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February 16, 2016

Via Electronic Filing

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

Re: *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, GN Docket No. 12-354

Dear Ms. Dortch:

The Commission's April 2015 *Report and Order* adopting rules for expanded use of the 3550-3700 MHz band (the 3.5 GHz band) generally struck a reasonable balance between the interests of existing federal and commercial users and the needs of new entrants.[1] Consistent with that balance, Google addresses in this letter several issues regarding Citizens Broadband Radio Service Device (CBSD) operation in the new band and proposes resolutions that will improve utilization without causing harmful interference to incumbent users.

Specifically, and as explained below: (1) while allowing Priority Access (PA) licensees to report their own use of licensed channels, those reports should be tested for reasonableness against objective engineering criteria; (2) the Commission should allow network operators to deploy higher power devices when sited in signal-impeding clutter; and (3) for both accuracy and fairness reasons, the Commission should allow measurement of CBSD emissions using a root mean square (rms) detector.

1. **In establishing rules for determining whether PA channels are "in use," the Commission should permit PA licensees to report their coverage areas, but these requests for protection should be bounded by reasonable engineering considerations.**

The Commission's *Report and Order* recognized that "permitting opportunistic access to unused [PA] channels would maximize the flexibility and utility of the 3.5 GHz Band for the widest range of potential users."[2] The *Second FNPRM* sought comment on

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[1] *In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Report and Order and Second Further Notice of Proposed Rulemaking, 30 FCC Rcd. 3959 (2015) (*Report and Order* or *Second FNPRM*).
[2] *Id.* ¶ 72.

how best to do so.[3] In response, Google recommended that the Commission adopt an engineering definition of "use," under which PA licensees would report the contours of the areas for which they sought protection, based on their actual deployments.[4] This approach provides a readily administered, low-cost mechanism for establishing PA-protection requirements.

At the same time, to promote compliance and ensure that unused PA spectrum is available for General Authorized Access (GAA) use, there should be a check on the claims of PA licensees. To confirm that the protection requested is, indeed, based on reasonable technical considerations, the Commission should require all PA licensee claims to be measured against maximum service contour areas developed by a SAS. The SAS-developed maxima should be vetted through the certification process, and each SAS providing this functionality should be required to present its methodology to the Commission and place it in the public record. Further, in order to ensure that reasonable assumptions are used, SASs should be required to demonstrate that the methodology used in calculating claimed service areas is consistent with the methodology used to calculate protection to incumbents, grandfathered operations, and other PA licensees. For example, SASs should not be permitted to make propagation assumptions that suggest strong signal propagation over long distances when calculating PA licensee protected service contours, while simultaneously using a model that assumes significant attenuation when calculating protection of FSS operations. Once a SAS's model is approved through the certification process, PA licensees' protection area requests would be checked for reasonableness against that model, and the protection requests could be granted provided that the requested area is no more than twice the the area calculated by the SAS (or 41% greater in radius, for a circularly shaped area).

As an example, the table below sets forth illustrative maxima for individual CBSDs operating outdoors at street level (1.5 m height) in the Mountain View, California area, which are representative for other areas with similar terrain and clutter characteristics.

Type of CBSD	**Maximum Protected Service Area**
Category A	0.5 km^2
Category B (non-rural)	1.1km^2
Category B (rural)	3.1 km^2

Table 1: Proposed Maximum Protected Service Areas in Mountain View, California

[3] *Id.* ¶¶ 420-24.

[4] Comments of Google Inc., GN Docket No. 12-354, at 1-3 (filed July 15, 2015).

These values reflect the following assumptions:

- CBSD transmissions will not exceed the maximum EIRPs set forth in the Commission's order: 30 dBm for Category A CBSDs, 40 dBm EIRP for non-rural Category B CBSDs, and 47 dBm EIRP for Category B CBSDs.[5] The figures set forth above for Category B CBSDs assume the use of an omnidirectional antenna. Google expects that real-world deployments will use highly directional antennas, so the assumption of circular symmetry at the stated distance is very conservative.

- The minimum usable receive signal for an end user device is -96 dBm.[6] This figure reflects the 3GPP reference sensitivity for 10 MHz TD-LTE end-user equipment in 3GPP Bands 42 and 43 (3400-3800 MHz).[7]

- End user devices will operate with an antenna gain of 0 dBi or less. Antenna gains on small devices such as handsets and dongles are typically less than 0 dBi. Therefore, assuming 0 dBi gain is conservative.

- The data reflect outdoor operation. Indoor operation would be subject to additional building attenuation and reduced distances.

Based on these assumptions, when propagation losses from the CBSD transmitter exceed the limits below, the signal is no longer usable, thereby defining the edge of the service area boundary. For example, the signal of a Category A CBSD has reached the outer edge of its service area when it attenuates to 126 dB.

Type of CBSD	**Received power at the service area boundary**
Category A	30 dBm (max EIRP) - -96 dBm (end user device reference sensitivity) = 126 dB
Category B (non-rural)	40 dBm (max EIRP) - -96 dBm (end user device reference sensitivity) = 136 dB
Category B (rural)	47 dBm (max EIRP) - -96 dBm (end user device reference sensitivity) = 143 dB

Table 2: Received Power at Service Area Boundary for Each CBSD Category

The chart below captures data from over 70,000 propagation measurements collected in the vicinity of Mountain View, California,[8] and provides the relationship

[5] 47 C.F.R. § 96.41(b).
[6] 3GPP TS 36.101 V13.2.1, Table 7.3.1-1.
[7] *Id*.
[8] Google collected these measurements pursuant to an experimental authorization granted by the Commission (Call Sign WH2XNF). For additional detail regarding how these measurements were collected, please see the attached Declaration of Dr. Andrew W. Clegg (Clegg Declaration).

between minimum received power and distance. Because the overwhelming majority, if not all, of the blue points (measured loss) exceed 126 dB at distances greater than 400 meters from the transmitter, a distance of 400 meters represents the maximum distance at which an end user device can receive a usable signal from a Category A CBSD. A radius of 400 m around a CBSD installation correlates to a service area of 0.5 km^2—the proposed protected service set forth in Table 1 above for Category A CBSDs.

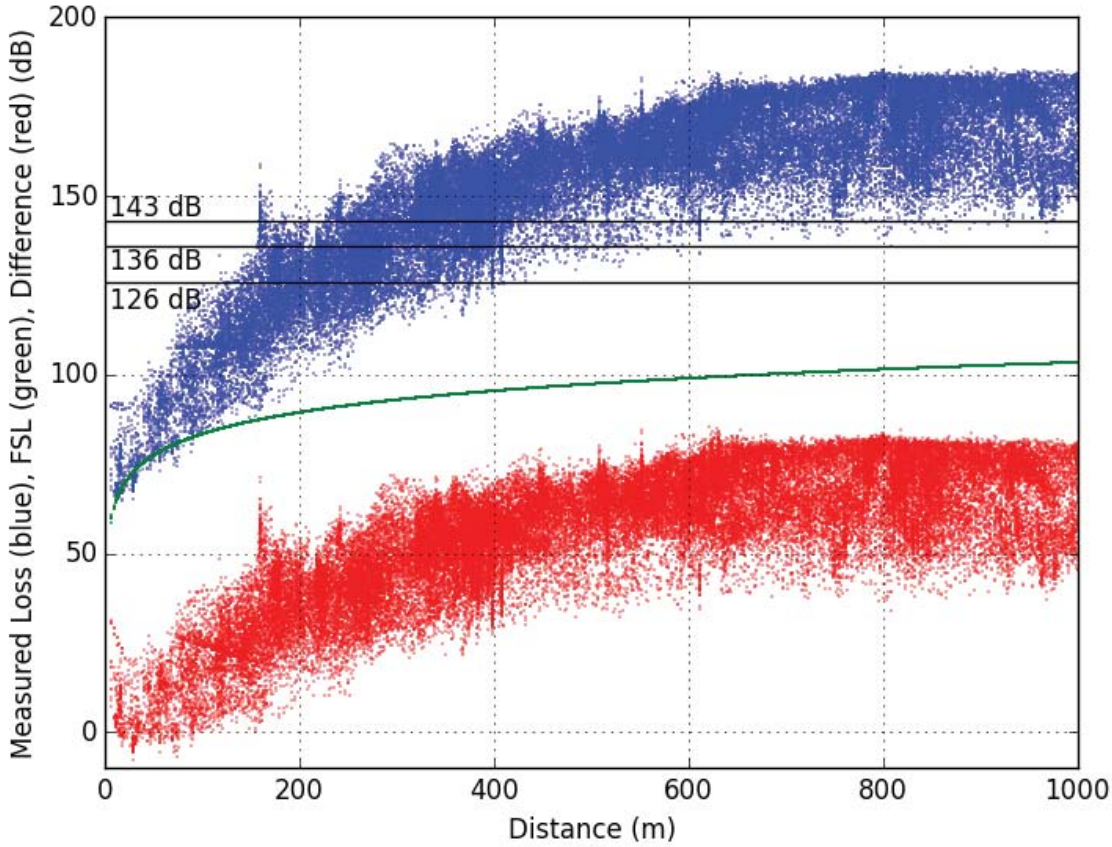

Chart 1: Propagation Loss Measured in Mountain View, California

By the same token, measured losses exceed 136 dB in almost all cases at 600 meters, and losses exceed 143 dB at 1 km. The corresponding maximum service area sizes are approximately 1.1 km^2 for non-rural Category B CBSDs and 3.1 km^2 for rural Category B CBSDs. These maximum service areas proposed above represent conservative estimates regarding the range of Part 96 devices in Mountain View, California.

More generally, Google's measurements illustrate two important principles that should inform the determination of maximum protected service areas. First, maximum protected service areas will almost always be substantially smaller than census tracts. The census tract that encompasses Google's test area in Mountain View, California, for example, is 27.6 km^2, or 55 times larger than the calculated maximum coverage area for

Category A devices operating at street level.[9] Second, the measurements illustrate the dramatic impact of clutter on CBSD signal propagation. As set forth in greater detail in the attached Clegg Declaration, measured path loss exceeded free space path loss predictions by 56.7 dB on average, and by as much as 85.3 dB,[10] over distances less than 1 km. Even Longley-Rice prediction substantially understated propagation losses: measured path loss exceeded the Longley-Rice predictions by, on average, 45.7 dB, and by as much as 78.1 dB.[11] Both the free space and Longley-Rice models underestimated path loss in more than 99.6% of measurements.[12] This is true even though the test area is a lightly cluttered environment, particularly as compared to rural areas with dense groves of trees, or urban areas with tightly packed, tall buildings. The impact of clutter cannot be ignored when determining the reasonableness of claimed CBSD service areas, and both PA licensees and SASs should be expected to account for clutter in making signal propagation calculations.

Ensuring that requests for protection are based on reasonable engineering considerations will support intensive use of the band. The approach proposed above allows significant flexibility to PA licensees while ensuring that their requests are not grossly excessive.

2. The Commission should allow network operators to deploy higher power CBSDs when sited in clutter.

As noted above, the Commission's *Report and Order* established maximum power levels for end user devices, Category A CBSDs, and Category B CBSDs.[13] In establishing these rules, the Commission limited outdoor operation of Category A CBSDs to no more than 6 meters above average terrain, and observed that these devices would likely be be used to offer small-cell or similar services.[14] Category B CBSDs, by contrast, are permitted to operate outside at greater heights and at higher power levels, and are expected to provide backhaul, coverage, or capacity for managed networks.[15] In July 2015, the Wireless Innovation Forum (WinnForum) filed a request for reconsideration of the Commission's *Report and Order*, asking that the maximum power levels be raised for both Category A and B CBSDs.[16]

WinnForum's request did not address the impact of CBSD height above clutter on signal protection. As illustrated by the measurements taken in Mountain View,

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[9] Office of Statewide Health Planning and Development, Tract 5046.01, http://gis.oshpd.ca.gov/atlas/places/tract/06085504601.
[10] Clegg Declaration, ¶ 8.
[11] *Id.*
[12] *Id.*
[13] *Report and Order* ¶ 213.
[14] *Id.* ¶¶ 206, 213.
[15] *Id.* ¶¶ 211, 213.
[16] Wireless Innovation Forum Petition for Reconsideration, GN Docket No. 12-354, at 5-9 (filed July 22, 2015) (WinnForum Petition).

California, and discussed above, clutter in the local environment, such as foliage or manmade structures, can have a substantial effect on signal propagation: When CBSD antennas are placed high above terrain and local obstructions, they will have a much larger impact on surrounding devices. On the other hand, when CBSD antennas are shielded by local clutter, they may be able to operate at higher power levels without impairing the use of the same frequencies by other nearby users.

To quantify the impact of local clutter on CBSD signal propagation, Google conducted an analysis using the model set forth in International Telecommunication Union (ITU) Recommendation P.452.[17] The model calculates propagation loss due to local clutter as a function of: (1) the height of a transmitter above ground level; (2) the height of local clutter above ground level; and (3) operating frequency.

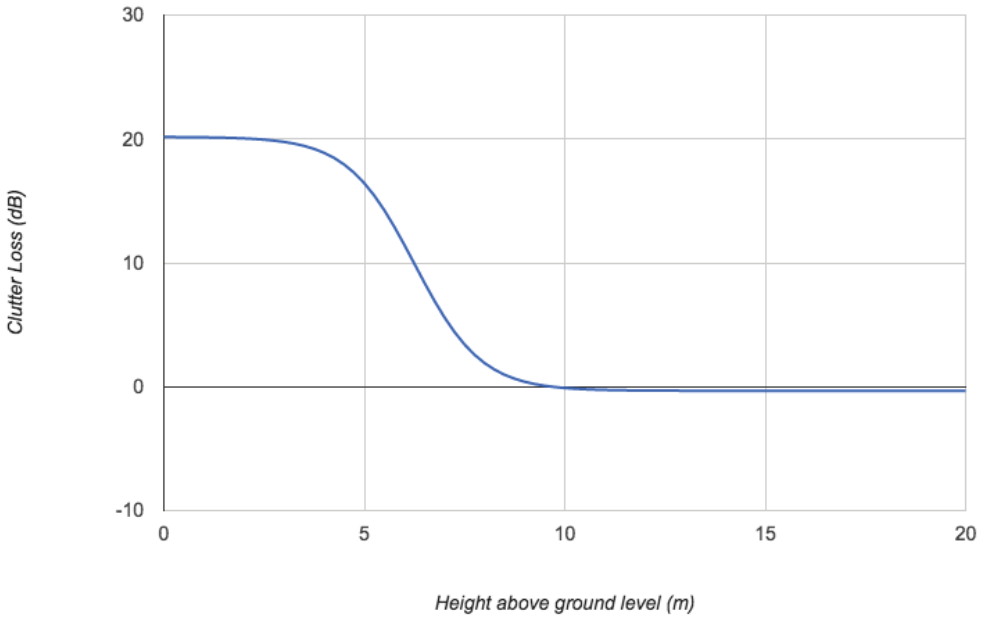

Chart 2: Clutter loss v. antenna height above ground level for clutter height of 10 m

As illustrated above, the model described in ITU-R P.452 demonstrates that additional losses are high when a transmitter is embedded in clutter and reduce to zero when the antenna height becomes equal to the local clutter height.[18]

Because transmissions from CBSDs embedded in clutter will experience greater attenuation, as set forth in the figure above and confirmed by common sense, the Commission should allow Category B devices with antenna heights at or below 75% of

[17] *See* Prediction Procedure for the Evaluation of Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.1 GHz § 4.5, ITU-R Recommendation P.452-15 (2015), *available at* https://www.itu.int/rec/R-REC-P.452/en.

[18] In this analysis, a clutter height of 10 meters was selected for illustrative purposes. Variability in clutter height is addressed on page 8, *infra*.

the local clutter height to operate at higher powers.[19] Category B devices deployed at elevations of more than 75% of the local clutter height should continue to be subject to the power limits set forth in the *Report and Order*.[20] And because it is expected that nearly all Category A devices will operate either indoors, where they will both be in clutter and experience additional building loss, or outdoors at low heights well below surrounding clutter,[21] all Category A CBSDs should be permitted to operate at the higher power levels requested by the WinnForum.

Of course, clutter height varies by location. SASs should be allowed to use clutter height models based on publicly available land use maps or gather their own data to support clutter modeling. For example, the clutter model in the ITU P.452 propagation loss model identifies nominal clutter heights associated with particular land use environments (e.g., urban, suburban, or rural), and such land use type maps are freely available for the United States.[22] The clutter models used by SASs can be validated during the SAS certification process.

Adopting this recommendation would yield the following power limit table:

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[19] In the abstract, devices operating at or below the clutter level should be subject to clutter loss. Limiting higher power transmissions to those antennas well within clutter is a conservative approach.

[20] Google agrees with the WinnForum that allowing rural transmitters to use an antenna gain of 17 dBi while limiting non-rural operations to gains of 16 dBi or lower makes little practical sense. WinnForum Petition at 6. The manufacturers of such devices will have no way to know in advance in which context they are deployed, and are therefore unlikely to invest in higher gain antennas specifically for the rural setting. Therefore, the 17 dBi maximum gain should apply across the board.

[21] 47 C.F.R. § 96.43(a).

[22] *See, e.g.*, MODIS Overview, https://lpdaac.usgs.gov/dataset_discovery/modis; National Land Cover Database, http://www.mrlc.gov/nlcd2011.php.

Device Type	Geographic Area and Height	Maximum Conducted Output Power	Maximum EIRP	Maximum Conducted PSD	Maximum Antenna Gain
End-user Device	all	n/a	23 dBm/10 MHz	n/a	n/a
Category A CBSD	all	30 dBm/10 MHz	36 dBm/10 MHz	20 dBm/MHz	6 dBi
Category B CBSD	non-rural, <=75% clutter height	40 dBm/10 MHz*	49 dBm/10 MHz	30 dBm/MHz*	17 dBi
Category B CBSD	non-rural, >75% clutter height	32 dBm/10 MHz*	41 dBm/10 MHz	22 dBm/MHz*	17 dBi
Category B CBSD	rural, <=75% clutter height	40 dBm/10 MHz*	56 dBm/10 MHz	30 dBm/MHz*	17 dBi
Category B CBSD	rural, >75% clutter height	32 dBm/10 MHz*	47 dBm/10 MHz	22 dBm/MHz*	17 dBi

** Decreasing with higher antenna gain.*

Table 3: Proposed Power Limits

Allowing higher power operations in situations where CBSD signals are likely to experience greater attenuation strikes the right balance in maximizing operator flexibility, incumbent protection, and frequency reuse.

3. **Using a Root Mean Square (rms) detector, not a peak detector in maximum hold, to measure compliance with in-band and out-of-band emissions limits will protect incumbents from harmful interference without crippling CBSD operations in the band.**

Just as setting appropriate power levels will make the 3.5 GHz spectrum more useful, developing a reasonable measurement method is critical to successful implementation of the *Report and Order*. In response to the Commission's *Report and Order*, CTIA filed a Petition for Reconsideration asking the Commission to revisit its approach to measuring compliance with the in-band and out-of-band emissions standards established in Part 96.[23] Google supports this request, and the

[23] Petition for Reconsideration of CTIA – The Wireless Association®, GN Docket No. 12- 354, at 2, 6-7 (filed July 23, 2015).

WinnForum—which includes a diverse group of companies with interests in the 3.5 GHz band—agrees.[24]

Satellite industry claims to the contrary should be rejected.[25] The Satellite Industry Association (SIA) makes the unremarkable observation that "peak emissions can have significant interference effects."[26] It is logically inconsistent, however, for SIA to ask the Commission to characterize interfering emissions by their peak amplitude, while not characterizing the system noise level of FSS earth stations in the same fashion. Characterizing interference effects based solely on peak emissions would depart from Commission precedent as well.

First, as pointed out by the WinnForum, all signals, including LTE, Wi-Fi, WiMax, and even Gaussian thermal noise[27] will have statistical variations in the instantaneous amplitude of the waveform.[28] For this reason, neither cellular, PCS, AWS, nor 700 MHz emissions are measured using peak hold.[29] Moreover, comparing LTE signals to Gaussian thermal noise illustrates the absurdity of SIA's position. The peak-to-average ratios and signal statistics of LTE and Gaussian thermal noise are generally similar, and thermal noise is typically evaluated using mean measurements.[30] Because the characteristics of these two types of emissions are similar, the measurement of their interference potential should be treated the same.[31]

If SIA insists that CBSD emissions be evaluated by their peak values, then, logically, the system noise of satellite receivers should be characterized by the same metric. An rms system noise temperature of 142.8 K corresponds to a "peak noise temperature" of 2263 K after application of a 12 dB crest factor appropriate for Gaussian noise. However, many satellite providers have argued that a 78 K system noise temperature is appropriate for calculating noise-to-interference ratios.[32] In other words, they believe a mean level is appropriate for characterizing their own operations.

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[24] Letter from Kumar Balachandran, *et al.,* to Marlene H. Dortch, Secretary, FCC, GN Docket No. 12-354 (filed Dec. 4, 2015) (WinnForum Ex Parte Letter).
[25] *See* Opposition of the Satellite Industry Association to Petitions for Reconsideration, GN Docket No. 12-354, at 5-6 (filed Oct. 19, 2015) (SIA Opposition).
[26] *Id.* at 6.
[27] Gaussian thermal noise is the noise attributed to natural random power fluctuations due to the thermal motion of molecules, atoms, and electrons.
[28] WinnForum Ex Parte Letter, Attach. at Slide 8.
[29] *Id.* at Slide 10.
[30] *See*, for example, Professor Rob Candler, A (Very) Little Bit About Noise (Apr. 2007), http://web.stanford.edu/class/me220/data/lectures/lect02/Noise_writeup.pdf.
[31] *See* WinnForum Ex Parte Letter, Attach.at Slides 19, 24.
[32] *See, e.g.*, Reply Comments of CBS Corporation, 21st Century Fox, Inc., Time Warner Inc., Viacom Inc., and the Walt Disney Company, GN Docket No. 12-354, Attachment A at 5, (filed Aug. 14, 2015).

SIA's assertion that CBSD emission levels should be measured using a peak detector, while their own system noise levels are exempt from such a requirement, is logically inconsistent and mathematically and physically unsound. The Commission should grant CTIA's Petition for Reconsideration with respect to this issue.

In sum, the Commission's implementation of its *Report and Order* should prioritize actual use and recognize the practical realities of CBSD operation. The Commission thus should (1) evaluate claimed PA service areas based on objective engineering criteria; (2) allow network operators to deploy higher power devices when sited in clutter; and (3) allow measurement of CBSD emissions using a root mean square detector.

Respectfully submitted,

Austin C. Schlick
Director, Communications Law
Aparna Sridhar
Counsel
Google Inc.

DECLARATION OF ANDREW W. CLEGG, Ph.D.

1. My name is Andrew W. Clegg. I am a spectrum engineering lead for Google Inc. Before joining Google, I served as electromagnetic spectrum manager at the National Science Foundation. In addition, I worked for several years in senior engineering positions at companies that are today part of AT&T Mobility, and at Comsearch, a spectrum management and wireless engineering company. I received my Ph.D. in radio astronomy, with a minor in electrical engineering, from Cornell University, and a B.A. in physics and astronomy from the University of Virginia.

2. In preparing this declaration, I have reviewed the *Report and Order and Second Further Notice of Proposed Rulemaking* in GN Docket No. 12-354,[1] including the Commission's proposals for the definition of "use" of Priority Access License (PAL) frequencies, as well as its proposals for optimizing protection of fixed-satellite service (FSS) operations.

Introduction

3. Google has collected hundreds of thousands of propagation measurements in the 3550-3700 MHz band (3.5 GHz band) for the purpose of refining propagation models used in its 3.5 GHz Spectrum Access System (SAS). This ongoing testing and measurement effort seeks to improve our understanding of the impact of clutter (e.g., buildings and foliage) on propagation loss. Many standard propagation models, such as free space loss (FSL) and Longley-Rice, do not take clutter into

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[1] *In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Report and Order and Second Further Notice of Proposed Rulemaking, 30 FCC Rcd. 3959 (2015) (*Report and Order* or *Second FNPRM*).

account, and as a result, they can substantially overestimate received signal strengths. This overestimation, in turn, will result in overstatements of the predicted service area over which 3.5 GHz networks can operate, and the potential for interference caused by new Citizens Broadband Radio Service Devices (CBSDs) operating in the 3.5 GHz band.

4. Our early experience measuring the impact of a Navy radar on LTE systems clearly demonstrated that clutter has a substantial impact at 3.5 GHz.[2] This declaration contains a high-level overview of the preliminary results from our measurements in the Mountain View, California, area and demonstrates in a more systematic fashion that FSL and Longley-Rice substantially underestimate propagation losses.

Test Environment

5. The data presented here were obtained in Mountain View under an experimental license (WH2XNF) issued by the Commission. Mountain View is a light industrial/residential area consisting mostly of relatively low (one- or two-story) commercial and residential structures, mixed with streets, parking lots, grass, and foliage. It is a relatively flat area: The root mean square terrain variation over the routes used for testing is 1.5 m, while the minimum and maximum heights on those routes are 0 and 17 m above mean sea level, respectively. The highest test point is on a highway overpass. Because the test area is relatively flat and lightly cluttered, it presents little complexity for terrain-aware propagation models such as Longley-Rice. It is also an

[2] *See* Reply Comments of Google Inc., Declaration of Dr. Andrew W. Clegg, ¶ 15, GN Docket No. 12-354 (filed Aug. 15, 2014).

area with only light-to-moderate clutter, particularly as compared to rural areas with dense groves of trees, or urban areas with tightly-packed tall buildings. It therefore provides an ideal environment for characterizing the effects of specific clutter objects on propagation. Figure 1 is an aerial view of the core test area, while Figure 2 shows the terrain relief.

Figure 1: **Aerial photo of core propagation test area in Mountain View, California.**

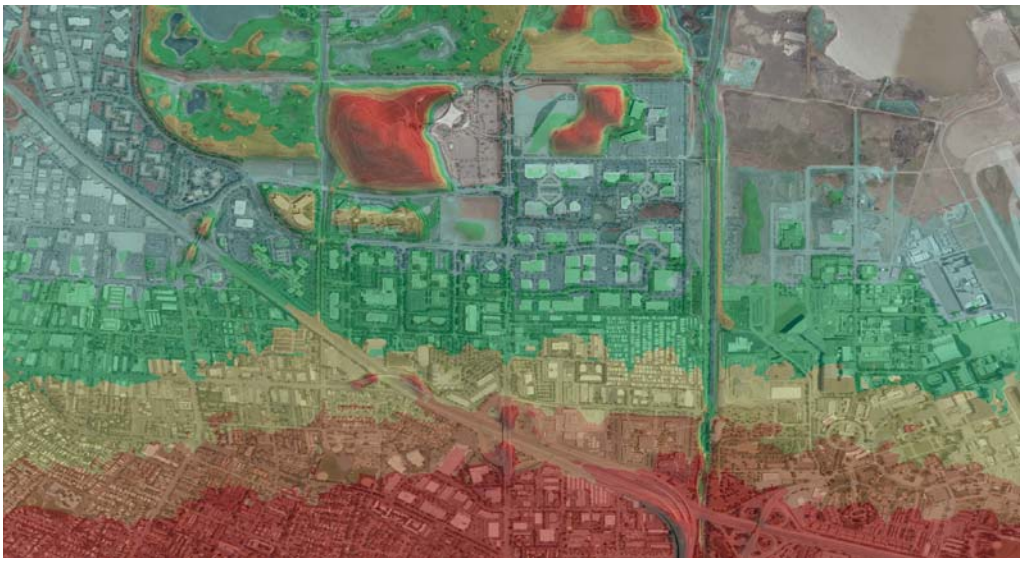

Figure 2: **Terrain elevation in the core propagation test area. Red corresponds to approximately 30 m above mean sea level, while gray is approximately mean sea level.**

Experimental Setup

6. Google has conducted its propagation tests using a stationary transmitter and a vehicle-mounted receiving system.

7. Transmitter system: The transmitter consists of a Software-Defined Radio (SDR) controlled by software running on a small compute module. The SDR signal, which transmits at about 15 dBm output, is connected to a power amplifier, and boosted to 34.8 dBm power. The output of the power amplifier is connected directly to the feed point of an omnidirectional antenna that has 11.6 dBi gain and 6.5 deg vertical beamwidth, with a center point approximately 1.5 m above ground level. The power amplifier includes a voltage monitor (V_{mon}) output, which provides a voltage that corresponds to a particular RF output power based on factory-provided calibration curves. V_{mon} is recorded to verify stability of the RF signal power throughout the course of testing.

8. Receiving system: The receiving system consists of the same model antenna used for the transmitter, mounted on the roof of a test vehicle, with a center point height of approximately 1.5 m. A preamplifier providing approximately 23 dBi gain is mounted at the feed point of the receive antenna. The output of the preamplifier is routed into the vehicle using a 2-m length of coaxial cable, then through a bandpass filter and limiter, and into a spectrum analyzer for measurement. The spectrum analyzer output is captured and recorded to disk files using commercial software. A 5 kHz span with 10 Hz resolution bandwidth was used on the spectrum analyzer, which

allows for ample Doppler spread of as much as +/- 800 km per hour[3] and resolution of about 3 km per hour.

9. Google utilized a continuous wave (CW) tone for the propagation tests, which allows the receiving system to utilize a relatively narrow (10 Hz) bandwidth, thereby reducing the displayed noise level on the spectrum analyzer and improving its sensitivity to weak received signals at the boundary of the test area. After accounting for pre-amplifier gain (23 dB) and cable/filter/limiter losses (0.5 dB) in the receive system, the noise level measured was equivalent to approximately -159.6 dBm received with an isotropic antenna within a single (10 Hz) resolution bandwidth. The variation in the noise level was measured to be approximately $\sigma = 5.5$ dB, as measured at the lower and upper band edges, away from the desired signal.

10. When processing the received data, Google considered a detection only if the peak amplitude of the CW signal in any 10-Hz bin across the spectrum was at least 5σ (27.5 dB) above the noise floor. Because the CW signal was generally Doppler spread across more than a single 10-Hz bin, a peak amplitude of 27.5 dB above the noise corresponds to a minimum received signal strength integrated across all Doppler shifts of approximately 4 dB larger than the 5σ single-bin limit, or 31.5 dB above the noise floor for a single bin. The minimum received signal detection level was therefore -128.1 dBm, or -159.6 dBm + 31.5 dB. Given the EIRP of our transmitter (46.4 dBm)

[3] In testing, reflections off airplanes at Doppler shifts of a few hundred km per hour were occasionally received. Doppler spread of ~100 km per hour (~330 Hz) was typical for vehicular motion at about 33 km per hour, due to reflections off oncoming traffic.

and the gain of our receive antenna (11.6 dBi), we could therefore measure propagation losses up to approximately 46.4 dBm + 11.6 dBi - -128.1 dBm, or 186.1 dB.

Results and Discussion

11. After conducting the propagation measurements described above, Google compared the path losses measured to those predicted by FSL and Longley-Rice. The comparisons are shown graphically in Figures 3 and 4. In each figure, the x-axis is the distance (m), and the y-axis is loss (dB). For each model, we calculated the predicted path loss for both the FSL and Longley-Rice models specific for that path, and those values are plotted in green. The difference between the measured value and the predicted value, for each specific path, is plotted in red. In the Longley-Rice analysis, the predicted loss (green dots) may be different for the same distance, depending on the specific terrain along the path from transmitter to receiver. The difference between measured and predicted values (red) are on a point-by-point basis, taking into account the specific terrain corresponding to each measured loss and its corresponding predicted loss for that path. For the Longley-Rice comparison, we utilized a 1” (30 m) terrain database, 1.5 m transmit and receive antenna heights, a time variability factor of 50%, and a situational variability factor of 50% as input parameters for the model. Because path loss fluctuates somewhat over time due to many factors, such as moving vehicles and changing weather patterns, the 50% time variability factor reflects an expectation that a stationary receiver located at a given point and making continuous measurements will capture the predicted path loss, or less, 50% of the time. The

situational variability factor accounts for observational repeatability of the measurements using different equipment, different personnel, or different methods.

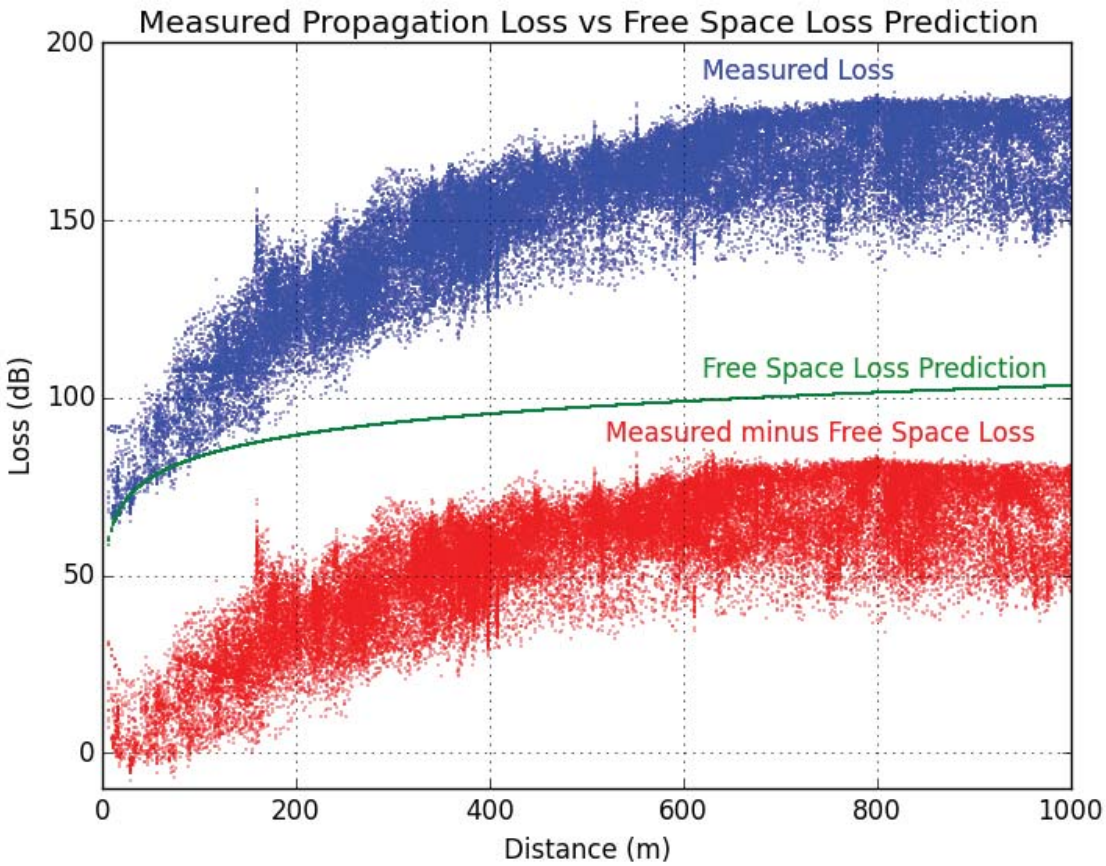

Figure 3: **Comparison of measured path loss to path loss predicted by the free space loss model.**

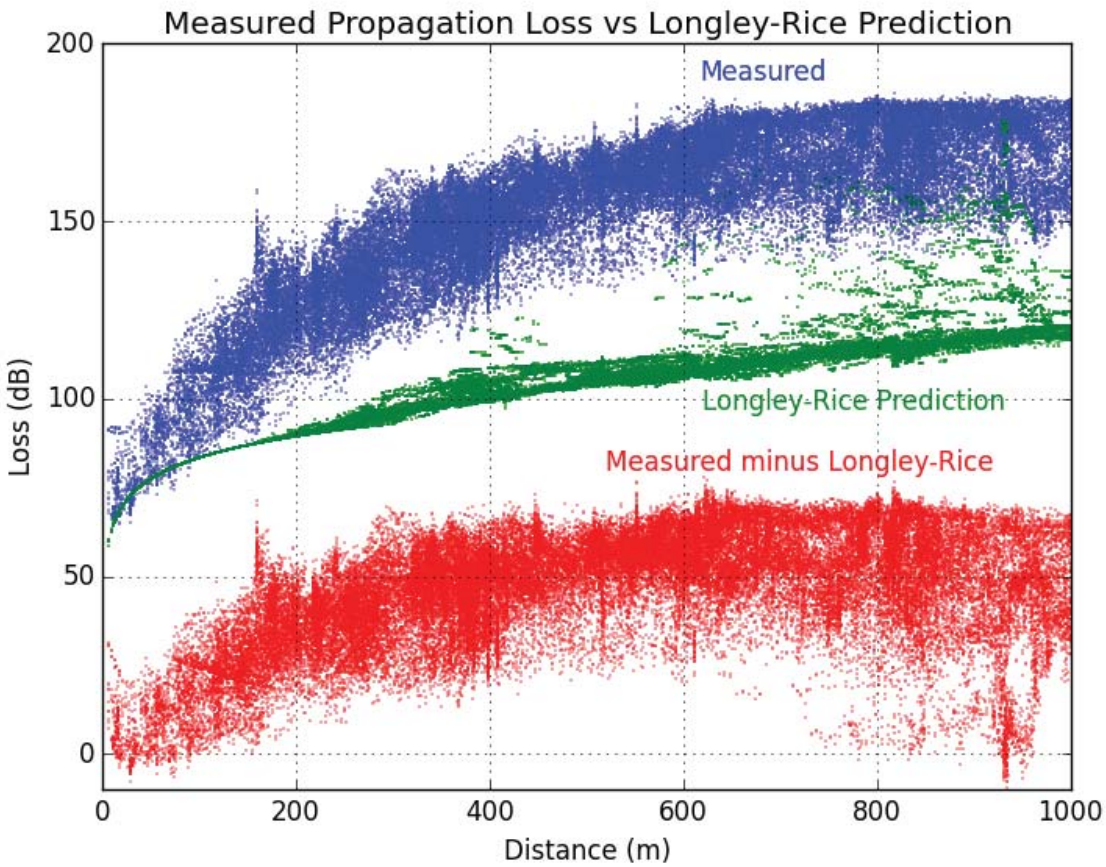

Figure 4: **Comparison of measured path loss to path loss predicted by the Longley-Rice model.**

12. In both cases, the measured propagation loss was almost always larger than the predicted loss. 99.7% of the measured values exceeded the FSL prediction. At distances greater than 90.1 m, 100% of measurements exceeded FSL prediction. The measured path loss value exceeded FSL by 56.7 dB on average, and by as much as 85.3 dB. In the latter case, the receiver was located immediately adjacent to the side of a large building, and the path was further blocked by several other buildings and foliage. In the 0.28% of points where FSL exceeded the measured value, the largest discrepancy was 7.8 dB (which occurred at a distance of 30 m), and the average discrepancy was 2.2 dB. Both values are considerably smaller than the spread in

measured values at distances less than 90.1 m, which was approximately 20 dB. The limited instances where measured loss is less than FSL is most likely due to multipath propagation, where a direct ray and a ray reflected off of the ground or a nearby building (for example) could add up in phase at the receive antenna, producing an effective path loss that is less than FSL. However, path loss due to multipath propagation that is less than FSL is generally only significant at very short distances (such as less than 90 m as observed here), and only with direct line of sight between the transmit and receive antennas.

13. In the Longley-Rice case, the measured path loss exceeded the predicted path loss in 99.6 % of the cases (essentially the same as for the comparison with FSL). The measured path loss exceeded the Longley-Rice prediction by, on average, 45.7 dB, and by as much as 78.1 dB. The largest delta was observed at the same geographical point where the 85.3 dB difference between FSL prediction and measured loss discussed above was observed. In the 0.43% of points where the Longley-Rice loss prediction exceeded the measured loss, the average difference was 2.4 dB, and the largest discrepancy was 9.3 dB, which occurred in the shadow of a ~30 m hill at a distance of approximately 934 m from the transmitter. However, within 10 m of this point at which the maximum discrepancy occurs, the measured loss exceeds the Longley-Rice prediction by an average of 3 dB. The hill is covered only by short grass, has no clutter (structures or foliage), and the path from the top of the hill back to the transmitter is unobstructed. As a result, the measurements reinforce the conclusion that Longley-Rice is a reasonable predictor of path loss in the absence of clutter, but it

significantly understates loss on cluttered paths, including almost all of our other measured data points.

Conclusion

14. This high-level summary of initial results from our propagation measurements in the Mountain View, California, area demonstrates that two standard propagation models (free space loss and Longley-Rice) underestimate typical propagation loss by 45 - 57 dB on average, more than 99.6% of the time, over distances less than 1 km. The data support the conclusion that the discrepancy is due to the existence of clutter (buildings and foliage) along the propagation path.

15. Google continues collecting 3.5 GHz propagation data in Mountain View and in other areas, and, based on these data, is deriving statistical models that can establish a lower limit of predicted path loss as a function of clutter along the affected paths. We intend to file the results of these studies with the Commission at a later date.

I, Andrew W. Clegg, declare under penalty of perjury that the foregoing declaration is true and correct. Executed on February 16, 2016.

Dr. Andrew W. Clegg