National Aeronautics
and Space Administration

National Oceanic and
Atmospheric Administration

Additional Sharing Study Results Using the NASA GPM Sensor

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Contents

List of Figures

List of Tables

1 Introduction

WRC-19 Agenda Item 1.13 seeks to study candidate frequency bands for the identification of International Mobile Telecommunications (IMT). The frequencies being considered under this Agenda Item range from 24.25-86 GHz. In order to determine if a band is suitable for IMT use, sharing studies are needed. The International Telecommunications Union Radiocommunication Sector (ITU-R) set up a Task Group (TG 5/1) to study the characteristics of potential IMT systems, provide guidance on sharing study methodologies, and consider the results of those studies. The goal of these studies was to evaluate current spectrum use by incumbent services and determine under what conditions IMT systems could operate compatibly. Specifically, with respect to compatibility with passive sensors operating in the Earth exploration-satellite service (EESS (passive)), the goal of the studies is to determine the necessary out-of-band emission limit to allow co-existence between IMT and EESS (passive).

The following sections in this report document the results of MATLAB analyses along with the methodologies used in the sharing studies between the EESS (passive) and potential IMT deployments. This analysis sought to adhere to the guidance from the Task Group to the extent possible, although there were some assumptions that deviated from the guidance of TG 5/1. Those assumptions were:

- No deployment of indoor UEs; see Section 4.3 for the justification. The lack of indoor UE deployments will slightly underestimate the total interference to the EESS, but the impact is expected to be negligible.
- No deployment of outdoor suburban open space BSs or UEs; see Section 4.3 for the justification. The lack of outdoor suburban open space BS and UE deployments will slightly underestimate the total interference to the EESS.

The studies contained in this report, for the given assumptions, have determined that the following out-of-band emission limits would be required to protect EESS (passive) systems operating in the 23.6-24 GHz band from potential deployments of IMT:

Table 1: Analysis Results in dBW/200MHz

	IMT Transmitter	**Baseline**	**With 50/50 UE/BS Interference Split**	**With Apportionment**
23.8 GHz, Single Element	Base Station	-45.2	-48.2	-51.2
	User Equip.	-38.0	-41.0	-44.0
23.8 GHz, Full Array	Base Station	-35.8	-38.8	-41.8
	User Equip.	-44.1	-47.1	-50.1

These limits were derived by calculating the aggregate interference levels for each time step in the simulation and then calculating the complementary cumulative distribution function (CCDF) of these aggregate interference levels. The EESS (passive) protection criteria for the 23.6-24 GHz band specifies that aggregate interference values of -166dBW/200MHz may occur in no more than 0.01% of the time steps. The exceedance of the protection criteria is defined as the difference between the protection criteria threshold of -166dBW/200MHz and the CCDF value at 0.01%. This exceedance (if any) is then subtracted from the TG 5/1 specified total radiated power (TRP) values of -20dBW/200MHz to determine the needed out-of-band limit. This limit is then further adjusted by two factors which reduce the limit:

- The 50%/50% UE/BS interference split of 3dB. This accounts for the proportional contribution of IMT BSs and UEs to the total IMT aggregate interference at the EESS receiver. If both BS and UE emissions separately meet the protection criteria, in aggregate it will exceed by 3dB.

- Apportionment of 3dB. This accounts for interference to the EESS from multiple services. If both IMT emissions and other co-frequency services separately meet the protection criteria, in aggregate it will exceed by $10\log_{10}$(number of active services).

During the course of the Task Group, many other assumptions were identified as possible sensitivity analysis options, such as: using increased deployment densities, indoor BS paired with outdoor UEs, etc. These or other assumptions could be examined in further studies with appropriate technical justification.

2 Analysis Approach

During the course of its work, TG 5/1 developed a set of agreed parameters and assumptions to be used in the sharing studies. The approach used in the analysis described in the following sections adheres to the approved parameters and assumptions to the extent possible, while examining each assumption for its technical merit. The sections below outline the exact methodologies and assumptions used. In the case of deviation from guidance of TG 5/1, explicit technical justifications are provided.

3 MATLAB Analysis Input Parameters

The EESS sensor parameters relevant for interference analysis are described in Table 2 below:

Table 2: Orbital and Sensor Parameters for GPM System

Orbital Parameters	**Values**
Shape	Circular
Altitude (at perigee)	399 km
Inclination Angle	65 degrees
Sensor Parameters	**Values**
Type	Conical Scan
Antenna Pattern	ITU-R RS.1813
Maximum Gain	46.6 dBi
Off-nadir Angle	48.5 degrees
Beam Dynamics	40 rpm

The parameters of IMT stations including base stations (BS) and user equipment (UE) are described in Tables 3 and 4 below:

Table 3: IMT Base Station Parameters

Parameters		Values
Network topology and characteristics (2×10^6 km^2 area)		213,600 total BSs (only 34,176 active per time step)
Antenna height (radiation centre)		6 m AGL
Downtilt		10 degrees
Network loading factor		20%
BS TDD activity factor		80%
Location		See Section 4.4
Antenna azimuth		Random
1	**Antenna characteristics**	
1.1	Antenna pattern	Refer to Recommendation ITU-R M.2101
1.2	Single element gain (dBi)	5
1.3	Horizontal/vertical 3dB beamwidth of single element (degree)	65 for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V
1.5	Antenna array configuration (Row x Column)	8x8 elements
Out-of-band array		1x1 for Single Element 8x8 for Full Array

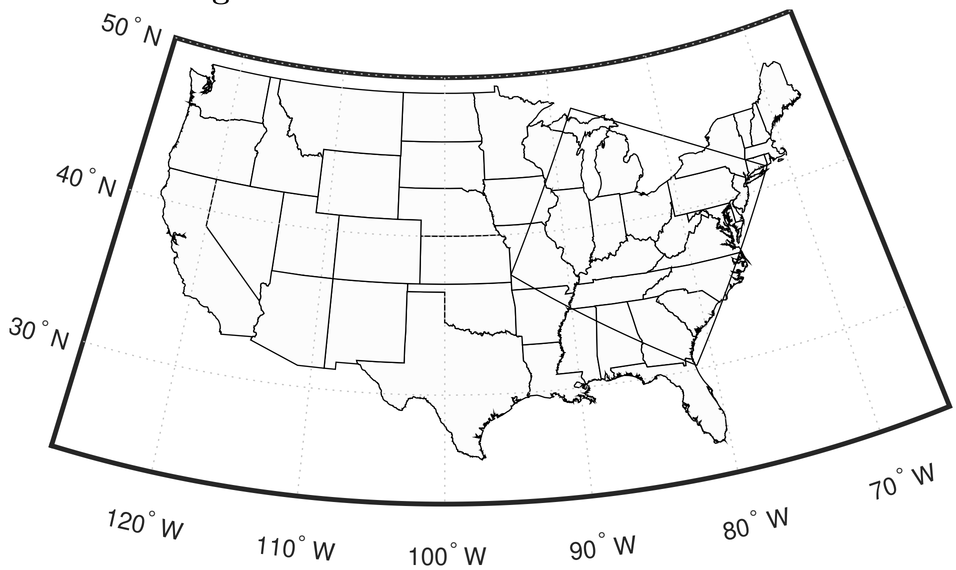
Table 4: **IMT User Equipment Parameters**

	Parameters	Values
	Network topology and characteristics (2×10^6 km^2 area)	667,945 total UEs (only 26,717 active per time step)
	Antenna height (radiation centre)	1.5 m AGL
	Body loss	4dB
	Network loading factor	20%
	UE TDD activity factor	20%
	Location	Within -60 to 60 degrees of BS antenna azimuth
	Distance from BS	Sampled from Rayleigh distribution with $\sigma = 32$ $d_{min} = 0$ and $d_{max} = 208$ with 99/95/90% of distances less than 97/78/68m, respectively
	Antenna azimuth	Within -60 to 60 degrees of UE-to-BS pointing vector
	Antenna elevation	Within -90 to 90 degrees of UE-to-BS pointing vector
1	**Antenna characteristics**	
1.1	Antenna pattern	Refer to Recommendation ITU-R M.2101
1.2	Single element gain (dBi)	5
1.3	Horizontal/vertical 3dB beamwidth of single element (degree)	90 for both H/V
1.4	Horizontal/vertical front-to-back ratio (dB)	25 for both H/V
1.5	Antenna array configuration (Row x Column)	4x4 elements
2	**Transmit power control**	
2.1	Power control module	Refer to Recommendation ITU-R M.2101
2.2	Maximum user terminal output power (dBm), P_{CMAX}	22
2.3	Transmit power (dBm) target target value per 180 kHz, P_{O_PUSCH}	-95
2.4	Path loss compensation factor, α	1
	Out-of-band array	1x1 for Single Element 4x4 for Full Array

4 Deployment of IMT Stations

The measurement area defined for the EESS (passive) sensors is defined in Recommendation ITU-R RS.2017 as a 2,000,000 km^2 area over which the interference statistics are to be calculated. For this study, the 2,000,000 km^2 area used is shown in Figure 1 below.

Figure 1: Measurement Area of Interest



The 2,000,000 km^2 area includes large bodies of water and some sections of ocean. While these are valid points for data collection, the area of the water should not be included in the determining of the number of potential IMT stations inside the measurement area. Within the confines of the 2,000,000 km^2 area shown above, 11% of the total is water. For the purposes of the calculations described in Sections 4.1 and 4.2 below, the area S is defined as the surface area of region in study (km^2) that excludes large bodies of water and ocean area. This is equal to 89% of 2,000,000 km^2, or 1,780,000 km^2. It should be noted that the area is only reduced for the purpose of the calculations in Sections 4.1 and 4.2; the entire area, including the water and areas with no IMT deployments, was considered when calculating the interference statistics.

4.1 Total Number of Base Stations

The total number of base stations ($N_{BStotal}$) located within the measurement area was derived from the following TG 5/1 Document 5-1/36 equation.

$$N_{BStotal} = S \cdot R_b \cdot (R_{aSU} \cdot (D_{BSSUO} + D_{BSSU}) + R_{aU} \cdot D_{BSU}) \quad (1)$$

with:

- R_a : the ratio of hotspot areas to areas of cities/built areas/districts (3% for suburban (R_{aSU}) and 7% for urban (R_{aU}));
- S : the surface area of region in study (km^2), excluding large bodies of water and ocean areas;
- R_b : the ratio of built areas to total area of region in study (5%);
- D_{BSSUO} : BS density in the outdoor suburban open space (0 BS/km^2);
- D_{BSSU} : BS density in the outdoor suburban hotspot (10 BS/km^2);
- D_{BSU} : BS density in the outdoor urban hotspot (30 BS/km^2).

The typical values for the above equation referenced from the technical characteristics document apply for deployments over a wide area such as a country or a large region and takes into account areas with little or no IMT deployment.

The calculated total number of base stations ($N_{BStotal}$) for the 2,000,000 km^2 measurement area is 213,600. Outdoor suburban open space base stations deployments are not evaluated in this study. This reduces the total number of base stations and thus reduces the potential interference; however, the impact is expected to be negligible.

The number of base stations ($N_{BSactive}$) transmitting simultaneously is derived using the default values for BS_{AF}, NLF given by the Document 5-1/36 equation.

$$N_{BSactive} = N_{BStotal} \cdot BS_{AF} \cdot NLF \tag{2}$$

with:

- $N_{BStotal}$: the total number of BSs per surface area (S);
- BS_{AF} : the BS TDD activity factor (80%);
- NLF : the network loading factor (20%).

The number of base stations simultaneously transmitting at any given time step is the total number of base stations inside the measurement area multiplied by the activity and loading factor: 213,600 · 80% · 20% = 34,176.

4.2 Total Number of User Equipment

The total number of UEs ($N_{UEtotal}$) within the measurement area was derived from

$$N_{UEtotal} = S \cdot R_b \cdot (R_{aSU} \cdot (D_{UESUO} + D_{UESU}) + R_{aU} \cdot D_{UEU}) \tag{3}$$

with:

- R_a : the ratio of hotspot areas to areas of cities/built areas/districts (3% for suburban (R_{aSU}) and 7% for urban (R_{aU}));
- S : the surface area of region in study (km^2), excluding large bodies of water and ocean areas;
- R_b : the ratio of built areas to total area of region in study (5%);
- D_{UESUO} : UE density in the outdoor suburban open space (0 UE/km^2);
- D_{UESU} : UE density in the outdoor suburban hotspot (30 UE/km^2);
- D_{UEU} : UE density in the outdoor urban hotspot (100 UE/km^2).

The calculated total number of UEs ($N_{UEtotal}$) for the 2,000,000 km^2 measurement area is 703,100. Per TG 5/1 guidance, up to 5% of the total UE could be deployed indoors. Since indoor UEs are not expected to have an appreciable impact the results of the sharing study, they were not considered. Therefore, the total number of UEs was reduced by 5% to 667,945. The number of UEs transmitting simultaneously ($N_{UEactive}$) was derived from the following formula

$$N_{UEactive} = N_{UEtotal} \cdot UE_{AF} \cdot NLF \tag{4}$$

with:

- $N_{UEtotal}$: the total number of UEs per land surface area (S);
- UE_{AF} : the UE TDD activity factor (20%);
- NLF : the network loading factor (20%).

The number of user terminals simultaneously transmitting at any given time step is the total number of user terminals inside the measurement area multiplied by the activity and loading factor: 667,945 · 20% · 20% = 26,717.

4.3 Consideration of Indoor and Outdoor Suburban Open Space BS/UE

Per the Task Group guidance, there could be a small percentage of BSs and UEs deployed in indoor and outdoor suburban open space environments. Of the twelve sharing studies submitted to TG 5/1, only three considered indoor deployment as it was determined that these types of deployments would have a negligible impact on the results. Outdoor Suburban Open Space deployments were also only considered in one of the twelve studies submitted to TG 5/1 for similar reasons.

This analysis does not consider indoor UEs or outdoor suburban open space BSs/UEs, and this will slightly underestimate the total interference to the EESS.

4.4 Deployment of Base Stations within the Measurement Area

While the computation of the total number of IMT stations inside the measurement area is determined using Document 5-1/36, it does not address how the resulting total number of stations are distributed inside the area.

This simulation distributes the total number of stations into areas based on the geographical information by the US and Canadian Census Bureaus. Stations are distributed proportionally into urban built up areas with populations of more than 50,000 as defined by 2010 US and Canadian Census Bureau Boundary shape files. Shape files for each urban area include the urban area boundary contour, area size and population.

For each selected urban area, the number of base stations allocated to that area (subject to a TG 5/1 maximum per km^2) was calculated from:

$$N_{BSurban_i} = N_{BStotal} \cdot \frac{UA_i}{UA_{total}} \tag{5}$$

with:

- $N_{BStotal}$: the total number of base stations in the simulation (213,600);
- UA_i : the population of the ith urban area;
- UA_{total} : the total population of all urban areas in the measurement area with populations greater than 50,000.

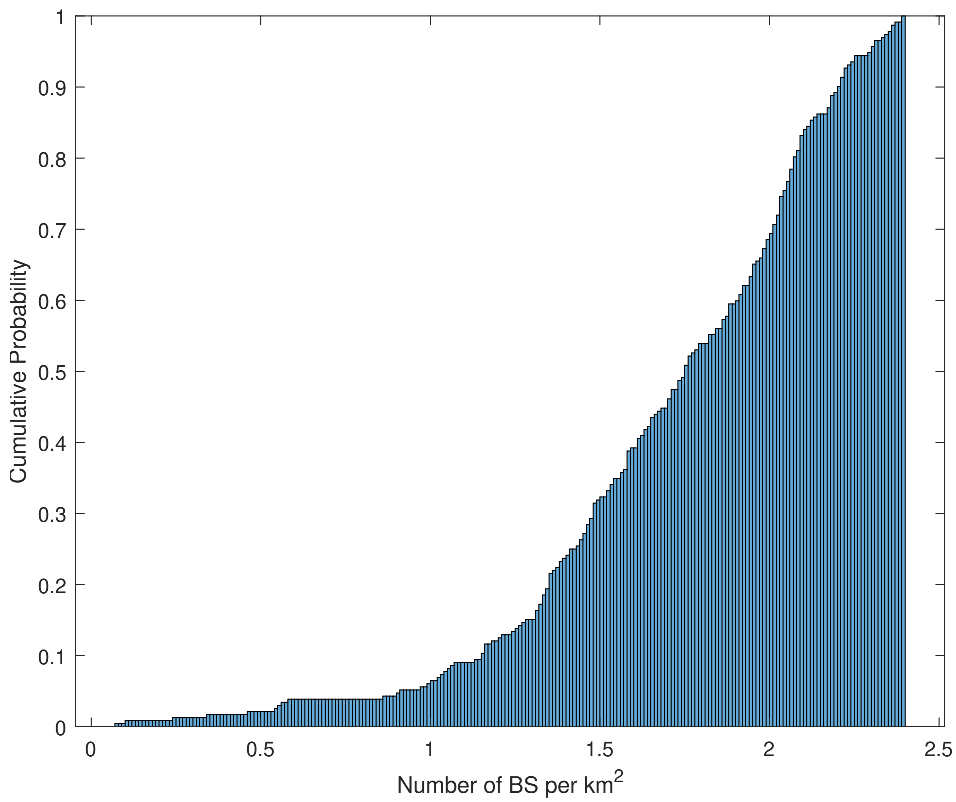
The base stations per urbanized area are located uniformly within each urban area per Recommendation ITU-R M.2101 Section 3.1.4, Figure 7, Approach 1. In order to conform to the equidistant cellular grid spacing described in Approach 1, the total number of base stations contained within the simulation is slightly higher than the maximum calculated 213,600. However, for any single time step, the number of active base stations never exceeds the value calculated from the Task Group guidance of 34,176.

Using the formula guidance given in Annex 1 of the Chairman's Report, the maximum number of BS that can be deployed in urban built up areas is:

$$N_{BSmaxBuiltAreaperkm^2} = R_{aSU} \cdot D_{BSSU} + R_{aU} \cdot D_{BSU} = 2.4 \text{ BS/km}^2 \tag{6}$$

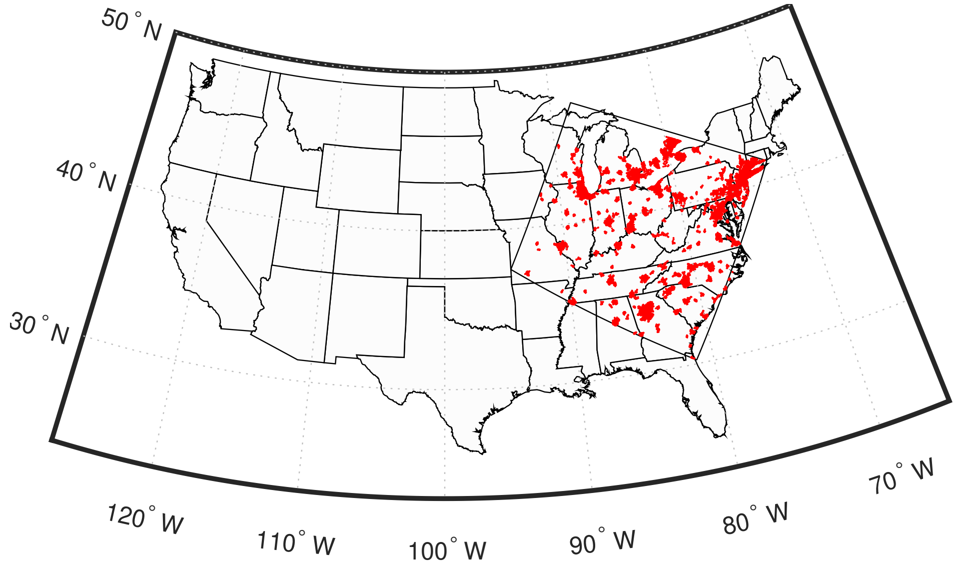
Figure 2 provides a histogram of the number of base stations per km^2 for all of the areas in the simulation. Figure 2 shows that, after the IMT BS simulation deployment, the maximum base station density is less than 2.4/km^2 and agrees with the expected maximum per TG 5/1 guidance.

Figure 2: CDF of BS per km^2



For each time step, only 34,176 of the total base stations are randomly selected to be transmitting. Figure 3 below shows, for one example time step, the location of the active base stations within the measurement area.

Figure 3: Active BS within Measurement Area of Interest



4.5 Deployment of User Equipment within the Measurement Area

For each time step, a total of 26,717 UEs are randomly placed within ±60 degrees azimuth of the physical aperture for each non-transmitting base stations. This means that no active user terminals are placed within ±60 degrees azimuth of the 34,176 active base stations. Due to the fact that for any given time step a single base station cannot be both receiving and transmitting, the set of transmitting UEs and receiving UEs are mutually exclusive for each time step. The UE distance from the base station is determined by using a Rayleigh distribution with σ=32, per the TG 5/1 guidance.

Also per Task Group and 3GPP guidance, the UEs inside of the specified ±60 degrees area are normally distributed, yet this seems counterintuitive. The use of a normal distribution means that the UEs are more likely to be located close to the boresight of the base station physical aperture. It is unclear to NASA and NOAA what physical phenomena would force all UEs to have a higher probability of being located close to the boresight of the base station antenna. In all other aspects of TG 5/1 guidance, when a random distribution is specified, it is always a uniform random distribution. A uniform distribution seems more appropriate; however, in order to adhere to the guidance of TG 5/1, a normal distribution was used in the NASA/NOAA analysis.

5 Total Radiated Power

Per TG 5/1 and 3GPP guidance, the maximum out-of-band emission levels of base stations and user equipment is specified as -13dBm/MHz (-20dBW/200MHz) total radiated power. Per TG 5/1 and 3GPP, total radiated power (TRP) is defined as the aggregate radiated power from all antenna elements. The TRP is calculated by integrating the entire antenna pattern along with the input power, per the equation below:

$$TRP \triangleq \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} P_{tx}\cdot g(\theta,\phi)\cdot sin(\theta)d\theta d\phi \tag{7}$$

Where P_{tx} is the conducted power (in Watts) that is input into the antenna, and $g(\theta, \phi)$ is the antenna gain along the (θ, ϕ) direction. The TRP methodology is being used due to the IMT industry assertion that they are unable to measure the input to the antenna port of IMT stations.

According to Recommendation ITU-R M.2101: *"An IMT system using an AAS (Advanced Antenna System) will actively control all individual signals being fed to individual antenna elements in the antenna array in order to shape and direct the antenna emission diagram to a wanted shape, e.g. a narrow beam towards a user. In other words, it creates a correlated wanted emission from the antenna. The unwanted signal, caused by transmitter OOB modulation, intermodulation products and spurious emission components will not experience the same correlated situation from the antenna and will have a different emission pattern. A non-correlated AAS has an antenna emission pattern similar to a single antenna element. In an adjacent frequency band situation with IMT as the interfering system, the antenna pattern for the unwanted emission can be assumed to have a similar antenna pattern as a single antenna element."*

The equation for TRP can be broken into three parts: the conducted power (in Watts) that is input into the antenna port, ohmic losses, and the total integrated gain (TIG):

$$TRP \triangleq \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} P_{tx} \cdot g(\theta,\phi) \cdot sin(\theta) d\theta d\phi = P_{tx}|_{dB} - L_{ohmic}|_{dB} + TIG|_{dB} \tag{8}$$

Total Integrated Gain for the adjacent-band case is calculated as below:

$$Total\ Integrated\ Gain \triangleq \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} A_A(\theta,\phi) \cdot sin(\theta) d\theta d\phi \tag{9}$$

Where $A_A(\theta, \phi)$ is the composite antenna pattern described in M.2101 for the BS or UE. In the single element out-of-band case, $A_A(\theta, \phi) = A_E(\theta, \phi)$, and evaluating the above integral for the BS and UE yields -4.8dBi and -2.4dBi, respectively[1]. In the case when the full array is used in the out-of-band domain, TIG does not take a single value, as it becomes a function of the instantaneous electrical scan and tilt angles of the beamformed pattern. However, we will use the single element case to demonstrate the remainder of the methodology for simplicity.

Since the maximum TRP for BSs per TG 5/1 guidance is -20dBW/200MHz this becomes:

$$BS_{TRP} = BS_{PTx} - 3dB_{\Omega} - 4.8dB = -20dBW/200MHz \tag{10}$$

Where BS_{PTx} is the BS antenna input power in dBW, before the TG 5/1 specified 3dB ohmic loss.

Since the maximum TRP for UEs per TG 5/1 guidance is -20dBW/200MHz this becomes:

$$UE_{TRP} = UE_{PTx} - 3dB_{\Omega} - 2.4dB \leq -20dBW/200MHz \tag{11}$$

Where UE_{PTx} is the UE antenna input power in dBW, before the TG 5/1 specified 3dB ohmic loss.

[1]The AAS single element antenna pattern models are simplified approximations of typical real antennas used to represent a service. For a given transmit power, the TRP is dependent upon the antenna pattern, or more specifically, on the integration of the antenna pattern. Therefore, if the maximum TRP of -20dBW/200MHz remains the same but a different antenna pattern was used the amount of interference calculated would change, this change would be equal to the difference between the TIG of the single element pattern and the TIG of the new pattern.

In the NASA/NOAA analysis, each base station operates at the out-of-band TRP specified by TG 5/1 and 3GPP, which is -20dBW/200MHz. Since the base stations operate at a fixed power level, the out-of-band TRP does not change.

Similarly for the UEs, the NASA/NOAA analysis uses the -20dBW/200MHz as the maximum out-of-band TRP level. This level is then reduced by the UE power control algorithm. The actual UE power control algorithm is based off of the in-band power levels, however the change in transmitted power is carried over to the out-of-band TRP, e.g. the power control algorithm calculates a 5dB reduction in power (from the maximum in-band level), and this 5dB would then also be subtracted from the out-of-band TRP, yielding -25dBW/200MHz.

The actual transmit power and appropriate gain patterns are still needed in order to determine the interference power received by the EESS sensor, as TRP is the integration of all radiated power in all directions. Thus, TRP is not equivalent to the power radiated in the direction of the EESS sensor. Starting from the definition of TRP and the TRP value of -20dBW/200MHz given by TG 5/1, the following equations are used in order to determine the interference to the EESS sensor:

For base stations:

$$\begin{aligned} EESS_{RxPwr} = BS_{PTx} - 3dB_{\Omega} + BS_{Gain}(\theta_1, \phi_1) - L_{P.525} - L_{P.676} \\ - L_{P.2108} + EESS_{Gain}(\theta_2, \phi_2) - L_{polar} \end{aligned} \tag{12}$$

with:

- If $BS_{TRP} = BS_{PTx} - 3dB_{\Omega} - 4.8dB = -20dBW/200MHz$, then $BS_{PTx} = -12.2dBW/200MHz$
- $BS_{Gain}(\theta_1, \phi_1)$ is the gain of the base station in the direction of the EESS sensor
- $L_{P.525}$ is the free-space path loss
- $L_{P.676}$ is the attenuation due to gaseous absorption
- $L_{P.2108}$ is the clutter loss
- $EESS_{Gain}(\theta_2, \phi_2)$ is the gain of the EESS sensor in the direction of the base station
- L_{polar} is the polarization loss, which is a fixed 3dB value

For user terminals:

$$\begin{aligned} EESS_{RxPwr} = UE_{PTx} - 3dB_{\Omega} - UE_{PwrCtl} + UE_{Gain}(\theta_1, \phi_1) - L_{P.525} - L_{P.676} \\ - L_{P.2108} + EESS_{Gain}(\theta_2, \phi_2) - L_{polar} - L_{body} \end{aligned} \tag{13}$$

with:

- If $UE_{TRP} = UE_{PTx} - 3dB_{\Omega} - 2.4dB = -20dBW/200MHz$, then $UE_{PTx} = -14.6dBW/200MHz$
- UE_{PwrCtl} is the reduction of power based on the UE power control algorithm, and $UE_{PwrCtl} \in [0, 63]$ dB
- $UE_{Gain}(\theta_1, \phi_1)$ is the gain of the user terminal in the direction of the EESS sensor

- $L_{P.525}$ is the free-space path loss
- $L_{P.676}$ is the attenuation due to gaseous absorption
- $L_{P.2108}$ is the clutter loss
- $EESS_{Gain}(\theta_2, \phi_2)$ is the gain of the EESS sensor in the direction of the user terminal
- L_{polar} is the polarization loss, which is a fixed 3dB value
- L_{body} is the body loss, which is a fixed 4dB value

NASA and NOAA are of the view that the above equations are consistent with the Task Group guidance; however, FCC/industry feedback is encouraged.

6 Base Station Antenna Pattern

Per TG 5/1 and 3GPP guidance, the base stations in some bands utilize an 8x8 beamforming antenna with 64 elements. However, since each base station has a total of 64 antenna elements that are used to construct three separate beams (one for each UE), using all elements for each beam is not possible. Therefore, the logical conclusion is that each of the three beams must be formed using a subarray of the full 8x8. NASA and NOAA are of the view that a 4x4 subarray seems appropriate; however, in order to adhere to the guidance of TG 5/1, the full 8x8 antenna pattern was used for each beam.

7 NASA Interference Calculation Methodology

Prior to starting the time-dependent portion of the simulation, the total number of base stations are deployed within the confines of the measurement area per the deployment methodology in Section 4. Then, the physical pointing angle of the base stations is randomly set with a uniform random variable in azimuth and a fixed 10 degree downtilt. The EESS satellite is then 'flown' over the entire simulation time and the latitude/longitude/altitude for each time step is calculated. Based on the latitude/longitude/altitude and the beam dynamics, the time steps for which the EESS Instantaneous Field of view (IFOV) is inside the measurement area are determined. Then, for time steps that the EESS IFOV is within the measurement area, the following procedure is applied:

1. Randomly select 34,176 of the total number of base stations to be active.
2. Randomly place 26,717 UEs in the measurement area relative to a base station that's not selected to be active in step 1.
   (a) These UEs are randomly placed within ±60 degrees azimuth of the physical aperture of non-transmitting base stations. The location of the UEs is determined by generating a random azimuth direction within ±60 degrees using a normal random distribution.
   (b) Determine the distance between each UE and BS using a Rayleigh distribution with σ=32.
   (c) Determine the lat/lon of the UE based on azimuth direction and great-circle distance computed from step 2a-b above.

3. Generate a random UE orientation (-60 to 60 degrees in azimuth with 0 being toward BS, -90 to 90 degrees in elevation both using uniform random distributions).

4. Compute the path loss for the BS-to-UE/UE-to-BS links using the 3GPP TR 38.900 Urban Microcell (UMi) Street Canyon specifications.

5. Compute the in-band coupling loss for the UE power control algorithm per TG 5/1 guidance.

6. Compute the UE receivers' carrier to noise ratio (C/N) and drop links with a C/N of less than -10dB. These links are not considered in the aggregate interference calculations.

7. Determine the out-of-band power spectral densities for each BS and UE.

   (a) Per TG 5/1 guidance, each BS has a constant out-of-band emission of -13dBm/MHz total radiated power (TRP).

   (b) The UE out-of-band level is controlled by the UE power leveling, with a maximum value of -13dBm/MHz TRP per TG 5/1 guidance. This level is then reduced by the UE power leveling algorithm. Details on UE power control algorithm are in Section 4.1 of ITU-R M.2101.

8. Compute the Az/El/Slant range between all combinations of active BS/UE and EESS sensor.

9. Calculate the corresponding antenna gains of the UE and BS in the direction of the EESS sensor.

10. Compute all propagation-based losses from the UE and BS (Recommendations ITU-R P.525 (Free-space path loss), P.2108 (Clutter), and P.676 (Atmospheric gaseous attenuation)) to the EESS sensor using slant range and elevation angle values.

11. Find the angle off boresight and compute the gain using Recommendation ITU-R RS.1813 from the EESS sensor toward the respective UE/BS.

12. Determine the interference seen at the EESS sensor on a per-UE/BS basis via the following:

    (a) $EESS_{RxPwr} = BS_{PTx} - 3dB_{\Omega} + BS_{Gain}(\theta_1, \phi_1) - L_{P.525} - L_{P.676} - L_{P.2108} + EESS_{Gain}(\theta_2, \phi_2) - L_{polar}$

    (b) $EESS_{RxPwr} = UE_{PTx} - 3dB_{\Omega} - UE_{PwrCtl} + UE_{Gain}(\theta_1, \phi_1) - L_{P.525} - L_{P.676} - L_{P.2108} + EESS_{Gain}(\theta_2, \phi_2) - L_{polar} - L_{body}$

13. Sum across all active UE/BS within a given time step to get the aggregate interference totals for that time step.

14. Repeat steps 1-13 above for all time steps that the EESS boresight vector is within the measurement area.

8 Simulation Results for 23.6-24GHz

The following section presents the simulation results for the potential interference from IMT systems into the 23.6-24 GHz EESS (passive) band.

8.1 Base Stations and User Equipment Pointing/Distances

Following the methodology in Section 7, after the locations of the BS are randomly determined, the next step is to determine the physical pointing of the BS and the location/pointing of the UEs. The following two figures show the PDF of the BS azimuth/elevations angles toward the UE as well as the UE toward the BS. Additionally, shown is the PDF of the separation distances between the BSs and the UEs.

Per TG 5/1:

For BS, the antenna pattern in the adjacent frequency band situation has therefore to be considered with the mechanical pointing in elevation (downtilt angle) and azimuth.

- *For UE, the antenna pattern in the adjacent frequency band situation has therefore to be considered randomly in elevation in the range -90 to 90 degrees and in azimuth in the range -60 to 60 degrees in the direction of the BS.*

Figure 4: PDF of BS-to-UE Electrical Azimuth Pointing Angles

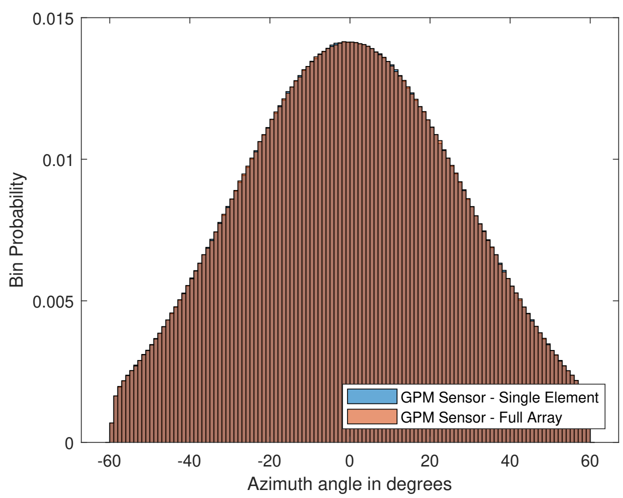


Figure 5: PDF of BS-to-UE Electrical Elevation Pointing Angles

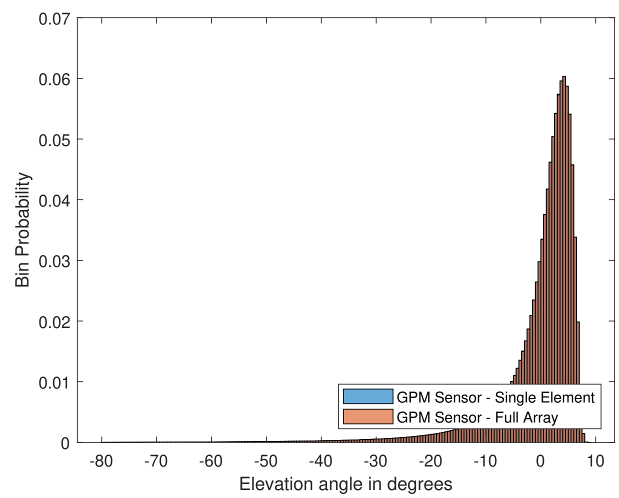


Figure 6: PDF of UE-to-BS Offset from Azimuth Pointing Angles

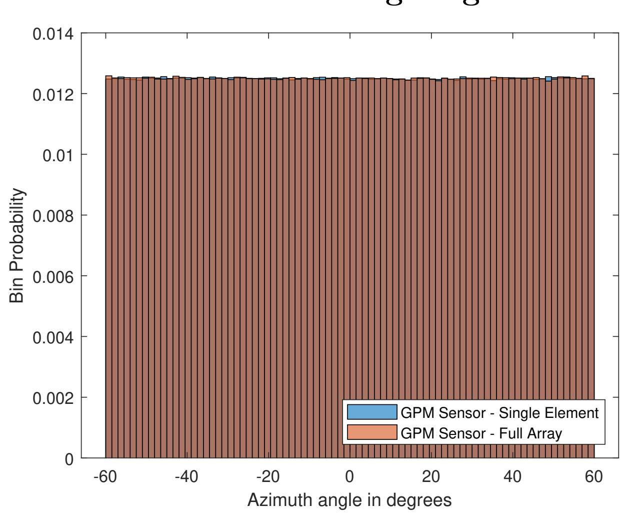
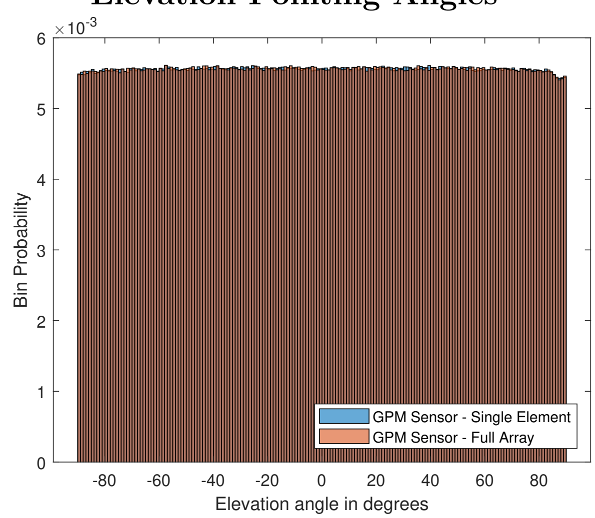


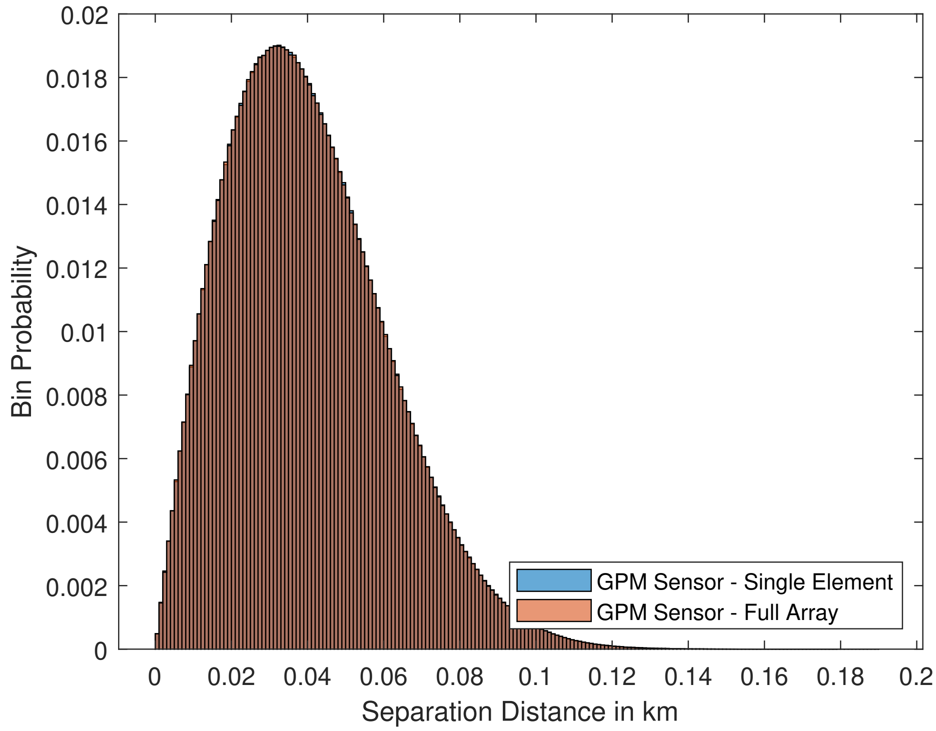
Figure 7: PDF of UE-to-BS Offset from Elevation Pointing Angles



TG 5/1 guidance regarding the distance between the BS and the UE is:

- *A log-normal/Rayleigh(32) distribution for the distance between UE and BS hotspot.*

Figure 8: PDF of UE-to-BS Separation Distances



8.2 BS/UE Gain

Based on the above-described pointing angles, the CDFs of the antenna gain from the BS toward the UE and the UE toward the BS are shown in Figures 9 and 10 below.

Figure 9: CDF of BS TX Gain toward UE

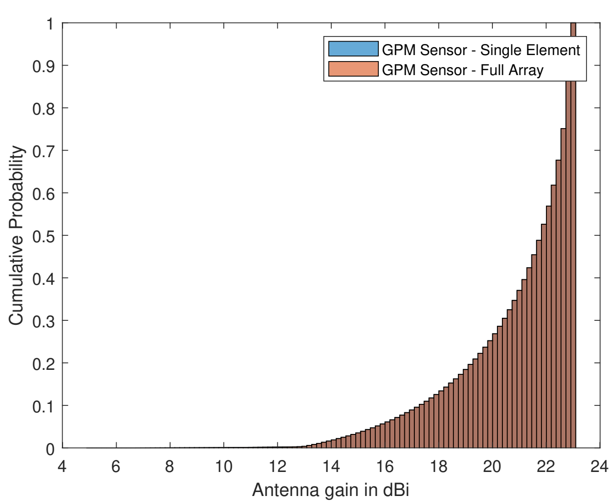
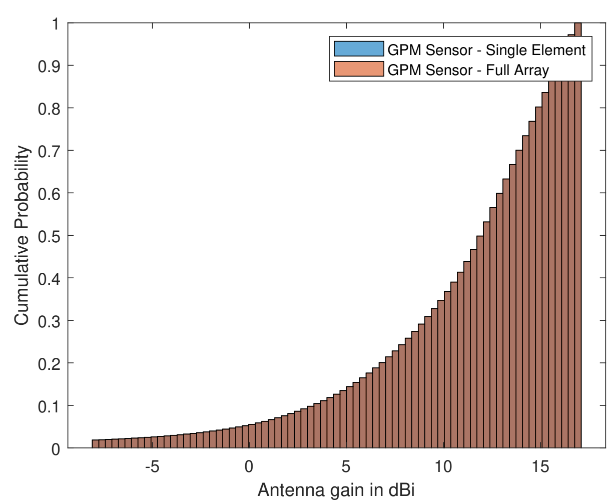


Figure 10: CDF of UE TX Gain toward BS



8.3 Propagation Losses

The propagation losses between the BSs and the UEs are determined by the TR 38.900 model, while the propagation losses between the BS/UE and the EESS sensor are set by combining free space path loss (ITU-R P.525), clutter (ITU-R P.2108) and attenuation due to gaseous absorption (ITU-R P.676).

Figure 11: PDF of Propagation Loss from TR 38.900

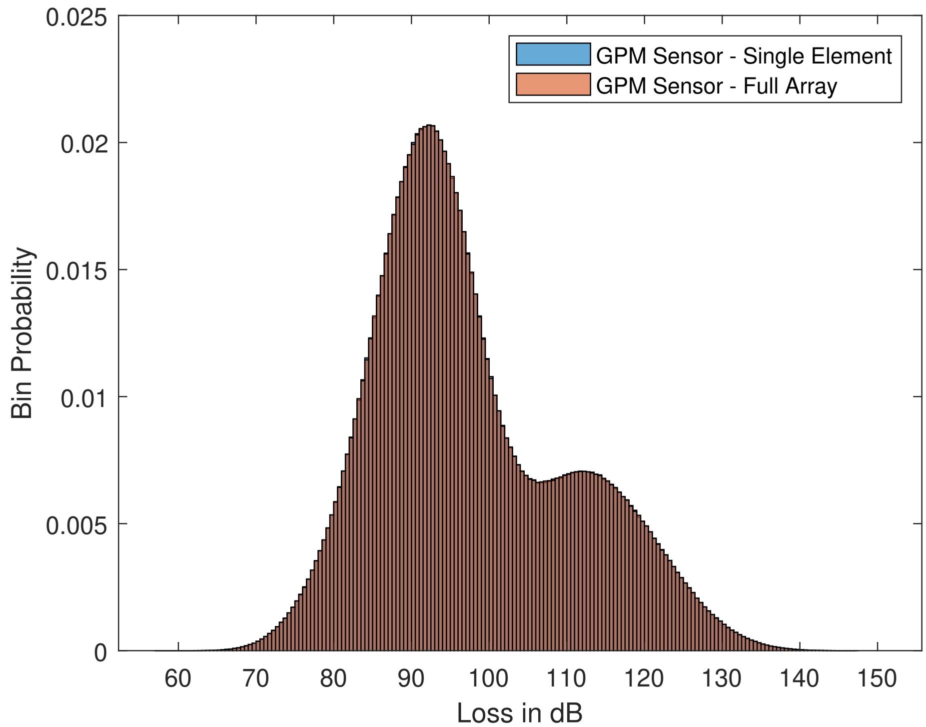


Figure 12: PDF of Clutter Loss from ITU-R P.2108

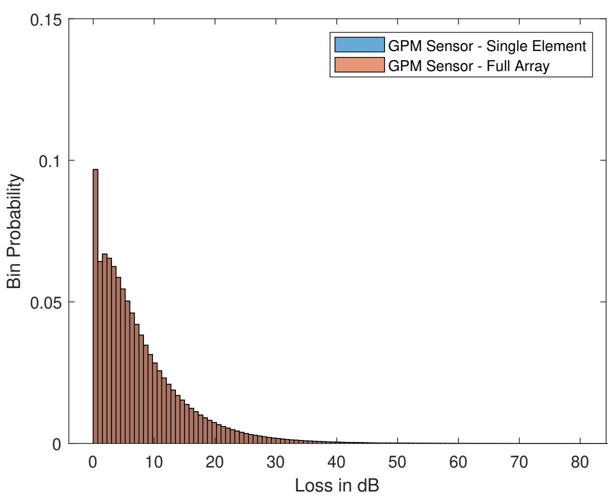
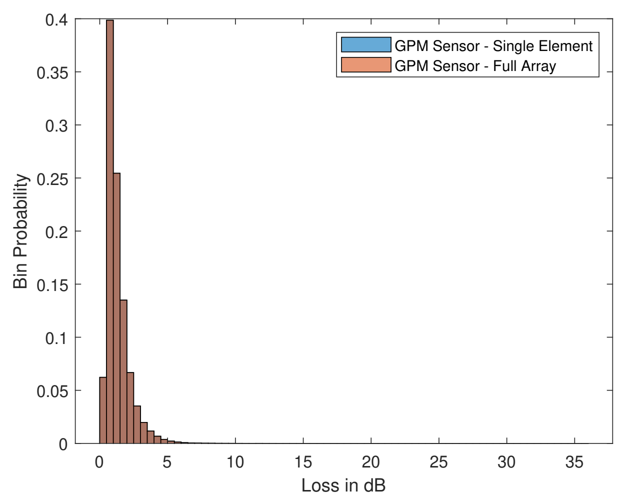


Figure 13: PDF of Atmospheric Loss from ITU-R P.676



8.4 User Equipment Transmit Power

The transmit power of the UEs in the simulation is determined by the power control algorithm. The following plots show the UE coupling loss as well as the resulting UE transmit power.

Figure 14: PDF of BS-to-UE Coupling Loss

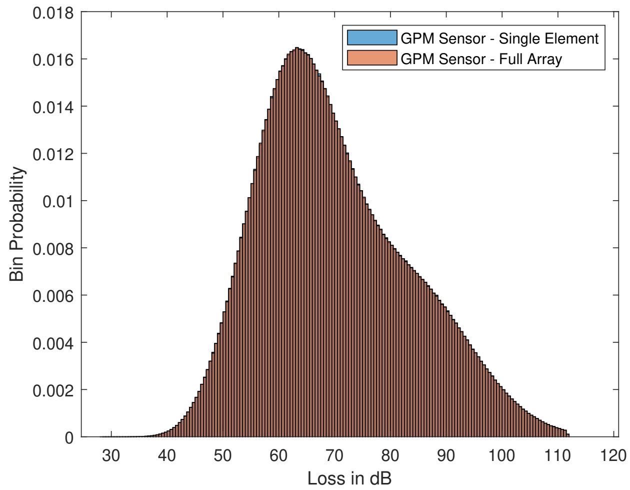


Figure 15: CDF of UE Transmit Power

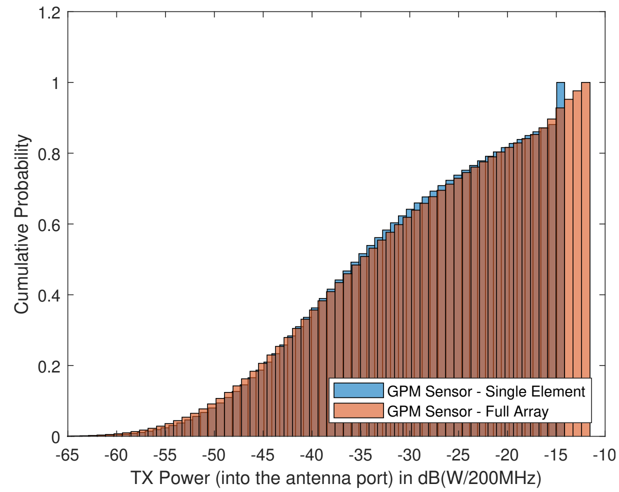
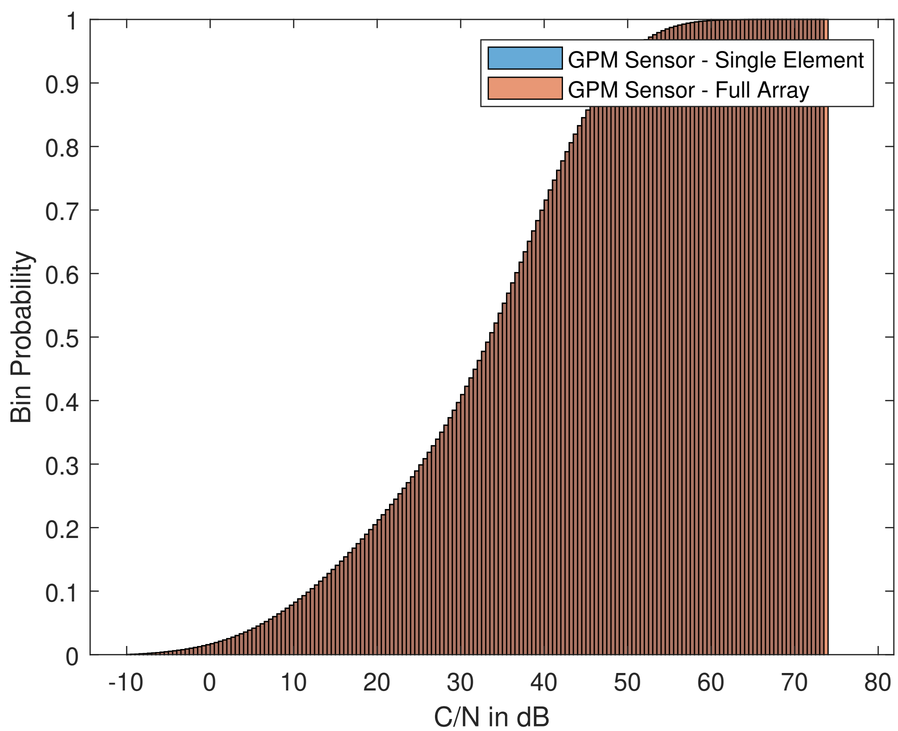


Figure 16: CDF of C/N at UE Receiver



8.5 Gain in the Direction of the EESS Sensor

Next, the gain in the direction of the EESS sensor was examined.

Figure 17: CDF of BS TX Gain toward EESS

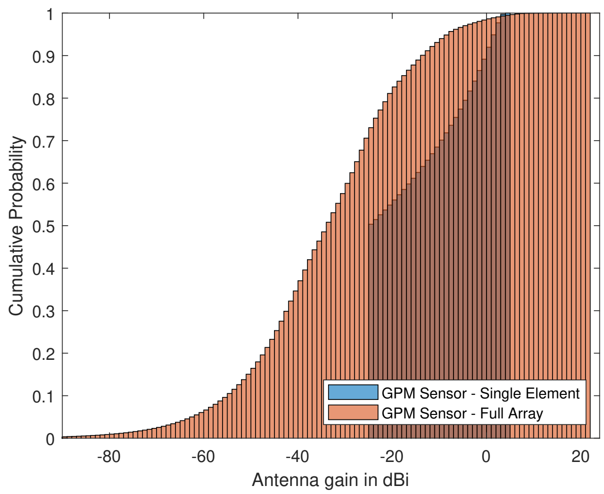
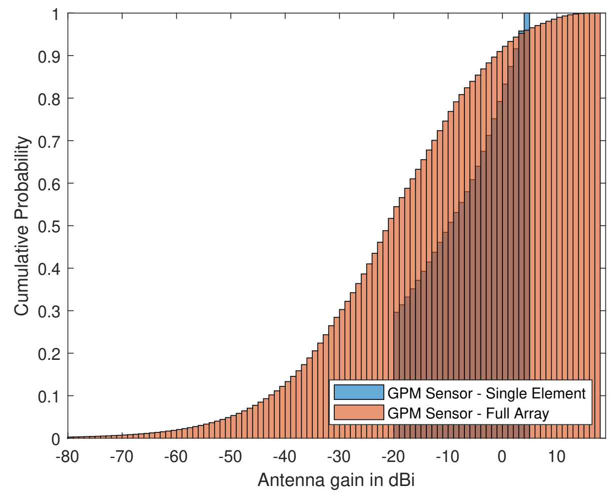


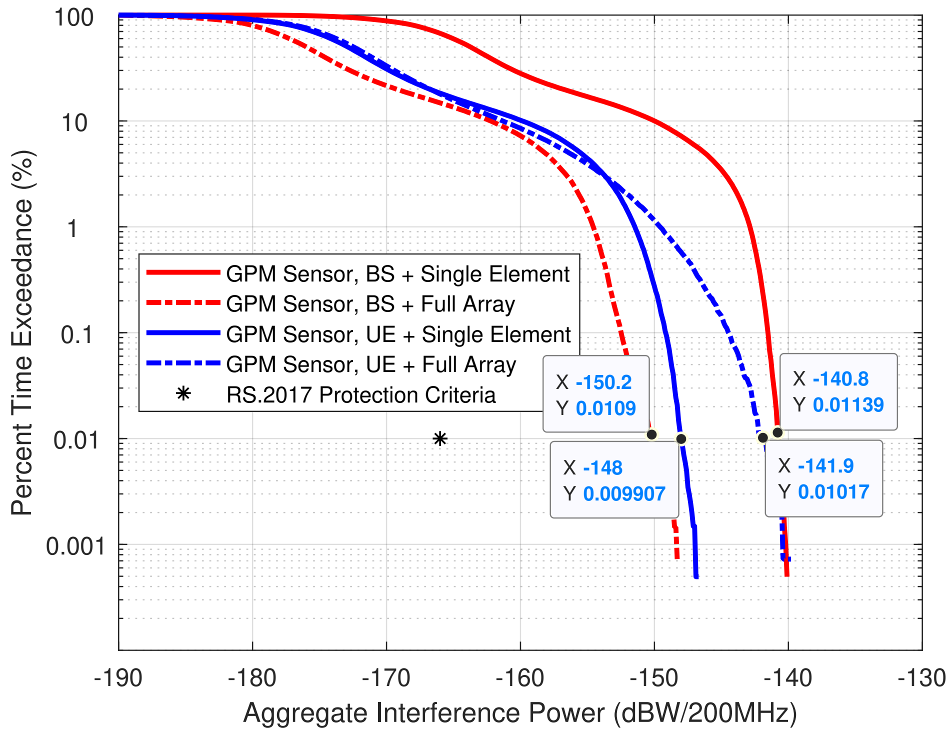
Figure 18: CDF of UE TX Gain toward EESS



8.6 Interference CCDFs

Per Section 7 above, all of the aggregate interference levels for each time step are calculated. Once this is complete for all time steps, the complementary cumulative distribution function (CCDF) of these aggregate interference values is calculated. The CCDF below demonstrates what percentage of the time steps the aggregate interference was above the specified level on the x-axis. The EESS (passive) protection criteria for the 23.6-24 GHz band specifies that aggregate interference values of -166dBW/200MHz may occur in no more than 0.01% of the time steps.

Figure 19: Interference CCDF for GPM Sensor (Out-of-Band Limits)



The total interference from BSs and UEs for the single element case is -140.8dBW/200MHz and -148.0dBW/200MHz, respectively. The total interference from BSs and UEs for the full array case is -150.2dBW/200MHz and -141.9dBW/200MHz, respectively. Based on the assumptions in this analysis and the EESS (passive) protection criteria, the out-of-band limits in Table 5 are proposed.

Table 5: Analysis Results in dBW/200MHz

	IMT Transmitter	Baseline	With 50/50 UE/BS Interference Split	With Apportionment
23.8 GHz, Single Element	Base Station	-45.2	-48.2	-51.2
	User Equip.	-38.0	-41.0	-44.0
23.8 GHz, Full Array	Base Station	-35.8	-38.8	-41.8
	User Equip.	-44.1	-47.1	-50.1

These limits were derived by calculating the aggregate interference levels for each time step in the simulation and then calculating the complementary cumulative distribution function (CCDF) of these aggregate interference levels. The EESS (passive) protection criteria for the 23.6-24 GHz band specifies that aggregate interference values of -166dBW/200MHz may occur in no more than 0.01% of the time steps. The exceedance of the protection criteria is defined as the difference between the protection criteria threshold of -166dBW/200MHz and the CCDF value at 0.01%. This exceedance (if any) is then subtracted from the TG 5/1 specified total radiated power (TRP) values of -20dBW/200MHz to determine the needed out-of-band limit. This limit is then further adjusted by two factors which further reduces the limit:

- The 50%/50% UE/BS interference split of 3dB. This accounts for the proportional contribution of IMT BSs and UEs to the total IMT aggregate interference at the EESS receiver. If both BS and UE emissions separately meet the protection criteria, in aggregate it will exceed by 3dB.

- Apportionment of 3dB. This accounts for interference to the EESS from multiple services. If both IMT emissions and other co-frequency services separately meet the protection criteria, in aggregate it will exceed by $10\log_{10}$(number of active services).

When examining the CCDF of the interference that was derived using the TG 5/1 and 3GPP TRP values of -20dBW/200MHz, it is shown that the percentage of time the aggregate -166dBW/200MHz interference threshold is exceeded is 70.96% in the case of the single element antenna model, and 24.46% in the case of the full array antenna model. This indicates the amount of data loss that the EESS systems would experience if the out-of-band limits of IMT stations are set to -20dBW/200MHz and not reduced.

Figure 20: Interference CCDF for GPM Sensor (Data Loss)