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July 7, 2016

VIA ELECTRONIC FILING

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

Re: Written *Ex Parte* Notice, GN Docket No. 14-177, IB Docket Nos. 15-256 and 97-95; RM-11664; and WT Docket No. 10-112

Dear Ms. Dortch:

The Boeing Company ("Boeing"), through its counsel, hereby responds to the June 23 letter of Straight Path Communications, Inc. ("Straight Path") challenging Boeing's technical findings that spectrum sharing is readily achievable between terrestrial 5G systems and receive-only earth stations operating with broadband fixed-satellite service ("FSS") systems in the 37.5-40.0 GHz ("37/39 GHz") band.[1]

Straight Path's letter repeatedly and significantly misstates the record, and urges the Commission to take steps wholly unsupported by the facts. Perhaps most significant, Straight Path argues that spectrum sharing in the 37/39 GHz band "will cripple the mobile industry's efforts to provide gigabit mobility to the American people."[2] Straight Path's claim is echoed by CTIA, which argues that the adoption of "unproven sharing frameworks" could "introduce uncertainty and prevent [5G] licensees from using their spectrum when and where they need it."[3]

To the contrary, technical information provided by Boeing makes it clear that spectrum sharing is both achievable and in full accord with the Commission's public interest objectives. Such arguments also disregard the fact that the 37/39 GHz band is a receive-only band for satellite services. The only risk to spectrum sharing is the potential for interference into satellite

[1] Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 1 (June 23, 2016) ("*Straight Path June 23 Letter*").

[2] *Id.*

[3] Letter from Brian M. Josef, Assistant Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 1 (June 24, 2016).

user terminals from 5G transmissions and not to 5G systems. Therefore, the Commission's consideration of spectrum sharing measures in the 37/39 GHz band will create no uncertainty for – much less, "cripple" – 5G deployment plans.

Straight Path also incorrectly asserts in its June 23 letter that:

- Boeing is trying to "cloud the record" in this proceeding by "misrepresenting the state of the art of phased array technologies for Fifth Generation wireless ("5G") and fixed satellite service ("FSS") technologies."[4] In fact, Boeing was heavily involved in the development of millimeter wave ("mmW") phased array technology as a contractor to the U.S. government. The current wireless industry effort to commercialize mmW capabilities rely heavily on technologies that were developed for U.S. government satellites and terrestrial military radio applications, including mmW modulations and coding, spread spectrum techniques, and mmW integrated circuits. Boeing is therefore fully aware of the capabilities of mmW systems, both with respect to the "state of the art" and their practical application in real-world deployments.

- Boeing's request for the Commission to revisit its "soft segmentation" approach to the V-band is somehow "untimely."[5] In fact, the Commission's Notice of Proposed Rulemaking ("NPRM") expressly acknowledged that it is appropriate to review the soft segmentation restrictions "in light of evolving technology permitting new options for co-existence of terrestrial and FSS."[6]

- The satellite industry is not taking sufficient steps to deploy satellite systems in the V-band and Boeing's plans to launch and operate a non-geostationary satellite orbit ("NGSO") FSS system in the V-band should be discounted because "[w]ithout any technical details, investment plans, or a specific timeframe, Boeing makes nothing but an empty claim."[7] Straight Path filed its letter on the same day that Boeing filed an application with the Commission to launch and operate its V-

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[4] *Straight Path June 23 Letter.*

[5] *Id.*

[6] Use of Spectrum Bands Above 24 GHz For Mobile Radio Services, GN Docket No. 14-177, Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band, RM-11664, et al., *Notice of Proposed Rulemaking*, FCC 15-138, ¶ 126 (2015) ("*Spectrum Frontiers NPRM*").

[7] *Straight Path June 23 Letter* at 2.

> band NGSO FSS system.[8] Boeing has now placed into the record far more detail regarding the plans for its use of the V-band than Straight Path (and arguably the terrestrial wireless industry) has made public regarding its own plans, rendering Straight Path's argument moot.

Straight Path also attempts to argue that, despite plain language to the contrary, CTIA did not state in two recent letters that 5G services are "unlikely to deliver extensive coverage in a market, but instead will be best suited . . . in densely populated areas"[9] and will be used "primarily for adding capacity and high-speed data"[10] to existing networks in areas "with the greatest population density."[11] Straight Path instead suggests that 5G likely will penetrate into the suburbs, albeit probably not in many rural areas.[12]

In making this argument, Straight Path misses the critical point. No one can predict for certain whether 5G systems will successfully provide broadband services in non-urban areas. Because of this uncertainty, it is critically important for the Commission to consider spectrum sharing opportunities in the V-band that will further ensure that the mmW communications evolution – including access to very high data-rate broadband connectivity – benefits all Americans in both urban and the most rural portions of the country. NGSO FSS satellite systems operating in the V-band will, by their very nature, provide advanced communications services to all locations in the United States, thereby fulfilling the Commission's statutory mandate to ensure that those living in rural, insular, and high cost areas have access to telecommunications and information services, including broadband Internet access service, that are "reasonably comparable to those services provided in urban areas."[13] The systems will also promote "the

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[8] *See* The Boeing Company Application for Authority to Launch and Operate a Non-Geostationary Low Earth Orbit Satellite System in the Fixed Satellite Service (S2966), SAT-LOA-20160622-00058 (Filed June 22, 2016), *available at http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/swr031b.hts?q_set=V_SITE_ANTENNA_FREQ.file_numberC/File+Number/%3D/SATLOA2016062200058&prepare=&column=V_SITE_ANTENNA_FREQ.file_numberC/File+Number.*

[9] Letter from Scott K. Bergmann, Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 2 (May 20, 2016) ("*CTIA May 20 Letter*").

[10] Letter from Brian M. Josef, Assistant Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 2 (May 24, 2016).

[11] *CTIA May 20 Letter* at 2.

[12] *See Straight Path June 23 Letter* at 2 (acknowledging that even its own economic analysis shows that 5G mobile services in millimeter bands will not be economically viable in areas with a population density of 10 people or less per square kilometer).

[13] 47 U.S.C. § 254(b)(3).

equitable distribution of radio service throughout the nation"[14] in order to achieve a "rapid, efficient, Nation-wide, and world-wide wire and radio communication service."[15]

5G Beams Pointed Above the Horizon. Turning to the technical issues of mmW spectrum sharing, Straight Path challenges Boeing's assertion that 5G base stations are unlikely to steer beams in an upward direction toward tall buildings (potentially reducing their isolation toward satellites overhead). Boeing explained that this scenario was unlikely "because of the substantial attenuation that results in these frequency bands from building materials (including the high reflectivity of windows at small angles of incidence)."[16] Straight Path makes no effort to challenge Boeing's observation about building attenuation, providing instead extensive data showing that there are many tall buildings in the United States, a fact not in dispute.[17]

Even if Straight Path was able to successfully penetrate modern building materials using upwardly pointing 5G base stations, such base stations would be adequately protected from satellite downlink transmissions because the buildings themselves would shield the base stations from line-of-sight ("LOS") events with the satellites. Assuming the use of 5G base station beamwidths of 9 degrees (for a 256-element base station) to 32 degrees (for a 16-element base stations), the aspect ratio of a normal building of 50 meters would largely or completely block an NGSO FSS satellite signal arriving at a 45-degree elevation angle. Similarly, even if the satellite signal is not entirely blocked, it will instead be reflected and attenuated by the urban canyon environment, resulting in a non-LOS ("NLOS") multi-path condition with significant attenuation and fading during the last 50 to 100 meters of propagation. This will significantly attenuate the arriving satellites signals below the ITU PFD limit which, by regulations, must be maintained by satellite systems in pure LOS conditions. Therefore, even if Straight Path were to employ upwardly pointed base stations to serve tall buildings, such installations would be adequately protected from satellite downlink transmissions.

Satellite Downlink Transmissions at ITU PFD Levels into 5G Base Stations. Boeing demonstrated in its June 17 response to Straight Path that 5G base stations will have at least 20 dB of isolation from satellite downlink transmissions.[18] In providing this analysis, Boeing assumed the use of a 5G base station array with an effective beamwidth and aperture size of approximately 8 centimeters (corresponding to a 128- to 256-element base station array).

[14] 47 U.S.C. § 307(b).

[15] 47 U.S.C. § 151.

[16] Letter from Bruce A. Olcott, Counsel to The Boeing Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 5 (June 17, 2016).

[17] *See Straight Path June 23 Letter* at 3.

[18] Letter from Bruce Olcott, Counsel to The Boeing Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177, at 8 (June 17, 2016) ("*Boeing June 17 Letter*").

Straight Path now argues that 5G operators may employ even smaller base station arrays.[19] Further, each base station array may be divided into sub-arrays in order to create multiple narrow beams, each originating from a small subset of the available array elements.

Straight Path seems to suggest that some 5G base station arrays may be as small as the phased arrays that will be routinely employed on 5G user terminals. Fortunately, Boeing already provided extensive analysis showing that 5G user terminals will not experience harmful interference from satellite downlink transmissions, analysis that Straight Path has not challenged. Protection of 5G receivers (both base station and handset) from satellite downlink transmissions is not purely a function of the sidelobe "isolation" of the receiving antenna, but rather a function of the absolute antenna gain directed towards the satellite interferer. This is evident in Boeing's prior analyses in the case of satellite interference levels into the mobile handset user.[20] In this case, the mobile handset is assumed to provide an absolute gain of 13 dBi but no isolation whatsoever. This case resulted in a minimal (less than 0.6 dB) interference contribution due to the satellite signal.

For base stations, as the various base station antenna sizes illustrated by Straight Path decrease, the actual peak gain of the base station also decreases, even though the "isolation" relative to peak is lowered. Straight Path's June 23 letter does not include the absolute gain of the identified base station patterns. Therefore, Boeing has provided these values below and computed the potential worst-case satellite interference levels for various base station antenna sizes in Tables 3a and 3b.

The individual steps for this computation are detailed in the figures below. First, Boeing aligned its antenna model with the Straight Path examples to avoid any future confusion regarding antenna performance. Figure 1 illustrates the aligned models.[21] In terms of absolute gains, Figure 2a shows an unscanned (broadside) array beam pattern for four base stations sizes, with axes in actual antenna gain (not relative levels). Likewise, Figure 2b shows a 35-degree scanned beam pattern for the same four base stations sizes, with axes in actual antenna gain (not relative levels). The gains are fully consistent with 5G base station capabilities and are identical to those used by Straight Path, which has included 256-element base stations examples in two of its previous submittals to the Commission.[22]

[19] *See Straight Path June 23 Letter* at 3.

[20] *Boeing June 6 Letter*, Attachment at 7.

[21] Antenna patterns are extracted from Straight Path's June 23 letter, Figures 1 and 2. Although the sidelobe levels could be reduced further in particular for the 64, 144, or 256 element base stations, Boeing chose to align with Straight Path's model for simplicity.

[22] Letter from Russell H. Fox and Angela Y. Kung on behalf of Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.* (Jan. 15,

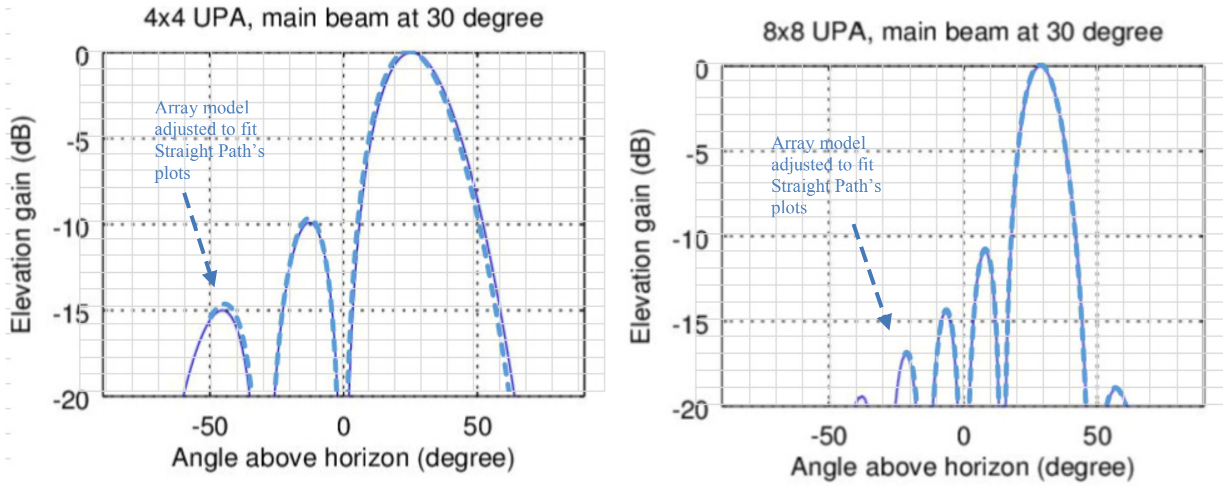

Figure 1 – Antenna Model Alignment Examples

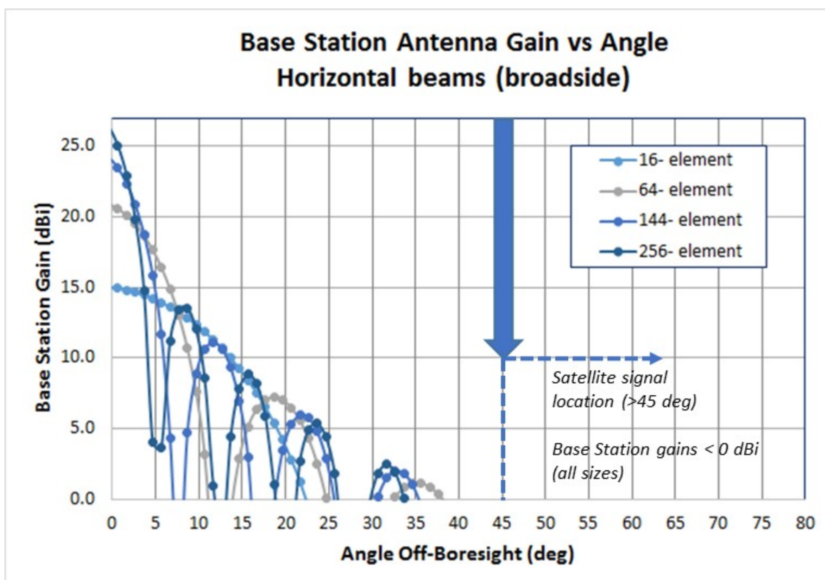

Figure 2a – Base Station Antenna Patterns at Broadside (in actual gain, dBi)

(continued…)

2015), Appendix A ("*Straight Path Jan. 15 Letter*") (employing 256-element base stations with 27 dBi peak gain); Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.* (Jan. 27, 2016), Appendix A ("*Straight Path Jan. 27 Letter*") (also using 256-element base stations with 27 dBi peak gain).

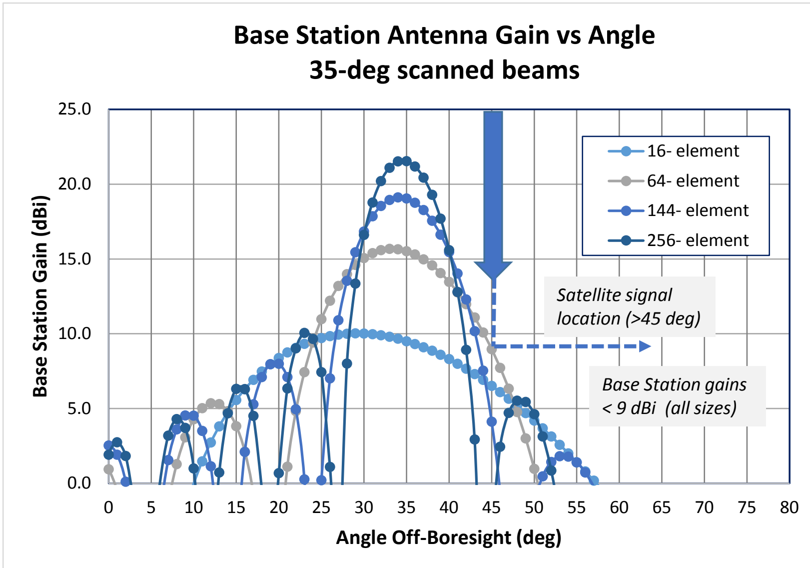

Figure 2b – Base Station Antenna Patterns Scanned to 35-degrees (in actual gain, dBi)

Boeing then summarized the gains and interference calculations for a potential satellite signal operating at the worst-case maximum -105 dBW/m2/MHz ITU PFD level and arriving at a 45-degree minimum elevation angle. In all cases, as shown in Table 3a, there is little degradation (less than 0.05 dB) for 5G links operating at or below the horizon. Table 3b shows the same calculation for a beam scanned up to 35 degrees above the horizon. For the 35-degree upward scanned beams, at most 0.4 dB degradation occurs for the scanned beam of a base station using an 8x8 phased array antenna.

BASE STATION CHARACTERISTICS				Broadside (horizontal Beam)						
Linear array dimension	Array Configuration	Total Elements	Peak Gain	Rolloff (relative gain) at 45-deg offset	Absolute Gain at 45-deg offset	Satellite Interference Level after antenna gain	5G receiver Noise density	Interference to Noise ratio, I_{SAT}/N_{5G}		5G link degradation
(cm)			(dBi)	(dBr)	(dBi)	(dBW/MHz)	(dBW/MHz)	(dB)	(%)	(dB)
1.55	4x4	16	15.1	16.4	-1.34	-159.6	-139.0	-20.6	0.9	0.04
3.10	8x8	64	21.1	26.5	-5.41	-163.7	-139.0	-24.7	0.3	0.01
4.65	12x12	144	24.6	26.6	-1.98	-160.2	-139.0	-21.3	0.7	0.03
6.20	16x16	256	27.1	30.0	-2.94	-161.2	-139.0	-22.2	0.6	0.03

Table 3a – Worst-Case Satellite Interference into Base Station (horizontal beams or below)

BASE STATION CHARACTERISTICS				35-degree scanned beam						
Linear array dimension	Array Configuration	Total Elements	Peak Gain	Rolloff (relative gain) at 45-deg offset	Absolute Gain at 45-deg offset	Satellite Interference Level after antenna gain	5G receiver Noise density	Interference to Noise ratio, I_{SAT}/N_{5G}		5G link degradation
(cm)					(dBi)	(dBW/MHz)	(dBW/MHz)	(dB)	(%)	(dB)
1.55	4x4	16	12.7	6.1	6.52	-151.7	-139.0	-12.8	5.3	0.22
3.10	8x8	64	18.7	9.7	8.97	-149.3	-139.0	-10.3	9.3	0.39
4.65	12x12	144	22.2	18.1	4.12	-154.1	-139.0	-15.2	3.0	0.13
6.20	16x16	256	24.7	19.2	5.53	-152.7	-139.0	-13.8	4.2	0.18

Table 3b – Worst-Case Satellite Interference into Base Station (35-degree upwards scanned beams)

5G Nulling of Satellite Signals. Straight Path seems to suggest in its June 23 letter that Boeing's sharing analysis is premised on requiring 5G base stations to null the signals from satellites overhead. Straight Path argues that there is "no guarantee that nulls can be formed to track multiple moving satellites."[23] Boeing, however, has never suggested that 5G base stations will need to null transmissions from satellites. Instead, Boeing has always asserted that the inherent beamforming utilized by 5G base stations will achieve any necessary satellite signal rejection, an argument that is again fully validated by the analysis provided above.

Straight Path is also incorrect in arguing that Boeing's proposal to allow satellites to operate in the 37.5-40.0 GHz band at the ITU PFD limit "will create a major reduction of coverage for 5G fixed and mobile services and severely damaging the economics and prospect of 5G deployments in this band."[24] Straight Path's own assessment, using its own referenced analyses, shows that satellite downlink transmissions at the higher ITU PFD level result in no more than a 0.7 dB interference degradation.[25] Unfortunately, Straight Path then equates this to a 15 percent decrease in coverage range.[26] This is highly overstated as the noise increase can be easily compensated by equivalent additional gain from the base station antenna (an 8 percent increase that, as shown from the aperture sizes in Table 3, results in a truly minor change in already minimal noise levels). This can hardly be called a "major reduction of coverage" nor be claimed to be "severely damaging the economics of and prospects of 5G deployments in this band."[27]

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[23] *See Straight Path June 23 Letter* at 5.

[24] *Id* at 5.

[25] *See Straight Path Jan. 27 Letter* at Attachment B.

[26] *See id.*

[27] *See Straight Path June 23 Letter* at 5.

Satellite Transmissions into 5G Control Channels. Boeing's analysis above for smaller base station antennas also addresses Straight Path's concern regarding 5G system "control signals."[28] Straight Path states that these signals use "different wide beams… all covering or scanning through the entire coverage area of the cell."[29] Assuming Straight Path's example of a 4x4 (1.55 centimeter) array, which generates 32 degree beams, the station would generate a peak gain of at most 10.5 dBi when scanned directly to a 45-degree upward angle. Even in this extreme case, the 5G system control channel would experience only a 0.6 dB noise increase for a short transient period.

If a base station were to instead utilize a broadcast-style beam that covers "the entire coverage area of the cell,"[30] the gain of such a beam would be corresponding lower according to its beamwidth. For example, a 90-degree coverage beam would have less than 5 dBi at its peak. Similarly, a 120-degree coverage beam would have 2 dBi of gain, with similar gain throughout its coverage area. It is unlikely that any such beam could service a mobile user even for low-rate control and synchronization functions. Assuming such links are designed to operate at a highly negative signal-to-noise ratio ("SNR"), however, they would have modulations and coding that would allow the 5G system terminals and base stations to achieve significant processing gain over thermal noise. Since the satellite signal would be uncorrelated to any waveform schemes utilized by the 5G system, the processing gains used in such channels would apply to reject the satellite signals as well. This also applies to the case where a higher-gain base station could be scanning a narrow beam for system purposes. Such beams will be able to operate with the negligible degradations shown above for a broad range of base station sizes with coverage below 35-degrees above the horizon. Should a high-gain base station be scanned above 35 degrees skyward for system control, timing, or acquisition purposes, the satellite signals should be uncorrelated and easily distinguished from desired 5G user signals due to the robustness of 5G system control modulations and coding and the transient nature of the NGSO FSS signals as the satellites move across the field of view.

5G and Satellite Interference is Correctly and Statistically Modeled. Straight Path also repeats in its June 23 letter that "Boeing misunderstands… analysis of the aggregated 5G interference to FSS ground stations," claiming that Boeing assumes "there is only a single dominant 5G interferer at a given time while the contribution of other interfering 5G base stations and mobile stations can be ignored."[31] This clearly misstates the approach that was employed in Boeing's June 17 letter, wherein Boeing stated its assumption of "one signal per base station (or, one bi-directional link from one 5G mobile unit to each base station) assumed to

[28] *Id.* at 3.

[29] *Id.*

[30] *Id.*

[31] *Id.* at 6.

be present at any time and at any portion of the frequency band."[32] Boeing does not assume one 5G interferer present at an satellite earth station receiver, but rather one interfering signal generated per base-station at any given time or frequency. This is illustrated below in Figure 3 for a typical configuration of 19 base stations operating in a 3-sectored frequency re-use pattern. The presence of a dominant interferer (usually from the closest base station) merely reflects the observation in Boeing's statistical simulations that there is in general one dominant contributor among the base station(s).

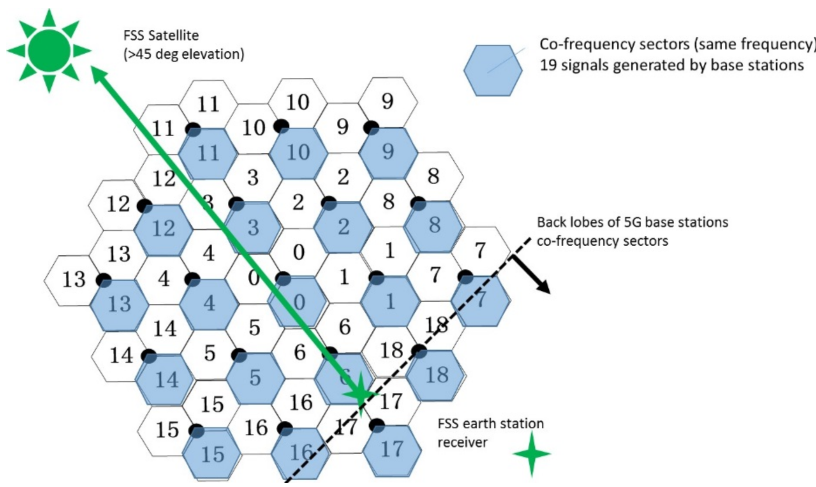

Figure 3 – 5G and Satellite System Interference Modeling (19-cell example – per IMT-2020/3GPP)[33]

With regard to NLOS and LOS path loss modeling, Straight Path again asserts that Boeing has only modeled NLOS conditions (which it acknowledges are predominant in urban deployments, which account for 80 percent of the US population).[34] Boeing's initial modeling results submitted on June 6 focused on urban deployments as the densest concentration of 5G base stations and likely requiring the highest base station power (EIRP) to address high NLOS path loss conditions.[35] Updates submitted by Boeing in its July 5, 2016 letter included additional suburban/rural models with mixed LOS and NLOS conditions, with results showing the strong potential for spectrum sharing at the Commission's originally proposed 5G base station EIRP

[32] *Boeing June 17 Letter* at 8 (*emphasis added*).

[33] *See* ITU-R M IMT-2020 [IMT.MODEL] "Modeling and simulation of transmissions from IMT networks for use in sharing and compatibility studies" – draft recommendation rev.4 (June 25, 2016).

[34] *Straight Path June 23 Letter* at 6.

[35] Letter from Bruce Olcott, Counsel to The Boeing Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 (June 6, 2016) at Attachment 1 ("*Boeing June 6 Letter*").

density limit of 62 dBm per 100 MHz.[36] As discussed in Boeing's 5 July letter, this EIRP level is adequate to achieve 5G data rate and deployment goals, with further study being required to develop guidelines for operation at any higher EIRP levels. Such guidelines can include mandated usage of power-control for transmissions versus user range, off-axis EIRP level limits, and other mechanisms inherent in 5G system operation for beamforming and self-interference control.

Beamforming Technologies are Necessary and Ready for Deployment. In its June 23 letter, Straight Path asserts that, in order for a base station to achieve sidelobes below 50 dB, a 1000-element array would be required and would be "[a]n expensive and difficult feat to achieve."[37] Interestingly, Straight Path uses a slightly larger 1024-element array in its example of 5G base stations needed to support a higher EIRP level.[38] As Boeing and other parties continue to assert, current technologies are available to provide integrated beamforming solutions, rather than just the single devices quoted in the recent Straight Path letter. Straight Path's presumptions notwithstanding, 4G, 5G, and satellite services will each benefit from phased array beamforming technologies and the "higher level of integration and the continuous drive towards lower cost design and manufacturing processes."[39]

The Way Forward

Given the extraordinary potential for co-primary spectrum sharing between 5G terrestrial and satellite systems in the 37/39 GHz band, the Commission should use this opportunity to adopt modest and reasonable measures – including rules proposed by the Commission in the NPRM necessary to ensure 5G self-compatibility – that will facilitate the robust deployment of terrestrial 5G services and concurrently ensure the availability of very high data-rate, satellite-delivered broadband services to all consumers in the United States and globally. Specifically, Boeing requests that the Commission adopt the following reasonable provisions:

- Adopt a 5G base station power limit of 62 dBm EIRP, as proposed in the NPRM,[40]
- Require 5G systems to use beam forming and power control,

[36] Letter from Bruce Olcott, Counsel to The Boeing Company, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 4-5 (July 5, 2016).

[37] *Straight Path June 23 Letter* at 6.

[38] Letter from Davidi Jonas, CEO and President, Straight Path Communications, Inc., to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al.*, at 1 (June 20, 2016).

[39] *Straight Path June 23 Letter* at 6. Contrary to Straight Path's assertions, integrated solutions and optimized manufacturing processes do not necessitate lower performance.

[40] *See Spectrum Frontiers NPRM,* ¶ 274.

- Require the confidential disclosure of 5G base station locations,
- Lift the prohibition on satellite end user receivers in the 37/39 GHz band,[41]
- Impose no limits on receive-only gateway facilities in the 37/39 GHz band, and
- Permit satellites to transmit in the 37/39 GHz band at the ITU power levels.

These measures would result in no appreciable harm to 5G system operators. In fact, some of these measures (such as beam forming and power control) are likely to be uniformly employed by 5G system operators to avoid causing interference into their own systems.

Thank you for your attention to this matter. Please contact the undersigned if you have any questions.

Sincerely,

Bruce A. Olcott
Counsel to The Boeing Company

[41] *See* 47 C.F.R. § 25.202(a)(1), footnote 3.