Potential Metrics for Assessing the Impact of ESC Sensors and Networks on CBRS Deployments

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Preface

Spectrum Access Systems (SASs) must protect Environmental Sensing Capability (ESC) sensors from harmful interference caused by Citizens Broadband Radio Service Devices (CBSDs) in the vicinity of the sensors. Therefore, the presence of an ESC sensor can impact the ability to deploy or operate CBSDs. This Technical Report presents options for computing metrics by which the impact of ESC sensors (and networks of ESC sensors) on Citizens Broadband Radio Service (CBRS) deployments can be measured, and the metrics may be used by ESC operators to optimize or improve ESC sensor design and siting.

Contributors

WInnForum Members

- Khalid Al-Mufti, Commscope
- Serge Barbosa Da Torre, Google
- Virgil Cimpu, Ericsson
- Andrew Clegg, Google
- Mark Gibson, Commscope
- John Glossner, Optimum Semiconductor Technologies
- Ariful Hannan, Commscope
- Yi Hsuan, Google
- Masoud Olfat, Federated Wireless

Other Subject Matter Experts

- Jesse Caulfield, Key Bridge Wireless

Potential methods for assessing the impact of ESC sensors and networks on CBRS deployments are proposed.

1 Introduction and Summary

This document presents options for computing metrics by which the impact of ESC sensors and ESC networks on CBRS deployments could be measured.

- Option A attempts to estimate the population impacted by the deployments of sensors and networks.
- Option B attempts to estimate the overall impact on CBRS networks by counting the number of CBSDs that must reduce power to mitigate interference to ESC sensors and networks.

It is important to note that the metrics presented here are for the purpose of comparing the impacts of different ESC sensor locations and configurations. They are not for the purpose of determining actual impact to specific populations or CBSDs. In other words, the metrics are proxies for impact, not the actual impacts. They are useful for investigating ways to reduce the impact of particular sensor sites and operating configurations.

Also note that the metrics presented here may or may not be used by individual ESC operators, and individual ESC operators may also use other metrics that are not listed here. Users should inquire with an ESC operator if they desire more detail on metrics that are in use by that operator.

1.1 DPA Protection

Figure 1 shows the lower 48 states Dynamic Protection Areas (DPA) locations. DPAs are areas that may be activated or deactivated as necessary to protect Department of Defense (DOD) radar systems. An Environmental Sensing Capability (ESC) sensor is used to monitor DPA activity. A Spectrum Access System (SAS) is required to incorporate ESC sensor data to protect incumbent DOD radar systems.

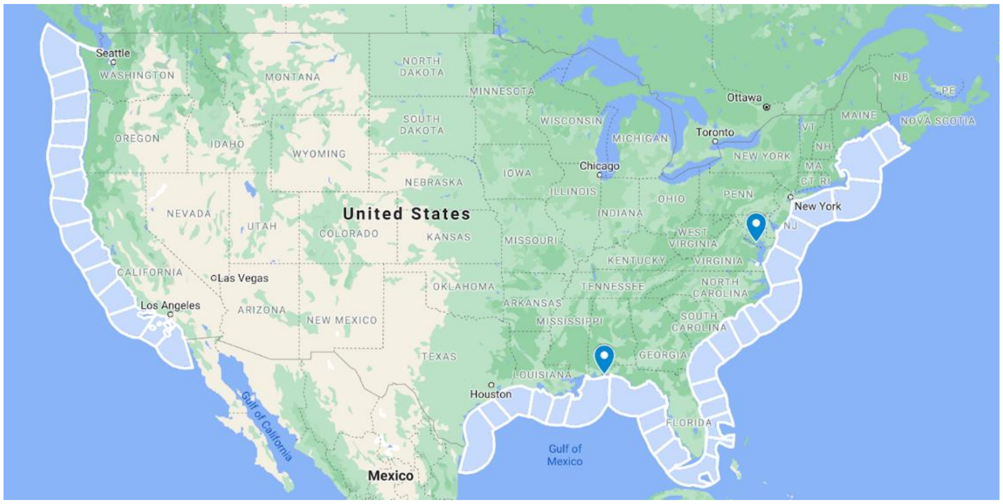
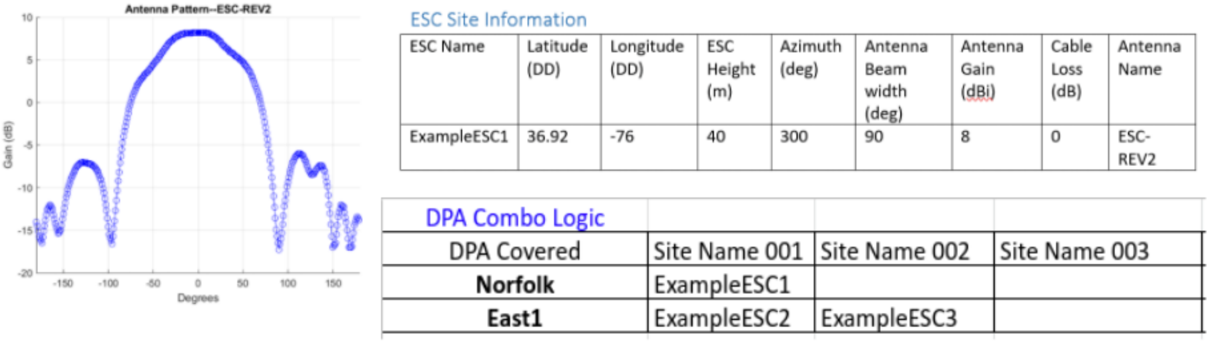


Figure 1: US Coastal Dynamic Protection Area (DPA) Locations

1.2 ESC Coverage

The National Telecommunications and Information Administration (NTIA) has developed Matlab software capable of determining if a DPA is adequately covered by an ESC.

Figure 2 shows representative inputs for the NTIA software. The NTIA software takes characteristics of the sensor such as location, height, antenna azimuth, antenna pattern, and cable loss as input. A list of sensors per DPA is input into the software. The NTIA software then computes if the DPA is adequately covered by the sensors, i.e. for 99% of the DPA and with some acceptable expected statistical reliability (typically 50% or 95% confidence depending on coastal zone).



ESC Site Information

ESC Name	Latitude (DD)	Longitude (DD)	ESC Height (m)	Azimuth (deg)	Antenna Beam width (deg)	Antenna Gain (dBi)	Cable Loss (dB)	Antenna Name
ExampleESC1	36.92	-76	40	300	90	8	0	ESC-REV2

DPA Combo Logic

DPA Covered	Site Name 001	Site Name 002	Site Name 003
Norfolk	ExampleESC1		
East1	ExampleESC2	ExampleESC3	

Figure 2: NTIA Matlab Inputs

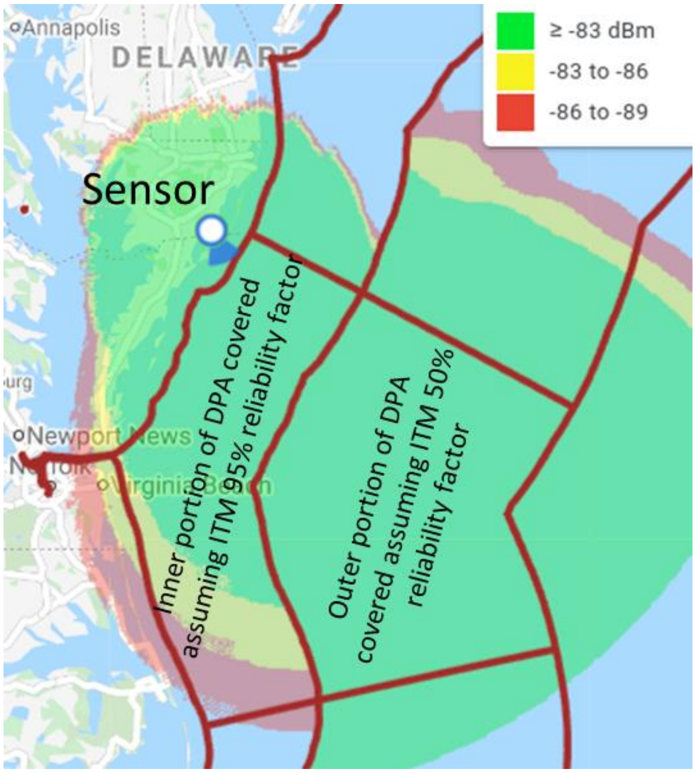


Figure 3: Example of DPA coverage from one sensor (ExampleESC1 sensor from Fig. 2). The predicted received signal strength from a radar is shown in the key, in units of dBm/MHz. ESC sensors are required to detect radar signals down to -89 dBm/MHz.

Figure 3 illustrates such DPA coverage in one example involving one sensor monitoring one DPA. The 70 km coastal zone would be assessed with a 95% reliability in the ITM propagation model, and further coastal area would be assessed with a 50% reliability. Note that the coverage is designed to properly cover the DPA but not too much, as over-coverage will increase impact as will be seen later.

1.3 SAS Protection Requirements

ESC sensors are considered as incumbents that SAS needs to protect against harmful interference from deployed CBSDs. Hence each SAS is required to use information about ESC locations and antenna characteristics when assigning spectrum in order to ensure this protection. Each ESC network operator supplies to every SAS data similar to the NTIA Matlab inputs.

A key difference is that the ESC sensor network operator may provide custom protection requirement criteria to the SAS in the form of a relaxed interference protection threshold or some effective antenna pattern that may differ from the actual measured antenna pattern used for DPA coverage certification.[1] The typical motivation is, for example, to include the effect of clutter in the immediate vicinity of the sensor's antenna protecting the sensor from interference in the backside direction. Such clutter is otherwise not included in the default ITM propagation model

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[1] Wireless Innovation Forum Technical Specification TS-0112, "Requirements for Commercial Operation in the U.S. 3550-3770 MHz Citizens Broadband Radio Service Band," version 1.9.1, R2-ESC-07(b), p. 65 (2020)

used by SASs to protect the sensor. It can also be for smoothing out the backside antenna nulls that are not precisely known in the real world due to electromagnetic effects caused, for example, by conducting materials in the vicinity of the antenna, or due to sample variations in the construction of the antenna.

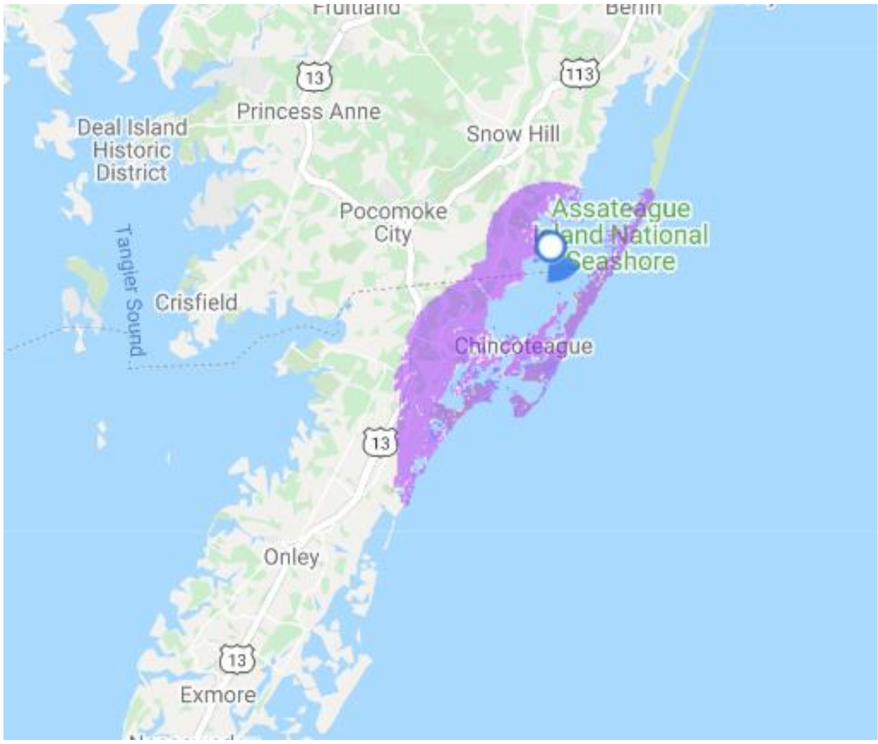

Figure 4: Area impact of ExampleESC1 sensor from Fig. 2.

Figure 4 shows an example of impact caused by an imaginary ESC sensor, using a smoothed antenna pattern in the backside. The area of impact is defined as the area where a single Category B CBSD with a height of 25 m above ground level, pointing directly towards the sensor, would have its nominal maximum allowed power of 47 dBm/10 MHz reduced by the SAS to avoid interfering with the sensor.

The purple area in Figure 4 is called a "whisper zone," and it is computed by aggregating all pixels for which the overall path loss (including sensor antenna pattern masking) is within 146 dB (computed as 37 dBm/MHz Category B EIRP minus -109 dBm/MHz protection level[2]).

The population impact is defined as the total population within that whisper zone.

Annex A provides more information on how the whisper zone and population impact are computed.

Because a SAS is required to receive sensor site location information from all ESC network operators and protect the ESC sensors accordingly, it is incumbent upon the ESC network

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[2] The protection level is established in NTIA Technical Memorandum 18-527, "Procedures for Laboratory Testing of Environmental Sensing Capability Sensor Devices," p.3 (2018).

operators to transmit the ESC network parameters that minimize population impact but still protects the ESC sensor from harmful interference.

1.4 Impact Mitigation

Figures 5 and 6 provide another example of the DPA coverage and whisper zone impact of an imaginary ESC sensor placed atop the new Cape Henry Lighthouse in Virginia Beach and pointing inland to cover the Norfolk DPA. The impacted population based on option A is 1.25 million pops.

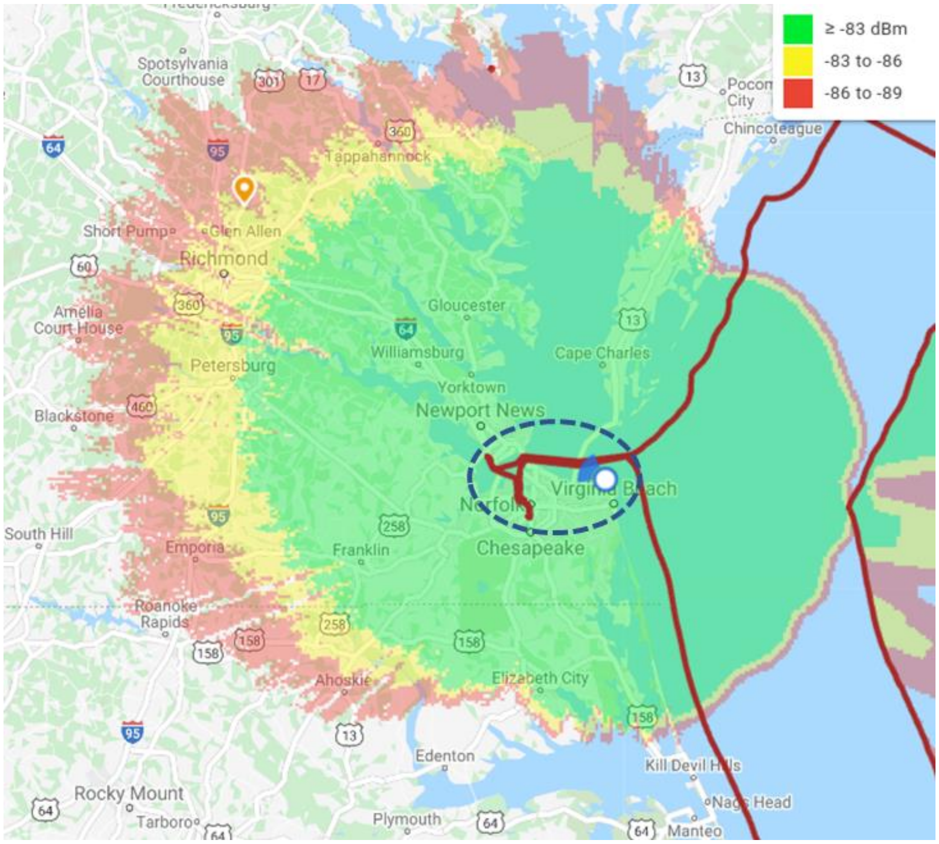

Figure 5: Coverage of Norfolk DPA (thin red polygon, highlighted by blue dashed ellipse) by an imaginary ESC sensor atop the new Cape Henry Lighthouse in Virginia Beach, showing the coverage of the sensor for detecting DOD radar.

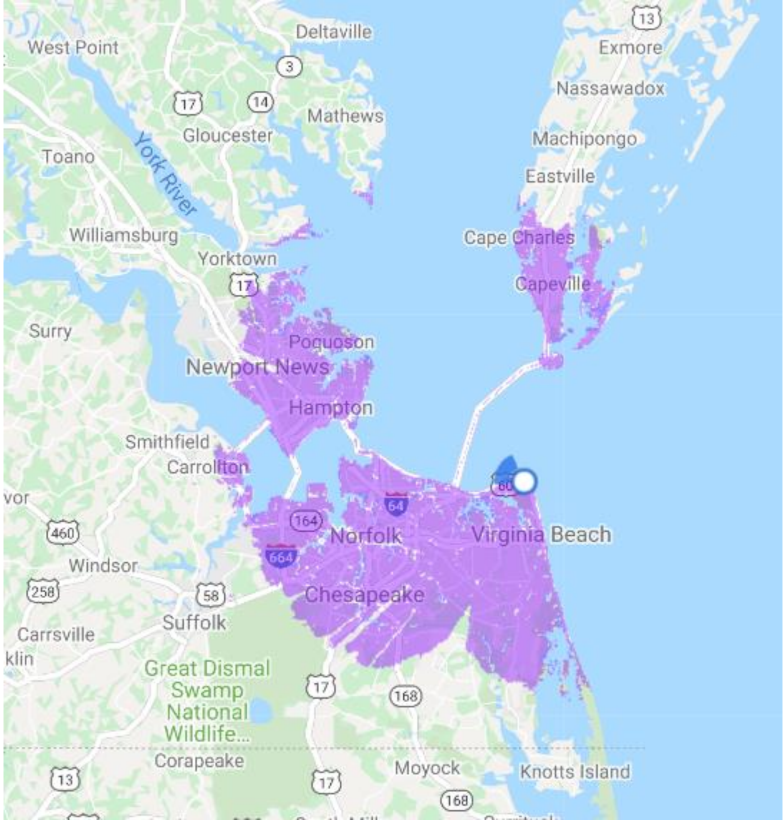

Figure 6: Impact (whisper zone) of the imaginary sensor atop the Cape Henry lighthouse.

One can note that the Norfolk DPA is covered too well, and the coverage extends well beyond the Norfolk DPA boundaries. A simple way to mitigate the impact is to simply add some attenuation at the output of the sensor antenna to reduce DPA coverage and at the same time the population impact.

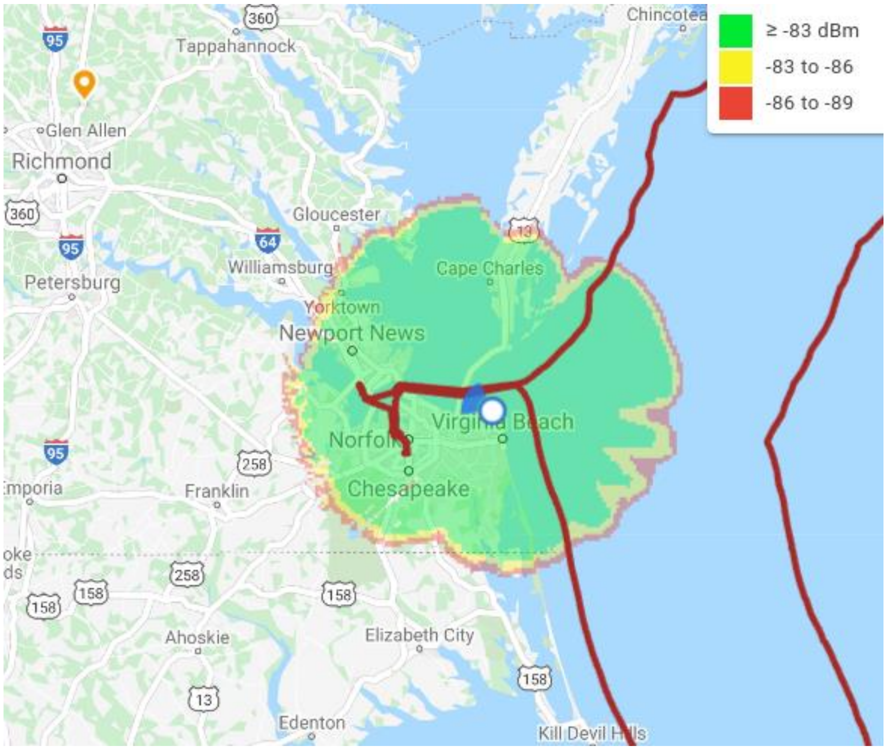

Figure 7: Norfolk DPA coverage of the imaginary sensor atop the Cape Henry Lighthouse with 50 dB extra attenuation added to the output of the antenna compared to Figure 5.

Figure 7 shows the same sensor coverage with an extra attenuation of 50 dB. The coverage is well adapted to the DPA boundaries, and the new pop impact has been substantially reduced.

More generally the means that can be used to reduce impact to the CBRS network falls within three categories:

1. Choose sensor locations carefully
    a. Place the sensors away from heavily-populated areas
    b. Use natural terrain obstruction (hills, etc.) to shield the sensor from populated areas
    c. Leverage clutter (i.e., buildings and foliage) in the immediate vicinity of the antenna to reduce the antenna’s sensitivity toward populated areas
2. Design the sensor configurations carefully
    a. Use advanced antenna design with excellent front-to-back and front-to-side attenuation.
    b. Use careful azimuth pointing to cover the DPA while reducing sensitivity to populated areas
    c. Use attenuation on the output of the sensor antenna to reduce unnecessary “spillage” of coverage beyond the DPA boundary
3. Reduce number of sensors and sensor locations
    a. Colocate sensors of a single network (for example, two sensors monitoring different DPAs) to reduce the number of distinct whisper zones
    b. Reduce the number of ESC networks and sensors by sharing when possible

c. Avoid over-engineering the ESC sensor network by not multiplying unnecessarily the number of redundant sensors.

2 Option A: Single Exposure Population Impact

This method determines the population that resides within areas in which a single CBSD with its maximum EIRP pointed directly at an ESC sensor[3] is predicted to exceed the interference criterion of the sensor. See Annex A for a high-level summary of how the impact is computed. Note that Option A does not consider aggregate interference. The impact is based on the existence of only one CBSD in the ESC sensor neighborhood at a time and is therefore extremely conservative. The population impact also does not consider the case that the siting of a CBSD in a given location is impacted, but that the population using that CBSD (i.e., its coverage area) might extend into adjacent populations that otherwise don’t show as impacted. Four (or more) quantities may be computed:

1. The impact of a single sensor (per-sensor impact)
2. The impact of the sensor(s) of a network required to monitor a specific Dynamic Protection Area (DPA), while taking into account populations that may be impacted by multiple sensors monitoring different DPAs (per-DPA impact)
3. The impact of all of the sensors in a network while not double-counting populations that are impacted by two or more sensors in the same network (per-network impact)
4. The impact of all ESC networks combined is computed, also while avoiding double-counting populations (total ESC impact)

The geographic area under study is divided up into individual pixels j.[4] This area constitutes all areas that are within the neighborhood distance of any ESC sensor. The neighborhood distance for each sensor is 40 km for Category A and 80 km for Category B. A standard CBSD antenna height (above ground level) of 6 m (Cat A) or 25 m (Cat B) is chosen for the purpose of calculating propagation loss.

The following variables are used:

I_{max}	Interference criterion for ESC sensors (dBm/10 MHz)
$G_{i,j,k}$	Antenna gain of ESC sensor i (dBi) of network k toward point j
$L_{i,j,k}$	Propagation loss from sensor i of network k to center of pixel j (dB)
POP_j	Population of pixel j
$EIRP_{max}$	Max EIRP of a CBSD (dBm/10 MHz) (i.e., 47 or 30)

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[3] This is a good hypothesis both for CBSD using omnidirectional antenna (typically Cat A) and multi-sector CBSD where at least one sector tends to point somewhat towards the sensor (within +-60 deg for 3-sector deployment).

[4] The choice of pixel size is a compromise between map resolution and computational speed and may also be informed by the complexity of terrain in the area. Recommended values range from 5 – 20 arcsec, with 10 arcsec having shown to be a good compromise. Note that the number of computations scales with the inverse square of the pixel resolution.

$n_{i,k}$	Total number of pixels within the neighborhood of ESC sensor i in network k
$I_{i,j,k}$	Interference to sensor i of network k from a CBSD in pixel j, = $EIRP_{max} - L_{i,j,k} + G_{i,k}$
m_k	The total number of sensors in the ESC network k
q	The total number of ESC networks

The population impact for an individual sensor *i* in ESC network *k* is computed as follows:

$$IMP_{i,k} = \sum_{j=1}^{n_{i,k}} POP_j \left[I_{i,j,k} > I_{max} \right], \qquad \text{[Eq. 1]}$$

where the square bracket (Iverson Bracket) function equates to 1 if the condition inside is true and 0 otherwise. In this example, a given POP_j is counted in the sum only if the predicted interference from pixel *j* into sensor *i* of network *k* ($I_{i,j,k}$) exceeds the sensor's interference criterion.

The population impact for the ESC sensor network *k* is:

$$IMP_k = \sum_{i=1}^{m_k} \sum_{j=1}^{n_{i,k}} POP_j \left[I_{i,j,k} > I_{max}, POP_j \text{ not already counted} \right]. \qquad \text{[Eq. 2]}$$

The population impact for all ESC networks combined is:

$$IMP = \sum_{k=1}^{q} \sum_{i=1}^{m_k} \sum_{j=1}^{n_{i,k}} POP_j \left[I_{i,j,k} > I_{max}, POP_j \text{ not already counted} \right] \qquad \text{[Eq. 3]}$$

Some advantages of Option A are that it is simple to explain, relatively straightforward to calculate, and measures impact by population, which are characteristics that are likely to resonate with both technical and non-technical members of the CBRS community.

Note that the method can be modified to allow for various levels of multiple exposure, instead of a single CBSD. For example, the ESC sensor interference criterion could be lowered by X dB to account for the impact of simultaneous exposure to $10^{X/10}$ CBSDs. Similarly, $EIRP_{max}$ can be adjusted to account for alternative CBSD models. For example, $EIRP_{max}$ could be taken as 15 dBm in order to model the impact on indoor Category A CBSDs (30 dBm max EIRP - 15 dB building entry loss).

As an alternative, the method can also be modified to scale the population impacted with a factor proportional with the extra interference (i.e., the power reduction created by an IAP-like algorithm), so as to effectively count the population loss of capacity.

3 Option B: Model Deployment Power Impact

Another potential method for determining the impact of individual ESC sensors, an ESC network, or all ESC networks combined is to examine the impact on allowable transmit power for CBSDs in a model deployment. For example, the impact can be gauged by the number of CBSDs that must reduce their transmit power as a result of the presence of an ESC sensor.

Reference can also be made to the histogram of power reductions required, and perhaps a mathematical metric from that distribution can be derived, although that is for future study.

Here, we specifically recommend using the NTIA deployment model, which was used to compute potential interference impact to DPAs. The model deployed CBSDs in a random population-weighted distribution. The NTIA deployment model is provided both on a per DPA basis, for which there is overlap among multiple sets of CBSDs, and on a global basis that can be used for the whole US without any issue of CBSD overlap.[5] The analysis performed here used the national deployment model dataset. Also note that for this study, each CBSD is assumed to be operating on the same frequency.

The individual sensor impact is modeled as follows. For each CBSD *j* in the model deployment, its nominal EIRP (i.e., its EIRP in the absence of any ESC or incumbent protections) is $\mathrm{EIRP}_{0,j}$.[6] Then an individual ESC sensor *i* from ESC network *k* is introduced, and the CBSDs in the model deployment are subjected to the standard Iterative Allocation Process (IAP). The allowed EIRP for CBSD *j* after IAP, caused by the existence of sensor *i* in network *k* (and no other considerations), is given by $\mathrm{EIRP}_{i,j,k}$. The impact of the sensor is the number of CBSDs that must reduce power due to the presence of the sensor:[7]

$$IMP_{i,k} = \sum_j \left[EIRP_{i,j,k} < EIRP_{0,j}\right], \qquad \text{[Eq. 4]}$$

where, as before, the square brackets denote the Iverson Bracket function (=1 if the condition is true, 0 otherwise), and therefore the sum counts the number of CBSDs that must reduce power due to an ESC sensor.

The impact of the *k*th network is computed in a similar fashion. All sensors in the network are deployed, and IAP is run. After IAP, the power of the *j*th CBSD as a result of consideration of all of the sensors in the *k*th network is given by $\mathrm{EIRP}_{j,k}$. The overall impact of the *k*th network is given by counting the number of impacted CBSDs:

$$IMP_k = \sum_j \left[EIRP_{j,k} < EIRP_{0,j}\right]. \qquad \text{[Eq. 5]}$$

Finally, all sensors in all ESC networks are considered, and IAP is run once again. The impact is computed in the same fashion as for the individual sensor and individual network case. The EIRP of the *j*th CBSD after considering all sensors in all networks is EIRP_j. The overall impact due to all ESC networks combined is given by counting the number of impacted CBSDs:

$$IMP = \sum_j \left[EIRP_j < EIRP_{0,j}\right]. \qquad \text{[Eq. 6]}$$

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[5] The NTIA global and per-DPA deployment models are available in Github: https://github.com/Wireless-Innovation-Forum/Spectrum-Access-System/tree/master/data/research/deployment_models

[6] Note that in this option, compared to option A, *j* denotes a specific CBSD, not a pixel.

[7] The count is summed across all CBSDs under study, regardless of neighborhood or location, because IAP will only affect CBSDs that are within a neighborhood. If there is no impact to a CBSD (either inside or outside a neighborhood) then the "before and after" power is the same and the CBSD does not contribute to the count.

This particular set of metrics is appropriate and convenient for several reasons:

1. No separate propagation model, and resulting discussion of the proper inputs thereto, is needed. The propagation model is built into the approved SAS requirements. (Note that this is also the case for Option A)
2. A simple metric as put forward here foregoes the necessity of involving population density in the calculation. Instead, that impact is intrinsic to the CBSD deployment model.
3. The impacts are calculated natively by the application of the standardized IAP, which is already in successful commercial use in all SASs.
4. The impact is based on a neutral (NTIA-derived) CBSD deployment model.

For future study, additional or alternative metrics to this Option can be created based upon the distribution of power reductions that are required to meet sensor protection requirements.

4 Option C

A third metric was proposed but no data were available with which to analyze it. For completeness, Option C is included as Annex B.

5 Analysis and Results

In this section the results of running the population impact study are reviewed. Scripts for running population (Option A) and CBSD (Option B) impact metrics are available on the WinnForum Github repository.[8,9] There are sample ESC json files in Github. Actual ESC sensor data are not public.

5.1 Introduction

As part of the population study, three out of four currently-operating ESC operators agreed to provide their data to a neutral third party, although two of the three operators that shared data use the same sensors. The results were aggregated and are presented below. The group agreed to use the data with some of the sensors being excluded due to ongoing interference analysis.

5.2 Option A Individual Sensors

Figure 8 shows the results of aggregated sensor data for all ESC sensors versus the impacted population. Of the 146 sensors covering all coastal US DPA’s the vast majority have minimal population impact with notably 80 sensors having fewer than 5000 people impacted.

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[8] https://github.com/Wireless-Innovation-Forum/Spectrum-Access-System/tree/master/src/studies/esc_impact_pop

[9] https://github.com/Wireless-Innovation-Forum/Spectrum-Access-System/tree/master/src/studies/esc_impact_sim

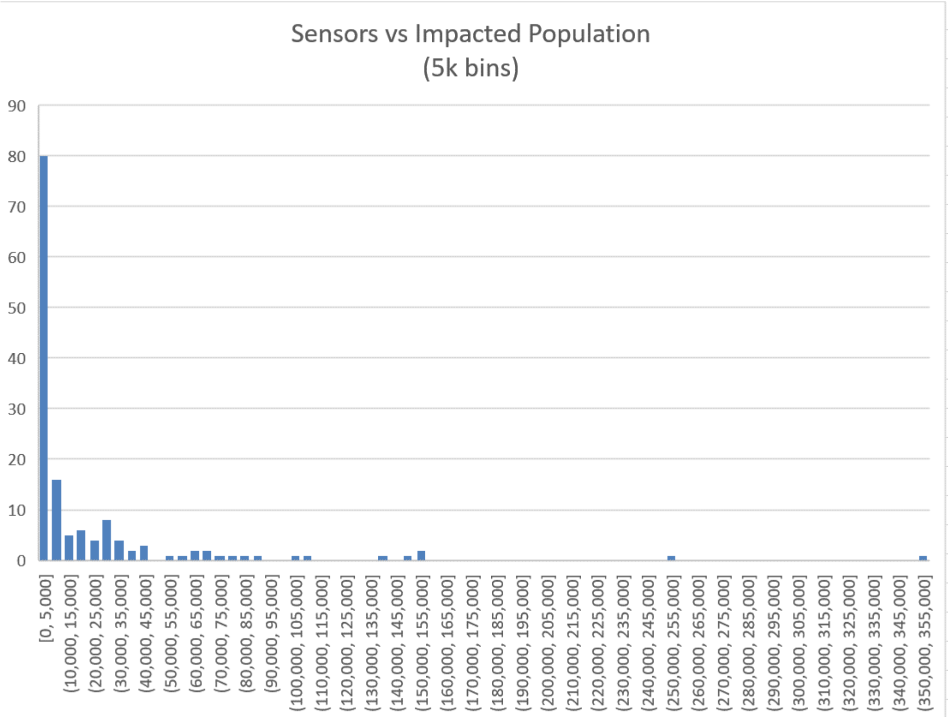


Figure 8: Distribution of the number of sensors (y-axis) impacting a given range of population (x-axis) using Option A.

The code was run with a single combined json sensor file with default arguments:

```
python esc_pop_impact.py -esc_fads=testdata/combined-sensors.json
```

Significant default parameter values are given in Table 1.

Table 1: Option A Individual Sensor Parameters

Default Parameter	Value	Meaning
--grid_arcsec	10	Grid calculation resolution (in arcsec)
--budget_offset_db	0	A budget link offset
--category	B	CBSD category. A, B, or indoor. B computes the affected population within an 80km radius.
--force_radius_km	0	If set, the neighborhood radius if forced to a non-standard value
--nbor_pop_only	False	When true it computes the total neighborhood population (not just the affected population)

5.3 Option A Normalized Population Impact

Since some sensors are placed in heavily populated areas and others are placed in sparsely populated areas it was considered to normalize the impacted area by dividing the impacted population by the total population within an 80 km radius of the sensor.

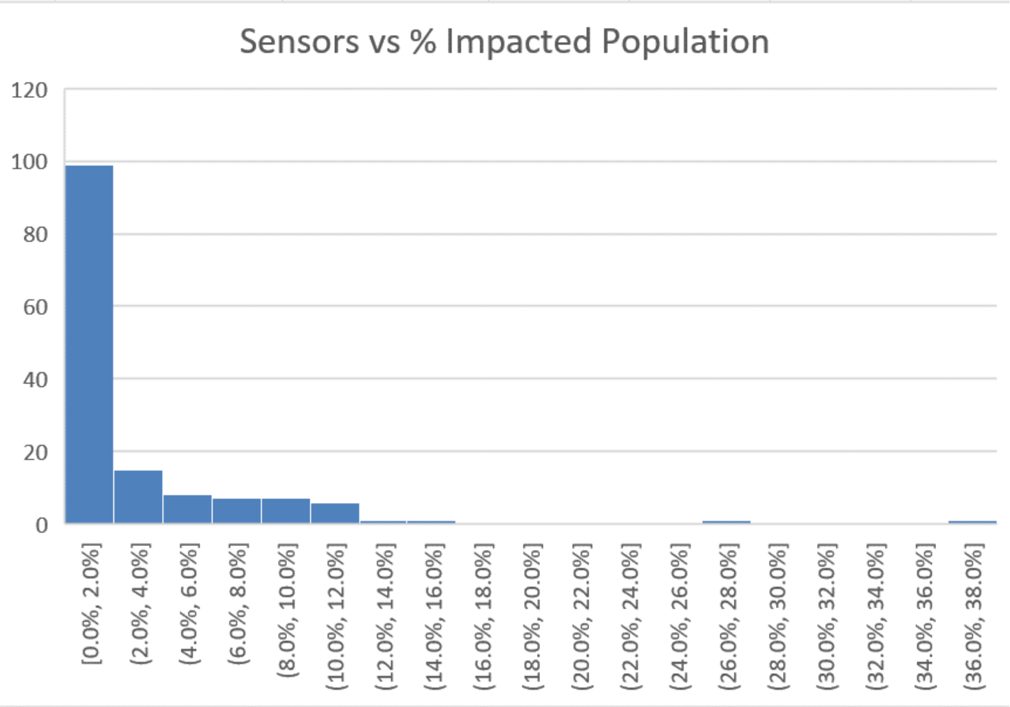


Figure 9: Option A Number of Sensors versus % Impacted Population within 80 km

Figure 9 shows the numbers of sensors versus the percent impacted population. Running the combined json sensor file with the flag –nbor_pop_only gives the total population within 80 km of the sensor. While the vast majority of sensors have very low *percent population* impact, it is not simple to conclude that normalizing the data results in better information. For example, the worst-case sensor with 37.6% population impact only encompasses a total population of 54,433 people. In contrast, a sensor with 13.8M people within an 80 km neighborhood had zero population impact.

5.4 Option A Individual Sensors Distribution Statistics

Table 2 gives the distribution of 146 sensors. Min/Max/Average/Std Dev are computed based on the impact of individual sensors. However, this has some population overlap. The network-based computation in Option A removes duplicate population counts. For the 146 combined ESC sensors the impacted population without duplicates is 2,645,709 people. The de-duplicated total number of people living within an 80 km radius of the impacted population is 74,751,160.

Table 2: Option A Individual Sensors Distribution Statistics

146 sensors	Impacted Population	Total Population	Impact / Total Population
Network	2,645,709	74,751,160	3.5%
Min	0	12,444	0%
Max	353,271	13,846,585	37.6%
Average	21,223	2,277,758	2.7%
Std Dev	45,809	3,231,552	4.8%

It is important to note that Min/Max impacted are not correlated to the Min/Max total population. The minimum impacted population of 0 had multiple sensors with no impact. The largest total population with no impact is 13.8 million people. Similarly, the maximum impacted population of 353,271 did not come from the largest total population but from a total population of 3,998,192.

Finally, Average and Standard Deviation were computed on an individual sensor basis and include population overlaps. For example, the average population impact is 21,223. If duplicates are removed the average impact would be 2,645,709/146 = 18,121.

5.5 Option A DPA Results

Another method of normalization evaluated was per DPA. In this case six DPAs were chosen with three on the east coast and three on the west coast. Each contributing ESC network sensor operator provided a list of sensors covering specific DPAs. These sensors were combined into one json file per DPA. The six files were then independently run through the population impact estimator.

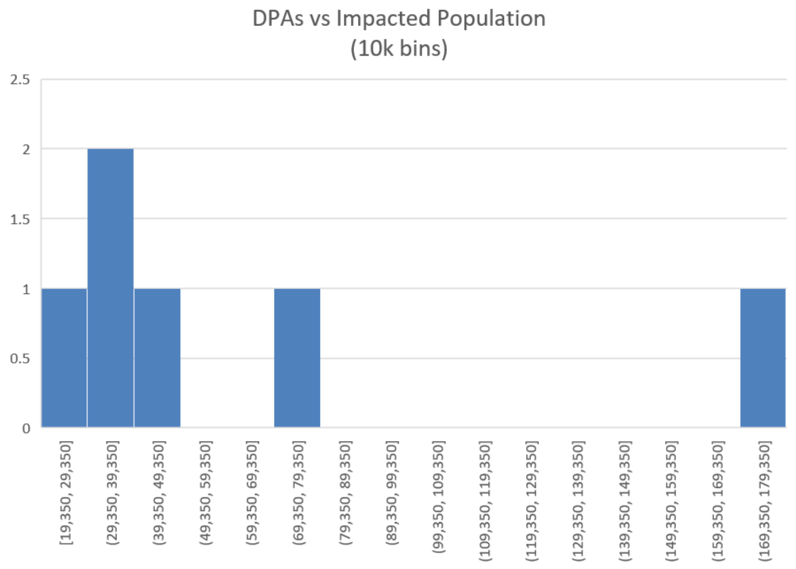


Figure 10: Option A Count of DPAs (y-axis) vs. Impacted Population (x-axis) for a limited sample of six DPAs.

Figure 10 shows the population impact on a per DPA basis. Similar to individual sensors, most DPAs have low population impacts but with notable exceptions. The maximum population impacted is 172,584 and happens to be on the east coast.

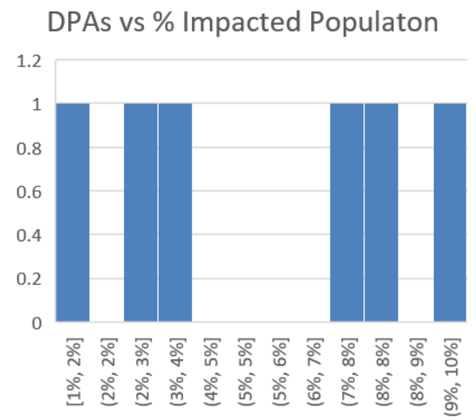


Figure 11: Option A DPA vs. Percent Impacted Population

Figure11. Shows DPAs normalized to percent of impacted population. The worst-case impact is 10% and happens to be the same DPA as the maximum population impacted. The total population with duplicates removed within an 80 km radius of the worst-case DPA is ~1.8 million people.

Table 3: Option A DPA Distribution Statistics

6 DPAs 23 sensors	Impacted Population	Total Population	Impact / Total Population
Network	364,082	8,720,538	4.2%
Min	19,350	359,119	0.9%
Max	172,584	2,819,235	9.8%
Average	60,553	1,451,552	5.3%
Std Dev	57,496	969,250	3.5%

Table 3 shows the DPA distribution statistics. The network statistics were generated by combining all 23 sensors (covering the six DPAs) into a single json file. The 364,082 impacted population across the 6 DPAs is within 0.2% of summing the impact of the individual DPAs. The same is true for the total population within 80 km of the 23 sensors. This implies that the sensors in the DPAs do not overlap in population.

Normalizing per population within 80 km of an ESC sensor covering a particular DPA results in the same problem as normalizing to all people within an 80 km radius of a sensor. The DPA with the largest total population within 80 km of all ESC sensors needed to cover that DPA is 2,819,235 people but only 69,769 (2%) are impacted.

5.6 Option B CBSD Power Reduction for Six DPAs

Option B was run for the same six DPAs as Section 5.5 Option A. The code computed that 447 CBSDs within range of the ESC sensors would be impacted. Figure 12 shows a bar chart of the CBSDs and the amount of power reduction in dB due to the ESC sensors.

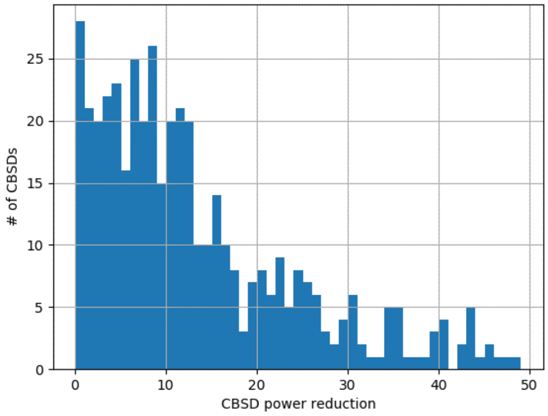
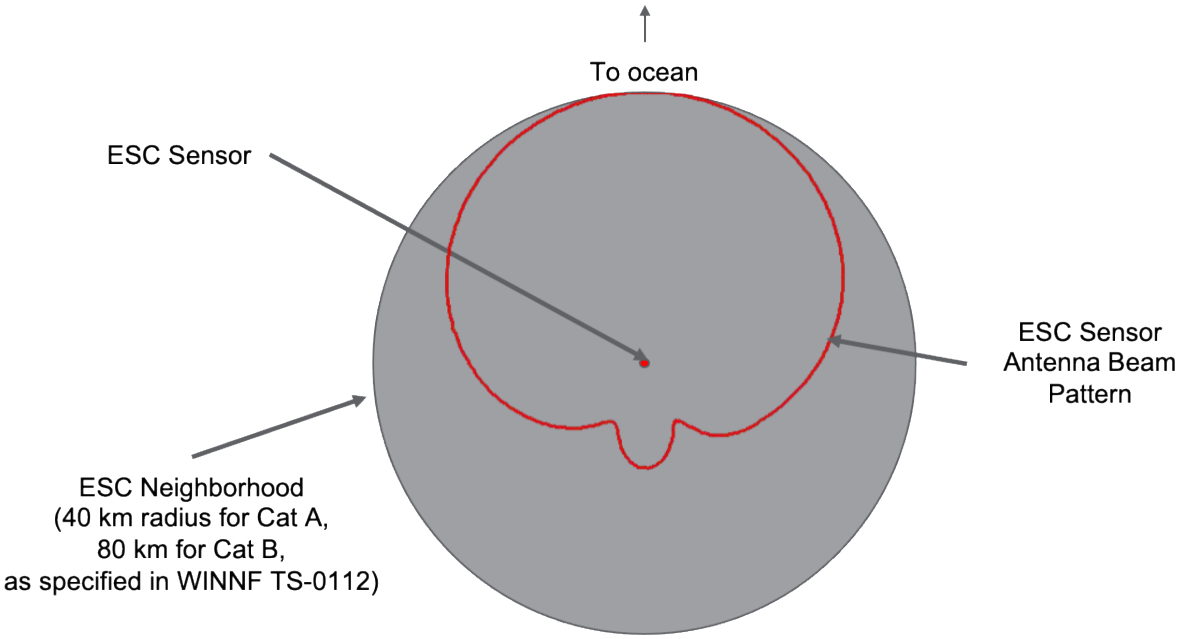
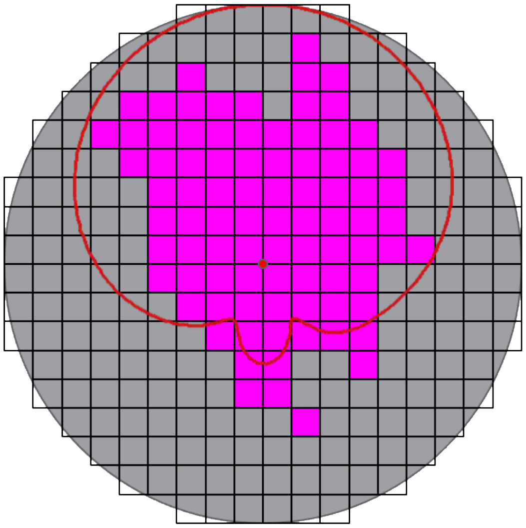


Figure 12: Option B CBSD Power Reduction, over six sample DPAs

For the six DPAs evaluated, there were on average 75 CBSDs affected per DPA. The maximum was 176 CBSDs and the minimum was 29 CBSDs.

Annex A: Overview of Population Impact Methodology (Option A)





- Divide the ESC sensor neighborhood into pixels
- For each pixel in turn, place a CBSD at the center of the pixel, pointed directly at the ESC sensor
  - Assume a particular EIRP and antenna height for the CBSD
- Compute total path loss from the CBSD to the sensor, including propagation loss and the impact of the sensor's antenna pattern
- If the EIRP of the CBSD minus the total path loss exceeds the interference threshold of the ESC sensor, shade the pixel. Otherwise the pixel remains clear
- Repeat for all of the pixels in the ESC neighborhood, using only a single CBSD at a time (i.e., there is always only one CBSD within the ESC neighborhood)
- The totality of the shaded pixels is the single-exposure whisper zone for that sensor
  - The shape and extent of the whisper zone will depend on the ESC antenna pattern, the ESC antenna height, the local terrain, the CBSD height, and the CBSD EIRP
- Compute the sum of the population in the shaded pixels

Annex B: Option C, Model Deployment Power Impact per Distance

Option A, population impact, is advantageous for its simplicity. Option B, aggregate interference, is advantageous for using the same process used by SASs in protecting ESC sensors (IAP). However, the followings are noticeable:

1- The initial requested EIRP for each CBSD has a significant role on the number of CBSDs impacted by ESC sensor protection. Assuming the maximum EIRP per CBSD will result in conservative values for IMP in *Eq. 6*.

2- In option B, IMP *(Eq. 6)* is calculated based on the number of CBSDs requested to reduce EIRP. However, many CBSD deployments may tolerate some level of EIRP reduction, without significant impact to the services they provide to users. Therefore, to measure the impact of ESC protection to the services provided to users, a different metric such as some statistics of CBSD power reductions might be more suitable. An example of such statistics is the average power reduction per CBSD, combined with the number of CBSDs impacted.

3- The impact of ESC sensor protection on CBSDs varies significantly based on the distance of the CBSD to the ESC sensor. Therefore, counting the number of CBSDs with EIRP reduction, or calculating the average EIRP reduction per CBSD over the whole region may not accurately represent the actual impact.

Similar to Option B, in Option C, the CBSDs are deployed according to NTIA model (as described in footnote 4), and the requested EIRP values per CBSD, CBSD category, antenna heights, as well as indoor vs. outdoor status may be randomly distributed.

Then, the area around ESC sensors may be divided into rings, according to the distance to the ESC sensor, and the metrics may be calculated per ring. One such metric is the average EIRP reduction per CBSD category, combined with the number of CBSDs impacted. Figure *B.1* depicts an example of using Option C, where different colors represent different values for EIRP reductions. The metrics in this option may be used to compare ESC impact by adjusting the ESC sensor antenna pattern, ESC sensor installation parameters, or propagation model used to calculate IAP results.

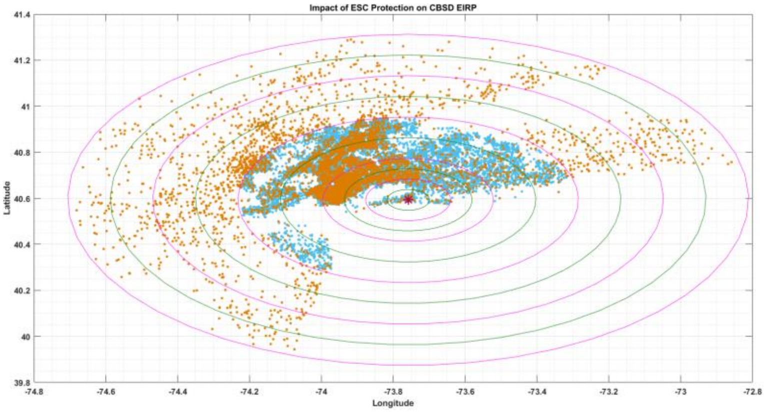


Figure B.1: CBSDs deployed per Ring

For the case of multiple ESC sensors, the rings may be defined differently. For example, the metric may be calculated based on the shortest distance to any point on the contour of the DPA, rather than the distance to a single point (single ESC location).