if anything, provides a somewhat conservative basis for spectrum-sharing assessments because other reasonable estimates for base station loading factors fall below the 20% level.

1.3. Other Factors

The effective radiated power (ERP) limits that NextNav proposed in its Petition are based on power spectral density (PSD) to remain consistent with the power limits that apply in other sub-one gigahertz bands. A power limit based on PSD means that the power is limited in a given bandwidth. A power limit based on PSD constrains the amount of power transmitted per unit of bandwidth, rather than imposing a single aggregate power cap across the entire channel. A PSD limit ensures that emissions are distributed in an evenly controlled manner, which prevents excessive concentration of energy in any particular frequency segment while maintaining spectral efficiency and minimizing interference with adjacent services. Using a PSD-based limit is significant because it imposes a strict constraint on the maximum emissions level permitted within a given bandwidth. By contrast, the existing FCC Part 90 rules set a limit on each emission regardless of the channel bandwidth and therefore do not limit the maximum aggregate emissions level. Accordingly, the current rules authorize M-LMS licensees to deploy a maximum average radiated power that is bounded only by the number of emissions in the band. In fact, many non-M-LMS licensed operations used mostly by toll and rail operators (e.g., 6C, ATA, SeGO) utilize multiple emissions in each of the non-LMS blocks.[23]

In addition, the radiated power limit in the five-megahertz uplink segment proposed by NextNav would emit significantly less power than what is currently allowed, even if the current M-LMS licensee deploys only a single emission.[24] NextNav has *not* proposed a 30 W transmit level in the 902-907 MHz band, but rather an ERP limit of 3 W. While the current ERP limit under section 90.205(l) of the FCC's rules is 30 watts peak power, NextNav is proposing a lower limit of 3 W average power. Also, in reality, 900 MHz handheld mobile 5G UEs will transmit at significantly less power than proposed since standard 3GPP conducted power for mobile devices is 200 milliwatts (23 dBm) and mobile devices typically have negative antenna gain, especially when transmitting at sub-1 GHz frequencies. 5G NR handsets also use power-control algorithms that adjust the handset's transmit power dynamically to maintain the minimum power needed for reliable communication. These intrinsic power-control functions of 5G not only conserve battery life but also reduce the potential for interference. This means, even when the UE is transmitting (only 0.045% of the time per the activity factor calculation above), it is rarely transmitting at full power. In fact, an NTIA CSMAC analysis, which was developed to

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[23] *See* NextNav Reply Comments at 50-51.

[24] NextNav Comments at 12-13.

ensure coexistence between cellular networks and Federal operations in the AWS-3 band, indicated that the UE radiated power is less than 10 dBm (10 mW) EIRP ~95% and ~60% of the time in suburban and rural settings, respectively.[25] Taken together, these features mean that actual power in the 902-907 MHz band will typically fall well below 23 dBm (0.2 W), which represents an enormous reduction relative to the current rules.

Finally, some other users of the lower 900 MHz band have expressed concerns about the proposed mobile operations in the uplink segment.[26] The current M-LMS rules allow transmissions not only from fixed stations, but also from vehicular and mobile devices.[27] The proposed 5G mobile uplink operation is consistent with the current rules and does not introduce any additional coexistence burdens, especially given that the proposed uplink power level is (1) significantly less than what is currently allowed, (2) transmitted only a small fraction of time, and (3) constantly controlled to emit no more power than necessary. On the downlink, NextNav is proposing emissions from fixed stations only and thereby eliminating coexistence concerns that may result from high-power mobile operations.

1.4. San Francisco, CA Case Study

To test the observation that the proposed high-power 5G downlink operation will not cause more emissions than what is currently allowed under Part 90 rules, NextNav examined an actual M-LMS deployment cluster constructed by NextNav in downtown San Francisco. NextNav constructed the cluster and began operating it in 2012.[28] At its peak, the cluster consisted of 34 sites with an average inter-site distance of 325 meters. **Appendix A.1** lists these M-LMS site details, including transmitter site coordinates, heights, and on-air dates. Serving a dense, urban, multipath environment requires a design that allows for good M-LMS beacon measurements from at least four different transmitters to be selected and used by the receiver at any location within the network to provide good trilateration performance. These sites were used as part of Communications Security, Reliability, and Interoperability Council (CSRIC) testing in the indoor location testbed[29] and were required

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[25] CSMAC Report.

[26] NextNav Reply Comments at 26.

[27] *See* 47 C.F.R. §§ 90.155(e), 90.357(a) n.1.

[28] NextNav's subsidiary Progeny was initially granted an experimental license requiring Progeny to demonstrate that "its M-LMS system [would] not cause unacceptable levels of interference to Part 15 devices that operate in the 902-928 MHz band" before it could commence commercial operations. *In re Request by Progeny LMS, LLC for Waiver of Certain Multilateration Location and Monitoring Service Rules*, Order, 26 FCC Rcd 16878, 16889 ¶ 29 (2011), https://docs.fcc.gov/public/attachments/DA-11-2036A1_Rcd.pdf. NextNav was permitted to commence commercial operations in 2013. *In re Request by Progeny LMS, LLC for Waiver of Certain Multilateration Location & Monitoring Service Rules*, Order, 28 FCC Rcd 8555, 8559 ¶ 32 (2013) ("2013 Progeny Waiver Order").

[29] TechnoCom, *Indoor Test Report to CSRIC III-WG3: Bay Area Stage-1 Test Bed* (Jan. 31, 2013), https://transition.fcc.gov/bureaus/pshs/advisory/csric3/WG3_Indoor_Test_Report_Bay_Area_Stage_1_Test_Bed_Jan_31%20_2013.pdf.

to demonstrate good performance in this multipath heavy San Francisco downtown area. Each transmitter operated at 30 watts peak ERP with a 10% duty cycle. Considering the same cluster area, NextNav then produced a comparable 5G design meeting the positioning reference signal (PRS) coverage objective.[30] **Figure 1** compares the resulting radio frequency prediction comparison between the actual M-LMS deployment at its peak and its 5G counterpart (**Appendix A.2** describes the simulations settings). The results demonstrate that 5G PRS can provide coverage with a substantially smaller number of sites.

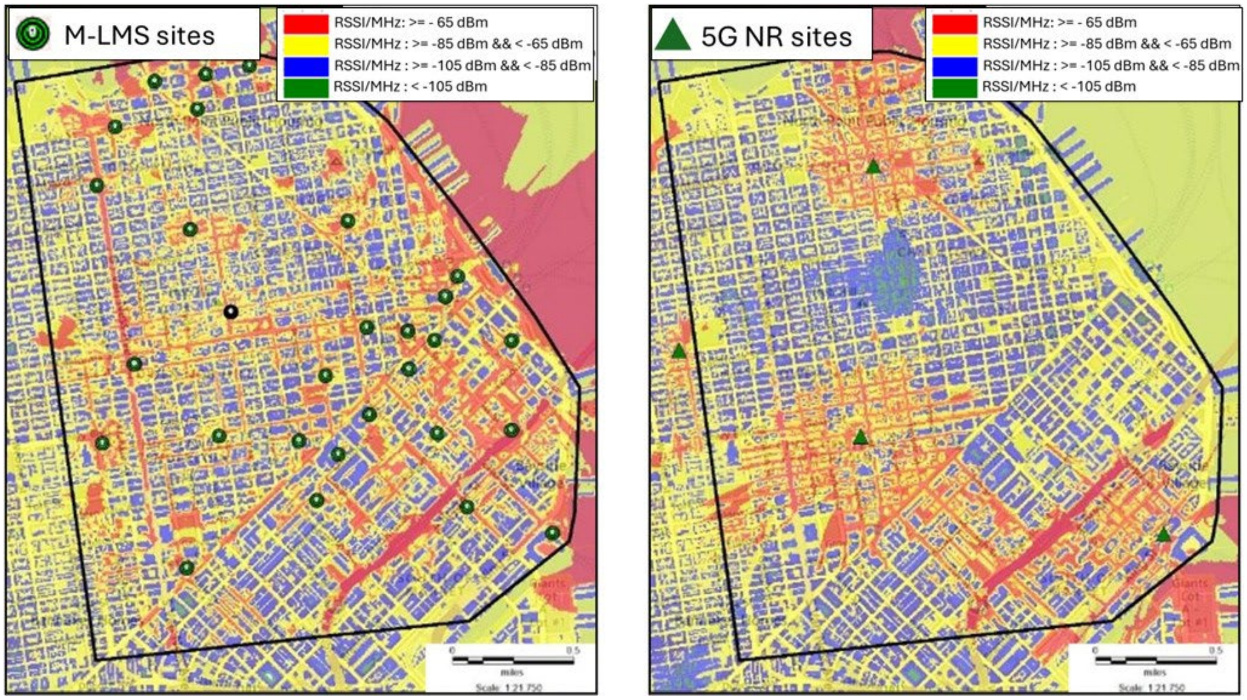

Figure 1: RF signal strength prediction comparison between San Francisco M-LMS deployment (left) and estimated 5G deployment (right). The red areas indicate the strongest signals while the green areas indicate the weakest.

Figure 2 below compares the resulting signal strength distributions within the highlighted area contour (in black line) between the two scenarios, and the plots indicate that the proposed 5G downlink operations will not result in more emissions into the band than the currently allowed M-LMS operations. In fact, for this particular example, the analysis shows that 5G will result in similar outdoor emissions to that of the M-LMS deployment, while 5G indoor emissions will be substantially lower than M-LMS indoor emissions. For example, the analysis predicts that there is roughly 28% probability that the M-LMS indoor signal will be stronger than -80 dBm, while the probability for that same signal strength is only 11% for 5G. Additionally, the average indoor emissions for M-LMS are -84 dBm whereas 5G average emissions are -91 dBm, meaning M-LMS indoor emissions would be five times stronger than that of 5G.

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[30] The objective for accurate positioning is that the device must be able to see four or more serving cells. This is stricter than a traditional 5G system which would normally only need at least one cell for coverage.

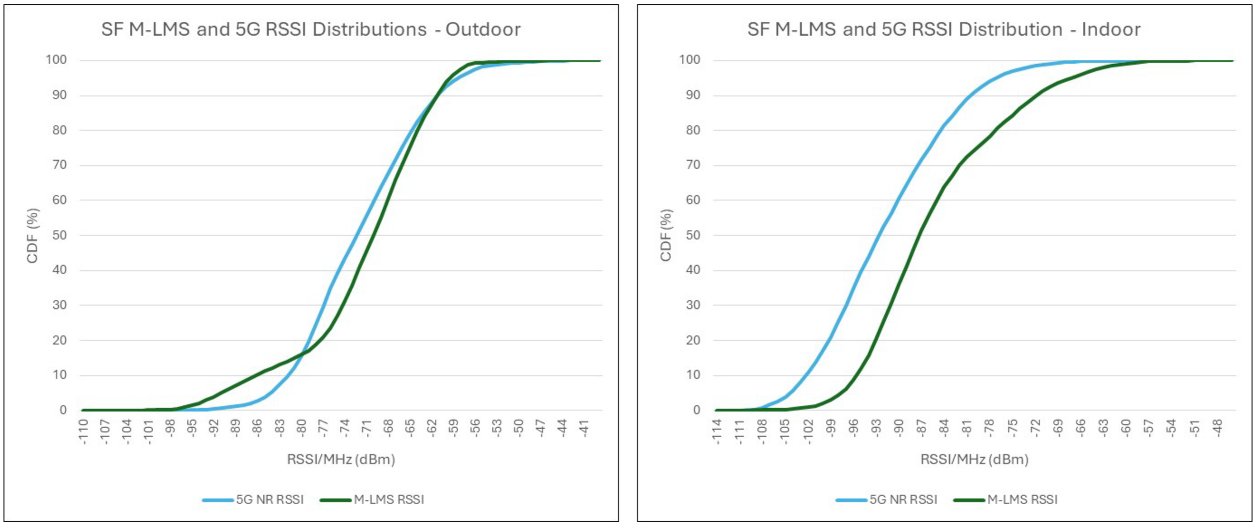

Figure 2: RF signal strength prediction distribution comparison between San Francisco M-LMS and estimated 5G (NR) deployments for outdoor (left) and indoor (right) environments. The RF signal strength is comparable outdoors, and stronger for M-LMS indoors.

In authorizing commercial operations in 2013, the Commission specifically required NextNav's subsidiary, Progeny, to "create a website and toll-free help desk to enable Part 15 device users to notify Progeny and seek assistance in investigating and mitigating potential interference issues" and report any complaints to the Commission.[31] Since the 2013 order, NextNav has not fielded even a single confirmed complaint that the M-LMS deployment was impacting Part 15 operations in any way, let alone causing unacceptable levels of interference to those devices.[32] Moreover, the current-generation M-LMS deployment in San Francisco is using a 10% duty cycle, which is lower than the 20% duty cycle NextNav proposed in 2013 for its beacon PNT system and was later authorized for use by the M-LMS system.[33]

2. Simulation Analysis

The proposed 5G deployment will operate among the existing noise environment of the lower 900 MHz band and have, at most, a marginal effect on the overall radiofrequency environment for Part 15 devices. This section presents a system-level simulation study designed to evaluate the effect of 5G emissions on Part 15 device operations in shared spectrum environments. The section quantifies the incremental interference introduced by 5G emissions compared to the existing interference from Part 15 devices. Additionally, the section examines the relative interference effects of 5G and M-LMS emissions on Part 15 systems.

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[31] 2013 Progeny Waiver Order, 28 FCC Rcd at 8568 ¶ 30.

[32] While NextNav received a handful of inquiries regarding its San Francisco M-LMS deployment, root-cause analyses determined that NextNav was not the source of any concerns that were raised.

[33] *See* 2013 Progeny Waiver Order, 28 FCC Rcd at 8562 ¶ 17 n.45.

The simulation methodology uses well-established 3GPP evaluation models to assess the feasibility of coexistence between different combinations of Part 15, 5G NR, and M-LMS systems. The simulation replaces macro and small cell network elements in the original 3GPP models with representations of 5G, M-LMS, and Part 15 device networks. The simulation also assumes that Part 15 devices operate in a device-to-device (D2D) communication framework, where devices act as both transmitters and receivers within a shared spectrum environment.

To assess coexistence under real-world conditions, the study defines four distinct radiofrequency emissions scenarios: (A) Part 15 devices operating on their own, with no emissions from other Part 15 devices, 5G NR, or M-LMS systems, (B) Part 15 devices operating in the presence of emissions from other Part 15 devices, but not 5G NR or authorized M-LMS systems, (C) Part 15 devices operating in the presence of emissions from other Part 15 devices and 5G NR, but not from authorized M-LMS, and (D) Part 15 devices operating in the presence of emissions from other Part 15 devices and authorized M-LMS systems, but not from 5G NR. The evaluation includes detailed assumptions about device density, propagation characteristics, and operating conditions, with further technical specifications outlined in **Appendix B**.

The simulation results provide a comparative analysis of interference levels. Detailed specifications for various measures are presented and summarized through a common measure of comparing Signal-to-Interference-plus-Noise Ratio (SINR) Cumulative Distribution Functions (CDFs). The findings indicate that interference from other Part 15 devices is the dominant factor affecting Part 15 performance, while the additional impact of 5G interference remains minor. The study further demonstrates that deploying a 5G-based PNT network would improve overall SINR conditions for Part 15 devices compared to deploying the currently authorized M-LMS PNT system in the lower 900 MHz band.

2.1. System-Level Part 15 Interference Simulation

The first objective of this simulation study is to evaluate the incremental impact of 5G emissions over existing Part 15 interference among Part 15 devices. Further, the simulation compares the incremental impact of 5G emissions to the impact of M-LMS emissions on the performance of Part 15 systems. The methodology of this simulation study is based on the combination of the evaluation methodology described in 3GPP Technical Report (TR) 36.872, Annex A.1.1 (Scenario 1)[34] with appropriate elements of the evaluation methodology described in 3GPP TR 36.843, Annex A.2 (System simulation scenarios).[35]

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[34] 3rd Generation Partnership Project 36.872 V12.1.0; Technical Specification Group Radio Access Network; Small cell enhancements for E-UTRA and E-UTRAN - Physical layer aspects (Release 12), accessible at: https://www.3gpp.org/ftp/Specs/archive/36_series/36.872/36872-c10.zip.

[35] 3rd Generation Partnership Project TR 36.843 V12.0.1; Technical Specification Group Radio Access Network; Study on LTE Device to Device Proximity Services; Radio Aspects (Release 12), accessible at: https://www.3gpp.org/ftp/Specs/archive/36_series/36.843/36843-c01.zip.

Although the evaluation methodology in 3GPP TR 36.872, Annex A.1.1 (Scenario 1) was developed for LTE (Release 12), it applies to the Part 15, 5G, and M-LMS coexistence scenarios evaluated in this section by following these general approaches:

- The macro cell network in 3GPP TR 36.872, Annex A.1.1 (Scenario 1) is replaced by either the 5G or the M-LMS network.
- The small cell network in 3GPP TR 36.872, Annex A.1.1 (Scenario 1) is replaced by Part 15 device networks, which are considered to be D2D communication networks, where a number of active Part 15 devices are dropped across the geographical area of the macro network (either 5G or M-LMS) depending on the estimated Part 15 device density provided in **Appendix C**. Each active Part 15 device acts as a transmitter and communicates with another Part 15 device acting as a receiver within the coverage of the transmitting Part 15 device.[36]
- Both macro (5G or M-LMS) and Part 15 device networks operate in the same carrier frequency and overlap the assumed one-megahertz operating bandwidth of an active Part 15 device. **Appendix B** includes detailed assumptions of the simulation study.
- As mentioned above, elements of the evaluation methodology in 3GPP TR 36.843, Annex A.2 more realistically represent the characteristics of Part 15 device networks in the simulation. For example, the channel models in Section A.2.1.2 of Annex A.2 are more realistic for communication between Part 15 devices that are typically placed below the rooftop, while both indoor and outdoor device placement leads to propagation characteristics that are captured well by those channel models.

Appendix B summarizes in further detail the key simulation assumptions for both 5G/M-LMS (macro) and Part 15 device networks.

2.2. Evaluation Target and Scenarios

The Part 15, 5G, and M-LMS coexistence system-level simulation study aims to evaluate the incremental impact of 5G or M-LMS emissions on the performance of the Part 15 device networks. We evaluate the following four simulation scenarios for that purpose:

- *Scenario A (No Interference)*: The Part 15 networks operate only in the presence of Additive White Gaussian Noise (AWGN), without interference from other Part 15, 5G, or M-LMS systems. Each active Part 15 device is assumed to transmit to another Part 15 device (D2D communication) within its coverage radius, while all other interference sources (from Part 15, 5G, or M-LMS systems) remain turned off.

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[36] Note that the coverage of an active Part 15 device refers to the radius of active Part 15 devices and is equal to 100 meters. *See* Appendix B.

- *Scenario B (Only Part 15 Interference)*: The Part 15 networks operate in the absence of 5G or M-LMS interference. Each active Part 15 device is assumed to transmit to another Part 15 device (D2D communication) within its coverage radius, while all other Part 15 transmitting devices are considered as interference. In this scenario, the 5G and M-LMS networks are turned off. While there are other sources, such as non-M-LMS licensees and ISM operations that could also impact Part 15 operations, the current analysis uses a conservative assumption to only consider interference from other Part 15 devices.

- *Scenario C (Part 15 + 5G Interference)*: The Part 15 networks operate in the presence of 5G interference. In this scenario, there is 5G interference transmitted by the base stations of the 5G network in addition to the Part 15 interference generated as in Scenario B.

- *Scenario D (Part 15 + M-LMS Interference)*: The Part 15 networks operate in the presence of M-LMS interference. In this scenario, in addition to the Part 15 interference generated as in Scenario B, there is also M-LMS interference transmitted by the base stations of the M-LMS network.

Based on the active Part 15 device density per sector, calculated in **Appendix C**, the active Part 15 device density per kilometer squared (km^2) is equal to ~10.4 devices per km^2 for the assumed 5G inter-site distance (ISD) of 1.732 km,[37] as described in **Appendix B**. The 400-meter ISD assumption of the M-LMS network is more conservative than the actual San Francisco M-LMS deployment, whose average ISD is 325 meters. Based on the estimated density of active Part 15 devices, we calculate the total number of active Part 15 devices dropped in the 5G or the M-LMS network. **Appendix B** contains the detailed simulation assumptions.

2.3. Simulation Results

The simulation reveals that 5G network emissions are generally no more pronounced than Part 15 device emissions and often far less meaningful than what unlicensed devices alone would produce, principally due to the 5G NR system's use of directional antennas and longer inter-site distances (i.e., lower density) relative to unlicensed deployments. Moreover, the proposed 5G network operations emit markedly less emissions than a fully realized version of the M-LMS PNT system that the FCC has already licensed would.

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[37] This ISD option in 3GPP TR 36.843, Annex A.2, is a more appropriate selection for sub-1 GHz carrier frequencies, as also shown in Table A.2.1.1-1 of Annex A.2, accessible at: https://www.3gpp.org/ftp/Specs/archive/36_series/36.843/36843-c01.zip. This assumption is also consistent with the results of the 5G RF analysis in Section 2.3, as shown in the 5G base station positions in the right graph of Figure 2.

Following the evaluation methodology described in Section 2.1, **Figure 3** illustrates which type of interference—from other Part 15 devices or from the 5G network—is the most dominant. The results in **Figure 3** assume transmit EIRP of 30 dBm for all active Part 15 devices (not the maximum allowed EIRP of 36 dBm) and 100-meter radius (coverage). **Figure 3** also assumes 70% of the devices are dropped indoors and 30% are dropped outdoors. **Appendix B** and **Appendix C** include the full list of the key simulation assumptions for this study.

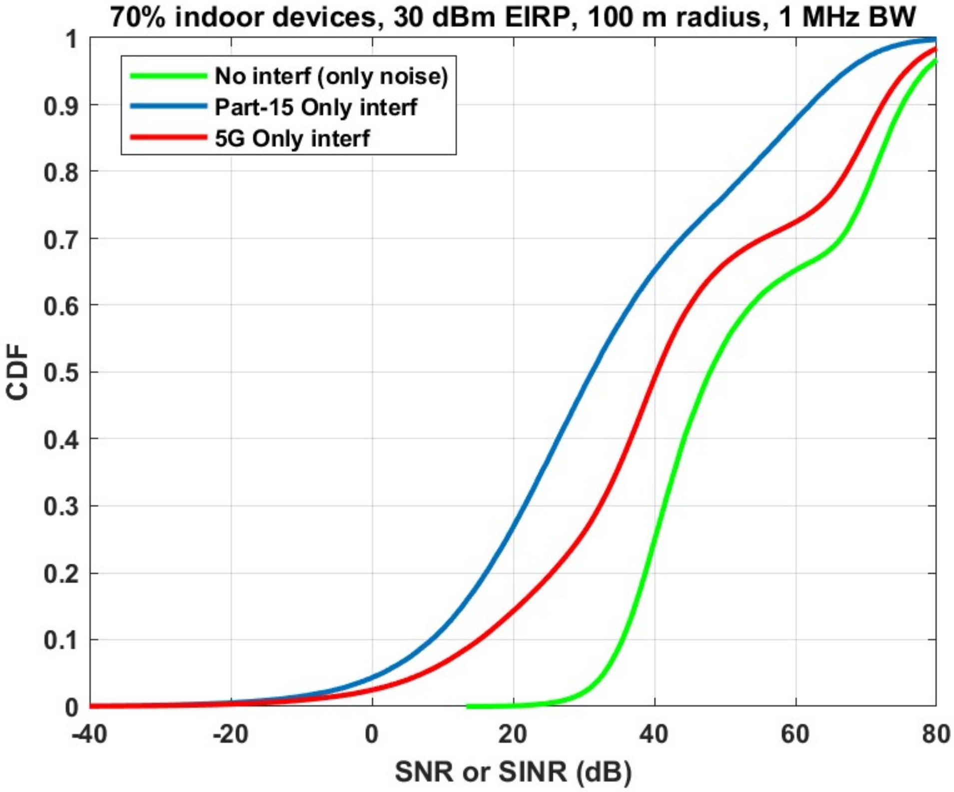

Figure 3: Part 15 SINR CDFs when only noise, Part 15, or 5G interference is present.

The green curve in **Figure 3** shows the Signal to Noise Ratio (SNR) CDF, which is valid in the theoretical scenario where there is no interference (only noise). The SNR CDF can be used as reference for the other two curves in **Figure 3**—the blue curve shows the SINR CDF when interference only from other Part 15 devices is present. The red curve shows the SINR CDF when interference only from the 5G network is present. As expected, both the blue and red curves (with interference) are shifted to the left (lower SINR regime) compared to the green curve (without interference). When comparing the blue and the red curves, the results indicate that interference from other Part 15 devices is the dominant interference source compared to 5G interference. Therefore, the impact of additional 5G interference (Part 15 + 5G interference) is expected to only be incremental compared to Part 15-only interference. This expectation is verified by the results in **Figure 4**, as described below.

To quantify the impact of the different interference sources on Part 15 devices, **Figure 4** shows the SNR and SINR CDFs for the four scenarios described in Section 2.2, i.e., Scenario A (Only noise, no interference), Scenario B (Only Part 15 interference), Scenario C (Part 15 + 5G interference), and Scenario D (Part 15 + M-LMS interference) corresponding to the green (SNR), blue (SINR), red (SINR), and magenta (SINR) curves, respectively. The rest of the simulation assumptions are the same as for **Figure 3**. **Table 3** summarizes the mean (average), median (50th percentile of the CDF), and edge (5th percentile of the CDF) values for the four evaluated scenarios.

Figure 4 presents the SINR CDFs. Comparing Scenario C to Scenario B for the mean values in **Table 3** allows for a quantification of the incremental impact of 5G emissions on Part 15 devices. The analysis shows that 5G emissions introduce an average SINR loss of just 1.6 dB as compared to unlicensed emissions alone. This SINR loss represents the degradation in signal quality for Part 15 devices when exposed to both Part 15 device and 5G network emissions (Scenario C) compared to their performance under only Part 15 device emissions (Scenario B).

The resulting SINR loss of 1.6 dB is smaller than the SINR loss from Scenario A (no interference) to Scenario B (Only Part 15 interference). It is also considerably smaller than the SINR loss between a fully deployed M-LMS network that the FCC's rules currently allow compared to a fully deployed 5G PNT network that NextNav has proposed the FCC's rules permit. Indeed, using 5G networks for PNT services instead of pursuing the currently authorized M-LMS network would *decrease* SINR loss for unlicensed devices operating in the lower 900 MHz band PNT network by 2.7 dB on average.[38] In other words, the deployment of longer ISDs and directional antennas in the 5G network compensates for the higher transmit EIRP of 5G compared to M-LMS and leads to an average SINR gain of approximately 1.1 dB (comparing the mean values in **Table 3**) for the Part 15 devices experiencing Part 15 and 5G interference compared to Part 15 and M-LMS interference (Scenario C vs. Scenario D). Finally, the SNR/SINR difference increases when considering the median or edge values compared to the mean values discussed above, without changing the key observation that 5G interference compared to interference from other Part 15 devices or the M-LMS network impacts Part 15 operations the least.[39]

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[38] This figure can be seen by comparing the mean values in Table 3. The analysis also assumed a 10% duty cycle for the M-LMS system and the predicted SINR loss due to the M-LMS system will be more than for a 5G system using the 20% duty cycle NextNav had proposed.

[39] In practical Part 15 network deployments, it is expected that intrinsic capabilities of Part 15 receiver equipment will be the limiting SNR/SINR factor, especially for low-cost devices. Typically, maximum SINR/SNR values of Part 15 devices will fall well below 30 dB. Nevertheless, even considering this behavior of practical Part 15 receivers, the conclusions of this section do not change.

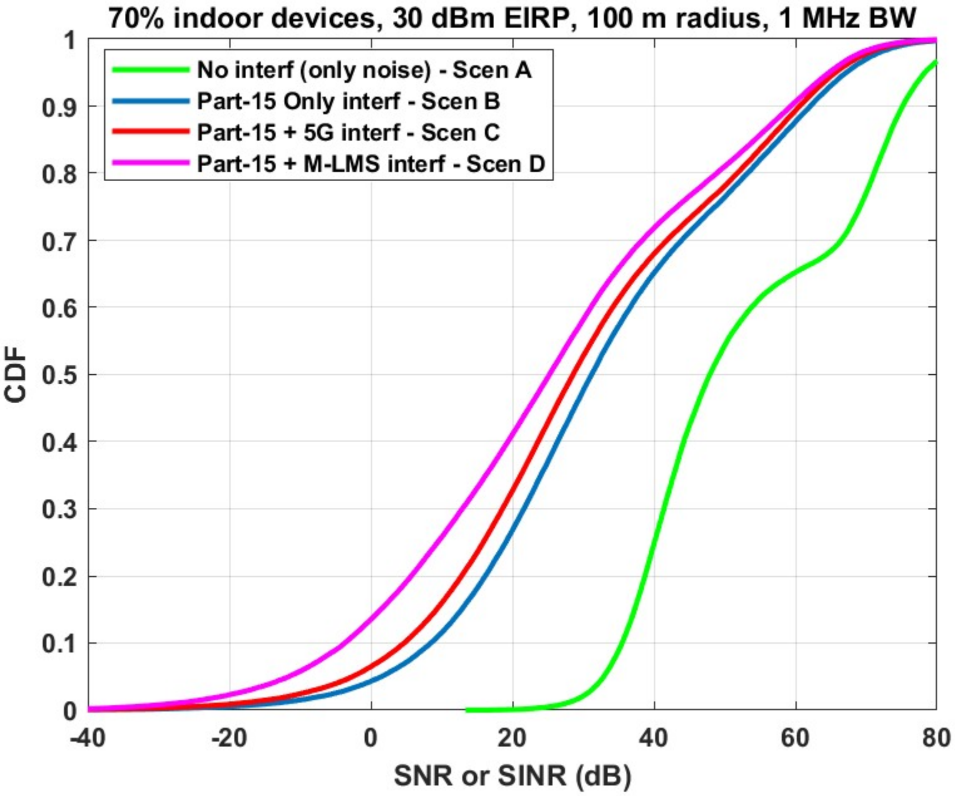

Figure 4: SINR CDFs for the four scenarios described in Section 2.2.

Table 3: Mean, median, and edge SNR/SINR values (in dB) for the investigated coexistence scenarios[40]

Scenario	**Mean SNR/SINR**	**Median SNR/SINR**	**Edge SNR/SINR**
Scenario A	**73.1**	**47.9**	**32.9**
Scenario B	**62.4**	**31.2**	**1.5**
Scenario C	**60.8**	**28.6**	**-2.6**
Scenario D	**59.7**	**25.2**	**-11.6**

The system-level simulation study provides a comprehensive analysis of interference effects on Part 15 device operations in shared spectrum environments. The results indicate that interference from other Part 15 devices is the primary factor affecting performance and show how 5G interference contributes, at most, an incremental SINR loss of approximately 1.6 dB. Moreover, the study demonstrates that a 5G-based PNT network would generate significantly less of an emissions effect on Part 15 operations than a fully realized version of the M-LMS network that the FCC has already licensed and authorized for deployment.

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[40] *See supra* note 38.

2.4. Part 15 In-Building Signal Analysis

The majority of Part 15 use cases occurs in indoor environments such as asset tracking, smart home, Internet of Things (IoT) and security. The analysis in this section focuses on comparing the predicted indoor signal strength of Part 15 deployments and 5G deployments. We selected the Northern Virginia area surrounding Dulles Airport for this analysis because it contains a mix of urban and suburban morphologies as well as densely populated commercial and residential buildings (a map of the area is included in **Appendix D**). The analysis was conducted using a popular RF prediction tool.[41] The 5G RF design yielded a total of 302 three-sector sites (i.e., 906 5G transmitters) covering an area of 663 square miles. The area of interest contained more than 350,000 buildings and Part 15 transmitters were placed in 18,696 buildings whose footprints exceed 624 square meters as shown in **Figure 5**. All the Part 15 devices were assumed to be indoors and at the center of the buildings. Detailed parameters used for this analysis are included in **Appendix D**.

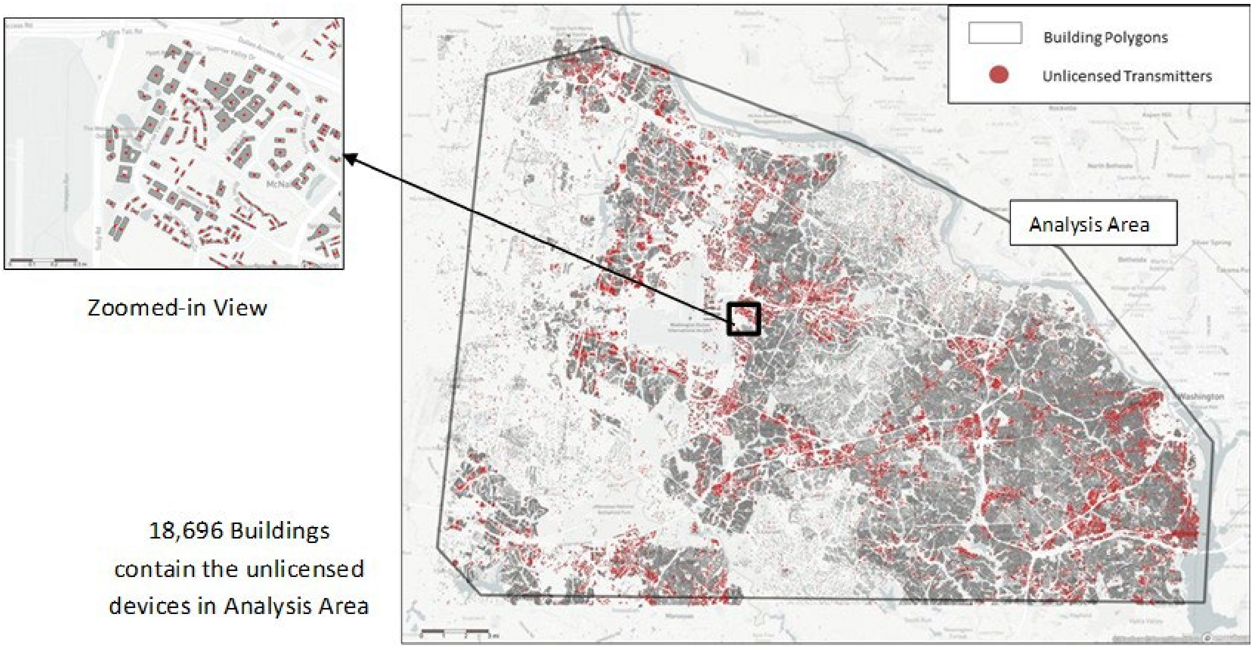

Figure 5: Building polygons and Part 15 transmitter locations in the reference area.

We conducted the 5G and Part 15 signal simulations separately and then compared the resulting indoor signal strength predictions. The prediction results of the above zoomed-in example area are captured in **Figure 6** and **Figure 7**, which show that the Part 15 signal strength is overwhelmingly stronger than that of 5G. We note that the analysis assumed a Part 15 device transmit level of 30 dBm EIRP, which is 6 dB less than what the Part 15 rules allow.

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[41] InfoVista, *Ensure Your 5G Network Delights Your Customers*, http://infovista.com/solutions/5g-solutions (last visited Feb. 24, 2025).

Figure 6: Predicted indoor signal strengths: Part 15. The red areas indicate the strongest signals while the green areas indicate the weakest.

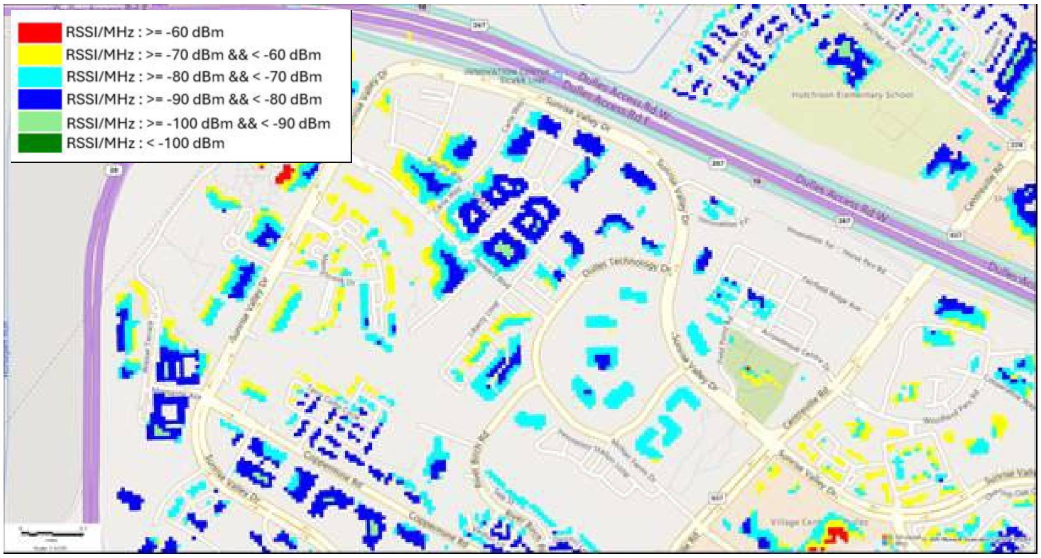

Figure 7: Predicted indoor signal strength: 5G. The red areas indicate the strongest signals while the green areas indicate the weakest.

To better illustrate the difference in signal strengths, **Figure 8** shows the indoor signal strength difference between Part 15 and 5G for each of the buildings considered. The vast majority of the buildings analyzed showed 20 dB or higher signal strength difference, where the indoor Part 15 signal strength was 100 times more or higher than that of 5G.

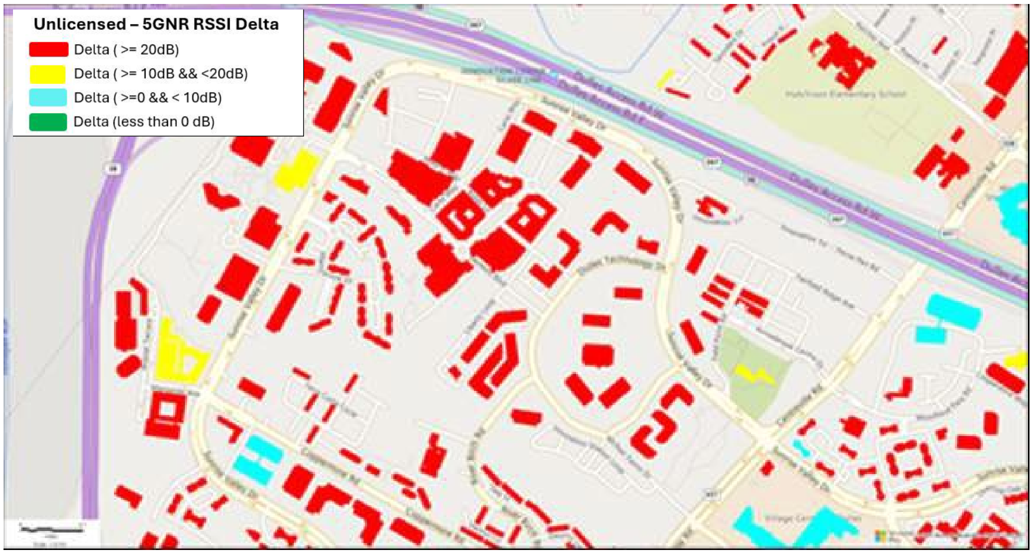

Figure 8: Part 15 and 5G indoor signal strength difference. The red areas indicate the largest signal difference (i.e., Part 15 is 100 times or more stronger than 5G) while the green areas indicate the smallest (i.e., 5G indoor signal is stronger than that of Part 15).

Table 4 summarizes the indoor signal strength simulation results, derived from the signal strength difference distribution between Part 15 and 5G, as shown in **Figure 9**. In **Figure 9**, the y-axis represents the distribution of indoor signal strength differences, while the x-axis indicates the difference between Part 15 and 5G signal levels. In this graphic, positive values signify stronger Part 15 indoor signals relative to those of 5G. The analysis, which considers 18,696 buildings, shows that fewer than 0.3% of locations would experience stronger indoor 5G signal levels than Part 15 devices produce. Additionally, in more than 99% of buildings, the indoor Part 15 signal levels exceed those of the 5G signals by at least 10 dB. Consequently, the Part 15 signal-to-interference ratio (SIR) exceeds 10 dB in more than 99% of locations and surpasses 20 dB in more than 97% of locations.[42] An SIR of 10 dB provides sufficient link margin to ensure that technologies such as Z-Wave and LoRaWAN continue to operate at expected performance levels.[43]

Table 4: Indoor signal strength delta summary

RSSI Delta (Part 15 – 5G NR)	Building Count and Percentage	
	Units	% of Units
RSSI Delta ≥ 20 dB	18,175	97.21%
20 dB > RSSI Delta ≥ 10 dB	350	1.87%
10 dB > RSSI Delta ≥ 0 dB	119	0.64%
RSSI Delta < 0 dB	52	0.28%
Total	18,696	100%

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[42] The signal-to-interference ratio (SIR) differs from the more common signal-to-interference-plus-noise ratio (SINR) in that it reflects a comparison of two signals that does not take noise into consideration.

[43] Refer to Section 3 for SINR requirements for LoRaWAN and Z-Wave.

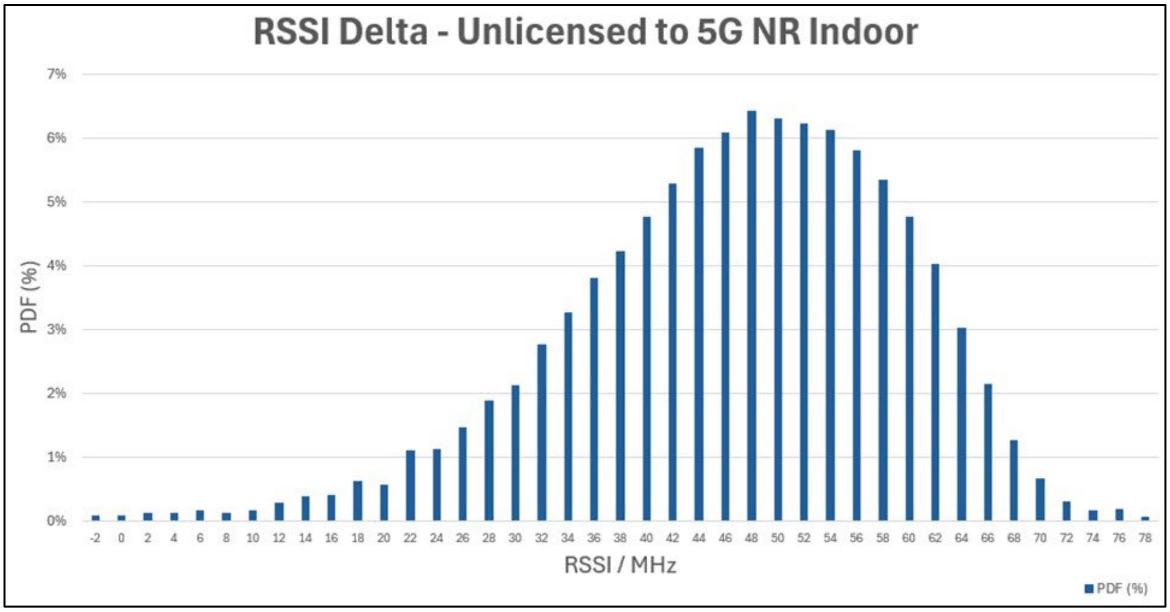

Figure 9: Indoor Part 15 and 5G NR signal strength difference distribution.

In sum, indoor signal strength simulations reveal that Part 15 signals are overwhelmingly stronger than 5G signals in nearly all analyzed buildings. These findings underscore that the proposed 5G network operations present minimal risk of unacceptable levels of interference to Part 15 devices and, in many cases, perform better than the existing interference landscape. The results also support the feasibility of 5G and Part 15 coexistence while highlighting the advantages of leveraging 5G for PNT services over M-LMS deployments.

3. Part 15 Technology Analysis

Despite lower operating power and still lower practical risks, commenters representing various unlicensed technologies operating in the lower 900 MHz band have raised concerns about the potential for 5G deployment to cause unacceptable levels of interference to unlicensed devices operating in the band.[44] The following section provides a more in-depth analysis illustrating the feasibility of coexistence between LoRaWAN, RAIN RFID, Wi-Fi HaLow, Wi-SUN, and Z-Wave technologies and the proposed 5G operations in the 902-928 MHz band. We analyze each technology in terms of its operational characteristics, mechanisms for interference mitigation, and its ability to adapt to the

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[44] *See, e.g.*, Comments of Wi-Fi Alliance at 2-5, WT Docket No. 24-240 (Sept. 5, 2024); Comments of WISPA - The Association For Broadband Without Boundaries at 6-7, WT Docket No. 24-240 (Sept. 5, 2024); Letter from Jerry Sumiec, Continental Automotive Systems, Inc. and Marcus Lichtenberg, Continental Automotive Technologies GmbH, to the Secretary of the FCC, WT Docket No. 24-240 (Sept. 4, 2024); Comments of Silicon Labs at 3-4, WT Docket No. 24-240 (Sept. 3, 2024).

shared spectrum environment. The need for unlicensed technologies to coexist with one another and with other incumbent services in the lower 900 MHz band has made them remarkably well-equipped to continue performing well alongside 5G.

LoRaWAN, which is a key enabler of IoT applications, demonstrates robust coexistence potential through its frequency agility and resilience to interference. The system's uplink, organized into frequency sub-bands, can avoid co-channel overlaps with 5G uplink frequencies, thanks to its frequency-agility capabilities, to ensure minimal disruption of communications links. For the downlink transmissions to LoRaWAN endpoints, which are much less frequent than uplink transmissions, advanced techniques such as retransmissions and adjustable spreading factors bolster its ability to sustain reliable communication, even in the presence of 5G downlink emissions. Simulation results indicate that the delta impact of 5G on LoRaWAN's SINR is minimal and manageable through these inherent mechanisms.[45]

RAIN RFID similarly benefits from strong design features that enhance its robustness in interference-prone environments. Its frequency-hopping protocols and robust desired signal conditions ensure its operations remain resilient, even with the additional contributions from 5G downlink. In scenarios where interference may slightly increase latency, the impact is negligible and unlikely to cause delays or interruptions in performance. The RAIN Alliance's guidance underscores the expectation of variability in real-world conditions and further affirms RAIN RFID's capability to adapt effectively to shared spectrum use.

Wi-Fi HaLow, which leverages the IEEE 802.11ah standard to support higher bandwidth connectivity compared to the other 900 MHz Part 15 technologies highlighted in this report, low power consumption, and high device density, exhibits exceptional flexibility with its wide channel options and coexistence features, such as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) and Subchannel Selective Transmission (SST). Its ability to dynamically select modulation and coding schemes based on interference levels, along with its relay and sectorization architecture, ensures robust performance. Analysis reveals that 5G uplink and downlink impacts are negligible, with Wi-Fi HaLow seamlessly reverting to more robust configurations if necessary, maintaining connectivity and functionality.

Wi-SUN, which was designed for IoT applications like smart metering and smart city infrastructure, exhibits resilience through its use of frequency hopping, Frequency Shift Keying (FSK) and Orthogonal Frequency Division Multiplexing (OFDM) modulation, and mesh architecture. These features enable Wi-SUN to dynamically adapt to interference,

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[45] The LoRa Alliance provided an alternative analysis with several mistaken assumptions. *See* LoRa Alliance, Notice of Ex Parte, WT Docket No. 24-240 (Dec. 6, 2024), https://www.fcc.gov/ecfs/document/12081988818373/1. NextNav plans to address the LoRa Alliance analysis in a separate filing.

optimize paths, and maintain reliable communication in shared spectrum environments. Simulation studies confirm that the incremental impact of 5G interference is minimal and well within the operational tolerance of Wi-SUN systems.

Z-Wave, which is a prominent technology for smart home and IoT deployments, similarly adapts to shared spectrum challenges through its retransmission protocols, channel assessment capabilities, and robust link budget margins. While only one of its backup channels overlaps with the proposed 5G band plan, specifically the 5G downlink, the probability of collision is low due to 5G network loading factors and Z-Wave's inherent ability to avoid interference through mechanisms such as Clear Channel Assessment (CCA).[46] Simulations affirm that the incremental impact of 5G on Z-Wave performance is marginal and does not result in unacceptable levels of interference.

In summary, these Part 15 technologies are equipped with sophisticated interference mitigation mechanisms and are designed to thrive in the inherently shared and uncoordinated spectrum of the 900 MHz band. NextNav's analyses demonstrate that the proposed 5G operations will coexist harmoniously with these technologies, ensuring the continued functionality of diverse IoT and industrial applications.

3.1. LoRaWAN

LoRaWAN (Long Range Wide Area Network) supports the IoT ecosystem, and is utilized in applications such as smart cities, industrial automation, environmental monitoring, and asset tracking. Globally, more than 350 million LoRaWAN-enabled devices have been deployed, with a significant concentration expected in the United States.[47]

LoRaWAN is an FDD system organized in the following frequency plan in the 902-928 MHz band (**Figure 10**). Communication over this frequency band occurs through endpoints that transmit on the uplink and gateways that transmit on the downlink.

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[46] Z-Wave Alliance, *Z-Wave Long Range PHY and MAC Layer Specification* v2.0 (July 3, 2023), https://zwave.cc/assets/doc/2024A%20Specification%20Package/Z-Wave%20Stack%20Specifications/Z-Wave%20Long%20Range%20PHY%20and%20MAC%20Layer%20Specification.pdf.

[47] Semtech Corp., *LoRa Platform for IoT*, https://www.semtech.com/lora (last visited Feb. 24, 2025). The LoRa Alliance makes numerous claims contrary to the observations and analysis presented in this report. *See, e.g.,* LoRa Alliance, Notice of Ex Parte, WT Docket No. 24-240 (Dec. 6, 2024), https://www.fcc.gov/ecfs/document/12081988818373/1. These claims suffer from the erroneous premise that LoRaWAN has some kind of presumptive "right-of-way" in the 902-928 MHz band. It does not. *See* 47 C.F.R. § 15.5. NextNav will address the LoRa Alliance's false premise and other errors in the LoRa Alliance's claims in a separate filing.

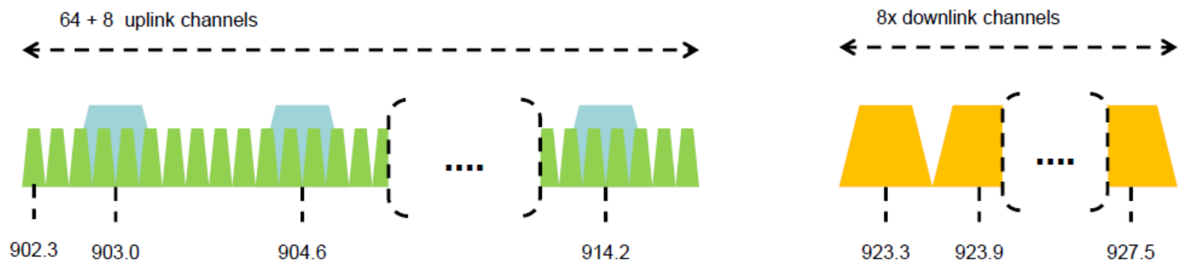

Figure 10: LoRaWAN frequency plan in the 902-928 MHz band.

The LoRaWAN uplink in the 902-928 MHz band has sixty-four 125 kilohertz uplink channels grouped into eight frequency sub-bands (FSBs). At the center of these eight sub-bands, there can also be eight 500 kilohertz uplink channels.[48] The LoRaWAN system typically uses one or two of the eight sub-bands, with the endpoints commonly frequency-hopping across the 125 kilohertz channels.[49] **Table 5** shows the organization of sub-bands in the LoRaWAN uplink. Of these uplink sub-bands, only sub-bands one through three are co-channel with the proposed 5G uplink frequencies (902-907 MHz).

Table 5: LoRaWAN uplink sub-bands, frequencies, and channels

Uplink Sub-Bands	Frequencies (MHz)	Channels
Sub-band 1	902.3 - 903.7	0-7
Sub-band 2	903.9 - 905.3	8-15
Sub-band 3	905.5 - 906.9	16-23
Sub-band 4	907.1 - 908.5	24-31
Sub-band 5	908.7 - 910.1	32-39
Sub-band 6	910.3 - 911.7	40-47
Sub-band 7	911.9 - 913.3	48-55
Sub-band 8	913.5 - 914.9	56-63

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[48] LoRa Alliance, Inc., *RP002-1.0.3 LoRaWAN® Regional Parameters* (May 5, 2021), https://lora-alliance.org/wp-content/uploads/2021/05/RP002-1.0.3-FINAL-1.pdf.

[49] LoRaWAN gateways can cover multiple 125-kilohertz channels, and the number of sub-bands supported depends on the regional frequency plan and the gateway's design. The US915 plan divides the available 125 kilohertz channels into two groups (or sub-bands), with eight channels in each group. Many U.S. gateways are built to monitor both sub-bands, although lower-cost gateways might only cover one and rely on network server algorithms to handle the remaining channels. This approach is described in the LoRaWAN Regional Parameters document published by the LoRa Alliance. *See* LoRa Alliance, Inc., *RP002-1.0.3 LoRaWAN® Regional Parameters* (May 5, 2021), https://lora-alliance.org/wp-content/uploads/2021/05/RP002-1.0.3-FINAL-1.pdf; *see also* Barani Design Technologies, *LoRaWAN USA Frequencies, Channels and Sub-bands for IoT Devices* (Apr. 23, 2019), https://www.baranidesign.com/faq-articles/2019/4/23/lorawan-usa-frequencies-channels-and-sub-bands-for-iot-devices discusses 1 sub-band gateways with default FSB2 commonly used in The Things Network; Cisco, *Cisco Wireless Gateway for LoRaWAN Data Sheet* (updated May 23, 2021), https://www.cisco.com/c/en/us/products/collateral/se/internet-of-things/datasheet-c78-737307.html - refers to 2 sub-band or 16 channel gateways used for commercial applications.

Even where the sub-bands are co-channel with 5G uplink, given the low duty cycle and low transmit power of 5G UEs (see Section 1.1), the proposed 5G uplink band will not significantly impact LoRaWAN performance. The LoRaWAN system has frequency agility—that is, the ability to shift operating frequency to account for interference. Moreover, gateways can always be configured to a specific sub-band. Choosing one of sub-bands four through eight, which are not co-channel with the proposed 5G uplink band, would eliminate any problems related to 5G co-channel coexistence. For example, a commonly used LoRaWAN configuration in the U.S. (The Things Network[50]), which currently uses sub-band two with an eight-channel gateway, can be configured to use one of sub-bands four through eight.

The LoRaWAN downlink consists of eight 500 kilohertz channels in the frequency range from 923 to 927.8 MHz, see **Table 6**. However, the majority of LoRaWAN use cases are uplink driven. Because transmissions on the downlink are limited to initial device activation procedure, occasional acknowledgements, and link adjustments in most LoRaWAN applications, the LoRaWAN downlink is not frequently used.[51] Even when the downlink is in use, the network loading of the proposed 5G downlink further lowers any collision risk with the LoRaWAN downlink.

On both the LoRaWAN uplink and downlink,[52] system features, such as retransmissions and adjustment of spreading factors, extend symbol duration, increase processing gains, and ultimately improve robustness. While these features were initially developed for LoRaWAN to overcome interference from other Part 15 devices,[53] these same techniques can be used to enable LoRaWAN to operate successfully in the presence of the proposed 5G downlink.

Table 6: LoRaWAN downlink frequencies and channels

Downlink Channels	Frequencies (MHz)
0	923.3
1	923.9
2	924.5
3	925.1

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[50] Barani, *Frequently Asked Questions: LoRaWAN USA Frequencies, Channels and Sub-bands for IoT Devices* (Apr. 23, 2019), https://www.baranidesign.com/faq-articles/2019/4/23/lorawan-usa-frequencies-channels-and-sub-bands-for-iot-devices discusses 1 sub-band gateways with default FSB2 commonly used in The Things Network.

[51] Semtech, AN1200.86 v1.0 *LoRaWAN® and LoRaWAN* § 3.1.1 (Mar. 2024).

[52] LoRa Alliance, Inc., *LoRaWAN™ 1.0.3 Specification* (July 2018), https://lora-alliance.org/wp-content/uploads/2020/11/lorawan1.0.3.pdf.

[53] Semtech, *AN1200.22 LoRa™ Modulation Basics*, Application Note, Revision 2, Section 5.4 (May 2015), https://www.frugalprototype.com/wp-content/uploads/2016/08/an1200.22.pdf discusses Part 15 interference limited links and LoRaWAN characteristics that are built to overcome them.

Downlink Channels	Frequencies (MHz)
4	925.7
5	926.3
6	926.9
7	927.5

For any downlink co-channel cases that are not overcome by the above mechanisms, practical system considerations indicate that there would be no unacceptable levels of interference from the 5G downlink to the LoRaWAN downlink. This shared band is already interference limited due to the large number of Part 15 devices. Several commenters have noted that LoRaWAN system operation is not limited by receiver sensitivity levels. For instance, as the LoRa Alliance pointed out,[54] the LoRaWAN system and devices have mechanisms to adjust various parameters (such as spreading factor and channel selection) dynamically to operate in an interference-limited environment. These same mechanisms could be applied equally to overcome potential 5G downlink interference impacts.

NextNav performed simulations with realistic assumptions regarding interference from other Part 15 devices,[55] as well as a reasonable coverage radius (operating point), to assess the incremental effect of the 5G downlink interference on Part 15 SINR on top of the Part 15 interference environment described in Section 2.2. The simulation results show the limited impact of the 5G downlink on the LoRaWAN downlink co-channel interference: LoRaWAN has the ability to handle high interference-to-signal ratios. Specifically, the LoRaWAN downlink can operate at very low SINRs ~-8 dB (SF7) to -21 dB (SF12) as a function of the spreading factor (SF).[56] The SINR simulation results from Section 2.3 are reproduced in **Figure 11** for reference, with annotation of the operating point.

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[54] NextNav Reply Comments at 42-45; *See* ETSI, ETSI TR 103 526 V1.1.1, *System Reference Document (SRdoc), Technical Characteristics for Low Power Wide Area Networks Chirp Spread Spectrum (LPWAN-CSS) Operating in the UHF Spectrum Below 1 GHz* (Apr. 2018), https://www.etsi.org/deliver/etsi_tr/103500_103599/103526/01.01.01_60/tr_103526v010101p.pdf.

[55] *See* Appendix B for the key simulation assumptions for both 5G/M-LMS (macro) and Part 15 device networks.

[56] ETSI, ETSI TR 103 526 V1.1.1, *System Reference document (SRdoc); Technical characteristics for Low Power Wide Area Networks Chirp Spread Spectrum (LPWAN-CSS) operating in the UHF spectrum below 1 GHz* (Apr. 2018), https://www.etsi.org/deliver/etsi_tr/103500_103599/103526/01.01.01_60/tr_103526v010101p.pdf.

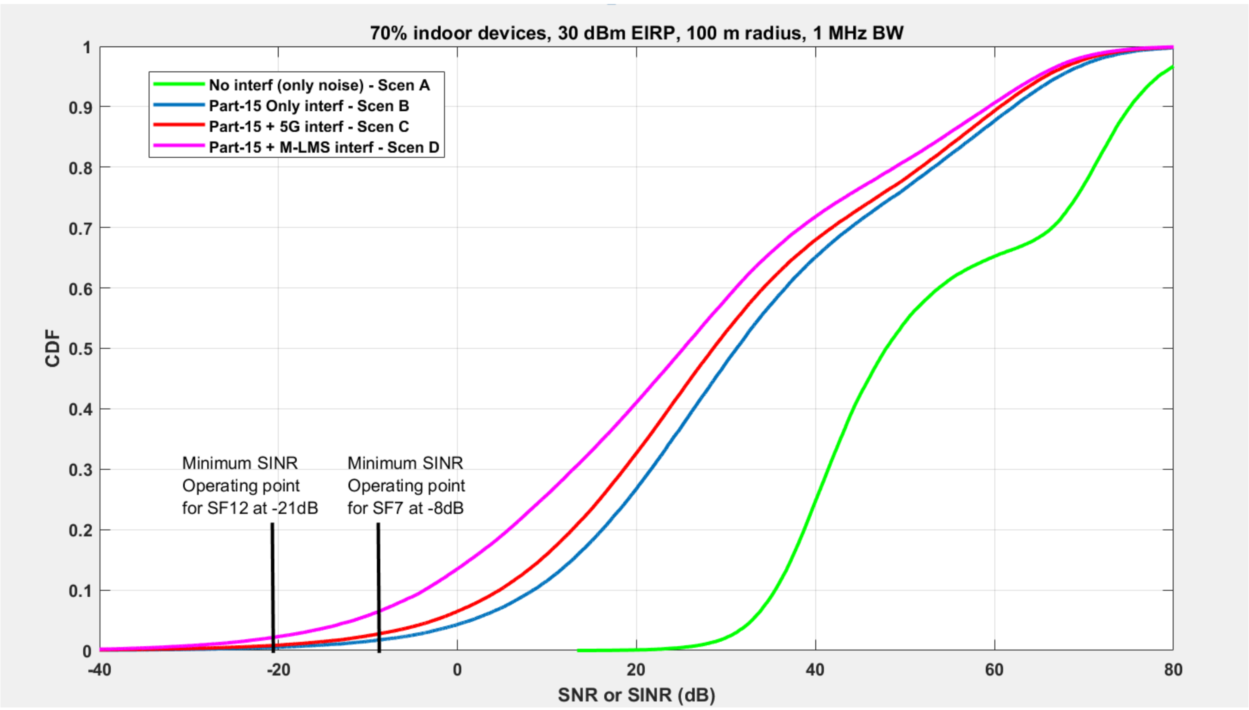

Figure 11: Simulation results from Figure 4 (Section 2.3) with annotation of operating points (-8 dB and -21 dB).

Comparing Scenario B versus C in **Figure 11** above, the incremental impact on SINR from 5G interference is approximately 1.6 dB comparing the mean values (50th percentile of the CDFs). Critically, at the operating point limit of SF7 (shown as the black vertical line), there is almost no impact (less than 1%) on the probability of an outage. Similarly, at the operating point limit of SF12 (shown as the black vertical line), there is still lesser impact (less than 0.3%) on the probability of an outage when compared to the operating point limit of SF7. Since the predicted outage is only for a single LoRaWAN downlink transmission, the overall probability of an outage is even more reduced by the aforementioned retransmission mechanism. Further, the minor impact to outage probability can also be overcome by choosing a higher spreading factor (which provides roughly 3 dB improved SINR per SF increment). In LoRaWAN, such an adjustment can be done by the network server[57] on the gateway and communicated to the endpoint using the downlink.[58]

3.2. RAIN RFID

This section examines the technical features and real-world applications of RAIN RFID technology and how they would respond to 5G operations. The analysis confirms that RAIN

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[57] The Things Network, *LoRaWAN Architecture*, https://www.thethingsnetwork.org/docs/lorawan/architecture/ shows network server controlling gateway configuration (last visited Feb. 26, 2025).

[58] LoRa Alliance, Inc., *LoRaWAN™ Specification* v1.0 (Jan. 2015), https://content.cdntwrk.com/files/aT0xNDI4Mzc3JnY9MSZpc3N1ZU5hbWU9bG9yYXdhbi1zcGVjaWZpY2F0aW9uLXYxLTAmY21kPWQmc2lnPWY0Mjc0NWQ4ZjY2YjM2ZmVjMTIzZDNhOGNhZTQzZWI0.

is engineered to perform reliably in the presence of multiple interference sources, including those from the proposed 5G deployment. Detailed link budget assessments and latency overhead evaluations demonstrate that, even under challenging conditions beyond those that a 5G network would realistically be expected to produce, any additional delay remains minimal and well within acceptable operational limits.

Interference to RAIN operations can come from many different sources, including other nearby RAIN readers and tags, other Part 15 operations, ISM devices, and licensed services in the band. With respect to 5G operation, the analysis shows that interference to a RAIN device would be highly probabilistic. For a 5G transmission to affect a RAIN system, all of the following would have to be true simultaneously:

- the proposed 5G system is operating close enough to RAIN operations to cause an impact;[59]
- the base station or UE is actually transmitting (a function of load/activity factor);
- a RAIN inventory cycle is occurring during the base station or UE transmission;[60] and
- the RAIN reader's channel overlaps with the 5G band.

A simultaneous concurrence of all of the events necessary for 5G signals to produce a real-world impact on RAIN is not impossible, but it is highly improbable.

Despite the low risk of a signal intersection, the analysis examines how 5G signal intersection with RAIN operations would affect the RAIN link budget and outlines the methodology used to assess these effects. The discussion culminates with a presentation of the results and a focused analysis on the expected delay overhead caused by interference. The results demonstrate that RAIN protocols are effective and robust in the face of impairment, and these defining characteristics will not change when faced with 5G operations.

3.2.1. Foundational Design and Deployment Characteristics

RAIN is used throughout the commercial, industrial, and government sectors for asset tracking, inventory management, shipment verification, and related purposes.[61] In the United States, RAIN operates in the 902-928 MHz band using frequency hopping spread spectrum (FHSS) consistent with section 15.247 of the Commission's rules that govern FHSS systems. RAIN's implementation of FHSS uses a 50-channel hopping sequence. RAIN's channel raster uses 500 kilohertz channelization with an occupied channel

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[59] The proposed 5G impact level is a function of the reader's received signal strength.

[60] RAIN transmissions are not continuous in many deployment scenarios (e.g., use of handheld readers).

[61] Impinj, Inc., *About RFID and RAIN RFID*, https://www.impinj.com/products/technology/about-rfid (last visited Feb. 23, 2025).

bandwidth of approximately 250 kilohertz.[62] FHSS involves rapidly changing the frequency of transmission within a specified band according to a pseudo-random sequence. By "hopping" between different channels, it makes it more difficult for interference on any single frequency to disrupt communication. Even if interference were to occur on one channel, the system quickly moves to another channel. Additionally, FHSS systems can benefit from coexisting with other systems in the same band because they have the ability to avoid channels experiencing interference. This characteristic makes FHSS particularly useful in shared spectrum environments, like those used by RAIN RFID systems.

As for deployment characteristics, designs vary. But across all deployments, the RAIN Alliance emphasizes the importance of realistic user expectations given the complex and variable nature of the radiofrequency environment in the 902-928 MHz band. As part of a definitive field guide for RAIN deployment, for example, the Alliance discourages RAIN users from assuming that "a single Query command would allow all the tags to be read" even though the protocol calls for that performance level.[63] The "real-world RF environment does not support this reliably," the Alliance warns. "Do not assume that all tags in the zone will respond to a lone query command."[64] According to the Alliance, RAIN users should "plan for interference" and "expect latency to vary." The Alliance's admonitions are well-founded: RAIN devices rarely reach their theoretical optimum performance due to commonplace radiofrequency variables that contribute to occasional missed reads and variable latency.

The RAIN Alliance also urges users to adopt conservative deployment strategies to reduce the number of lost readings. In the same field guide that seeks to temper user expectations about devices ever operating at their theoretical maximums, the Alliance recommends that "read zones" should be "shorter" in size and be located "well within the limits of the tag and reader." The Alliance adds that "[a]ttempts to maximise or 'stretch' the effective read zone can backfire by introducing unanticipated interference."[65] As with the incorporation of advanced FHSS technology into the RAIN standard, incorporating conservative system design principles in the Alliance's field guide helps provide a sound framework to safeguard

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[62] Various aspects of the RAIN system design and related considerations are governed from a publication of the RAIN Alliance, *RAIN RFID System Design Guidelines Air Interface and Protocol Considerations* (May 2020), https://rainrfid.org/wp-content/uploads/2020/05/RAIN-Alliance-System-Design-Guidelines-V.1.0.pdf, and the GS1, *EPC Radio-Frequency Identity Generation-2 UHF RFID Standard*, Release 3.0 (ratified Jan. 2024), https://www.gs1.org/standards/rfid/uhf-air-interface-protocol.

[63] The RAIN Alliance published "RAIN RFID Lessons From the Field" in 2021. Authored collaboratively by members of the Alliance, the document compiles real-world experiences and technical insights from diverse RAIN RFID deployments with the stated purpose of sharing lessons learned, best practices, and practical guidance to help operators, system integrators, and end-users design and implement more robust and efficient RFID solutions in the complex 902–928 MHz radiofrequency environment. *See* The RAIN Alliance, *RAIN RFID Lessons Learned From the Field* (Mar. 2021), https://therainalliance.org/wp-content/uploads/2021/04/RAIN_RFID_Lessons_learned_from_the_field.pdf.

[64] *Id*. at 13.

[65] *Id*. at 9.

RAIN deployments against additional emissions, including the very limited potential from 5G sources.

3.2.2. RAIN Read Scenarios

There are two types of RFID readers: mobile and fixed.[66] Mobile readers are portable and can be carried by personnel to scan items manually. Fixed readers are stationary devices that typically monitor RFID tags continuously within their range. Fixed readers are often used in either a portal or gateway configuration.[67]

As described by one RFID reader supplier, "[a]n RFID portal works by creating a threshold through which the RFID-tagged items must pass through in order to be read. Most RFID portals are stationed at dock doors, or in a doorway between two rooms. Additionally, small RFID portals can be on either side of a conveyor belt or other type of manufacturing line so that products automatically pass through."[68]

Gateway readers, in contrast, are fixed readers mounted in the ceiling of a building or structure with the benefit of allowing "businesses to monitor RFID tagged items in near real-time."[69] Various factors weigh on the potential of interference on RAIN RFID deployments, including the number of tags being inventoried, the time the tag spends in a read zone (i.e., the area for which a reader can "reach" a tag), and the distance between the reader and tag.

3.2.3. Markets and Applications

RAIN RFID technology has a diverse market distribution. Different sectors use RAIN in different volumes and typically for distinct operational needs. Expressed as a percentage of tag volume, the largest users of RAIN devices in 2023, which is the latest year for which data is available, were as follows:

- Retail apparel and footwear (64%)
- Assets, parts, logistics containers (22%)
- Retail other (inc. anti-counterfeiting) (6%)
- Medical/health care (4%)

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[66] Martial A., *Using A Fixed RFID Reader In Retail*, KORONA POS (last updated on June 19, 2024), https://koronapos.com/blog/fixed-rfid-reader/.

[67] Suzanne Smiley, *RFID Portal Readers vs. RFID Gateway Readers*, atlasRFIDstore (Nov. 10, 2023), https://www.atlasrfidstore.com/rfid-insider/rfid-portal-readers-vs-rfid-gateway-readers/.

[68] *Id*.

[69] *Id*.

- Air baggage (1%)
- People Tracking/Monitoring (1%)
- Other (2%)[70]

Retail and medical applications are two good examples of the different use cases available for RAIN devices. Retail companies use RAIN for inventory control, loss prevention, fulfillment, checkout, and product recall[71] at production facilities, distribution centers, and retail stores.[72] Most of these deployments are indoors. Production and distribution processes primarily use portal readers, while retail stores also often use portal readers at store doors combined with overhead readers or mobile hand-held readers to periodically read the tags while inventory is stationary. Healthcare providers rely on RAIN for purposes such as patient tracking, inventory management, medication management, asset tracking, and compliance and documentation. Most use cases involve small counts of items in the field and close reads of items. Deployments utilize combinations of handheld readers, portal readers, and fixed infrastructure at close range.[73] While RF interference challenges differ by use case, common themes—such as the use of RAIN applications at discrete times and locations—emerge across diverse applications.

3.2.4. RAIN Technology Summary

RAIN is a passive communication technology[74] governed by the Electronic Product Code (EPC) Radio-Frequency Identity Generation-2 UHF RFID Standard. This standard intends to cover UHF RFID usage worldwide and contemplates operation between 860 MHz and 930 MHz.[75] A RAIN deployment uses a reader to read and write tags.[76] In the U.S., the reader is an active transceiver that supports up to one watt (1W) conducted power with up to 6 dBi of allowable antenna gain resulting in up to +36 dBm EIRP. The tags are passive devices that harvest energy from the reader's transmission to process the protocol and modulate a signal to communicate back to the reader. The protocol allows for frequency hopping governed by section 15.247 of the Commission's rules for operation in the 902 MHz to

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[70] IdTechEx. *Beyond 2023: A Look at the Progress, Trends, and Prospects of RFID Technology*, https://www.idtechex.com/en/research-report/rfid-forecasts-players-and-opportunities-2023-2033/927 (last visited Feb. 24, 2025).

[71] Joanna Furlong, *RFID for Retail: Know the Pros and Cons*, Business.com (updated Nov. 25, 2024), https://www.business.com/articles/rfid-for-retail/.

[72] atlasRFIDstore, *Retail Inventory Management with RFID*, https://www.atlasrfidstore.com/rfid-resources/rfid-applications/retail-inventory-management/ (last visited Feb. 24, 2025).

[73] Redbeam, *RFID in Healthcare: Advantages and Top Uses* (June 11, 2024), https://redbeam.com/blog/healthcare-rfid.

[74] The RAIN Alliance, *What Is RAIN?*, https://therainalliance.org/what-is-rain-rfid/ (last visited Feb. 23, 2025).

[75] GS1, *EPC® Radio-Frequency Identity Generation-2 UHF RFID Standard*, Release 3.0 (ratified Jan. 2024), https://ref.gs1.org/standards/gen2/.

[76] The terms "reader" and "interrogator" are both used in the industry and may be used interchangeably.

928 MHz band. When operating in this band, the reader will hop with a pseudo-random hopping pattern across 50 channels with channel centers spaced 500 kilohertz apart.

The most common architecture for RFID readers is a monostatic design, where the reader receives and transmits via the same antenna at the same time.[77] Alternatively, a bistatic reader uses separate antennas to transmit and receive.[78] In either case, the reader design will typically consist of a bandpass filter before the low-noise amplifier (LNA) to filter out-of-band signals. Because RAIN operates on different frequency bands in different regions of the world, this filter may need to be selected to match the region of operation. Small, low-cost tags are also critical to RAIN proliferation, leading to the creation of tags designed for worldwide operations to maximize manufacturing volume and reduce costs. When optimized for worldwide operations, tags receive and perform well across the entire 860 MHz to 930 MHz band specified in the RFID Standard. Some sources even document how well certain tags operate beyond this frequency band. For example, the Avery Dennison Belt tag supports a read range of greater than 10 meters between 840 MHz and 1 GHz when mounted on plastic.[79]

Tags commonly implement an envelope detector prior to demodulation.[80] All energy received across the full passband (e.g., 860 MHz to 930 MHz) contributes to the RF envelope, thus tag operation is impacted by all energy present in the passband. This means that RAIN tags used in the U.S. today are not only subject to interference from other Part 15 and licensed users in the 902-928 MHz band but additionally from users outside of the band, including any downlink transmissions on 3GPP Bands 5 and 26.[81] In light of this broad flexibility to accept other frequency inputs, the impact of a 5G signal in the lower 900 MHz band on RAIN operations is likely to be even less than demonstrated in the analysis described in Section 2.

3.2.5. RAIN Protocol Operation

A RAIN reader transmits a continuous wave (CW) tone at a pre-selected frequency. As an initial step, all tags that receive sufficient energy from this CW tone will power on and listen for modulated data from the reader. Next, the reader sends protocol data. An inventory round sequence may be initiated with a Select command to request that only a subset of tags participate in the round. In the absence of a Select command, tags will participate in the inventory round depending on their internal state. The inventory round begins with a

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[77] Suzanne Smiley, *Monostatic vs. Bistatic RFID*, Atlas RFID Store (July 18, 2024), https://www.atlasrfidstore.com/rfid-insider/monostatic-vs-bistatic-rfid/.

[78] *Id.*

[79] Atlas RFID Store, *ATLAS Smartrac Belt RFID Tags (NXP UCODE 8)* (PDF) (2021), https://bit.ly/4hPyhhg.

[80] Xiaoming Teng, *A UHF Passive RFID Tag Front-End Design With a Novel True Random Number Generator*, IEEE Access (July 30, 2024), https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10473071.

[81] Band 5 and 26 downlink frequency ranges are 869-894 MHz and 859-894 MHz, respectively.

"Query" command that sets communication parameters defining which tags should reply, defines how the tags should be configured to reply (e.g., modulation and timing), and sets a Q value defining how many access times will be made available to tags in the field.[82] Upon receipt of a "Query" command, Tags select a random number from 0 to 2^Q-1. If the tag selects 0, it transmits a new random number. If the reader receives that random number, the reader acknowledges it with an acknowledgement (ACK) that contains what the reader believed to be that tag's random number. If the tag receives the same random number that it transmitted, it responds with its tag data ID number (*i.e.*, its EPC). The reader then sends a "QueryRep" command that tells the tags to decrement their original random number by one, and the protocol continues with tags that are now at zero responding with new random numbers. There are mechanisms for tags that have been inventoried to be excluded from subsequent inventory rounds. A reader may run a series of Queries until no tags respond, thus ensuring that all desired tags in reach have an opportunity to respond. The reader hops to the next frequency based on a reader's configured time duration per frequency hop. At that point, a new inventoried round may be initiated via a "Query" command. Because tags retain their inventoried state, it is possible to inventory a set of tags across hops with each tag responding only once.

The RAIN protocol is designed to operate in the presence of interference. For example, if an interferer disrupts communication during a random number exchange between a tag and reader, the tag will not receive an ACK, would not set its "inventoried" state flag, and would return to participate in the next inventory round along with other tags that were not inventoried. This would result in a read delay of the tag, until the next inventory round which may be on the same channel or the next channel in the hopping sequence, depending on the nature of the interference source and the configuration of the reader. Note that as long as at least one hopping channel is free from interference to allow the protocol to complete, all reachable tags can be inventoried, with some impact on tag read latency, as will be quantified in a following subsection.

3.2.6. Impact on RAIN Link Budget

This section evaluates the potential impact of the proposed 5G operation by assessing the risk of a 5G base station operating in the band alongside a RAIN tag or reader from a link budget perspective. The analysis quantitatively demonstrates that while interference may occur under certain conditions, it remains highly unlikely in the vast majority of deployment scenarios. To illustrate this outcome, the evaluation focuses on two deployment scenarios that reflect typical use cases of this technology.

The first scenario, shown below in **Figure 12** pertains to the retail industry, where the reader and tags are assumed to be used inside a big box retail store. The link distance between

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[82] RFID4U, *RFID Basics - EPC Gen2 Reader Commands and Q Parameter*, https://rfid4u.com/epc-gen2-reader-commands-and-q-parameter/ (last visited Feb. 23, 2025).

the tag and the reader can vary but will generally be short, from one to two meters for a handheld reader device, to up to between three to four meters for a fixed reader installation on a ceiling. The study assumes a maximum distance of 3.6 meters, as given by a height of three meters and a horizontal distance of two meters.

The RAIN channel model documented in Section 4 of the RAIN Alliance “RAIN RFID System Design Guidelines” is utilized to analyze this scenario. Note that this analysis accounts for what appears to be an error in the Friis channel definition, see Equations 1, 4, and 5 where a factor of 2π is captured in the denominators in lieu of 4π, which was corrected in this analysis. Specifically, Equation 1 which is documented in the RAIN Alliance document as:

$$P_{tag,read} = P_{reader,TX} \times \left(\frac{\lambda}{2\pi R}\right)^2$$

is replaced with:

$$P_{tag,read} = P_{reader,TX} \times \left(\frac{\lambda}{4\pi R}\right)^2$$

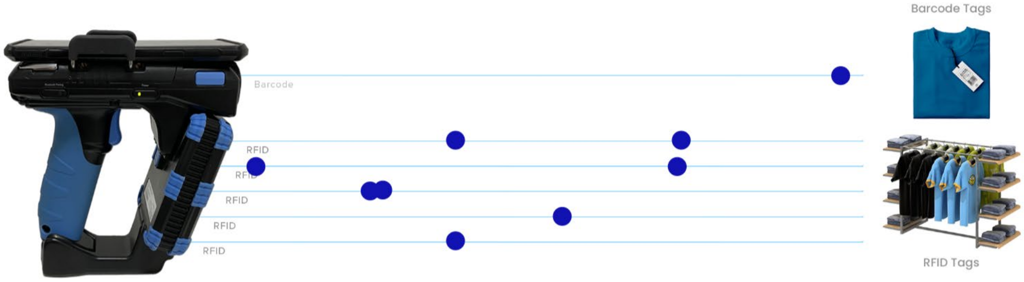

Figure 12: First Representative Scenario – Retail.

The second scenario pertains to the use of the RAIN technology in a factory, warehouse, or similar environment as shown in **Figure 13**.

Figure 13: Second Representative Scenario – Factory.

The reader and tags may be situated at relative distances of various lengths, from short ranges of a few meters to longer link distance as supported by RAIN equipment. The analysis assumes that link distances are typically several meters[83] (or "generally 3-5 m[eters]"[84]) and could exhibit non-line of sight characteristics.[85]

The RAIN Alliance channel model documented in the RAIN Alliance "RAIN RFID System Design Guidelines" is expected to be too benign for this case. Environmental clutter, metal equipment, and other objects are likely to lead to channel impairments beyond what is modeled in this particular channel model. To be conservative, a more stringent channel model is employed in the analysis of this representative scenario. This channel model is based instead on the 3GPP Indoor Factory (InF) dense low channel specified in the 3GPP TS 38.901. Finally, the analysis accounts for the backscatter technology characteristics detailed in the RAIN Alliance "RAIN RFID System Design Guideline."

3.2.6.1. Analysis Methodology

Assuming that all RAIN RFID systems will provide a uniform -70 dBm signal at the reader across all use cases as specified in the RAIN Alliance's comments overlooks the variability that can arise depending on numerous factors tied to both the environment and the system design. Several environmental variables, including multipath propagation, interference, physical obstacles, and the orientation of the tags, affect the signal strength received at an RFID reader.[86] These elements can create significant variation in the power received at the reader. Additionally, the power characteristics can be influenced by the specific tag, reader, and antenna designs used in the system. Different tags might have different sensitivities, and readers might work at different power outputs, all of which further complicates the uniformity of the signal strength. Not every RAIN RFID system will produce or receive a uniform -70 dBm signal at the reader for all or even most use cases.[87]

Rather than assuming a single type and power of RAIN signal, this analysis assesses signal strength dynamically. The signal strength of the RAIN signal becomes a function of, for example, the use case and associated environment, the channel model corresponding to the link between the RAIN reader and tag, and the distances between reader and tag.

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[83] GS1, *What Is the Read Range for a Typical RFID Tag?* (modified Aug. 30, 2024), https://bit.ly/43a4JGK.

[84] Invengo, What Is the Reading and Writing Range of RFID Card Reader?, https://www.invengo.com/what-is-the-reading-and-writing-range-of-rfid-card-reader.html (last visited Feb. 23, 2025).

[85] Gayle Harrop, *The Difference Between RFID and RAIN RFID*, Tamarack Products (Sept. 20, 2023), https://bit.ly/439B9B5.

[86] Joint Comments of RAIN Alliance and AIM Inc., WT Docket No. 24-240 (Sept. 5, 2024) (RAIN & AIM comments).

[87] *See* GS1, *What Is the Read Range for a Typical RFID Tag?* (modified Aug. 30, 2024), https://support.gs1.org/support/solutions/articles/43000734166-what-is-the-read-range-for-a-typical-rfid-tag-, and the RAIN Alliance, *RAIN RFID Lessons Learned From the Field* (Mar. 2021), https://therainalliance.org/wp-content/uploads/2021/04/RAIN_RFID_Lessons_learned_from_the_field.pdf.

To correspond to U.S. standards, the RAIN reader is assumed to have a receiver bandwidth of 500 kilohertz, which is about two times wider than the modulated signal bandwidth and matches the channel spacing used in deployments of the RAIN systems in the U.S. 902-928 MHz band.

For the Factory scenario, the reader transmit power is assumed to be 30 dBm (1 W), consistent with section 15.247 of the Commission's rules and 27 dBm (0.5 W) for the Retail scenario where lower transmit power levels than permitted by the FCC are typically used. The reader gain is assumed to be 6 dB in the direction of the tag for both the transmit and receive paths,[88] as permitted by the rules. The tag is assumed to have an omni antenna with an antenna gain of 0 dBi.

The RAIN tag is assumed to have an efficiency, defined as the ratio of the tag backscatter power to the received power, of -15 dB for the Retail scenario, where less expensive tags may be used, to -8 dB for the Factory scenario. These assumptions are based on data documented in Section 4 of the RAIN Alliance "RAIN RFID Design Guidelines" for various vendors.

3.2.6.2. Analysis

This section analyzes RAIN RFID signal strength and the potential impact of 5G operations in both Retail and Factory scenarios. RAIN signal strengths are shown as a function of the investigated scenario and distances between the reader and tag in **Figure 14** and **Figure 15**. The range of signal strengths encompasses various regimes, including strong signals above -50 dBm, signals at the level of -70 dBm identified in the submission from the RAIN Alliance to the FCC as well as some weaker signals below -80 dBm for some longer link distances in the Factory scenario.

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[88] Using an assumed 6 dB in the direction of the tag for both the transmit and receive paths is reasonable even in multi-tag environments because far-field RAIN panel antennas have wide 3 dB beamwidths. The Times 7 Slimline A5020 RAIN antenna, for example, has a 3 dB beamwidth of 115 degrees and, similarly, the Laird Impinj IPJ-A-1000-USA antenna has a 3 dB beamwidth of 70 degrees. *See* Times-7, *Compact Outdoor RAIN RFID Antenna (Slimline A5020)*, https://support.impinj.com/hc/article_attachments/360000695880 (last visited Feb. 25, 2025); Laird, *Far-Field Panel Antennas (S9028PCLJ-IP1/S9028PCRJ-IP1)*, https://support.impinj.com/hc/article_attachments/17291002266387 (last visited Feb. 25, 2025).

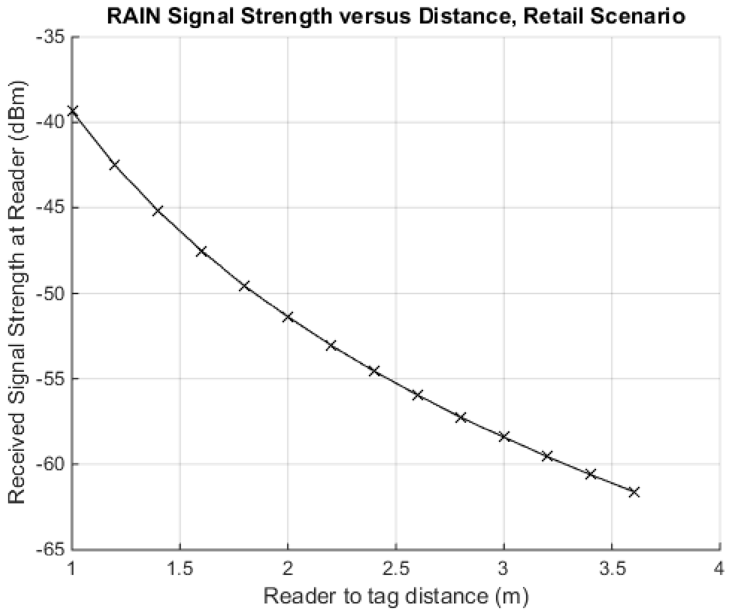

Figure 14: RAIN Signal Strengths for Retail Scenario.

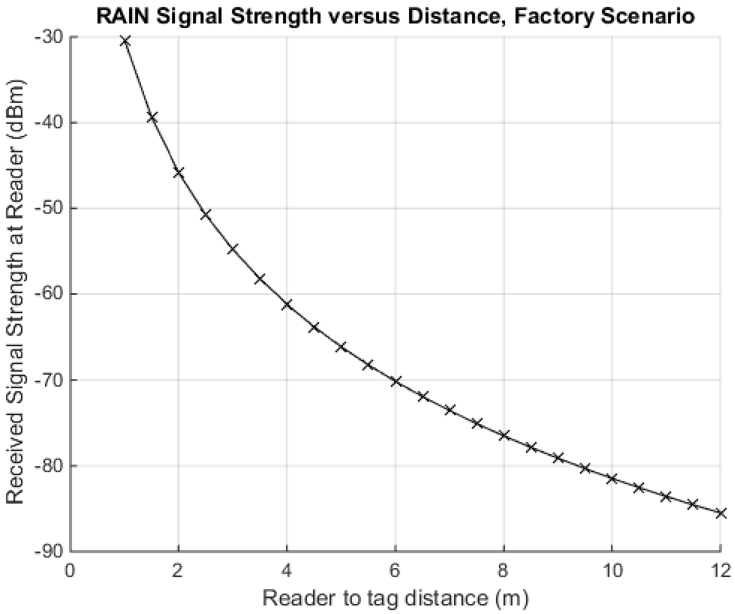

Figure 15: RAIN Signal Strengths for Factory Scenario.

The analysis of the two scenarios projects relatively strong tag signals at the reader due to predicted short ranges of operations. Using the 10 dB SINR metric provided by the RAIN Alliance,[89] this means similarly strong interference must be present to impact RAIN operations. For example, the expected signal level received by the reader whose tag is 1.5 meters away in the above Retail scenario is roughly -47 dBm and an interference signal stronger than -57 dBm would be required to hinder the reader's operation at the impacted

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[89] RAIN Alliance and AIM Inc. Comments on NextNav Petition, WT Docket No. 24-240 (Sept. 5, 2024).

channel. Further, the reader may experience interference from many sources, including other RAIN readers and tags, whose impact to the reader is cumulative.

For the planned 5G uplink operations, 5G UEs, which are characterized by a significantly lower transmit power level (typically lower than Part 15 limit) and duty cycle in conjunction with RAIN's frequency hopping, do not cause unacceptable levels of interference to RAIN devices. For downlink operation, Section 2.3 **Figure 3** clearly shows that the intra-/inter-Part 15 interference is the dominant source of the interference, rather than 5G. The analysis also shows that 5G downlink contribution to estimated intra-/inter-Part 15 interference in the lower 900 MHz band will be marginal at best and does not cause unacceptable levels of interference to Part 15 devices, such as RAIN systems. Indeed, **Figure 16** provides an extraction of the 5G indoor signal strength distribution with 500-kilohertz resolution bandwidth from the Northern Virginia simulation analysis in Section 2.4. The figure shows that approximately 95% of the indoor locations analyzed will experience 5G signal level of -70 dBm or less, providing sufficient margins for RAIN operations with tag distances up to four meters away.

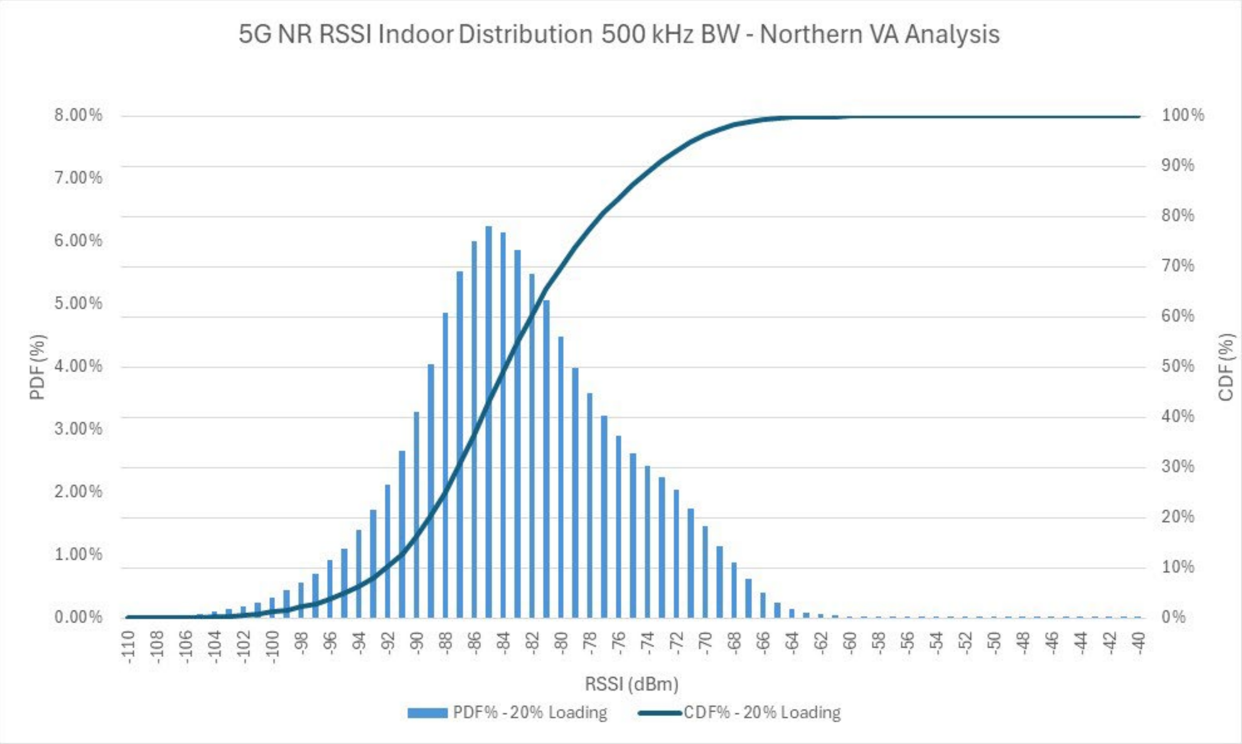

Figure 16: 5G RSSI to indoor - Northern VA simulation.

3.2.6.2.1. Other Factors

Other factors also minimize potential interference. For example, the proposed 5G downlink transmission will not be continuous. Additionally, a RAIN system employs frequency hopping specifically to operate in the presence of interference. These characteristics significantly reduce the probability of impact from a 5G system in real-world scenarios. As described, the RAIN hopping sequence ensures operation in the U.S. across the entire 902-928 MHz band. Therefore, as described above, for 5G downlink transmissions to have an impact on a RAIN system, all of the following must be true simultaneously:

1. A 5G base station must be close enough to the RAIN system to cause potential impact, which is also RAIN deployment-specific because differing RAIN reader/tag ranges yield differing interference resiliency as shown in **Figures 15 and 16**,
2. The RAIN system must be conducting an inventory round,
3. The RAIN system must be operating at a frequency which overlaps with the NextNav proposed downlink band, and
4. The 5G equipment must be transmitting at the same time (i.e., considering loading factor).

The cascaded probability for all four of these conditions to occur simultaneously is exceedingly low. And the low probability of all the specified conditions aligning concurrently ensures that, in practical applications, 5G operations will not cause unacceptable levels of interference to RAIN devices.

3.2.6.2.2. Impact of Interference on Read Latency

As previously described, the RAIN protocol is designed to operate in the presence of interference. Based upon operation of this protocol, a RAIN deployment which experiences an impact from a 5G source, which should be a rare occasion as explained in the previous section, could experience an increase of read latency. This section will quantify that impact.

In this section, the expected delay overhead as a result of the SINR target not being met on one or more dwells, and being met after frequency hopping to a channel that experiences lower interference is studied. The mathematical formulation for the delay overhead is derived and the quantitative results for various conditions are shown in **Figure 17**.

The analysis begins with a calculation of the expected delay overhead due to hopping across channels where SINR cannot be met until a channel is reached where SINR can be met. The expected latency overhead is analyzed quantitatively using the mathematical formulation below.

Let L be the expected latency overhead to be computed, N the total number of channels available in the band and I the total number of channels impaired due to the presence of interference in the band. Let d be the dwell time. Computing L requires breaking the possible outcomes into a set of scenarios to then calculate a latency and a probability. The sum of the scenarios multiplied by their respective probabilities reveals the expected value.

Each scenario has a different likelihood of occurrence. The analysis assumes that the device randomly selects a channel, and if it is impaired, tries again, repeating as necessary until a clean channel is selected. Therefore, the scenarios can be described as: selecting a clean channel on the first try, selecting a clean channel on the second try, and so forth. The scenarios are characterized by the number of impaired channels encountered before a clean channel is found, which can be from 0 to I.

The probability of getting a clean channel on the first try is $(N-I)/N$, and of getting an impaired channel, I/N. If the first channel is impaired, the odds of getting a clean channel on the second try are now $\big((N-1)-(I-1)\big)/(N-1) = (N-I)/(N-1)$ and the odds of getting a second impaired channel are $(I-1)/(N-1)$. The following table summarizes this pattern:

Scenario	**Likelihood**	**Explanation**
0 impaired	$\frac{N-I}{N}$	$(N-I)$ clean options out of N channels
1 impaired	$\frac{I}{N}\times\frac{N-I}{N-1}$	Odds the first one was bad, I/N, times $(N-I)$ clean options out of $(N-1)$ channels
2 impaired	$\frac{I}{N}\times\frac{I-1}{N-1}\times\frac{N-I}{N-2}$	Odds the first two were bad, $(I/N)\times((I-1)/(N-1))$, times $(N-I)$ clean options out of $(N-2)$ channels
3 impaired	$\frac{I}{N}\times\frac{I-1}{N-1}\times\frac{I-2}{N-2}\times\frac{N-I}{N-3}$	
i impaired	$\left(\prod_{j=0}^{i-1}\frac{I-j}{N-j}\right)\times\frac{N-I}{N-i}$	

The analysis must also consider the delay in each scenario. The time of the transmission does not align with the dwell times. So, if the first channel is impaired, the delay could be anywhere from 0 to d, corresponding to an arrival at the end or the beginning of the dwell time. Since this is a uniform distribution, the expected value of this delay is $d/2$. Each additional impaired channel simply adds d. So, for the case when i impaired channels are encountered, the delay is $d/2 + d \times (i-1)$.

Finally, multiplying each scenario's delay by the likelihood from above and then adding them together results in the following equation for the expected latency overhead L:

$$L = \sum_{i=1}^{I} \left(\left(\frac{d}{2} + d \times (i-1) \right) \times \frac{N-I}{N-i} \times \prod_{j=0}^{i-1} \frac{I-j}{N-j} \right)$$

The numerical results for L, in milliseconds, act as a function of the number of impaired channels I as shown in **Figure 17**. Note that the results assume $N = 50$ channels and $d = 200$ milliseconds, consistent with the assumptions in the RAIN Alliance submission to the FCC, where the traversal of the frequency hopping sequence is said to complete in ten seconds.

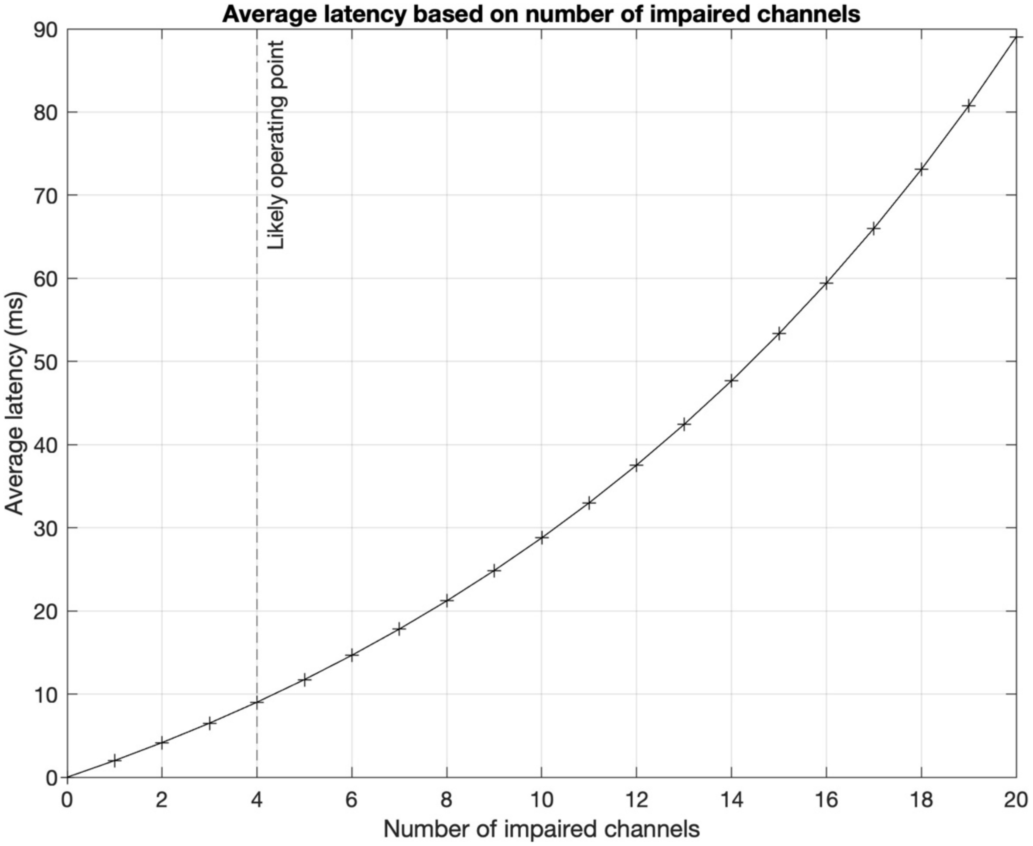

Figure 17: Expected Latency Overhead as a Function of Impaired Channels.

The ten-megahertz 5G downlink signal could overlap up to 19 RAIN channels, but due to the 20% base station loading factor, the expected number of impaired channels would be four, assuming the 5G signal was strong enough to cause any impairment. As illustrated by **Figure 17** above, the expected latency overhead amounts to less than ten milliseconds in this case, and still falls under 90 milliseconds even if 19 channels are impaired.[90]

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[90] In a multi-tag environment, RAIN RFID readers can read in excess of 1,000 reads per second, or more than one per millisecond. Therefore, the additional 10 milliseconds of expected latency is *not* per tag.

While the average (expected) latency overhead can be negligible, the maximum latency overhead can theoretically be higher, assuming the worst-case scenario where the frequency hopping sequence is constructed in such a way that all impaired channels are traversed consecutively prior to dwelling on a channel where SINR can be met. However, such conditions are unlikely to occur, given that frequency hopping sequences are equipped with randomization properties which allow channels throughout the band to be traversed within a given time interval and interfered frequencies tend to be correlated by frequency. The likelihood is further reduced by real-world base stations operating at a load factor far less than 100%, as previously discussed, pushing the expected latency overhead even lower.

3.3. Wi-Fi HaLow

Wi-Fi HaLow (High Efficiency Low Power) is a newer technology based on the IEEE 802.11ah standard. Wi-Fi HaLow supports an OFDM-based physical layer with five available channel bandwidth options: one megahertz, two megahertz, four megahertz, eight megahertz, and sixteen megahertz (the four, eight, and sixteen megahertz channels are optional).[91] It also uses a variety of modulation schemes, including binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and 16 to 256 quadrature amplitude modulation (QAM).[92] These techniques work to mitigate interference and signal degradation by distributing data across multiple subcarriers. It is capable of supporting high data rate connections up to 347 Mbps.[93] With wideband and high data rate capability, it is not surprising popular early use cases for Wi-Fi HaLow seem to be data-intensive ones such as 4K video cameras and Wi-Fi bridges.[94]

Other features of Wi-Fi HaLow also optimize for co-existence. First, the minimum channel spacing for Wi-Fi HaLow is one megahertz, which provides frequency agility for flexible

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Rather, any delay due to an impaired channel is not accumulative among tags, but those unread tags could be read on the next unimpaired dwell. That is, the 10-millisecond expected delay applies to groups of tags, each experiencing the same delay.

[91] *ISO/IEC/IEEE International Standard - 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 2: Sub 1 GHz License Exempt Operation*, in *ISO/IEC/IEEE 8802-11:2018/Amd.2:2019(E)* (Apr. 19, 2019), https://ieeexplore.ieee.org/document/8694176 ("Wireless LAN MAC and PHY Specifications Amendment 2").

[92] Kevin Walsh, *Wi-Fi HaLo: Worth the Wait*, Wi-Fi Alliance Beacon, https://www.wi-fi.org/beacon/kevin-walsh/wi-fi-halow-worth-the-wait (last visited Feb. 23, 2025).

[93] Four spatial streams, 16 MHz channel.

[94] Lorex, Corp., *HaLow*, https://www.lorex.com/pages/halow?srsltid=AfmBOoo0_rbm1FHaGWRkuinzyI9l2NMTEdOJxQcGiuPUfapdiL08mEvB (last visited Feb. 23, 2025); Loocam, *Wireless Bridge Point-to-Point 900 MHz Outdoor WiFi Bridge with 2000 Feet Long-Range Transmission Distance*, https://loocam.com/products/wireless-bridge-point-to-point-900mhz-outdoor-wifi-bridge-with-2600-feet-long-range-transmission-distance (last visited Feb. 23, 2025).

channel assignments.[95] Second, CSMA/CA allows devices to listen to other transmissions before sending data, thereby minimizing the risk of collisions. Third, with SST, HaLow devices can select narrow channel sizes for transmissions to avoid fading and/or interference. Finally, Wi-Fi HaLow supports a relay architecture in which Access Points (APs) and stations (STAs) can act as relay agents to extend the coverage of an AP,[96] with the AP coverage area partitioned into sectors covering a subset of devices. All these features collectively provide robust mechanisms for Wi-Fi HaLow devices to mitigate potential interference and coexist with other Part 15 operations, as well as the planned 5G system.

For 5G uplink operations, 5G UEs would not cause unacceptable levels of interference to Wi-Fi HaLow operations because of the 5G UE's significantly lower transmit power level (typically lower than the Part 15 limit) and low duty cycle. In fact, 5G UEs are better coexistence agents than uncoordinated Part 15 operations. For instance, Wi-Fi HaLow wideband use cases, such as 4K video streaming, should pose more coexistence challenges to Part 15 operations than the planned 5G system.

In the context of 5G downlink operations, NextNav's simulation study shows that the 5G downlink's estimated contribution to intra-/inter-Part 15 interference in the lower 900 MHz band is marginal at best. The SINR impact of 5G downlink is 1.6 dB on average, as explained in Section 2.3. Therefore, 5G downlink does not cause Part 15 performance to degrade to an unacceptable level, even without factoring in the Wi-Fi HaLow coexistence features, which would improve the results. Depending on the channel bandwidth size, Wi-Fi HaLow also supports up to 11 different Modulation and Coding Schemes (MCSs), each separated by 1–5 dB in minimum receiver sensitivity.[97] In other words, a degradation in SINR of one to five dB would simply prompt Wi-Fi HaLow devices to use more robust MCS levels to sustain their connectivity rather than making them inoperable. Again, this MCS request would only occur to the extent that robust MCS levels are needed, which likely will not be the case due to the predicated marginal impact of 5G downlink signals.

Some may argue that, for Wi-Fi HaLow devices already using the most robust MCS level, additional SINR degradation resulting from the planned 5G operation could cause connections to fail. While such scenarios are possible, Wi-Fi HaLow devices operating at the edge of their coverage can be rendered inoperable by any source of interference, not just 5G. The simple reality is that unlicensed operations are unpredictable and uncoordinated. All Part 15 operations that deliver their respective services, including Wi-Fi HaLow, have had to accept the uncertainties and ambiguities inherent in the lower 900 MHz band.

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[95] *See* Aegis-ip, *802.11ah Technology*, https://www.aegis-ip.com/story-HaLow.html (last visited Feb. 23, 2025).

[96] Wireless LAN MAC and PHY Specifications Amendment 2.

[97] Table 23-31—Receiver minimum input level sensitivity, Wireless LAN MAC and PHY Specifications Amendment 2.

3.4. Wi-SUN

Wi-SUN is a wireless standard for IoT applications based on the IEEE 802.15.4g physical layer (PHY) and the IEEE 802.15.4e Media Access Control layer (MAC), with higher layers specified by the Wi-SUN Alliance.[98] The acronym Wi-SUN means, "Wireless Smart Ubiquity Network." Some of the principal use cases include Advanced Metering Infrastructure (AMI) and Distribution Automation and Management for utilities, as well as Smart City IoT, home IoT applications, and many others. The Wi-SUN Alliance specifications include several "profiles" or technical specifications designed to optimize the technology's performance for a particular use case, including profiles for Home Area Networks (HAN) and Field Area Networks (FAN), which comprise multiple Neighborhood Area Networks (NAN).

The base PHY for Wi-SUN is an FSK technology, but the standard also supports an alternate OFDM-based PHY.[99] While FSK is more robust, OFDM offers higher bitrates. Both modulations have several modes as discussed further below, and the Wi-SUN standard supports mode switching between modes on a packet-by-packet basis, either FSK to FSK or FSK to OFDM.[100] The modulation mode switch is made possible by an overhead signaling packet that provides information on the new PHY modulation.

When using FSK modulation, Wi-SUN supports five data rates: 50, 100, 150, 200, and 300 kbps. In general, more bandwidth is required to support the higher bit rates, and FSK bandwidths range from 100 to 600 kilohertz. Wi-SUN also supports "data whitening," a process in which the Boolean function "exclusive or" (XOR) is applied to the data stream and a pseudo-random sequence. The resulting data stream has a more balanced distribution of ones and zeros, which makes the data stream more robust to frequency-specific noise.[101] In addition, Forward Error Correction (FEC) is an optional feature that improves sensitivity by roughly 2 to 4 dB but has the effect of cutting the bit rate in half. Also, since Wi-SUN supports FSK to FSK mode switching, FEC is only useful at times when a link is operating at the lowest bit rate (50 kbps).

In OFDM mode, Wi-SUN supports four bandwidths, and each has seven Modulation and Coding Schemes (MCSs). The supported bandwidths are 200, 400, 800, and 1200 kilohertz and MCSs range from MCS0 to MCS6, with MCS0 being the most robust and supporting the

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[98] everythingRF, *What is Wi-SUN?*, https://www.everythingrf.com/community/what-is-wi-sun (last visited Feb. 24, 2025).

[99] The SUN standard also supports Offset Quadrature Phase Shift Keying (O-QPSK) modulation, but this is not part of the Wi-SUN standard at this time.

[100] Eric Mauger, *LPW -201: Advanced Features Coming to Sub-GHz Networks*, Silicon Labs (2023), https://www.silabs.com/documents/public/presentations/lpw-201-advanced-features-coming-to-sub-ghz-networks.pdf.

[101] Grant Christiansen, *Design Note DN509: Data Whitening and Random TX Mode*, Texas Instruments (2010), https://www.ti.com/lit/an/swra322/swra322.pdf?ts=1739903829225&ref_url=https%253A%252F%252Fwww.google.com%252F.

lowest bit rate and MCS6 supporting the highest bit rate of 2400 kbps. However, when conditions support higher bit rates, as is the case with bursty interfering waveforms like 5G, the higher bit rates translate to a shorter transmission time.

Wi-SUN FAN supports a mesh architecture that consists of border routers, intermediate routers, and leaf nodes. The Wi-SUN FAN profile is used for Automated Meter Reading, Advance Metering Infrastructure, Distribution Automation and Management, and other outdoor applications. Wi-SUN FAN also supports Internet Protocol version 6 (IPv6), and an associated routing protocol called Routing Protocol for Low Power and Lossy networks (RPL) to support multi-hop and many-to-one communications.[102] RPL is a proactive protocol for networks prone to packet loss. It allows Wi-SUN nodes to change paths based on changes in the propagation environment. All Wi-SUN FAN nodes can communicate in both the upstream and downstream directions.

Finally, Wi-SUN supports both CSMA/CA and frequency hopping, to further manage and mitigate interference. A Wi-SUN node accesses a channel using CSMA/CA by randomly selecting a backoff value within the transmission time and delaying transmission accordingly. It then performs CCA to check if the channel is idle. If the channel is idle, the node transmits the packet. If the channel is busy, the node retries CCA with an extended backoff range until access is granted. Wi-SUN nodes also employ a pseudo-random channel hopping sequence, unique to each node, for both unicast and broadcast transmissions, enhancing network reliability in noisy channel conditions by dynamically switching data transmission across different channels.

In summary, Wi-SUN supports several features that enable its resilience in the presence of other signals operating in the band. These features include:

- FSK modulation with optional FEC;
- Frequency hopping;
- CSMA/CA;
- Support for OFDM modulation with shorter transmission times;
- Modulation mode switching (FSK to FSK or FSK to OFDM); and
- Mesh architecture with RPL to proactively optimize paths.

NextNav's analysis shows that 5G waveforms in the lower 900 MHz band as proposed will have a very small effect on Wi-SUN performance. For Wi-SUN operation in the 902-907 MHz portion of the band, uplink transmissions from 5G UEs will not cause unacceptable levels of interference due to their low power relative to other Part 15 devices and their low activity factor. Part 15 devices operating in the band represent much larger coexistence risk than 5G emissions due to the Part 15 devices' higher power and more frequent transmissions. In the 918-928 MHz 5G downlink band, the likelihood of co-channel

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[102] GeeksforGeeks, *RPL (IPv6 Routing Protocol)* (last updated June 18, 2024), https://www.geeksforgeeks.org/rpl-ipv6-routing-protocol/.

operation with Wi-SUN is minimal due to Wi-SUN's ability to frequency hop across the entire band. When co-channel operation does occur, NextNav's analysis in Section 2.3 above shows that the incremental SINR impact resulting from the 5G downlink will be a mere 1.6 dB on average relative to the interference and noise already present in the band created by the many other uncoordinated Part 15 transmissions. In general, the many features that Wi-SUN employs to maximize the probability of successful transmissions in the presence of other Part 15 interfering signals allow the technology to operate successfully in a shared band like the lower 900 MHz band and will allow Wi-SUN to operate successfully in the presence of the proposed 5G network.

3.5. Z-Wave

According to the Z-Wave Alliance, Z-Wave is "the most widely used wireless protocol for the smart home and Internet of Things ('IoT') industries," and it is estimated there are more than 100 million devices deployed utilizing the Z-Wave protocols.[103] The Alarm Industry Communications Committee (AICC) also highlights Z-Wave as an important technology used by the alarm industry.[104]

Z-Wave technology uses four frequencies in the United States: classic Z-Wave operates on 908.42 MHz and 916 MHz, while Z-Wave Long Range (LR) operates on the default 912 MHz and the backup 920 MHz channel. Of these, only the backup LR channel at 920 MHz[105] overlaps NextNav's proposed 5G band plan; specifically, it overlaps the 5G downlink. The other frequencies used in the U.S. will be adjacent to the proposed 5G uplink bands, where 5G power will be limited to out-of-band emissions and will not cause unacceptable levels of interference.

On the one back-up channel that overlaps with the 5G downlink, the probability of the Z-wave transmissions colliding with co-channel 5G downlink transmissions will be mitigated by the 5G downlink network loading factor. Specifically, a 5G network working at much less than 100% loading factor will mean that there could be collision only a fraction of the time. For example, with a 20% network loading factor, assuming a 20% occupancy for 5G downlink transmission in time, the Z-wave LR transmission will overlap in time with the 5G downlink transmissions only 20% of the time. Even if there is a collision with 5G downlink, the Z-Wave communication may still succeed if there is enough link budget margin based on the operating point of the system, which is often well above sensitivity limits. Alternately, if the link budget margin does not allow for link success in the case of a

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[103] Comments of the Z-Wave Alliance at 2, 3, WT Docket No. 24-240 (Sept. 5, 2024).

[104] Comments of AICC at 4–6, WT Docket No. 24-240 (Sept. 5, 2024).

[105] Silicon Labs, for example, has explained that the 920 MHz is the backup channel for LR. *See* Silicon Labs, Anson Huang, *Design With Z-Wave to Extend Your Wireless Range 1 Mile*, Silicon Labs (Mar. 26, 2021), https://www.silabs.com/documents/public/presentations/design-with-z-wave-to-extend-your-wireless-range-1-mile-tw.pdf.

collision, retransmission capability built into the Z-Wave MAC protocol[106] will allow for successful communication using one retransmission attempt with success probability >96%[107] and using two retransmission attempts with success probability >99.2%.[108] CCA[109] can also allow for Z-Wave LR to further avoid collisions with 5G downlink interference during transmission by querying the availability of the channel from the PHY layer before transmitting and thus avoiding downlink interference.

Even for the co-channel case, NextNav's simulation analysis shows that the 5G downlink contribution to already existing intra-/inter-Part 15 interference is marginal at most and does not cause unacceptable levels of interference. In Section 2, NextNav performed simulations with realistic Part 15 interference environment as well as reasonable coverage radius for Part 15 devices to assess the incremental effect of the 5G interference on top of the Part 15 interference. The results from Section 2.3, **Figure 4**, are reproduced in **Figure 18** for ease of reference and illustrate that the 5G downlink interference creates a very small SINR impact.

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[106] Z-Wave Long Range PHY and MAC Layer Specification v2.0 discusses how the MAC protocol supports retransmission.

[107] If p is the probability of success in a single attempt, then after 1 retransmission attempt, the probability of successful transmission equals $p + (1-p) \times p$. With p = 1- probability of failure = 1-0.2=0.8, one obtains a successful transmission probability after 1 retransmission attempt equal to 96%.

[108] If p is the probability of success in a single attempt, then after 2 retransmission attempts, the probability of successful transmission equals $p + (1-p) \times p + (1-p)^2 \times p$. With p = 1- probability of failure = 1-0.2 = 0.8, one obtains a successful transmission probability after 2 retransmission attempts equal to 99.2%.

[109] Z-Wave Long Range PHY and MAC Layer Specification v2.0 discusses how the MAC protocol supports CCA.

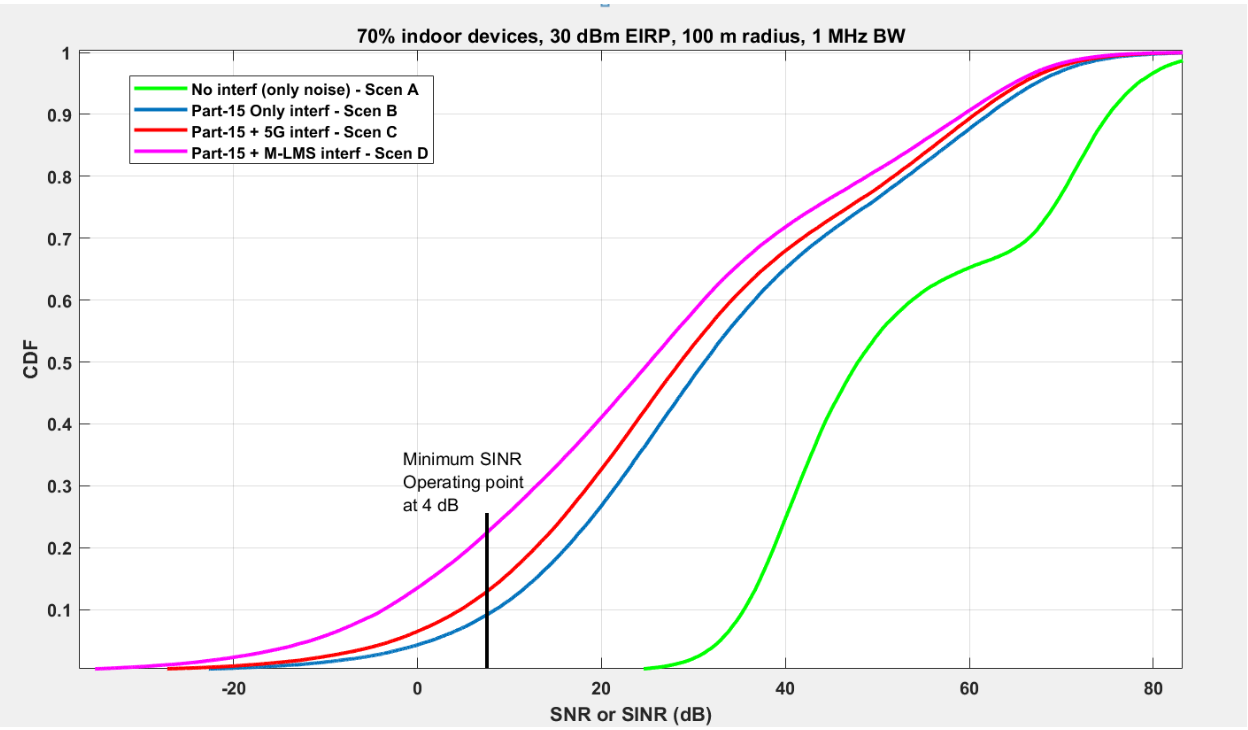

Figure 18. Simulation results from Figure 4 (Section 2.3) with annotation of operating point (4 dB)

Comparing the Scenario B and C plots in **Figure 18**, the incremental impact on SINR from 5G interference is ~1.6 dB comparing the mean values. Most importantly, at the operating point limit of Z-Wave LR minimum SINR, which is roughly 4 dB[110] and marked on **Figure 18**, the outage probability only increases by less than three percent in the presence of 5G downlink emissions compared to approximately twelve percent increase in outage probability for the M-LMS case. Also, the predicted outage is for a single Z-Wave transmission. The previously mentioned retransmission mechanism inherent in Z-Wave technology will further reduce the actual outage probability. 5G emissions at this level are acceptable because they do not measurably impact Z-Wave system operation, especially since any predicted effects occur on an optional channel of Z-Wave systems.

Conclusions

This analysis helps confirm that introducing 5G operations will not cause unacceptable levels of interference to unlicensed devices in the lower 900 MHz band. 5G network operations would generally emit no more than what is already permitted under Part 90

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[110] Based on SNR derived from noise figure assumptions of 10 dB, an LR bandwidth of ~580 kilohertz and chipset sensitivity of -110 dBm, result in an SNR/SINR requirement of ~ 4 dB. *See* Silicon Labs, ZGM230S Z-Wave 800 SiP Module Data Sheet, https://www.silabs.com/documents/public/data-sheets/zgm230s-datasheet.pdf (last visited, Feb. 27, 2025) (providing chipset sensitivity).

rules. Any addition to existing Part 15 emissions in the band as a result of 5G operations would be marginal at best. And unlicensed devices already rely on an array of adaptive mechanisms to manage intra- and inter-Part 15 interference, which will remain the dominant coexistence factor even with 5G deployment.

Real-world analysis further reinforces these conclusions. A study of NextNav's San Francisco M-LMS deployment operating in compliance with FCC regulations shows that for many years it produced greater on-the-ground emissions than 5G would without a single confirmed interference complaint from unlicensed operators. This long-lasting case study supports the conclusion that 5G will have no greater impact on unlicensed operations than existing licensed or unlicensed operations do. Additionally, this study's comprehensive radiofrequency analysis of the major unlicensed technologies operating in the lower 900 MHz band—including LoRaWAN, RAIN RFID, Wi-Fi HaLow, Wi-SUN, and Z-Wave—demonstrates that each technology possesses robust interference mitigation mechanisms, such as frequency hopping, adaptive modulation, and retransmission protocols. These features will help ensure that unlicensed devices can continue to function seamlessly in the presence of 5G operations. Given these findings, the introduction of 5G will not materially alter the existing noise environment, much less cause unacceptable levels of interference to unlicensed devices.

Appendix A: San Francisco M-LMS and 5G Simulation Analysis

1. San Francisco M-MLS site information

The table below provides information regarding NextNav's TerraPoiNT deployment in San Francisco, California. The table lists each base station's NextNav site identification number, its geographic coordinates, the transmitter height above ground, and its on-air date. All facilities remained operational through at least January 22, 2020, when selective decommissioning began as part of next-generation network planning and deployment.

Site ID	Latitude	Longitude	Height Above Ground (Meters)	On-Air Date
CASFO0001	37.785538	-122.397995	83.2	3/20/12
CASFO0002	37.785095	-122.408844	115.8	3/20/12
CASFO0003	37.78664	-122.40323	112.8	3/20/12
CASFO0004	37.791924	-122.40032	99.7	7/6/12
CASFO0017	37.789146	-122.40675	57.9	9/28/16
CASFO0019	37.79135	-122.39826	158.2	3/20/12
CASFO0031	37.79308	-122.414185	73.2	10/23/12
CASFO0055	37.77935	-122.38893	37.2	3/17/14
CASFO0071	37.792145	-122.403534	247.7	2/28/13
CASFO0072	37.78954	-122.4002	175.9	8/15/12
CASFO0073	37.78573	-122.392166	179.2	11/9/12
CASFO0074	37.794033	-122.39736	155.1	3/20/12
CASFO0094	37.781384	-122.407455	36.9	9/10/14
CASFO0172	37.78092	-122.395706	27.1	6/21/16
CASFO0174	37.79122	-122.392044	79.9	6/20/16
CASFO0175	37.79531	-122.39637	179.5	5/6/16
CASFO0176	37.798767	-122.40498	21.0	9/1/16
CASFO0177	37.785305	-122.41521	71.0	6/21/16
CASFO0201	37.80839	-122.41273	17.4	9/19/16
CASFO0203	37.804596	-122.423294	27.1	8/24/16
CASFO0241	37.784924	-122.42434	76.2	9/28/16
CASFO0279	37.807865	-122.41625	14.9	6/27/16
CASFO0281	37.80097	-122.424774	36.6	10/10/16
CASFO0282	37.807423	-122.42017	18.9	9/19/16
CASFO0060	37.77717	-122.41765	109.1	3/20/12
CASFO0069	37.80572	-122.41684	18.3	6/14/12
CASFO0070	37.798218	-122.41742	72.7	10/12/12

Site ID	Latitude	Longitude	Height Above Ground (Meters)	On-Air Date
CASFO0075	37.789856	-122.42182	82.9	10/3/12
CASFO0087	37.78423	-122.40575	51.1	11/7/12
CASFO0004	37.791924	-122.40032	99.7	7/6/12
CASFO0031	37.79308	-122.414185	73.2	10/23/12
CASFO0072	37.789555	-122.40022	175.9	8/15/12
CASFO0074	37.794056	-122.39738	155.1	3/20/12
CASFO0075	37.789856	-122.42182	82.9	10/3/12

2. M-LMS and 5G simulation assumptions and settings

The simulations of NextNav's actual M-LMS network in San Francisco and a comparable 5G NR design used the following assumptions and settings.

2.1. M-LMS coverage analysis

For the 34 deployed M-LMS sites, the Radio Frequency (RF) propagation simulation employed the following settings.

- Locations and properties: used actual deployed locations and heights (see Appendix A section 1 table)
- Frequency: 2x2 MHz bandwidth in M-LMS B and C block
- Transmitted power: Peak ERP of 30 W
- Inter-site distance: Average 325 meters based on actual site locations
- Activity factor: 10% duty cycle as NextNav's M-LMS operation

2.2. 5G NR coverage analysis

5G NR sites were estimated to offer coverage similar to the M-LMS coverage and meeting the PRS coverage with four or more 5G transmitters visible.

- Locations and properties: Google Earth estimated location and height at each structure with three-sector configuration
- Frequency: 10 MHz Downlink at 923 MHz center frequency (918 ~ 928 MHz)
- Conducted transmit power per transmitter: 40 W or 46 dBm
- Number of transmit diversity: 4
- Antenna: 4-port sector antenna with 15.4 dBi gain, and Horizontal Beamwidth (HBW) of 60 degrees and Vertical beamwidth (VBW) of 7.6 degrees

- Total EIRP: 46 dBm + 6 dB (4 Tx) + 15.4 dBi – 1.4 dB (cable loss) = 66 dBm
- Inter-site distance: 1,660 meters[111]
- Activity factor: 20% downlink loading factor

2.3. Settings common to both coverage analyses

- Prediction model: InfoVista Planet Universal Model (aka Orange's radio propagation model)
- Building penetration loss: 20 dB outer wall penetration loss + 0.5 dB/meter pathloss inside building

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[111] The average inter-site distance is based on the San Francisco 5G design.

Appendix B: Part 15 System-Level Simulation Assumptions

Table B.1 summarizes the main M-LMS and 5G network parameters used in the simulation. Unless explicitly stated, the evaluation follows the methodology of 3GPP TR 36.872, Annex A.1.1.[112]

Table B.1: Summary of the main 5G network parameters in the simulation

Parameter	Value for 5G network	Value for M-LMS network
Layout	Hexagonal grid, 19 Macro sites, 3 sectors (cells) per site	Hexagonal grid, 19 Macro sites, 1 sector (cell) per site
Carrier frequency	923 MHz	
Total system bandwidth	10 MHz	Total of 7.5 MHz[113]
Effective bandwidth	1 MHz (see **Appendix C**)	
BS total average transmit power	52 dBm (four transmit antennas with 46 dBm per antenna)	45 dBm[114] (one transmit antenna)
Inter-site distance (ISD)	1,732 m (see Section 3)	400 m (see Section 3)
Pathloss, Line of Sight (LoS) probability, and lognormal shadowing	According to ITU Urban Macro model[115]	
Building penetration	For outdoor Part 15 devices: 0 dB For indoor Part 15 devices: 20 dB+0.5d_{in} per external building wall in the signal path, where d_{in} is an independent uniform random value within (0, 25) m for each link	
Antenna height	25 m	
Antenna pattern	According to Table A.2.1.1-2 in 3GPP TR 36.814[116]	2D Omnidirectional
Antenna gain	14 dBi	0 dBi
Maximum transmit EIRP	52 + 14 = 66 dBm	45 + 0 = 45 dBm
Activity factor (modeled according to Section 7 of	20% (see Section 2.1)	10% (typical value in current deployments)

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[112] 3GPP TR 36.87 (Release 12), accessible at: https://www.3gpp.org/ftp/Specs/archive/36_series/36.872/.

[113] M-LMS B and C blocks.

[114] 30 W peak ERP with 2 dB peak-to-average ratio is converted to 45 dBm average EIRP.

[115] 3rd Generation Partnership Project TR 38.901 V18.0.0; Study on channel model for frequencies from 0.5 to 100 GHz (Release 18), accessible at: https://www.3gpp.org/ftp/Specs/archive/38_series/38.901/.

[116] 3rd Generation Partnership Project TR 36.814; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9), accessible at: https://www.3gpp.org/ftp/Specs/archive/36_series/36.814/.

Parameter	Value for 5G network	Value for M-LMS network
Recommendation ITU-R M.2101[117])		

Table B.2 summarizes the main Part 15 network parameters in the simulation. Unless explicitly stated, the evaluation follows the methodology in 3GPP TR 36.872, Annex A.1.1.

Table B.2: Summary of the main Part 15 network parameters in the simulation

Parameter	Value
Layout	Clusters of Part 15 devices uniformly random within the 5G or M-LMS macro geographical area; a single Part 15 transmitter and a single Part 15 receiver device are dropped within each cluster
Carrier frequency	923 MHz
Total system bandwidth	1 MHz (see **Appendix C**)
Part 15 total transmit power (single transmit antenna)	24 dBm (see **Appendix D**)
Pathloss, Line of Sight (LoS) probability, and lognormal shadowing	According to Section A.2.1.2 of Annex A.2 in 3GPP TR 36.843 for outdoor-to-outdoor, outdoor-to-indoor, and indoor-to-indoor Part 15 D2D communication (note the additional references therein)
Placement of active Part 15 devices	70% indoors and 30% outdoors
Building penetration	For outdoor Part 15 devices: 0 dB For indoor Part 15 devices: 20 dB+0.5d_{in} per external building wall in the signal path, where d_{in} is an independent uniform random value within (0, 25) m for each link
Antenna height	1.5 m
Antenna pattern	2D omnidirectional
Antenna gain	6 dBi (see **Appendix D**)
Transmit EIRP	24 + 6 = 30 dBm
Number of Part 15 transmitting devices dropped within each cluster	1
Total number of Part 15 transmitting devices	513 for 5G and 27 for M-LMS (based on device density calculated in **Appendix C** and 19 Macro site layout for each network)
Part 15 dropping	According to Configuration #4b in Table A.2.1.1.2-5 in 3GPP TR 36.814 with 100% probability of Part 15 devices dropped within cluster

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[117] International Telecommunication Union, Recommendation ITU-R M.2101-0, *Modelling and Simulation of IMT Networks and Systems for Use in Sharing and Compatibility Studies* (Feb. 1, 2017), https://store.accuristech.com/standards/itu-r-m-2101-0?product_id=2816619&srsltid=AfmBOooqNy0XW9iz2BlRtmFJANT9l0Qqw-8ni7HZsL7QeIXPMoObIHm1.

Parameter	Value
Radius for Part 15 receiving device in a cluster (Part 15 radius)	100 m
Minimum distance between 5G BS and Part 15 device cluster	35 m
Minimum distance between Part 15 devices in a cluster	3 m (see 3GPP TR 36.843)
Part 15 Noise Figure	10 dB

Appendix C: 900 MHz Part 15 Device Density Estimation

To derive the number of active Part 15 devices in the simulated 5G and M-LMS network environments, this study calculated the per-sector density of active Part 15 devices as follows:

$$Active\ Devices\ per\ Sector = \frac{Total\ Device\ Count\ \cdot\ DL\ Overlap\ probability\ \cdot\ Activity\ Factor}{Total\ 5G\ Sector\ Count}$$

Total Device Count. Consistent with Part 15 proponents' claims in the record,[118] the estimated total device count for this calculation is 5 billion. We recognize that, given potential growth in the number of Part 15 devices in the band,[119] this total device count may be significantly higher by the time the proposed 5G network is in operation.

Downlink Overlap Probability. We then multiply the total device count by the probability of a Part 15 device operating frequency overlapping with that of the planned 5G downlink (918-928 MHz). The study estimates this probability to equal the percentage of the 26 MHz of lower 900 MHz band that the planned 10 MHz of 5G downlink takes up, which is 0.38.

Activity Factor. We then multiply the product of the total device count and the probability of overlap with the planned 5G downlink by an activity factor to arrive at the estimated number of active devices whose operating frequencies overlap with the downlink. A conservative, uniform 1% activity factor is assumed across all the Part 15 devices.

Total 5G Sector Count. Finally, we divide this estimated number of relevant, active Part 15 devices by the estimated number of sectors to derive our per-sector active Part 15 device density value. A total of 70,000 5G sites is used for this analysis.[120] Given that there are typically three sectors per site, there would be a total of 210,000 sectors.

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[118] *See, e.g.*, Reply Comments of Itron, Inc. at 4, WT Docket No. 24-240 (Sept. 20, 2024) (claiming that there are "[b]illions of unlicensed devices in the 902-928 MHz band"); Reply Comments of LoRa Alliance at 4-5, WT Docket No. 24-240 (Sept. 20, 2024) (summarizing similar claims in the record). "[P]roceedings demonstrate, there are presently billions of unlicensed devices operating in the band." Comments of LoRA Alliance at 9, WT Docket No. 24-240 (Sept. 5, 2024).

[119] *See, e.g.*, Rain & AIM comments at 4-7 (describing projected growth in unlicensed Part 15 devices in the band).

[120] *See In re Communications Marketplace Report*, 2024 Communications Marketplace Report, GN Docket No. 24-119, FCC 24-136 ¶ 75 (rel. Dec. 31, 2024) ("WIA estimates that 244,800 macrocell sites were in operation at the end of 2023"). Given that there are four nationwide operators, but three of them are well established with many more sites than the fourth, a suitable denominator to calculate an average number of sites per established nationwide operator is 3.5, and 244,800 / 3.5 = ~70,000.

The resulting active device count per 5G sector is:

$$Active\ Devices\ per\ Sector\ = \frac{5\ billion\ \cdot\ 0.38\ \cdot\ 0.01}{210{,}000} = 91.6$$

We then further multiply this active device count by the probability of frequency overlap among these devices to identify the number of such devices that would be interfering with one another.[121] This probability is a function of many factors including the channel bandwidths and channel plans of the various Part 15 technologies involved. Since there are both narrowband and wideband Part 15 technologies that support different degrees of frequency agility, we assume for purposes of this analysis a uniform 1 MHz Part 15 channel bandwidth for all Part 15 devices. We thus estimate the probability of frequency overlap between two transmitting Part 15 devices to be 0.1 (1 MHz divided by 10 MHz 5G downlink span). The estimated per-sector density of Part 15 devices that are active, that transmit in frequencies overlapping with NextNav's planned 5G downlink band, and that interfere with one another, is therefore:

$$\begin{aligned} &Device\ Density\ per\ Sector \\ &\quad = Active\ Devices\ per\ Sector\ \cdot\ probability\ of\ inter-Part\ 15 \\ &\qquad interference\ = 91.6\ \cdot\ 0.1\ \approx 9.2 \end{aligned}$$

As described above, the probability of inter-Part 15 interference used (0.1) as an approximation of the expected probability of total overlap between the 1 MHz bands of any pair of Part 15 devices. This probability value does not account for potential interference caused by fractional, or "nonzero," overlaps between the transmission bands of two Part 15 devices. If we account for the probability of all such interference scenarios, then the probability of inter-Part 15 interference would be approximately twice as much (about 0.2) and, as a result, the per-sector density of active Part 15 device density would also be twice as much. The exact formulas for the probability of collision (i.e., nonzero overlap) between two equal-length sub-bands (of length l each) within a given overall bandwidth L are shown below, where l is equal to the assumed 1 MHz Part 15 channel bandwidth and L is equal to the 10 MHz 5G downlink span. However, to be conservative, we used 0.1 for purposes of this simulation.

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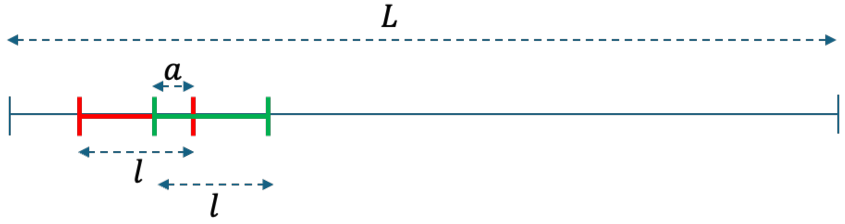
[121] Most of these Part 15 devices operate in an uncoordinated manner and are expected to create contention and interference to one another, especially given the enormous device count existing in the band. From the underlying interference condition perspective, these Part 15 devices are not only subjected to interference from one another, but also from other non-Part 15 systems in the band such as non-M LMS, amateur radio, and ISM devices. However, for this analysis, inter-Part 15 interference is the focus and other interference sources are not considered.

$$P(C) = \frac{l(2L - 3l)}{(L - l)^2} \cong \frac{2l}{L}$$



Appendix D: Part 15 Indoor Simulation Assumptions

This indoor simulation study predicts and compares the indoor signal strength of Part 15 deployments and 5G deployments. The study focused on the Northern Virginia area surrounding Dulles Airport because of the mix of urban and suburban morphologies as well as densely populated commercial and residential buildings in the area. A map of the area is shown below in **Figure 19**.

Figure 19: Part 15 Indoor Simulation Area of Interest.

We conducted the 5G and Part 15 signal simulations separately. For the 5G signal simulation, the study used InfoVista Planet, an industry standard RF propagation tool widely used by MNOs.[122] We used the pre-tuned Universal Model developed by Orange[123] as the propagation model, and the 3-dimension building polygons from the Federal Emergency Management Agency Geospatial Resource Center.[124]

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[122] InfoVista, *Accurate and Efficient Wireless Network Planning,* https://www.infovista.com/products/planet/rf-planning-software (last visited Feb. 24, 2025) & InfoVista, *Our Customers: They Deliver The Networks People Love With Us*, https://www.infovista.com/our-customers (last visited Feb. 24, 2025).

[123] Hello Future Orange, *Orange's Radio Propagation Model: An Essential Element in Mobile Network Development* (June 24, 2024), https://hellofuture.orange.com/en/oranges-radio-propagation-model-an-essential-element-in-mobile-network-development/ & Hello Future Orange, *MWC 2019: 5G, the Right Model for Deploying the Right Technologies* (Feb. 25, 2019), https://hellofuture.orange.com/en/mwc-2019-5g-the-right-model-for-deploying-the-right-technologies/.

[124] FEMA, *USA Structures*, https://gis-fema.hub.arcgis.com/pages/usa-structures (last visited Feb. 24, 2025).

The simulation also used common 5G NR Radio deployment settings and certain other proposed 5G network assumptions, as listed below. We estimated the outdoor location of each 5G tower using publicly available online sources. The transmitter heights were assumed to be the structure heights at each location, and were estimated using the 3D height elevations taken in Google Earth.

- Transmitter frequency: 10 MHz downlink at center frequency 923 MHz (918 ~ 928 MHz)
- Conducted transmit power per transmitter: 40 W or 46 dBm
- Number of transmitters: 4
- Antenna: 4-port sector antenna with 15.4 dBi gain, HBW of 60 degrees and VBW of 7.6 degrees
- Total EIRP: 46 dBm + 6 dB (4 Tx) + 15.4 dBi – 1.4 dB (cable loss) = 66 dBm
- All sites have 3-sector configurations with 0, 120, and 240 degrees for the sector antenna orientations
- All antennas have 4 degrees down tilt
- 20% downlink loading factor

For the Part 15 device signal simulation, we used the following settings. As explained in **Appendix C**, we assumed 1 MHz bandwidth for all Part 15 devices. The simulation assumed one transmitter per indoor location.

- Transmitter frequency: 1 MHz Downlink at 923 MHz center frequency
- Conducted Transmit power per transmitter: 0.25 W or 24 dBm
- Number of transmitters: 1
- Antenna: Omni antenna with gain of 6 dBi
- Effective EIRP: 30 dBm (24 dBm Tx power + 6 dBi antenna gain)
- Transmitter height: 1.5 meters
- Receiver height: 1.5 meters