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March 13, 2018

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Re: GN Docket No. 17-183, *Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz*
***Ex Parte* Communication**

Dear Ms. Dortch:

On behalf of the Fixed Wireless Communications Coalition, Inc. (FWCC),[1] I am electronically filing this communication in the above-referenced docket.

This responds to "Frequency Sharing for Radio Local Area Networks in the 6 GHz Band (January 2018)," prepared by RKF Engineering Services, LLC on behalf of Apple Inc., Broadcom Limited, Cisco Systems, Inc., Facebook Inc., Google LLC, Hewlett-Packard Enterprise, Intel Corporation, Microsoft Corporation, MediaTek Inc., and QUALCOMM Incorporated, filed on January 26, 2018.[2]

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

[2] Letter from Paul Margie, Counsel to Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation to Marlene Dortch, Secretary, FCC (filed Jan. 26, 2018) (attachment) (RKF study).

A. SUMMARY

The RKF study purports to show that unlicensed devices (RLANs) can successfully coexist with the Fixed Service in the 6 GHz band.

Our analyses prove this is wrong. The uncontrolled distribution of RLANs, in the numbers and at the power levels RKF studied, will cause widespread harmful interference to fixed microwave receivers. Mostly using RKF's own numbers and assumptions, we ran a simulation that shows:

- **Every microwave receiver** in our eight-city study will see several cases of interference, each one strong enough to degrade the path fade margin by at least one dB (RKF's own interference criterion).
- **At least 70% of each city's microwave receivers** will receive far stronger interference that degrades the fade margin by 10 dB or more.
- **One microwave receiver in 33** will be hit with 40 dB or more of interference—enough to completely disable most links even under optimum conditions.

Some unknown number of microwave receivers will fail due to interference from an RLAN that has line-of-sight with the antenna, even from kilometers away—a condition RKF did not consider.

In Part E, below, we identify some of the other missteps in the RKF study that may have contributed to its erroneous results.

B. INTRODUCTION

It surprises us to see a notable array of companies, each at the forefront of technical innovation, putting their names to this study. Reputations certainly matter, but cannot overcome the realities of engineering.

Our submission has the following components:

- this letter, which introduces and summarizes the material to follow;
- Study 1: a simulation showing extensive and severe interference to Fixed Service links;
- Study 2: a theoretical analysis that supports the simulation;

- Study 3: a critique of the RKF study showing errors in its assumptions and approach that at least partially explain its wrong results; and

- Study 4: the application of an ITU-R recommendation relevant to RLAN interference.

1. *The importance of fade margin to fixed microwave*

Fixed microwave systems often carry time-critical information: synchronizing the movement of railroad trains, control of petroleum and natural gas pipelines, maintaining balance in the electric grid, backhaul to dispatch public safety and emergency vehicles, and connecting commercial centers with real-time financial and market data. Because downtime can cost lives, these systems must be engineered to extremely high levels of reliability, most typically 99.9999% (thirty seconds outage per year from all causes) or 99.999% (five minutes outage per year).

The 6 GHz bands at issue here, having about 90,000 links nationwide, are widely used for links that must span tens of miles.

High reliability is an engineering challenge, especially over long links. Changing conditions in the atmosphere cause reductions in received signal strength called “fading.” At 6 GHz all fading is caused by “multipath”: changes in temperature or humidity at different atmospheric elevations that refract (bend) an upward-traveling component of the signal back toward the receive antenna, just as a lens bends light rays. Because the refracted signal takes a longer path than the direct signal, it can arrive at the receiver out of phase with the direct signal, and partially cancel out the direct signal. This reduces the signal strength at the receiver by anywhere from a few dB to a few tens of dB. Movement of the air at the refracting elevations causes the received signal to fluctuate unpredictably over this range.

Multipath is a nighttime phenomenon. During the day solar heating of the land causes thermal updrafts that stir the air and prevent formation of the layers that produce refraction. At night the earth cools and the air, if otherwise undisturbed, will form the layers and cause fading.

Without precautions, fades would cause frequent outages. System designers combat the problem by building in “fade margin”—extra reserves of signal power to compensate for the loss of received power caused by fades.[3] Depending on the reliability needed, fade margins are typically in the range 25-40 dB.

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

A weak interference source may not cause an immediate outage, but it will cut into the fade margin and leave the system more vulnerable to outage from fades it could otherwise withstand. If the system is already in a fade condition, even a small degree of interference may be enough to bring it down.

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

Roughly speaking, interference that uses up 1-20 dB of fade margin leaves the system vulnerable to loss of communication from natural fade; 30 dB of interference causes errors in transmission; 40 dB shuts down the link. We use these numbers in our summary below.

National and international frequency coordination procedures, standards, and recommendations uniformly limit the acceptable long-term degradation of the fade margin to 1 dB. RKF implicitly claims to adopt this criterion.[4] We show, however, that the devices RKF studied will cause at least this much interference into ***every*** microwave antenna, and far more into some.

High reliability requires high fade margin; and high fade margin is expensive. Operators pay more for equipment that provides a few extra dB of fade margin because they need the added reliability—not to accommodate unlicensed devices.

2. Regulatory status of unlicensed devices

The Commission began approving unlicensed devices in 1938, just three years after opening its doors.[5] The guiding principles then, as now, were (a) preventing harmful interference to licensed services, and (b) requiring unlicensed devices to accept all incoming interference.[6] For the first half-century the Commission enforced the first principle by limiting unlicensed devices to extremely low power levels, and the second by ignoring any interference they might receive. Both practices made

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[4] RKF (page 11) states that it uses a ratio of interference level to receiver front end noise of -6 dB as a comparison threshold. This is equivalent to 1 dB reduction in fade margin.

[5] The earliest devices were phonographs that lacked an audio system but included a small AM transmitter for sending to an adjacent AM receiver. *See Operation of Radio Frequency Devices Without an Individual License*, Notice of Proposed Rulemaking, 2 FCC Rcd. 6135 at ¶ 2 (1987).

[6] 47 C.F.R. § 15.5.

unlicensed devices unreliable. Most early applications were in toys and non-critical gadgets like garage door openers.

That began to change in 1985, with the authorization of spread spectrum devices at relatively high powers. In time the new rules brought Wi-Fi, Bluetooth, ZigBee, and scores of other device categories. The generous power limits, coupled with robust broadband protocols, made unlicensed operation sufficiently reliable for commercial and industrial use, and for a wide range of consumer applications. With businesses and homes having come to depend on unlicensed devices, the Commission is sometimes in the awkward position of having to consider whether proposed new applications, equipment waivers, and the like will impair their operation. The reverse problem—of unlicensed devices causing interference to licensed services—so far has been rare, thanks to the Commission's prescience in allowing higher-powered unlicensed activity only in the ISM bands. Licensed operators avoid these bands anyway, due to the interference threat from ISM devices.[7]

The present proposal requests a stark departure from past policy and precedent: the introduction of unconstrained, relatively high-powered, unlicensed devices into a non-ISM band—one heavily used for critical communications.[8]

The rules require the user of an unlicensed device that causes harmful interference to turn it off.[9] In practice, though, this is rarely helpful. There is no record anywhere of unlicensed devices' ownership or location.[10] Even a victim operator who becomes aware of the interference is unable to find and identify the offending device.[11] Of course the Commission knows the difficulties of tracking down unlicensed interference. Rather than rely on locating and turning off an offending device, it tries to set unlicensed power levels low enough (along with other conditions on operation) to make interference unlikely to occur at all. Indeed, to qualify for unlicensed operation under the Communications Act, a

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[7] Unlicensed operation is also allowed at relatively high power at 57-71 GHz, a band that has never housed licensed applications.

[8] By comparison, when the Commission allowed unlicensed white space devices into the TV broadcast bands, it imposed a complex and thoroughly tested regime of limitations on frequencies and locations to protect licensed users. *See* 47 C.F.R. § 15 subpart H.

[9] 47 C.F.R. § 15.5(c).

[10] Exception: fixed white space devices transmit an identifier.

[11] AT&T explained that interference to a microwave link is hard to identify. It does not register as interference, being indistinguishable from naturally occurring fade. Even very weak interfering signals reduce the link's engineered fade depth. Operators have no way to monitor for this. Even an interfering device that malfunctions or is operated maliciously will go undetected. Comments of AT&T Services, Inc. in GN Docket No. 17-183 at 16-17 (filed Oct. 2, 2017).

device must not “transmit[] enough energy to have a significant potential for causing harmful interference.”[12]

3. Burden of proof

Because licensed microwave systems are entitled to interference protection from unlicensed devices, the burden of proof of non-interference must fall on the unlicensed proponents. We make a *prima facie* showing here that the unlicensed proponents cannot meet this burden, as interference is certain to occur. Unless the proponents can mount a rebuttal that persuasively eliminates any reasonable threat of interference, the Commission must reject their proposal.

C. SIMULATION (STUDY 1)

Study 1 below describes a simulation we carried out to assess the same unlicensed RLANs that RKF modeled. Where RKF’s assumptions are not clearly wrong, we adopt them as well.

1. Simulation method

Our simulation proceeds as follows:

1. For each of eight cities, specify a square 193 km (120 miles) on a side around the city center (not shown). We used Chicago, Houston, Los Angeles, New York, Phoenix, San Francisco, Seattle, and Washington.

2. From the FCC’s ULS licensing database, identify all of the lower 6 GHz receivers in the 193 km squares having 30 MHz channel bandwidths (total of 7,596 receivers). For each receiver, determine the latitude, longitude, azimuth, and antenna size.

3. Delineate a 20 x 10 km rectangular study area in front of each microwave receiver, as shown in Figure 1

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[12] *Ultra-Wideband Transmission Systems,* Second Report and Order and Second Memorandum Opinion and Order, 19 FCC Rcd 24558 at ¶ 68 (2004). The Commission added: “The requirements for unlicensed operation … ensure that such ‘apparatus’ do not transmit energy in a way that has a significant detrimental effect on the operation or development of the nation’s communications network.” *Id.* at ¶ 69 (footnote omitted).

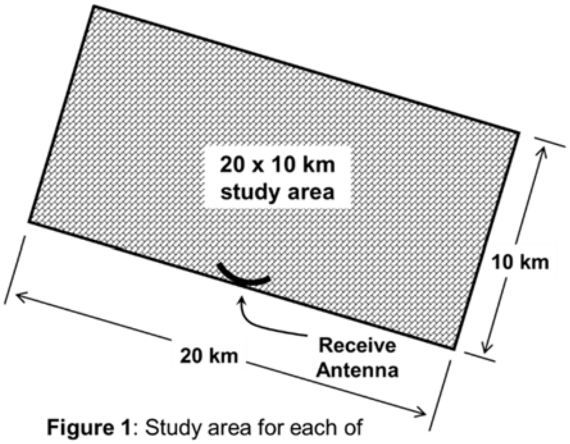

Figure 1: Study area for each of 7,596 microwave receivers

4. For each microwave receiver, use the antenna size, the WINNER II propagation model (as chosen and interpreted by RKF), and manufacturers' antenna specifications to determine the zones around the antenna from within which an RLAN will cause specified degrees of interference.[13]

5. Randomly distribute RLANs over each 20 x 10 km study area, at the density specified by RKF, but consider only the 0.6% of RLANs that RKF located outdoors. This gives 15.1 outdoor units per square kilometer in urban/suburban areas.[14] Assume these operate at 35 dBm, the power that RKF (page 18) specified for outdoor units.

6. For each receiver, count the number of RLANs that fall within its interference zones for specified levels of interference. Average the per-receiver results by city; then average those results over all eight cities.

7. Repeat step (6) 1,000 times for each antenna size and average the results.

Certain of our assumptions reduce predicted interference:

(a) we ignore the 99.4% of RLANs that RKF places indoors, as if building walls and windows offer perfect shielding;

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[13] We used the specifications for Commscope 6 GHz antennas model UHX*, where * is the antenna size in feet, for the 6, 8, 10, and 12 foot antennas; *e.g.*, the six-foot antenna has model number UHX6. The 4-foot antenna was model VHLP4. Other manufacturers' products will show similar results, as antenna performance depends more on the underlying physics than on the details of manufacture.

[14] Calculation: The area of CONUS is 7.664M km^2. RKF (at page 10) assumes interference will be concentrated in the urban/suburban parts of CONUS; it estimates those areas to be 5% of CONUS, or 383k km^2. RKF (at page 13) assumes 958M total units of which 0.6% are outdoors, for 5.748M outdoor units. Dividing gives 15.1 outdoor units per km^2.

(b) we place all RLANs at ground level, which overestimates the collective attenuation from ground clutter;

(c) we reduce antenna gain when the RLAN is in the near field of the receive antenna;

(d) we ignore RLANs within 30 meters of the receive antenna, as did RKF (page 33); and

(e) we consider only one RLAN at a time, which ignores the effects of aggregate interference.

These assumptions exclude RKF's (page 7) worst-case "corner-case geometries," which do not figure in our analysis.

We do take into account the antenna size at each individual microwave receiver. These vary from 4 to 12 feet in 2-foot increments. (There are also a small number of 3-foot antennas.) The antenna size is important because it determines the characteristic pattern of zones within which the receiver is susceptible to specified degrees of interference. Although RKF ignored it, antenna size is the single most important determinant of harm to a receiver from RLANs. Our simulation shows that smaller antennas tend to be less susceptible to severe interference; larger antennas are more susceptible.

2. *Simulation results*

Figure 2 shows three cases of interference into a six-foot antenna, the most commonly used size at 6 GHz.[15] On average, *per receive antenna*, 0.36 RLANs will cause a 20 dB reduction in fade margin, 0.11 RLANs will cause a 30 dB reduction, and 0.03 RLANs will cause a 40 dB reduction.

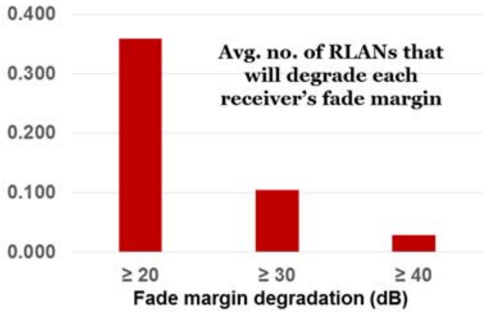

Figure 2: Average number of RLANs per receiver that will degrade a 6-foot receiver's fade margin by 20 dB (severe interference), 30 dB (errors likely), and 40 dB (link fails)

We can put this another way:

- One out of three receivers will see at least 20 dB loss of fade margin. (This is severe

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[15] The 6-foot antenna is a conservative choice, as the 8-, 10-, and 12-foot sizes are all more susceptible to interference.

interference that makes the receiver dangerously susceptible to fades.)

- One out of nine receivers will see a loss of 30 dB. (This leaves little or no fade margin; errors become likely.)
- One out of 33 receivers will see a 40 dB loss. (Most links fail.)

Study 1 below shows the results in more detail, with data pertaining to other antenna sizes and other levels of degradation. Receivers having 8-foot, 10-foot, and 12-foot antennas fare worse than the example above**.**

Virtually every fixed receiver of every size will have its fade margin degraded by at least one dB from each of several emitters. More than 70% of paths will receive interference that degrades the fade margin by 10 dB or more.

3. Alternative method

A different calculation produces similar predictions of interference without the complexities of simulation.

Figure 3 shows the zone in front of a six-foot antenna where an RLAN risks degrading the fade margin by 30 dB or more, using RKF's interpretation of the WINNER II propagation model. The area of the zone is 0.0078 square kilometers. We showed above, from RKF's data, an average of 15.1 outdoor RLANs per square kilometer. Multiplying these numbers predicts the average number of RLANs within the 30 dB degradation zone of a six-foot receiver: namely, 0.12. (This closely matches the 0.11 result shown at the middle bar of Figure 2.) It means every ninth microwave receiver is vulnerable to at least 30 dB of interference.

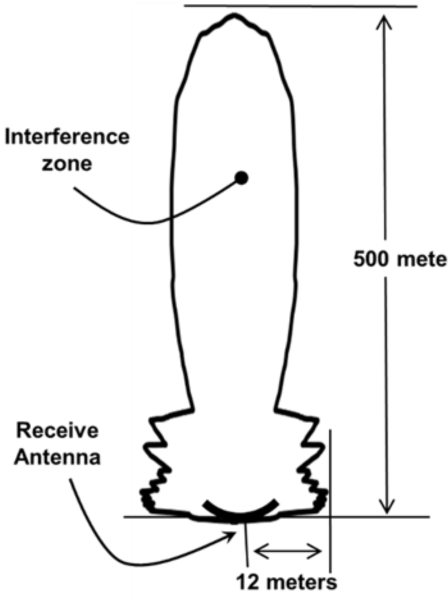

Figure 3: 30 dB interference zone for 6-foot antenna (horizontal scale magnified)

4. Conclusion

Both our simulation and the simpler geometrical analysis rely on RKF's numbers for RLANs, and also RKF's choice of propagation model. Both approaches show severe or disabling interference to large fractions of microwave receivers.

The Commission cannot lawfully permit unlicensed devices to cause these levels of interference to a licensed service carrying critical communications.

D. THEORETICAL ANALYSIS (STUDY 2)

Study 2 below sets out the theoretical analysis that underlies the simulation, developed from fundamental principles with all assumptions clearly spelled out.

E. DISCUSSION OF RKF SIMULATION (STUDY 3)

If our results are correct, it follows that RKF's analysis went badly off the rails. Unfortunately RKF's report is convoluted and hard to read in ways that make its assumptions and methods impossible to reverse-engineer.

Even so, we found some potentially serious problems. We discuss those in Study 3, below, and summarize them here. Because of the ambiguities and inconsistencies in RKF's report, we cannot be sure whether all of these are really errors or just inartful drafting, and if they are errors, whether and how much they affected RKF's results.

Ignoring line-of-sight propagation. RKF seems to analyze only non-line-of-sight interference paths: those that must penetrate intervening buildings, foliage, etc. It ignores line-of-sight propagation, which leads to far worse interference predictions: for a 10-foot microwave antenna, **40 dB of interference from 15 km away**. Line-of-sight can occur under the following circumstances:

- the RLAN is close to the 30-meter circle that RKF (page 33) assumed will contain no RLANs;
- the RLAN and the microwave receiver line up along a street;[16] or
- the microwave receive antenna is on a mountain top overlooking a city built on flat terrain (see example in Figure 4).[17]

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[16] An AT&T study encountered long interference paths of this type. *See* Study 4 at page 26.

[17] This configuration also occurs in Albuquerque NM, San Francisco CA, and Hollywood CA, among other places.

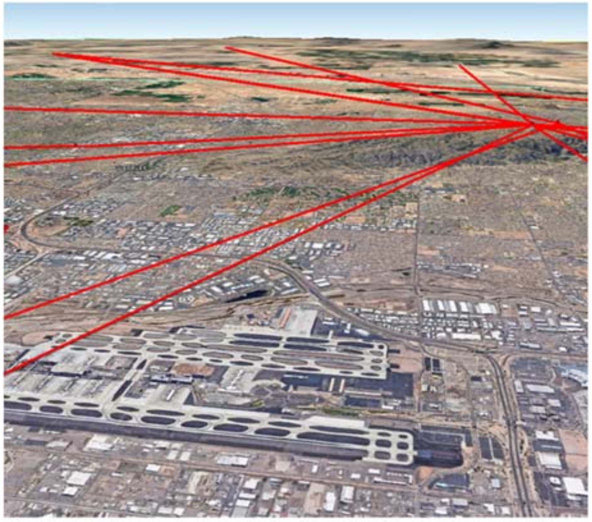

Figure 4: Line-of-sight from antennas on mountain near Phoenix (public safety links shown)

Wrong statistical standard. RKF relies on the WINNER II model to predict path loss and interference. WINNER II itself is an average of several path loss models that reflect different environments. RKF uses the model to predict an average likelihood of interference: an average of averages. But to predict that interference will not occur "on average" is not enough. RLAN proponents must establish that interference, if it occurs at all, will be extremely rare. To be 99% confident an RLAN signal will not cause interference would require reducing the RLAN power by 18 dB. See Study 3 at pages 20-21. To be 99.9% confident—which would still let through disabling interference far too often—requires reducing the RLAN power by 25 dB.

In the real world, "average" interference from obstructed signals is nearly always insignificant. Actual interference comes from the comparatively infrequent case of an emitter that happens to line up with a microwave receiver over an unobstructed path, possibly kilometers away.

RKF's need to invoke statistical reasoning is itself a bad sign. A convincing study should be able to establish there is simply no realistic chance of any harmful interference occurring, without recourse to probabilities.

Co-option of receiver fade margin to counter interference. RKF (page 15) says that peak RLAN usage will occur at 7-11 pm local time. It also says—incorrectly—(page 28) that multipath fading happens only after midnight, when RLAN activity is low. In fact multipath occurs all night from sundown to sunup, overlapping peak RLAN use.[18] RKF (page 28) claims not to use available fade margin "dB-for-dB" to relax interference protection, but ambiguities elsewhere leave open the possibility of RKF's exploiting receiver fade margin so as to understate the severity of interference. This would be unlawful under Section 15.5 and unacceptable in practice. Microwave receivers need all of their fade margin starting at sundown. It would take only sparse RLAN use at any nighttime hour to cause microwave outages.

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[18] *See* Figure 13 in Study 3 at page 24,

> ***Ignoring "barren areas."*** RKF (page 16) overlooked 95% of the U.S. landmass on the ground of low population density.[19] Yet thousands of long-haul 6 GHz microwave links that connect population centers pass over lightly occupied land. Typically they make interconnections at relay facilities sited in sparsely populated areas that have little ground clutter to attenuate signal. With few structures in the way, even one RLAN kilometers from the tower can have line of sight and take down a link.
>
> ***Ignoring antenna size***: an important predictor of RLAN interference.
>
> ***Errors in close-range calculations.*** Interference is most likely from an RLAN between 30 meters and 1 kilometer from a microwave receive antenna. RKF's calculations in this range use an oversimplified version of the WINNER II model.

See Study 3 below for more instances and more detail on those above.

Important: It is not our responsibility to track down RKF's mistakes. Moreover, even if RKF were to satisfactorily explain all of the points we raise above, that is not enough to rebuild its case. To prevail, RKF would also have to overturn our predictions of harmful interference.

RKF's obligations in this respect and ours are not symmetrical. RKF's employers, being proponents of unlicensed operation, have the burden of proving their devices will not cause harmful interference to critical licensed services. We showed such interference ***will*** occur; and we made clear our assumptions, methods, and criteria. Unless the proponents can prove us wrong, the Commission cannot lawfully authorize unconstrained unlicensed devices of the kind RKF described.

F. APPLICATION OF ITU-R RECOMMENDATION (STUDY 4)

The International Telecommunication Union (ITU) is an international body that recommends technical standards that help countries avoid causing radio interference to each other's operations. The same standards also inform the internal regulations of most countries, including the United States.

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[19] RKF (page 11) also supposes that only urban and suburban residents would ever want to use 6 GHz RLANs—sheer guesswork.

Recommendation ITU-R F.1706 studies the interference into a point-to-point fixed microwave receiver from “nomadic” (mobile) wireless emitters. It allows for a maximum aggregate degradation to the receiver of 0.5 dB under free space propagation conditions.[20]

Our own study is far more tolerant than the ITU’s: we consider only interference cases much higher than 0.5 dB; we allow for non-free-space propagation by using RKF’s interpretation of WINNER II;[21] and we consider only one emitter at a time, ignoring aggregate effects—and even so, we find unacceptable interference.

Yet the ITU-R F.1706 assumptions remain relevant to the analysis. Study 4 below discusses a report by AT&T (through the former Bell Labs) that found long free-space paths even in urban areas—not surprising, inasmuch as fixed microwave antennas are invariably high off the ground. A mobile emitter can be a particular threat, emerging unpredictably from behind a building into a receiver boresight, where it will cause interference from kilometers away.

As in Figure 4 above, links carrying public safety traffic are vulnerable to free-space (line of sight) interference from locations where consumers would be free to operate unlicensed emitters. Any such interference would be devastating: into a 10-foot antenna, an unlicensed 35 dBm EIRP emitter will cause 40 dB of degradation (link shutdown) from 15 km away. This is not acceptable from unlicensed operation under the Commission’s rules.

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[20] *Protection criteria for point-to-point fixed wireless systems sharing the same frequency band with nomadic wireless access systems in the 4 to 6 GHz range*, Recommendation ITU-R F.1706 at 1 (2005), available at

[21] WINNER II also allows for free-space propagation, although RKF did not implement that option.

CONCLUSION

The RLAN devices described in the RKF report will cause harmful interference to large numbers of 6 GHz fixed microwave receivers. On both practical and legal grounds, the Commission must refrain from authorizing any such devices in the 6 GHz fixed service bands.

Respectfully submitted,

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cc: Paul Margie, Counsel to Apple Inc., Broadcom Corporation, Facebook, Inc., Hewlett Packard Enterprise, and Microsoft Corporation

TECHNICAL CERTIFICATION

I am a technically qualified person who either prepared or reviewed all of the materials in this submission. I certify that the technical statements therein are correct to the best of my knowledge.

George Kizer

March 12, 2018

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Author, multiple peer-reviewed technical articles in professional journals
Editor, Wiley IEEE Series on RF and Microwave
President, National Spectrum Management Association
Chairman, TIA TR-45 Working Group for Microwave Systems
Former Chairman, TIA

Studies Regarding RKF's *Frequency Sharing for Radio Local Area Networks in the 6 GHz Band* Proposal

George Kizer
March 9, 2018

Study 1 - The Simulation

This paper explores the potential for unlicensed band sharing with the existing lower 6 (5.925 - 6.425) GHz and the upper 6 (6.525 - 6.875) GHz band radio systems. The study by RKF Engineering Services considers unlicensed emitters at three power levels: 19, 24 and 35 dBm EIRP ([1], page 18) with anticipated deployment of 50%, 30% and 20% respectively ([1], page 23). RKF [1] predicts a deployment of 958 million unlicensed 6 GHz units by 2025 ([1], pages 11 and 13). As RKF notes on page 16, "… approximately 95% of CONUS is either rural or barren, which implies that interference will be predominately concentrated in urban and suburban areas". The contiguous United States is approximately 3,000,000 square miles suggesting most of the deployment would be over 150,000 square miles. That suggests deployment density would be on the order of 6,667 units per square mile (2,574 units per square kilometer). Many of these units will be indoors. RKF suggests 0.6 % of the units (6 million) will be outdoor ([1], page 13). On average there will be 40 outdoor units per square mile (15 units per square kilometer).

The simulation will require detailed knowledge of the microwave receiver antennas involved. For purposes of simulation, we will assume the most popular models are typical of all antennas of the same diameter.

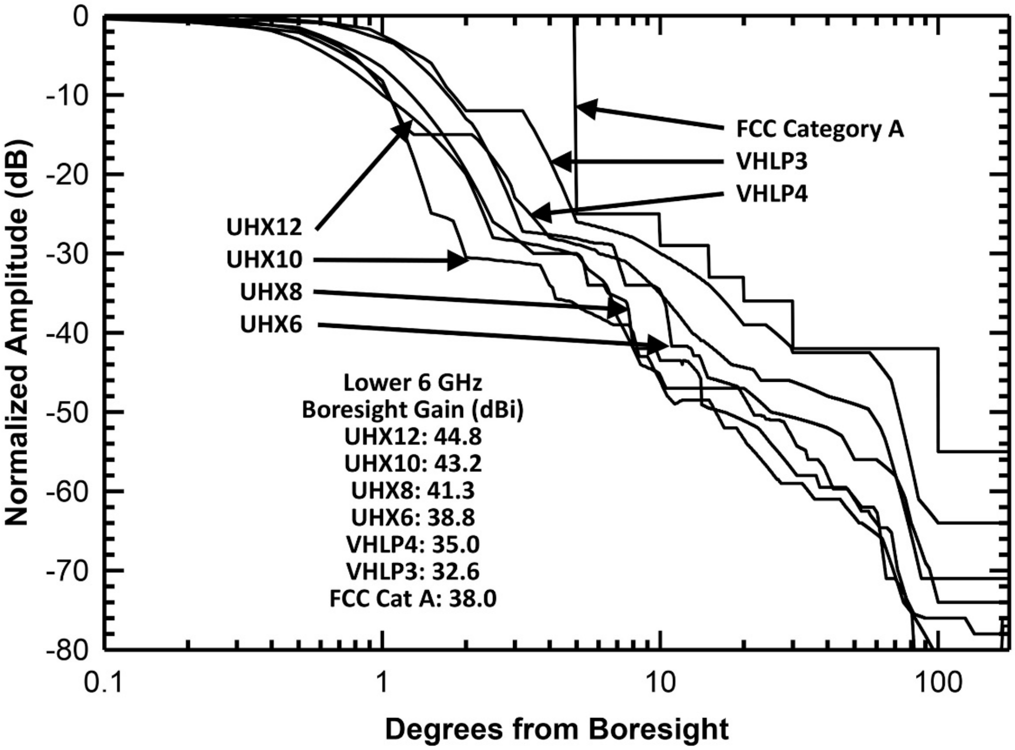


Figure 1 – Radiation Patterns for the Antennas Used in the Simulation

In the above figure, the antenna's diameter in feet is the number at the right on the model name. Each size of antenna has different rejection (depending upon antenna face as well as polarization) for a given azimuth off boresight. For this simulation, the most conservative values (greatest rejection value) were used. See the Antenna Data References below for the sources of the data. The vendor-supplied radiation patterns were somewhat granular. The vendor suggests linear interpolation between given data points. For purposes of these simulations the radiation patterns were linearly interpolated to one tenth of a degree. Since some of the interfering transmitters might be close to the receive antenna, the near field decoupling was calculated [12] [13] and used to reduce the antenna gain for those situations.

We wish to simulate the effect of the unlicensed RLAN deployment on the performance of the fixed microwave service (FS). We will investigate the 30 MHz channels in eight cities: Chicago, Houston, Los Angeles, New York, Phoenix, San Francisco, Seattle, and Washington. The method of analysis for a particular interfering link is outlined in Study 3, below. The path parameters were taken from the FCC ULS data base for the lower 6 GHz.

We assumed a hypothetical rectangular grid in front of the antenna: 10 kilometers to the left and to the right and 10 kilometers deep. The receive antenna is assumed to be centered at the edge of the grid.

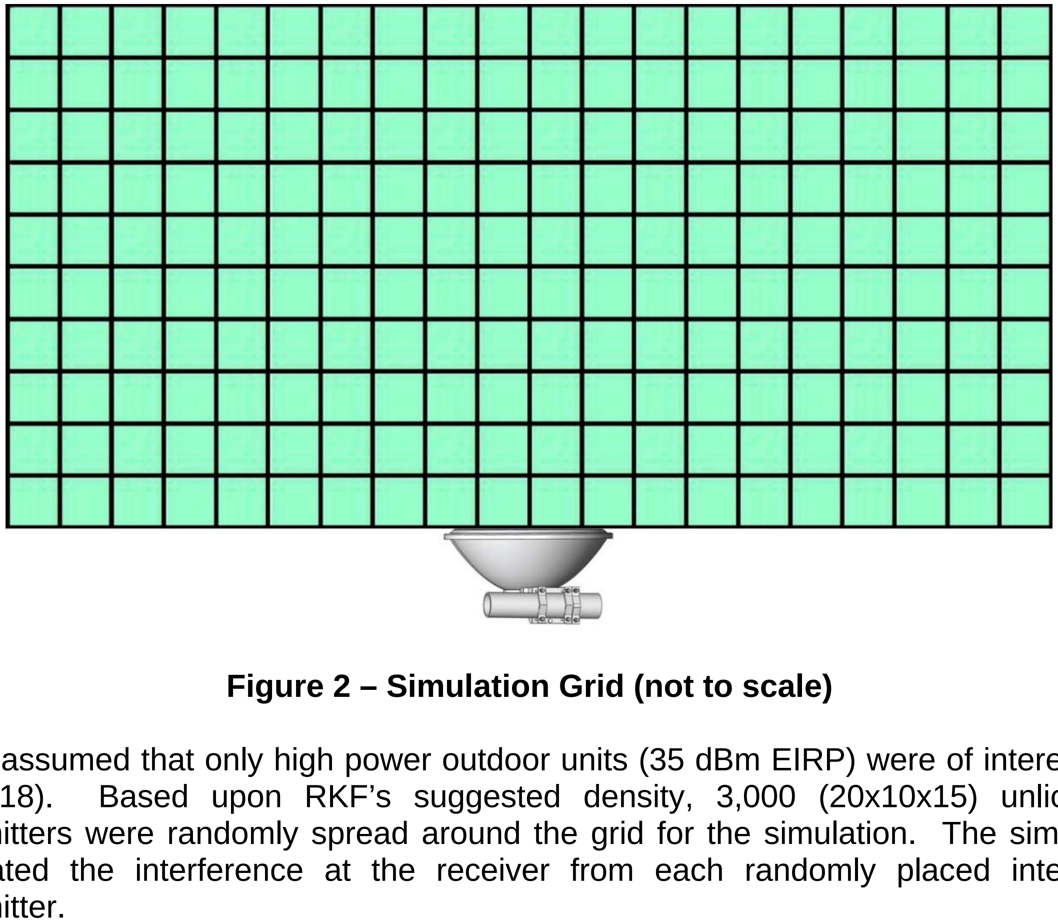


Figure 2 – Simulation Grid (not to scale)

It was assumed that only high power outdoor units (35 dBm EIRP) were of interest ([1], page 18). Based upon RKF's suggested density, 3,000 (20x10x15) unlicensed transmitters were randomly spread around the grid for the simulation. The simulation calculated the interference at the receiver from each randomly placed interfering transmitter.

The simulation used the WINNER II propagation model, as chosen and interpreted by RKF. Since we limited the study to RKF's outdoor transmitters, building attenuation was not a factor. As suggested by RKF ([1], page 33) transmitters were excluded within 30 meters of the receive antenna. The impact of other transmitters was estimated as a reduction in receiver fade margin. By RKF's criterion, any reduction of fade margin exceeding 1 dB would be considered excessive interference. ([1], pages 5, 6 and 11 cite a I/N = -6 db criterion which is equivalent to a 1 dB fade margin degradation.) That is consistent with national [18] and international [7] recommendations.

Results:

The simulation was conducted on all paths in the 20 km x 10 km grid in each of the eight cities referenced above. For purposes of analysis, each path was assumed to have two sites with receivers employing the antenna listed in the ULS data base.

During the simulation the following interference formula was calculated:

Interference (dBm) = EIRP (dBm) – WINNER II Path Loss (dB) + Antenna Gain) (dBi)
– Antenna Side Lobe Rejection (dB) – Near Field Loss (dB) (1)

The composite fade margin was calculated and results were collected. **All paths experienced multiple cases of interference strong enough to degrade the path fade margin at least one dB. More than 70% of each city's paths received far stronger interference: degradation of the fade margin by 10 dB or more.** The following shows the numbers of unlicensed emitters causing each specified loss of fade margin, with each emitter considered individually (no aggregate interference):

City	Number of Paths	Fade Margin Reduction >1 dB	Fade Margin Reduction ≥ 10 dB	Fade Margin Reduction ≥ 20 dB	Fade Margin Reduction ≥ 25 dB	Fade Margin Reduction ≥ 30 dB	Fade Margin Reduction ≥ 40 dB
Chicago	492	5.601	1.253	0.380	0.206	0.115	0.030
Houston	838	5.621	1.257	0.357	0.200	0.121	0.033
Los Angeles	513	5.474	1.225	0.370	0.197	0.121	0.029
New York City	452	5.585	1.273	0.389	0.217	0.119	0.032
Phoenix	231	5.647	1.305	0.377	0.223	0.130	0.041
San Francisco	301	5.543	1.241	0.354	0.199	0.121	0.037
Seattle	266	5.671	1.242	0.359	0.203	0.120	0.030
Washington DC	705	5.558	1.226	0.369	0.214	0.114	0.031
Average	475	5.587	1.253	0.369	0.207	0.120	0.033

Table 1 - Average Number of Interference Cases per Receiver

Each city had a different distribution of various antenna sizes which contributed to the variation in each city's statistics. The simulation was repeated using a single antenna of each size and repeating the simulation 1000 times with different random distributions of emitters. For each antenna size, the following shows the average numbers of unlicensed emitters causing each specified loss of fade margin:

Antenna	Fade Margin Reduction >1 dB	Fade Margin Reduction ≥ 10 dB	Fade Margin Reduction ≥ 20 dB	Fade Margin Reduction ≥ 25 dB	Fade Margin Reduction ≥ 30 dB	Fade Margin Reduction ≥ 40 dB
12 Ft	7.838	1.775	0.535	0.285	0.143	0.045
10 Ft	5.398	1.225	0.372	0.207	0.118	0.030
8 Ft	5.509	1.244	0.375	0.214	0.116	0.031
6 Ft	5.682	1.278	0.370	0.202	0.117	0.029
4 Ft	3.285	0.735	0.216	0.112	0.057	0.015
3 Ft	4.352	0.976	0.283	0.147	0.077	0.024

Table 2 - Average Number of Interference Cases per Antenna

Surprisingly the larger antennas are more sensitive to interference. Apparently their higher gain is more important than their sidelobe performance.

To investigate antenna interference sensitivity, the Exclusion Zone (area in which an interfering transmitter will cause a defined degradation in fade margin) for each antenna size was calculated. The area (km^2) of the Exclusion Zone was calculated for each antenna size for each defined level of fade margin reduction.

	12 Ft	10 Ft	8 Ft	6 Ft	4 Ft	3 Ft	Category A
Fade Margin Reduction >1 dB	0.443	0.308	0.314	0.323	0.186	0.243	1.027
Fade Margin Reduction ≥ 10 dB	0.114	0.079	0.081	0.083	0.048	0.063	0.264
Fade Margin Reduction ≥ 20 dB	0.034	0.024	0.024	0.025	0.014	0.019	0.079
Fade Margin Reduction ≥ 25 dB	0.019	0.013	0.014	0.014	0.008	0.010	0.044
Fade Margin Reduction ≥ 30 dB	0.011	0.007	0.008	0.008	0.005	0.006	0.025
Fade Margin Reduction ≥ 40 dB	0.003	0.002	0.002	0.002	0.001	0.002	0.008

Table 3 – Exclusion Zone Areas (km^2) by Antenna Size

The Exclusion Zone sizes are as shown below (note the variations in vertical and horizontal scale):

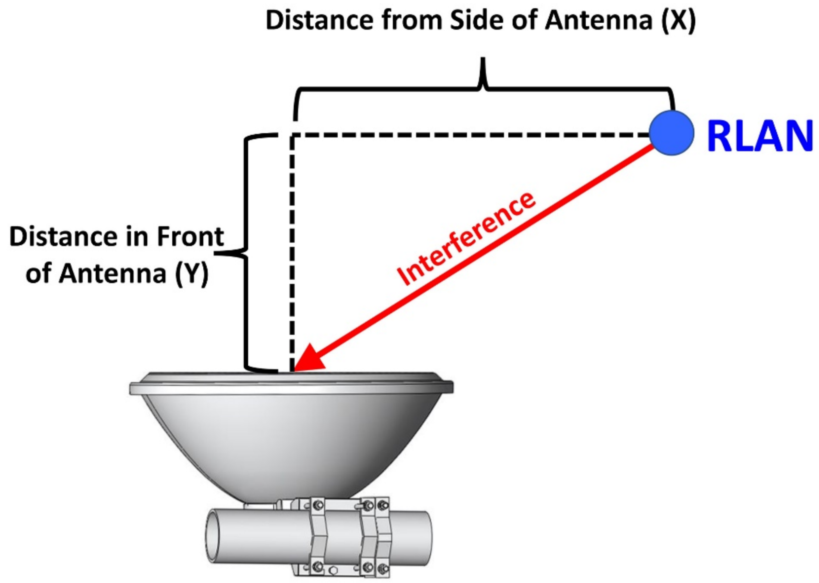
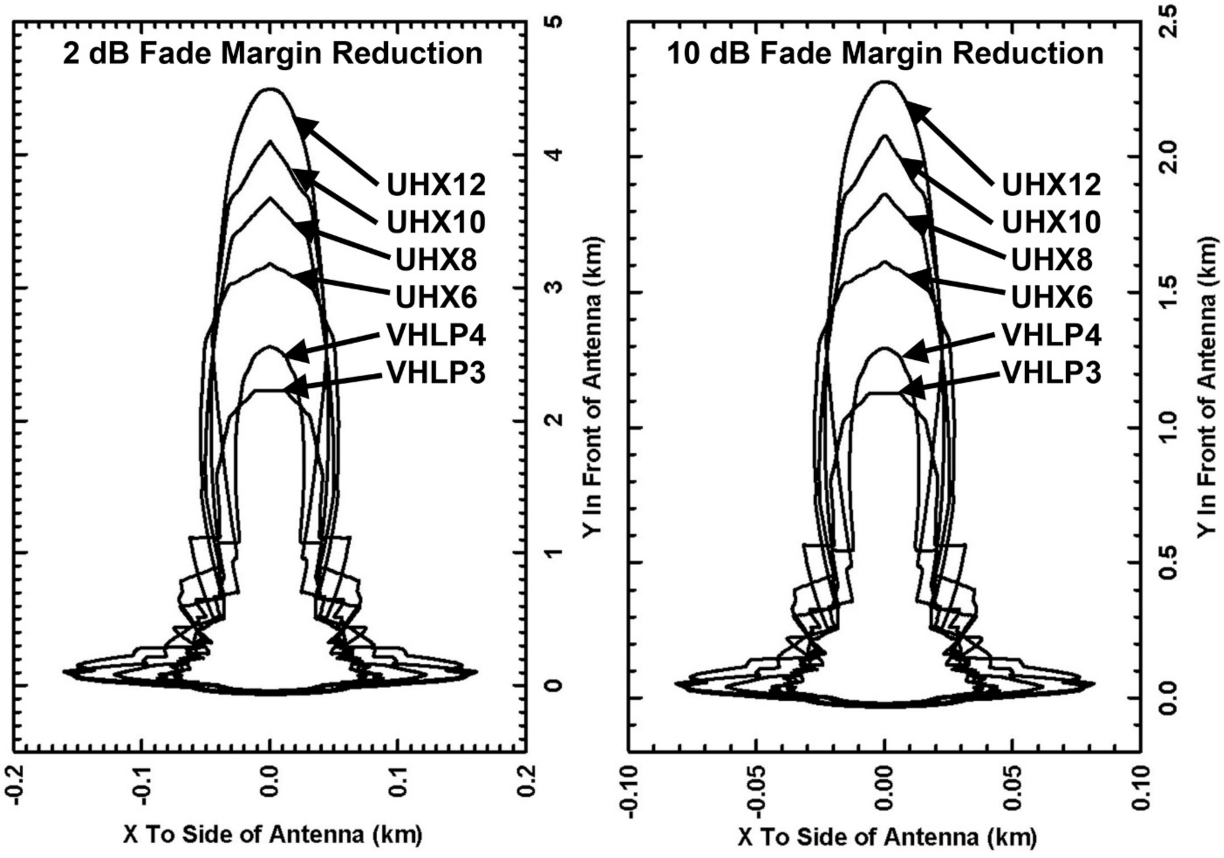


Figure 3 – X and Y on Exclusion Zones



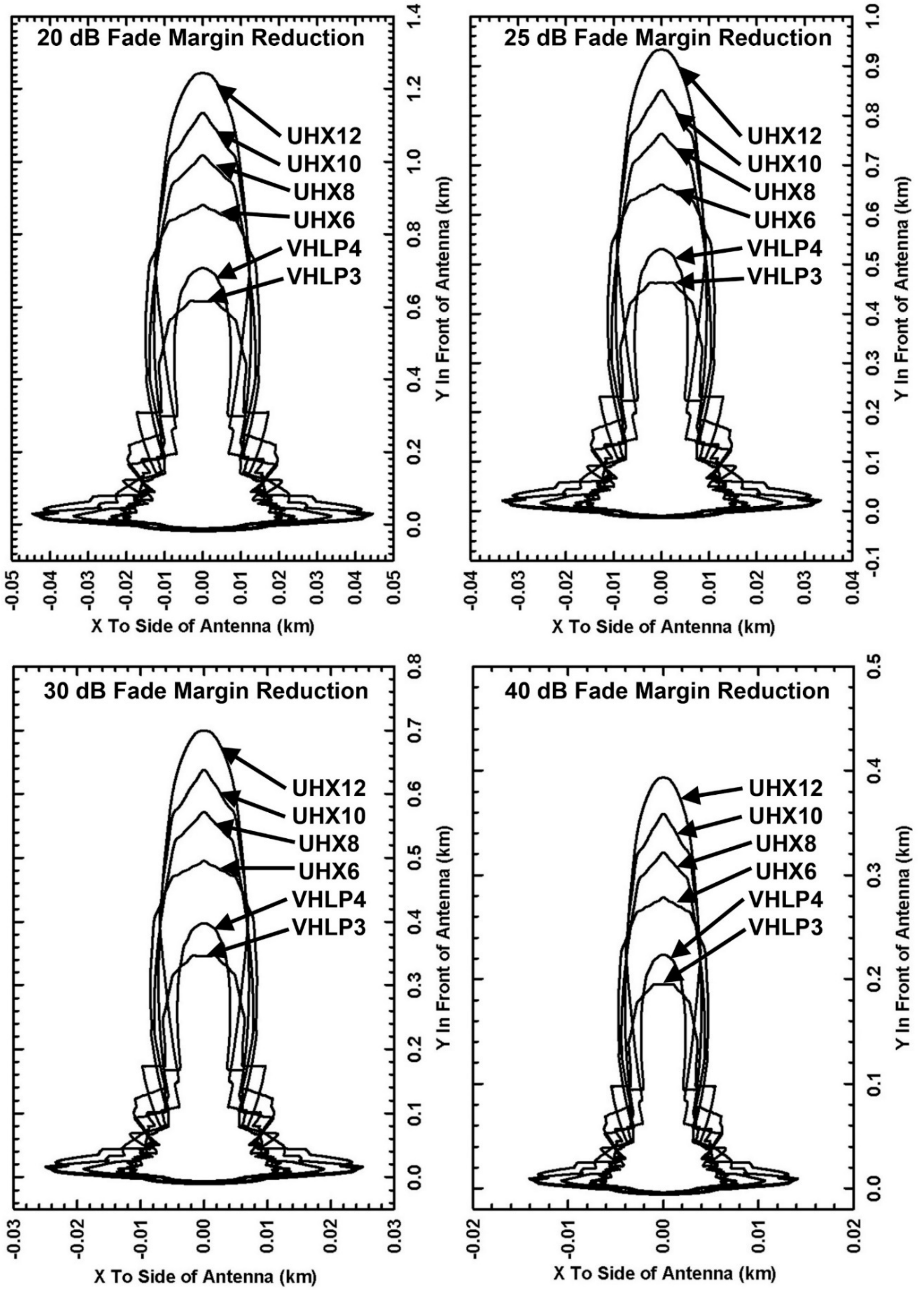


Figure 4 – Exclusion Zones

If an interfering transmitter is placed in the Exclusion Zone in front of the antenna, it will cause the specified fade margin reduction (or greater) to occur.

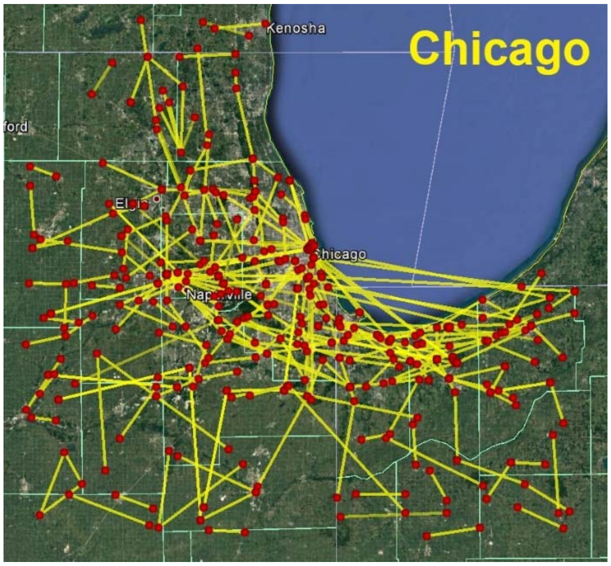
Before moving on, let's work an example.

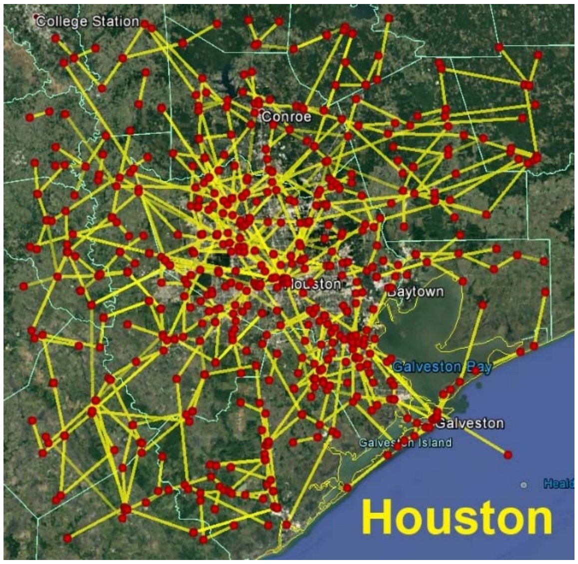
> We will assume a 30 MHz channel receiver with a 5 dB noise figure. From Table 5 below, the receiver noise is -94 dBm.
>
> Interference (dBm) = EIRP (dBm) – WINNER II Path Loss (dB)
> + Antenna Gain (dBi) – Antenna Side Lobe Rejection (dB)
> – Near Field Loss (dB) [(1) above]
>
> WINNER II Path Loss (dB) $\cong$ 150 + 40 $\log_{10}$(distance, km) [(10) below]
>
> Assume a boresight distance of 2 km from a 10 foot (UHX10) antenna and the RLAN with +35 dBm EIRP. The antenna has 43.2 dBi boresight gain. With boresight, side lobe rejection is zero and from Table 8 we are well outside the antenna near field cross-over point (near field loss is zero). Now we can calculate interference at the receiver.
>
> Interference (dBm) = +35 - 162 + 43.2 - 0 - 0 = -83.8 dBm
>
> Relative Interference Power (dB) = Interference (dBm) – Receiver Noise (dBm)
> = -83.7 – (-94) = 10.4 dB
>
> From Table 6 (or equation (5)) we would expect a reduced fade margin of about 11 dB. That is consistent with Figure 4 above. (The result is outside the 20 dB fade margin reduction (FMR) Exclusion Zone but just inside the 10 dB FMR Exclusion Zone.)

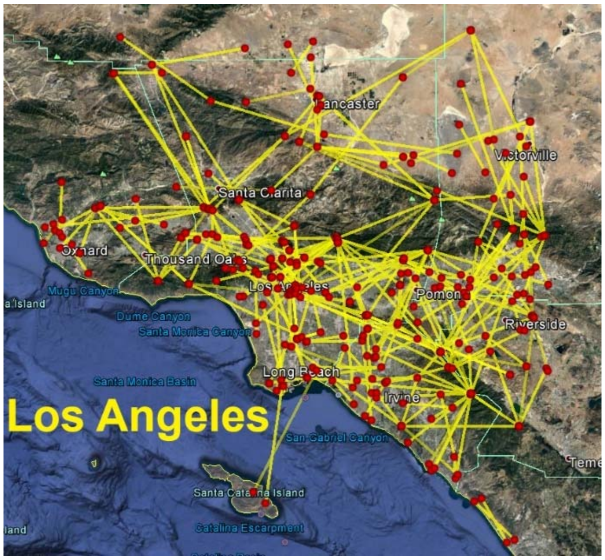
Fade Margin Reductions (FMR) of 2 to 20 dB represent varying degrees of path performance degradation. FMR of 30 to 40 dB represents occasional or constant path outage. **All microwave antennas have a strip of area in front of them in which they are sensitive to interference, from a few hundred meters to a few kilometers long – even in urban/suburban environments. These results are at sharp contrast with the RKF study.**

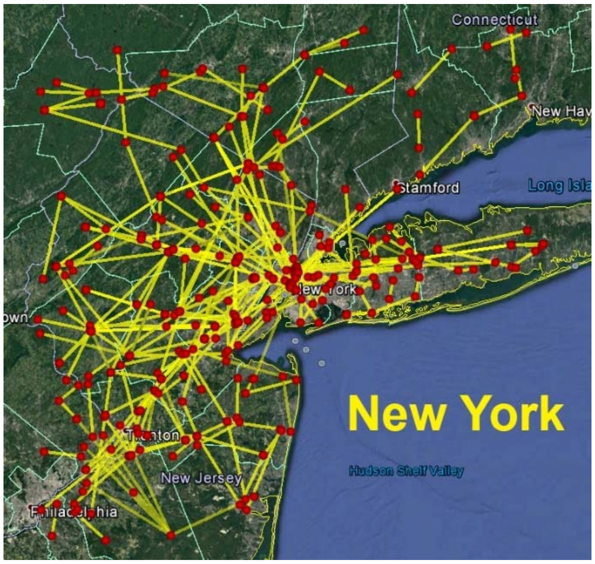
Study 2 – Theoretical Analysis

The following illustrations map existing 30 MHz bandwidth channels in the lower 6 GHz band in several urban areas:









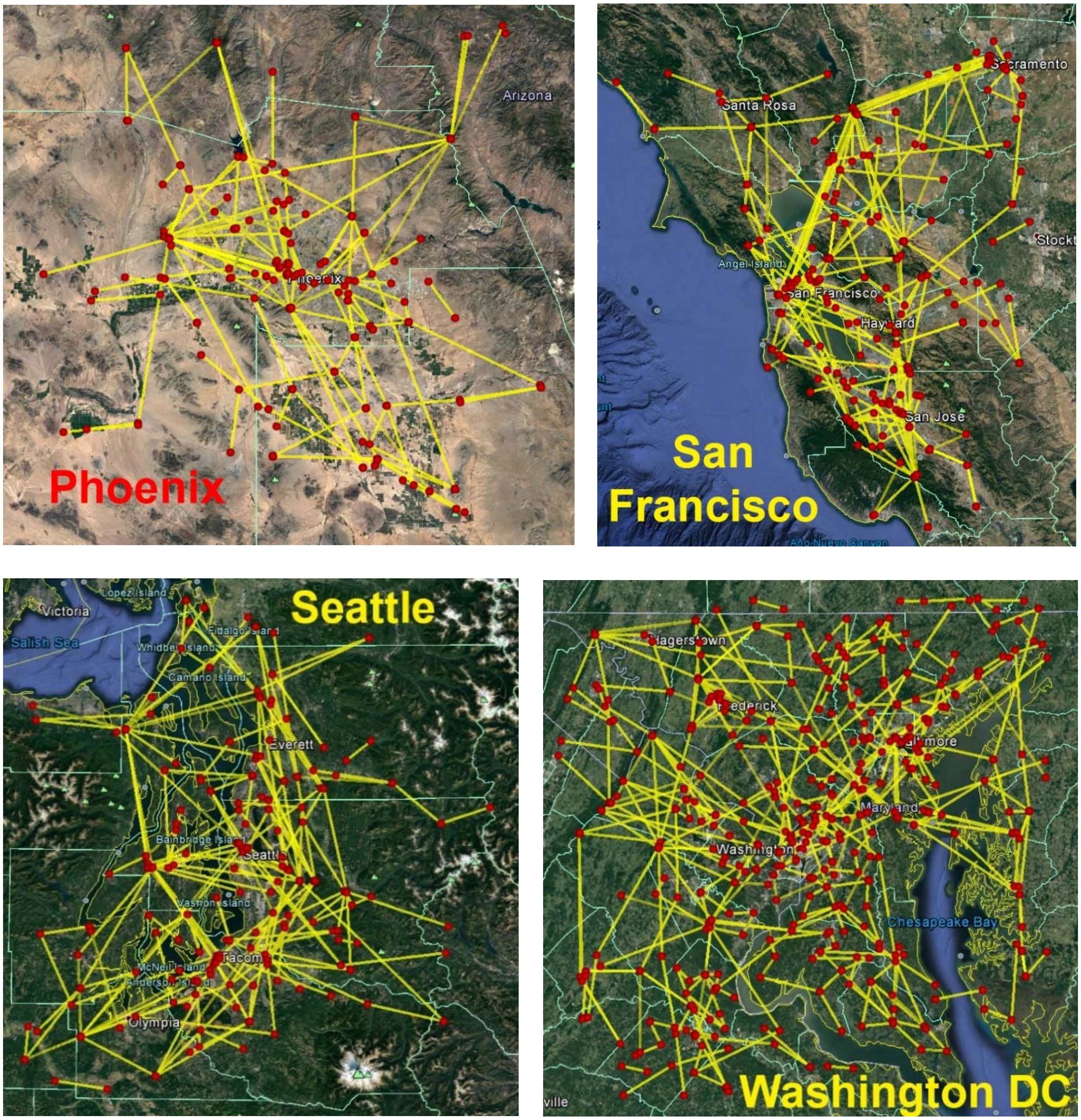


Figure 5 - Existing 30 MHz Fixed Point-to-Point Microwave Links

In view of the densities, it is probable some unlicensed units will be in the boresights of existing fixed radio paths. As we shall see later, this is a significant issue.

Determining the Impact of Unlicensed Interference

When sharing spectrum, the standard approach is to limit interference so that it increases the receiver front end noise by no more than a tolerable amount. Most national and international administrations allow a fixed microwave receiver front end noise to be increased 1 dB for an intra-system interferer or 0.4 dB for an inter-system ("foreign") interferer ([7], Table 4). This implies the interference must be 6 dB or 10 dB respectively less than the receiver front end noise. We shall use the 6 dB value (I/N = -6 dB) for this study since it is the value used by RKF ([1], pages 5, 6 and 11).

[Allowable] Foreign System Interference = Radio Front End Noise – 6 dB (2)

Receiver front end noise N is given by the following ([12], page 674, formula (A.54)).

$$N(\mathrm{dBm}) = -114 + NF(\mathrm{dB}) + 10\,\mathrm{Log}(B) \qquad (3)$$

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

Since the typical receiver noise figure in this band is about 5 dB ([1], page 29), and I/N = -6 dB, the allowable foreign system interference I would be the following.

$$I(\mathrm{dBm}) = -115 + 10\,\mathrm{Log}(B) \qquad (4)$$

The channel bandwidths having commercial significance are the following:

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

Table 4 – Most Used Band Channel Bandwidths (MHz)

We can calculate receiver front end noise N and the allowable interference power I:

Channel Bandwidth (MHz)	Receiver Noise N (dBm)	Allowable Interference I (dBm)
60	-91	-97
30	-94	-100
20	-96	-102
10	-99	-105
5	-102	-108

Table 5 – Receiver Front End Noise and Allowable Interference Power

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

$$RFM = \{10 \log_{10} [\, 10^{N/10} + 10^{I/10} \,]\} - N \qquad (5)$$

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

If we relate I to power relative to N, we can set N = 0 and I as the dB level of power relative to N. Using this approach gives the following chart showing impact of interference power: [Relative Interference Power (dB) = Interference (dBm) – Receiver Noise (dBm)]

Relative Interference Power (dB)	Decrease in Fade Margin (dB)
-10	0.4
-6	1.0
-2.3	2.0
0	3.0
1.8	4.0
3.3	5.0
9.5	10.0
14.9	15.0
20.0	20.0
25.0	25.0
30.0	30.0
40.0	40.0

Table 6 – Impact of Interference Power on Path Fade Margin

RKF ([1], pages 5 and 11) proposes a relative interference power (I/N) of -6 dB. This is equivalent to a reduction in fade margin of 1 dB. Keep in mind that at the 6 GHz frequencies, path fading is multipath only: changing refractions from atmospheric layers that can interfere destructively with the direct signal.

If the fade margin decreases 3 dB, over the long term outage time tends to double. If it decreases 10 dB, outage time increases by a factor of ten. If it decreases 20 dB, outage time increases by a factor of 100. And so on.

From the availability perspective: assume the path has availability of 99.999% in the absence of interference. If the fade margin is decreased by 3 dB, the availability on average drops to 99.998%. If fade margin decreases by 10 dB, the availability drops to 99.99%. If fade margin decreases by 20 dB, the availability drops to 99.9%.

Estimating the Impact on FS of an Unlicensed Transmitter

The basic parameters for the frequency bands of interest are the following:

Band Name	Lower 6 GHz	Upper 6 GHz
Frequency Range (GHz)	5.925 - 6.425	6.525 - 6.875
Center Frequency (F)	6.175 GHz	6.7 GHz
Band Bandwidth	500 MHz	350 MHz
Free Space Wavelength	0.0485 meters	0.0447 meters

Table 7 - Band Characteristics

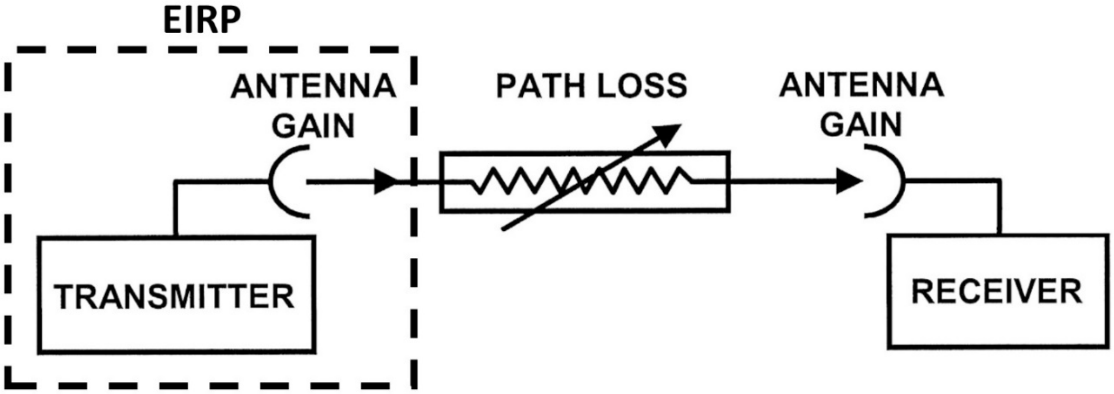


Figure 6 – Typical Radio Path

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

Received Power (dBm) = transmitter power (dBm) + transmit antenna gain (dBi) + free space loss (dB) + receive antenna gain (dBi) (6)

= transmitter EIRP (dBm) + free space loss (dB) + receive antenna gain (dBi) (7)

We will consider worst case conditions in which the unlicensed transmit antenna is directly in front of the microwave receive antenna ("boresight" conditions) and both antennas are operating in the far field zone. For the unlicensed transmitter, its transmit antenna will be so small it will always be operating in the far field. The fixed service antennas are much larger and have significant near field zones. The loss in antenna gain in the near field region can be calculated ([12], pages 265-274, and [13]) if necessary.

Antenna Size		Distance to Crossover (meters)	
(Feet)	(Meters)	Lower 6 GHz	Upper 6 GHz
3	0.91	34.4	37.4
4	1.22	61.2	66.4
6	1.83	137.8	149.5
8	2.44	244.9	265.8
10	3.05	382.7	415.3
12	3.66	551.1	598.0

Table 8 –Near / Far Field Crossover Distance ($2 D^2 / \lambda$, meters)

If both antennas are operating in the far field region, free space path loss (dB) is given by the following formula ([12], page 670, formula (A.28)).

FSL (dB) = 92.5 + 20 Log F (GHz) + 20 Log d (kilometers) (8)
FSL = Free Space Loss
F = Frequency of radio wave
= 6.175 GHz, center frequency for Lower GHz
= 6.700 GHz, center frequency for Upper 6 GHz
d = Distance between antennas

The gain G of a typical parabolic antenna can be given by the following:

G (dBi) = 17.9 + 20 Log F (GHz) + 20 Log d (meters) (9)
See [12], page 675, equation (A.63), with E = 55.:

Antenna Size		Antenna Gain (dBi)	
(Feet)	(Meters)	Lower 6 GHz	Upper 6 GHz
3	0.91	32.9	33.6
4	1.22	35.4	36.1
6	1.83	38.9	39.6
8	2.44	41.4	42.1
10	3.05	43.4	44.1
12	3.66	45.0	45.7

Table 9 – Typical Receive Antenna Gains

For lower 6 GHz, a popular antenna (See [12], page 130, Figure 5.17) is 10 feet. We saw its extensive use in the eight cities in Study 1. We will use it in the following examples.

The Path Propagation Model

RKF suggests ([1], pages 32 to 35) using the WINNER II propagation model [6] for paths between 30 meters and 1 kilometer and the ITM/STRM+P.2108 [14] [15] [11] merged model for paths between 1 and 5 kilometers. No details of how the ITM, STRM or P.2108 pieces were merged are given. We will use the RKF WINNER II model for the entire path range. This will make our analysis rather conservative in the 1 to 5 km range. Specifically, we will underestimate interference in the 1 km to 5 km range by 10 dB to 20 dB respectively ([1], page 34).

The WINNER II path loss models are summarized in Table 4-1 of [6]. RKF chose the urban (UMa) and suburban (SMa) macro models to implement. These are valid over the propagation distances of 10 to 50 meters, on the low end, to 5 km on the high end. Most significant estimated interference occurs with path distances less than 5 km. The WINNER II models [6] define one Line of Sight (LOS) model from short distances to a breakpoint (d_{BP}) and Non-Line of Sight (NLOS) beyond that point. Sees Figure 14 and

15 below for examples. RKF ([1], page 33) discusses both LOS and NLOS modeling but from RKF's Figure 4-2 and 4-3 ([1]) (also see Figure 9 below) it appears only the NLOS model was implemented. (We conclude this because the WII Combined models do not change shape over the entire 0 to 5 km range.) Also, to implement the combined LOS/NLOS model fully, a definition of d_{BP} would have been needed. (The definition in the WINNER II model seems inappropriate since it assumes propagation between a 25 meter high base station and a 1.5 meter high user receiver, different from the case under consideration.) Such a definition is not in the RKF analysis. We have to conclude that LOS as defined in the WINNER II model was not considered. This can lead to error since, for short propagation distances, LOS is often the primary interference mechanism. As noted in Study 4 below, it is also the interference mechanism for longer distances in some cases.

For the Urban and Suburban NLOS cases in the 2 to 6 GHz range, the path loss equations in the WINNER II model ([6], Table 4-1) are exactly the same except the urban model has 3 dB more loss. Unaccountably, the RKF's graphs (Figure 4-2 and 4-3) show different curves with differences greater than 3 dB. This implies the RKF urban and suburban losses are represented by significantly different equations. We will assume the worse case (WII Combined Urban) from RKF's analysis. If there is an (unexplained) reason for the difference, our analysis of suburban degradations will be understated. Using the same (conservative) model for both Urban and Suburban cases sidesteps the issue of how to determine when to use one or the other. RKF does not explain how it handled this.

Based upon a curve fit to data in Figures 4-2 and 4-3 of the RKF analysis, the WINNER II Combined Urban may be described as follows:

$$\text{Median Path Loss (dB)} \cong 150 + 40 \log_{10}(\text{distance, km}) \qquad (10)$$

For all analysis of RKF's work, we will use this model.

Interference Degradation

RKF assumes unlicensed transmitters of 19, 24 and 35 dBm EIRP ([1], page 18) with essentially omnidirectional antennas ([1], pages 19 through 21).

Based upon a 35 dBm EIRP transmitter and a 10 feet microwave receive antenna, the following are the expected lower 6 GHz interference levels for a range of interference path distances, assuming the interfering device is directly in front of the 30 MHz channel receiver's antenna:

Interference Path (km)	WINNER II Path Loss (Lower 6 GHz) (dB)	Received Interference Power (dBm)	Fade Margin Reduction (dB)
1	150.0	-72	22.2
2	162.0	-84	10.6
3	169.1	-91	4.8
4	174.1	-96	2.2
5	178.0	-100	1.0

Table 10 – Received Interference in a 30 MHz Channel

35 dBm transmit EIRP and 10 foot receive antenna

All existing FS microwave links have already been frequency coordinated so that other FS transmitters may have already caused the interference limit to have been reached. The above represents additional interference beyond the previously coordinated level. All of the receive power levels in the table can negatively impact existing fixed radio paths. We will determine the level of impact.

For 6 GHz paths in the absence of external interference, availability will be dominated by multipath fading. Multipath outage is estimated by fade margin using the Vigants' formula [17]. It can be reformatted to estimate the increase in outage seconds:

$$L = 10^{RFM/10} \quad (11)$$

L = multiplicative loss of available seconds

RFM = reduction in fade margin(dB)

Reduction in fade margin due to interference may be calculated using equation (5) with values from Table 5 for N and Table 6 for I.

Based upon a given pre-interference availability, loss of fade margin (RFM) can be used to infer loss of availability.

$$OSP = SIAY\ (1 - [\ AVAILP/100\ ]) \quad (12)$$

$$OSA = OSP\ 10^{RFM/10} \quad (13)$$

$$AVAILA = 100\ (1 – (OSA\ /SIAY\ )) \quad (14)$$

OSP = outage seconds prior to fade margin reduction

AVAILP(%) = availability prior to interference

SIAY = seconds in a year = 31,557,600

OSA = outage seconds after interference

AVAILA(%) = availability after interference

From the above we may determine the loss of availability in the above cases. We will consider 30 MHz channel paths with 99.999% (316 annual outage seconds) and 99.9999% (32 annual outage seconds) path availability.

If we use WINNER II as the path loss model rather than free space loss, we get the following results for estimated interference based upon the previously described conditions in Table 10.

		99.999% Availability Without Interference	99.999% Availability Without Interference	99.9999% Availability Without Interference	99.9999% Availability Without Interference
Interference Path Length (km)	Loss of Fade Margin (dB)	Availability With Interference	Additional Outage Seconds per year	Availability With Interference	Additional Outage Seconds per year
1	22.2	99.8330%	52374	99.98330%	5237
2	10.6	99.9886%	3273	99.99886%	327
3	4.8	99.9970%	647	99.99970%	65
4	2.2	99.9984%	205	99.99984%	20
5	1.0	99.9987%	84	99.99987%	8

Table 11 – Impact of a Single Boresight Interference Case on FS Path Availability Assuming WINNER II Propagation Loss, 35 dBm Transmit EIRP and 10 Foot Receive Antenna

If all interference propagation is characterized by the WINNER II propagation model, the typical case will impact FS links if the interferers are within about 5 kilometers of the FS receiver.

Study 3 – A Critique of the RKF Analysis

First, let's review the parameters of the proposed Radio Local Area Network (RLAN) devices [1]:

Peak EIRP transmitter power varies from approximately 19 dBm to 35 dBm (Table 3-4, page 18). Antenna patterns are all essentially omnidirectional (Figures 3-4 to 3-9, pages 19-21) when parallel to the earth. There is probably some additional discrimination for high vertical angles, but the effect is negligible. Per page 23, " … EIRP values are treated isotopically (radiate equally in all directions) once seeded into the model for a given source location."

Transmitter channel bandwidths will be 20 MHz (10%), 40 MHz (10%), 80 MHz (50%) and 160 MHz (30%). The channels will be spread essentially uniformly between 5.925 GHz and 7.125 GHz. The choice of channel bandwidth or specific frequency are apparently unconstrained.

Transmitter heights indoors and outdoors are defined in Tables 3-10 and 3-11, pages 25 and 26. Outdoor installations are 1.5 meters for 95% of the cases. Indoor heights are approximately 60% to 70% at 1.5 meters and 20% to 30% at 4.5 meters. There is no stated basis for these assumptions.

From Table 3-1, page 12, we learn that 10% of the transmitters are high activity (transmitting between 0.11% and 0.44% of the time) and 90% are low activity (transmitting 0.00022% of the time). There is no stated basis for these assumptions. As stated in page 15, these are average statistics. Peak activity during "busy hour" ("busy hour" rates) is not stated. The source of these statistics is not stated. Whether or not equipment will enforce these limits is also not stated. Busy hours are assumed to be 7 PM to 11 PM local time (page 15). We show below that these include the times when 6 GHz Fixed Service radio paths are under maximum stress from multipath fading.

Figure 7 – FS Microwave Links in Lower and Upper 6 GHz

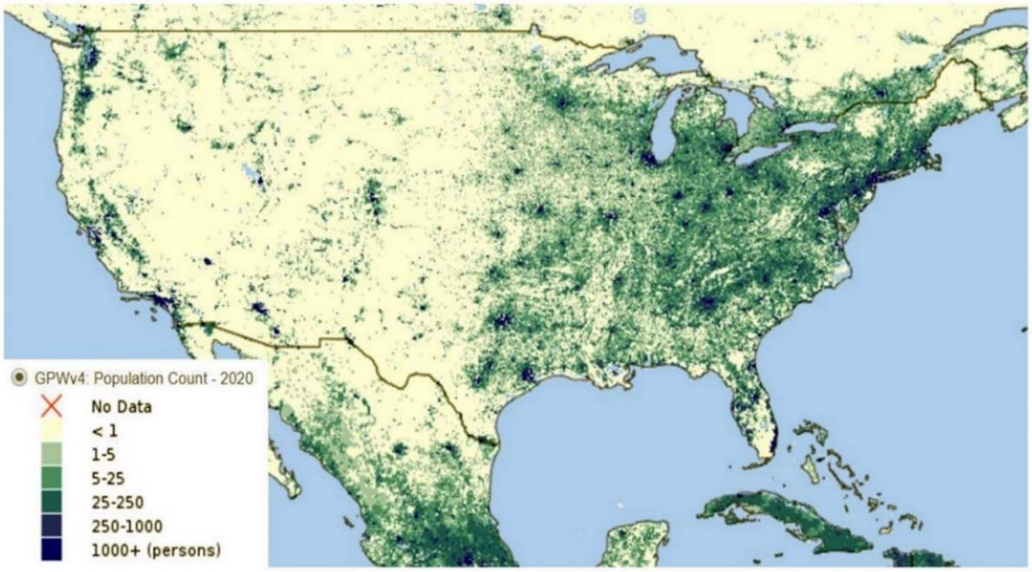


Figure 8 [1] - U.S. Population

RKF's exclusion of barren [rural] areas from consideration ([1], pages 12 and 13) is concerning. There are many FS links in areas where few people live (compare Figures 7 and 8). Some may provide critical telecommunications services not available from the typical urban providers. But some carry communications between population centers, often through relay facilities in sparsely populated areas having very little ground clutter to attenuate signal. Even a small number of RLANs in the "wide open prairie" have the potential to interfere with FS receivers many kilometers away.

RKF's pages 26 and 27 list various interference mitigation methods. None appears to have been incorporated into the proposed equipment, and it remains to be seen whether any would be adequate to prevent the interference we predict.

RKF's pages 27 through 30 are an overview of general design considerations for FS microwave links. In general this was an excellent overview. We quibble with a few statements. The statement is made "In the 6 GHz band, the typical per hop availability objective is set at 99.999%." In fact, virtually all public safety, power, oil pipeline and railroad circuits are designed to 99.9999% availability. The statement "… multipath fading [the primary path propagation degradation] generally occurs during the period midnight to 8:00 am …" is simply wrong. Multipath fading occurs when static atmospheric layers form due to lack of air turbulence in the absence of solar heating. This begins at sunset and goes away at sunrise. RKF states further "Since the RLAN busy hour is before midnight, and multipath occurs primarily after midnight, there should be a relaxation of the IPC and a significant portion of the link fade margin can be used to relax, dB-for-dB, the IPC." We strongly disagree and return to this issue below.

The transmitters RKF analyzed have channel bandwidths of 20, 40, 80 and 160 MHz. In general the FS channels are narrower than 80 and 160 MHz. We will study the most popular bandwidth, 30 MHz. It should be noted that currently many users are licensing multiple channels per path to achieve more aggregate path transmission bandwidth. Table 12 summarizes the 30 MHz channel utilization near the geographic center of eight metropolitan areas.

Number of Channel Pairs	1	2	3	4	5	6	7	8
Channel Pair Bandwidth (MHz)	60	120	180	240	300	360	420	480
Chicago	100.0%	37.6%	31.3%	22.4%	11.0%	7.5%	6.1%	5.7%
Houston	100.0%	37.0%	18.1%	12.8%	5.4%	4.2%	2.6%	2.1%
Los Angeles	100.0%	35.5%	24.6%	18.9%	14.4%	10.3%	9.4%	7.0%
New York City	100.0%	31.2%	23.0%	16.4%	13.1%	11.1%	9.3%	7.7%
Phoenix	100.0%	35.9%	24.7%	19.9%	16.5%	12.1%	9.5%	8.7%
San Francisco	100.0%	44.5%	21.6%	17.6%	12.6%	9.0%	6.3%	4.3%
Seattle	100.0%	31.2%	18.4%	16.2%	10.2%	10.2%	9.4%	6.8%
Washington DC	100.0%	32.5%	27.4%	20.0%	16.2%	15.5%	13.8%	6.0%
Average	100.0%	35.7%	23.6%	18.0%	12.4%	10.0%	8.3%	6.0%

Table 12 – Per Path Channel Utilization

RKF's pages 33 through 35 overview the path propagation model for interference into the FS receive antenna. We agree that WINNER II [6] is an excellent choice for average propagation, but it is not intended to cover all possible environments and conditions. RKF failed to include variations included in the model such as lowering of path loss as the taller station's height is increased. As we note later, it does not appear LOS was modeled by RKF even though WINNER II includes that model and it is applicable to RLAN / FS interference in some circumstances (see below).

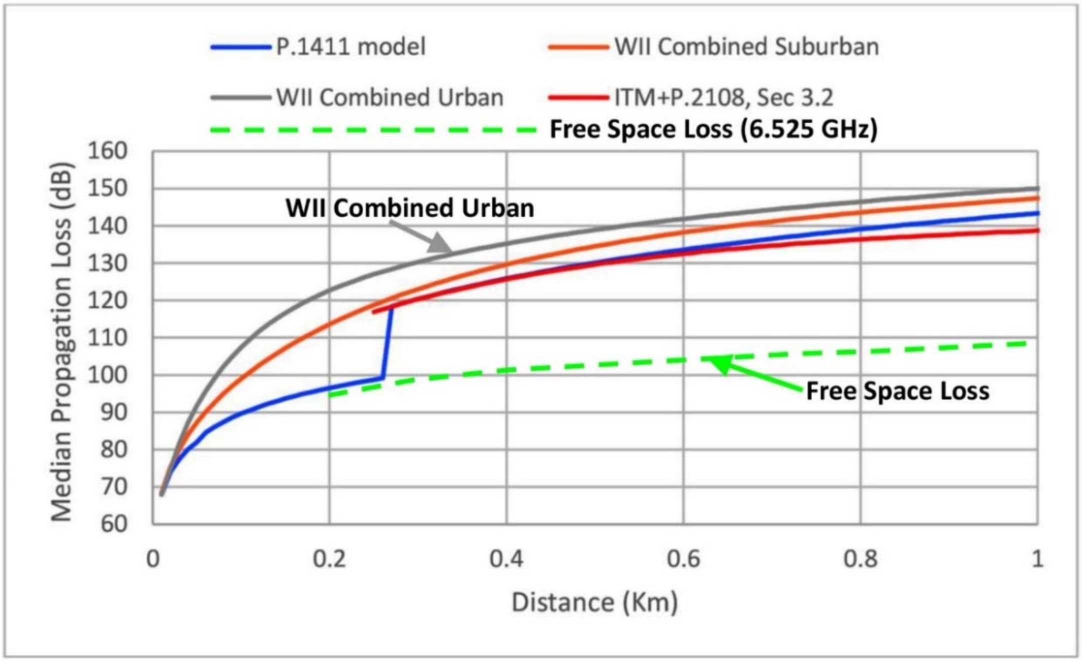


Figure 9 [1] - *Propagation Model Comparison*

	LOS	NLOS
P.1411	3.48 dB	6.89 dB
Winner II	4 to 6 dB	8 dB

Table 13 [1] - *Lognormal Shadowing Standard Deviation for P.1411 and Winner II*

We notice in the model specification ([6], page 37)

> "Usually, even for the same scenario, existence of LOS component substantially influences values of channel parameters. Regarding to this property, most WINNER scenarios are differentiating between LOS and NLOS conditions. To enable appropriate scenario modelling, transitions between LOS and NLOS cases have to be described. For this purpose distance dependent probability of LOS is used in the model."

It does not appear LOS was incorporated into RKF's final merged model (specifically the lack of LOS propagation for shorter distances than the LOS – NLOS breakpoint d_{BP}), unlike the ITU-R P.1411 model.

The WINNER II channel model is a group of average sub-models. The RKF model appears to be an amalgam of these models – basically an "average of averages" approach. While this model may give a reasonable estimate for the typical ("average") NLOS path (although it has greater path loss than any of the other models apparently considered in Figure 9 above), it fails to give a picture of the variability of actual propagation. The typical result will exceed expectations 50% of the time and under perform 50% of the time. That is, half the time the interference will be greater than predicted. The received signal level in a NLOS environment is highly variable; RKF puts the standard deviation at 8 dB ([1], page 34) and RKF states the received signal level (RSL) is log-normal (a normal probability distribution curve applies for RSL). It follows that if the testing were run at the 99% confidence level (commonly used for statistical investigations), the predicted interfering signal level not exceeded would have increased by 18 dB (99% probability implies 2.3 standard deviations = 8 dB x 2.3).

Page 28 claims the RLANs are low duty cycle. There appears to be no way to enforce this. In any event, even a short interference episode to one microwave receiver can cause an entire network to lose synchronization and stay out of service for 15 minutes or more while it resynchronizes. This is catastrophic for systems that can tolerate only 30 seconds or 5 minutes outage per year (99.9999% and 99.999% respectively).

RKF’s pages 45 through 51 overview the FS aggregate interference simulation. RKF discloses that 1,904 FS paths will exceed the interference threshold it specified. We note that this is a 50% confidence result. It is unclear how many paths would have failed if the paths were tested at the 99% confidence level (with average propagation loss 2.3 standard deviations less than the average case). Certainly the actual number of interference cases will far exceed the 1,904 cases RKF predicted ([1], page 45). At this level of confidence, the model would have had to have been modified to include some proportion of LOS propagation. Certainly the count of paths receiving interference would be far higher than 1,904.

RKF goes into a long, convoluted explanation – ultimately flawed as noted below – as to why the 1,904 paths for which it conceded interference will occur don’t present a problem. The explanation starts with an assumption of 99.999% availability (yet many are 99.9999%) and compounds the error with using the wrong propagation model (ITR-R P.530 [9] rather than Vigants ([18] [19]), assuming RLANs are seldom operating (yet offering no method of ensuring that), inferring QAM operating mode from transmission bandwidth (but ignoring the effect of forward error correction to radio transmission bandwidth), using the wrong spectral efficiency of the various QAM modes (Wikipedia was the technical source), and assuming that diversity operation improves path performance in an interference environment (where in fact interference affects both main and diversity antennas about equally).

Bottom line, RKF “derives” an unrealistic and overly optimistic expectation of path fade margin:

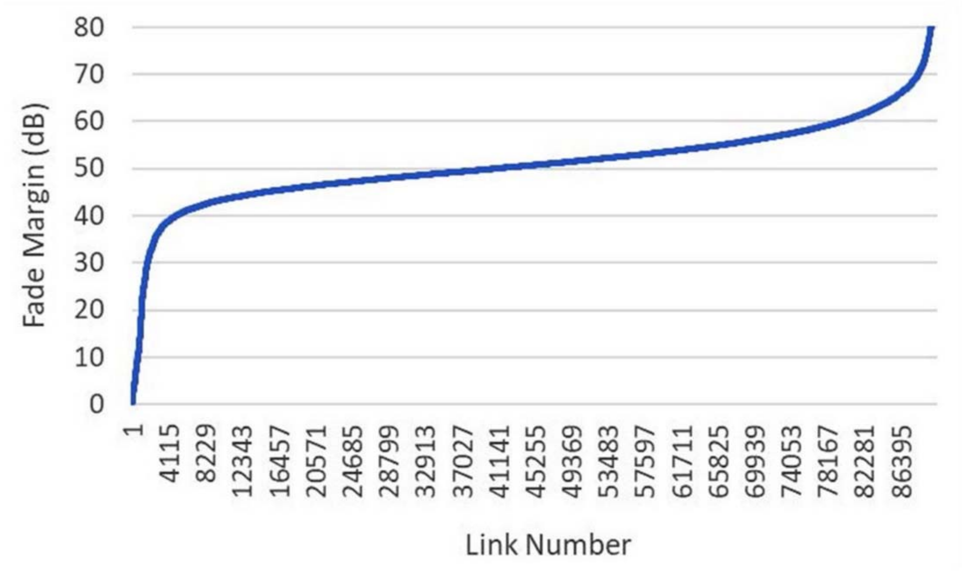


Figure 5-13 - FS ULS Station Calculated Link Margins

Figure 10 – RKF's [1] FS Fade Margin Estimate

In fact, the actual fade margins are about 10 dB less.

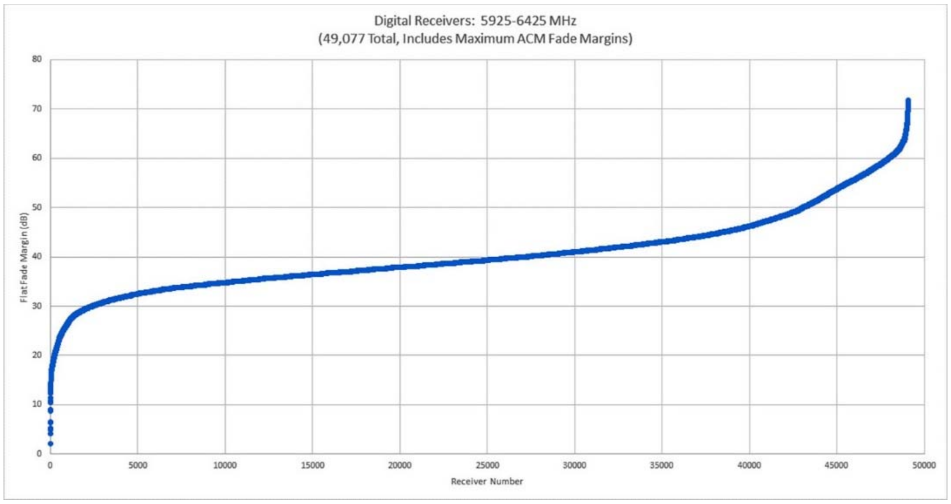


Figure 11 – Actual [4] Licensed Lower 6 GHz FS Fade Margins

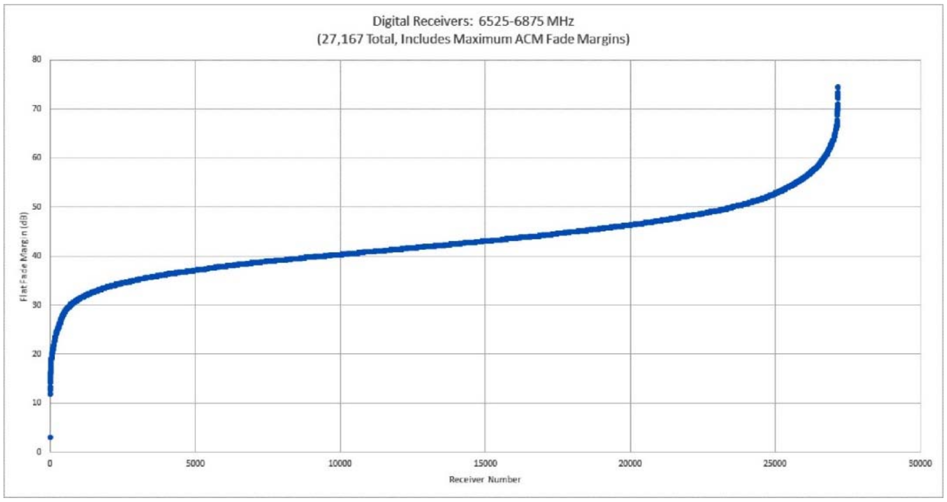


Figure 12 – Actual [4] Licensed Upper 6 GHz FS Fade Margins

With multipath fading being the main source of path performance degradation, RKF's incorrect estimation of path fade margin means **the expected path outage would be ten times greater than RKF predicts**. If RKF predicted the path would have 99.999% availability, the actual estimate would be 99.99%.

To evaluate the performance of FS links under the influence of interference, we must understand the statistical nature of the interference. RKF described the issue clearly on page 51:

> "Given that the duty cycle of each RLAN is low, the statistical variation of the interference, over time, to the FS receivers will be high. The calculation of the link availability used [ITU-R Recommendation] P.530 and added the calculated RLAN interference distribution with the assumption that RLAN interference, multipath and rain fade are all independent. Thus, the link availability calculation involves a convolution of the probability density functions of each of the impairments."

RKF's assumption that RLAN interference and multipath are independent is incorrect and produces incorrect results. It implies interference ordinarily occurs only when the FS receiver is operating at normal received signal level. In that situation, the appropriate I/N would be -6 dB plus fade margin. **RKF's assumption amounts to saying the entire receiver fade margin is available to absorb RLAN interference.**

RKF also raised this issue on pages 28 and 29 under the paragraph heading "3.2.5.2 Typical Parameters and Effects that Reduce Interference Not Included in this Analysis." It says:

> "FS link performance is dominated by multipath-related microwave fading. However, multipath fading generally occurs during the period midnight to 8:00 am, when RLAN activity is lowest and some relaxation of the long-term IPC [Interference Protection Criteria] may be possible. In analyzing the impact of RLAN

> interference to FS link availability, interference and multipath fading were assumed to be independent. **Since the RLAN busy hour is before midnight, and multipath occurs primarily after midnight, there should be a relaxation of the IPC and a significant portion of the link fade margin can be used to relax, dB-for-dB, the IPC.**" (emphasis added)

Similarly, on RKF's page 30, the Table 3-12, "RLAN Interference Reduction Factor Not Considered in this Report," states that "RLAN operation outside of Multi-path fading period" was not considered – but under the heading "IPC Relaxation" it says, "Majority of fade margin can be used dB-for-dB by RLANS from 8:00 am to midnight."

This is a potentially serious error. In fact multipath fading and RLAN interference would most often occur at the same time. An assumption to the contrary would be fatal to reliable FS operation. As noted above, FS multipath starts shortly after sunset and lasts until sunup. The sundown to sunup duration of multipath fading has been extensively documented by Bell Labs ([16] Figures 3 and 4) ([17] Figure 2) on paths near Atlanta, Georgia. This period of multipath activity completely covers RKF's period of RLAN busy time of 7 PM to 11 PM local time ([1], page 15). The following figure ([12], Figure 9.5, page 323) illustrates how the sundown-to-sunrise period is subject to intense multipath activity that regularly takes up tens of dB of fade margin.

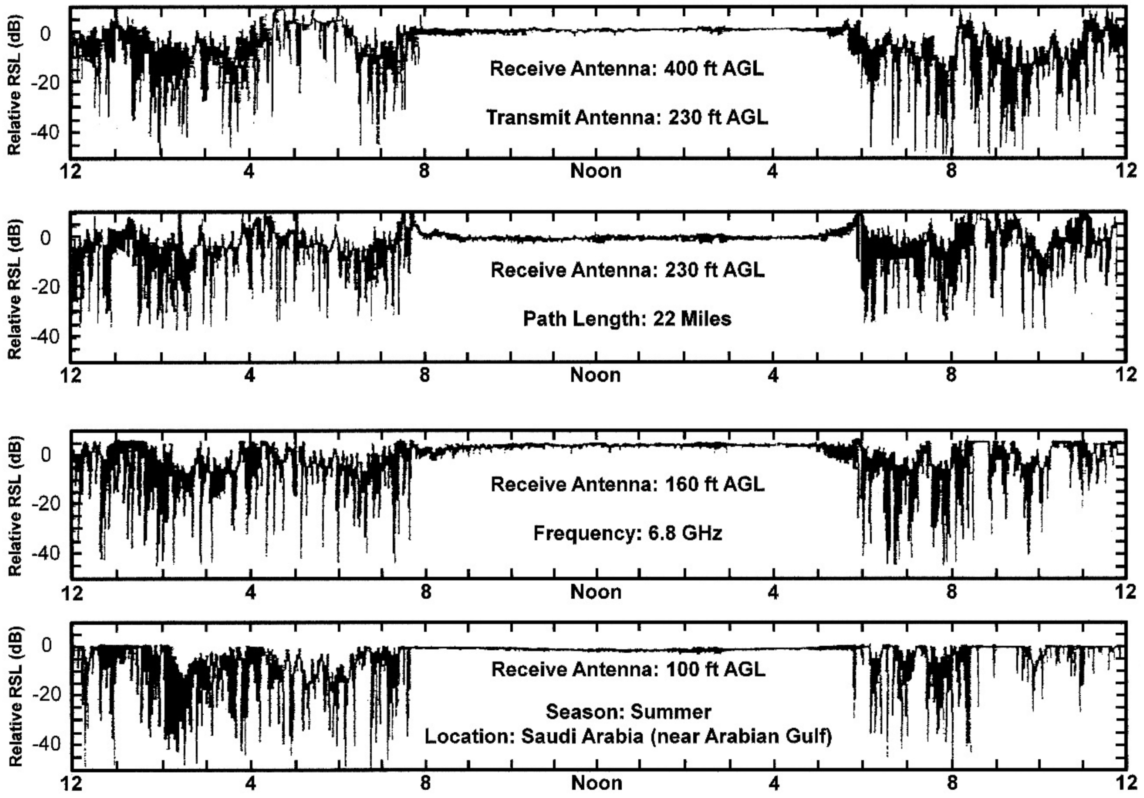


Figure 13, Example of FS Multipath Fading

It is unclear from RFK's write-up whether it relies on a direct dB-for-dB use of the FS path fade margin to counter RLAN interference. RKF's incorrect statement that RLAN interference and FS fading are independent in time suggests it may be taking advantage of a (nonexistent) statistical independence of the two factors. Any procedure that incorporates that assumption will yield significant error whose maximum magnitude will be on the order of total path fade margin.

RKF's use of receiver fade margin to explain away the effects of RLAN interference would go a long way toward explaining the differences between their analyses and ours, which shows all FS paths being adversely impacted by the widespread deployment of RLANs. RKF would take away FS link fade margin when it is needed most.

We emphasize, though, that the RLANs are a severe interference threat even if RKF does not rely on using fade margin. Table 3 shows that most antennas in use have an exclusion area in front of the antenna of 0.002 km^2 for fade margins of 40 dB. Using RKF's estimate of 15 outdoor RLANs per km^2, on average one in 33 antennas will have an RLAN in its exclusion zone at any moment. In Houston, with 838 paths in our study area, about 50 receive antennas will have RLANS in their 40 dB exclusion zones. Each time one of those RLANs turns on with 35 dBm EIRP, the link will go down regardless of whether or not the FS path is fading. This is an unacceptable risk.

Even if RKF's analysis using an "average of averages" model were mathematically sound, it still fails to address the main concern at issue here. We are reminded of the W. W. Watt quotation, "Do not put your faith in what statistics say until you have carefully considered what they do not say." The issue here is not some "typical" NLOS interference path. We are concerned about the atypical LOS or NLOS interference path that causes interference to a microwave receiver. RKF's application of the WINNER II Combined Urban propagation model simply cannot assess the likelihood of this interference with the precision needed to adequately protect the FS.

Study 4 – Overview of ITU-R Recommendation F.1706 [8]

RKF largely ignored LOS propagation,

This ITU-R recommendation analyzes a typical digital point to point radio (DRRS) being potentially interfered with by a radio local area network (RLAN) also called a Nomadic Wireless Access System (NWAS). The equipment parameters are listed in Tables 1 and 2, page 3 of [8]. The DRRS operates in a 30.2 MHz radio channel, has a typical parabolic antenna, and has an EIRP of 75.5 dBm. The NWAS has a channel bandwidth of 16 MHz, an omnidirectional antenna and an EIRP of 20 or 30 dBm. Both indoor and outdoor operation of the NWAS was considered. The analysis is self-explanatory and not worth repeating. However, the use of free space (LOS) propagation rather than a propagation model like WINNER II is probably counterintuitive.

AT&T (formerly Bell) Laboratories studied NLOS propagation at 6 GHz in five major urban areas [20] [21]. As expected they generally encountered obstructed propagation paths. However, all urban areas displayed some long LOS paths. AT&T labs noted [21] “In both types of neighborhoods, LOS propagation carried signals long distances along the street where the transmitter was deployed.” The consistent occurrence of LOS paths suggests this is the reason that ITU-R recommends using LOS as the propagation model when doing interference analysis. The RKF median propagation model ignores LOS and does not predict the long LOS paths AT&T found.

The nomadic case has interfering transmitters moving randomly around an urban environment. At any time the mobile transmitter could appear at a location where there is line of sight transmission to the victim receiver. AT&T observed such cases in urban environments even with low antenna transmitters and receivers [20]. RKF says a large number of stationary transmitters will be deployed. Like the nomadic case, those transmitters will occasionally be placed in such a way that line of sight propagation occurs between the transmitter and the victim receiver, as when both line up with the same street.

ITU-R Recommendation F.1411-9 [10] overviews propagation in a Non-Line of Sight (NLoS) environment.

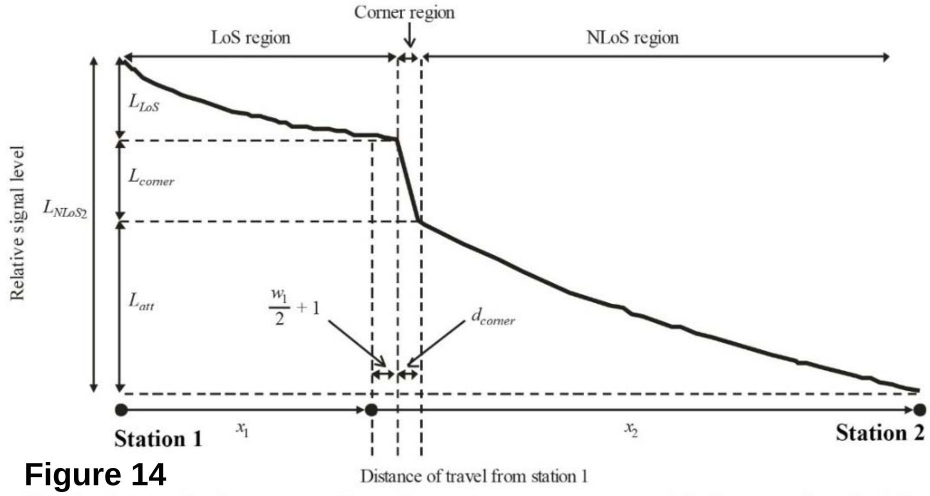


Figure 14

Typical trend of propagation along street canyons with low station height for frequency range from 2 to 38 GHz

Radio wave propagation travels in a normal LOS mode (attenuation on a 20 $\log_{10}$(distance) basis) until an obstruction is encountered. Beyond the obstruction, loss is much greater (typically on an approximately 40 $\log_{10}$(distance) basis).

The loss versus distance relationship is a very complicated function of the radio path environment. This is usually dealt with by taking the average of many different path measurements.

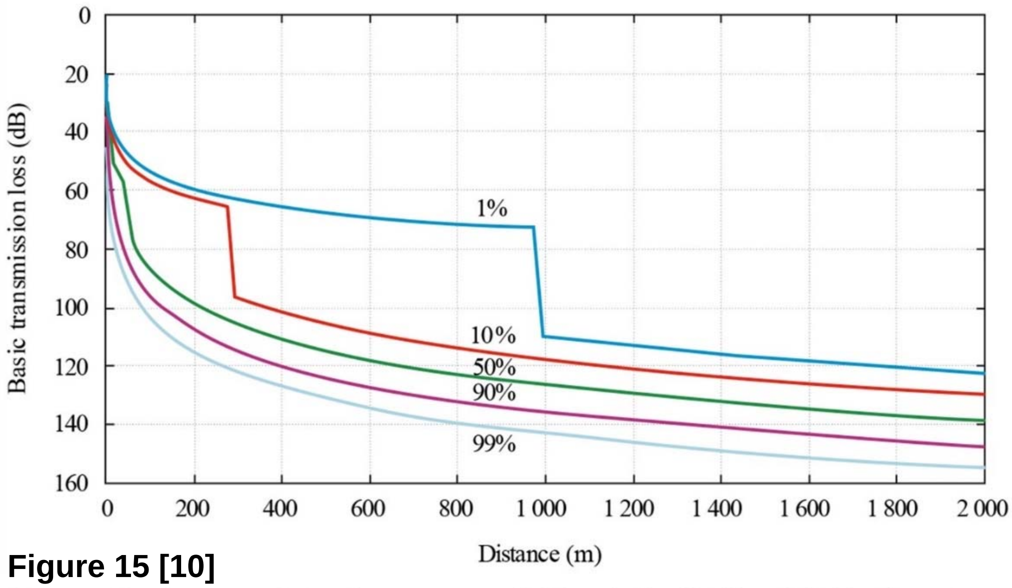
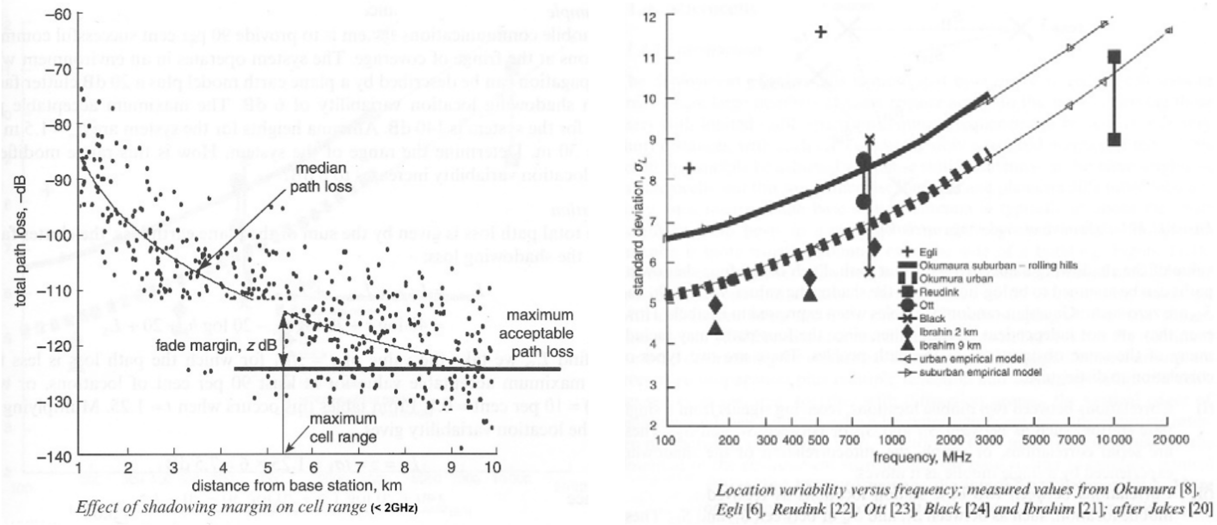


Figure 15 [10]

Curves of basic transmission loss not exceeded for 1, 10, 50, 90 and 99% of locations (frequency = 400 MHz, suburban)

Since the terrain is typically unpredictable (an ad hoc mixture of vegetation, street furniture and buildings) the results for each path are different. The results can be plotted as a series of averaged curves.

The “typical path” curve is the curve for path loss not exceed 50% of the time. This is the curve attempted to be predicted by algorithms such as WINNER II because these relate most directly to cell site coverage.



Effect of shadowing margin on cell range (< 2GHz)

Location variability versus frequency; measured values from Okumura [8], *Egli* [6], *Reudink* [22], *Ott* [23], *Black* [24] *and Ibrahim* [21]; *after Jakes* [20]

Figure 16 - NLOS Actual Path Loss Variability Versus Model Estimate [3]

Interference analysis, however, requires curves showing extreme values. In virtually all interference cases, the dominant interference comes from a small number of transmitters with line of sight propagation to the victim receiver.

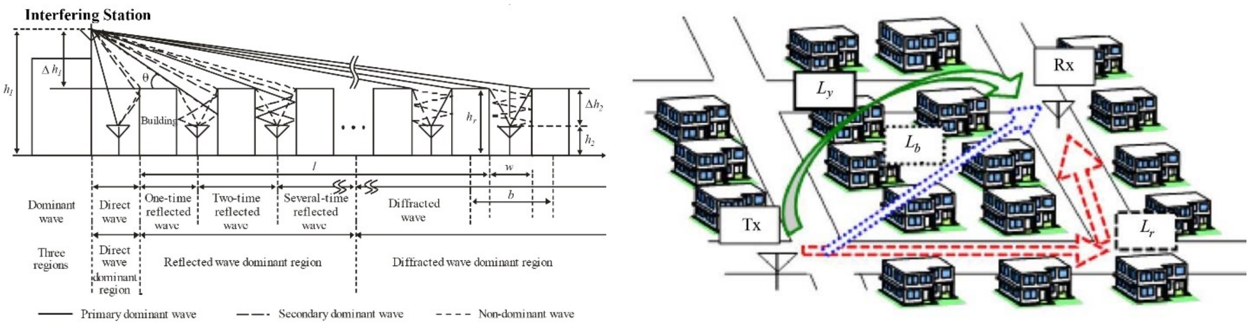


Figure 17 – Line of Sight and Non-Line of Sight Interference Paths [10]

For a large number of potential interferers, we need to know the path loss not exceeded a very small percentage of time, since that will represent the path loss of the dominant interfering transmitters. That is the limitation of the WINNER II Combined Urban model proposed by RKF. It predicts average received levels. It simply cannot predict the relatively small number of LOS interference cases. It takes only one line of sight interference case to shut down an FS receiver.

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RPE 1729L

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