HWG | HARRIS, WILTSHIRE & GRANNIS LLP

October 7, 2019

Ex Parte

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

Re: *Unlicensed Use of the 6 GHz Band*, ET Docket No. 18-295; *Expanding Flexible Use in Mid-Band Spectrum between 3.7 and 24 GHz*, GN Docket No. 17-183

Dear Ms. Dortch:

On October 3, 2019, representatives from Apple Inc., Broadcom Inc., Charter Communications, Inc, Cisco Systems, Inc., Hewlett Packard Enterprise, Marvell Semiconductor, Inc., Qualcomm Incorporated, and the Wireless Internet Service Providers Association met with representatives of the FCC's Office of Engineering and Technology. A complete list of attendees is attached.

We discussed the attached presentation which supplements the proceeding's already deep record demonstrating that the introduction of RLAN devices into the 6 GHz band will not cause harmful interference to FS links. The presentation found that the effect of RLAN devices on fixed-service receivers, even accounting for rare deep-fade events, is minimal and does not rise to the level of harmful interference. To demonstrate this, the study analyzed the effect of RLANs on FS receivers experiencing realistic patterns of multipath fade. It found that expected RLANs operations would have negligible impact on FS links, even accounting for deep fades. Therefore, in order to show any measurable impact, the analysis had to force both an unrealistically high I/N level and unrealistically high duty cycles into the model. We in no way endorse a finding that interference at these levels would occur (in fact, they are vastly higher than anything we have predicted, even in unlikely worst-case scenarios). However, these results demonstrate that, even with extreme and unrealistic assumptions, any interference to FS links would not rise to the level of *harmful* interference because it would be fleeting, very rare, and would not seriously degrade operations.

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

Sincerely,

Paul Margie
Counsel to Apple Inc., Broadcom Inc., Cisco Systems, Inc., and Hewlett Packard Enterprise

Encl.
Cc: Meeting Participants

MEETING PARTICIPANTS

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Multipath Fading

October 3, 2019

Executive Summary

- As we have shown, actual RLAN interference from low-power indoor (LPI) and very-low-power (VLP) operations will fall below -6 dB I/N the vast majority of the time. In rare cases when there is a risk of exceeding this value, the FS link will almost certainly be unaffected due to a high carrier-to-noise ratio (C/N).
- FS receivers are designed with such high C/Ns to minimize the effect of atmospheric fading, which is an effect that dwarfs any potential interference from RLAN devices.
  - In fact, as we will show, almost all links have far *higher* C/N than they need to perform at the required level.
- Thus, the risk that RLAN interference will have a material effect on an FS link is not just the very low probability of a given I/N value, but the probability that this will coincide with an atmospheric fade of sufficient magnitude to jointly exhaust the available SNR.
- To make the safety margin clear, we examined RLAN/FS interactions using an extreme I/N figure that is far higher than anything suggested on the record: +20 dB I/N.
- We do not endorse this I/N number as a reasonable assumption in any way. But even if this level were somehow seen, and even if it coincided with a fade event, the result will still not cause harmful interference.

Multipath Fading Overview

Multipath Fading Overview

- As microwave signals travel long distances, the signals can take slightly different paths. Signals travelling different paths can arrive at the receiver at different times, potentially resulting in a form of self-interference.
- This phenomenon is called multipath fading.

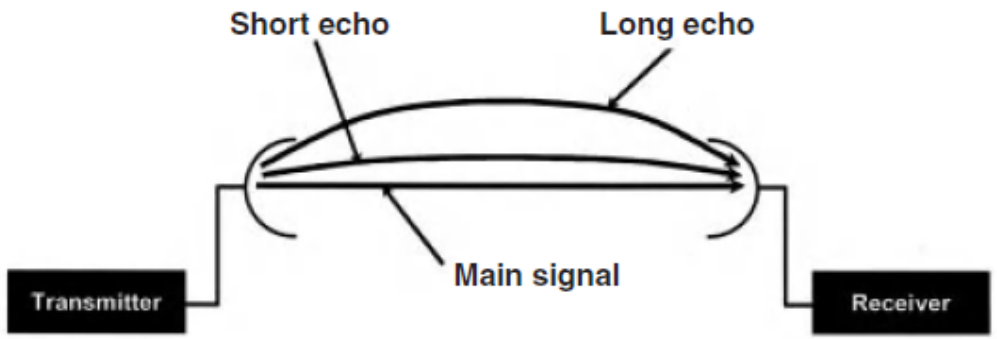
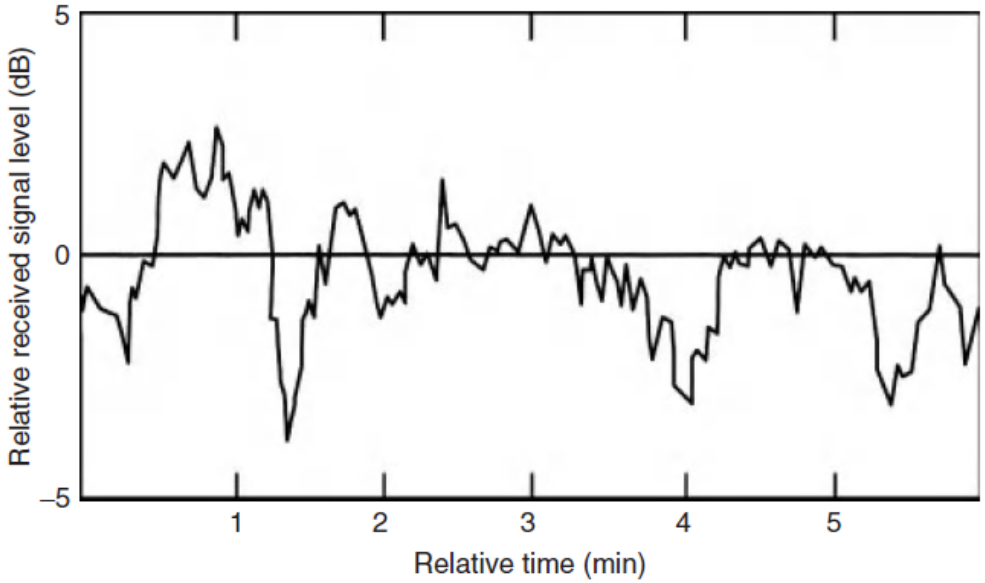


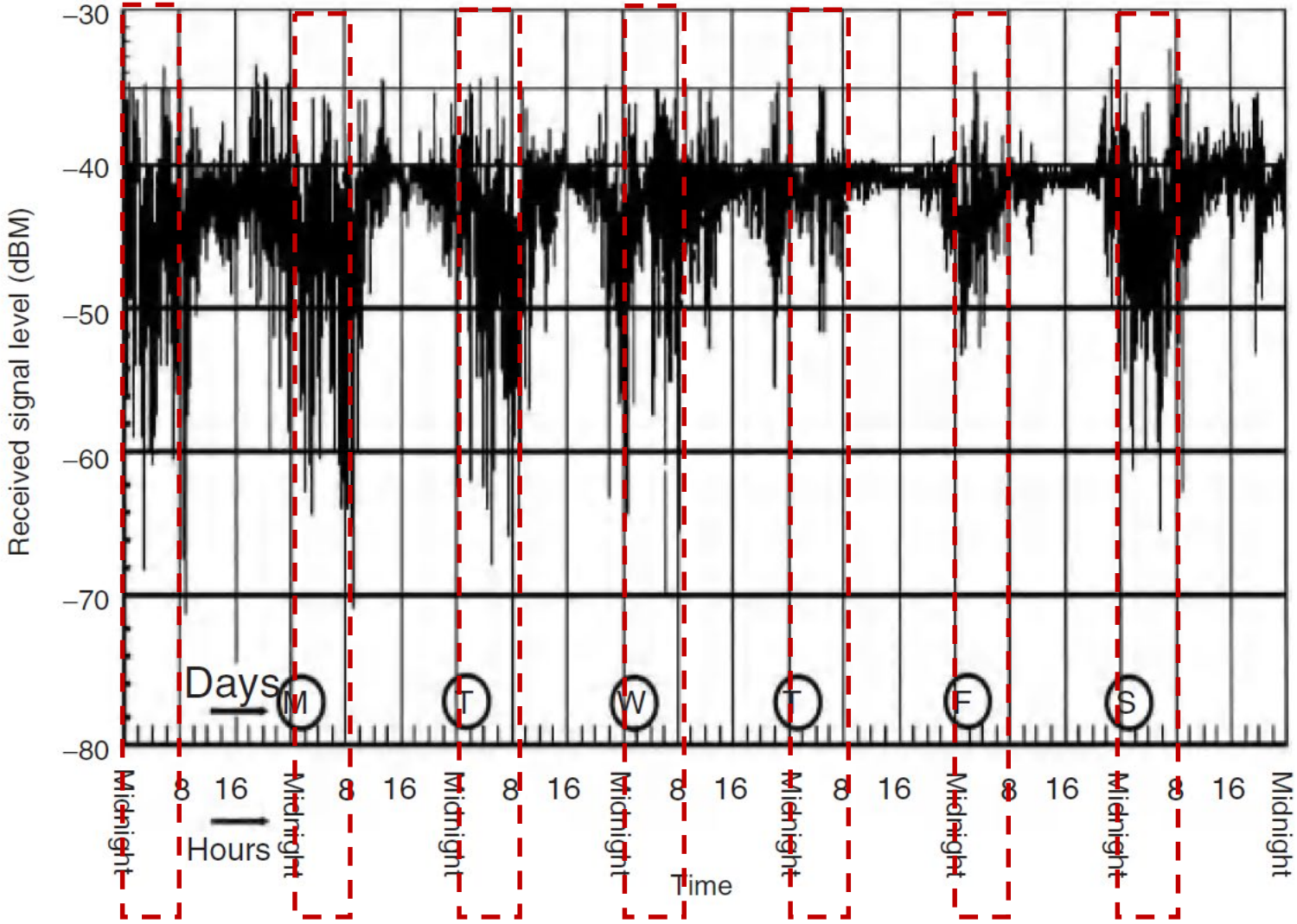
Figure 5.34 Desired and multipath signals.



G. Kizer, “Digital Microwave Communication”, 2013

Multipath Fading is at its Worst at Night

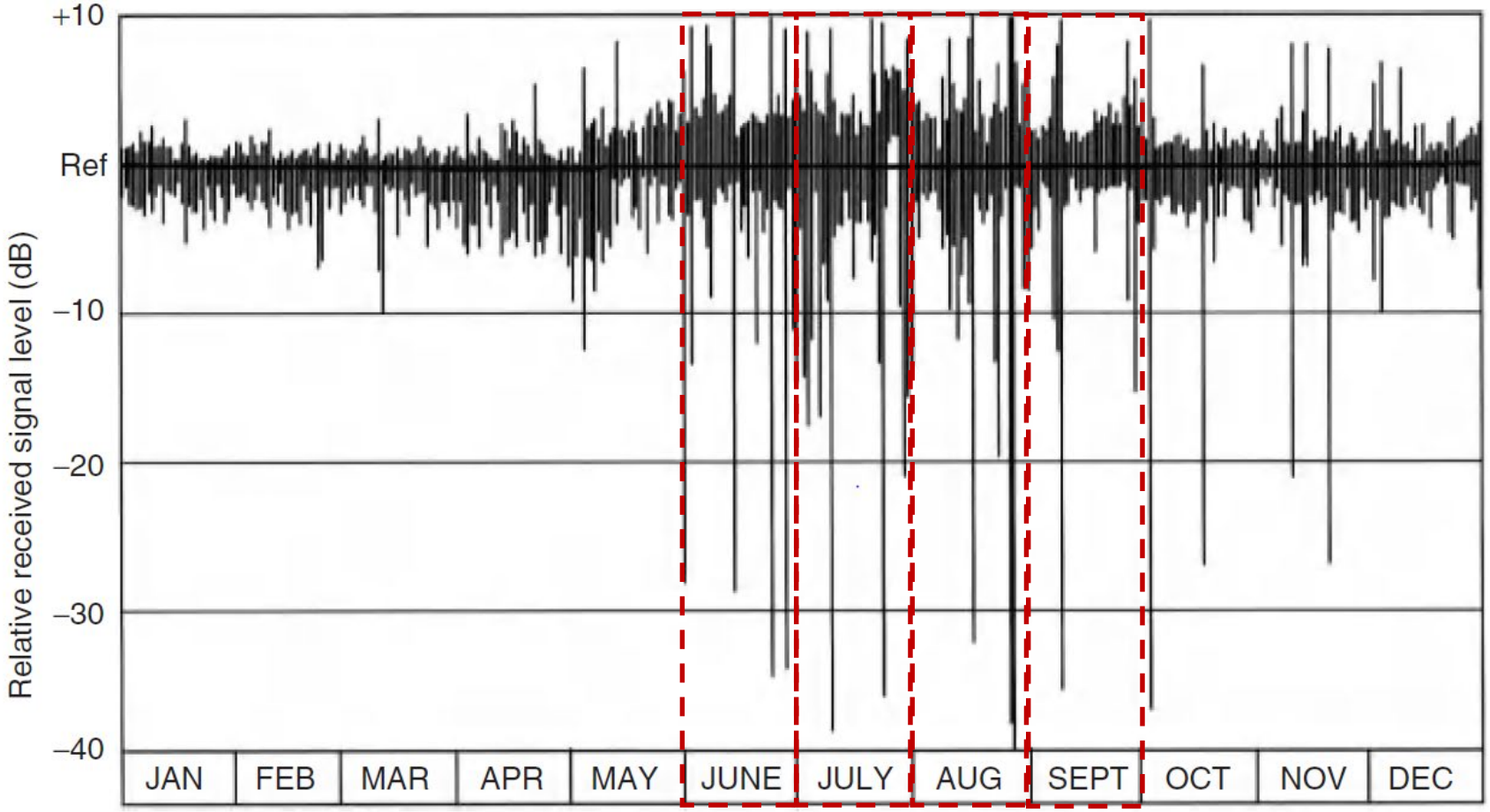
- Multipath fading typically occurs at night[1]
- According to NTIA, it is worst between midnight and 8 a.m.[2]



1. G. Kizer, “Digital Microwave Communication”, 2013
2. NTIA Technical Report, “INTERFERENCE PROTECTION CRITERIA Phase 1 - Compilation from Existing Sources”

Multipath Fading is at its Worst During Summer Months, when the Days are Longest

- Multipath fading activity increases during the summer and decreases in the winter
  - Peak fading occurs around August
  - Minimum fading occurs around January



1. G. Kizer, “Digital Microwave Communication”, 2013

The Deeper the Fade, the Shorter the Duration; Spatial Diversity is Effective in Mitigating Deep Fades

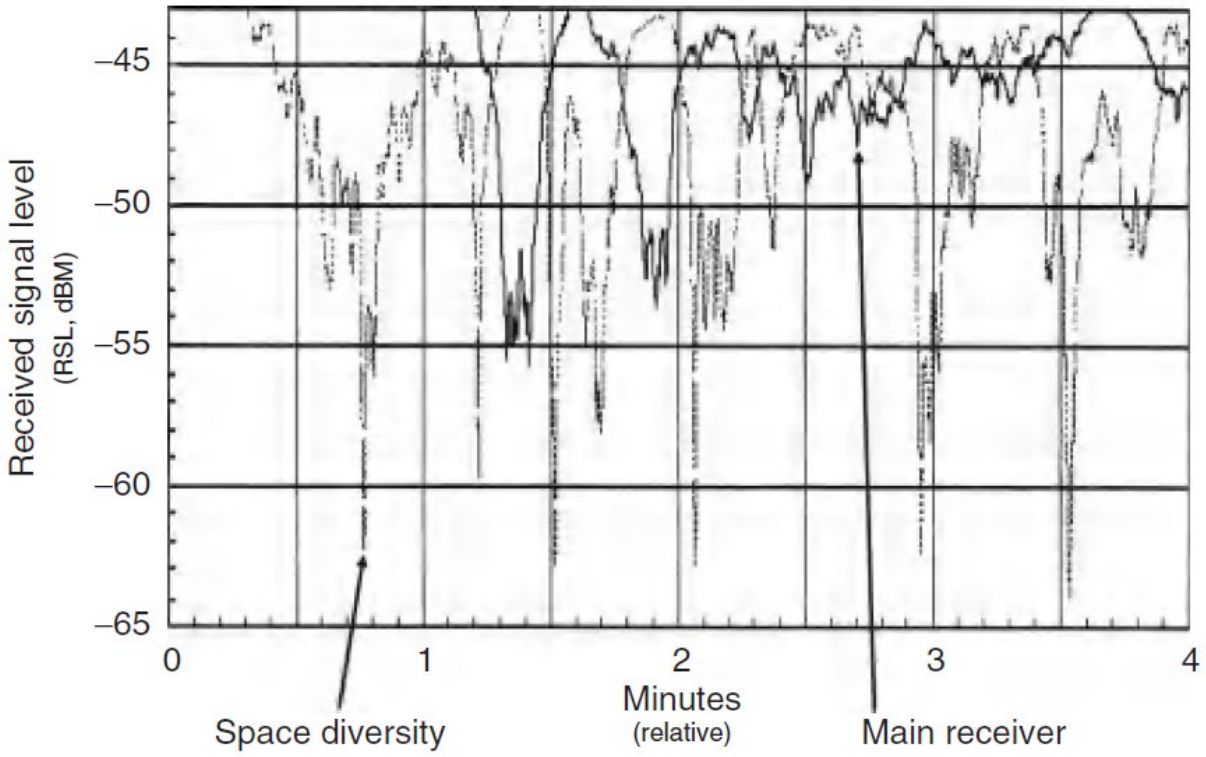
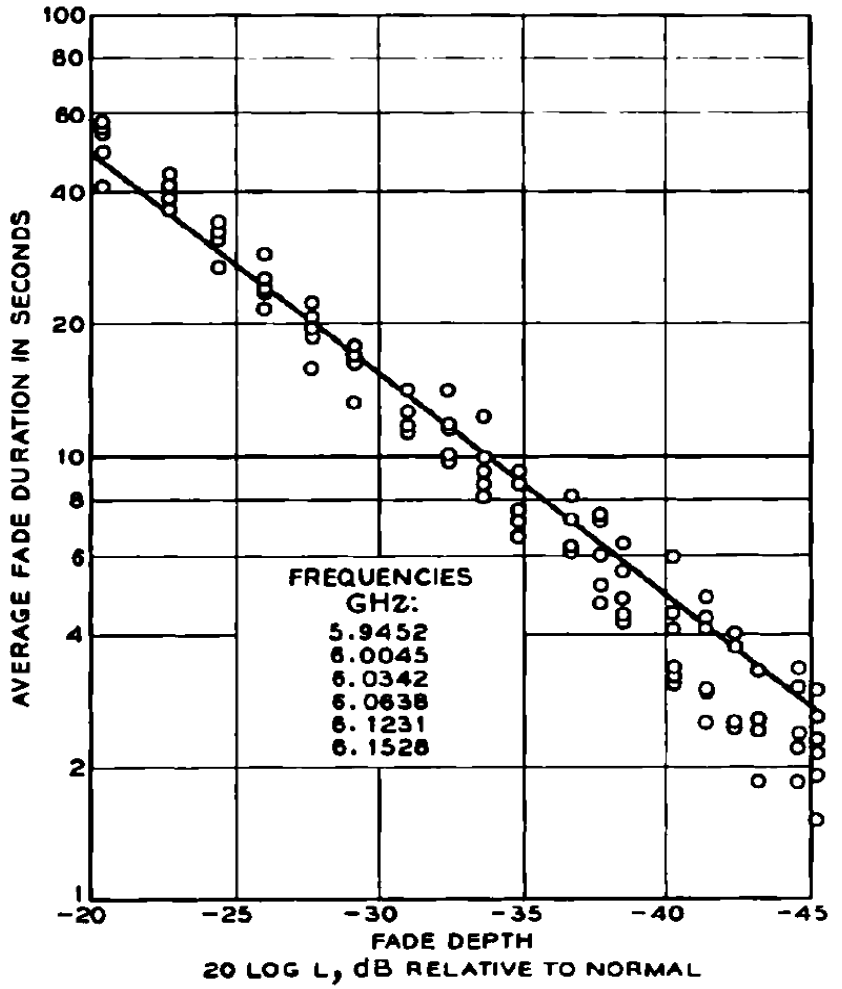


Figure 9.2 Deep microwave path fading.

G. Kizer, "Digital Microwave Communication", 2013

6 GHz Measurements Made in West Unity, Ohio (41°N)



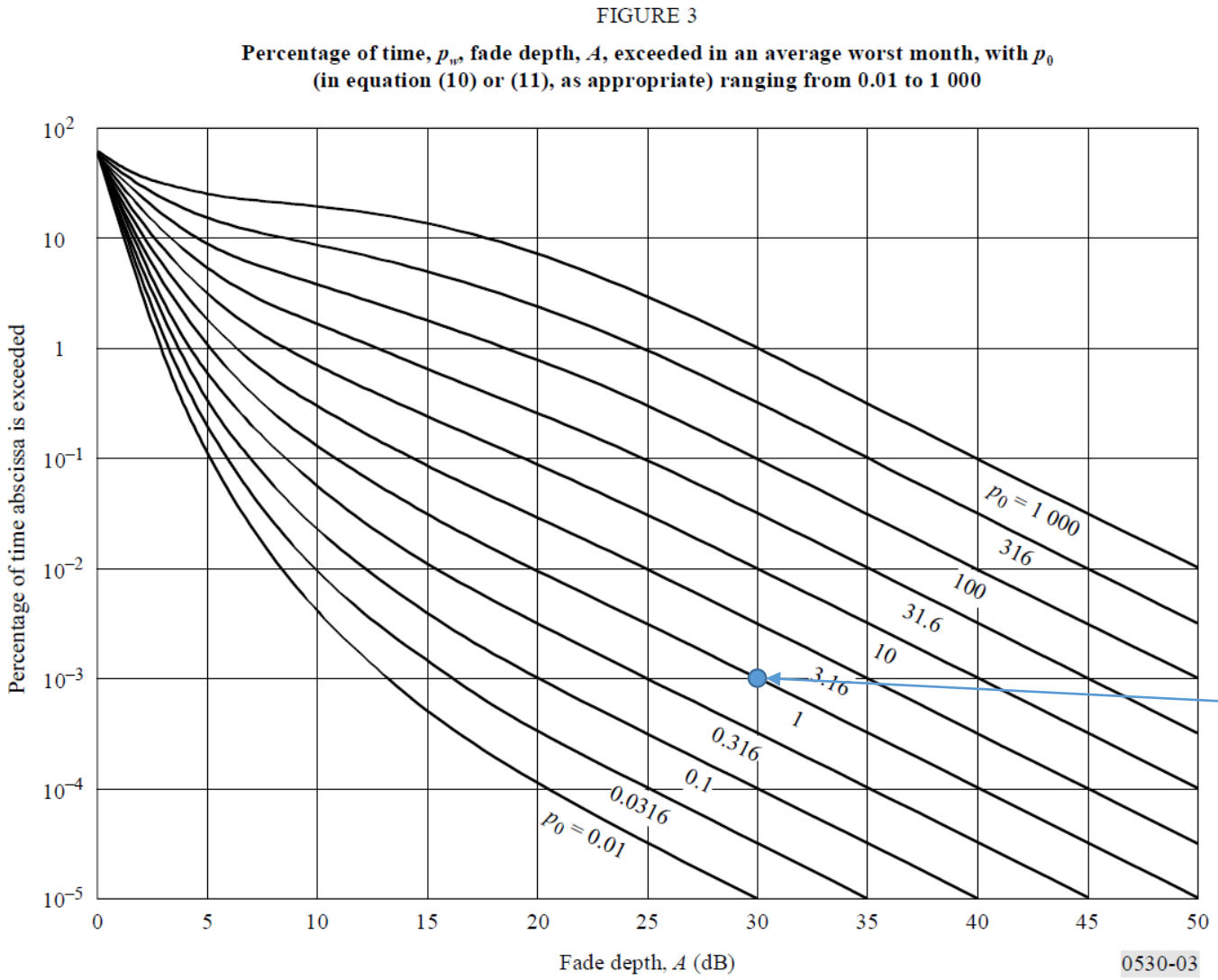
Reference: A. Vigants, "Number and Duration of Fades at 6 and 4 GHz," The Bell System Technical Journal, Vol. 50, No. 3, March 1971

Link Designers Use a Standard Model to Predict the Probability and Severity of Fading for a Given Link

- ITU-R Rec. P.530-17 provides a model which allows engineers to design a link with sufficient fade margin to achieve availability goals, given link specific-characteristics.*
- The major driver in this model is the parameter P_0, which is a function of:
  - Lowest (TX/RX) antenna height relative to sea level
  - Link distance
  - Path elevation angle
  - A location-specific geoclimatic parameter called dN1, the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of the worst month (e.g., August) in an average year

* The model has been continuously revised—most recently as of December 2017.

For Each P_0 Value, the ITU Model Provides the Probability of a Given Fade Depth at a Given Time



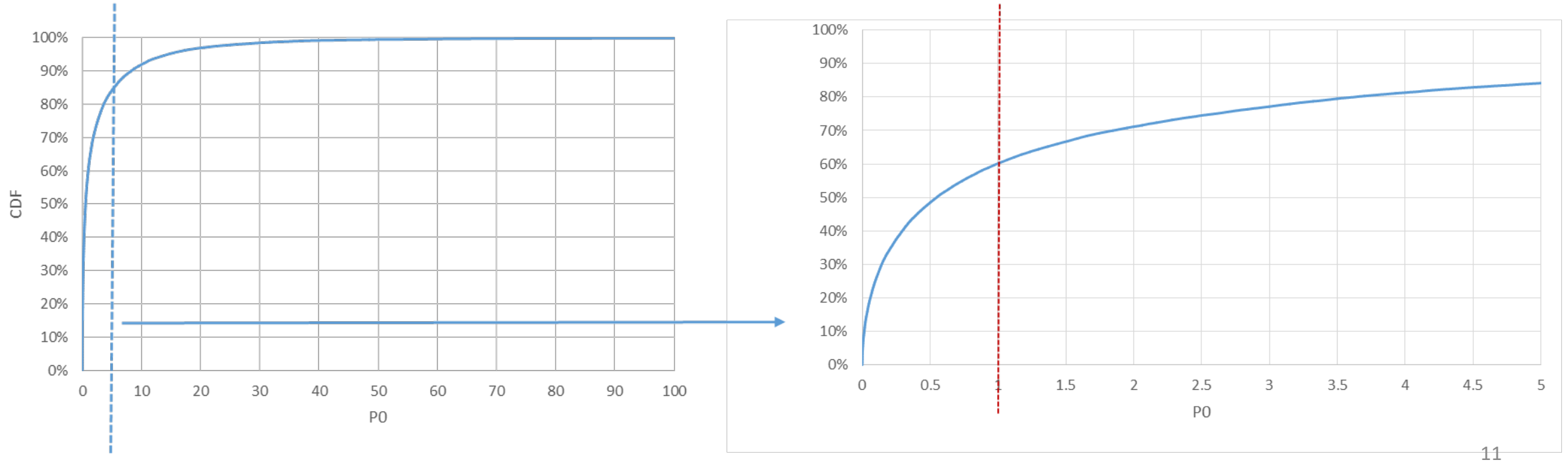
The model confirms that, for any given link there is always an inverse relationship between the magnitude of a multipath fade and its probability.

A link with a P_0 value of 1 could achieve 99.999% reliability with 30 dB in fade margin

Multipath Fade Analysis of Part 101 FS links in U-NII-5 and U-NII-7

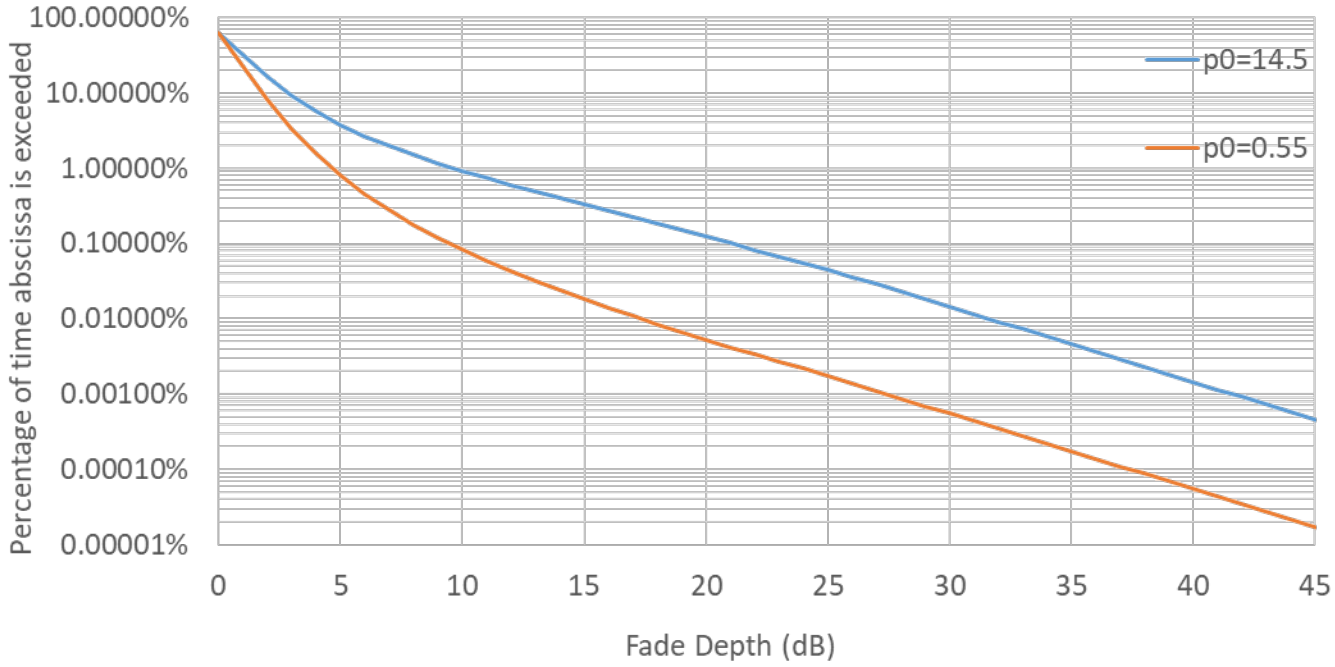
Analysis of P_0 Values for Part 101 Links in UNII-5/7 Show that 30 dB in Fade Margin is Sufficient to achieve 99.999% reliability for 60% of Links

- The geolocation coordinates, ground elevation, and height-to-center-RAAT for Rx and Tx antennas information in the ULS are sufficient to determine the appropriate P_0 Value
- As of January 23, 2019, there were 83,837 FS links listed in the ULS and 83,494 links had sufficient information to derive P_0 value
- Over 25% of the links have a P_0 value < 0.1. The median P_0 value is 0.55, ~60% have a P_0 value < 1 and 95% of the links have a P_0 value < 14.5



Deep Fades Occur for Very Limited Time Even During the Worst Month

- Percentage of time fade depth will be exceeded in August was calculated for the 50th and 95th P_0 percentiles
  - For a median link, at least 20 dB of margin will remain unused 99.995% of the time
  - For a 95th percentile link, 20 dB of margin will remain unused 99.88% of the time
- This means that **an extreme 20 dB of interference will have no effect 99.88% of the time**, even including links that experience the most severe fading (95th percentile P_0).

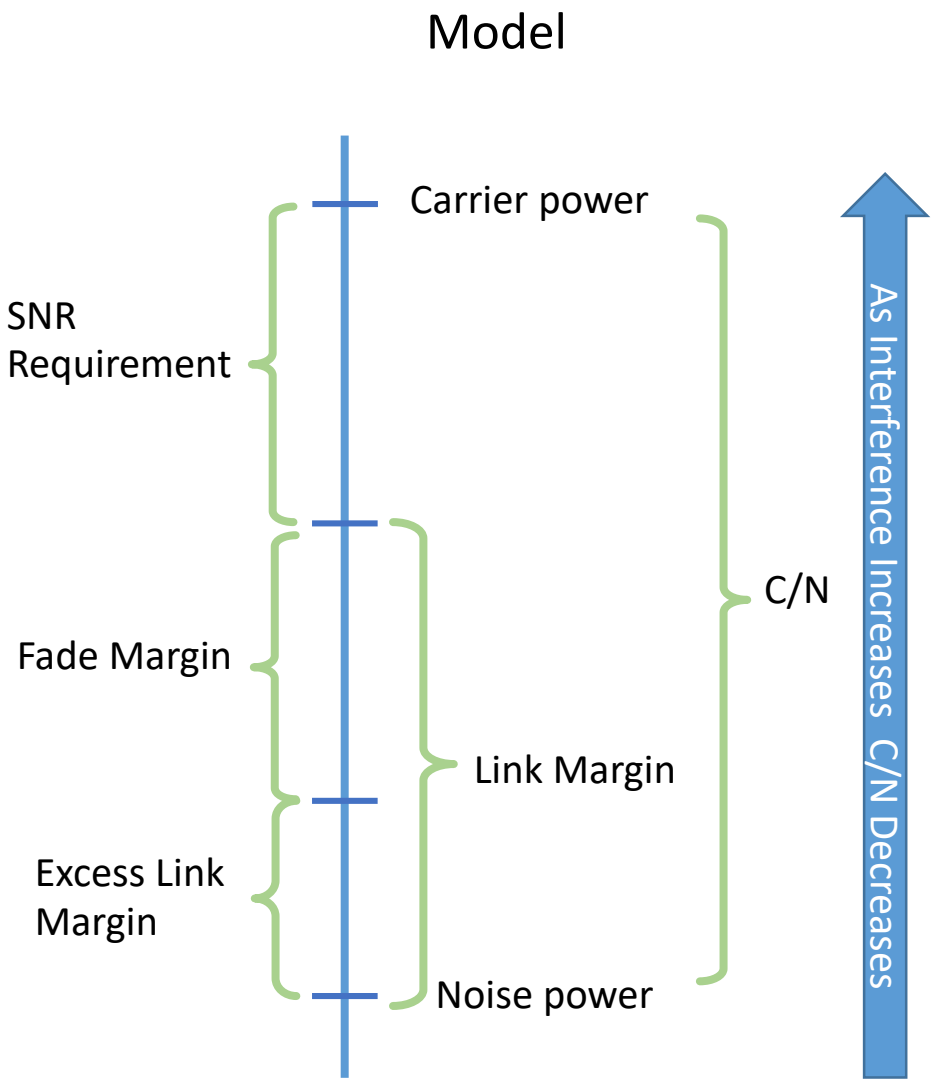


	P_0 = 14.5 (95%tile)		P_0 = 0.55 (50%tile)	
Fade	% of time exceedance	Sec/Mo	% of time exceedance	Sec/Mo
> 40 dB	1.5e-3	38.8	5.5e-5	1.5
> 30 dB	1.5e-2	388.4	5.5e-4	14.7
> 20 dB	1.2e-1	3,292.4	5.3e-3	141.1
> 10 dB	9.3e-1	24,825.9	8.3e-2	2,215.9

This table assumes 31 day in a month = 2,678,400 seconds

Case Studies on 50th Percentile and 95th Percentile P_0 Links

- To demonstrate the exceptionally small risk from even extreme interference from RLANs operating in the U-NII-5 and U-NII-7 bands, we conducted a case study of real 30 MHz FS links at the 50th P_0 percentile and 95th P_0 percentile
  - These are real links drawn from ULS, that are representative of links with 50th and 95th P_0 values.
- We assume
  - Extremely intensive FS link utilization: 100% capacity at 2048 QAM with no gaps between FS packets.** This is more than more than 600 TB per month for a single link.
  - Unrealistically high level of interference: **+20 dB I/N transmitting continuously** (i.e., 100% duty cycle).
  - Multipath fade magnitude and duration as predicted by P.530
  - Adaptive modulation and coding (ACM) capabilities.
- Throughput will be reduced, if necessary, for the duration of the time that multipath fade and interference exhaust available link margin.



** We note that these particular links were not capable of 2048 QAM, but used this for a more representative analysis for modern links.

Projected SNR Requirement and Data Rate Ranges for FS Operating at 30 MHz Bandwidth

- We obtained the projected data rate and SNR requirement for each modulation between 4-QAM and 2048 QAM from three publicly available data sheets assuming 5 dB noise figure and 30 MHz operation

Required SNR and Data Rate		
	Projected Data rate (Megabits/sec)	SNR Required (dB)
4-QAM	37	5.7-6.2
16-QAM	73	11.7-12.2
32-QAM	93	16.2-16.7
64-QAM	123	15.7-19.7
128-QAM	147-148	18.7-23.2
256-QAM	172-173	22.2-26.2
512-QAM	197	27.2-28.2
1024-QAM	222	30.2-31.2
2048-QAM	244	34.7-35.2

Data rate and required SNR derived from SAF Integra DS, Redline RDL 5000 DS, and ALFOplus2 datasheets assuming 5 dB Noise Figure and 30 MHz operation

Analysis of FS Link With Typical Multipath Fading (50th percentile)

50th Percentile FS Link Baseline (no RLAN Interference):
Minimal Degradation from Multipath Fade Alone

- Representative 30 MHz link has C/N = 68.38 dB
- Without interference, link would fall below 2048 QAM for 7.1 seconds during the worst month.
- This does not account for the link's spatial diversity antenna, which is expected to address the vast majority of deep fade events.

Fade	Remaining C/N (dB)	Modulation (QAM)	Peak Throughput Capability (Mbits/sec)
< 10 dB	> 58.38	2048	244
> 10 dB, ≤ 20 dB	< 58.38, ≥ 48.38	2048	244
> 20 dB, ≤ 33.18 dB	< 48.38, ≥ 35.2	2048	244
> 33.18 dB, ≤ 37.18 dB	< 35.2, ≥ 31.2	1024	222
> 37.18 dB, ≤ 40.18 dB	< 31.2, ≥ 28.2	512	197
> 40.18 dB, ≤ 42.18 dB*	< 28.3, ≥ 26.2	256	173

* Deeper fades occur for only fractions of a second, if at all.

50th Percentile Link with Unrealistic Interference (+20b dB I/N, 100% Duty Cycle) Minimal Degradation Even from Extreme Levels of Interference

- Even assuming unrealistically high **continuous** interference at + 20 I/N, C/(N+I) = 48.38 dB
- Thus, even under these extreme interference conditions, the link would only be expected to experience 0.00488% potential reduction in throughput capability during the worst month.
- However, given the link has a spatial diversity antenna, the actual impact is expected to be even less then predicted here, because the diversity antenna reduces the effect of multipath fading.

FS 50th percentile P_0:	0.55
FS C/N:	68.38 dB
RLAN I/N:	+20 dB
RLAN Duty Cycle:	100%
FS Throughput Degradation (Worst Month):	**0.00488%**

50th Percentile FS Link with Unrealistic Interference (+20b dB I/N, Duty Cycles <100%) Even Less Impact than Minimal Degradation Caused by Continuous Interference

- Taking into account real-world RLAN duty cycles reduces the tiny effect even further.
- RLAN transmissions are bursty, and as a result an RLAN is **never** continuously transmitting energy
- Additional real-world factors would reduce the impact even further:
  - An RLAN is far less likely to be transmitting in the middle of the night/early morning when deep fades are most likely
  - The FS likely has inter-frame spacing between its data packets and may not be operating at maximum capacity
  - The FS has a spatial diversity antenna that is expected to handle ~99% of deep fade events
  - Critical links may also have redundant rings, use frequency diversity, and have fiber as a primary or back-up

Interference	Potential Capacity Reduction (Worst Month)	Availability (Worst Month)
Continuous	0.00484%	99.99990%
35%	0.00169%	99.99997%
10%	0.00048%	99.99999%
5%	0.00024%	100.00000%
2%	0.00010%	100.00000%
1%	0.00005%	100.00000%
0.50%	0.00002%	100.00000%

Analysis of FS Link With Abnormally Severe Multipath Fading (95th percentile)

95th Percentile FS Link Baseline (no RLAN Interference): Limited, but Noticeable Degradation Due to Multipath Fading

- Representative link has C/N = 64.97 dB
- Without interference, link would fall below 2048 QAM for 409.5 seconds during the worst month.
- This does not account for the link's spatial diversity antenna, which is expected to address the vast majority of deep fade events.

Fade	Remaining C/N (dB)	Modulation (QAM)	Throughput (Mbits/sec)
< 10 dB	> 54.97	2048	244
> 10 dB, ≤ 29.77 dB	< 54.97, ≥ 35.2	2048	244
> 29.77 dB, ≤ 33.77 dB	< 35.2, ≥ 31.2	1024	222
> 33.77 dB, ≤ 36.77 dB	< 31.2, ≥ 28.2	512	197
> 36.77 dB, ≤ 38.77 dB	< 28.2, ≥ 26.2	256	173
> 38.77 dB, ≤ 41.77 dB	< 26.2, ≥ 23.2	128	148
> 41.77 dB, ≤ 45.27 dB	< 23.2, ≥ 19.7	64	123
> 45.77 dB, ≤ 48.77 dB	< 19.7, ≥ 16.7	32	93
> 48.77 dB, ≤ 52.77 dB	< 16.7, ≥ 12.2	16	73
> 52.77 dB, ≤ 58.77 dB	< 12.2, ≥ 6.2	QPSK	37

95th percentile FS Link with Unrealistic Interference (+20b dB I/N, 100% Duty Cycle)

Slight Degradation, but Likely Not Unnoticeable Compared to Effects of Fade, Even in This Unrealistic Case

- Even Assuming unrealistically high continuous interference at + 20 I/N occurs, C/(N+I) = 44.97 dB
- Thus, even under these extreme interference conditions, this unusually vulnerable link would only be expected to experience 0.1941% potential reduction in throughput capability during the worst month .
- However, because the link has a spatial diversity antenna, the actual impact is expected to be *even less* then predicted here, because the diversity antenna reduces the effect of multipath fading.

FS 95th percentile P_0:	14.5
FS C/N:	64.97 dB
RLAN I/N:	+20 dB
RLAN Duty Cycle:	100%
FS Throughput Degradation (Worst Month):	**0.1941%**

95th percentile FS Link with Unrealistic Interference (+20b dB I/N, Duty Cycles < 100%)

Minimal Degradation with Realistic Duty Cycles

- Taking into account real-world RLAN duty cycles reduces the effect even further.
- Link maintains availability greater than five-9s even with 35% duty cycle (far higher than studies predict for 6 GHz RLAN devices).
- As in the earlier example, this does not take into account that:
  - An RLAN is far less likely to be transmitting in the middle of the night/early morning when deep fades are most likely
  - The FS likely has inter-frame spacing between its data packets and may not be operating at maximum capacity
  - The FS has a spatial diversity antenna that is expected to handle 99% of deep fade events
  - Critical links may also have redundant rings, use frequency diversity, and have fiber as a primary or back-up

Interference	Throughput Reduction (Worst Month)	Availability (Worst Month)
Continuous	0.1939%	99.998075%
35%	0.0679%	99.999326%
10%	0.0194%	99.999808%
5%	0.0097%	99.999904%
2%	0.0039%	99.999962%
1%	0.0019%	99.999981%
0.50%	0.0010%	99.999990%

For example worst-case links in our July 31 New York City Lidar presentation, the effect would be even smaller than the previous examples.

- Even Assuming unrealistically high continuous interference at + 20 I/N occurs, C/(N+I) = 60.6 and 48.5 dB
- Thus, even under these extreme interference conditions, these urban link would only be expected to experience 0.00066% and 0.000001% potential reduction in throughput capability during the worst month.
- In addition to highlighting the robustness of FS links in general, it also highlights the fact that urban links, which tend to be shorter, are also even more robust to interference than average.

Link 1 (WHS328)	
FS C/N:	80.6 dB
RLAN I/N:	+20 dB
RLAN Duty Cycle:	100%
FS Throughput Degradation (Worst Month):	**0.00066%**

Link 2 (KEH21)	
FS C/N:	68.5 dB
RLAN I/N:	+20 dB
RLAN Duty Cycle:	100%
FS Throughput Degradation (Worst Month):	**0.000001%**

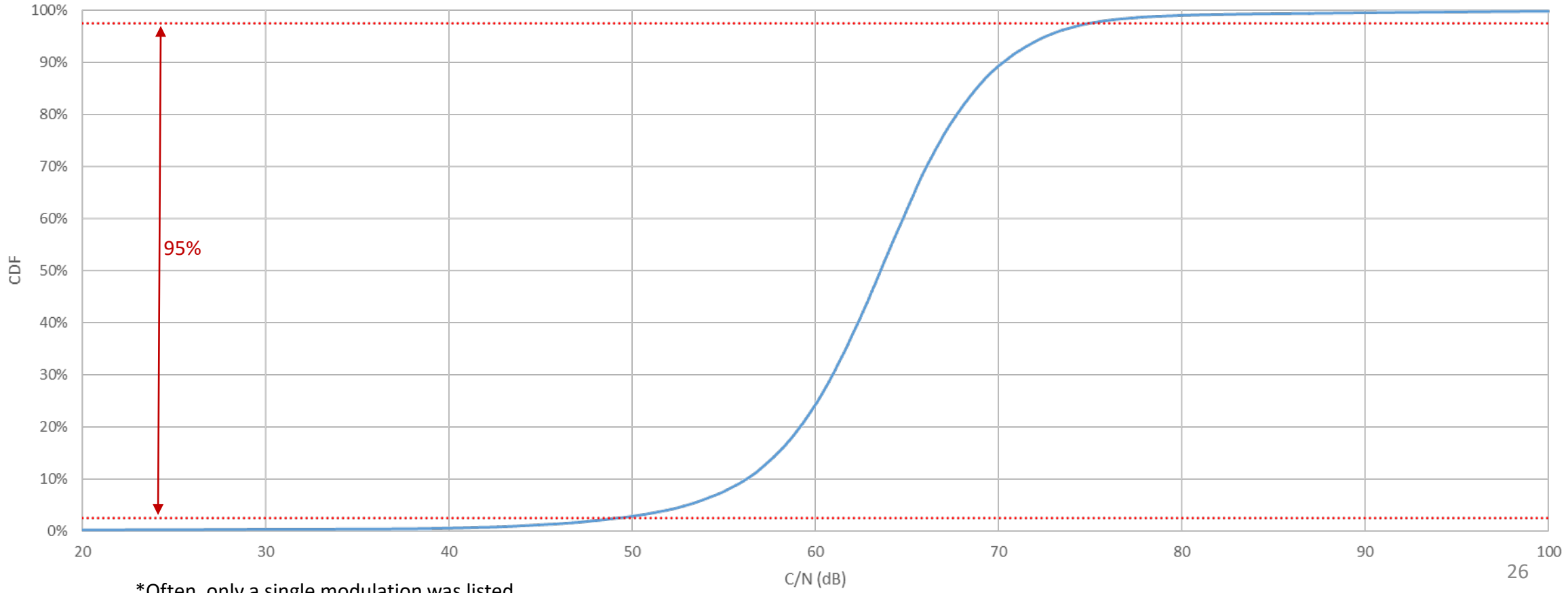
Correlation Between P_0 and C/N

Multipath Fading Is Primarily Mitigated by Adequate Fade Margin and Diversity

- Multipath fading is primarily mitigated by FS designers by:
  - Ensuring large C/Ns
  - Employing spatial diversity antennas; and
  - Employing frequency diversity
- To understand the relationship between multipath fading and C/N margin, we plotted the C/N and P_0 value for 83,494 Part 101 FS links
- We also explored the correlation between C/N, P_0 Value, and spatial antenna diversity

Part 101 Links in the U-NII-5 and U-NII-7 bands have large C/Ns

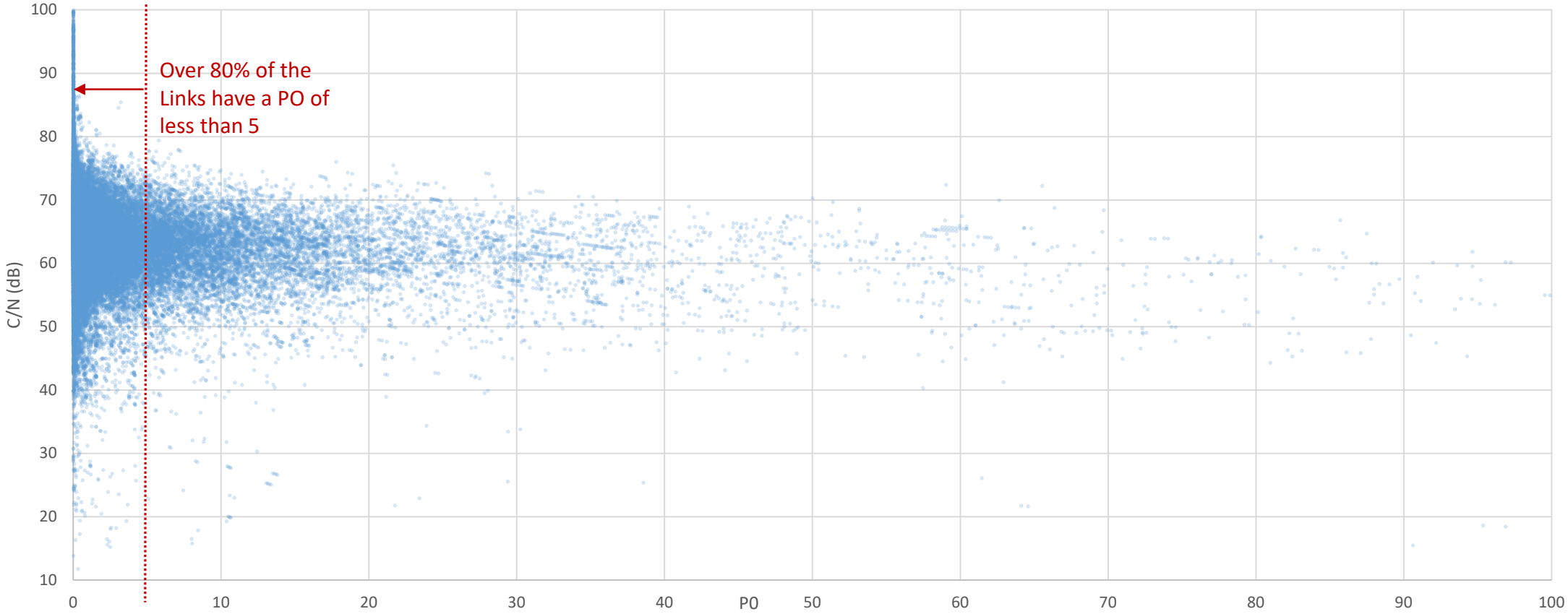
- To derive the C/N of the 83,494 links, we picked the lowest modulation* records for the multi-record links, for the narrow purpose of ensuring link connectivity during the most extreme conditions.
- The middle 95% of these 83,494 fixed links had a C/N between 49.2-74.9 dB



*Often, only a single modulation was listed

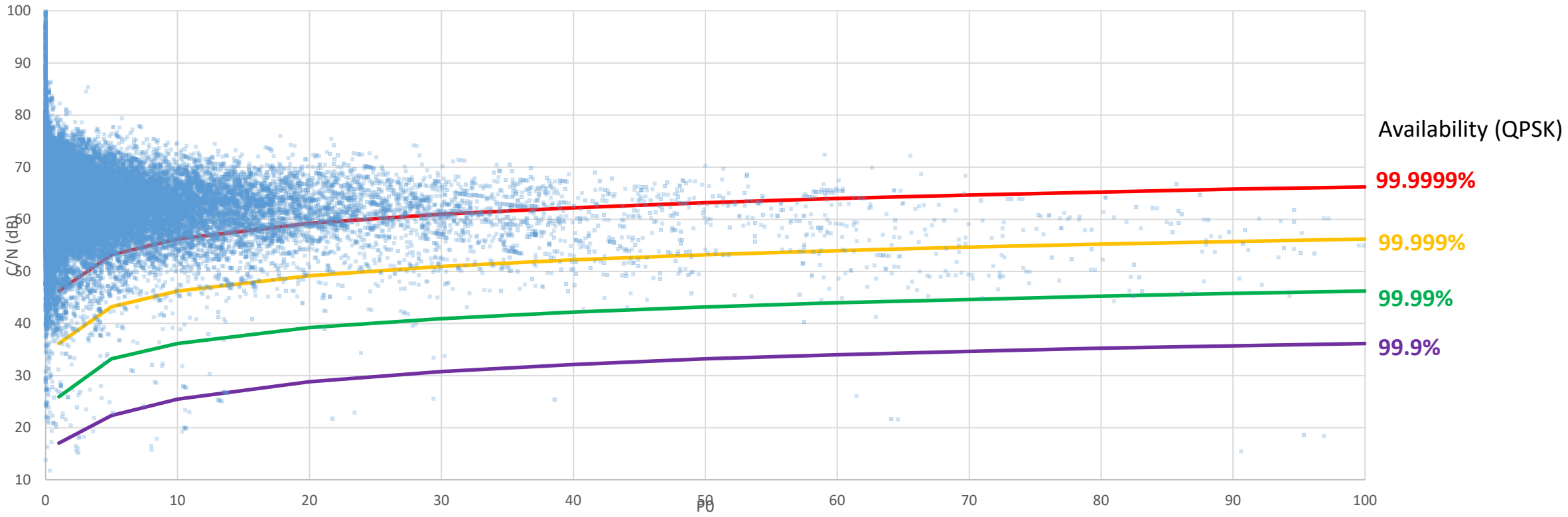
US FS Links Have More than Ample C/N Relative to P.530 Projections

- Since multipath fading is primarily addressed by large margins, and multipath fading is the dominant factor in ensuring adequate link availability, we expected to see a strong correlation between C/N and P_0 value
- However, there was no correlation between the P_0 values and the link C/N calculated from the 83,494 Part 101 Links in ULS; the vast majority appear to have significantly more margin than needed



Majority Part 101 Links Typically have a Far Greater C/N than Required to Keep the Link Operational at 99.9999% Availability

- Given that even extremely unlikely interference would typically result in reduced modulation to QPSK mere seconds per worst month, we compared what the C/N should be for QPSK for four availability design targets listed below, which resulted in:
  - 99.1% of links had a C/N exceeding 99.999% curve
  - 95.5% of links had a C/N exceeding 99.9999% curve

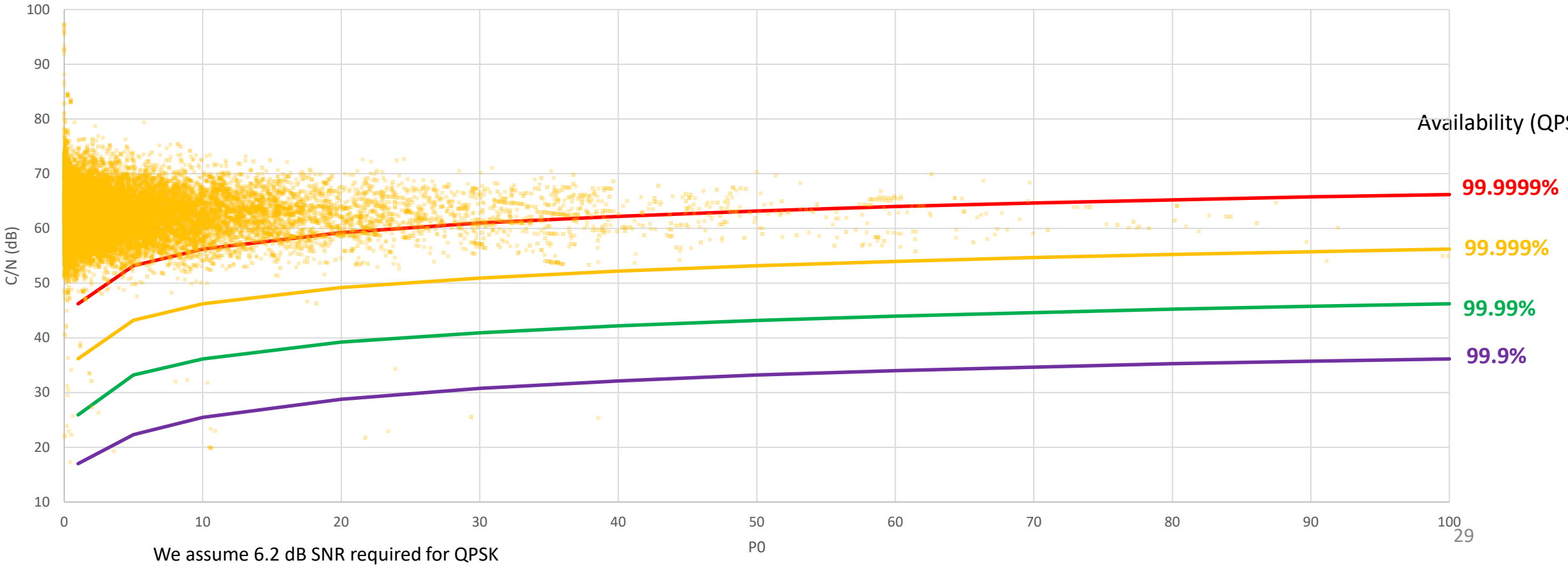


We assume 6.2 dB SNR required for QPSK

*See appendix for more information pertaining to C/N

Links With Spatial Diversity Have Even Higher C/N on Average

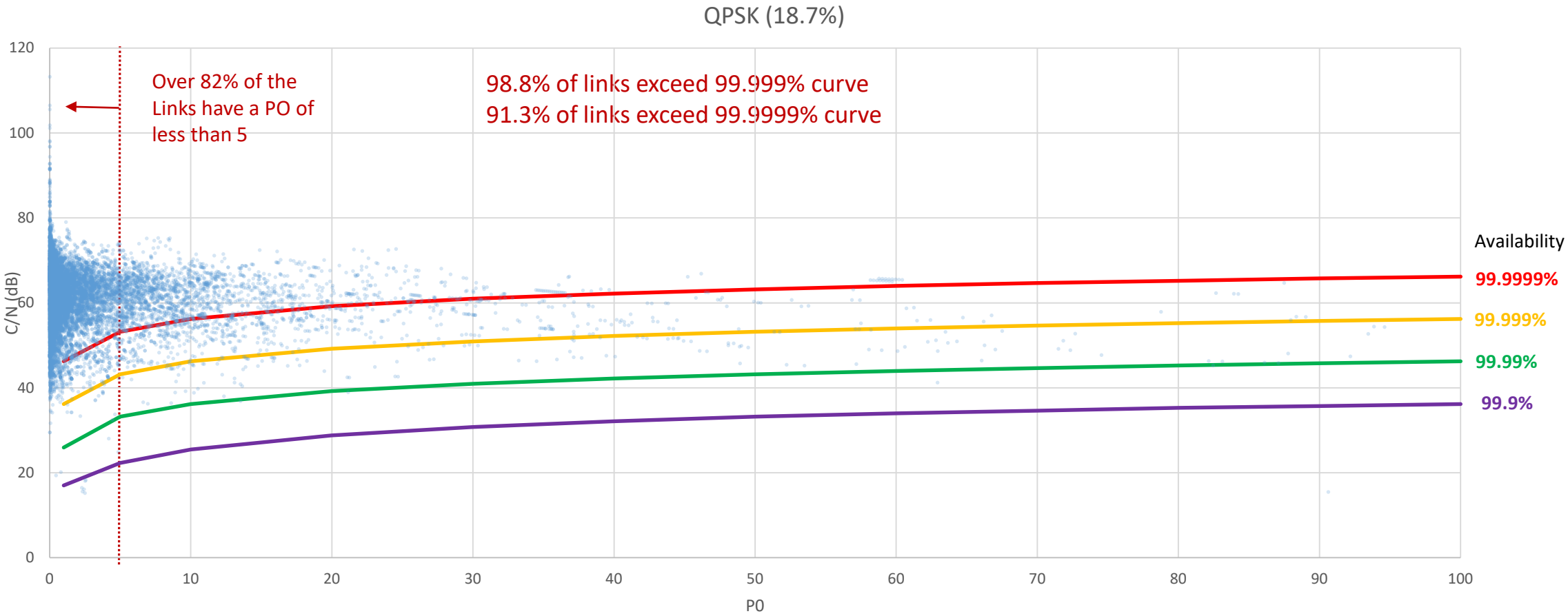
- 30.5% of the Links have spatial diversity, which is expected to mitigate the vast majority of multipath fading, we expected these links to have a lower C/N on average
- However, we found that over 96% of the links had a C/N well in excess than that required to achieve 99.9999% EVEN WITHOUT the diversity antenna
  - 99.4% of links had a C/N exceeding 99.999% curve
  - 96.1% of links had a C/N exceeding 99.9999% curve



We assume 6.2 dB SNR required for QPSK

The vast majority of links listing QPSK have a C/N Well in excess of a Five-9's or Six-9's Availability Design Target

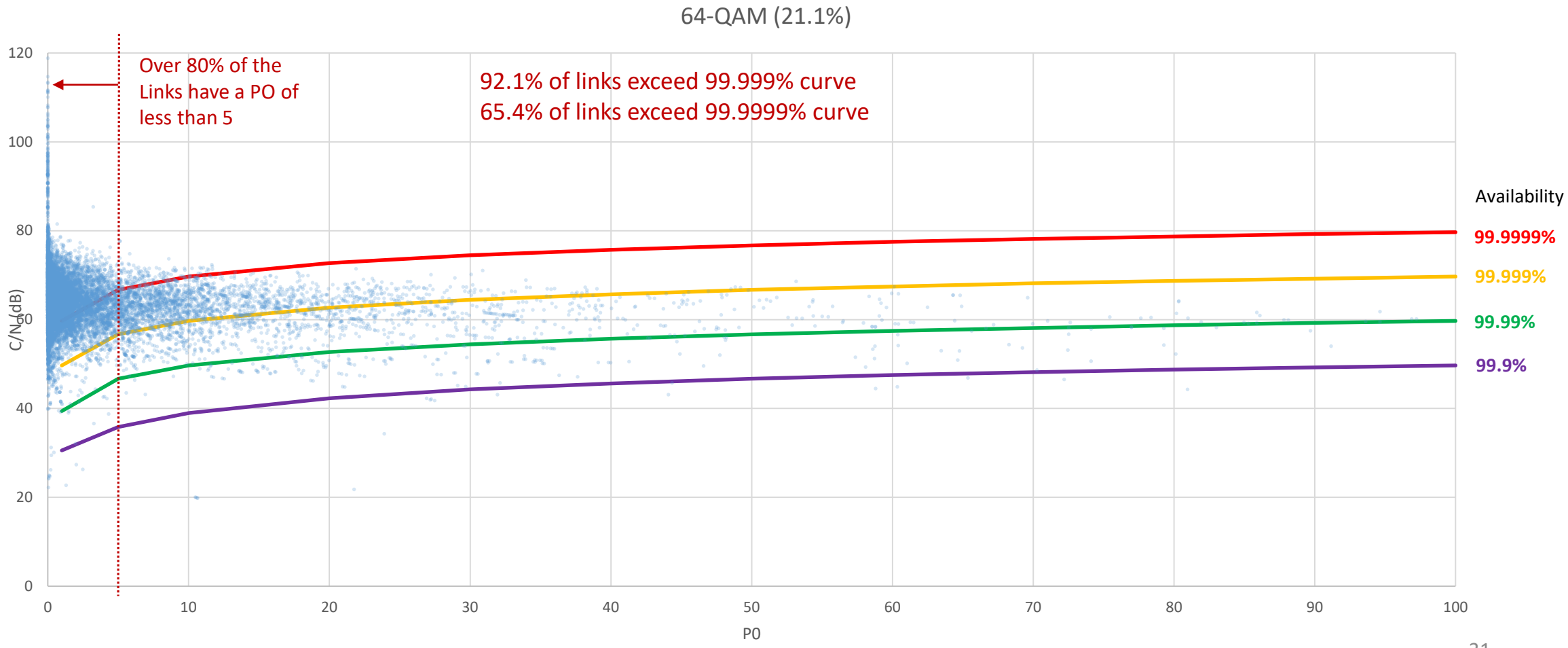
- We then reviewed the C/N for those links in the data set when operating at QPSK* as the modulation and found that the vast majority had C/N far greater than even 99.999% availability design target for that modulation



* The vast majority of these links normally operate at a higher order modulation, and use QPSK as the most robust modulation for fallback.

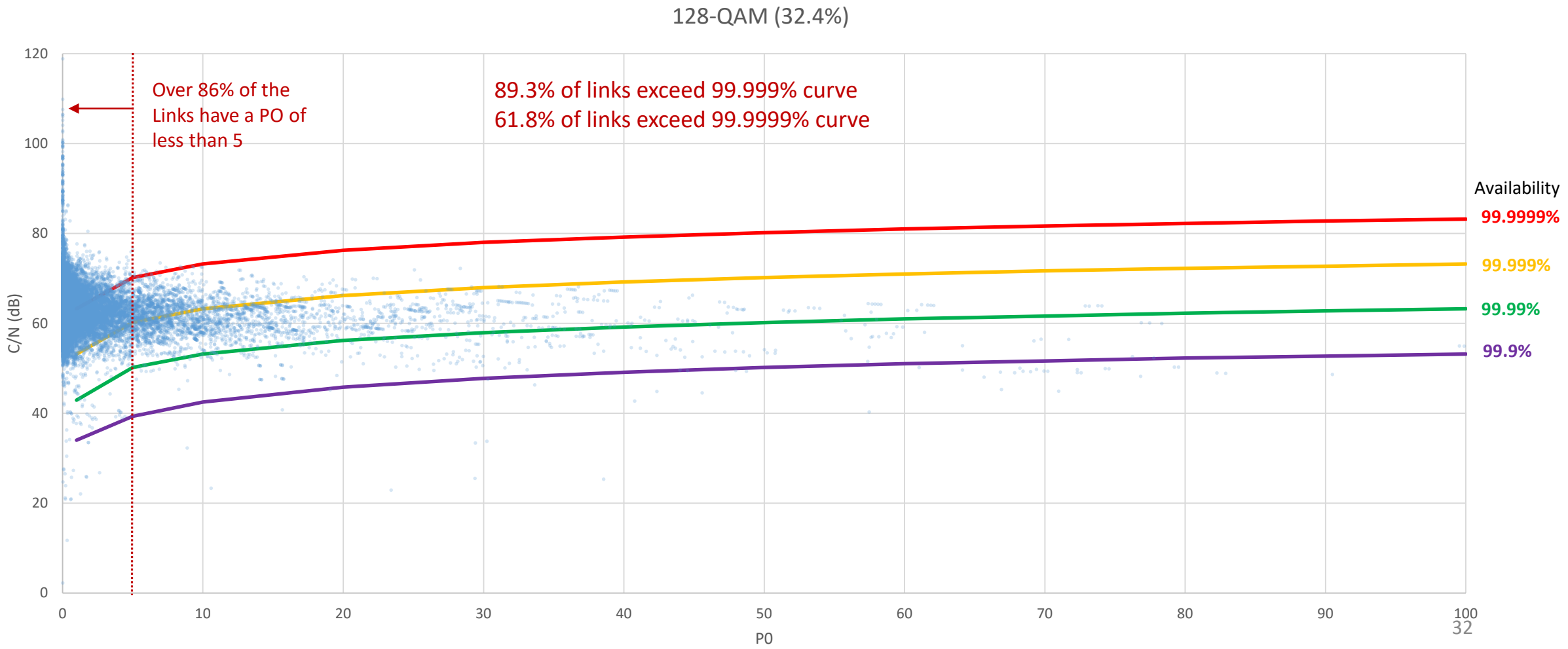
The vast majority of links listing 64 QAM have a C/N WELL in excess of a Five-9's Availability Design Target

- We then reviewed the C/N for only those links in the data set listing 64QAM as the modulation and found that the vast majority had C/N far greater than 99.999% availability design target for that modulation



The vast majority of links listing 128 QAM have a C/N WELL in excess of a Five-9's Availability Design Target

- We then reviewed the C/N for only those links in the data set listing 128 QAM as the modulation and found that the vast majority had C/N far greater than 99.999% availability design target for that modulation



Conclusion

Conclusion

- This study clearly demonstrates:
  - That extremely high fade margins used in FS link design make FS links very robust against even unrealistic RLAN interference
  - Deep multipath fades happen so rarely that even periods of extreme interference would only lead to a very short duration of throughput degradation measured in seconds per month
  - Likewise, even these extreme interference incidents do not appear to affect availability
  - It appears that many FS links operate at a power level exceeding what is necessary to maintain very high reliability
- To reiterate, these results assume interference at +20 dB I/N, which is radically higher than our studies have reasonably predicted for any scenario.
- The FCC can confidently move forward with enabling LPI and VLP in UNII-5 and UNII-7

Thank You

Parameters of the 50th Percentile and 95th Percentile P_0 Links Operating at 30 MHz Bandwidth and the P.530 Projected Fade for the Average Worst Month

Link Details	50th Percentile	95th Percentile
Rx Call Sign	WPOR222	WPQS389
Link Length	14.40 KM	41.99 KM
Antenna Gain	38.8 dBm	43.4 dBi
EIRP	68.6 dBm	69.8 dBm
Bandwidth	30 MHz	30 MHz
Modulation	128 QAM	128 QAM
Rx Ground Elevation	7.1 meters	266 meters
Rx Height to Center RAAT	30.2 meters	71.6 meters
Spatial Diversity	Yes	Yes
Noise Figure	5 dB	5 dB
C/N	68.38 dB	64.97 dB

Fade	50th Percentile Sec. / Worst Mo	95th Percentile Sec. / Worst Mo
> 40 dB	1.5	38.8
> 30 dB	14.7	388.4
> 20 dB	141.1	3,292.4
> 10 dB	2,215.9	24,825.9