Sharing Considerations Between Small Cells and Geostationary Satellite Networks in the Fixed-Satellite Service in the 3.4-4.2 GHz Frequency Band

Executive Summary

The Satellite Industry Association ("SIA") submits this study of the sharing between proposed small cell systems and geostationary satellite networks in the fixed-satellite service (FSS) in the 3.4-4.2 GHz frequency band for inclusion in the record in response to the FCC's Notice of Proposed Rulemaking ("NPRM") on Small Cells.[1] The study supplements the information provided in SIA's comments regarding the need for enforceable exclusion zones around earth stations to protect FSS services.[2]

The results of the sharing study confirm that exclusion zones will be required. Specifically, the study demonstrates that the following minimum separation distances must be maintained between a small cell and a receiving FSS earth station in order to protect the latter station from excessive levels of interference:

- up to 487.0 km for in-band interference protection;
- up to 36.6 km for out-of-band interference protection; and
- up to 18.91 km for LNA/LNB overdrive interference protection.

In performing the study, SIA has made assumptions regarding the technical characteristics of small cells based upon the FCC NPRM and the comments of various parties.[3] Furthermore, the study considers a single interferer only and does not address the potential interference from an aggregation of small-cell devices. Thus, depending on the final characteristics of small cells, and their expected deployment characteristics, the above distances might need to be revised.

1 Introduction and Scope

The study was performed using the software (simulation) tool Visualyse, which can provide output in the form of protection zone contours based on terrain models. As noted above, SIA has made certain assumptions regarding the operational parameters of the proposed small cells, and these assumptions are described in the following sections.

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[1] *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band*, Notice of Proposed Rulemaking and Order, GN Docket No. 12-354, FCC 12-148 (rel. Dec. 12, 2012).

[2] *See* Comments of the Satellite Industry Association, GN Docket No. 12-354 ("SIA Comments") at 13-17; Reply Comments of the Satellite Industry Association, GN Docket No. 12-354 ("SIA Reply Comments") at 14-20.

[3] *See* Google Comments at 11-12, Motorola Comments at 6-8, Qualcomm Comments at 18, Redline Communications Comments at 4 and Wireless Internet Service Providers Association Comments at 18, *filed in* GN Docket No. 12-354.

2 In-band Interference

The Radiocommunication Sector of the International Telecommunications Union ("ITU-R") previously conducted a thorough sharing analysis between transmitting IMT-Advanced wireless systems and FSS receiving systems operating in the 3.4-4.2 GHz and 4.5-4.8 GHz bands. The results of the ITU-R study are contained in Report ITU-R M.2109. This chapter provides a similar study for in-band interference, using typical FSS parameters and assumed operating parameters for the small cell operations.

2.1 FSS System parameters and criteria

Table 1 contains typical downlink FSS parameters for the 3.5 GHz band that were used in the study.

Table 1

Typical downlink FSS parameters in the 3.5 GHz band

Parameter	Typical value
Range of operating frequencies	3550-3650 MHz
Typical elevation angles	5°, 30°
Antenna reference pattern	Recommendation ITU-R S.465-5
Antenna diameter	2.4 m
Antenna height above ground	3.0 m
Receiving system noise temperature	100 K

The elevation angles were chosen to reflect the range of elevations towards satellites across the geostationary arc providing service to earth stations located in the United States.

Two interference criteria were identified for use when assessing the interference from small cells to FSS:

- Single-entry interference
  - Short term: I/N = -1.3 (not to exceed for more than 0.001667% of the time)
  - Long term: I/N = -10 (not to exceed for more than 20% of the time)

The single-entry interference criteria values are obtained from Report ITU-R M.2109. The long term interference standard is defined in Recommendation ITU-R S.1432-1, and the short term interference standard is defined in Recommendation ITU-R SF.1006.

The aggregate interference case is still being analyzed. An update of this study including the aggregate interference case is expected to be submitted later.

2.2 Small Cell Parameters Including the Interference Criterion

The Small Cell parameters assumed for the studies are provided in Table 2, below.[4]

Table 2

Assumed Small Cell base station parameters

Parameter	Value
EIRP density range: Small Cell	-10, 0, 13 dBW/MHz
Antenna height above ground	1 m
Antenna direction	Peak towards FSS receiving Earth station
Emission Bandwidth	1 MHz

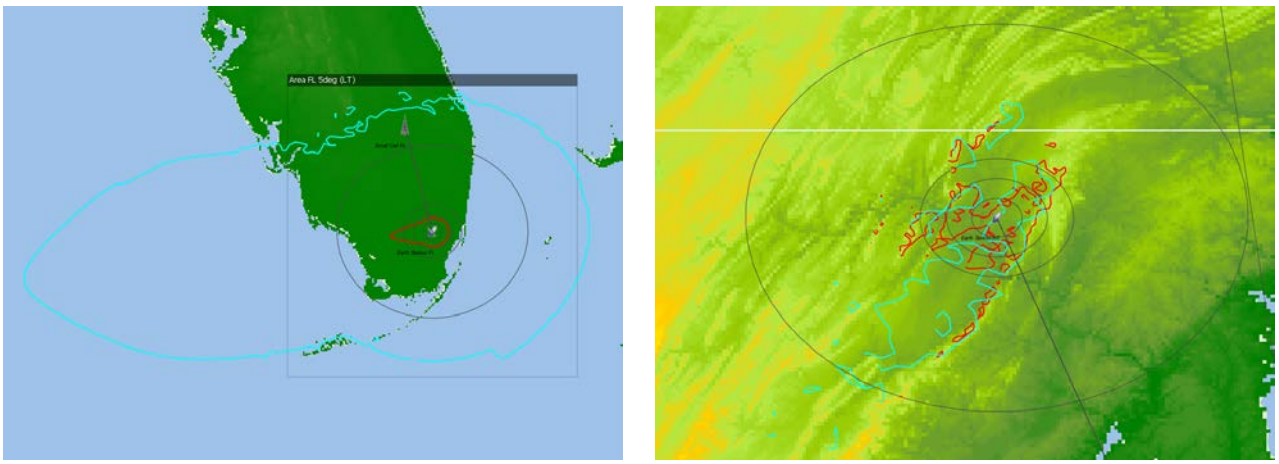
2.3 Simulation

An interference scenario using the above assumptions was modeled in Visualyse. The analysis used the propagation model contained in Recommendation ITU-R P.452-14, which is commonly used in ITU sharing studies. The analysis used the terrain model USGS GTOPO30, a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). The impact of terrain was investigated for two example locations: Maryland and Florida. These two locations were chosen to consider a relatively flat terrain scenario (Florida) and a hilly terrain scenario (Maryland). This section provides a brief overview of the Visualyse simulation.

Figure 1

Map Showing Minimum Required Distance Separation
Between a Small Cell Station and an FSS Receiving Earth Station

(Earth Station Elevation Angle: 5°, Small Cell EIRP Density: 0 dBW/Hz)



Notes:

1) The circles shown in black are 10, 20, 30 and 100 kilometers in radius.
2) The contour in light blue shows the short-term interference criteria, and the red contour shows the long-term interference criteria.

[4] *See* footnote 3 above.

Figure 1 shows FSS receiving earth stations located in Florida and Maryland, each with an antenna height of 3m, and the base station of a small cell transmitting with an EIRP density of 0 dBW/MHz. Areas where the protection criteria defined in Section 2.1 are not met were calculated using the Visualyse tool and are marked on the appropriate map.

The following contours are shown in Figure 1:

- The contour in light blue depicts the area where the interference exceeds the threshold level of I/N -1.3 dB for the single, short-term interference case. The simulation is calculated using a grid with 6 km resolution.
- The contour in red depicts the area where the interference exceeds the threshold level of I/N of -10 dB for the single, long-term interference case. The simulation is calculated using a grid with 2 km resolution.

As demonstrated in Figure 1, the maximum separation distance varies significantly based on the topography.

2.4 Results

The results are contained in Table 3 below. The plots generated by the simulations in Visualyse can be found in Annex A and are shown for each case.

Table 3

Maximum required separation distances (in km) due to in-band interference

Location	FSS antenna	Interference	Small Cell EIRP (dBW)		
(-)	Elevation (°)	Mode	-10	0	13
Florida	5	Long-term	31.2	43.4	63.5
		Short-term	363.7	425.3	487.0
	30	Long-term	11.4	21.1	35.6
		Short-term	91.2	238.1	410.0
Maryland	5	Long-term	60.1	98.7	107.4
		Short-term	72.3	141.9	252.5
	30	Long-term	64.9	98.7	107.4
		Short-term	72.3	141.9	252.5

The data contained in Table 3 lead to the following conclusions:

- In order to mitigate long-term interference, a distance separation of up to 107.4 kilometers is required between a transmitting small cell station and an FSS receiving Earth station.

- In order to mitigate short-term interference, a distance separation of up to 487.0 kilometers is required between a transmitting small cell station and an FSS receiving Earth station.

- Separation distances for Maryland can be larger than those for Florida. This is attributed to the fact that the Maryland site is located at a higher ground elevation and the specific terrain provides an increased line of sight.

  The topography around an FSS Earth station influences the results significantly. For the flat area surrounding the Florida Earth station, the results shows a decrease in separation distance when the Earth station elevation is increased from 5° to 30°. However, in the

mountainous area of the Hagerstown, Maryland Earth station, elevation angle has little impact.

3 Unwanted Emission Interference[5]

A transmitting station produces signals outside of its pass-band and assigned bandwidth that may fall within the pass-band of a receiver operating in an adjacent frequency band. If the power of these unwanted emissions of the transmitting station is high enough, it could prevent the adjacent band receiver from successfully recovering the signal intended for it.

In order to reduce the risk of such interference, a transmitting station utilizes one or more filters to attenuate the power of its unwanted emissions.[6] In conjunction with the installation of filters, the impact of unwanted emissions of a transmitting station can potentially also be reduced by increasing the frequency separation between the transmitting cell and the impacted FSS receiving Earth station.[7]

In its NPRM, the Commission requested comment on the appropriate out-of-band emission limit for small cells operating in the 3.55-3.65 GHz band. The Commission also noted that under the existing rules for the 3.65-3.7 GHz band, the out-of-band emission limit is 43+logP dB, where "P" represents the output power of the transmitter, specified in Watts, within the license band of operation.[8]

The Radiocommunication Sector of the International Telecommunications Union ("ITU-R") conducted a thorough sharing analysis between transmitting IMT-Advanced wireless systems and FSS receiving systems operating in the 3.4- 4.2 GHz and 4.5- 4.8 GHz bands. The results of the ITU-R study are contained in Report ITU-R M.2109. As part of this analysis, the impact of unwanted emission interference from a transmitting IMT-Advanced station into an FSS receiving Earth station was studied for a number of unwanted emission masks. The analysis in ITU-R Report M.2109 showed that a single transmitting cell that is compliant with the 43+10logP out-of-band emission mask must maintain a geographic separation distance of up to 18 kilometers relative to an FSS receiving earth station in order to protect this latter station from excessive levels of

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[5] In other sharing studies, the term "out-of-band" interference has been used. However, out-of-band emissions are a subset of unwanted emissions (any emission outside of a station's assigned bandwidth) that also includes spurious emissions. Out-of-band emissions occur in the out-of-band domain, which is defined as the range immediately outside the station's assigned bandwidth and up to 250% of the emission's necessary bandwidth. Emissions beyond this range would be considered spurious emissions. In order to avoid confusion with these terms, the broader term "unwanted emission" is used here. *See* Appendix 3 to the ITU Radio Regulations.

[6] An FSS receiving Earth station also employs filters to reduce the power level of out-of-band frequencies that it would otherwise be subjected to from other transmitters operating in adjacent frequency bands.

[7] This assumes that the attenuation of the filter of the (interfering) transmitting station and/or the (interfered with) receiving station increases with increasing frequency offset relative to its primary pass-band.

[8] Pursuant to Section 90.1323(a), compliance with the 43+10Log P limit is based on the use of measurement instrumentation employing a resolution bandwidth of 1 MHz or less, but at least one percent of the emission bandwidth of the fundamental emission of the transmitter, provided the measured energy is integrated over a 1 MHz bandwidth.

interference.[9] Other studies employing different unwanted emission masks with different operating assumptions indicated that distance separations of up to 51 kilometers would be required.[10]

SIA conducted its own analysis on the impact of the unwanted emissions of a small cell transmitter on an FSS receiving Earth station. For SIA's analysis, the following conditions were assumed:

- interference threshold I/N = -20 dB[11]
- two out-of-band emissions masks:
  - 43+10log(P) as mentioned in the NPRM
  - 45 dB attenuation of the 1st adjacent channel (from Table 6 of Report ITU-R M.2109)
- Interfering small cell frequency directly adjacent to FSS signal

The results are contained in Table 4 and show that a distance separation of up to 36.6 kilometers must be maintained between a transmitting cell station and an FSS receiving Earth station. The simulation is calculated using a grid with 0.5 km resolution. The plots generated by the simulations in Visualyse can be found in Annex B and are shown for each case.

Table 4

Maximum separation distance due to out-of-band interference

Location	**FSS antenna**	**Out-of-band mask**	**Small Cell EIRP (dBW)**		
(-)	**Elevation (°)**		**-10**	**0**	**13**
Florida	5	43+10log(P)	8.9	8.9	8.9
		45	3.8	7.8	18.9
	30	43+10log(P)	2.4	2.4	2.4
		45	- (1)	1.9	4.8
Maryland	5	43+10log(P)	4.1	4.1	4.1
		45	1.0	3.1	36.6
	30	43+10log(P)	4.1	4.1	4.1
		45	0.9	3.1	15.5

(1) The distance was not calculated as it was below the sample size of the simulation.

As can been seen in Table 4, for the case of an FSS receiving earth station located in Florida with an antenna height of 3m above ground and a small cell transmitting with an EIRP density of 13 dBW/MHz, the results show that:

- The interference threshold is exceeded within a maximum distance of 36.6 km away from the FSS receiving earth station.

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[9] *See* Annex H of Report ITU-R M.2109.

[10] *See* Section 8.1.4.1 of Report ITU-R M.2109.

[11] This threshold is derived from Recommendation ITU-R S.1432, which specifies that the degradation to an FSS link should not exceed 1% (or -20 dB) from all non-primary sources of interference – which includes out-of-band interference. For this calculation, it is assumed that the Small Cell is the only non-primary source of interference and that the link degradation requirement could not be exceeded more than 20% of the time. It should be noted, however, that there may be other non-primary sources of interference in various parts of the C-band (*e.g.*, non-federal radiolocation and ultra-wide band devices under Part 15). As a result, it may not be appropriate to allocate the entire 1% limit on non-primary interference into FSS to the out-of-band impact of the proposed small cells alone.

4 LNA/LNB Overdrive

An FSS receiving Earth station typically employs a Low Noise Amplifier (LNA) or Low Noise Block (LNB) amplifier at (or very close to) the output ports of its receiving antenna in order to amplify the received satellite signal. These amplifiers are wideband devices with the frequency of operation typically ranging from 3.4-4.2 GHz or 3.7-4.2 GHz when the receiving station is configured to receive C-band satellite transmissions. Although a satellite receiver is tuned to receive a transmission within a narrow bandwidth, such tuning occurs after the LNA/LNB. Accordingly, the LNA/LNB receives not only the intended satellite transmission but also other unwanted signals that operate within its pass-band.

As with most active amplifiers, the input-output gain characteristics of an LNA/LNB can be divided into two primary operating regions – linear and non-linear. For normal operation, the LNA/LNB operates in the linear region because any change in the input power level of the received signal results in a corresponding change in the output power level of the device. Accordingly, the incoming satellite signal is amplified without being distorted. However, if the input power level of the signal is strong enough, it will drive the operating point of the LNA/LNB into the non-linear region. In this region of operation, a change in the input power of the received signal does not result in a corresponding exact change in the output power level. Consequently, the incoming satellite signal is distorted.

Manufacturers of LNA/LNBs typically provide the input power at the 1 dB gain compression point, *i.e.*, the operating point where the gain of the device is 1 dB less than its nominal value (in the linear operating region). There is a large variance between devices of this power level, with input power levels typically ranging anywhere from -44 dBm to -60 dBm. However, a median value of -55 dBm can be used as a representative number.

The maximum input power that can be fed into the LNA/LNB and still maintain linear operation is unique to each device but is approximately 10 dB below the input power level associated with the 1 dB gain compression point.[12] Accordingly, the maximum power that can be fed into the LNA/LNB and have the device remain in the linear mode of operation is approximately -65 dBm.

In Report ITU-R M.2109, the ITU-R analyzed the possibility of the LNA/LNB of an FSS receiving Earth station being driven into non-linear operation from the transmissions of an interfering IMT-Advanced station. Under the assumptions that: 1) the input power above which the LNA/LNB would be driven into non-linear operation was -60 dBm, and 2) an IMT-Advanced micro cell base station transmitted with an EIRP density of 22 dBm/MHz, the analysis showed that a minimum distance separation of up to 1.95 kilometers would need to be maintained between the IMT-Advanced micro cell base station and the FSS receiving Earth station. If the IMT-Advanced station transmits with an EIRP density of 46 dBm/MHz, the distance separation increases to 30.5 kilometers.

SIA conducted its own analysis on LNA/LNB overdrive of an FSS receiving Earth station from a wireless system small cell transmission. For its analysis, the following conditions were assumed:

- Threshold of LNA/LNB overdrive at -65 dBm
- A single small cell interferer (no aggregate interference analysis was conducted)
- Small cell emission bandwidth of 1 MHz
- Free space propagation model
- Elevation angles of the FSS receiving Earth station: 5° and 30°

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[12] *See* Section 8.1.1 and Annex E of Report ITU-R M.2109.

- Antenna size of the FSS receiving Earth station: 2.4 m
- Off-axis antenna pattern of the FSS receiving Earth station: Recommendation ITU R S.465
- The small cell is located in the azimuth direction of the main lobe of the FSS receiving antenna

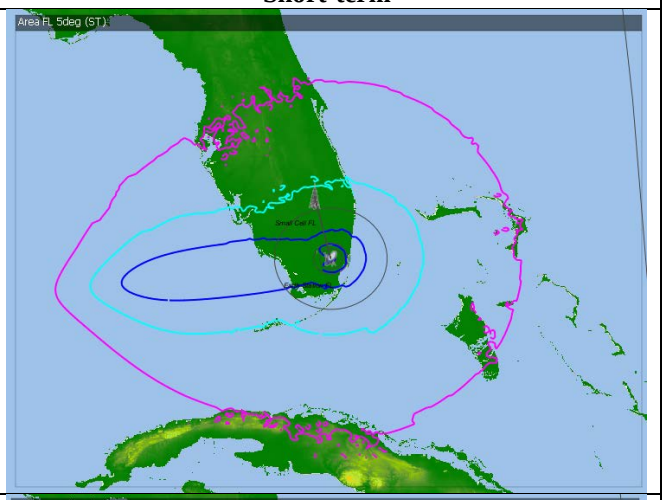
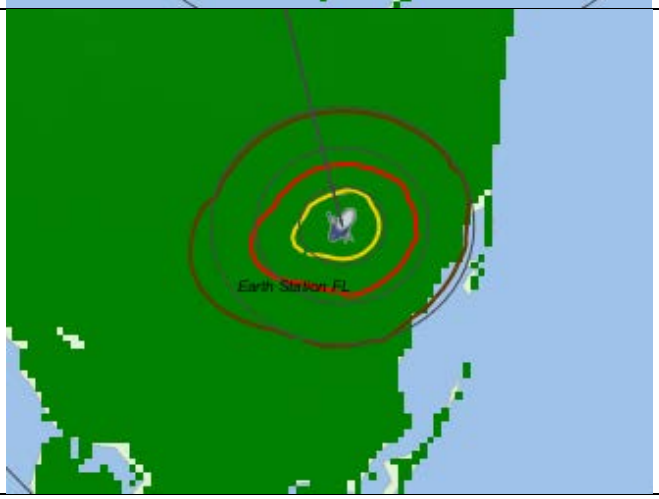
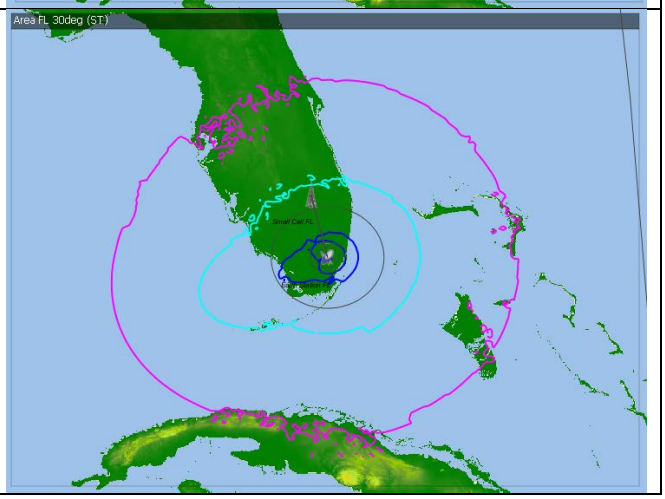
Table 5

Maximum separation distance for LNA/LNB overdrive

Max interference	dBW	-95					
Earth station elevation angle	°	5			30		
Earth station antenna gain towards horizon	dBi	14.5			-4.9		
Small Cell EIRP Density	dBW/MHz	-10	0	13	-10	0	13
Required loss	dB	99.5	109.5	122.5	80.1	90.1	103.1
Frequency	MHz	3600					
Distance	km	0.63	2.00	8.91	0.07	0.21	0.95

The results are contained in Table 5 and show that a distance separation of up to 8.91 kilometers must be maintained between a transmitting cell station and an FSS receiving earth station to avoid exceeding the criterion for LNA/LNB overdrive interference from a single source.

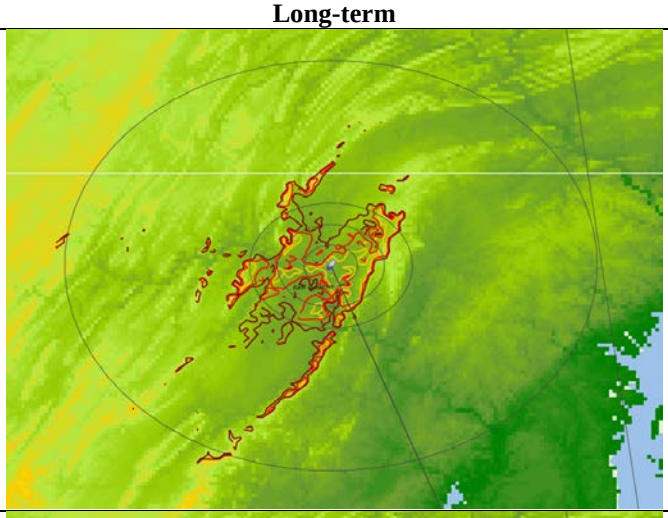
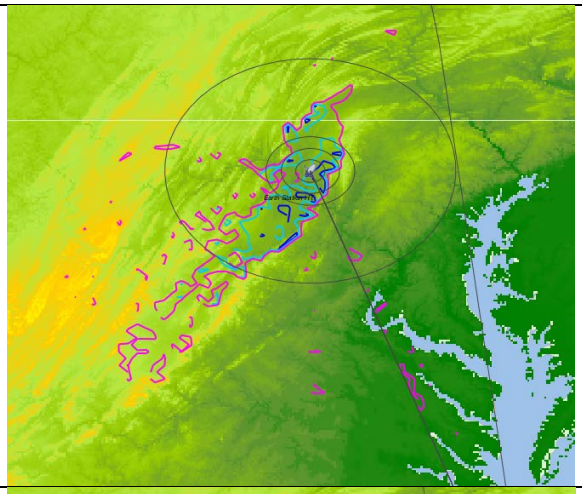
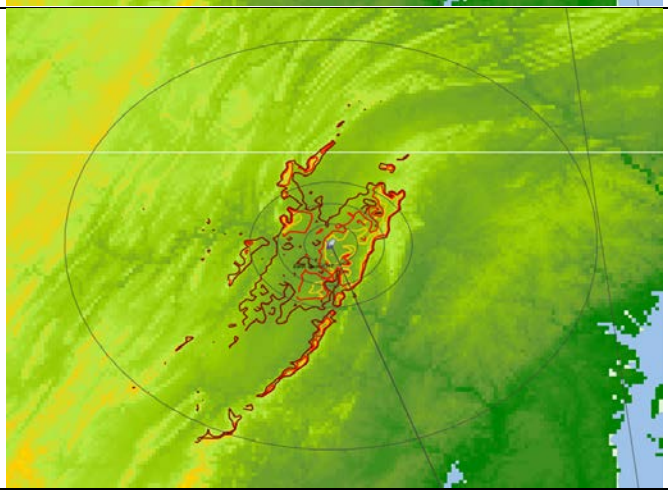
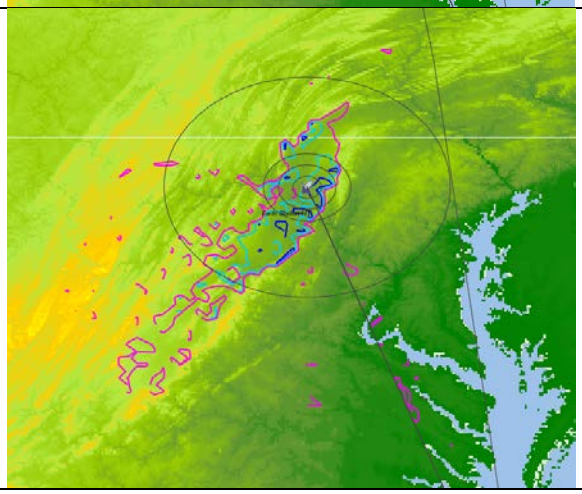
Annex A: I/N in-band interference

Florida	Long-term	Short-term
5°		
30°		

<u>Legend:</u>

Color	Mode	Small Cell EIRP
Dark-red	Long-term	13
Red	Long-term	0
Orange	Long-term	-10
Purple	Short-term	13
Light-blue	Short-term	0
Blue	Short-term	-10

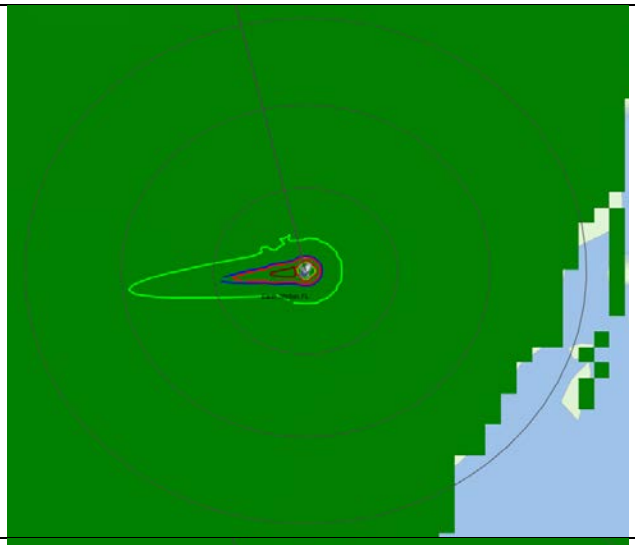
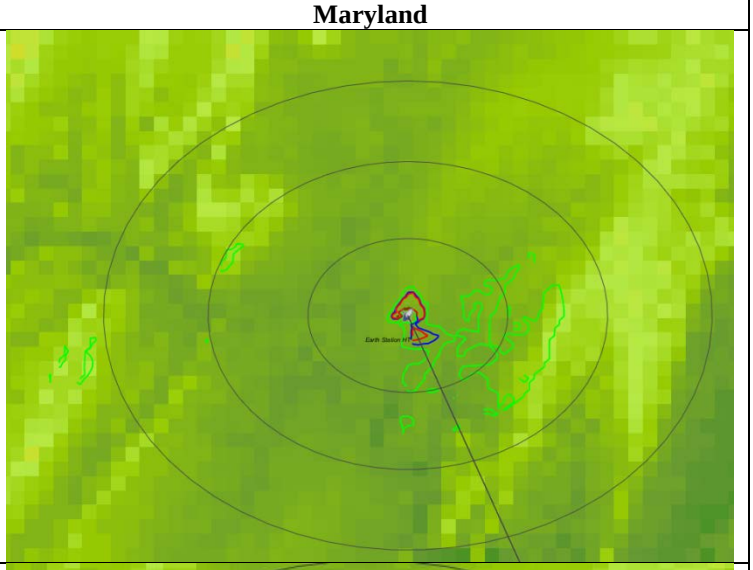
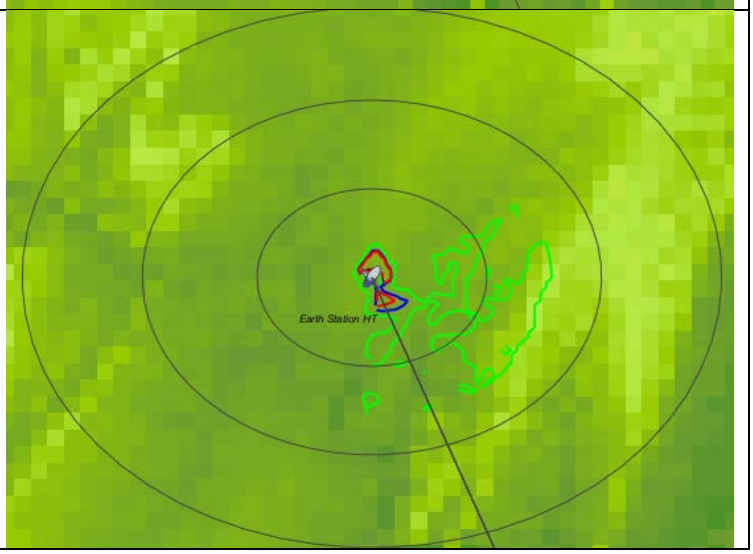
Annex A (continued): I/N in-band interference

Maryland	Long-term	Short-term
5°		
30°		

Legend:

Color	Mode	Small Cell EIRP
Dark-red	Long-term	13
Red	Long-term	0
Orange	Long-term	-10
Purple	Short-term	13
Light-blue	Short-term	0
Blue	Short-term	-10

Annex B: I/N out-of-band interference

	Florida	Maryland
5°		
30°		

Legend:

Color	OOB mask	Small Cell EIRP
Light-green	45	13
Red	45	0
Dark-red	45	-10
Blue	43-10Log(P)	n/a