June 1, 2016

Ms. Marlene H. Dortch, Secretary
Federal Communications Commission
The Portals
445 Twelfth Street S.W.
Washington, D.C. 20554

Re: *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, GN Docket No. 14-177

*Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5-28.35 GHz and 37.5-40 GHz Bands*, IB Docket No. 15-256

Dear Ms. Dortch:

AT&T Services Inc., ("AT&T"); Ericsson ("Ericsson"); Nokia ("Nokia"); Samsung Electronics America ("Samsung"), T-Mobile USA, Inc. ("T-Mobile") and Verizon ("Verizon" and, with AT&T, Ericsson, Nokia, Samsung and T-Mobile, the "Joint Filers") submit this *ex parte* letter in the above-captioned proceedings to supplement the record regarding potential co-existence between terrestrial mobile broadband (fifth generation or "5G") and Fixed Satellite Service ("FSS") systems sharing the 28 GHz band. As discussed below, simulations based on reasonable engineering assumptions demonstrate that: (i) interference from existing transmit FSS earth stations into 5G networks can be addressed by requiring those satellite earth stations to reduce their power flux density ("PFD") at 10 meters above ground level to -77.6 dBm/m$^2$/MHz at 200 meters; and, (ii) limitations on Upper Microwave Flexible Use ("UMFU") licensees are not required to manage aggregate interference from 5G networks into existing FSS receivers that are part of current FSS geostationary ("GEO") or non-geostationary ("NGSO") operations.

On May 6, the Joint Filers submitted to the FCC the results of a detailed simulation performed by Nokia to consider co-existence between FSS and UMFU in the 28 GHz band, as well as engineering analyses refuting many unrealistic claims regarding the potential for UMFU to FSS interference.[1] The Joint Filers hoped the analysis might serve as a starting point for further,

[1] *See* Letter from the Joint Filers to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al*. (filed May 6, 2015) ("*May 6 Joint Letter*") at

more refined studies on coexistence that incorporated additional information from both the 5G and FSS communities. While the Joint Filers have continued to supplement the study by adding additional material from 5G standards organizations and refining included assumptions, information regarding the FSS systems has been sorely lacking. The Joint Filers have requested additional detail on the FSS systems at 28 GHz on numerous occasions, but have not been given any additional data—beyond what is already incorporated—with respect to satellite receiver links (*e.g*., typical signal power at the satellite, used channel bandwidth, filter characteristics and selectivity, receiver sensitivity, modulation scheme, coding scheme/coding rates, frame structure, *etc*); satellite receive gain contours (including the spot beam coverage area on earth for each class); and clarifications on data already provided (some provided range values appear to be in question). As the FCC's Technical Advisory Committee recently observed, "[t]o make informed decisions about frequency allocations that maximize efficiency of spectrum use while still minimizing interference interactions between services, the FCC must be supplied with all of the tools that make prediction of levels of interference possible," and therefore "the Commission needs sufficient technical details about all of the affected services," including "detailed information about the operations of such services, a prediction of the level at which interference will become harmful to each service, and quantitative modeling about the interactions between services over a wide variety of expected conditions."[2]

To date, the *Nokia Simulation* is the only analysis submitted in this docket that uses statistical models to estimate the potential impact on FSS satellite receivers from the deployment of widespread 5G systems. The type of deterministic, worst case link budget analyses between a user equipment ("UE") device or base station ("BS") submitted by the Satellite Operators does not serve as a sound engineering basis upon which to extrapolate the impact of network deployments over hundreds, or thousands, of square kilometers with multiple sectors using sophisticated beamforming techniques.[3] And, as the Joint Filers have discussed with SIA, the

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Attachment 1, "FSS and UMFU Coexistence Simulations," Nokia (May 6, 2016) ("*Nokia Simulation*").

[2] Basic Principles for Assessing Compatibility of New Spectrum Allocations , A White Paper , Spectrum and Receiver Performance Working Group, FCC Technological Advisory Council , Release 1.1 (December 11, 2015) at 18.

[3] *See* Letter from EchoStar, Inmarsat, Intelsat, O3b Limited, OneWeb, SES Americom, Inc., and ViaSat Inc. (collectively, the "Satellite Operators") to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al*. (filed May 12, 2015) ("*Satellite Operators Letter*"); *cmp*. Letter from Peter Pitsch, Intel Corporation, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al*. at Attachment 1, p. 1 (filed May 12, 2015) ("*Intel Letter*") (noting "Today's cellular networks are complex systems with many dynamic features. The methodology chosen to model coexistence must properly reflect the dynamic nature of these systems. Deterministic methodologies in most cases are unreliable and unrepresentative of reality.").

assumptions used do not reflect reasonable engineering assumptions about either UMFU or FSS systems:

- The Satellite Operators' analysis assumes free space path loss from the 5G networks to the satellite at full power. This assumption moves beyond "worst case" to unrealistic, and is precisely why the *Nokia Simulation* uses statistical distributions to model aggregate impact—to be at all reflective of real world operations, the analysis must consider the distribution of indoor and outdoor devices (indoor devices will not impact FSS at all) and the clutter, diffraction and other non-line of sight ("NLOS") losses at different satellite look angles (which can vary depending upon the distribution of urban sites—where virtually no [UEs] will have actual line of sight ("LOS")—to rural areas that may exhibit greater LOS percentages, but overall lower deployment densities). As Verizon has noted, "[UEs] typically operate with power control, with only [UEs] at the cell edge operating at or near peak power levels, while those closer to the base station operate at lower power levels" and "[UEs] also are highly unlikely to be in use (i.e., transmitting) at all times"; thus, "a diverse mix of [UEs], some indoors and some outdoors, operating at different power levels and only a fraction of the time, is a much more realistic terrestrial operating scenario."[4] Further even though UEs at the cell edge are operating at or near peak power levels, their antenna elevations angles are lower than for those closer to the base station, due to pointing towards base station, which means that UEs operating at or near peak power levels have larger antenna gain discrimination towards FSS space station than UEs operating at lower power levels.

- In addition, as Verizon recently observed, the Satellite Operators' "assumed 'off-axis gain reduction toward GSO' of 6 dB … is much too low, given the beamforming to be used for the return link (*i.e.*, from UEs to base stations) and the relative angle to the satellite."[5] As shown in Nokia's modeling, filed with the FCC on May 13, the gain reduction should be 22 dB for Class 1 satellites.[6] Similarly, the Satellite Operators' severely understate BS gain reduction—they assumed 25 dB of BS discrimination for an FSS earth station with a 15º elevation angle, whereas Nokia calculated 48 dB for larger arrays (256 cross-polarized elements).[7] The Joint Filers continue to provide SIA with additional information on the typical beamforming used in 5G UE and BS, and are

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[4] *See* Letter from Gregory M. Romano, Vice-President and Assistant General Counsel, Verizon, to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al*. (filed May 19, 2015) ("*Verizon Letter*") at 1.

[5] *Id*.

[6] *See* Letter from the Joint Filers to Marlene H. Dortch, Secretary, Federal Communications Commission, GN Docket No. 14-177 *et al*. (filed May 13, 2015) ("*May 13 Ex Parte*") at Att. 1, p. 21; *see also* Exhibit A at 9.

[7] Exhibit A at 9.

including the charts attached as Exhibit A for the record in this proceeding. These charts show representative 5G BS and UE beam patterns normalized to appropriate EIRPs, with and without sidelobe suppression. Given the dynamic nature of the beamforming for uplinks in a 5G system, statistical modeling averaging over large scale deployments—as Nokia has done—is the only reasonable method for assessing the impact of UMFU UE devices on satellite systems.[8]

- The Satellite Operators' analysis similarly fails to account for the mismatch between the bandwidth of UMFU devices and FSS gateways. Different satellite systems use different parts of the 28 GHz band. The FSS operations should not be bundled together, as the potential impact of UMFU systems will depend on the actual overlap between 5G and FSS bandwidths.

- The Satellite Operators have also overstated the power from 5G systems. The Satellite Operators modeled power of 23 dBm and 43 dBm EIRP per 100 MHz for UE, even though those maximum power levels apply to the entire 5G bandwidth, which is likely to be at least 200 MHz and potentially all 850 MHz in the current LMDS A Block. Correctly accounting for this factor significantly increases the potential number of simultaneously transmitting UEs and BSs.

- In lieu of providing data on their actual receiver performance and related characteristics necessary to model RF impacts on their systems, the Satellite Operators have used an unrealistic -12.2 dB interference-to-noise ("I/N") ratio as a basis for their co-existence calculations. As the Joint Filers have previously documented, there is overwhelming engineering evidence that -12.2 dB is overstated and that figure is not even used as a protection criteria in their own systems. Indeed, using that I/N, the Satellite Operators derive a 16.5 dBm/MHz/1000 $km^2$ limit they claim is necessary to protect their operations—notwithstanding that these FSS systems have presumably been designed to co-exist with 28 GHz point-to-multipoint systems, which are highly unlikely to meet those limits. As previously noted, the Joint Filers have not been provided with details on the characteristics of FSS operations in the 28 GHz band, which hardly reflects the public process recommended by the TAC.

- As a final matter, the Satellite Operators use their analysis to derive an "aggregate emission limit" expressed as an EIRP limit per MHz per $km^2$, arguing that each UMFU geographic license should have that limit as a condition scaled to the area of the license. This limit, however, ignores that different satellite systems have different spot beams and

[8] Indeed, as Intel notes in its comparison of "the amount of inter-cell interference generated at the receiver of an LTE user device between the two cases of 'with' . . . and 'without' … beamforming implemented at the base stations," the "impact of additional inter-cell interference on the system of this example translates to a throughput loss of about 70% for cell edge users, again unacceptable in a real network." *Intel Letter* at Att. 1, p. 2.

antenna gains, and a uniform, worst case emissions limit—which may even impose limits on UMFU licenses that are not within any FSS spot beam—defies logic.

To further a reasonable technical dialog on co-existence, the Joint Filers have continued to refine and develop the *Nokia Simulation*, taking into account revised FSS parameters for the various FSS classes,[9] as well as undertaking additional engineering analyses around FSS/UMFU sharing. The Joint Filers have also continued to work with SIA to promote a fuller understanding of how 5G UMFU systems will be deployed and why co-existence is possible without onerous regulations on UMFU licensees. And, the Joint Filers' further work, summarized below, clearly reinforces the conclusion in the earlier *May 6 Joint Letter* that regulations on UMFU licensees are unnecessary to protect FSS operations:

- The Joint Filers have attached, as Exhibit A, an analysis quantifying the impact of building diffraction on 5G BS emissions. These calculations were based on methodologies developed pursuant to Recommendation ITU-R P.526-13,[10] and use geometry and other parameters developed in discussions with SIA. The analysis uses the Fresnel integral approach calculating Fresnel cosine and sine using Matlab's global adaptive quadrature integration method with $10^{-15}$ tolerance. For the satellite elevation angles provided by SIA, the calculations show that 5G signals are subject to 24.9 dB of losses at the worst case where the elevation angle to the satellite is at 39.06º, and may be subject to up to 50 dB of attenuation where the satellite is at a 5º elevation angle—30 dB more than the 20 dB of losses assumed in the *Nokia Simulation* and 50 dB more than the 0 dB of losses assumed in the Satellite Operators' joint filing when they computed their proposed UMFU aggregate emission limit of 16.5 dBm/MHz/1000 $km^2$.

- In its initial simulation, Nokia did not have time to model the impact of typical sidelobe suppression or mechanical downtilt in assessing the aggregate effects of 5G BS on FSS systems. It is expected, however, that, while configurations may vary, a representative 5G system might have approximately 30 dB of sidelobe suppression and operate with 6º or more of mechanical downtilt. In Exhibit B, Nokia has provided revised analyses that consider these factors individually and in aggregate, as well as considering operation at higher EIRPs. It should be emphasized that the 5G use cases are not fully defined, and there will be a variety of potential configurations that could be deployed. What the Joint Filers have attempted to do is to model representative types of deployments involving a

[9] The revised analyses conducted by Nokia incorporate revised Class 1, 2 and 3 data provided by SIA, which now provide a range of elevation angles to the FSS classes and revise the orbital distance for Class 3 from 1,200 km to 8,000 km. Nokia's analysis utilizes the lowest elevation angle for the range, which should represent the worst case for co-existence. SIA also provided data for a new Class 4, but given the very low number of Class 4 earth stations that are planned for the U.S., that case should not drive regulatory policy.

[10] *See* http://www.itu.int/rec/R-REC-P.526-13-201311-I (last visited May 25, 2016).

variety of configurations and conditions, including the power levels, degree of downtilt, amount of sidelobe suppression, mix of LOS/NLOS and indoor/outdoor BSs, to provide an realistic picture of what systems might look like and the absence of any threat to FSS systems under real world conditions.

Taking those factors into consideration, as well as changes to the FSS class data provided by SIA (although not considering some additional significant factors like diffraction and system loading), Nokia's results still demonstrate very large numbers of simultaneously transmitting BSs can operate within the FSS receive areas without raising interference problems. Even using a very protective -6 dB I/No, the data shows that 36,000 active BS sectors could be transmitting at 62 dBm/100 MHz without impacting Class 1 FSS operations, 21,600 could be simultaneously transmitting without affecting Class 2 FSS operations, and 40,000 could be simultaneously transmitting without affecting Class 3 FSS systems.[11] Even at higher operating power levels of 75 dBm/100 MHz, the number of active BS sectors that can be simultaneously transmitting is the same for both Class 1 and Class 2 FSS systems, although the number of actively transmitting BS sectors drops to a still robust 12,000 for Class 3 FSS systems.

- The *Nokia Simulation* similarly does not take into consideration the network loading for 5G systems. Nokia reported the number of "active" BS sectors for purposes of its simulation, but the number of actually deployable BS sectors will scale inversely with the activity factor for BSs in the network. For purposes of AWS-3 coordination, the Defense Spectrum Organization and National Spectrum Consortium recently held an "AWS-3" Industry Day at which time they noted that, for coordination purposes, their modeling "uses the simplified scaling of handset EIRP levels proposed by Verizon and adopted by the DoD Industry working group in 2014," which "involves a simple shift in the EIRP power distributions" to "40% for rural and 60% for urban/suburban."[12]

- In terms of characterizing BS and UE 5G emissions, it also is clear that use of maximum power creates an unrealistic, rather than "worst case," assumption. As shown in Exhibit C, modern radio networks very rarely operate at maximum power due to power control. Exhibit C, which was based on actual measurements from AT&T's HSPA+ and LTE network, showed that BSs operated at maximum power only 0.8% of the time, were at

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[11] These results are also consistent with Intel's modeling. The *Intel Letter* provided a Cumulative Distribution Function ("CDF") for a 5G BS using 12º of downtilt, comparing that to a BS with no downtilt. The CDF indicates "that up to a 5 dB loss in geometry, with respect to its median, results when downtilt is not considered in the modeling of the network. *This loss translates to about 60% loss in throughput performance to the cell edge user, rendering the system quite unrealistic*." *Intel Letter* at Att. 1, p. 1 (emphasis in original).

[12] *See* http://www.defenseinnovationmarketplace.mil/dynamicspectrum.html (requires membership) at 22.

half power or below 90.4% of the time, and were 10 dB below maximum power 13.2% of the time. The data also shows that UE operate a maximum power only 0.4% of the time, at less than half power 89.8% of the time, and 10 dB down from maximum power 78.1% of the time. This correlates with Intel's recently submitted findings, where it notes that "there is on the average about 10 dB difference in the received interference at any given LTE user device if power control is not considered," and concludes "not including power control in sharing studies in which a cellular system is the interferer largely overestimates the amount of interference generated by the cellular network."[13]

- The parties also further analyzed the antenna patterns for the Class 1 through Class 3 systems studied, determining the beam coverage area for the 3 dB points of those systems. As shown in calculations by Ericsson in Exhibit D, these areas ranged from approximately 11,000 $km^2$ for Class 1 and Class 2, to approximately 1,200,000 $km^2$ for Class 3. In either case, this falls far short of full CONUS coverage, and any analysis of potential co-existence issues would have to consider both the area covered by the satellite receive beam and the specific characteristics of the satellite receiver—the larger the satellite receive beam, the lower the gain of the satellite receive antenna. The Satellite Operators' analyses also have been using peak value for satellite receiver antenna gain uniformly over the whole terrestrial satellite spot beam area, whereas the 3 dB contours computed in Exhibit D are a fraction of the total reported areas. For Class 1 and Class 2, roughly 65% of the total area covered by the satellite receive beam has receive gain less, or much less, than 3 dB below peak gain.

- In prior discussions with the FCC, the Joint Filers indicated that 5G BSs, in some configurations, might use EIRPs of up to 75 dBm/100 MHz, but that such increased power would not significantly increase the potential interference as modeled by Nokia. To understand this, it is necessary to understand how the BS will be configured for higher power operation. In order to meet a 62 dBm/100 MHz EIRP level for a 5G BS, an array constructed from 64 cross-polarized antenna elements (8 in horizontal and 8 in vertical dimension), is assumed. It is further assumed that the transmit power per cross-polarized element is roughly 21 dBm/100 MHz and the antenna gain of each cross-polarized element is 5 dBi. Then, the total EIRP of the antenna array becomes $5 + 21 + 20 \times \log_{10}(64) = \sim 62$ dBm/100 MHz. To obtain a higher EIRP level of 75 dBm/100 MHz, the same basic cross-polarized element is assumed, again with an antenna element gain of 5 dBi but with 22 dBm/100 MHz of transmit power. To produce the higher EIRP level, a bigger array is constructed with 256 cross-polarized elements (16 in horizontal and 16 in vertical dimensions). The total EIRP then becomes $5 + 22 + 20 \times \log_{10}(256) = \sim 75$ dBm/100 MHz. It is to be noted that an increase of base station EIRP by 13 dB from 62 to 75 dBm/100 MHz does ***not*** necessarily translate into a corresponding increase of interference into satellite receivers by 13 dB, since the off-axis gain towards the satellite of the larger array used to deliver the higher EIRP level will be

[13] *Intel Letter* at Att. 1, p. 3.

lower than that of the smaller array, thus in-part compensating for the increased EIRP level. As stated above, an array with 64 cross-polarized elements (8 in horizontal and 8 in elevation dimensions) is used to generate an EIRP of 62 dBm/100 MHz, whereas an array of 256 elements (16 in azimuth and 16 in elevation dimensions) is used to generate an EIRP of 75 dBm/100 MHz. The boresight elevation patterns of the two array configurations with sidelobe suppression of 30 dB is displayed in Exhibit B at page 7. As evident in the figure, the pattern corresponding to the larger array is significantly narrower than that of the 8x8 array in the elevation angle range of 5º to 25º, thus providing a higher level of interference suppression in the direction of the satellite receivers. This observation is further confirmed by the results shown in Exhibit B, page 8, which displays the normalized mean antenna array gain (or discrimination) towards the satellite receivers. As seen in the figure, the 16x16 exhibits mean antenna array discrimination roughly 14 dB higher than that of the 8x8 array at an elevation angle of 15º. This higher level of array discrimination roughly offsets the EIRP increase of 13 dB that is attained with the16x16 array, thereby resulting in the same interference level and consequently the same number of simultaneously transmitting APs supported with both array types for Class-1 and Class-2 satellite receivers. For Class 3 satellite receivers, at a minimum elevation angle of 5º, the improvement in the antenna discrimination with 16x16 array is about 7 dB, resulting in the overall interference level rise of 6 dB due to the higher EIRP transmission level. This is shown in Exhibit B at page 9 assuming 100% LoS propagation conditions to the Class 3 satellite receiver. Finally, we note that the relative shapes of the two interference curves in Figure 3 is independent of the satellite receiver class or the LoS/NLoS channel mix; the satellite receiver class and the LoS/NLoS channel mix only effect the absolute level of the interference observed in the plot. We also note that these implementations are just examples on how to meet the EIRP levels. Other implementations are possible.

- As a final matter, the Joint Filers have also attached, as Exhibit E, a revised FSS into uplink ("UL") 5G interference analysis for Class 3 FSS. As the Joint Filers previously noted, the free space propagation methods used previously in the broader Class 1-Class 3 analysis provided on May 6th was not appropriate for the distances implicated by Class 3. The Joint Filers suggested that it may be more appropriate to use models that were being developed by 3GPP for intersystem interference, specifically the "urban Macro" and "rural Macro" ('UMa" and "RMa") models. Exhibit E now provides the results of that analysis, and the expected coordination distance drops to approximately 5 km or less.

Putting this all together, as expected, a rigorous statistical simulation of aggregate interference from 5G systems to FSS space stations shows no significant problem even with large numbers of BS sectors simultaneously transmitting. And, as expected, the number of active sectors increases as the satellite receive area gets larger—while the analyses show a number of active sectors that does not scale linearly with the size of the FSS receive area, it should be noted that the larger receive areas occur at lower elevation angles where the effects of diffraction, LOS/NLOS, and clutter will provide greater attenuation of the 5G signals—the *Nokia Simulation* utilizes only 20

dB of loss uniformly for all FSS classes, even though the losses have been shown to be much greater at low elevation angles. Thus, the additional work conducted by the Joint Filers underscores their original conclusion that 5G systems will not cause problematic aggregate impact to FSS from any realistic combination of scenarios.

As always, the Joint Filers remain committed to working with both SIA and its individual members to refine and improve the analysis.

Respectfully submitted,

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Verizon

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**Exhibit A:**
**Knife–Edge Diffraction Analysis for 28 GHz**

# Analysis of Diffraction Loss on the 5G-to-FSS-Satellite Path at 28 GHz

The analysis in this appendix was performed based on the assumptions discussed between SIA and Joint Filers.

Buildings can be major obstructions in the LOS path between terrestrial 5G systems deployed in urban and dense urban environments and FSS satellite receivers, leading to potentially significant diffraction loss that should be considered in the analysis of interference from 5G systems into FSS satellite receivers.

Relevant parts of the diffraction model are described in following paragraphs.

The solution to diffraction on the edge of an object is given using Fresnel integrals (equations 6 & 7 in [1]):

$$F_c(\nu) = \int_0^{\nu} \exp\left( j \frac{\pi s^2}{2} \right) \, ds = C(\nu) + jS(\nu), \tag{1}$$

where $j$ is complex operator, C($v$) and S($v$) are Fresnel sine and cosine respectively:

$$C(\nu) = \int_0^{\nu} \cos\left( \frac{\pi s^2}{2} \right) \, ds, \tag{2}$$

$$S(\nu) = \int_0^{\nu} \sin\left( \frac{\pi s^2}{2} \right) \, ds, \tag{3}$$

where ν is a geometrical parameter defined in equation 4 below.

Recommendation ITU-R P.526-13 [1] describes complex model for numerical integration (equation 8 in [1]) for positive values of $v$, but having tools such as Matlab allows effortless high-precision direct numerical integration of Fresnel equation. A standard, global adaptive quadrature method was used to compute integrals up to $10^{-15}$ tolerance, which is close enough to machine error.

The single knife-edge obstacle case is described in [1] chapter 4.1, equations 28 & 30:

$$v = sign(\theta) \sqrt{\frac{2\, h\, \theta}{\lambda}}, \tag{4}$$

$$J(\nu) = -20 \log \left( \frac{\sqrt{\left[1 - C(\nu) - S(\nu)\right]^2 + \left[C(\nu) - S(\nu)\right]^2}}{2} \right), \tag{5}$$

where $\lambda$ is a wavelength, $h$ is a height of the obstructing object, $\theta$ is diffraction angle (both $h$ and $\theta$ are positive in NLOS case – see simulation world/geometry in the next chapter).

Again, approximate solutions were not considered due to more than enough computing power.

$J$ was multiplied by -1, which yields diffraction gain instead of loss. It also makes final results more intuitive, as object shadow is directly seen. Assumed frequency: 28 GHz.

## Simulation world/geometry

Even compared to sizes of large cities, satellites can be considered point objects at infinity. At any point in time, azimuth and elevation towards specific satellite is constant across large areas.

Simulation results in next section are based on simulation world/geometry depicted in Figure 1.

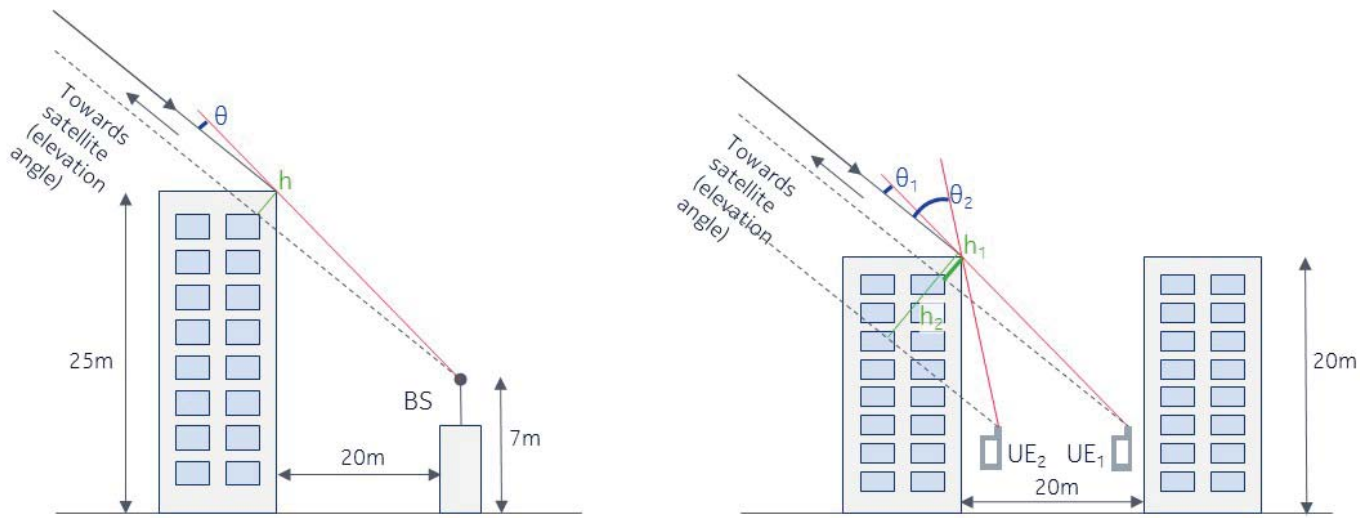


***Figure 1: Simulation worlds/geometries for BS and UE cases***

Geometry used to obtain the plots in Figure 2a and Figure 2b (results for BS case) is as follows:

- Building height 25m,
- Building distance 20m,
- BS antenna height 7m.

Geometry used to obtain the results for UE cases is as follows:

- Building height 20m,
- Building distance 20m,
- UE antenna height 1.5m.

Wherever distance to the building is defined, it applies to distance between diffracting edge wall and antenna. The used value of nominal distance between the buildings (20m) comes from Recommendation ITU-R P.452-16 [2] for urban/dense urban environment. Building heights were chosen based on statistical data shared by United States Census Bureau.

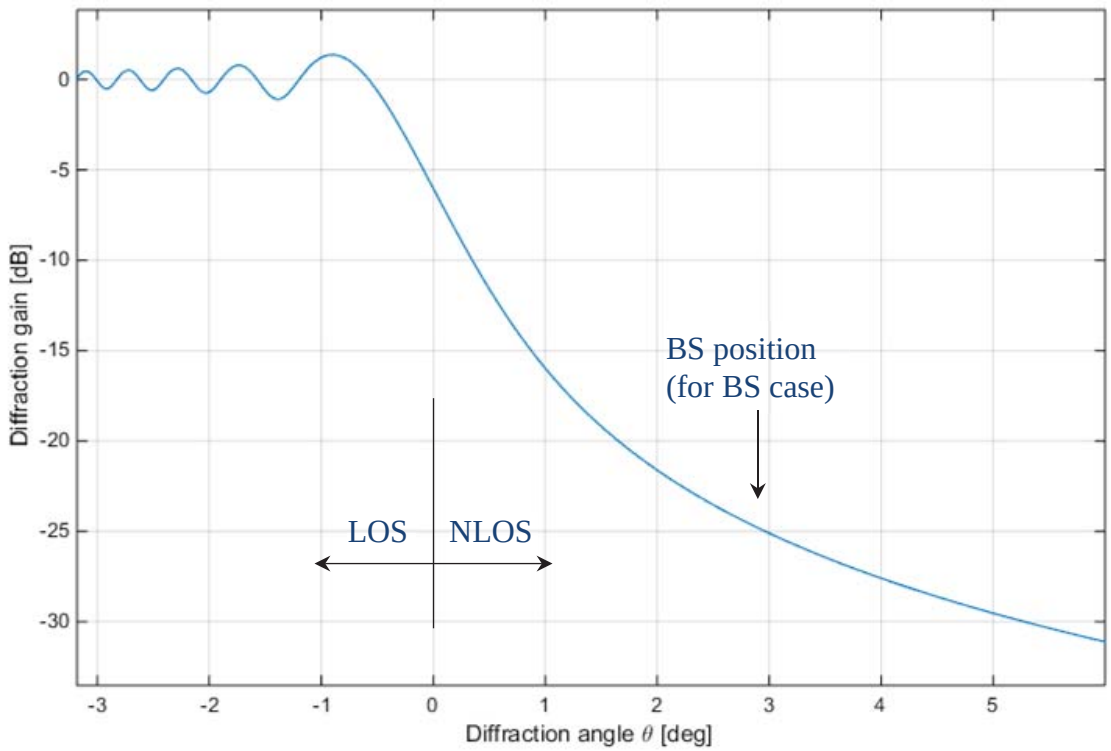


***Figure 2a: Diffraction gain as a function of diffraction angle for BS case (low θ values)***

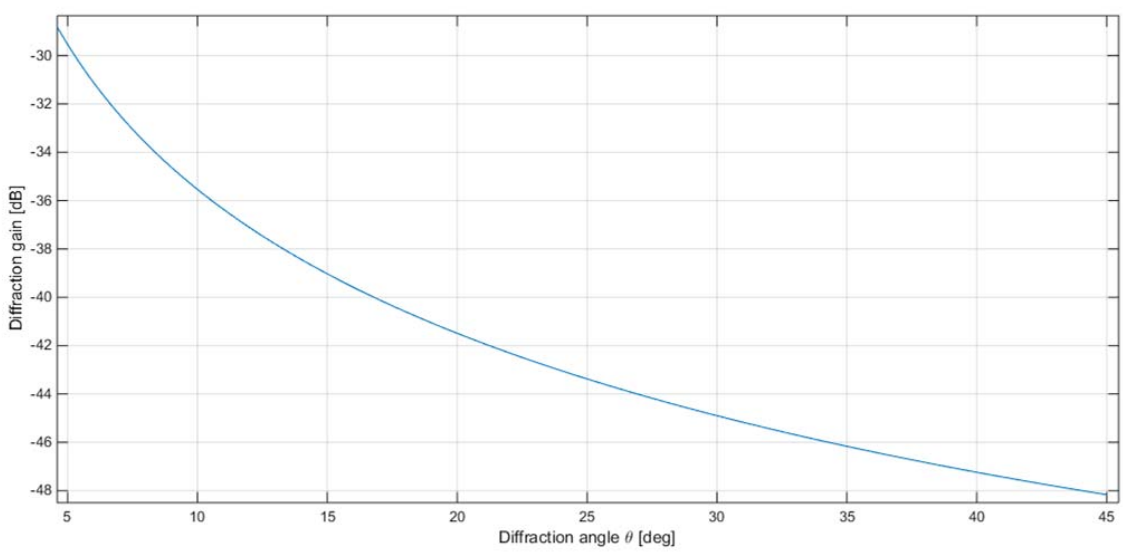


***Figure 1b: Diffraction gain as a function of diffraction angle for BS case (high θ values)***

**Exhibit B:**
**Updated Downlink 5G into FSS Coexistence Analysis at 28 GHz**

NOKIA

Nokia Networks

# Updated Downlink 5G into FSS Coexistence Analysis at 28GHz

## System-level Simulation results

Eugene Visotsky, Kamil Bechta, Prakash Moorut

Nokia - Bell Labs

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# Preliminaries

- FSS protection criterion: $I_{5G}/N_{thermal} < -12.2\ dB$ (results for 6 dB and 0 dB are also presented)

$$N_{thermal} = -198.6 + 10\log_{10} NT\ (dBm/Hz)$$

- Space Station Parameters

| Parameter | SS Class 1 | SS Class 2 | SS Class 3 |
|---|---|---|---|
| Elevation angle range (degrees) | 15-55 | 15-55 | 5 – 50 |
| Orbit distance (km) | 36000 | 36000 | 8000 |
| Max Space Station antenna gain (dBi) | 61 (***58 dBi used***) | 61 (***58 dBi used***) | 30 (***27 dBi used***) |
| NT (K) | 1000 | 650 | 570 |
| $N_{thermal}$ (dBm/Hz) | -168.6 | -170.5 | -171.0 |

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# Evaluation scenario and methodology

| Simulation parameters | | Comments |
|---|---|---|
| Methodology | Average receiver power (dBm/Hz) ***per sector*** is computed at the space station receiver<br>Average receive power is calculated by averaging over all DL transmissions in the system | • Given an interference protection criterion, this can be used to compute the number of ***simultaneously*** active sectors<br>• Needs to be translated to AP density under certain assumptions |
| 5G System layout | 3GPP-defined 19-site (57 sectors) system, ISD = 200m | |
| *EIRP = 62 dBm/100 MHz*<br>5G AP antenna configuration | • 64 (8x8) cross-polarized elements<br>• Element antenna gain =5 dBi<br>• ***6 degree mechanical downtilt***<br>• 16 horizontal/vertical beams with ***side-lobe control*** | • Total number of elements = 128<br>• Max AP array gain = 23 dBi<br>• Peak-to-sidelobe ratio = 30 dB |
| *EIRP = 75 dBm/100 MHz*<br>5G AP antenna configuration | • 256 (16x16) cross-polarized elements<br>• Element antenna gain =5 dBi<br>• ***6 degree mechanical downtilt***<br>• 16 horizontal/vertical beams with ***side-lobe control*** | • Total number of elements = 512<br>• Max AP array gain = 29 dBi<br>• Peak-to-sidelobe ratio = 30 dB |
| 5G AP-to-FSS (space station) pathloss model | NLoS: Free space pathloss + ***20 dB + 4 dB***<br>LoS: Free space pathloss + ***4 dB*** | • 20 dB models NLoS clutter and ***vegetation*** losses<br>• 4 dB models 1 dB atmospheric loss + 3 dB polarization loss |
| 5G AP TX power | ***39 dBm/100 MHz/per sector (EIRP = 62 dBm/100 MHz)***<br>***46 dBm/100 MHz/per sector (EIRP = 75dBm/100 MHz)*** | |

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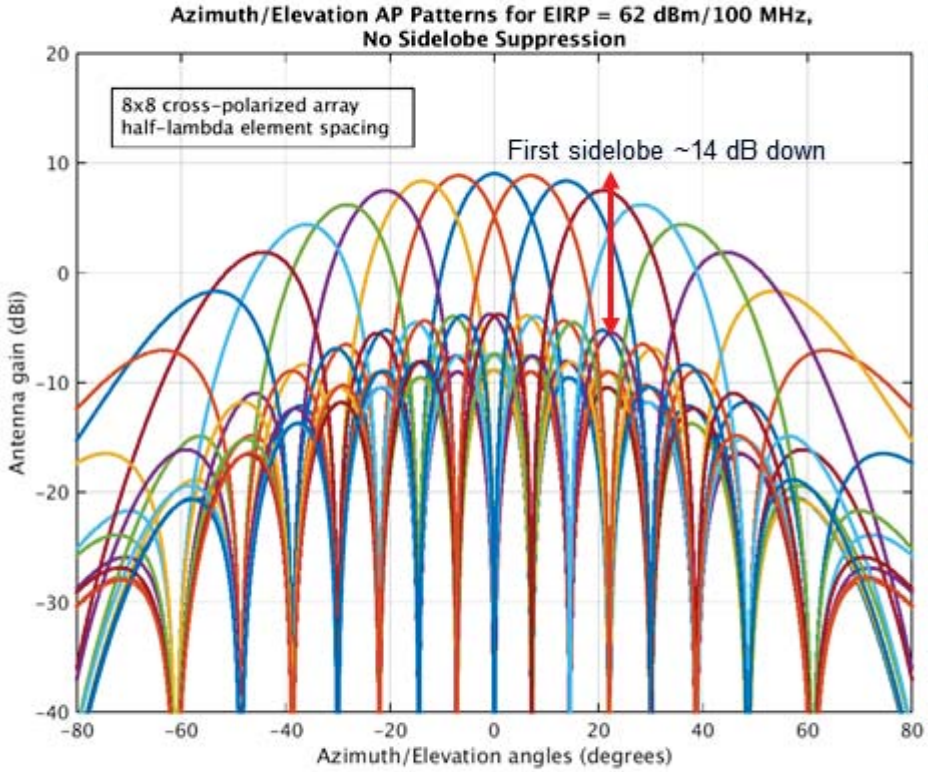
# 5G AP Beam Patterns, EIRP = 62 dBm/100 MHz, No Sidelobe Suppression




64 cross-polarized elements (8x8)
TX power per cross-polarized element = 21 dBm/100 MHz
Element antenna gain = 5 dBi
Max AP array gain = 9 + 9 + 5 = 23 dBi
Max EIRP = 21 + 10*log10(64) + 23 = 62 dBm/100 MHz
16 horizontal and elevation beams used for steering to the UEs

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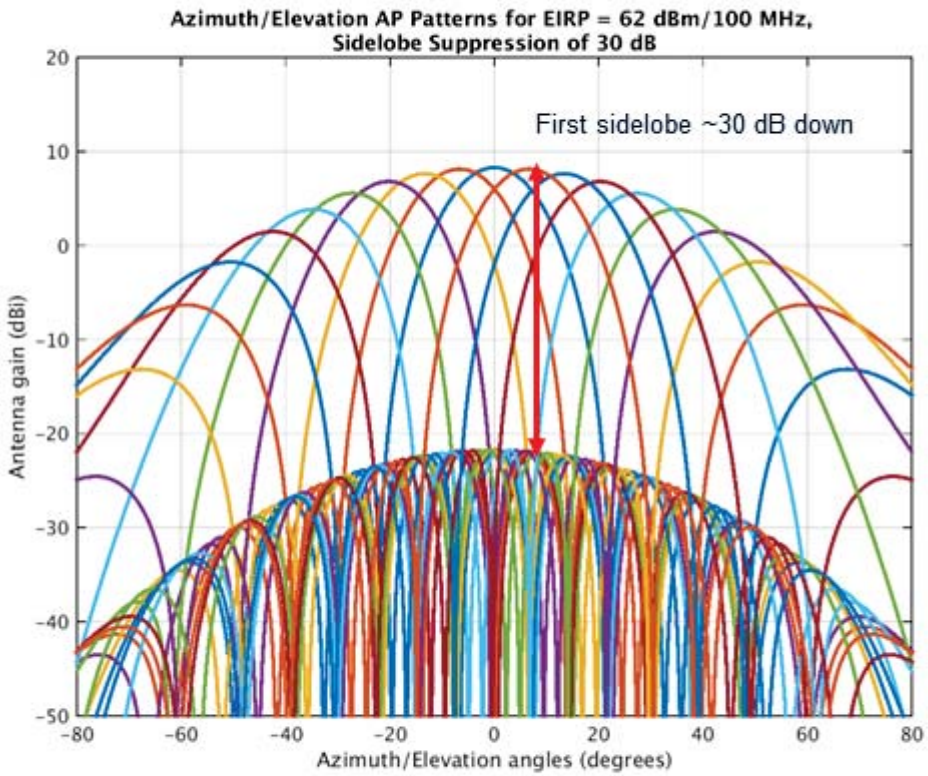
# 5G AP Beam Patterns, EIRP = 62 dBm/100 MHz, 30 dB Sidelobe Suppression




64 cross-polarized elements (8x8)
TX power per cross-polarized element = 21 dBm/100 MHz
Element antenna gain = 5 dBi
Max AP array gain = 9 + 9 + 5 = 23 dBi
Max EIRP = 21 + 10*log10(64) + 23 = 62 dBm/100 MHz
16 horizontal and elevation beams used for steering to the UEs
Chebychev window used for sidelobe suppression

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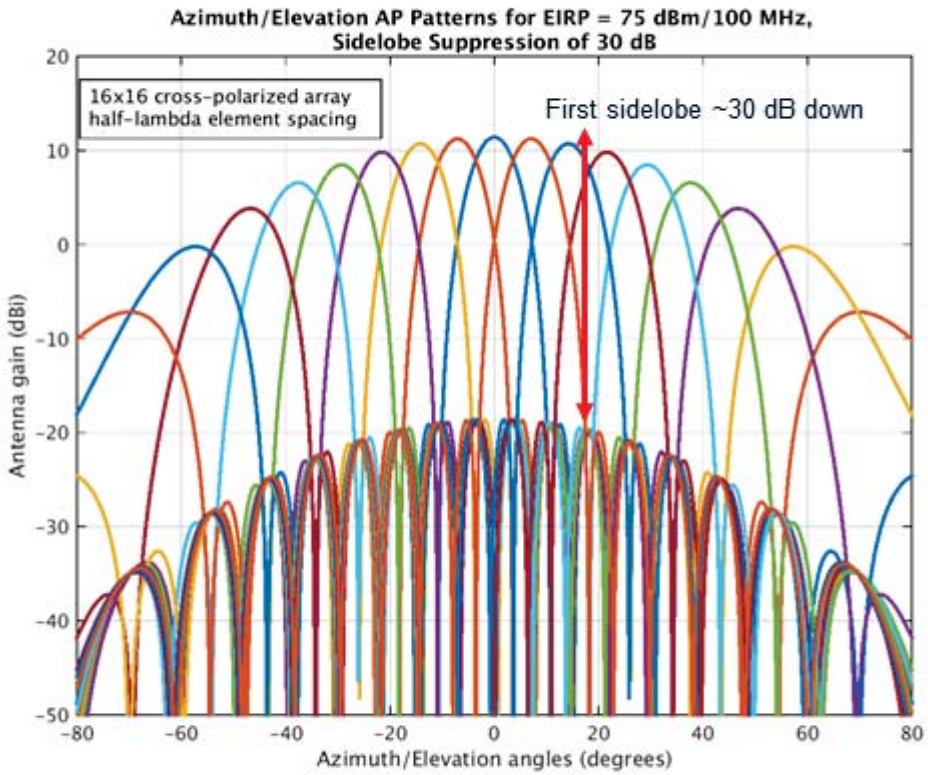
# 5G AP Beam Patterns, EIRP = 75 dBm/100 MHz, 30 dB Sidelobe Suppression




256 cross-polarized elements (16x16)
TX power per cross-polarized element = 22 dBm/100 MHz
Element antenna gain = 5 dBi
Max AP array gain = 12 + 12 + 5 = 29 dBi
Max EIRP = 22 + 10*log10(256) + 29 = 75 dBm/100 MHz
16 horizontal and elevation beams used for steering to the UEs
Chebychev window used for sidelobe suppression

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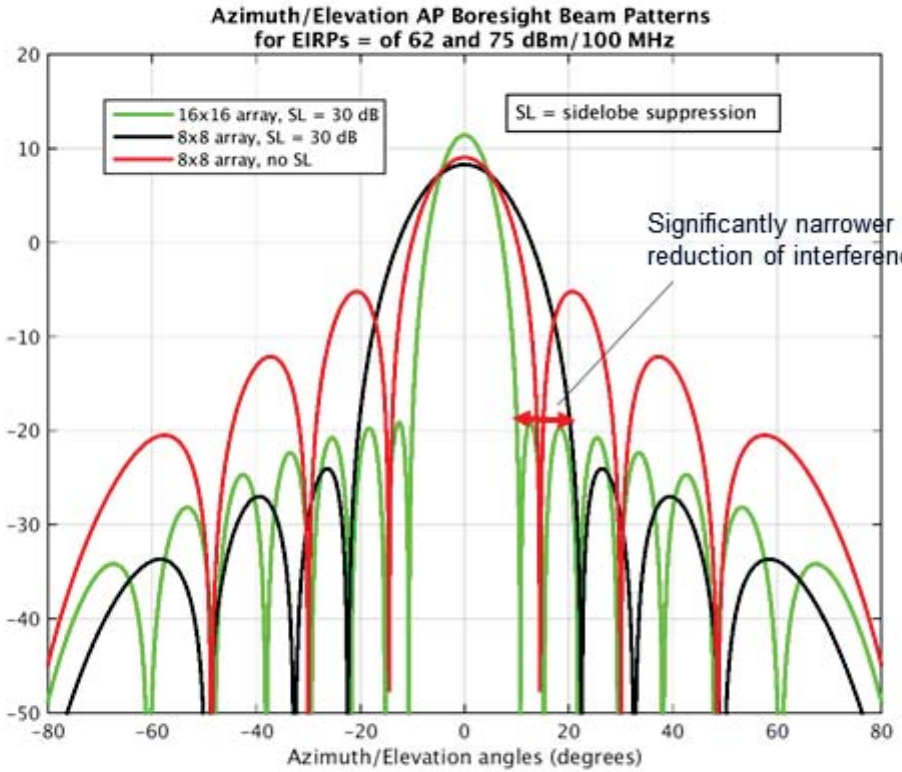
# 5G AP beam boresight patterns, EIRP = 62 and 75 dBm/100 MHz




Significantly narrower main beam with 16x16 array– reduction of interference in the elevation angle range of 10 to 25 degrees

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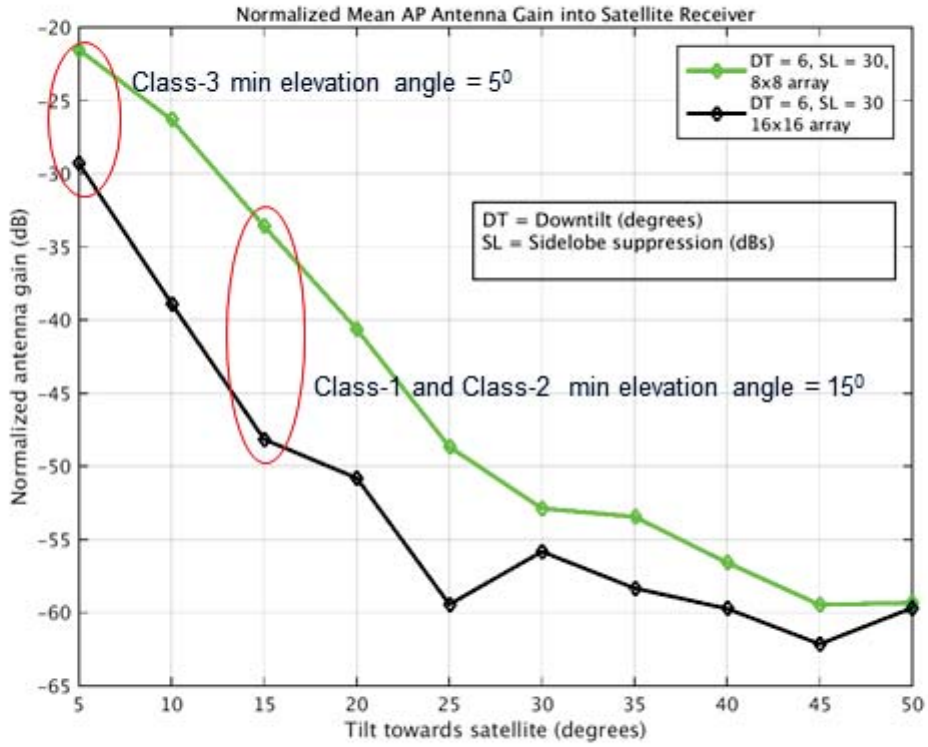
# Mean 5G AP antenna discrimination vs. elevation angle

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