Sharing between FSS and 5G Systems at Frequencies around 28 GHz

Corrected, June 24, 2016

Table of Contents

1 Introduction

This study addresses FSS earth station emissions into a 5G terrestrial mobile system (hereafter referred to as "5G") at frequencies around 28 GHz.

1.1 Methodology for analyzing interference into 5G stations

The separation distance around an FSS transmit earth station necessary to protect a 5G receive station is computed for all azimuths around the earth station. In order to analyze the maximum impact on a 5G receiver needed in order to come up with a coordination trigger level, a "worst case" situation is considered where the 5G station is assumed to be pointing toward the FSS earth station at all azimuth angles. The separation distance is computed using two propagation models, one given in ITU-R Recommendation P.452 and a non-line-of-sight model provided by a large group of academia and industry researchers presented to Globecom '16, here referred to as the ABG model.

The analysis is performed for both GSO and NGSO earth stations. For the GSO case, a ViaSat station located in Englewood, CO is used as a representative FSS earth station in the continental US (CONUS). In addition, an earth station located in Anchorage, AK (14.93 deg.) where the smallest elevation angle among ViaSat stations occurs within the United States, and an earth station in Carlton, MN (33.31 deg.), with the smallest elevation angle within CONUS have been analyzed. For the NGSO case, the O3B earth station located in Vernon, TX is considered. The analysis is repeated for these locations to quantify the effect of lower elevation angles on the maximum separation distance.

2 System Characteristics

The following tables and figures provide the characteristics of the FSS systems used in this analysis. The earth station characteristics for the GSO system are provided in the ViaSat FCC application for this earth station. For the sake of brevity, only parameters of the Englewood, CO, earth station are reported here for the GSO case. Among the generations of ViaSat systems, the ViaSat 1 characteristics represent the worst case interference situation due to the higher earth station EIRP levels as compared with the second and third generation systems (please refer to the ViaSat *ex parte* filing dated April 21, 2016). The NGSO system characteristics are provided in the O3B technical narrative for the Vernon, TX gateway. Note that the antenna pattern references are those given in the ITU's Antenna Pattern Library.

Table 1 - FSS Earth and Space Station Characteristics

Parameter	ViaSat		O3B	
	Value	Source	Value	Source
FSS Earth Station				
Location				
Name	Englewood	ViaSat Application (1)	Vernon	O3B Filing (2)
Coordinates (lat / long)	39.5 / -104.9 deg	ViaSat Application	34.2 / -99.3 deg	O3B Filing
Height	10 m	ViaSat Application	10 m	Assumed
Elevation angle	43.0 deg	Computed	-	-
Minimum elevation angle	-	-	5 deg	Assumed
Transmitter				
Antenna peak gain	65.3 dBi	ViaSat Application	64.9 dBi	O3B Filing
Antenna gain pattern	APEREC013V01	Assumed	APEREC013V01	Assumed
Antenna efficiency	70%	Assumed	70%	Assumed
Frequency	28 GHz	Assumed	28 GHz	Assumed
Signal EIRP	69 dBW	ViaSat Application	78.7 dBW	O3B Filing
Signal power	3.7 dBW	Computed	13.8 dBW	Computed
Signal bandwidth	416 MHz	ViaSat Application	216 MHz	O3B Filing
Signal power density	-82.4 dBW/Hz	Computed	-69.5 dBW/Hz	Computed
Feed loss	0 dB	Assumed	0 dB	Assumed
FSS Space Station				
Orbit				
Type	GSO	ViaSat Application	NGSO	O3B Filing
Object name	VIASAT 1	Space-Track	O3B FM8	Space-Track
Epoch (UTC)	2016-06-01 08:35:37	Space-Track	2016-06-01 08:04:25	Space-Track
Orbit inclination	0.022 deg	Space-Track	0.032 deg	Space-Track
Right ascension of ascending node	323.45 deg	Space-Track	11.00 deg	Space-Track
Eccentricity	0.00023	Space-Track	0.00022	Space-Track
Argument of perigee	106.12 deg	Space-Track	87.22 deg	Space-Track
Mean anomaly	194.51 deg	Space-Track	261.82 deg	Space-Track
Semi-major axis	42165 km	Space-Track	14444 km	Space-Track

(1) ViaSat Application: SES-LIC-20110328-00379

(2) O3B Filing: "Technical Information to Supplement the Existing Schedule S for the Texas Gateway Earth Station"' dated March 27, 2013

Figure 1 – GSO FSS Transmit Earth Station Antenna Pattern

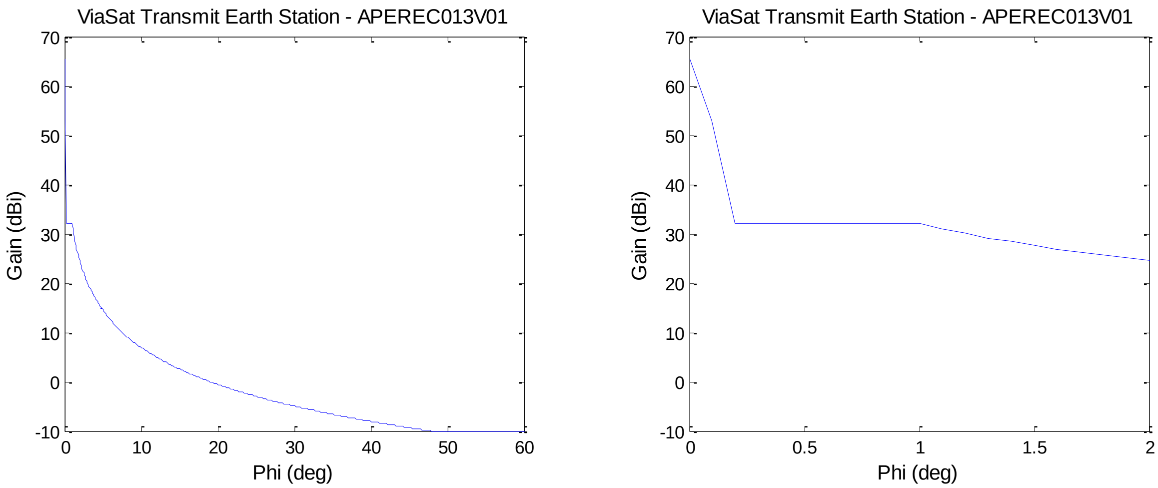
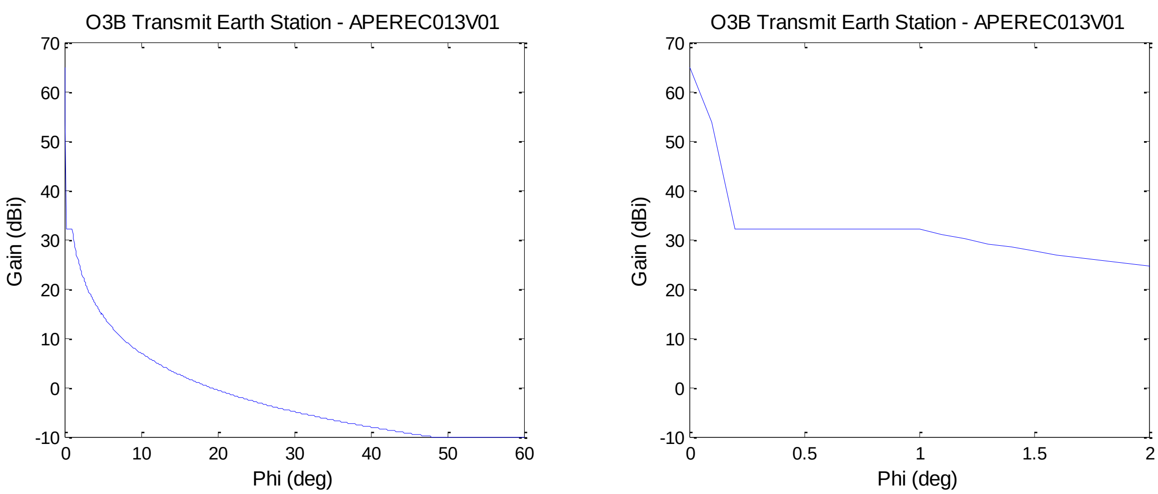


Figure 2 – NGSO FSS Transmit Earth Station Antenna Pattern



The 5G system characteristics used in this analysis are shown in the following table and figures.

Table 2- 5G Base and Mobile Station Characteristics

Parameter	5G Base Station		5G Mobile Station	
	Value	Source	Value	Source
Deployment				
Environment	Urban	Assumed	Urban	Assumed
Number				
Englewood	4350	Assumed	13050	Assumed
Vernon	870	Assumed	2610	Assumed
Activity factor	10 - 50 %	Assumed	10 - 50 %	Assumed
Area (delta lat x delta long)	0.2 x 0.2 deg	Assumed	0.2 x 0.2 deg	Assumed
Percent indoor	20 %	Assumed	20 %	Assumed
Building loss (max / sigma / min)	36 /12 / 0 dB	USWP 3M/2	36 /12 / 0 dB	USWP 3M/2
Base Station				
Antenna				
Height range	0 - 20 m	Assumed	0 - 3 m	Assumed
Azimuth range	0 - 360 deg	Assumed	0 - 360 deg	Assumed
Elevation range	-90 - 0; 0 - 80 deg	Assumed	0 - 90; -80 - 0 deg	Assumed
Elevation range percent	90; 10 %	Assumed	90; 10 %	Assumed
Array elements (column x row)	16 x 16	Intel Filing (1)	2 x 4	Intel Filing
Element gain	5.0 dBi	Intel Filing	5.0 dBi	Intel Filing
Peak gain	29.1 dBi	Intel Filing	14.0 dBi	Intel Filing
Gain pattern	3GPP	Intel Filing	3GPP	Intel Filing
Receiver				
Frequency	28 GHz	Assumed	28 GHz	Assumed
Noise figure	6.5 dB	Intel Filing	8.5 dB	Intel Filing
Noise temperature	1005 K	Computed	1763 K	Computed
Feed loss	2.5 dB	Intel Filing	2.5 dB	Intel Filing
I/N requirement	-6 dB	Assumed	-6 dB	Assumed

(1) Intel Filing: Reply Comment of Intel Corporation dated February 26, 2016

Figure 3A – 5G Receive Base Station Antenna Pattern

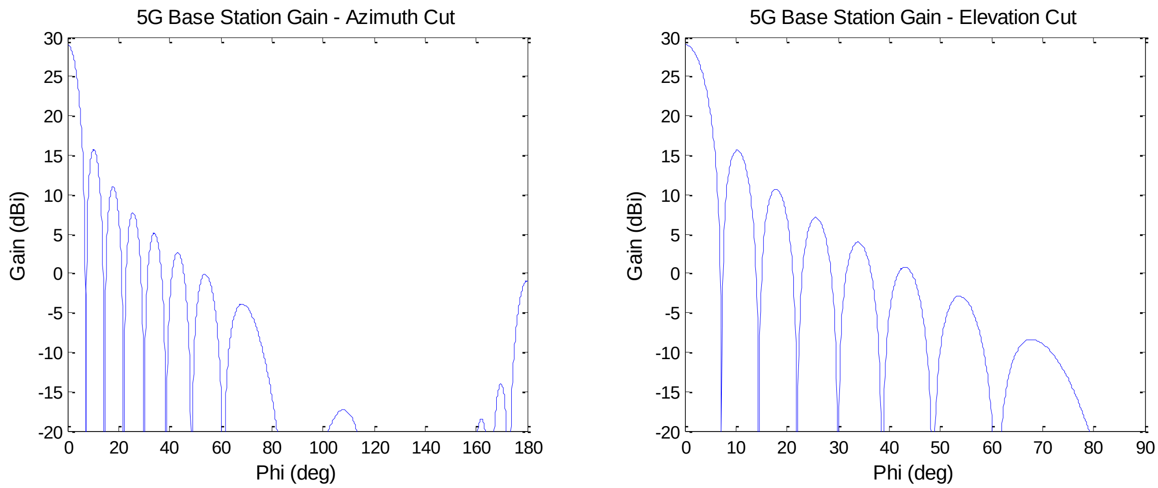
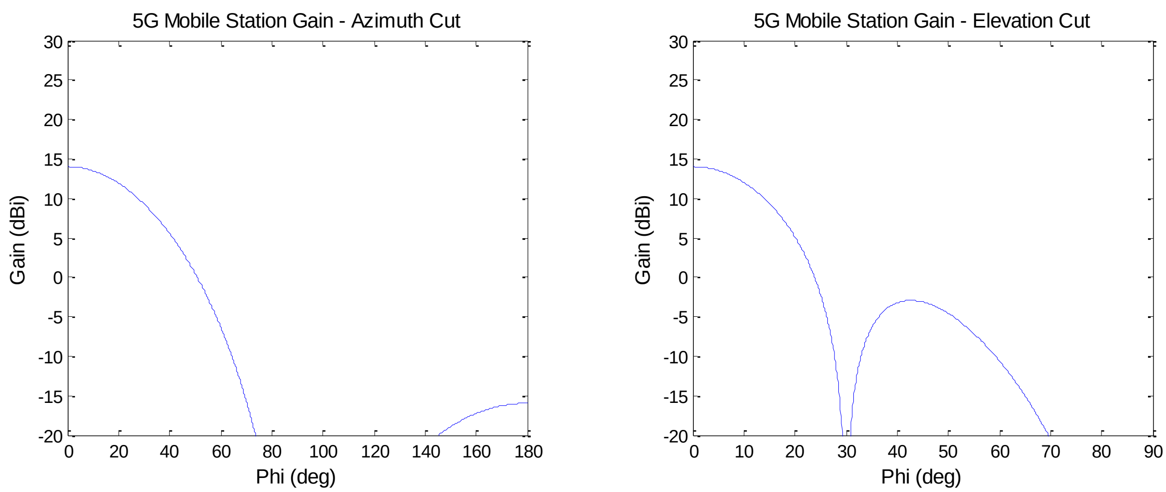


Figure 3B – 5G Receive Mobile Station Antenna Pattern



3 Propagation Models

Two propagation models are considered for the terrestrial path (i.e., FSS earth station emissions into 5G receive stations). One model is described in ITU-R Recommendation P.452. Note that this model includes a clutter loss based on a clutter height and distance that are dependent on the environment (urban, suburban, rural, etc.). Details of the application of this clutter loss are provided in ITU-R P.452. It should be noted that the clutter model in P.452 limits the clutter loss to about 20 dB in all environments and for all clutter heights. Also, due to the short distances involved, the appropriateness of the P.452 model for the case of interference into the 5G mobile station needs to be verified.

The second model considered is a non-line-of-sight model provided by a large group of academia and industry researchers presented to Globecom '16, here referred to as the ABG model (please see Annex 1).

These models are used to calculate the propagation loss in order to determine the required separation distance between the FSS transmit earth station and the 5G receive base and mobile stations.

Table 3 summarizes the propagation models used in this analysis.

Table 3 - Propagation Models

Parameter	Urban Macro	Source
Terrestrial Path Propagation		
Model	P.452-14	ITU-R P.452-14
Percentage of time basic loss is not exceeded	20%	Assumed
Average radio-refractive index lapse rate	45 N-units/km	ITU-R P.452-14
Sea-level surface refractivity	330 N-units	ITU-R P.452-14
Path center latitude	40 N	ITU-R P.452-14
Clutter height	20 m	ITU-R P.452-14
Clutter distance	0.02 km	ITU-R P.452-14
Obstruction loss (max / sigma / min)	0 / 0 / 0 dB	Assumed
Model	ABG	Globecom '16 (1)
Alpha	3.4	Globecom '16
Beta	19.2	Globecom '16
Gamma	2.3	Globecom '16
Sigma (with shadowing)	6.5	Globecom '16
Sigma (no shadowing)	0	Globecom '16
Polarization discrimination		
5G wrt FSS	3 dB	Assumed

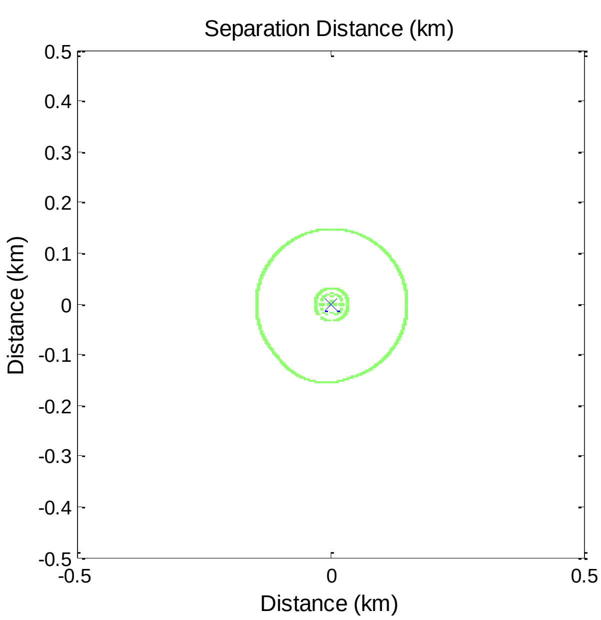
(1) Please see Annex 1

4 Results

4.1 GSO FSS earth station into 5G base station

The following plots illustrate the worst-case separation distance between a GSO FSS transmit earth station and a 5G receive base station. The 5G receive station is assumed to be pointing toward the GSO transmit earth station at all azimuth angles, since this orientation represents the worst case. It should be noted that other orientations besides this singular worst case orientation were also analyzed, and in the majority of cases the 5G base station is not impacted even when very close to the satellite earth station. The propagation model is based on either ITU-R Recommendation P.452 or the ABG model, as noted in the figures.

Figure 4A - 5G base station pointed toward GSO FSS earth station (Englewood)
Propagation model: P.452



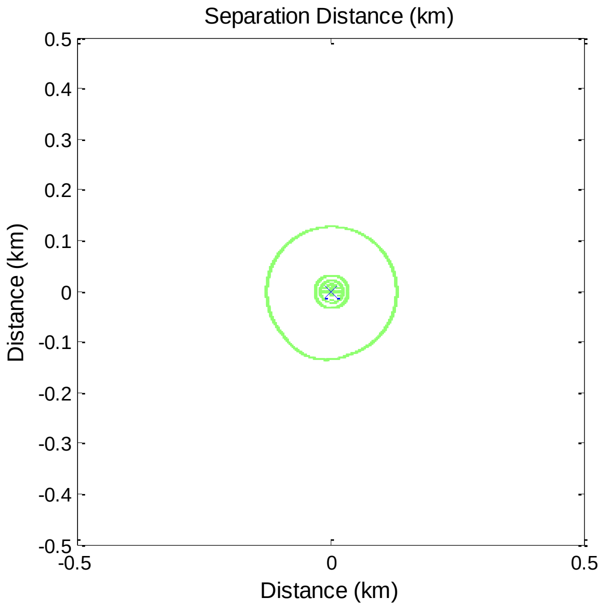
Scenario:
Environment : Urban Macro
Propagation model : P.452
Env. loss (mean, sigma, min) : 0.0, 0.0, 0.0 dB

Interfering transmitter:
Name : ViaSat Transmit Earth Station
Location name, lat / long : Englewood, 39.5 / -104.9 deg
Peak gain : 65.3 dBi
Gain pattern : APEREC013V01
EIRP : 69.0 dBW
Height : 10.0 m
Elevation angle : 43.0 deg
Azimuth angle : 195.8 deg

Wanted receiver:
Name : 5G Receive Base Station
Peak gain : 29.1 dBi
Gain pattern : 3GPP
Height : 20.0 m
Pointing scenario : Toward
Elevation angle : -10.0 deg
Azimuth angle : Varies
I/N requirement : -6.0 dB

Maximum separation distance: : 155 m

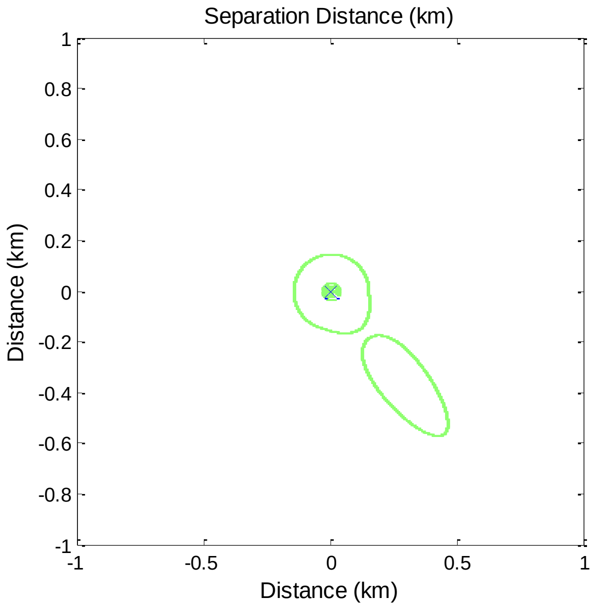
Figure 4B - 5G base station pointed toward GSO FSS earth station (Englewood)
Propagation model: ABG



Scenario:	
Environment	: Urban Macro
Propagation model	: ABG with no shadowing
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB
Interfering transmitter:	
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Englewood, 39.5 / -104.9 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 43.0 deg
Azimuth angle	: 195.8 deg
Wanted receiver:	
Name	: 5G Receive Base Station
Peak gain	: 29.1 dBi
Gain pattern	: 3GPP
Height	: 20.0 m
Pointing scenario	: Toward
Elevation angle	: -10.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB
Maximum separation distance:	: 135 m

The separation distances will be larger for earth stations that operate at a lower elevation angle than was considered for Englewood, CO case. A review of the ViaSat earth station locations shows that the minimum elevation angle occurs at Anchorage, AK (14.93 deg.). Of the earth stations located in CONUS, the minimum elevation angle occurs at Carlton, MN (33.31 deg.). The above analysis is repeated for these locations to quantify the effect of lower elevation angles on the maximum separation distance, with the results shown below.

Figure 5A - 5G base station pointed toward GSO FSS earth station (Anchorage)
Propagation model: P.452



Scenario:

Environment	: Urban Macro
Propagation model	: P.452
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB

Interfering transmitter:

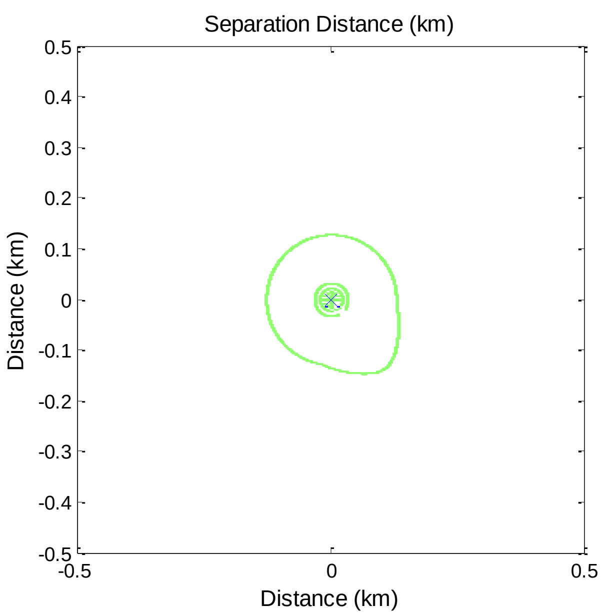
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Anchorage, 61.2 / -149.9 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 14.9 deg
Azimuth angle	: 141.6 deg

Wanted receiver:

Name	: 5G Receive Base Station
Peak gain	: 29.1 dBi
Gain pattern	: 3GPP
Height	: 20.0 m
Pointing scenario	: Toward
Elevation angle	: -10.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB

Maximum separation distance: : 716 m

Figure 5B - 5G base station pointed toward GSO FSS earth station (Anchorage)
Propagation model: ABG



Scenario:

Environment	: Urban Macro
Propagation model	: ABG with no shadowing
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB

Interfering transmitter:

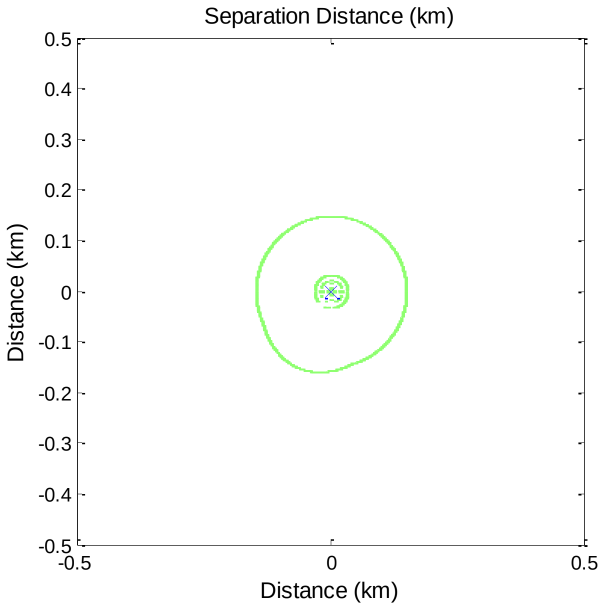
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Anchorage, 61.2 / -149.9 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 14.9 deg
Azimuth angle	: 141.6 deg

Wanted receiver:

Name	: 5G Receive Base Station
Peak gain	: 29.1 dBi
Gain pattern	: 3GPP
Height	: 20.0 m
Pointing scenario	: Toward
Elevation angle	: -10.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB

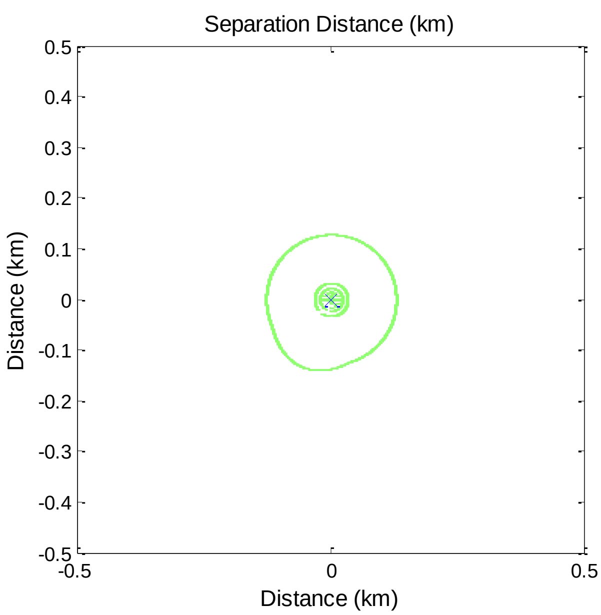
Maximum separation distance: : 172 m

Figure 6A - 5G base station pointed toward GSO FSS earth station (Carlton)
Propagation model: P.452



Scenario:	
Environment	: Urban Macro
Propagation model	: P.452
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB
Interfering transmitter:	
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Carlton, 46.7 / -92.5 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 33.3 deg
Azimuth angle	: 204.9 deg
Wanted receiver:	
Name	: 5G Receive Base Station
Peak gain	: 29.1 dBi
Gain pattern	: 3GPP
Height	: 20.0 m
Pointing scenario	: Toward
Elevation angle	: -10.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB
Maximum separation distance:	: 164 m

Figure 6B - 5G base station pointed toward GSO FSS earth station (Carlton)
Propagation model: ABG



Scenario:	
Environment	: Urban Macro
Propagation model	: ABG with no shadowing
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB
Interfering transmitter:	
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Carlton, 46.7 / -92.5 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 33.3 deg
Azimuth angle	: 204.9 deg
Wanted receiver:	
Name	: 5G Receive Base Station
Peak gain	: 29.1 dBi
Gain pattern	: 3GPP
Height	: 20.0 m
Pointing scenario	: Toward
Elevation angle	: -10.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB
Maximum separation distance:	: 145 m

The following plot shows the maximum separation distances between the ViaSat earth stations and a 5G base station pointed toward the GSO station as a function of the 5G base station protection requirement (I/N) varying from 0 to -10 dB. This is done to cover a wide ranges of 5G network SINR scenarios in terms of outage probability, loading, etc. The solid blue curve show results using the P.452 propagation model and the dashed black curve show results for the ABG model. Note that these results are dependent on the assumptions made for the GSO earth station antenna characteristics and pointing direction.

Figure 7A – Maximum separation distance as a function of the 5G base station I/N protection requirement – Englewood

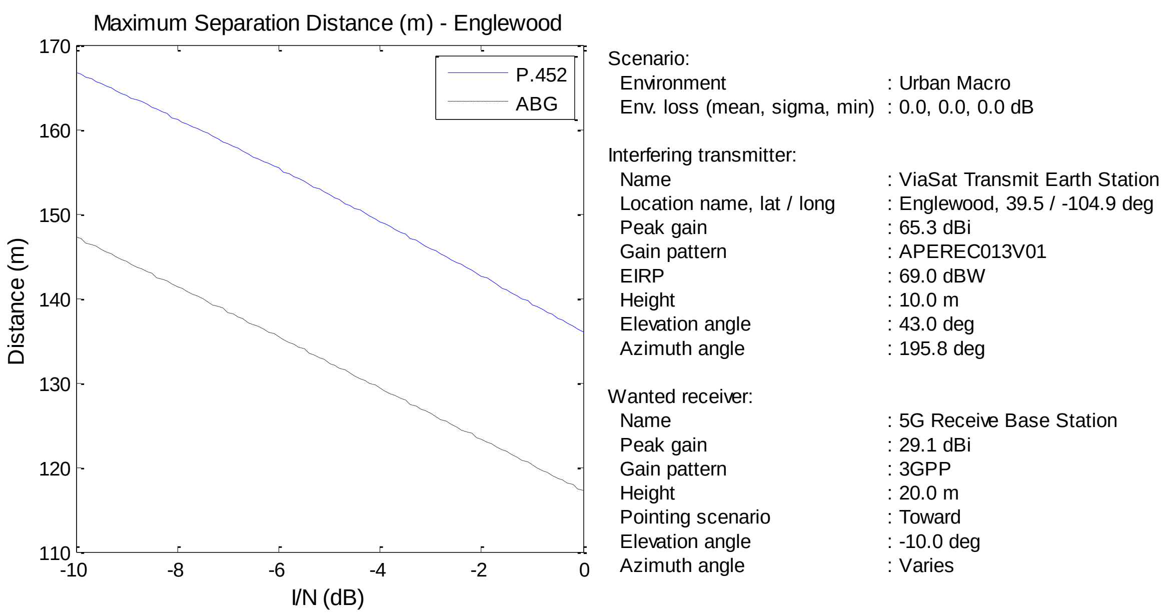


Figure 7B – Maximum separation distance as a function of the 5G base station I/N protection requirement – Anchorage

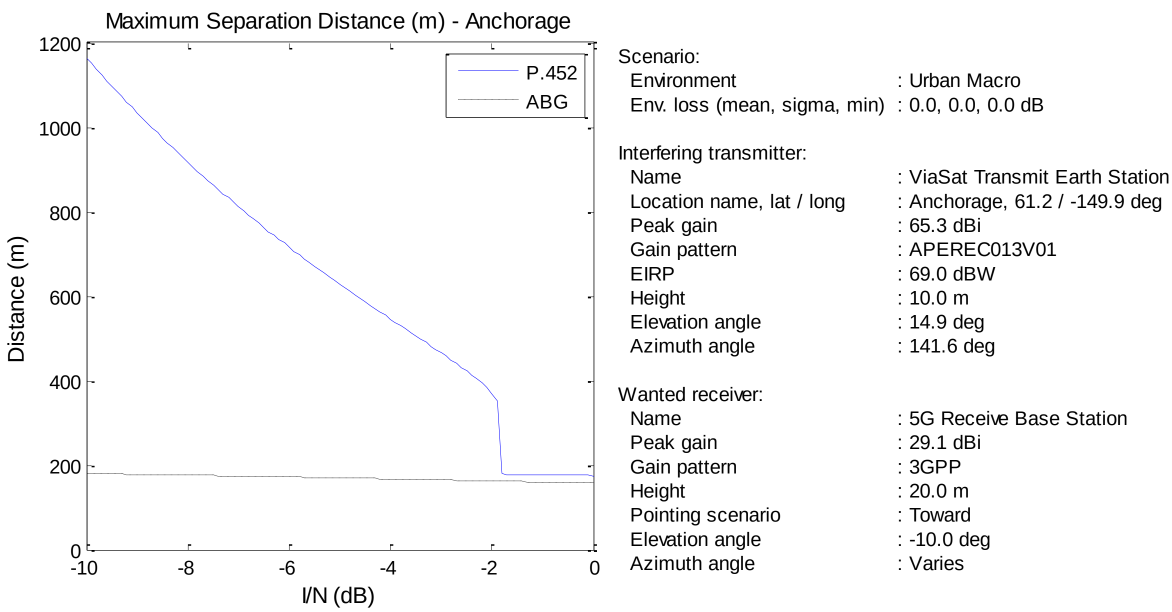
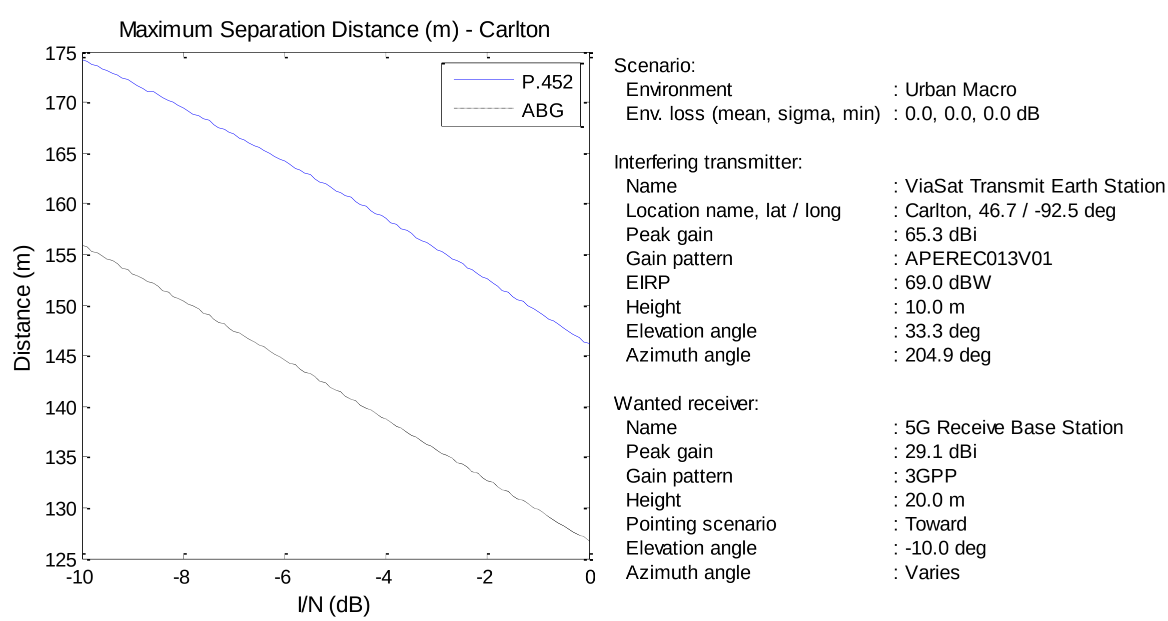


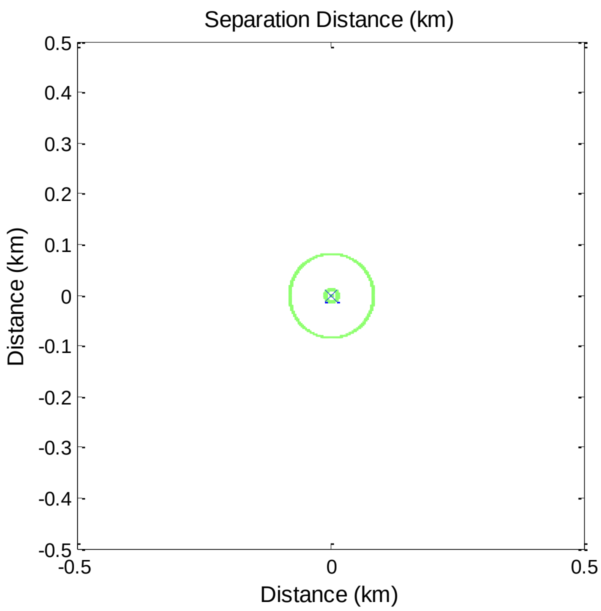
Figure 7C – Maximum separation distance as a function of the 5G base station I/N protection requirement – Carlton



4.2 GSO FSS earth station into 5G mobile station

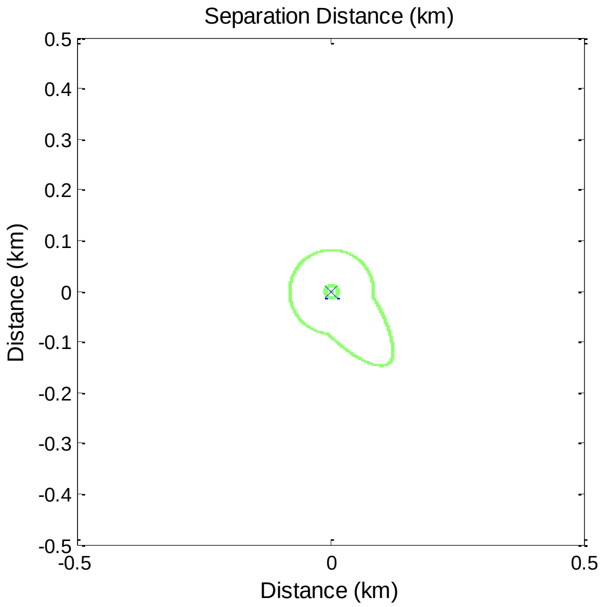
The following plots illustrate the separation distance between a GSO FSS transmit earth station and a 5G receive mobile station. For this case, only the ABG propagation model is used since the clutter model in ITU-R P.452 is likely not applicable for the short separation distances involved. It should also be noted that given a 5G mobile station would be beam-formed towards its corresponding base station, the likelihood of its beam being directed at the GSO earth station should generally be quite low. It should be noted that a mobile station antenna height of 3 meters is used to cover a larger set of form factors including CPEs.

Figure 8 - 5G mobile station pointed toward GSO FSS earth station (Englewood)
Propagation model: ABG



Scenario:	
Environment	: Urban Macro
Propagation model	: ABG with no shadowing
Env. loss (mean, sigma, min)	: 0.0, 0.0, 0.0 dB
Interfering transmitter:	
Name	: ViaSat Transmit Earth Station
Location name, lat / long	: Englewood, 39.5 / -104.9 deg
Peak gain	: 65.3 dBi
Gain pattern	: APEREC013V01
EIRP	: 69.0 dBW
Height	: 10.0 m
Elevation angle	: 43.0 deg
Azimuth angle	: 195.8 deg
Wanted receiver:	
Name	: 5G Receive Mobile Station
Peak gain	: 14.0 dBi
Gain pattern	: 3GPP
Height	: 3.0 m
Pointing scenario	: Toward
Elevation angle	: 0.0 deg
Azimuth angle	: Varies
I/N requirement	: -6.0 dB
Maximum separation distance:	: 83 m

Figure 9 - 5G mobile station pointed toward GSO FSS earth station (Anchorage)
Propagation model: ABG



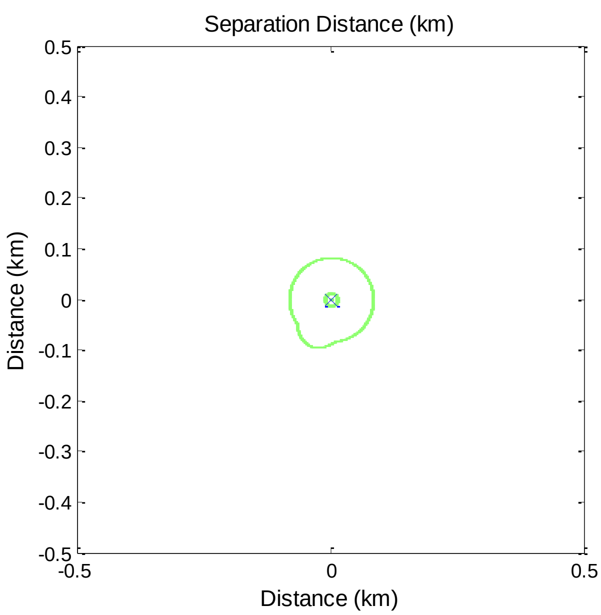
Scenario:
- Environment : Urban Macro
- Propagation model : ABG with no shadowing
- Env. loss (mean, sigma, min) : 0.0, 0.0, 0.0 dB

Interfering transmitter:
- Name : ViaSat Transmit Earth Station
- Location name, lat / long : Anchorage, 61.2 / -149.9 deg
- Peak gain : 65.3 dBi
- Gain pattern : APEREC013V01
- EIRP : 69.0 dBW
- Height : 10.0 m
- Elevation angle : 14.9 deg
- Azimuth angle : 141.6 deg

Wanted receiver:
- Name : 5G Receive Mobile Station
- Peak gain : 14.0 dBi
- Gain pattern : 3GPP
- Height : 3.0 m
- Pointing scenario : Toward
- Elevation angle : 0.0 deg
- Azimuth angle : Varies
- I/N requirement : -6.0 dB

Maximum separation distance: : 180 m

Figure 10 - 5G mobile station pointed toward GSO FSS earth station (Carlton)
Propagation model: ABG



Scenario:
- Environment : Urban Macro
- Propagation model : ABG with no shadowing
- Env. loss (mean, sigma, min) : 0.0, 0.0, 0.0 dB

Interfering transmitter:
- Name : ViaSat Transmit Earth Station
- Location name, lat / long : Carlton, 46.7 / -92.5 deg
- Peak gain : 65.3 dBi
- Gain pattern : APEREC013V01
- EIRP : 69.0 dBW
- Height : 10.0 m
- Elevation angle : 33.3 deg
- Azimuth angle : 204.9 deg

Wanted receiver:
- Name : 5G Receive Mobile Station
- Peak gain : 14.0 dBi
- Gain pattern : 3GPP
- Height : 3.0 m
- Pointing scenario : Toward
- Elevation angle : 0.0 deg
- Azimuth angle : Varies
- I/N requirement : -6.0 dB

Maximum separation distance: : 100 m

Figure 11 plots the maximum separation distances between the earth station located in Englewood, CO and the 5G station pointed toward the GSO FSS station as a function of the 5G mobile station protection requirement (I/N) varying from 0 to -10 dB. As in the case of base station, this is done to cover a wide range of 5G mobile station performance scenarios.

Figure 11A – Maximum separation distance as a function of the 5G mobile station I/N protection requirement – Englewood

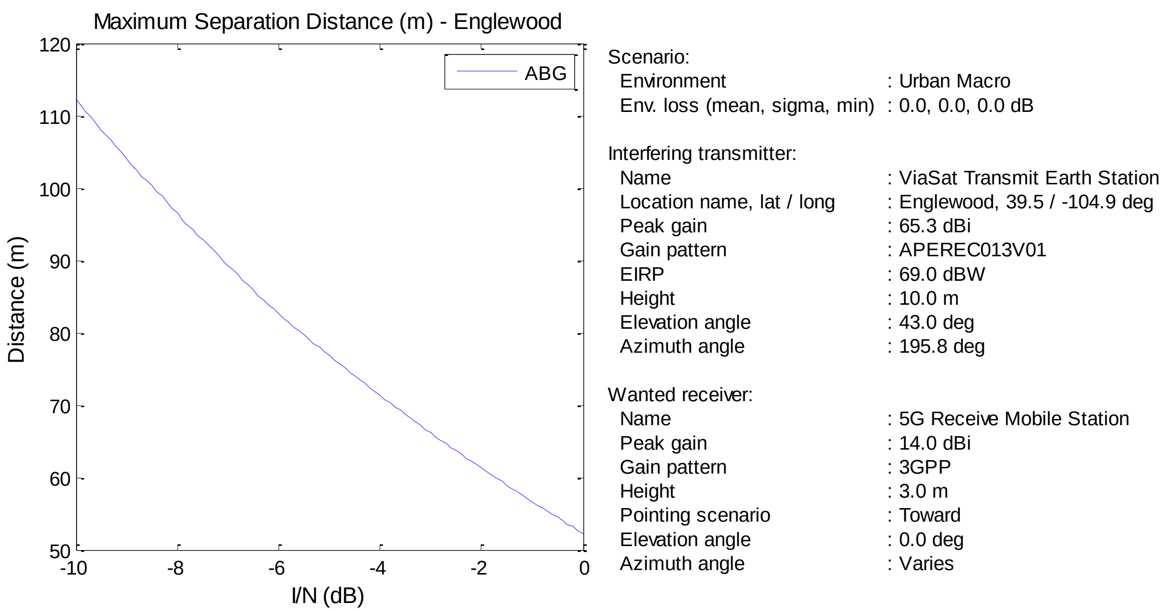


Figure 11B – Maximum separation distance as a function of the 5G mobile station I/N protection requirement – Anchorage

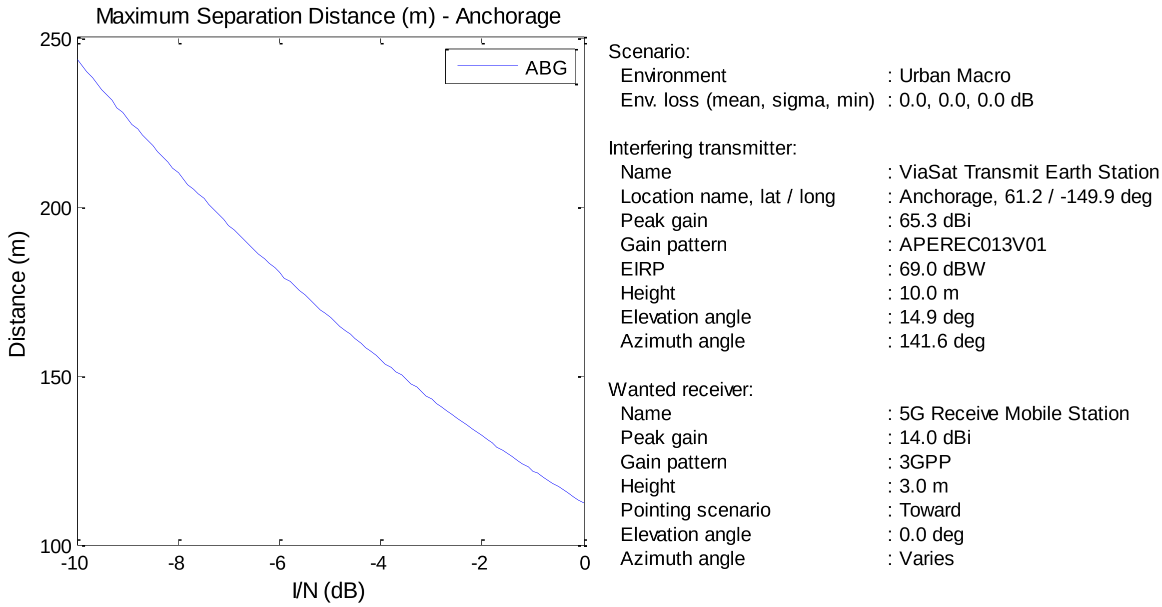
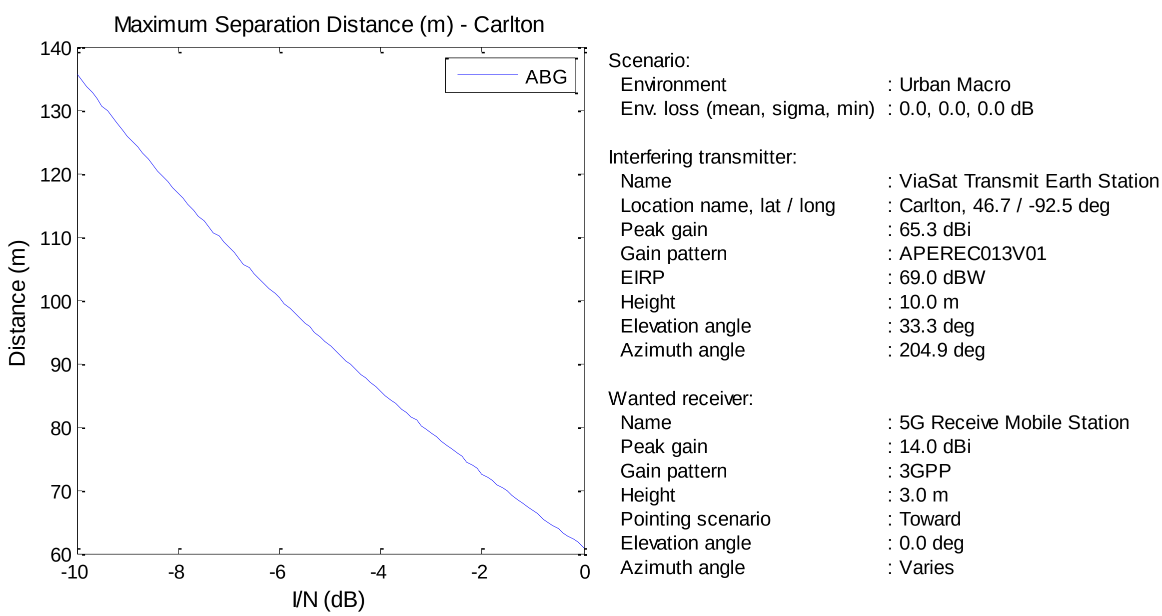


Figure 11C – Maximum separation distance as a function of the 5G mobile station I/N protection requirement – Carlton



4.3 NGSO FSS earth station into 5G base station

The maximum separation distance around a NGSO earth station needed to protect a 5G base station is calculated in the same manner as for the GSO case, except that the NGSO earth station pointing is a function of time. The following plots show the time dependence of the NGSO earth station pointing direction for a single pass of one satellite, and the resulting maximum separation distance. Again, the propagation model is based on either ITU-R Recommendation P.452 or the ABG model. Figures 12A and 12B illustrate the time dependency of the azimuth and elevation angles of the NGSO satellite studied here.

Figure 12A – NGSO FSS earth station azimuth angle

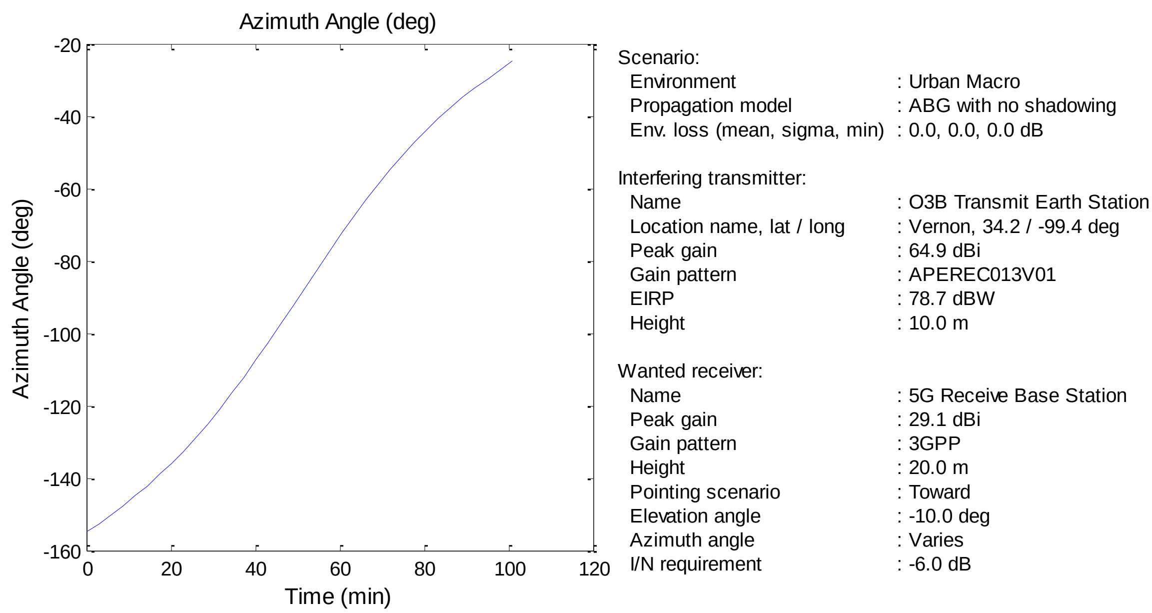


Figure 12B – NGSO FSS earth station elevation angle

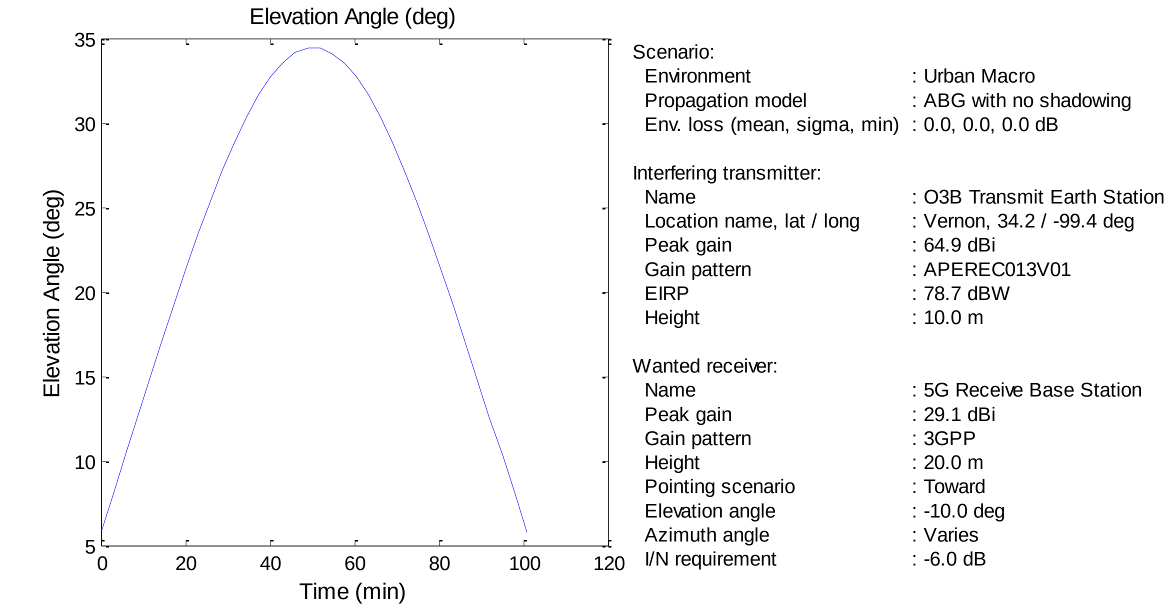


Figure 13A - 5G base station pointed toward NGSO FSS earth station (Vernon)
Propagation model: P.452

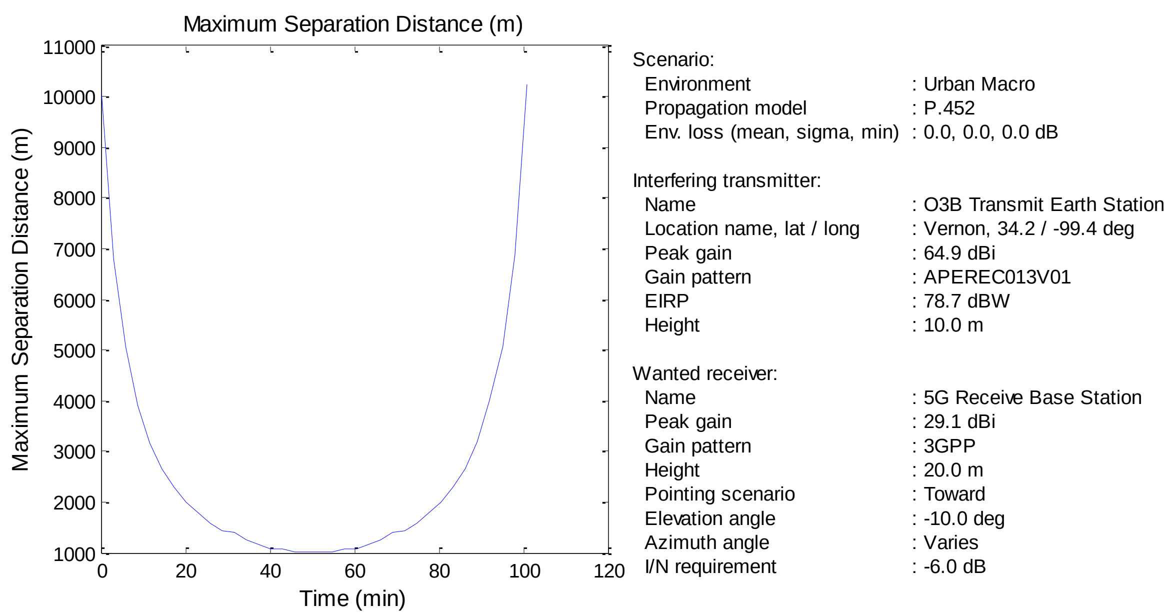
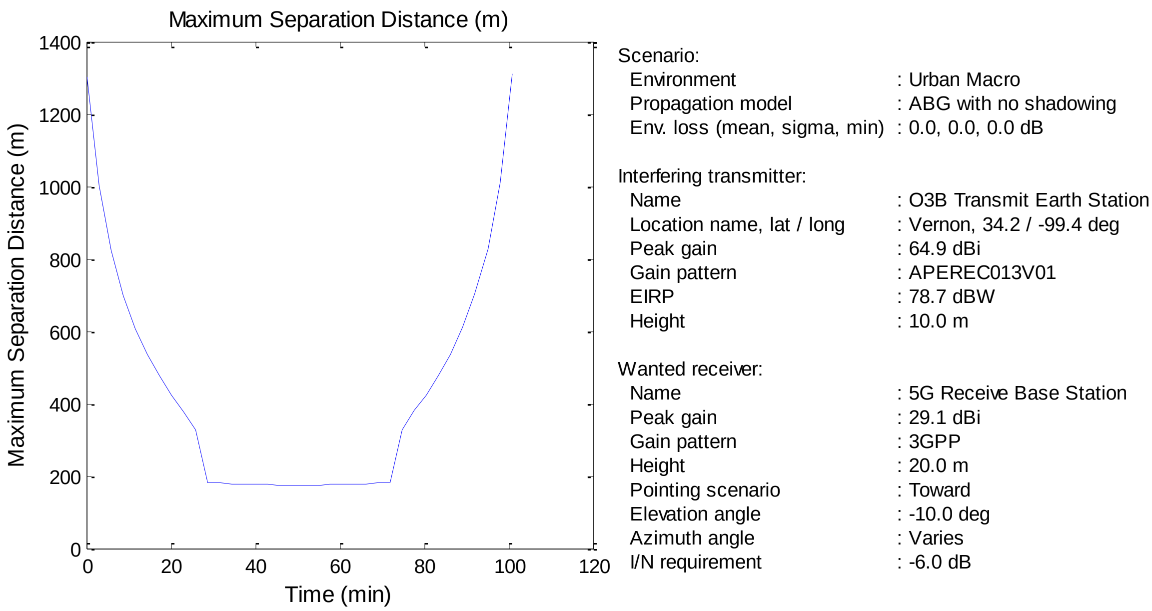


Figure 13B - 5G base station pointed toward NGSO FSS earth station (Vernon)
Propagation model: ABG



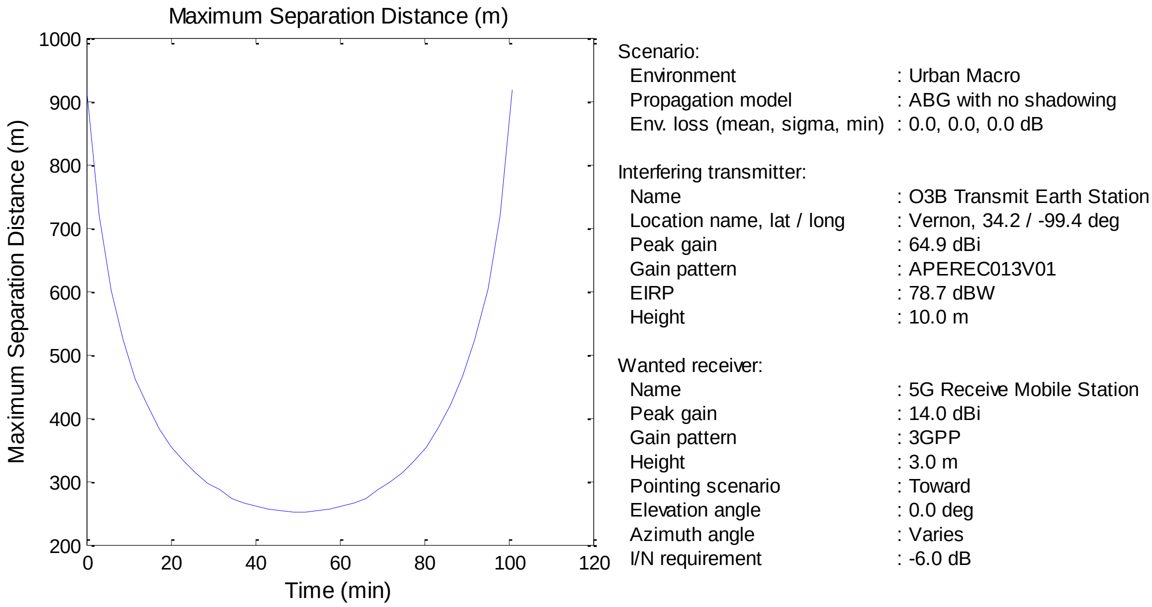
These results show that the maximum separation distance around the NGSO earth station needed to meet the 5G base station protection criterion is on the order of 1.3 to 10 km, using the P.452 propagation model[1], and 0.2 to 1.3 km for the ABG model. However, this worst-case interference occurs for a short time during the satellite pass, and only for base stations that are pointed toward the NGSO earth station. The separation distance is significantly reduced as the satellite passes more directly overhead and the NGSO earth station elevation angle increases, and when the 5G base station is not pointed directly toward the earth station.

4.4 NGSO FSS earth station into 5G mobile station

The following plots illustrate the separation distance between a NGSO FSS transmit earth station and a 5G receive mobile station. As for the GSO case, it should also be noted that given a 5G mobile station would be beam-formed towards its corresponding base station, the likelihood of its beam being directed at the NGSO earth station should generally be quite low.

[1] As also evident from the discontinuous behavior of P.452 in figure 7B, P.452 faces difficulties in adequately predicting propagation loss in short distances as this model was developed based on data from long paths and was probably not intended to be used for distances as short as the ones addressed in this study. As such, we are of the view that ABG model presents a much better alternative to P.452 for this case. Therefore, we have only used the ABG model for the case of NGSO earth stations.

Figure 14 - 5G mobile station pointed toward NGSO FSS earth station (Vernon)
Propagation model: ABG



These results show that the maximum separation distance around the NGSO earth station needed to meet the 5G mobile station protection criterion is on the order of 900 m. Again, this worst-case interference occurs for a short time during the satellite pass, and only for mobile stations that are pointed toward the NGSO earth station. The separation distance is significantly reduced as the satellite passes more directly overhead and the NGSO earth station elevation angle increases.

Table 4 summarizes the maximum separation distances around the FSS transmit earth station for the cases considered in this analysis.

Table 4 - Summary of results – FSS earth station into 5G station

Scenario	Location	Elevation angle (deg)	Maximum Separation Distance	
			P.452	ABG
GSO FSS earth station into 5G base station	Englewood, CO	43.01	155 m	135 m
	Anchorage, AK	14.93	716 m	172 m
	Carlton, MN	33.31	164 m	145 m
GSO FSS earth station into 5G mobile station	Englewood, CO	43.01	-	83 m
	Anchorage, AK	14.93	-	180 m
	Carlton, MN	33.31	-	100 m
NGSO FSS earth station into 5G base station	Vernon, TX	5 - 35	1 - 10 km	200 - 1300 m
NGSO FSS earth station into 5G mobile station	Vernon, TX	5 - 35	-	200 - 900 m

For the cases considered in the analysis, the required maximum separation distance to protect a 5G base station pointing toward the GSO FSS earth station is in the range of around 135 to 716 meters, depending on the elevation angle of the GSO earth station and the assumed propagation conditions. The required separation distance around a NGSO is time dependent and is in the range of 200 m – 10 km, again depending on the elevation angle of the NGSO earth station and the assumed propagation conditions.

The maximum separation distance around a GSO earth station required to protect the 5G mobile station is less than 180 m for the cases considered in this analysis. For the NGSO case, the separation distance varies with time within a range of around 200 – 900 m.

The impact on the separation distance of varying the 5G protection requirement (I/N) over a range of -10 to 0 dB is illustrated in the following figures.

Figure 15A – Maximum separation distance as a function of the 5G base station I/N protection requirement – P.452

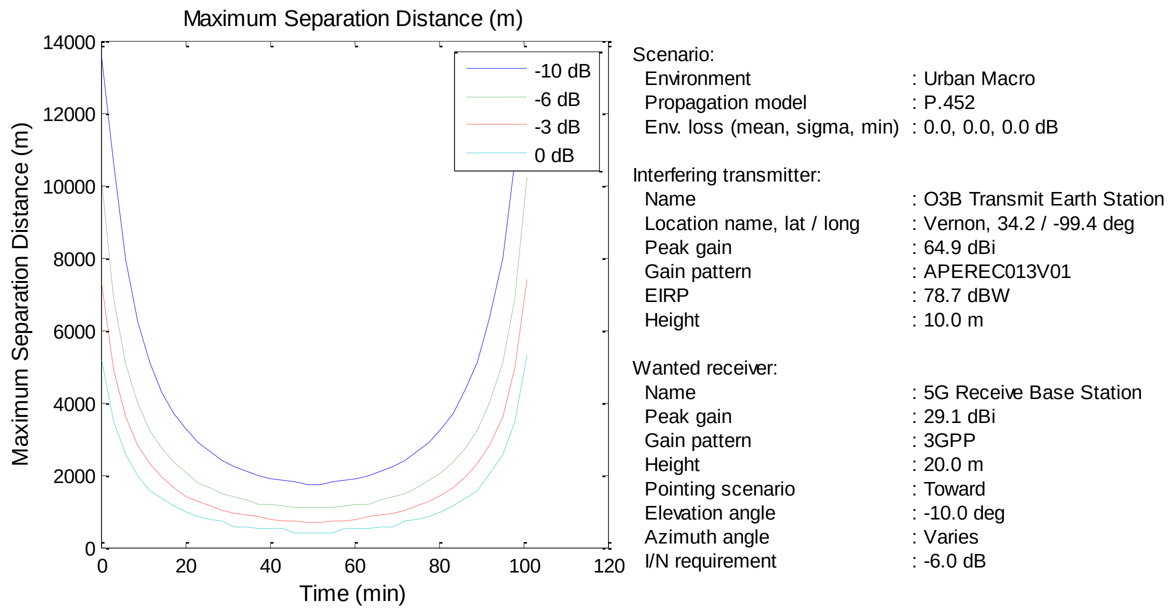


Figure 15B – Maximum separation distance as a function of the 5G base station I/N protection requirement – ABG

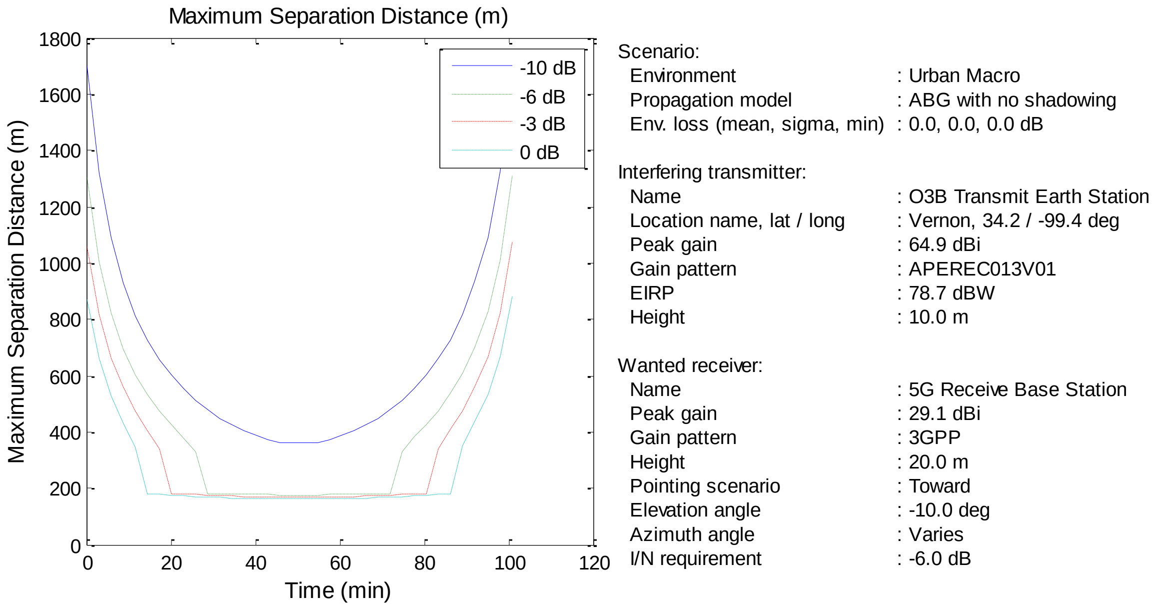
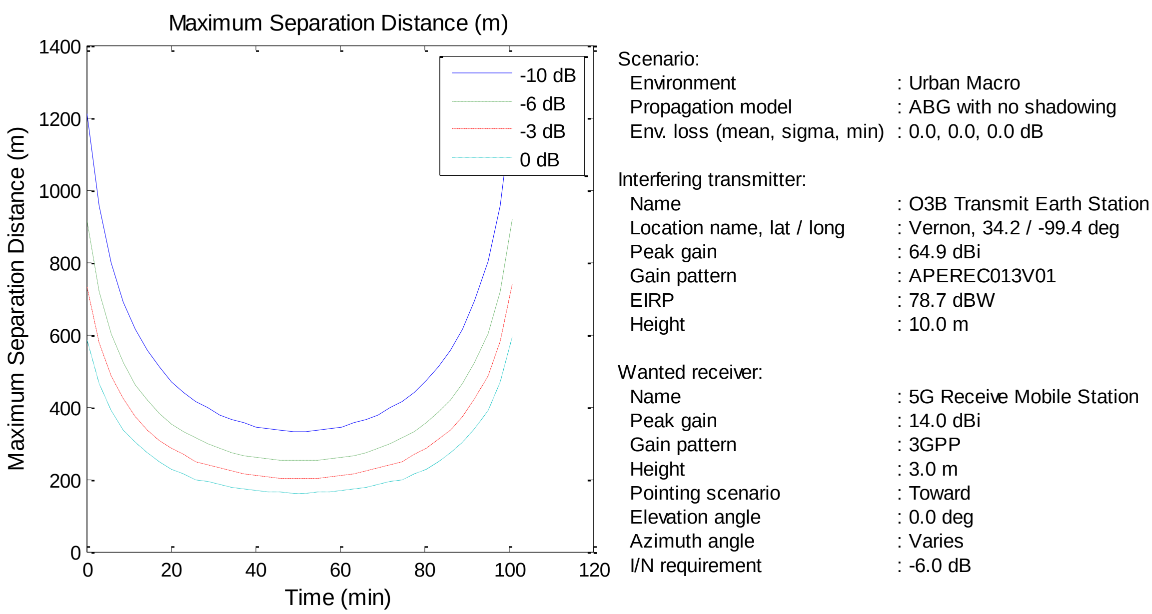


Figure 16 – Maximum separation distance as a function of the 5G mobile station I/N protection requirement – ABG



5 Power flux density (pfd) as a coordination trigger for protection of 5G terrestrial system

In order to arrive at a reasonable coordination trigger level, we note that assuming an acceptable intra-system carrier to noise and interference (CINR) of -3 dB as the onset of outage of a typical cellular base station, one can translate into I/N as follows:

$I_{ext}/N = C/N - C/I_{ext}$; where C is the received wanted signal level of the terrestrial system, $N = N_{th} + I_{intra}$ is the sum of thermal noise and intra-system interference of the terrestrial system (or CINR of the terrestrial system), and I_{ext} is the interference added to the receiver noise floor due to external interference, in this case from FSS earth station transmissions. Therefore, $I_{ext}/N = -6$ dB represents a reasonable value associated with a C/I_{ext} of 3 dB.

Next, the 5G protection requirement can be defined as a power flux density level at the 5G receive antenna using the following expression:

$$pfd = I/N + 10\log(4\pi/\lambda^2) - G + k + T$$

where:

pfd = power flux density, dBW/m^2 in 1 Hz
I/N = interference-to-noise protection requirement, dB
λ = wavelength, m
G = 5G receive antenna gain, dBi
k = Boltzmann constant, −228.6 dBJ/K
T = 5G receive noise temperature, K

The following table shows the resulting protection requirement expressed as a pfd level using the 5G receiver characteristics described earlier in our previous filing (please see Reply Comment of Intel Corporation dated February 26, 2016).

Table 5 - 5G protection requirement expressed as pfd level

Parameter	Base Station	CPE	Mobile Station
I/N requirement (dB)	-6	-6	-6
Frequency (GHz)	28	28	28
Receive antenna gain (dBi)	29.1	23	14
Implementation loss (dB)	3	3	3
Receive noise figure (dB)	6.5	7.5	8.5
Receive noise temperature (K)	1005.4	1340.8	1763.0
Boltzmann constant (dBJ/K)	-228.6	-228.6	-228.6
Noise power density (dBW/Hz)	-198.6	-197.3	-196.1
Wavelength (m)	0.011	0.011	0.011
PFD (dBW/m^2 in 1 Hz)	-180.3	-172.9	-162.7
PFD (dBm/m^2 in 1 MHz)	-90.3	-82.9	-72.7

This pfd protection level could be considered as a coordination threshold where if the level is exceeded, the FSS and 5G operators would coordinate, for example, through implementing interference mitigation techniques such as shielding.

6 Conclusions

This study addresses the interference condition between a representative FSS systems and 5G base and mobile stations.

The analysis shows that for the system characteristics and deployment scenarios considered here, the required maximum separation distance to protect a 5G base station pointing toward the GSO FSS earth station is in the range of around 135 to 716 meters, depending on the elevation angle of the GSO earth station and the assumed propagation conditions. The analysis also shows that the maximum separation distance required to protect the 5G mobile station is less than 180 m for the cases considered in this analysis.

The required separation distance around a NGSO earth station is time dependent and is in the range of 200 m to 10 km, again depending on the elevation angle of the NGSO earth station and the assumed propagation conditions. However, this worst-case interference occurs for a short time during the satellite pass, and only for base stations that are pointed toward the NGSO earth station. The separation distance is significantly reduced as the satellite passes more directly overhead and the NGSO earth station elevation angle increases. The required separation distance will be further reduced for base stations pointed away from the NGSO earth station.

The maximum separation distance around a NGSO earth station required to protect the 5G mobile station varies with time within a range of around 200 – 900 m.

The study also considers pfd levels as a coordination trigger to protect the terrestrial 5G systems, and arrives at a protection level of -90.3 dBm/m^2/MHz.

Annex 1

Globecom '16 ABG Propagation Model

(Excerpt from "5G Channel Model for bands up to 100 GHz", Revised version 2.0, March 2016)
(Source: http://www.5gworkshops.com/5GCM.html)

6.2 Path loss models

To adequately assess the performance of 5G systems, multi-frequency path loss (PL) models, LOS probability, and blockage models will need to be developed across the wide range of frequency bands and for operating scenarios. Three PL models are considered in this white paper; namely the close-in (CI) free space reference distance PL model [Andersen 1995][Rappaport 2015][SunGCW2015], the close-in free space reference distance model with frequency-dependent path loss exponent (CIF) [MacCartney 2015], [Haneda 2016] and the Alpha-Beta-Gamma (ABG) PL model [Hata 1980] [Piersanti ICC2012][[MacCartney GC2013] [MacCartney 2015] [Haneda 2016]. These models are described in the following text and are then applied to various scenarios. Note that the path loss models currently used in the 3GPP 3D model is of the ABG model form but with additional dependencies on base station or terminal height, and with a LOS breakpoint. It may also be noted that the intention is to have only one path loss model (per scenario and LOS/NLOS) but that the choice is still open for discussion.

Table 6 shows the parameters of the CI, CIF, and ABG path loss models for different environments for omni-directional antennas. It may be noted that the models presented here are multi-frequency models, and the parameters are invariant to carrier frequency and can be applied across the 0.5-100 GHz band.

The CI PL model is given as [Rappaport 2015][MacCartney 2015] [SunGCW2015]

$$\mathrm{PL}^{CI}(f,d)[dB] = \mathrm{FSPL}(f,1\,m) + 10n\log_{10}\left(\frac{d}{1\,m}\right) + X_{\sigma}^{CI}, \quad (7)$$

where f is the frequency in Hz, n is the PLE, d is the distance in *meters*, X_{σ}^{CI} is the shadow fading (SF) term in dB, and the free space path loss (FSPL) at 1 m, and frequency f is given as:

$$\mathrm{FSPL}\ (f,1\,m) = 20\log_{10}\left(\frac{4\pi f}{c}\right), \quad (6)$$

where c is the speed of light.

The ABG PL model is given as :

$$\begin{aligned}\mathrm{PL}^{ABG}(f,d)[dB] = {} & 10\alpha\log_{10}(d) + \beta \\ & + 10\gamma\log_{10}(f) + X_{\sigma}^{ABG}\end{aligned}, \quad (7)$$

where α captures how the PL increase as the transmit-receive in distance (in meters) increases, β is a the floating offset value in dB, γ captures the PL variation over the frequency f in GHz,, and X_{σ}^{ABG} is the SF term in dB.

The CIF PL model is an extension of the CI model, and uses a frequency-dependent path loss exponent given by:

$$\mathrm{PL}^{CIF}(f,d)[dB] = \mathrm{FSPL}(f,1\,m) + 10n\left(1 + b\left(\frac{f-f_0}{f_0}\right)\right)\log_{10}\left(\frac{d}{1\,m}\right) + X_{\sigma}^{CIF} \quad (9)$$

where n denotes the path loss exponent (PLE), and b is an optimization parameter that captures the slope, or linear frequency dependency of the path loss exponent that balances at the centroid of the frequencies being modeled (e.g., path loss increases as f increases when b is positive). The term f_0 is a fixed reference frequency, the centroid of all frequencies represented by the path loss model, found as the weighed sum of measurements from different frequencies, using the following equation:

$$f_0 = \frac{\sum_{k=1}^{K} f_k N_K}{\sum_{k=1}^{K} N_K} \quad (10)$$

where K is the number of unique frequencies, and N_k is the number of path loss data points corresponding to the k^{th} frequency f_k. The input parameter f_0 represents the weighted frequencies of all measurement (or Ray-tracing) data applied to the model. The CIF model reverts to the CI model when $b = 0$ for multiple frequencies, or when a single frequency f = f_0 is modelled. For InH, a dual-slope path loss model might provide a good fit for different distance zones of the propagation environment. Frequency dependency is also observed in some of the indoor measurement campaigns conducted by co-authors. For NLOS, both a dual-slope ABG and dual-slope CIF model can be considered for 5G performance evaluation (they each require 5 modelling parameters to be optimized), and a single-slope CIF model (that uses only 2 optimization parameters) may be considered as a special case for InH-Office [MacCartney 2015]. The dual-slope may be best suited for InH-shopping mall or large indoor distances (greater than 50 m). The dual slope InH large scale path loss models are as follows:

Dual-Slope ABG model :

$$PL_{Dual}^{ABG}(d) = \begin{cases} \alpha_1 * 10\log_{10}(d) + \beta_1 + \gamma * 10\log10(f) & 1 < d \le d_{BP} \\ \alpha_1 * 10\log_{10}(d_{BP}) + \beta_1 + \gamma * 10\log10(f) + \alpha_2 * 10\log_{10}(\frac{d}{d_{BP}}) & d > d_{BP} \end{cases} \quad (11)$$

Dual-Slope CIF model:

$$PL_{Dual}^{CIF}(d) = \begin{cases} FSPL(f,1m) + 10n_1\left(1 + b_1\left(\frac{f - f_0}{f_0}\right)\right)\log_{10}(\frac{d}{1m}) & 1 < d \le d_{BP} \\ FSPL(f,1m) + 10n_1\left(1 + b_1\left(\frac{f - f_0}{f_0}\right)\right)\log_{10}(\frac{d_{BP}}{1m}) + 10n_2\left(1 + b_2\left(\frac{f - f_0}{f_0}\right)\right)\log_{10}(\frac{d}{d_{BP}}) & d > d_{BP} \end{cases} \quad (12)$$

In the CI PL model, only a single parameter, the path loss exponent (PLE), needs to be determined through optimization to minimize the SF standard deviation over the measured PL data set [SunGCW2015] [Sun VTCS2016] [Rappaport2015]. In the CI PL model there is an anchor point that ties path loss to the FSPL at 1 m, which captures frequency-dependency of the path loss, and establishes a uniform standard to which all measurements and model parameters may be referred. In the CIF model there are 2 optimization parameters (n and b), and since it is an extension of the CI model, it also uses a 1 m free-space close-in reference distance path loss anchor. In the ABG PL model there are three optimization parameters which need to be optimized to minimize the standard deviation (SF) over the data set, just like the CI and CIF PL models [MacCartney2015][Sun VTCS2016]. Closed form expressions for optimization of the model parameters for the CI, CIF, and ABG path loss models are given in [MacCartney 2015], where it was shown that indoor channels experience an increase in the PLE value as the frequency increases, whereas the PLE is not very frequency dependent in outdoor UMa or UMi scenarios [Rappaport 2015],[SunGCW2015],[Thomas VTCS2016],[Sun VTCS2016]. The CI, CIF, and ABG models, as well as cross-polarization forms and closed-form expressions for optimization are given for indoor channels in [MacCartney 2015].

Table 6. CI, CIF and ABG model parameters for different environments

Scenario	CI/CIF Model Parameters	ABG Model Parameters
UMa- LOS	$n=2.0$, $\sigma_{SF} = 4.1$ dB	NA
UMa- nLOS	$n=3.0$, $\sigma_{SF}= 6.8$ dB	$\alpha=3.4$, $\beta=19.2$, $\gamma=2.3$, $\sigma_{SF} = 6.5$ dB
UMi-Street Canyon-LOS	$n=2.1$, $\sigma_{SF} = 3.76$ dB	NA
UMi-Street Canyon-nLOS	$n=3.17$, $\sigma_{SF} = 8.09$ dB	$\alpha=3.53$, $\beta=22.4$, $\gamma=2.13$, $\sigma_{SF} = 7.82$ dB
UMi-Open Square-LOS	$n=1.85$, $\sigma_{SF} = 4.2$ dB	NA
UMi-Open Square-nLOS	$n=2.89$, $\sigma_{SF} = 7.1$ dB	$\alpha=4.14$, $\beta=3.66$, $\gamma=2.43$, $\sigma_{SF} = 7.0$ dB
InH-Indoor Office-LOS	$n=1.73$, $\sigma_{SF} = 3.02$ dB	NA
InH-Indoor Office-nLOS single slope (FFS)	$n=3.19$, $b=0.06$, $f_0= 24.2$ GHz, $\sigma_{SF} = 8.29$ dB	$\alpha=3.83$, $\beta=17.30$, $\gamma=2.49$, $\sigma_{SF} = 8.03$ dB
InH-Indoor-Office nLOS dual slope	$n_1=2.51$, $b_1=0.12$, $f_0= 24.1$ GHz, $n_2=4.25$, $b_2=0.04$, $d_{BP} = 7.8$ m, $\sigma_{SF}=7.65$ dB	$\alpha_1=1.7$, $\beta_1=33.0$, $\gamma=2.49$, $d_{BP} = 6.90$ m $\alpha_2=4.17$, $\sigma_{SF} = 7.78$ dB
InH-Shopping Malls-LOS	$n=1.73$, $\sigma_{SF} = 2.01$ dB	NA
InH-Shopping Malls-nLOS single slope (FFS)	$n=2.59$, $b=0.01$, $f_0= 39.5$ GHz, $\sigma_{SF} = 7.40$ dB	$\alpha=3.21$, $\beta=18.09$, $\gamma=2.24$, $\sigma_{SF} = 6.97$ dB
InH-Shopping Malls-nLOS dual slope	$n_1=2.43$, $b_1=-0.01$, $f_0= 39.5$ GHz, $n_2=8.36$, $b_2=0.39$, $d_{BP} = 110$ m, $\sigma_{SF} = 6.26$ dB	$\alpha_1=2.9$, $\beta_1=22.17$, $\gamma=2.24$, $d_{BP} = 147.0$ m $\alpha_2=11.47$, $\sigma_{SF} = 6.36$ dB

Note: the parameters of ABG model in the LOS conditions are not mentioned for the UMa and UMi scenarios because the α is almost identical to the PLE of the CI model, and also γ is very close to 2, which indicates free space path loss with frequency, and this is modelled in both the CI and CIF models within the first meter of free space propagation.