May 6, 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"), Nokia ("Nokia"); Samsung Electronics America ("Samsung"), T-Mobile USA, Inc. ("T-Mobile") and Verizon ("Verizon" and, with AT&T, Nokia, Samsung and T-Mobile, the "Joint Filers") submit this *ex parte* letter in the above-captioned proceedings to summarize the results of a detailed, but preliminary, simulation conducted by Nokia to assess potential interference between terrestrial mobile broadband (fifth generation or "5G") and Fixed Satellite Service ("FSS") systems sharing the 28 GHz band.[1] As discussed below, the simulation demonstrates 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.

Background

While the FCC has encouraged FSS licensees and the mobile industry to cooperatively develop sharing proposals for the 28 GHz band, the technical analysis of co-existence between FSS systems and 5G networks submitted to the FCC to date has been relatively simplistic and worst

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

case and does not provide a sound engineering basis upon which to make policy decisions with respect to sharing. As an initial matter, both O3b Networks ("O3b") and ViaSat, Inc. ("ViaSat") submitted studies that used satellite protection margins of -12.2 dB for purposes of their calculations, instead of using actual signal-to-interference-plus-noise ratios for the deployed systems.[2] The -12.2 dB criteria is presumably derived from Recommendation ITU-R S.1432, which was developed by ITU-R Working Party 4A in 2000. Recommendation S.1432 specifies a 6% ΔT/T interference allowance (equivalent to a -12.2 dB interference–to-noise ratio ("I/N")) for co-primary services, which is also the coordination trigger between satellite networks in Article 5 of the Radio Regulations. There is, however, general recognition in the satellite community that this interference level was developed when satellite networks were considered to be power limited, whereas today satellite networks tend to be interference limited and, as such, this protection level is very conservative.[3] Indeed, ITU-R S.1432 specifies portions of the aggregate interference budget that should be allotted to the different sources of interference for a FSS system operating below 15 GHz: interference from other FSS systems (25% or 20% depending on if the victim system uses frequency re-use or not), from systems having co-primary status (6%) and from all other sources (1%). The tolerance limit for interference from other FSS systems is thus 20-25% and not 6%. So S.1432 effectively uses different criteria for different systems and would allocate a total of 27% to 32% of clear-sky noise for interference.

To put the use of a -12.2 dB I/N protection margin into perspective, the Joint Filers have reviewed the link budgets for some of the Ka-band satellite applications submitted to the FCC for operating, or soon to be operating, satellites,[4] in particular looking at the uplink portion of the link budget for gateway type uplinks. As shown in *Table 1* below, looking at intra-system interference and adjacent satellite interference ("ASI"), the overall I/N ratios on the uplink for these systems are all well above the -12.2 dB criterion used in the studies already submitted to the FCC—in one case by over 20 dB.

[2] *See* "Interference analysis between O3b FSS earth stations and mmW MS/FS stations operating in the 28 GHz," Attachment, Filing by O3b Networks, GN Docket No. 14-177 (Mar. 24, 2016) at Table 3, p. 2 ("*O3b Study*"); available at: http://apps.fcc.gov/ecfs/comment/view?id=60001519678 (last visited May 2, 2016); *Ex Parte* Notice of ViaSat, Inc., GN Docket No. 14-177 (Apr. 21, 2016) at Att. 1, Table 1, p. 1 ("*ViaSat Study*"); available at: http://apps.fcc.gov/ecfs/comment/view?id=60001654895 (last visited May 2, 2016).

[3] *See* Section 5/9.1.2/3.1.1 of CPM report to WRC-15.

[4] All the numbers in the table came either directly from the link budgets included with the FCC application or were derived directly from those link budgets. See FCC applications for call signs S2902, S2181, S2917, S2180, S2834, S2472, and S2747 for networks Viasat-2 through Viasat-1, respectively.

System	Location (°W. L.)	Frequency Band[5]	$C/N_{thermal}$ up (dB)	$C/I_{intra-system}$ up (dB)	C/I $_{up}$, ASI (dB)	Overall C/I_{up} (dB)	Overall I/N_{up} (dB)
Viasat-2	69.9	28.1-29.1 GHz	18.2	25.5	18.9	18.0	0.2
AMC-16	85	28.4-28.6 GHz					6.96 - 0.69
Viasat 89W	89	28.1-29.1 GHz	18.2	25.5	18.9	18.0	0.2
Jupiter 1	107.3	28.35-28.6 GHz	22.8	20.8	19.6	17.1	5.7
AMC-15	105.5	28.4-28.6 GHz					2.99 - 8.45
Jupiter 1	107.3	28.35-28.6 GHz	22.8	20.8	19.6	17.1	5.7
Anik F2	111.1	Inc. 28.35-28.6 GHz	16.9			15.6	1.3
Viasat-1	115.1	28.1-29.1 GHz	12			13.1	-1.1

Table 1: Comparison of Overall Uplink I/N for Gateway type Links for Representative Systems

The O3b and ViaSat interference studies also suffer from other inconsistencies and technical limitations. Both, for example, utilize a boundary limit of 47 dBμV/m to determine the potential for FSS to 5G interference, but ViaSat uses a 5.5 MHz bandwidth to determine the boundary limit per megahertz while O3b uses a bandwidth of 100 MHz.[6] Perhaps most troubling, both of the studies assume different, and more lenient, levels of protection to safeguard UMFU operations against FSS interference, as opposed to the very stringent protection threshold applied to their own FSS systems.

Nokia's FSS/UMFU Co-Existence Simulation

To establish a more analytical framework for future discussions, Nokia has conducted a detailed, but preliminary, simulation of interference effects between 5G and FSS systems in 28 GHz. Preliminary results were presented to interested members of the Satellite Industry Association ("SIA") on April 29th, although the attached study incorporates some additional refinements undertaken over the past week. Two scenarios were simulated –

- Scenario 1 — Emissions from different classes of satellite uplink earth stations into 5G base station receivers on the ground

- Scenario 2 – Aggregate emissions from 5G base stations on the ground into the uplink receivers at the GSO and NGSO satellites

The results of each of these scenarios (using three categories of earth stations that were defined by SIA for Nokia) are summarized below and discussed in greater detail in the attached appendix, along with simulation assumptions and methodology.[7] It should be emphasized,

[5] This does not represent all frequency bands in the FCC application for the systems listed, only those that overlap with the 27.5-28.35 GHz band or are in the immediate vicinity of that frequency band. As such, it is believed these should still be representative.

[6] *O3b Study* at p. 2; *ViaSat Study* at Attachment 2, p. 2.

[7] For purposes of its simulation, Nokia defined certain earth station classes based on parameters provided by SIA. Nokia defined Class 1 earth stations as having a 30º elevation angle with a 36,000 kilometer orbit distance and a 60

however, that these results are preliminary. Nokia anticipates that the simulation will continue to be refined to incorporate some additional criteria and further input from carriers, manufacturers, and the satellite community.

Scenario 1 (FSS to UMFU) - Results and Discussion

Based on its simulation, Nokia determined that, at any reasonable protection margin, the required separation distances between existing FSS earth stations and the "edge" of the 5G system is manageable—at a reasonable protection margin of -6 dB I/N, the distance where less than 5% of links fall below the protection threshold (the criteria used to establish the cell edge for purposes of 3GPP calculations) is less than 400 meters for Class 2 earth stations and less than 50 meters for Class 1 earth stations. On that basis, the Joint Filers believe co-existence with existing FSS earth stations could be addressed through adoption of a PFD limit on FSS licensees requiring those earth stations to meet a PFD, at 10 meters above ground level, of -77.6 $dBm/m^2/MHz$ at 200 meters.[8] It is relatively self-evident that this should not be problematic for either existing Class 1 or Class 2 earth stations, but the Joint Filers also submit that compliance for existing Class 3 earth stations is readily achievable. While Nokia's calculations show that Class 3 earth stations nominally could interfere with 5G systems at a distance of 28 kilometers using a -6 dB I/N, there are several reasons to believe that distance is vastly overstated. First, the separation distance for existing Class 3 earth stations is defined by instances where the antenna is oriented directly at the horizon—an azimuth of operation that occurs only as the NGSO satellites "rise" or "set." Because interference at the horizon could be addressed with some manmade or environmental shielding, compliance should be readily achievable. Second, the free space path loss used in the Nokia model is not accurate at all distances. Nokia plans to refine its calculations using more realistic models that are based on ongoing work in 3GPP regarding 5G base station ("BS")-to-BS interference. In any event, the limited number and rural locations of existing Class 3-type earth stations would not significantly impact 5G deployment.

Scenario 2 (UMFU to FSS) - Results and Discussion

For aggregate 5G interference into existing FSS receivers, Nokia evaluated FSS protection criteria (*i.e.*, $I_{5G}/N_{thermal}$) at -12.2 dB, -6 dB and 0 dB, using noise temperatures of 650K and 1000K. Nokia used the SIA-provided parameters defined for Class 1, 2, and 3 earth stations to create a cumulative distribution function ("CDF") of relative 5G BS-into-FSS space station

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dBi antenna gain at the space station. For Class 2 earth stations, Nokia used similar parameters, but with a 14.6º elevation angle. For Class 3, Nokia used a 5º elevation angle, a 1000 km orbit distance, and 30 dBi space station antenna gain. *Nokia Simulation* at 6.

[8] This PFD limit was derived at 28 GHz based on an I/N margin of -6 dB, a receiver noise figure of 5 dB, 3 dB of implementation margin and a 16 dBi 5G receiver antenna gain which is lower than the maximum antenna gain of 23dBi assumed in the simulation. A lower antenna gain is typically computed in the simulation towards the earth station since the receive beam is pointed in the direction of the transmitting UE, and it is statistically unlikely to coincide with the direction towards the earth station. While the 200 m area is smaller than the zone calculated by Nokia, existing earth station licensees should also be able to utilize natural or manmade shielding to achieve the required PFD.

antenna gain in dB, and the number of simultaneously transmitting 5G sectors that could be within the spot beam of the space station. The mix of stations was also varied from purely "rural" systems to dense "urban" systems with varying mixes of outdoor (line-of-sight or "LOS") and non-line-of-sight ("NLOS") paths between the BSs and the FSS system. While Nokia varies the mix of LOS/NLOS sites between 0 and 100%, the more extreme assumptions regarding a large percentage of LOS sites appears unrealistic given real-world vegetation/foliage losses and likely 5G deployment cases. Therefore, only a more realistic subset of LOS/NLOS combinations is reported in Table 5 of the *Nokia Simulation*.

Importantly, Nokia's study uses SIA-provided parameters that are very conservative in a number of respects. As an initial matter, the satellite noise and receive beam gain figures are based on the most sensitive projections about *future, planned* satellite network deployments, not necessarily satellite networks that currently exist. Thus, it is unclear whether the SIA parameters are realistic in an environment where a mere 3 dB difference in the receiver sensitivity and FSS antenna gain can change the aggregate interference results by a factor of 2. As an example, the SIA-supplied parameters for Class 3 earth stations used a satellite orbital distance of approximately 1,000 km, even though the closest deployed system has an orbital distance of 8,062 km.[9] Incorporating the actual deployed system orbital distance would increase, by a factor of 63, the number of simultaneously active BS sectors within the spot beam for Class 3 systems. It is also critical to understand that the sensitivity of the satellite system to 5G aggregate interference also correlates with a smaller spot beam size. Because 5G BSs outside the spot beam are irrelevant, a smaller number of simultaneously active BS sectors in the table may not accurately represent the potential impact of widespread 5G deployment—a Class 3 FSS satellite at an orbital distance of 8,062 km with 30 dBi would have a coverage area at nadir of approximately 500,000 km^2, while a Class 1 FSS satellite with 57 dBi covers 20,000 km^2, roughly 1/25th the area.

If Nokia's simulation reveals anything, it is that aggregate impact is highly sensitive to system protection criteria, receiver sensitivity, and propagation loss assumptions. Changing the I/N from -12.2 dB to -6 dB and then to 0 dB results, respectively, in four-fold and sixteen-fold increases in the number of BS sectors that can be active. And, as shown in Table 5 of preliminary results, even factoring in a limited 12 degrees of 5G antenna down tilt and some sidelobe suppression radically increases the number of possible active BS sectors—for the Class 1 case using 50/50 LOS/NLOS, a -6 dB I/N and a noise temperature of 650K, the number of active BSs goes from approximately 3,200 to over 45,000.

In addition, we note that all 5G BS sectors simultaneously transmitting is a condition unlikely to occur in real world networks. In fact, in current deployments, network loading rarely exceeds 30%, thus allowing a roughly three-fold increase in the number of sites deployed without adversely impacting satellite links. Similar loading factors, in fact, were used in AWS-3 co-ordination discussions. Second, the results only consider outdoor deployments, because indoor 5G BSs will not contribute to aggregate interference impacts towards the FSS receiver. Finally,

[9] *See O3b Study* at p. 1, n. 1.

the study is assuming that all base stations are synchronized and analyzes interference during a time-division duplexing period when all base stations are in transmit mode. If spectrally- or geographically-adjacent operators are not synchronized, it would mean that some percentage of the deployed base stations are not operating in transmit mode and, instead, user equipment is likely to be radiating in those areas. While Nokia intends to conduct further modeling of the impact of user equipment on FSS receivers, it is generally acknowledged that user equipment has a much smaller impact on FSS receivers than base station transmissions, and therefore an unsynchronized collection of licensees would present a more favorable interference case than what Nokia has modeled.

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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Attachment 1: FSS and UMFU Coexistence Simulations

1. Fixed Satellite Service (FSS) into Upper Microwave Flexible Use (UMFU) Base Station (BS) Interference Simulation

In the following analysis, interference level from an FSS Earth Station transmitter, located a certain distance from a 5G system deployment, is considered at a 5G Base Station receiver. The analysis is based on a certain link-level protection criterion which is characterized as an FSS interference-to-thermal noise ratio (I/N) observed at the Base Station receiver. Specifically, link-level protection criteria of -12.2, -6 and 0 dB I/N were considered in the study. Starting with the link-level protection criterion, a 5G system level protection criterion is defined as the minimum distance between the FSS Earth Station and the "edge" of the 5G system deployment, such that 95% percent of uplink (UL) links in the cell that is *nearest* to the FSS Earth Station transmitter are protected under the link-level protection criteria defined above. The distance to the "edge" of the system deployment is defined as the minimum distance between the Earth Station transmitter and the 5G base stations in the system deployment. Figure 1 illustrates an example of the 5G system layout and the definition of the minimum protection distance. The parameters used in system simulations are outlined in Table 1. The system is laid out according to the 3GPP Urban Micro (UMi) scenario [1], with User Equipment (UE)-to-Base Station pathloss values computed at 28 GHz.

The details of the UL interference calculations are as follows. For each UE in the system, an elevation and azimuth beam is activated to receive the intended UL transmission based on the preferred azimuth and elevation beam index feedback from the UE to its serving Base Station. Each UE selects its preferred elevation and azimuth beam from the elevation and azimuth codebook based on the long-term receive power measurements obtained for all beams in the codebooks. For the results reported here, a Discrete Fourier Transform (DFT)-based codebook with 16 entries was used for beam selection in the azimuth and elevation dimensions. The elevation and azimuth patterns are symmetric and displayed in Figure 2. Given the preferred azimuth and elevation beam, the interference for each UL UE is computed according to:

$$I_{FSS} = EIRP_{FSS} - PL_{FSS-to-5G} + G_{DFTaz} + G_{DFTele} + G_{FSSaz},$$

where:

> $EIRP_{FSS}$ is the EIRP of the FSS transmitter towards the horizon,
>
> $PL_{FSS-to-5G}$ is the pathloss between the FSS Earth Station and the 5G Base Station, computed as free-space pathloss (FSPL) plus additional 20 dB of clutter losses,
>
> G_{DFTaz} and G_{DFTele} are the azimuth and elevation beamforming gains in the direction of the FSS Earth Station of the azimuth and elevation beams selected to receive the intended UE transmission at the BS,
>
> G_{FSSaz} is the azimuth pattern gain of the FSS Earth Station in the direction of the "victim" 5G Base Station.

Note that G_{DFTaz} and G_{DFTele} are lower than the maximum azimuth and elevation beamforming gains, since the beams in general are pointed away from the FSS Earth Station when receiving transmissions from UEs distributed randomly in the azimuth plane and at a lower elevation than the 5G Base Station.

The “victim” Base Station is defined as the station that is closest to the Earth Station transmitter. The assumed azimuth pattern of the FSS Earth Station is shown in Figure 3 [2]. Note that the azimuth pattern is normalized to 0 dBi maximum gain since the azimuth antenna gain of the FSS Earth Station is already accounted for in the $EIRP_{FSS}$ value. For the interference analysis, three classes of FSS Earth Stations were considered: Class 1 with $EIRP_{FSS}$ of 12.2 dBm/MHz, Class 2 with $EIRP_{FSS}$ of 24.1 dBm/MHz, and Class 3 with $EIRP_{FSS}$ of 48 dBm/MHz, as provided by Satellite Industry Association (SIA).

Given a certain $EIRP_{FSS}$ level and positioning of the Earth Station relative to the 5G system layout, an interference level is calculated for all UEs attached to the “victim” Base Station. This calculation is then performed multiple times with randomized positions of the UEs in the system and randomized positions of the Earth Station transmitter around the 5G system layout, but with fixed distance between the edge of the 5G system and the FSS Earth Station transmitter. It is assumed that the Earth Station azimuth is always directed toward the center of the 5G system layout. The percentage of protected UL links attached to the “victim” Base Station is displayed as a function of the distance between the FSS transmitter and the 5G system edge in Figure 4 for Class 1 and Class 2, and in Figure 5 for Class 3. Given the 95% protection target, results on the minimum distance between the 5G system and FSS Earth Station transmitters are summarized in Table 2. As can be seen in the table, the required separation distance is highly dependent on the assumed protection threshold as well Earth Station $EIRP_{FSS}$ towards the 5G system. It is planned to extend this analysis by considering more sophisticated terrestrial propagation models between 5G Base Stations and FSS Earth Station transmitters, such as Urban Macro (UMa) and Rural Macro (RMa), statistical propagation models defined in [1].

2. Aggregate UMFU Base Stations Interference into FSS Space Station Simulation

In this analysis, aggregate interference from a number of simultaneously transmitting 5G Base Stations is considered at an FSS Space Station Receiver. The final output of the analysis is the number of simultaneously transmitting base stations such that the interference threshold at the FSS Space Station is not violated. Interference thresholds of -12.2 dB, -6 dB and 0 dB I/N at the FSS Space Station Receiver are considered in this study. Furthermore, three classes of Space Station receivers are considered in this study, with their parameters summarized in Table 3, as provided by SIA. To compute aggregate interference into the Space Station receiver, an average interference level from a single Downlink (DL) sector transmission is computed via simulations by averaging over all DL transmissions in the 5G system layout shown in Figure 1. For a given DL transmission to an UE, the interference generated into the FSS Space Station receiver is given as follows:

$$I_{5G} = EIRP_{5G} - PL_{5G-to-SS} + G_{DFTaz\_norm} + G_{DFTele\_norm} + G_{SS\_3dB},$$

where:

$EIRP_{5G}$ is the EIRP of the 5G Base Station transmitter,

$PL_{5G-to-SS}$ is the pathloss between the 5G Base Station and the Space Station receiver,

G_{DFTaz_norm} and G_{DFTele_norm} are the normalized azimuth and elevation beamforming gains in the direction of the Space Station receiver of the DFT beams selected for DL transmissions to the UE,

G_{SS_3dB} is the gain of the Space Station antenna within its 3dB-contour.

Thus, it is assumed that the entire 5G system deployment falls within the 3dB-contour of the Space Station receiver. The transmit beam gains are normalized to 0 dBi gain since the Base Station EIRP already accounts for the beamforming gain of the 5G Base Station. Note that G_{DFTaz_norm} and G_{DFTele_norm} are lower than the maximum azimuth and elevation beamforming gains, since the beams in general are pointed away from the Space Station receiver when transmitting to the UEs distributed randomly in the azimuth plane and at a lower elevation than the 5G Base Station. Finally, it is assumed that the elevation direction towards the Space Station receiver from any 5G Base Station is given by the tilt angles in Table 3 per Space Station class, as provided to us by SIA. For the results, $EIRP_{5G} = 62\ dBm/100MHz$.

The average 5G DL receive power observed at the Space Station receiver is recorded in Table 4. In the table, a mix of line-of-sight (LoS) and non-line-of-sight (NLoS) channel conditions into the Space Station receiver is considered when calculating aggregate interference. In LoS conditions, FSPL model plus additional atmospheric and polarization losses of 4 dB are assumed. In the NLoS channel conditions, FSPL model is again used, with additional 20 dB of clutter loss on top of the 4 dB of atmospheric and polarization losses. Thus, the total additional losses assumed in the NLoS model is 24 dB. Table 4 reports results for two thermal noise levels at the Space Station receiver, $N_{SS_{thermal}}$ = −170.5 dBm $/\ Hz$ (satellite noise temperature of 650K) and −168.6 $dBm\ /\ Hz$ (satellite noise temperature of 1000K), and for three levels of interference protection at the Space Station receiver, $I_{5G}/N_{SS_{thermal}}$ = -12.2, -6, and 0 dB.

We note that the results in Table 4 are fairly pessimistic as it is unlikely that LoS channel conditions will occur with high probability at 28 GHz, where signal propagation characteristics are adversely affected not only by blockage due to buildings and other structures but also by vegetation.

In light of the above observation, Table 5 displays results with smaller LoS probabilities. Also, a mechanical tilt of 12 degrees is employed at the 5G base stations. Finally, a sidelobe suppression technique is applied on top of the DFT beams for improved interference control into Space Station receiver. Comparing Table 4 and Table 5, we observe dramatic increase in the number of sustained 5G Base Stations especially for Class 1 Space Station. It is planned to extend this analysis by considering aggregate interference from 5G User Equipment (UEs) into a Space Station receiver.

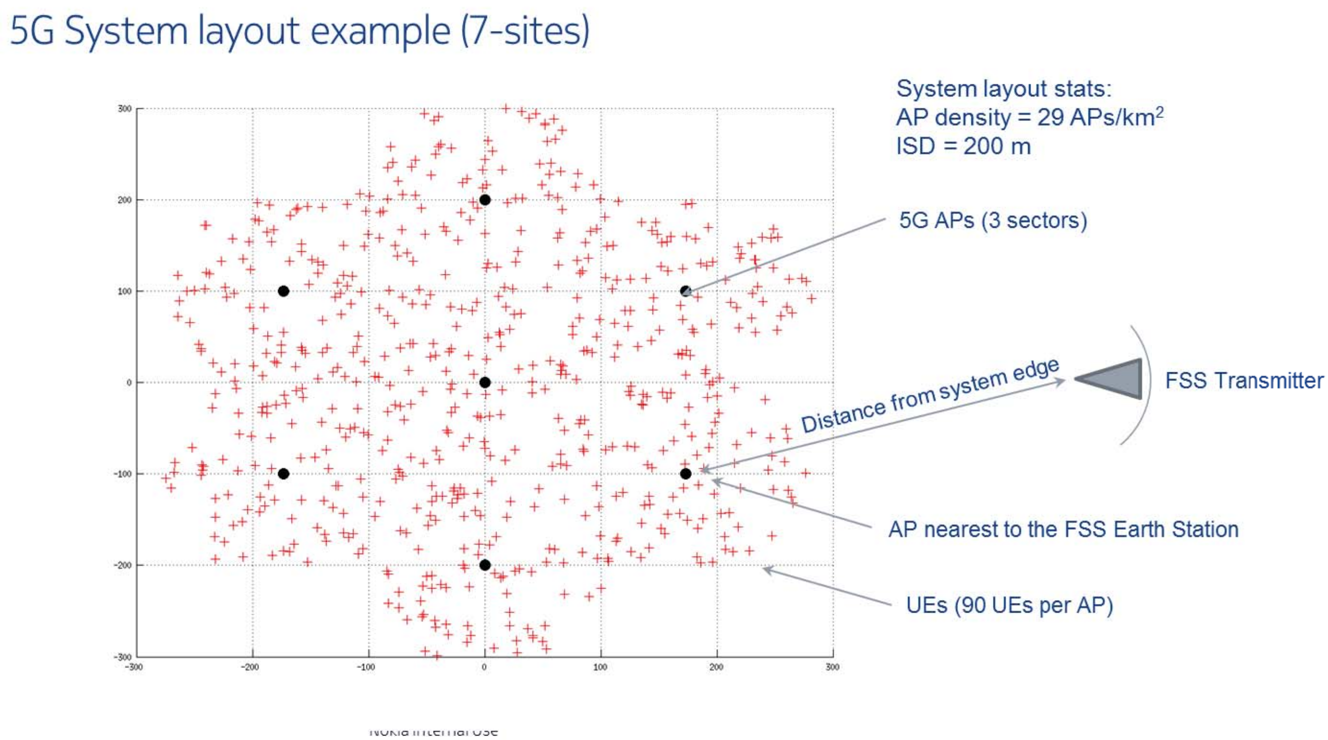

Figure 1. 5G System Deployment Example

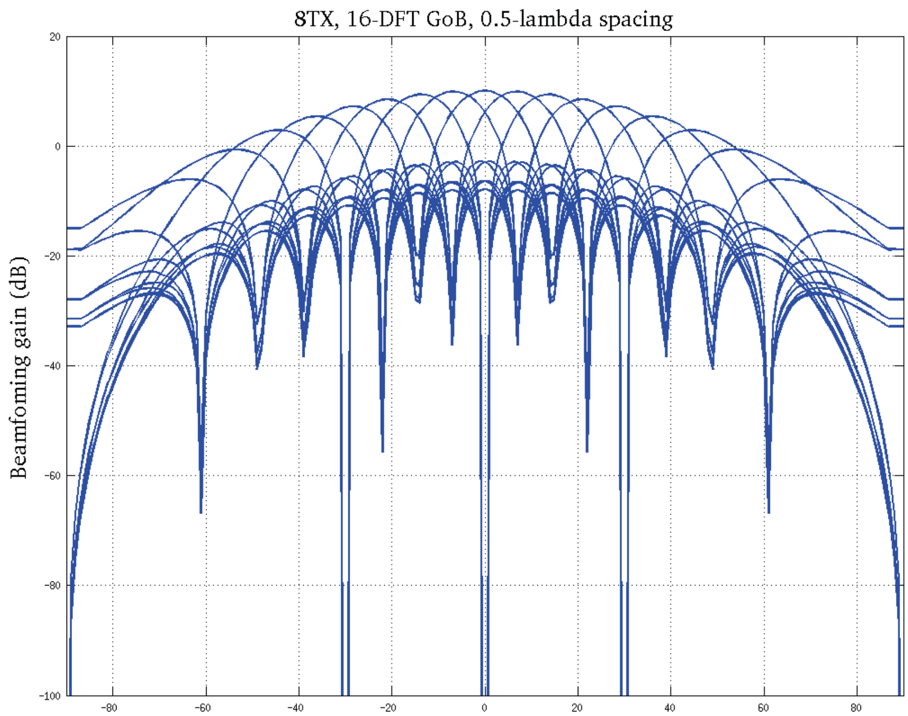

Figure 2. 5G BS DFT Codebook Beam Patterns

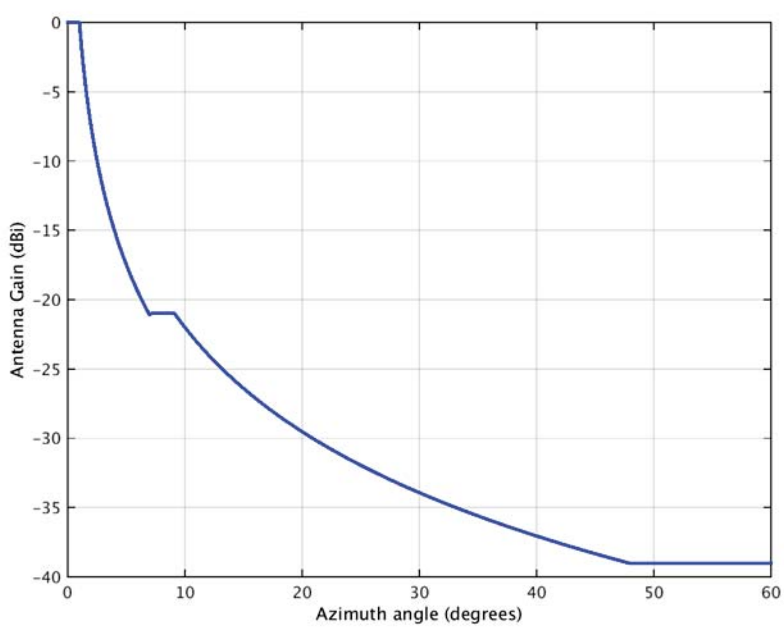

Figure 3. FSS Earth Station Azimuth Pattern

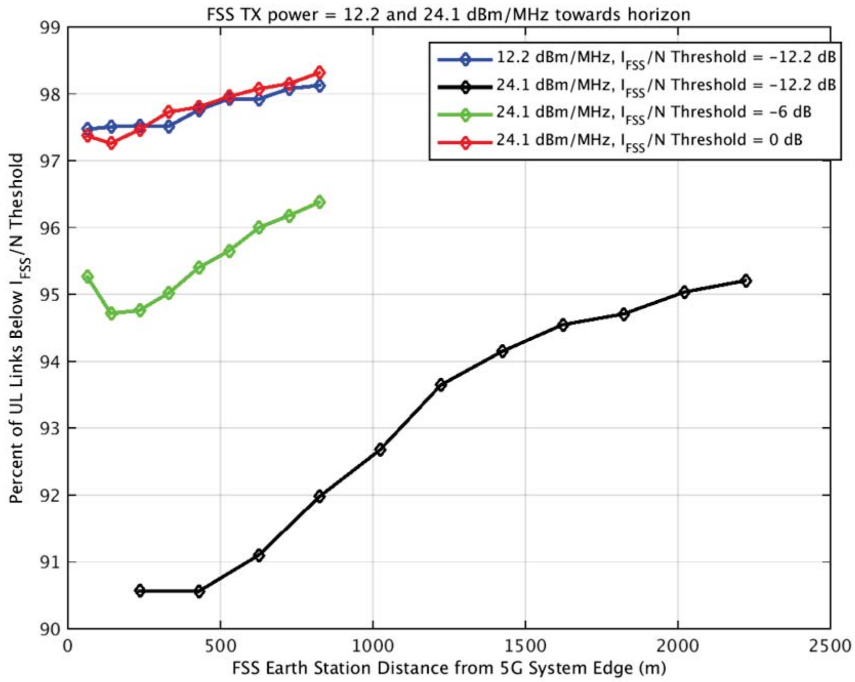

Figure 4. Percentage of Protected Links for Class 1 and Class 2 FSS Earth Station Transmitters

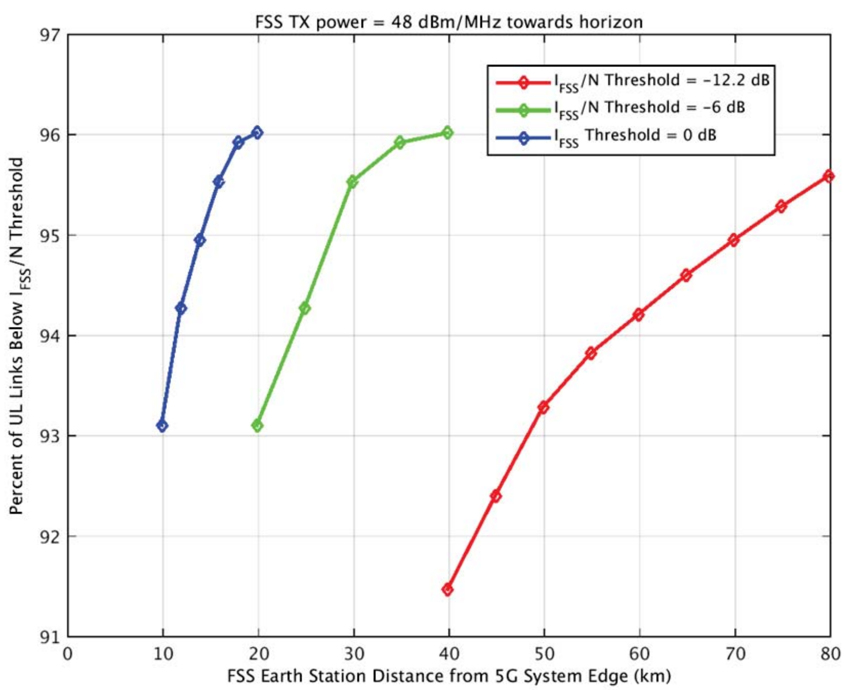

Figure 5. Percentage of Protected Links for Class 3 FSS Earth Station Transmitters

Table 2. 5G System Simulation Parameters

Simulation parameters		Comments
5G System Layout	3GPP-defined 19-site system (57 sectors), ISD = 200m	3GPP Urban Micro (UMi) scenario
5G Base Station antenna configuration	64 (8x8) cross-polarized elements Antenna element gain = 5 dBi	Total number of elements = 128 Max BS antenna gain = 23 dBi
5G UL MIMO configuration	4-bit elevation and 4-bit azimuth (16 entries) DFT codebook is used to steer the base station array	Best codebook entry per UE in elevation and azimuth is selected at the Base Station based on UE feedback
FSS-to-5G pathloss model	Free-space + 20 dB additional attenuation	
5G Base Station NF	5 dB	
5G Base Station antenna height	10m AGL	

Table 3. Required UL 5G Protection Distance Results

Earth Station Class	Required UL Protection Distance		
	-12 dB Protection Threshold	-6 dB Protection Threshold	0 dB Protection Threshold
Class 1	< 50 m	< 50 m	< 50 m
Class 2	1500 m	400 m	< 50 m
Class 3	70 km	28 km	15 km

Table 4. Space Station Parameters

Space Station Class	Parameter	Value
Class 1	Elevation angle (degrees)	30
	Orbit	36000 km
	Antenna gain in the 3 dB contour	57 dBi
Class 2	Elevation angle (degrees)	14.6
	Orbit	36000 km
	Antenna gain in the 3 dB contour	57 dBi
Class 3	Elevation angle (degrees)	5
	Orbit	1000 km
	Antenna gain in the 3 dB contour	27 dBi

Table 5. 5G into Space Station Receiver Aggregate Interference Results

Earth Station Class, 5G AP -> FSS LoS/NLoS channel mix	Average receive power (dBm/Hz) at Space Station from a single 5G sector	Number of simultaneously transmitting 5G sectors					
		NT = 650K			NT = 1000K		
		$TH = -12.2\ dB$	$TH = -6\ dB$	$TH = 0\ dB$	$TH = -12.2\ dB$	$TH = -6\ dB$	$TH = 0\ dB$
Class 1, Rural (100% LoS)	-209 dBm/Hz	~400	~1600	~6400	~600	~2400	~9600
Class 1, Urban (75% LoS/25% NLoS)	-210 dBm/Hz	~500	~2000	~8000	~800	~3200	~12800
Class 1, Urban (50% LoS/50% NLoS)	-212 dBm/Hz	~800	~3200	~12800	~1200	~4800	~19200
Class 1, Urban (25% LoS/75% NLoS)	-215 dBm/Hz	~1500	~6000	~24000	~2500	~10000	~40000
Class 1, Urban (10% LoS/90% NLoS)	-219 dBm/Hz	~3700	~14800	~59200	~5800	~23200	~92800
Class 2, Rural (100% LoS)	-204 dBm/Hz	~130	~420	~2080	~200	~800	~3200
Class 2, Urban (75% LoS/25% NLoS)	-205 dBm/Hz	~170	~680	~2720	~270	~1080	~4320
Class 2, Urban (50% LoS/50% NLoS)	-207 dBm/Hz	~250	~1000	~4000	~400	~1600	~6400
Class 2, Urban (25% LoS/75% NLoS)	-210 dBm/Hz	~500	~2000	~8000	~800	~3200	~12800
Class 2, Urban (10% LoS/90% NLoS)	-214 dBm/Hz	~1200	~4800	~19200	~1800	~7200	~28800
Class 3, Rural (100% LoS)	-208 dBm/Hz	~320	~1280	~5120	~500	~2000	~8000
Class 3, Urban (75% LoS/25% NLoS)	-209 dBm/Hz	~420	~1680	~6720	~660	~2640	~10560
Class 3, Urban (50% LoS/50% NLoS)	-211 dBm/Hz	~630	~2520	~10080	~1000	~4000	~16000
Class 3, Urban (25% LoS/75% NLoS)	-214 dBm/Hz	~1200	~4800	~19200	~2000	~8000	~32000
Class 3, Urban (10% LoS/90% NLoS)	-218 dBm/Hz	~2900	~11600	~46400	~4600	~18400	~73600

Table 6. Improved 5G into Space Station Receiver Aggregate Interference Results

Earth Station Class, 5G AP -> FSS LoS/NLoS channel mix	Average receive power (dBm/Hz) at Space Station from a single 5G sector	Number of simultaneously transmitting 5G sectors					
		NT = 650K			NT = 1000K		
		$TH = -12.2\ dB$	$TH = -6\ dB$	$TH = 0\ dB$	$TH = -12.2\ dB$	$TH = -6\ dB$	$TH = 0\ dB$
Class 1, Rural/Urban (50% LoS/50% NLoS)	-223 dBm/Hz	~11300	~45200	~180800	~17900	~71600	~286400
Class 1, Urban (25% LoS/75% NLoS)	-226 dBm/Hz	~22500	~90000	~360000	~35600	~142400	~569600
Class 1, Urban (10% LoS/90% NLoS)	-230 dBm/Hz	~56600	~226400	~905600	~89700	~358800	~1435200
Class 2, Rural/Urban (50% LoS/50% NLoS)	-213 dBm/Hz	~1100	~4400	~17600	~1700	~6800	~27200
Class 2, Urban (25% LoS/75% NLoS)	-216 dBm/Hz	~2300	~9200	~36800	~3600	~14400	~57600
Class 2, Urban (10% LoS/90% NLoS)	-220 dBm/Hz	~5700	~22800	~91200	~9000	~36000	~144000
Class 3, Rural /Urban(50% LoS/50% NLoS)	-211 dBm/Hz	~700	~2800	~11200	~1100	~4400	~17600
Class 3, Urban (25% LoS/75% NLoS)	-214 dBm/Hz	~1400	~5600	~22400	~2200	~8800	~35200
Class 3, Urban (10% LoS/90% NLoS)	-218 dBm/Hz	~3600	~14400	~57600	~5700	~22800	~91200

3. Reference

[1] 3GPP TR 36.873 V12.2.0 (2015-06), Study on 3D channel model for LTE (Release 12)

[2] 47 CFR 25.209 - Antenna performance standards.