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September 25, 2017

VIA ELECTRONIC FILING

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

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

Dear Ms. Dortch:

Chris Murphy and Daryl Hunter of ViaSat, Inc. ("ViaSat"), and the undersigned, met on September 21 and 22, 2017 with Commission staff listed below.

The purpose of the meetings was to discuss the report prepared by Roberson and Associates, LLC, enclosed as Attachment A, demonstrating the ability of small satellite earth station uplinks in the 47.2-48.2 GHz and 50.4-52.4 GHz band segments to coexist with terrestrial wireless operations. ViaSat also discussed the slides attached as Attachment B.

Please contact the undersigned if you have any questions regarding this submission.

Respectfully submitted,

/s/

John P. Janka
Elizabeth R. Park

Attachments

cc:
Office of Engineering and Technology (September 21)
Ronald Repasi
Bahman Badipour
Nicholas Oros

International Bureau (September 21)
Thomas Sullivan
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Kerry Murray
Jose Albuquerque
Chip Fleming

Wireless Telecommunications Bureau (September 22)
Joel Taubenblatt
Blaise Scinto
John Schauble
Matthew Pearl (by phone)

ATTACHMENT A

SPECTRUM FRONTIERS: Q/V BAND SATELLITE-5G COEXISTENCE

M. BIRCHLER, J. CHAPIN, P. ERICKSON, M. NEEDHAM & K. ZDUNEK

25 SEPTEMBER 2017

v1.0

This analysis was generated by Roberson and Associates, LLC for ViaSat.

Table of Contents:

1 EXECUTIVE SUMMARY

This analysis of a typical deployment scenario shows that small Fixed Service Satellite (FSS) Earth Stations (ES) with uplink transmissions between 47.2-50.2 and 50.4-52.4 GHz communicating with geostationary-orbit spacecraft can be located in the same urban areas as Fifth-Generation (5G) wireless Base Stations (BS) without the need for coordination.[1]

The analysis utilizes standard methodologies, parameters, metrics and models, extended and supplemented as necessary to support the specific scenario under study.

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. This metric is used to determine 99%, 98% and 95% probability geographic contours for $I_{es}/\eta_{bs} \leq -6$ dB.

The baseline confidence probability contour data has been evaluated with respect to absolute area, and also is described by way of example with respect to a specific urban region (i.e., Cook County, Illinois). The results indicate that any area where potential coexistence issues exist is very small, and the chances of such a circumstance actually arising in any given real-world deployment is extremely small.

The reported total 99% confidence probability contour area for $I_{es}/\eta_{bs} \leq -6$ dB is less than 0.0036 km^2, and the 98% contour less than 0.00042 km^2, which constitute less than 0.00009% and 0.00001% of Cook County, respectively. Furthermore, the overall probability likelihood that an individual 5G BS will actually experience $I_{es}/\eta_{bs} > -6$ dB is only 0.24% or approximately 1 chance in 416. Thus, the results of this analysis show that coexistence between FSS ESs and 5G BSs is feasible without the need for coordination.

Notably, these results are based on conservative assumptions, including path loss, use of peak side lobes (instead of actual lower values at different off-axis angles), considering only BS antennas with essentially omni-directional coverage, calculating much-higher confidence levels for received power density than commonly used, not accounting for attenuation from roof blockage, assuming all-outdoor 5G deployment, and never considering the operation of an ES at an elevation angle above a minimal value.

Moreover, the foregoing calculations do not take into account the mitigating effects of other factors, such as (i) inherent 5G BS antenna array techniques developed to allow 5G systems to cope with self-interference and interference between other 5G systems, or (ii) FSS ES physical isolation, both of which would virtually eliminate the chance of a real-world problem ever actually arising.

[1] Note: The results of this analysis depend on the characteristics of the satellite system at issue; the methodology readily could be applied to systems with other architectures or physical configurations.

2 SPECTRUM COEXISTENCE SCENARIO

2.1 Overview

This analysis provides a technical assessment for the case of a small Fixed Service Satellite (FSS) Earth Station (ES) transmitting to a spacecraft in geostationary orbit, and located near a Fifth-Generation wireless (5G) Base Station (BS). The assessment scenario under study is shown in the following figure.

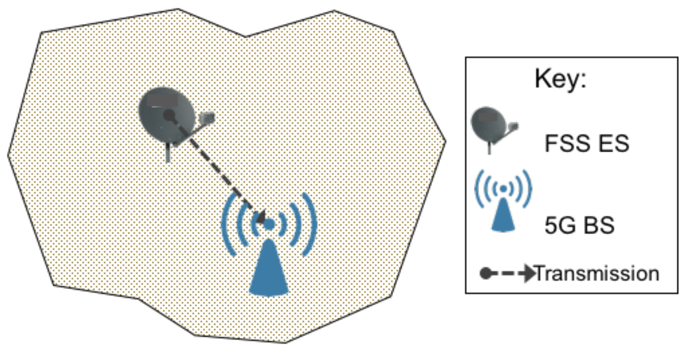

Figure 1. Spectrum Coexistence Scenario

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. The specific spectrum of interest is the Q/V bands (i.e., 47.2-50.2 and 50.4-52.4 GHz).

This assessment utilizes standard methodologies, parameters, metrics and models to the greatest possible extent. Where necessary these resources were extended/supplemented to support the specific scenario under study. Primary sources for this work can be found in [1]-[11].

The following sections describe the key components of this analysis.

2.2 FSS ES System

The information in this section on FSS ES system deployment and parameters was provided by ViaSat.

2.2.1 General Description

The FSS ES system uses an offset fed parabolic reflector antenna of approximate 1.8-meter diameter. It can be installed using ground mounts or on existing structures such as building roofs. The antenna boresight is pointed at a nominal vertical elevation angle of between 35 and 55 degrees relative to the horizon as dictated by the orbital location of the target satellite.

The power amplified (PA) output in this study is typically 7.15 milliwatts per right and left hand circular polarization for each 1 MHz of modulated bandwidth.

2.2.2 ES Antenna Pattern

To determine the ES antenna parameters needed for this study, an antenna being developed for this application was modeled by ViaSat. The design is based on a commercially available reflector. When in operation the ES antenna is pointed substantially upward in elevation and must have clear view of the sky in the direction of the target satellite. In order to assess the interaction with terrestrial 5G systems, the ES antenna gain well off the main beam is of primary interest.

The ES antenna performance data indicate that for 10 to 90 degrees from the main beam, the side lobe peaks plotted in dB as a function of angle are a straight line. This follows the process of M.1851 Table 5 [2]. Other literature (i.e., ECC PT1 #54 [3]) shows several examples of a reflector antenna with similar side lobe response. Therefore, the following side lobe mask as a function of the angular distance from the main beam is appropriate.

$$GAIN_{es}(\alpha) = -5 - \alpha/3 \quad (10^\circ \le \alpha \le 90^\circ) \qquad (1)$$

$$= -35 \quad (\alpha > 90^\circ)$$

Where:

α = the arc distance to the main beam (not defined for $\alpha < 10^\circ$)

The following figure plots the mask of Equation (1).

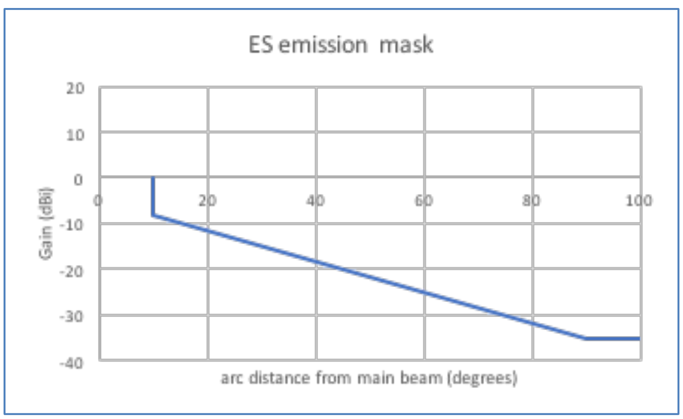

Figure 2. FSS ES Antenna Mask

The choice to use a mask matching the peaks (as opposed to the averages of the ripple) is conservative and ignores the possibility of lower sidelobes below this peak value in the final antenna design. However, this mask is more reflective of actual performance, compared with the 25.209 mask [4], which documents an upper bound regulatory limit.

2.3 5G BS System

2.3.1 General Description

The baseline deployment scenario used is described as the "Outdoor Urban hotspot" in Table 12 (Deployment-related parameters for bands between 45.5 GHz and 52.6 GHz) of [8]. These IMT-

2020 parameters were specified by the ITU [7] "to be used in sharing and compatibility studies for bands between 24.25 and 86 GHz."

- Antenna height (radiation center): 6 m (above ground level)
- Down-tilt: 10º
- Below rooftop base station antenna deployment
- Antenna polarization: Linear ±45º
- Horizontal/Vertical radiating element spacing: 0.5 of wavelength for both H/V
- 8x16 antenna array configuration

Continuing use of [8], we have selected the BS Noise Figure to be 12 dB as specified in the second table contained in Section 3 "System related parameters," column "37-52.6 GHz" (row 5.1).

2.3.2 BS Antenna Pattern

Since there are no commercial examples of 5G BS antennas in this band, a practical, conservative antenna performance model was needed. Using methods similar to M.2101 [5], the gain mask was determined from the theoretical linear array. An 8-element vertical by 16-element horizontal arrangement was assumed as it appears commonly in the literature.

The theoretical derivation of the normalized gain of a linear array is widely available. For example, [6] section 3, Equation 13.21 gives the normalized gain function with steering and uniform illumination. For this analysis, a broadside beam (i.e., no steering phase shift) with λ/2 element spacing is assumed. This results in the following equation.

$$AF_n = \frac{\sin(N\psi/2)}{N\sin(\psi/2)} \tag{2}$$

Where:

ψ	=	$\pi sin\phi$
ϕ	=	elevation angle above the main beam

Since there is a regular array of eight vertical elements, this results in the following elevation plot.

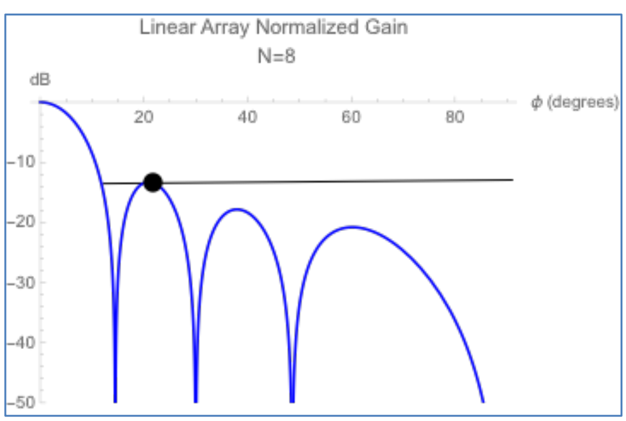

Figure 3. 5G BS Elevation Antenna Pattern

As the first side-lobe for this vertical configuration has a peak at approximately -13.3 dB, the mask was chosen to follow the theoretical value of the main lobe but limit the side-lobes to -13.3 dB. Because this analysis will be most sensitive to the sidelobe levels, the relatively small contribution of the element gain was not included. The peak gain is the product of the number of elements, so for the 8x16 array is $10\log_{10}(128)$ or 21 dB added to the normalized pattern.

In a similar manner, the horizontal gain of the 5G BS antenna is modeled based on a regular array of sixteen horizontal elements. This serves to narrow the main lobe of the pattern versus that of the vertical pattern. The relative gain in the horizontal pattern is shown in Figure 4 below for an assumed 120-degree sectored antenna. It is this pattern that will be used in determining the relative gain of the 5G BS as the antenna is rotated to different randomized orientations, per the methodology explained in Section 3.1.1. To simplify the analysis, a "block mask" of the pattern is employed, in which the relative gains of the main lobe (defined by the 3 dB beamwidth) and side lobes are constant as a function of angle. As with the elevation pattern, the relative gain in the side-lobes used in the analysis is also -13.3 dB. This approach is conservative, as it reflects the peak gains of the respective lobes, and does not factor in the lower actual gain of the side lobes and the associated nulls, as depicted in Figure 4.

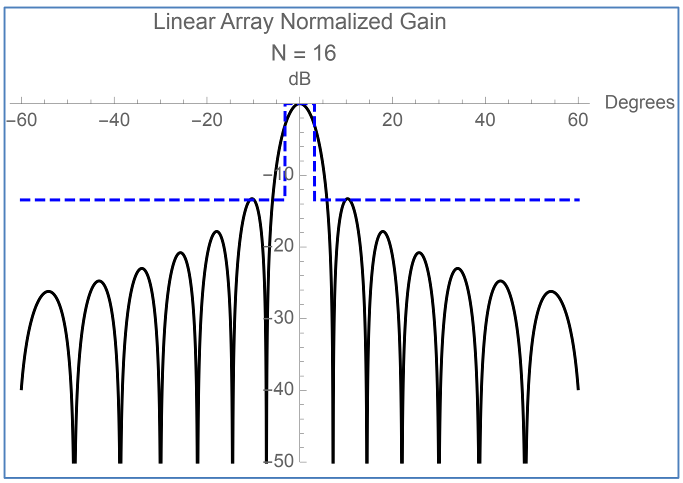

Figure 4. 5G BS Azimuthal Antenna Pattern with Block Mask

2.4 Coexistence Metric

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs} (dB). The following two sections describe the metric threshold selection and define the coexistence metric components.

2.4.1 Threshold Selection

Received power from an FSS ES is assessed as acceptable if $I_{es}/\eta_{bs} \leq -6$ dB.

The -6 dB I_{es}/η_{bs} threshold at the 5G BS demodulator input was selected to conform with an ITU Working Party 5D liaison to Task Group 5/1 for 5G system protection "*Irrespective of the number of cells and independent of the number of interferers*" [7]. This threshold is quite conservative. The 5G BS receivers are expected to be interference-limited because 5G is a multi-user system. Power received from other 5G co-channel transmissions will likely be much higher

than receiver noise power η_{bs}. Received FSS ES power at 6 dB below the noise floor will cause a negligible increase in total received undesired power given the presence of 5G co-channel transmissions. In other words, a more realistic assessment of 5G receiver performance would utilize I_{es}/I_{CO} (where I_{CO} is the co-channel, same-system interference power density), which would produce more favorable results with respect to coexistence of FSS ES and 5G BS in real-world scenarios.

2.4.2 Component Definitions

2.4.2.1 Noise Power Density

The 5G BS noise floor power density (η_{bs}) is defined as follows:

$$\eta_{bs} = -204 + NF_{bs} \quad (3)$$

Where:

η_{bs}	=	5G BS noise floor power density at the demodulator input (dBW/Hz)
-204	=	Absolute noise floor (kTB) power density (dBW/Hz)
NF_{bs}	=	Noise Figure of the 5G BS (dB)

2.4.2.2 Received Power Density

The FSS ES received power density (I_{es}) is defined as follows:

$$I_{es} = P_{T,es} + G_{es:\theta,\phi} + G_{bs:\theta,\phi} + G_{p:es,bs} - PL_{es\to bs}(d) \quad (4)$$

Where:

I_{es}	=	Received power density of the FSS ES at the 5G BS demodulator input (dBW/Hz)
$P_{T,es}$	=	Transmit power density of the FSS ES (dBW/Hz)
$G_{es:\theta,\phi}$	=	Antenna gain of the FSS ES in the azimuthal (θ) and elevation (ϕ) directions of the 5G BS (dBi)
$G_{bs:\theta,\phi}$	=	Antenna gain of the 5G BS in the azimuthal (θ) and elevation (ϕ) directions of the FSS ES (dBi)
$G_{p:es,bs}$	=	Polarization gain between the ES and BS antennas (dB)
$PL_{es->bs}$	=	Path loss between the FSS ES and 5G BS (incl. fading and deployment factors, dB)
d	=	Three-dimensional distance between the ES and BS antenna locations (m)

2.5 Propagation Model

We have implemented path loss models according to the methods described in the most recent versions of 3GPP TR 38.900 [10]. This document is largely equivalent to ETSI TR 138.900, "Study on channel model for frequency spectrum above 6 GHz" [11]. These documents describe propagation models to be used in evaluating 5G systems at frequencies from 6 to 100 GHz.

The relevant scenarios include "Urban Micro–Street Canyon" (UMi-SC) and "Urban Macro" (UMa), described in sections 6.2 and 7.2 of these documents. The UMi-SC model pertains to situations where 5G BSs are deployed below the rooftop levels of surrounding buildings, while UMa corresponds to BSs deployed above rooftop levels.

2.5.1 Median Path Loss

For the UMi-SC and UMa scenarios, the path losses are characterized in terms of sets of equations for the median path loss as functions of the 2D distance between BS and User Terminal (UT), the heights above ground of the BS and UT antennae, and the center frequency of transmission. For each of the two scenarios, there are equations for LOS and NLOS path losses (pertaining to cases where there is or is not a line-of-sight between the BS and UT antennae). Equations for the probability of being LOS are also provided for each scenario, which are a function of the 2D distance.

Values for an example set of input parameters are shown in Figure 5. Three curves are included, those being LOS, NLOS, and Combined median path loss. The Combined curve is the sum of the LOS and NLOS curves weighted by the respective probabilities of the path being LOS or NLOS.

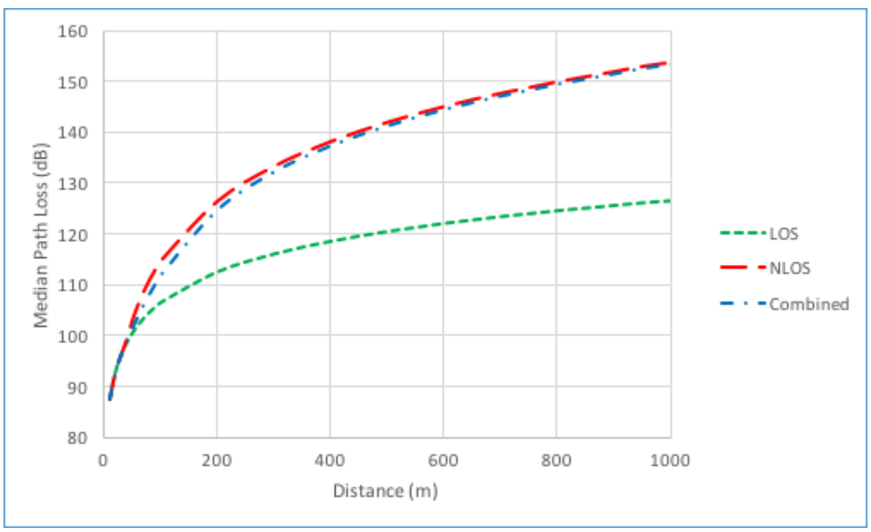

Figure 5. UMa Model Median Propagation Loss Curves

2.5.2 Log-Normal Shadowing

The models also include additive terms (in dB) to accommodate for statistical variation of the path loss to reflect location variability due to shadow fading, which is modeled according to a log-normal distribution (i.e. normal in dBs), with a specified standard deviation for each scenario and LOS/NLOS case.

Figure 6 shows example Probability Density Functions (PDFs) for a specific set of model input parameters. Three PDF curves are included, those being LOS, NLOS, and Combined path loss. The Combined curve is the sum of the LOS and NLOS curves weighted by the respective probabilities of the path being LOS or NLOS. Note that the LOS and NLOS curves have symmetric normally distributed PDFs while the Combined curve, being a weighted sum of the two constituent Normal curves, does not.

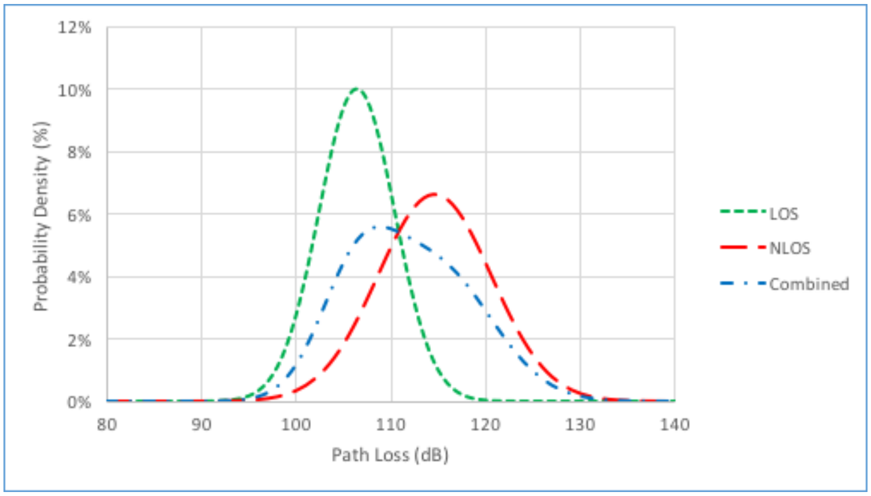

Figure 6. UMa Model Path Loss PDFs for a Given Distance

These PDFs will be used in the technical analysis to model probabilistic path loss, specifically to determine the probability that, at a given distance, the path loss will exceed the value necessary to achieve I_{es}/η_{bs}. = -6 dB.

Figure 7 shows the Cumulative Distribution Functions (CDFs) associated with the PDFs of Figure 6.

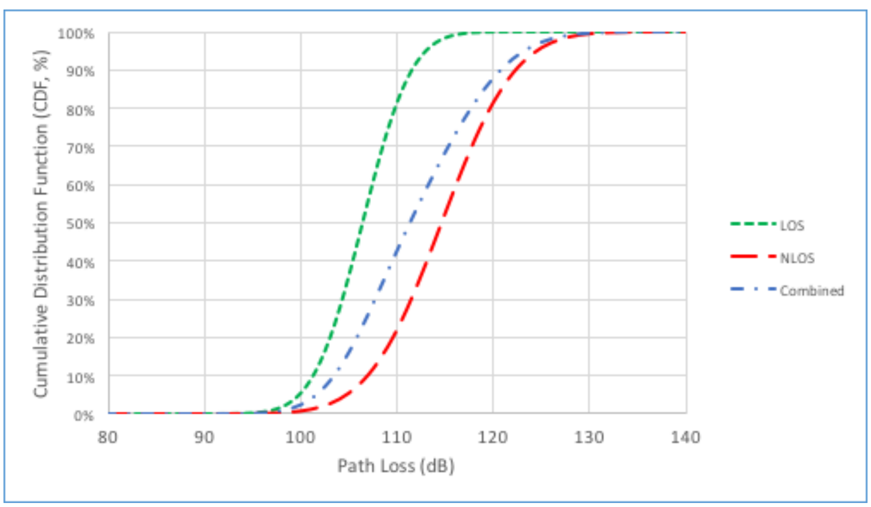

Figure 7. UMa Model Path Loss CDFs for a Given Distance

2.5.3 Path Loss Confidence Curves

The model can also be used to calculate path loss confidence curves. If a confidence value is specified, say X%, the path loss value for which there is a X% probability of being greater than or equal to as a function of distance can be determined. Figure 8 shows two path loss confidence curves (i.e., for 50% and 95% confidence values).

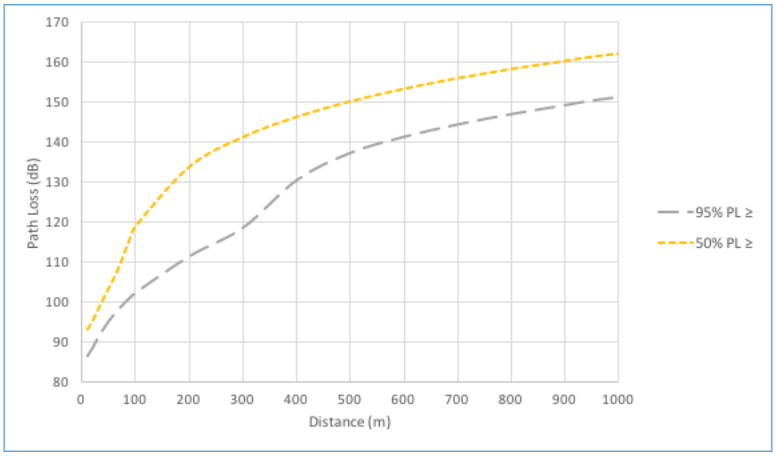

Figure 8. Example Path Loss Confidence Curves

Thus, at a distance of 500 m, there is a 50% likelihood that the path loss will be ≥ 150 dB and a 95% likelihood of being ≥ 137 dB. This path loss methodology will be used in the analysis to generate confidence curves for $I_{es}/\eta_{bs} \leq -6$ dB.

2.6 System Description

A specific instance of the system under analysis is shown in Figure 9. Note that the environment is urban. The FSS ES antenna is located on the roof of a building (height 25 m, which is the recommended value for h_{BS} in the utilized UMa propagation model [11]) that is taller than most of the surrounding structures. The 5G BS antenna is located below the rooftops of the surrounding buildings (height 6 m). The 5G BS is placed "around the corner" relative to the FSS ES building to indicate that NLOS propagation is a possible case.

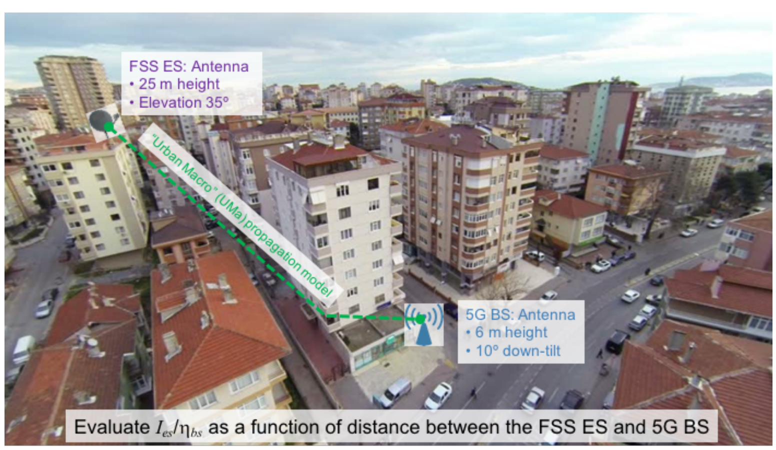

Figure 9. System Analysis Description

Additional details for the FSS ES and 5G BS characteristics/parameters can be found in sections 2.2 and 2.3, respectively.

Based on this system definition, we have selected the "Urban Macro" (UMa) propagation model [10]. The FSS ES plays the role of the "BS" and the 5G BS as the "UT" as defined in the UMa model. This is done because the UMa "BS" is defined as the device that is above surrounding rooftops while the UMa "UT" is defined to be below the rooftops.

In a LOS scenario, the highly unlikely "worst case" antenna configuration is that the boresights of both antennas are directly pointed at one another. We will allow the BS to be located along the full 360° around the fixed (in elevation and azimuth) ES. At each BS location, we will evaluate performance over the 360° range of random azimuthal BS antenna orientations.

3 TECHNICAL ANALYSIS

3.1 Methodology

3.1.1 General Overview

Figure 10 shows a simplified view of the analysis methodology. Recall that we have previously specified necessary system parameters such as antenna heights, elevation angles, etc., which are assumed to be in place.

We evaluate the possibility that the 5G BS may be placed at different locations around the FSS ES, while the ES is at a fixed location with a fixed antenna direction. The angle θ is used to denote the angle of the BS's location with respect to the ES; θ is defined to be 0° when the 5G BS is located in the azimuthal direction of the boresight of the FSS ES antenna.

Additionally, the azimuthal direction of the antenna of the BS is evaluated as being randomly oriented over a 360 degree range with respect to the ES. The BS antenna is assumed to comprise three sectored antennae, each with a beam capable of being scanned over 120 degrees, so that as the BS antenna is rotated in a random direction over 360 degrees the ES will always be within a sector's beamwidth.

This assumption is conservative, as a more likely case would have only a single sectored antenna, in which case the ES could be located in the BS antenna's back-lobe for many orientations. This more realistic assumption would result in two primary consequences, one, in most cases even if the BS antenna is looking toward the ES antenna it will not be located within the main beam of the ES antenna, and two, often the back lobe of the BS antenna will be oriented toward the ES antenna.

This often will be the case because the ES will be oriented in a southerly direction toward the geostationary orbital plane over the equator, and most BSs can be expected to be located outside the narrow main lobe of the ES antenna.

Conversely, the probability of the ES being in the BS antenna's main lobe, as opposed to a side lobe, is based on the relative beamwidth of the main lobe with respect to that of the side-lobe, as shown in Figure 4.

As the 5G BS is placed at different angles around the ES, the value of *d* for which $I_{es}/\eta_{bs} \le$ -6 dB at a specified confidence level (*X%*) is calculated. The set of these points over 360° around the ES creates the probability contour. The red shaded region indicates where a 5G BS placement would result in $I_{es}/\eta_{bs} \le$ -6 dB at less than, and the green region where $I_{es}/\eta_{bs} \le$ -6 dB at greater than the specified confidence value (*X%*).

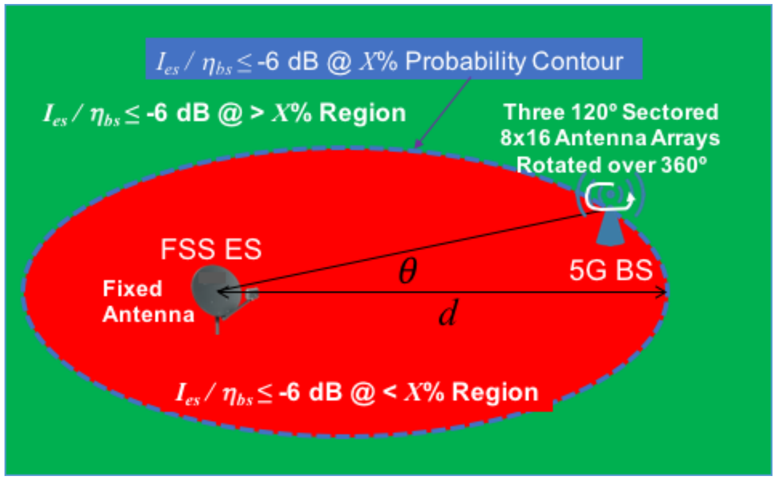

Figure 10. Analysis Methodology

Thus, the results of this analysis methodology enable insight into the sensitivity of 5G BS placement in the region of a FSS ES. The smaller the red region, the less sensitive the 5G BS is to placement.

We will calculate the probability contour using *X* = 99%, 98% and 95%, that is, the I_{es}/η_{bs} will not exceed the -6 dB threshold at that distance with these confidence levels. The confidence levels are based in turn on the statistical distribution of the received power density at the specified distance. The statistical variability from which this distribution arises is due to two variability factors: (1) the log-normal variation of the path loss around the calculated median path loss, as explained in Section 2.5.2, and (2) the probability of the ES being in the main lobe or side-lobe of the 5G BS as it is oriented in random directions, as explained above.

3.1.2 Assumption Discussion

Throughout the analysis, attempts have been made to use reasonably conservative assumptions whenever possible in constructing the coexistence model, particularly for cases where there might be uncertainty in actual deployments of FSS and 5G systems (especially for 5G, for which no actual deployments exist). Such conservative assumptions include:

- The location of the ES at a relatively high elevation, and the subsequent use of the Urban Macrocell path loss model (UMa), which provides lower path loss values than the Urban Microcell model (UMi – SC), for both LOS and NLOS cases;
- The modeling of the BS and ES antenna based on the peak values of the side-lobes, as opposed to, for example, average side-lobe gains;
- The assumption of 3-sectored BS antennas which provide essentially omni-directional coverage, as opposed to single-sectored antennae for which an ES might be located in the low-gain back-lobes; Notably this analysis does not consider the types of network

architectures that might be employed for other types of 5G deployments such as fixed-wireless applications that would not use an omni-directional antenna;

- The use of 99%, 98%, and 95% confidence levels for assessment of received power density levels, with the 99% and 98% being extremely conservative as compared to the already conservative 95% protection target used in [9];
- The assumption in the baseline analysis that there is no additional path loss attenuation due to shadowing from rooftop deployments, which would provide substantial additional attenuation of ES signals in the areas closer in to the ES location;
- The assumption that the 5G BS sites are located outdoors when, particularly at the high frequencies in question, indoor deployments might dominate; and
- The assumption that the ES elevation angle is at a minimal value of 35 degrees, while the elevation could extend up to 55 degrees.

3.1.3 Mathematical Formulation

If we substitute equations (3) and (4) for I_{es}/η_{bs} (in dB) the resulting composite expression is:

$$I_{es}/\eta_{bs} = P_{T,es} + G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} + G_{p:es,bs} - PL_{es\rightarrow bs}(d) + 204 - NF_{bs} \quad (5)$$

Note that in this formulation we have explicitly accounted for the fact that the elevation angle (ϕ) at which we must evaluate the FSS ES and 5G BS antenna patterns are functions of the distance between these antennas (d). Thus, given a specified I_{es}/η_{bs} value (e.g., -6 dB), we can solve for the distance (d) at which the antenna gains and propagation loss sum to the required value. That is:

$$I_{es}/\eta_{bs} - P_{T,es} - 204 + NF_{bs} - G_{p:es,bs} = G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} - PL_{es\rightarrow bs}(d) \quad (6)$$

Note that all of the values to the left of the equal sign in equation (6) are defined constants as shown in Table 1.

Parameter	Description	Value
I_{es}/η_{bs}	Ratio of FSS ES received power density (*Ies*) to 5G BS noise floor power density (η_{bs}) at the demodulator input (dB)	-6
$P_{T,es}$	Total transmit (i.e., both polarizations) power density of the FSS ES (dBW/Hz)	-78.46
NF_{bs}	Noise Figure of the 5G BS (dB)	12
$G_{p:es,bs}$	Polarization gain between the ES and BS antennas (dB) [looking for supporting reference]	-3

Table 1. Constant Parameter Definitions

Substitution of these constant values results in the following equation.

$$-116.54 = G_{es:\theta,\phi(d)} + G_{bs:\theta,\phi(d)} - PL_{es\rightarrow bs}(d) \quad (7)$$

The evaluation of equation (6) has been implemented in an Excel spreadsheet. The path loss solution uses the Combined (i.e., the weighted combination of the LOS and NLOS components)

PDF to determine the solution for a specified confidence level (e.g., the *PL* has a 95% probability of being greater than *x*), as was discussed in Section 2.5.2.

3.2 Results

The following results pertain to a set of system parameters and models that was chosen from key standards documents [7],[8].

3.2.1 Baseline

The analysis methodology described in Section 3.1 was applied to the system as described in Section 2. For convenience, the FSS ES parameters discussed in Section 2.2 are summarized in Table 2.

Parameter	Description	Value
Antenna Vertical Elevation	Boresight relative to the horizon (degrees)	35°
Antenna Height	Meters above the ground	25
Power Amplifier Output	Power density per right and left hand circular polarization (dBW/Hz)	-78.46

Table 2. FSS ES Parameter Summary

The 5G BS parameters discussed in Section 2.3 are summarized in Table 3.

Parameter	Description	Value
Antenna Height	Meters above the ground	6
Antenna Down-tilt	Degrees	10°
Antenna Location	Below local rooftops	N/A
Antenna Polarization	Linear	±45°
Antenna Array Size	Elements	8x16
Receiver Nose Figure	dB	12
BS Deployment Density	#/km^2	30

Table 3. 5G BS Parameter Summary

For the selected parameters of Table 1, Equation (7) shows the antenna port to antenna port coupling loss needed to keep I_{es}/η_{bs} from exceeding the -6 dB threshold is at least 116.54 dB. By combining the statistical variations of the path loss with those for the BS antenna gain variation due to random orientation of the BS azimuth, the following figure is the coupling loss at various confidence levels plotted as a function of separation distance.

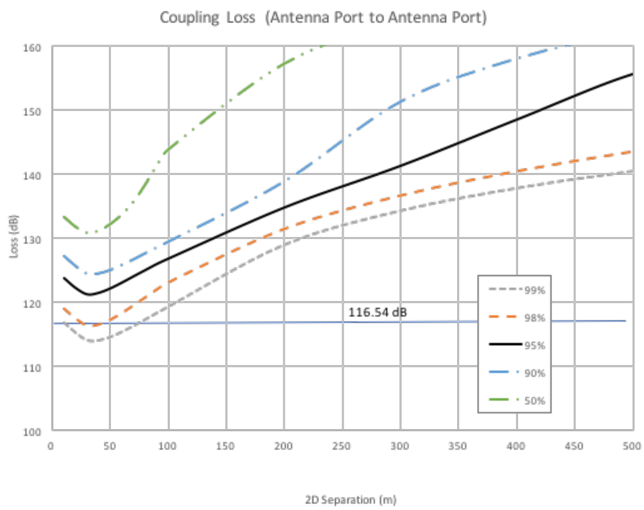

Figure 11. Antenna to Antenna Coupling Loss Confidence Curves

Note that at short separation distances, the elevation angles are large and antenna pattern losses dominate so for these parameters, the coupling loss has a minimum level at 35 m. Since only the 99 and 98 percentile confidence level curves have minima below the 116.54 dB threshold, only those two will provide non-trivial data for the subsequent analysis.

Figure 12 shows the results of the above described analysis. Only positive rotation angles are shown due to symmetry around 0º. The "Confidence Curve" shows the distance that the 5G BS would need to be placed from the FSS ES in order to achieve the specified $I_{es}/\eta_{bs} \leq$ -6 dB confidence level, absent consideration of any of the other factors discussed below. For example, for an angle θ (see Section 3.1.1) of 0º and a confidence level of 99%, the 5G BS would need to be placed at least 73 m from the FSS ES to achieve the specified result, absent the mitigating effects of other factors, such as inherent 5G BS antenna array techniques, and FSS ES physical isolation, as discussed in Sections 3.3.1 and 3.3.2. Note that the 95% plot is always 0 as explained above for Figure 11.

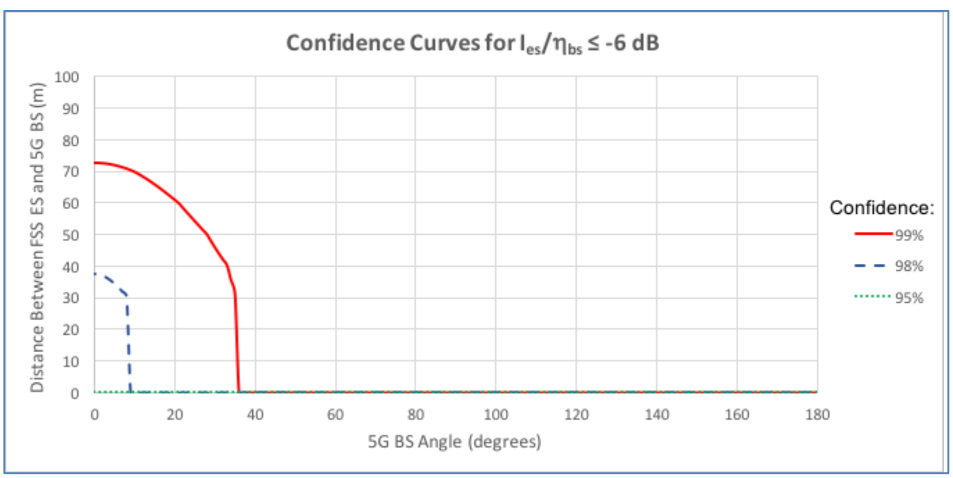

Figure 12. Baseline Analysis Results

Although Figure 12 is useful for obtaining distance information it does not provide a spatial context. This spatial contextual view is provided in Figure 13, which projects the distance data from Figure 12 onto a polar coordinate system.

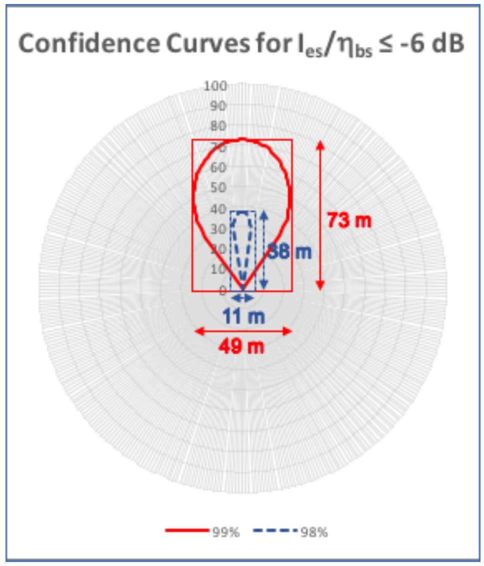

Figure 13. Baseline Analysis Results: Polar Projection

3.2.2 Coexistence Implications

Note that the area encompassed by the 99% contour is bounded by a rectangle of dimensions 73x49 m. Thus, the total area inside the 99% confidence curve is less than 0.0036 km^2.

The significance of a 0.0036 km^2 region can be assessed by comparison to a well-known urban county in which high capacity 5G mmWave BSs could likely be deployed, that being the Cook County, IL. Cook County is the second largest in the United States by population (2010 Census).

When "Cook County, IL" is entered into Google Maps, the returned region is shown by the light-red shaded area (see Figure 14). Note that the "Quick facts" section indicates that the population is 5.24 million and the area 4235 km^2.

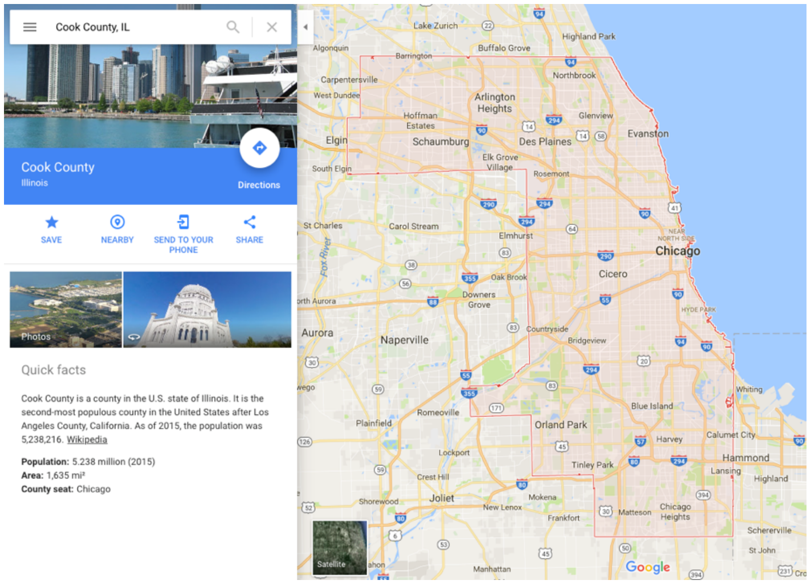

Figure 14. Google Maps: Cook County, IL

Therefore, a 0.0036 km^2 area constitutes only 0.00009% of the Cook County area. Were we to make the simplifying assumption of uniform population density, the number of Cook County residents living inside the 99% contour is approximately 4.4.

Note that if we use the still extremely conservative 98% contour the area is 0.00042 km^2, which is 0.00001% of the area with only 0.5 residents living inside.

Thus, given the availability of FSS ES deployment location flexibility, these extremely small footprints clearly support successful coexistence. Note that this is a worst-case result, as it neglects any improvements due to FSS ES antenna physical isolation and 5G antenna array techniques (see Sections 3.3.1 and 3.3.2).

3.3 Additional Mitigation Factors

The following two sections will discuss two likely mitigation techniques, those being FSS ES physical isolation and 5G BS antenna array techniques.

3.3.1 FSS ES Physical Isolation

Figure 15 shows the geometric implications for the case in which the FSS ES antenna is mounted on a modestly sized building. Note that the ES antenna is mounted 2 m above the roof of a 23 m tall building, resulting in a 25 m deployment height. The ES antenna is located at the roof center, which is a 16x16 m square.

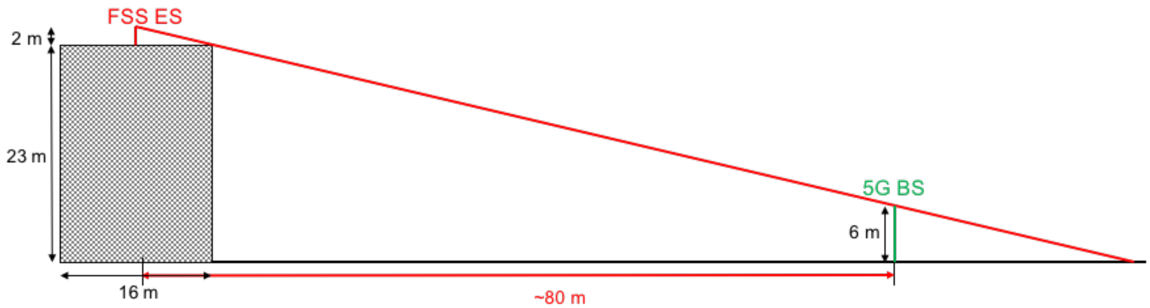

Figure 15. Geometry for Roof Blockage of FSS ES Signal

Drawing a line from the ES antenna that tangentially touches the building, we note that a 5G BS antenna that is 6 m above the ground will have "line of sight" to the ES antenna only at distances greater than approximately 80 m. If the BS is located closer than 80 meters then we would expect significant signal attenuation due to blockage by the roof itself. And, the closer the BS is to the building, the greater the R.F. attenuation due to roof blockage.

The FSS ES installation can be readily modified to provide additional R.F. isolation to a 5G BS. Figure 16 shows the case in which an R.F. barrier of height 0.5 m has been place on the roof edge in the boresight direction of the FSS ES antenna.

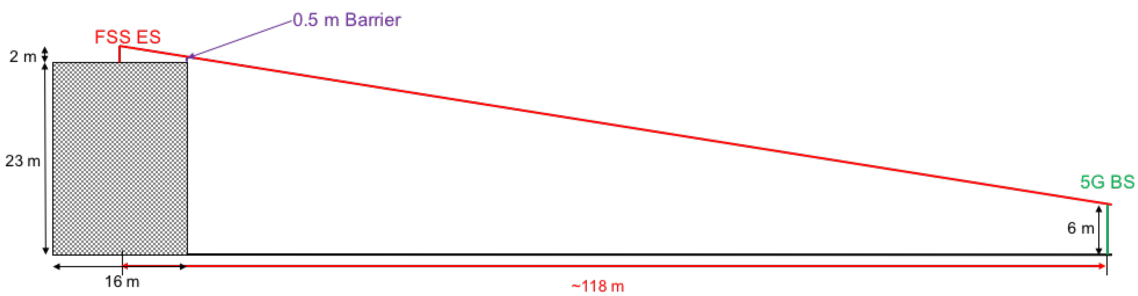

Figure 16. Geometry for Roof Plus Barrier Blockage of FSS ES Signal

Drawing a line from the ES antenna that tangentially touches the barrier top, we note that a 5G BS antenna that is 6 m above the ground will have "line of sight" to the ES antenna at a distance of approximately 118 m or greater.

In an open area, as the BS moves closer than 118 meters to the building blockage loss is primarily determined by diffraction loss. The height parameters used in Figure 16 were used to evaluate diffraction loss as a function of distance (2-D, from the ES antenna) at 50 GHz, with the resulting data shown in Figure 17 [12]. Note that at a distance of 100 m diffraction loss is greater than 7 dB, and at 90 m over 15 dB. Thus, significant additional diffraction loss can be expected.

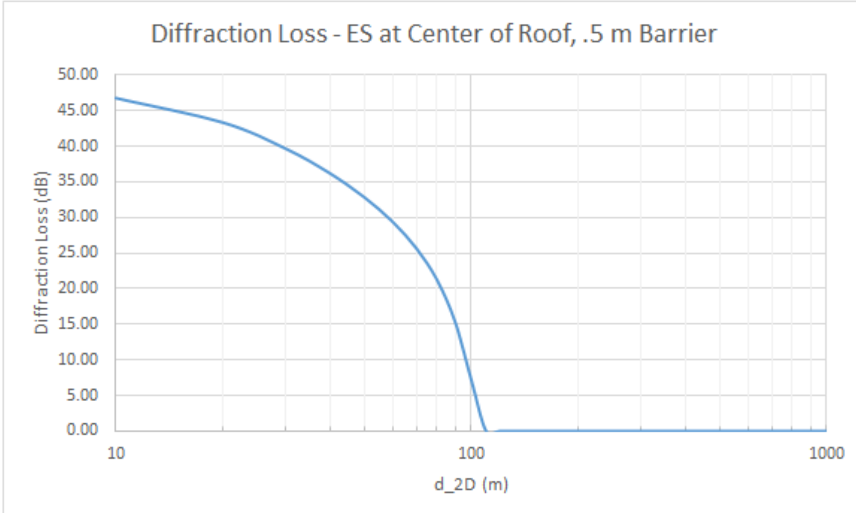

Figure 17. Diffraction Loss with a 0.5 m Barrier

Increasing the barrier height also increases to the "line of sight" distance and resulting diffraction loss at close-in distances. Given the directionality of the ES antenna, the barrier needs only be installed in the boresight antenna direction.

Certainly, scenarios can be envisioned that result in less favorable coexistence conditions. For example, the 5G BS antenna height could be increased to 10 or even 25 m, or the FSS ES antenna could be located off-center on the roof, or the building could be shorter and/or narrower. However, the above specific cases are intended to demonstrate that careful selection of ES deployment conditions can significantly enhance the ability of an FSS ES to coexist with a BS.

3.3.2 5G BS Antenna Array Techniques

Since it has direct and significant impact on system capacity and single user throughput, interference mitigation is a very active area in 5G research and standards. Many of the techniques developed for 5G systems to cope with self-interference and interference between co-existing 5G systems will provide an equal benefit against other co-existing systems, whether 5G or not. In order to provide some context in the area, examples of activity in each of the following classes are discussed.

3.3.2.1 Zero Forcing

Zero forcing is the 3D generalization of null steering in a cluttered local environment. Since there are multiple, indirect paths, this technique places a response null on any non-desired source. Thus, this technique is applicable in RF clutter environments using a Multiple Input – Multiple Output (MIMO) receiver. An example of work in this area can be found in "On the Performance of the MIMO Zero-Forcing Receiver in the Presence of Channel Estimation Error" [16], which discusses the performance of a MIMO Zero Forcing receiver with imperfect channel knowledge.

While MIMO techniques consider multiple paths through a cluttered environment, MultiUser MIMO (MU-MIMO) supports multiple users simultaneously. Thus MU-MIMO receivers are able to separate the signals from concurrent transmissions on the same frequency from different users. This is achieved by using the degrees of freedom provided by the multiple antenna and paths to separately isolate each individual signal. One relevant aspect of MIMO and especially MU-

MIMO is the suppression of other (non 5G) signals. Although, there is a paucity of literature of 5G MU-MIMO rejection of other wideband signals, there is a great deal on the ability to pick out a desired (or many desired) signals from a mix of other signals. An example of this capability is discussed in "LOS Throughput Measurements in Real-Time with a 128-Antenna Massive MIMO Testbed," [17], which provides performance results from a testbed designed to experiment with various aspects of Massive MIMO. Another paper, "AirSync: Enabling Distributed Multiuser MIMO With Full Spatial Multiplexing," [18] contains a study of a distributed Multi-User MIMO system using spatial multiplex and Zero Forcing that reports signal rejection of 25 dB.

3.3.2.2 Null Steering

Null steering is modifying the antenna pattern to produce a null in the direction of an interference source. As such, it implies a far field, plane wave model and is therefore commonly associated with phased arrays. When in an uncluttered RF environment, null steering works well. An example of work in this area can be found in "Optimization of Array Pattern for Efficient Control of Adaptive Nulling and Side Lobe Level," [14] which discusses an optimization technique applied to array synthesis with the constraint of reducing side lobe levels.

Null steering can achieve very deep rejections in many cases. "SoftNull: Many-Antenna Full-Duplex Wireless via Digital Beamforming," [15] analyses the performance of a transmit null steering algorithm to reduce self-interference for antenna structures supporting full-duplex operation, and reports reductions ranging from about 20 to 80 dB (see Figures 8-9 of [15]).

3.3.2.3 Antenna Side Lobe Control

The analysis provided in this paper assumes either standard reflectors for the ES and arrays with uniform amplitude taper for the BS antenna. These types of antennas, have a fairly high level of side lobes starting at -13.3 dB from the main beam. There exists a large number of techniques to further reduce the sidelobe level, each with its own characteristics; but industry standard antennas can readily achieve side lobe levels well below -20 dB. See "Side Lobe Level Reduction in Antenna Array Using Weighting Function," [13] which includes an analysis of various side lobe reduction techniques including a variety of commonly applied windows.

4 DISCUSSION OF RESULTS

The foregoing analysis of a typical deployment scenario shows that small Fixed Service Satellite (FSS) Earth Stations (ES) with uplink transmissions between 47.2-50.2 and 50.4-52.4 GHz, communicating with geostationary-orbit spacecraft, can be located in the same urban areas as Fifth-Generation (5G) wireless Base Stations (BS) without the need for coordination.[2]

The primary coexistence metric utilized is the ratio of FSS ES received power density (I_{es}) to noise floor power density (η_{bs}) at the 5G BS demodulator input, or I_{es}/η_{bs}. This metric is used to determine the 99%, 98% and 95% probability contours for $I_{es}/\eta_{bs} \leq$ -6 dB.

The baseline confidence probability contour data has been evaluated with respect to absolute area and also area relative to a specific county (i.e., Cook County, IL). The results indicate that for a

[2] Note: As noted earlier, the results of this analysis depend on the characteristics of the satellite system at issue; the methodology readily could be applied to systems with other architectures or physical configurations.

given ES, the area where a potential coexistence issue could exist is small, and the chances of such a circumstance actually arising in the real world is rare.

As reported in Section 3.2.2, the total 99% confidence probability contour area is less than 0.0036 km^2 and 98% contour less than 0.00042 km^2, which constitute less than 0.00009% and 0.00001% of Cook County, respectively. In order to assess how unlikely it is that a 5G BS will experience an I_{es}/η_{bs} greater than -6 dB, we will first utilize Figure 18, which is a magnified view of the region of interest from Figure 13.

We also have "turned around" the perspective to focus on confidence that the I_{es}/η_{bs} will be *greater than* (>) the -6 dB goal. So, if at a given distance the confidence of I_{es}/η_{bs} being ≤ -6 dB is X%, then the corresponding confidence that it will be > -6 dB is (100% - X%). Thus, the 99%, 98% and 95% regions become the 1%, 2% and 5% regions, respectively. Recall from Figure 11 that the 95 percentile curve never falls below the 116.54 dB threshold, so I_{es}/η_{bs} is less than -6 dB at all distances, and, we can therefore use the 5% percentile I_{es}/η_{bs} > -6 dB as a conservative ceiling value.

Therefore, the two regions of interest can be defined as follows:

- I_{es} / η_{bs} > -6 dB @ between 2% & 5% Region (Blue Shaded)
    - Area of the blue shaded rectangle
    - Size is ~420 m^2
- I_{es} / η_{bs} > -6 dB @ between 1% & 2% Region (Red Shaded)
    - Area of the red shaded rectangle minus area of the blue shaded rectangle
    - Size is ~3160 m^2

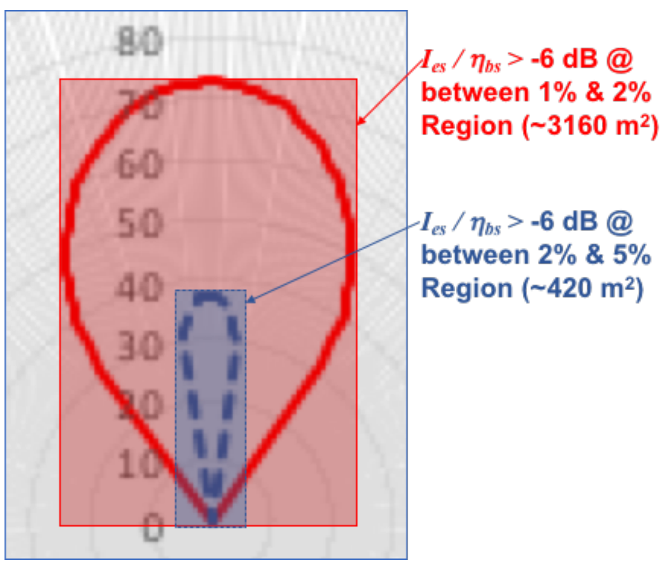

Figure 18. Approximate I_{es} / η_{bs} Greater Than -6 dB Confidence Regions

We can now make the conservative assumption that any 5G BS deployed in the red shaded region will have a probability of I_{es}/η_{bs} > -6 dB of 2% and in the blue shaded region of 5%. Thus, using the total region area (3160 m^2 + 420 m^2 = 3580 m^2) to weight these probabilities based on the

individual region areas, the resulting probability of I_{es}/η_{bs} > -6 dB assuming a uniform likelihood of 5G BS placement is approximately 0.024.

We can now make the (also conservative) assumption that the FSS ES is deployed in an area where 5G BSs are deployed at the standard density (specified in Table 12 of [7]) of 30 per km^2. Thus, the expected number of BSs falling within the confidence regions under discussion is approximately 0.1. That is, the chance of a BS being in the confidence regions under discussion is roughly 1 in 10.

This assumption is conservative because there will be large areas of, for example, Cook County in which no 5G BSs will be deployed. Moody's Investor Service recently published information claiming that 5G system deployment will likely cover only 50% of the United States population [19].

However, even if a 5G BS happens to be deployed in the discussed confidence regions (0.1 probability), the probability that the BS actually will experience an I_{es}/η_{bs} > -6 dB is 0.024. Therefore, the total probability that a 5G BS will actually experience I_{es}/η_{bs} > -6 dB under the terms of this analysis is only 0.0024, or approximately 1 chance in 416.

Notably, these results are based on conservative assumptions, including path loss, use of peak side lobes (instead of actual lower values at different off-axis angles), considering only BS antennas with essentially omni-directional coverage, calculating much-higher confidence levels for received power density levels than commonly used, not accounting for attenuation from blockage, assuming all-outdoor 5G deployment, and never considering the operation of an ES at an elevation angle above a minimal value.

Moreover, the foregoing calculations do not take into account the mitigating effects of other factors, such as FSS ES physical isolation and inherent 5G BS antenna array techniques, which virtually eliminate the chance of a real-world problem ever actually arising.

Thus, the results of this analysis show that coexistence between FSS ESs and 5G BSs (using the deployment scenario described in this paper) is feasible without the need for coordination.

5 REFERENCES

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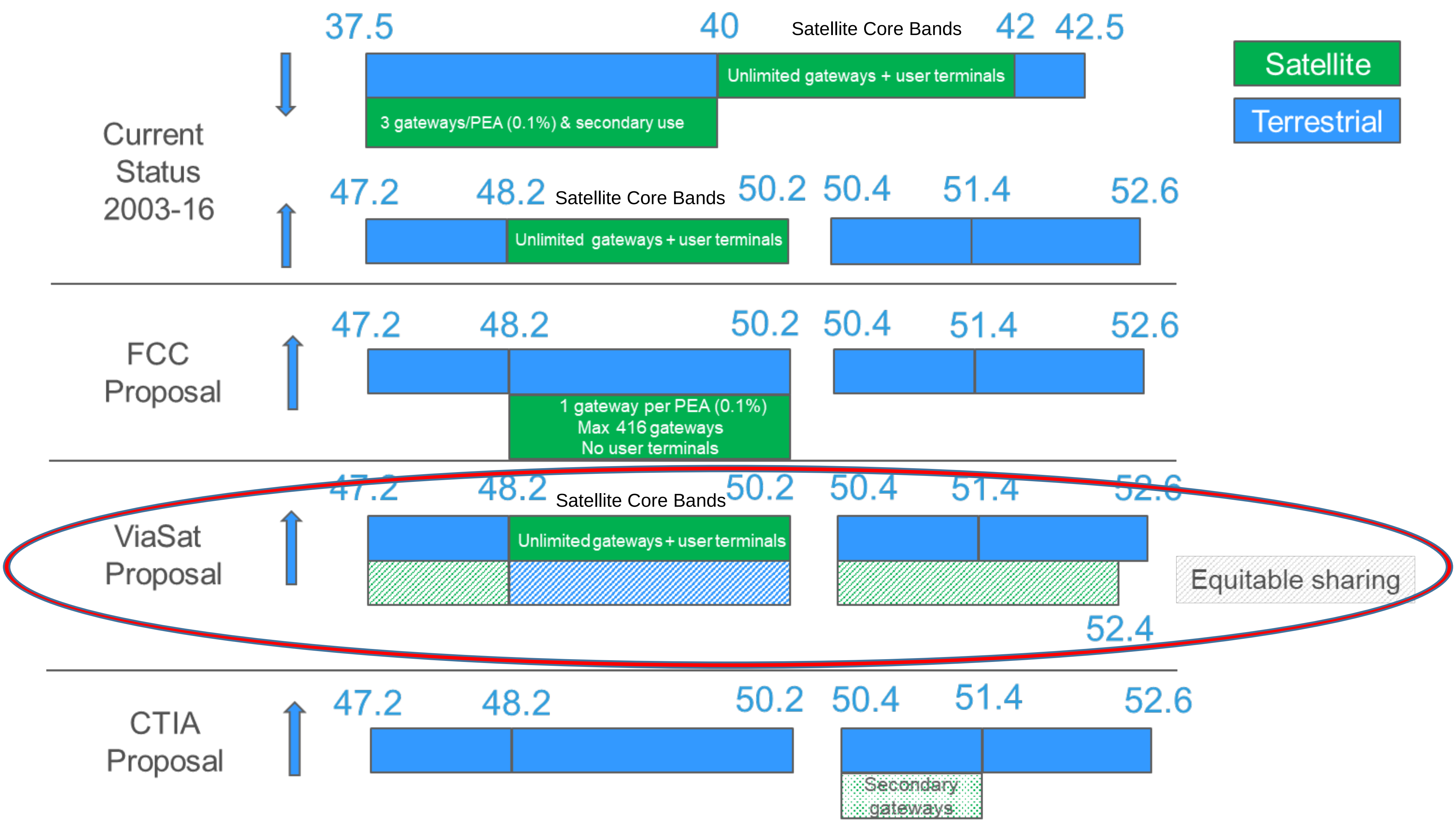
[19] Moody's Investemnt Service, "Telcos will tailor their 5G strategies to match their individual strengths," https//www.moodys.com, September 2017.

ATTACHMENT B

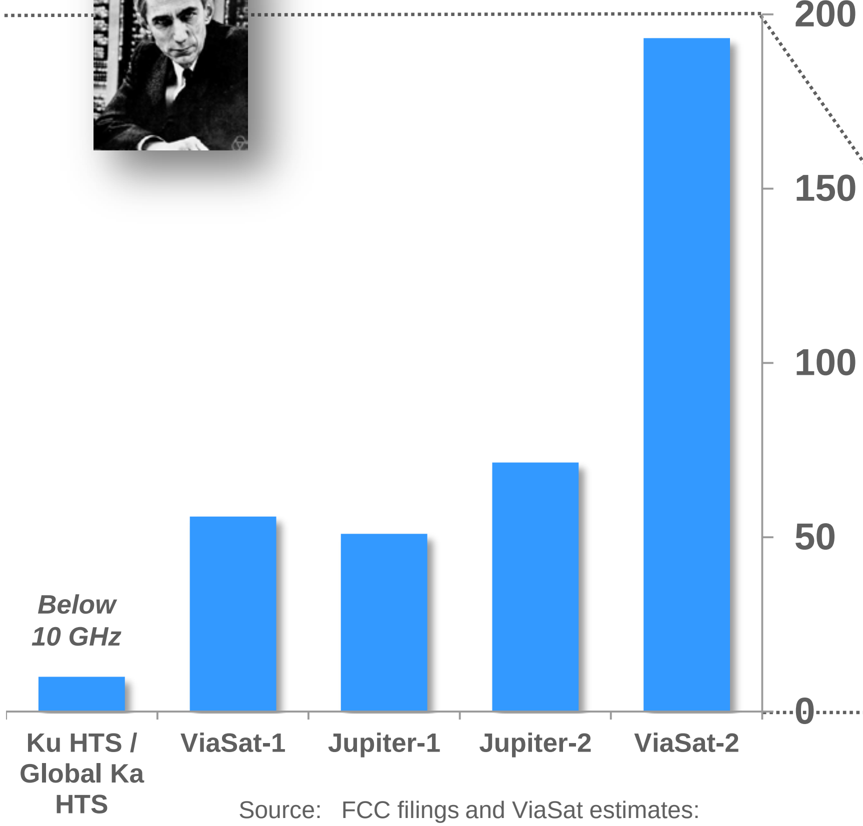
V-Band: Current Plan and Proposals



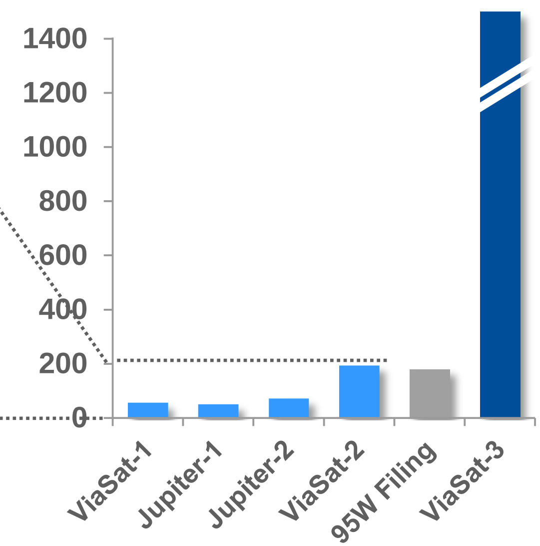
VS-2 Competitive Advantage

Capacity = W × $\log_2(1 + S/N)$

Claude Shannon



Gateway Uplink Capacity (GHz)



Source: FCC filings and ViaSat estimates:
ViaSat-1: SAT-LOA-20110722-00132, dated July 22, 2011
Jupiter-1: SAT-LOI-20091110-00119 dated November 10, 2009
Jupiter-2: SAT-MOD-20141210-00127, dated December 10, 2014
ViaSat-2: SAT-MOD-20160527-00053, dated May 27, 2016
95W Filing: SAT-LOA-20170621-00092, dated June 21, 2017 (18 gateways @ 10 GHz each)

ViaSat