NTIA Technical Report 21-551

Compatibility of Federal Systems Operating in the 5850-5925 MHz Band with Intelligent Transportation Systems and Unlicensed National Information Infrastructure Devices

Edward Drocella
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technical report

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

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U.S. DEPARTMENT OF COMMERCE

Adam Candeub
Acting Assistant Secretary of Commerce for Communications and Information
National Telecommunications and Information Administration

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ABBREVIATIONS/ACRONYMS

AGL	Above Ground Level
AP	Access Point
CDF	Cumulative Distribution Function
CONUS	Contiguous United States
CS	Channel Scaling
C-V2X	Cellular Vehicle-to-Everything
dB	Decibel
dBi	Decibels relative to an isotropic antenna
dBm	Decibel (referenced to 1 milliwatt)
DOD	Department of Defense
DOE	Department of Energy
DSRC	Dedicated Short Range Communication
EIRP	Equivalent isotropically radiated power
FCC	Federal Communications Commission
FDR	Frequency Dependent Rejection
GHz	Gigahertz
GIS	Geographic Information System
GMF	Government Master File
IF	Intermediate Frequency
I/N	Interference-to-Noise ratio
IMT	International Mobile Telecommunications
IPC	Interference Protection Criteria
ITM	Irregular Terrain Model
ITS	Intelligent Transportation System
ITU-R	International Telecommunication Union Radiocommunication Sector
km	Kilometers
log	Common logarithm
MHz	Megahertz
MRLC	Multi-Resolution Land Characteristics Consortium

NASA	National Aeronautics and Space Administration
NLCD	National Land Cover Database
NPRM	Notice of Proposed Rulemaking
NTIA	National Telecommunications and Information Administration
OBU	On Board Unit
OFR	Off Frequency Rejection
OOBE	Out-of-Band Emission
OTR	On-Tune Rejection
P2P	Point-to-Point
P2MP	Point-to-Multipoint
RDT&E	Research Development Test and Evaluation
RF	Radio Frequency
RSU	Road Side Unit
SP	Service Penetration
U-NII	Unlicensed National Information Infrastructure
US&P	United States and Possessions

EXECUTIVE SUMMARY

This Technical Report provides details about protection of federal operations in the 5.850-5.925 GHz (5.9 GHz) band from new operations considered by the Federal Communications Commission (FCC) as part of the agency's comprehensive review intended to allow for the highest and best use of the band.[1] As part of its ongoing effort to accommodate new commercial wireless services, the National Telecommunications and Information Administration (NTIA) worked with agencies that operate federal systems in the band to determine the protections needed to permit new commercial services to operate without causing impact to incumbent operations. To facilitate the FCC's expeditious review of the record, NTIA already submitted to the FCC a letter setting forth the relevant protection requirements derived from the numerous details provided in this Technical Report.[2]

Protection of Incumbent Federal Systems in the Band. Operations proposed by the FCC's *NPRM* must protect higher-priority federal systems in the 5.9 GHz band, where primary allocations include federal radiolocation services. The Department of Defense (DOD) operates fixed and mobile radars for surveillance (including airborne surveillance), test range instrumentation, airborne transponders, and testing in support of the tracking and control of airborne vehicles. The National Aeronautics and Space Administration and the Department of Energy also operate radar systems in the 5.9 GHz band.[3]

The FCC's *NPRM* proposed in relevant part to reduce the amount of spectrum in the band provided to Dedicated Short Range Communications (DSRC) service (governed as Intelligent Transportation System (ITS) operations), revise its DSRC/ITS service rules (and in doing so permit Cellular Vehicle-to-Everything (C-V2X) operations), and then permit unlicensed device operations in the remainder of the band (subject to Part 15 Unlicensed National Information Infrastructure (U-NII) rules).

Protection from ITS Operations. To facilitate spectrum sharing and optimize unencumbered ITS operations, NTIA finds that the number of so-called "coordination zones" can be reduced from the current 59 to 30, and the size of most coordination zones can be reduced from the current 75 kilometers.[4] NTIA finds that requiring C-V2X road side units (RSU) to comply with existing DSRC rules, as the FCC tentatively concluded in the *NPRM*,[5] adequately protects the primary 5.9 GHz band federal radiolocation services. Although these existing DSRC rules

[1] *See Use of the 5.580-5.925 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 19-138, 34 FCC Rcd 12603 (2019) (*NPRM*).

[2] *See* Letter from Charles Cooper, Assoc. Administrator, NTIA, to Ronald Repasi, Acting Chief, OET, FCC (Sept. 8, 2020), https://www.ntia.doc.gov/files/ntia/publications/docket_19_138_ntia_filing_september_8.pdf.

[3] The DOD also uses aeronautical and maritime mobile systems in or adjacent to the 5.9 GHz band; however, protection beyond that provided from devices under existing Part 15 rules is not required because these systems can only operate on a non-interference basis in this band.

[4] The protection requirements contained herein are premised upon the power and out-of-band emission levels contemplated by the Commission. Any deviation from those parameters may result in a change to these requirements.

[5] *See NPRM*, para. 47.

require that RSU installations within specified zones near federal radar locations must be coordinated with NTIA,[6] NTIA finds that the number and size of these zones generally can be reduced.[7] DSRC RSUs are not protected from harmful interference caused by incumbent federal operations.[8]

Protection from U-NII Operations. NTIA finds that, to protect federal radiolocation systems, operation of U-NII-4 ***outdoor*** point-to-point (P2P) and point-to-multipoint (P2MP) devices would require the imposition of exclusion zones.[9] To enforce the exclusion zones, NTIA believes that interference mitigation techniques such as geo-fencing can be employed to protect federal radiolocation operations. NTIA emphasizes the importance of ensuring that U-NII device operation is not permitted inside of these exclusion zones, especially in light of experience with U-NII devices in the 5 GHz band.[10]

For ***indoor*** U-NII-4 device operation, to reduce the potential for interference to federal radiolocation systems, specific rules must be adopted.[11] The rules should help ensure indoor devices are not deployed outdoors and that expedient and effective corrective measures be in place to eliminate interference should it occur, rather than imposing exclusion zones as a first measure to protect the federal systems.[12]

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[6] *See* 47 C.F.R. § 90.371(b).

[7] *See infra* Table 18.

[8] *See NPRM*, para. 47, *citing* 47 C.F.R. § 90.371(b).

[9] The required exclusion zones are set forth in *infra* Table 19. "U-NII-4" unlicensed devices are those for the 5.9 GHz band.

[10] *See* National Telecommunication and Information Administration Technical Report TR 20-544, *Lessons Learned from the Development and Deployment of 5 GHz Unlicensed National Information Infrastructure (U-NII) Dynamic Frequency Selection (DFS) Devices* (Dec. 2019), https://www.ntia.doc.gov/report/2019/lessons-learned-development-and-deployment-5-ghz-unlicensed-national-information. Section 8 describes interference to a federal radar from a U-NII device.

[11] *See infra* Section 8.3.

[12] *See Unlicensed Use of the 6 GHz Band*, Report and Order and Further Notice of Proposed Rulemaking, 35 FCC Rcd 3852 (2020), https://docs.fcc.gov/public/attachments/FCC-20-51A1.pdf.

1. INTRODUCTION

1.1 Background

The 5850-5925 MHz (5.9 GHz) band has been reserved for shared use by federal radiolocation systems and non-federal Dedicated Short Range Communications (DSRC). The Department of Defense (DOD) operates fixed and mobile radars for surveillance (including airborne surveillance), test range instrumentation, airborne transponders, and testing in support of the tracking and control of airborne vehicles. The National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) also operate radar systems in the 5.9 GHz band.[13] Non-federal DSRC operates as a service in the Intelligent Transportation System (ITS) designed to enable vehicle-related communications.

The Federal Communications Commission (FCC) has initiated a Notice of Proposed Rulemaking (*NPRM*) to take a comprehensive look at the 5.9 GHz band rules and propose appropriate changes to ensure that the spectrum supports its highest and best use.[14] For non-federal users, the FCC proposed to continue to dedicate spectrum in the upper 30 megahertz of the 5.9 GHz band to meet current and future ITS needs for transportation and vehicle safety-related communications, while repurposing the lower 45 megahertz of the band for unlicensed operations, such as Wi-Fi. The FCC *NPRM*:[15]

- Proposes to repurpose the lower 45 megahertz of the band (5.850-5.895 GHz) for unlicensed operations to support high-throughput broadband applications;

- Proposes that unlicensed device operations in the 5.850-5.895 GHz band be subject to all of the general Part 15 operational principles in the Unlicensed National Information Infrastructure (U-NII) rules;[16]

- Proposes to adopt technical and operational rules (e.g., power levels, out-of-band emissions limits) similar to those that already apply in the adjacent 5.725-5.850 GHz (U-NII-3) band;

- Proposes to continue to dedicate spectrum in the upper 30 megahertz of the 5.9 GHz band (5.895-5.925 GHz) to support ITS needs for transportation and vehicle safety-related communications;

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[13] The DOD also uses aeronautical and maritime mobile systems in or adjacent to the 5.9 GHz band; however, protection beyond that provided from devices under existing Part 15 rules is not required because these systems can only operate on a non-interference basis in this band.

[14] *Use of the 5.850-5.925 GHz Band*, Notice of Proposed Rulemaking, ET Docket No. 19-138, 34 FCC Rcd 12603 (2019).

[15] Federal Communications Commission Fact Sheet *Use of the 5.850-5.925 GHz Band* (Nov. 21, 2019), https://docs.fcc.gov/public/attachments/DOC-360940A1.pdf.

[16] *See* 47 CFR Section 15.407

- Proposes to revise the current ITS rules for the 5.9 GHz band to permit Cellular Vehicle-to-Everything (C-V2X) operations in the upper 20 megahertz of the band (5.905-5.925 GHz);

- Seeks comment on whether to retain the remaining 10 megahertz (5.895-5.905 GHz) for DSRC systems or whether this segment should be dedicated for C-V2X;[17] and

- Proposes to retain the existing technical and coordination rules that currently apply to DSRC, to the extent that DSRC operations continue in the 5.895-5.905 GHz band.

1.1.1 ITS Sharing with Federal Incumbents[18]

The existing DSRC rules for the protection of the 5.9 GHz federal radars with primary allocation require that roadside installations within 75 kilometers of 59 federal radar locations be coordinated with the National Telecommunications and Information Administration (NTIA).[19] The FCC believes that requiring those that deploy C-V2X equipment to coordinate installations within 75-kilometer coordination zones represents the most straightforward approach for enabling compatibility with federal operations. The FCC *NPRM* seeks comments on this proposal, and specifically on whether C-V2X operations at the proposed power levels would in any way alter the previous assumptions for sharing with federal radars.

The FCC *NPRM* seeks comments on what measures could be established for C-V2X equipment to ensure the federal radars are not subject to harmful interference. Proposals should address the potential impact from both roadside and on-board units and provide information as to how such interference could be mitigated by requiring technical or operational constraints on the C-V2X operations in the event harmful interference were to occur.

The FCC *NPRM* seeks comments on whether there are alternate methods to ensure that harmful interference is not caused to federal radars from C-V2X devices based on the proposals included in the *NPRM*. The FCC *NPRM* seeks comments on whether dynamic or location awareness methods should be used by C-V2X systems to automatically reduce power when nearing any of the sites designated for coordination, and whether or not such provisions should be made applicable to all C-V2X equipment. The FCC's consideration of on-board units in this regard could become relevant if it adopts final rules that specify different maximum power limits for C-V2X on-board units than those power limits for DSRC on-board units. Provisions also need to be in place to add new federal radar coordination sites. Proponents of any of these options should provide details specifying how the FCC could modify the interference protection rules.

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[17] The analysis assumes that DSRC will retain the remaining 10 megahertz (5.895-5.905 GHz) and C-V2X will be operating in the upper 20 megahertz of the band (5.905-5.925 GHz). The ITS coordination distances calculated in the analysis also cover the scenario of C-V2X operating in 5.895-5.925 GHz.

[18] *See NPRM,* paras. 47-48.

[19] *See* 47 CFR § 90.371.

1.1.2 U-NII Sharing with Federal Incumbents[20]

As to unlicensed devices in the 5.9 GHz band, the FCC notes that unlicensed devices currently share spectrum with DOD radar operations in the adjacent U-NII-3 band (5.725-5.850 GHz). The FCC *NPRM* proposes to adopt the same technical rules (e.g., radiated power, power spectral density, etc.) for 5850-5895 MHz (U-NII-4) unlicensed devices as those technical rules applied to U-NII-3 unlicensed devices. The FCC is aware of U-NII-3 devices causing interference to a U.S. Air Force radar tracking system; and therefore, seeks comments on whether there are any mitigation measures, such as technical or operational conditions or constraints, that it should consider for U-NII-4 operations to protect DOD radars in the 5.9 GHz band.

1.2 Objective

The objective of this study is to assess the compatibility of ITS and U-NII-4 devices with federal systems operating in the 5.9 GHz band based on the proposals in the FCC *NPRM*, and if necessary, identify changes to protect federal operations.

1.3 Approach

To conduct this study, NTIA used the following approach:

- Defined the technical parameters and the pertinent operational characteristics related to interference protection of the federal systems operating in the 5.9 GHz band;
- Defined the analysis methodology for computing aggregate interference from ITS and U-NII-4 systems to federal systems;
- Worked with representatives from the federal agencies with frequency assignments in the 5.9 GHz band to verify the technical and operational parameters to be considered in the analysis;
- Examined the different proposals in the NPRM to determine if changes are necessary to protect federal operations from interference;
- Reviewed the comments and reply comments filed in response to the NRPM; and
- Identified any changes to NPRM proposals or interference mitigations that are necessary to protect federal operations.

Section 2 of this report describes the technical and operational parameters, as well as the interference threshold, of the federal systems operating in the 5.9 GHz band. Section 3 describes the technical and deployment parameters for the ITS and U-NII-4 devices. Section 4 describes the engineering models used in the analysis. Sections 5, 6, and 7 provide the details of the

[20] *See NPRM,* paras. 53-57.

interference methodology for airborne, ground-based, and shipborne systems. Section 8 summarizes the results of the analysis and any changes to the proposals in the *NPRM*, or interference mitigations necessary to protect federal systems.

2. FEDERAL SYSTEMS

2.1 Overview

The DOD uses this band for a wide variety of radar applications including anti-air warfare radars, which are part of an advanced ground-based air defense missile system. DOD, NASA, and DOE also use this band for a variety of land-based and shipborne radars including such functions as surface search, navigation, land-mapping and imaging, and weapons fire control.

2.2 Allocation Table

The frequency allocation table shown below is extracted from the NTIA *Manual of Regulations and Procedures for Federal Radio Frequency Management*, Chapter 4 – Allocations, Allotments and Plans.

Table 1. United States Table of Frequency Allocations 5650 - 5925 MHz Band

Federal Table	Non-federal Table	FCC Rule Part(s)
5650-5925 MHz RADIOLOCATION G2 5.150 US245	5650-5830 MHz Amateur 5.150 5.282	RF Devices (15) ISM Equipment (18) Amateur (97)
	5830-5850 MHz Amateur Amateur-satellite (space-to-Earth) 5.150	
	5850-5925 MHz FIXED-SATELLITE (Earth-to-space) US245 MOBILE NG160 Amateur 5.150	ISM Equipment (18) Private Land Mobile (90) Personal Radio (95) Amateur (97)
5.150 The following bands: 13 553-13 567 kHz (center frequency 13 560 kHz), 26 957-27 283 kHz (center frequency 27 120 kHz), 40.66-40.70 MHz (center frequency 40.68 MHz), 902-928 MHz in Region 2 (center frequency 915 MHz), 2 400-2 500 MHz (center frequency 2 450 MHz), 5 725-5 875 MHz (center frequency 5 800 MHz), and 24-24.25 GHz (center frequency 24.125 GHz)		

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. 15.13.

5.282 In the bands 435-438 MHz, 1260-1270 MHz, 2400-2450 MHz, 3400-3410 MHz (in Regions 2 and 3 only) and 5650-5670 MHz, the amateur-satellite service may operate subject to not causing harmful interference to other services operating in accordance with the Table (see No. 5.43). Administrations authorizing such use shall ensure that any harmful interference caused by emissions from a station in the amateur-satellite service is immediately eliminated in accordance with the provisions of No. 25.11. The use of the bands 1260-1270 MHz and 5650-5670 MHz by the amateur-satellite service is limited to the Earth-to-space direction.

G2 In the bands 216-217 MHz, 220-225 MHz, 420-450 MHz (except as provided by US217 and G129), 890-902 MHz, 928-942 MHz, 1300-1390 MHz, 2310-2390 MHz, 2417-2450 MHz, 2700-2900 MHz, 3300-3500 MHz (except as provided by footnote US108), 5650-5925 MHz, and 9000-9200 MHz, the Federal radiolocation service is limited to the military services.

NG160 In the band 5850-5925 MHz, the use of the non-Federal mobile service is limited to Dedicated Short Range Communications operating in the Intelligent Transportation System radio service.

US245 In the bands 3600-3650 MHz (space-to-Earth), 4500-4800 MHz (space-to-Earth), and 5850-5925 MHz (Earth-to-space), the use of the non-Federal fixed-satellite service is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis. The FCC's policy for these bands is codified at 47 CFR 2.108.

2.3 Summary of Federal Systems[21]

This section provides the locations of the federal systems that operate in the 5.9 GHz band. Table 2 provides all the locations and system(s). Table 3 through Table 9 list the locations and systems used by each federal agency/service.

Table 2. All Federal System Locations

Facility Name	State	System Identifier
Anclote	FL	RL4
Cape Canaveral	FL	RL1, RL26
Cape San Blas	FL	RL1, RL4
Carabelle Field	FL	RL4
CGAS Cape Code	MA	AM4
Charleston	SC	RL26

[21] RL denotes radiolocation service systems; AM denotes aeronautical mobile service systems; MM denotes maritime mobile service systems.

Facility Name	State	System Identifier
Coastal Waters	US&P	RL 19, RL20, RL26, RL36
Edwards Air Force Base	CA	RL1, RL12
Edwards Air Force Base	CA	AM1
Eglin Air Force Base	FL	RL1, RL4, RL6
Fort Story	VA	MM2
Fort Walton Beach	FL	RL1
Holloman	NM	AM2
Honolulu	HI	RL19
Kalaeloa	HI	MM1
Kennedy Space Center	FL	RL10, RL25, RL26
Key West	FL	RL26
Kirtland Air Force Base	NM	RL24
Kokee Park	HI	RL1
Launch Vehicle	VA	RL13
MacDill	FL	RL4
Moorestown	NJ	RL19
Nevada Test and Training Range	NV	RL4, RL5, RL7, RL9, RL21
Norfolk	VA	RL19
Pacific Missile Range Facility Barking Sands	HI	RL34
Patuxent River	MD	RL5, RL18
Pearl Harbor	HI	RL26
Pillar Point	CA	RL2
Point Mugu	CA	RL1, RL5
Poker Flat Research Range	AK	RL14
Port Hueneme	CA	RL26
Saddle Bunch	FL	RL4
San Diego	CA	RL26
San Nicolas Island	CA	RL1, RL17
Tonopah Test Range	NV	RL9, RL22, RL23
Vandenberg	CA	RL1, RL3, RL8
Venice	FL	RL4
Vineyard Sound	MA	AM4
Wallops Island	VA	RL14, RL15, RL16
Webster Field	MD	RL19, RL33
White Sands Missile Range	NM	RL1, RL5, RL7, RL9, RL10, RL11, RL17, RL31, RL32

Facility Name	State	System Identifier
Yuma Proving Ground	AZ	RL22, RL35

2.4 Radiolocation Service

Table 3 provides the location of radiolocation systems used by the U.S. Air Force.

Table 3. Air Force Radiolocation System Locations

Facility Name	State	System Identifier
Anclote	FL	RL4
Cape Canaveral	FL	RL1
Carabelle Field	FL	RL4
Cape San Blas	FL	RL1, RL4
Edwards Air Force Base	CA	RL1
Eglin Air Force Base	FL	RL1, RL4, RL6, RL32
Fort Walton Beach	FL	RL1
Kennedy Space Center	FL	RL10, RL25
MacDill	FL	RL4
Nevada Test and Training Range	NV	RL4, RL5, RL7, RL9
Pillar Point	CA	RL2
Point Mugu	CA	RL5
Saddle Bunch	FL	RL4
Vandenberg	CA	RL1, RL3, RL8
Venice	FL	RL4
White Sands Missile Range	NM	RL1, RL5, RL7, RL9, RL31, RL32

Table 4 provides the location of radiolocation systems used by the U.S. Army.

Table 4. Army Radiolocation System Locations

Facility Name	State	System Identifier
White Sands Missile Range	NM	RL1, RL9, RL10, RL11
Yuma Proving Ground	AZ	RL22

Table 5 provides the location of radiolocation systems used by NASA.

Table 5. NASA Radiolocation System Locations

Facility Name	State	System Identifier
Edwards Air Force Base	CA	RL12
Launch Vehicle	VA	RL13

Facility Name	State	System Identifier
Poker Flat Research Range	AK	RL14
Wallops Island[22]	VA	RL14, RL15, RL16

Table 6 provides the location of radiolocation systems used by the U.S. Navy.

Table 6. Navy Radiolocation System Locations

Facility Name	State	System Identifier
Charleston	SC	RL26
Coastal Waters	US&P	RL 19, RL20, RL26, RL36
Honolulu	HI	RL19
Kennedy Space Center	FL	RL26
Key West	FL	RL26
Kokee Park	HI	RL1
Moorestown	NJ	RL19
Norfolk	VA	RL19
Pacific Missile Range Facility Barking Sands	HI	RL34
Patuxent River	MD	RL5, RL18
Pearl Harbor	HI	RL26
Point Mugu	CA	RL1
Port Canaveral	FL	RL26
Port Hueneme	CA	RL26
San Diego	CA	RL26
San Nicolas Island	CA	RL1
San Nicolas Island	CA	RL1, RL17
Webster Field	MD	RL19, RL33
White Sands Missile Range	NM	RL17
Yuma Proving Ground	AZ	RL35

Table 7 provides the location of radiolocation systems used by the DOE.

Table 7. DOE Radiolocation System Locations

Facility Name	State	System Identifier
Kirtland Air Force Base	NM	RL24
Nevada Test Site	NV	RL21
Tonopah Test Range	NV	RL9, RL22, RL23

[22] Includes transponders.

2.5 Aeronautical Mobile Service

Table 8 provides the location of aeronautical mobile systems used by the U.S. Air Force in the 5250-5850 MHz band. Although the aeronautical mobile service is not allocated in the 5 GHz band (including the band up to 5925 MHz), these systems have authorized frequency assignments in 5250-5850 MHz with a 160 kilometer (km) radius of operation at these locations. These operations are scheduled to migrate out of the band by 2027. Because of the lack of allocation and the migration out of the 5 GHz band, operations will not be authorized in the 5850-5925 MHz band; therefore, protection of aeronautical mobile systems from U-NII devices beyond Part 15 rules will not be required.

Table 8. Air Force Aeronautical Mobile System Locations

Facility Name	State	System Identifier
Edwards Air Force Base	CA	AM1
Holloman	NM	AM2

2.6 Maritime Mobile Service

Table 9 provides the location of maritime mobile systems used by the U.S. Navy. Although the maritime mobile service is not allocated in the 5850-5925 MHz band, these systems have authorized frequency assignments on a non-interference basis. Therefore, protection of maritime mobile systems from U-NII devices beyond the Part 15 rules is not required.

Table 9. Navy Maritime Mobile System Locations

Facility Name	State	System Identifier
Kalaeloa	HI	MM1
Fort Story	VA	MM2

2.7 Federal System Interference Threshold

If the nominal receiver noise floor is not provided, a theoretical receiver noise floor is calculated in Equation (1):

$$NoiseFloor_{Rx} = -174\frac{dBm}{Hz} + NF_{Rx} + 10log_{10}(Rx\ BW\ Hz) \qquad (1)$$

where:

NF_{Rx}: is the noise figure of the federal receiver (dB);

$Rx\ BW\ Hz$: is the 3 dB intermediate frequency (IF) bandwidth of the federal receiver (Hz);

Equation (2) defines the federal system receiver interference threshold as:

$$RIT_{\frac{dBm}{RX\ BW\ MHZ}} = NoiseFloor_{Rx} + Loss_{Insertion} + I/N_{ratio} - AntGain_{Rx} \qquad (2)$$

where:

$RIT_{\frac{dBm}{RX\,BW\,MHZ}}$: is the federal system receiver interference threshold i.e., the undesired signal power level predicted to cause interference to the federal receiver (dBm);

$Loss_{Insertion}$: is federal receiver insertion loss, which is assumed to be 2 dB;

I/N_{ratio}: is the interference protection criteria of the federal receiver, established to be -6 dB (dB); [23] and

$AntGain_{Rx}$: is the mainbeam 3 dB boresight antenna gain (dBi).

[23] Sanders, F. H., R. Sole, B. Bedford, D. Franc and T. Pawlowitz, *Effects of RF interference on radar receivers*, NTIA Technical Report TR-06-444, U.S. Department of Commerce, September 2006, http://www.its.bldrdoc.gov/publications/2481.aspx.

3. ITS DEPLOYMENT AND TECHNICAL PARAMETERS

3.1 Overview

This section provides the deployment and technical parameters of the ITS systems considered in the analysis. It is assumed that DSRC will retain the remaining 10 megahertz (5.895-5.905 GHz) and C-V2X will operate in the upper 20 megahertz of the band (5.905-5.925 GHz) with the following emission limits proposed in the FCC Fact Sheet, *Use of the 5.850-5.925 GHz Band* (Nov. 21, 2019).[24]

C-V2X is a standards-based communications system based on the 4G LTE-Pro system in 3GPP Release 14, with additional standard work currently underway to develop 5G C-V2X peer-to-peer mode. The 5G Automotive Association has suggested that the Commission adopt proposed technical rules for C-V2X operations that are based on the 3GPP standard and include:

Equivalent isotopically radiated power (EIRP)[25]:

23 dBm for vehicular and portable units; and

33 dBm for roadside units;

Out-of-band emissions (OOBE) measured at the antenna input (i.e., conducted OOBE limits) limited to:

-29 dBm/100 kHz at the band edge;

-35 dBm/100 kHz ± 1 megahertz from the band edge;

-43 dBm/100 kHz ± 10 megahertz from the band edge; and

-53 dBm ± 20 megahertz from the band edge.

OOBE-radiated limits: All C-V2X on-board units and roadside units will limit emissions to -25 dBm/100 kHz EIRP or less outside the band edges of 5.905 GHz and 5.925 GHz.

3.2 ITS Deployment Parameters

Multi-Resolution Land Characteristics (MRLC) 2011 National Land Cover Database (NLCD) data,[26] NLCD 2011, and 2010 U.S. Census population data were used to distribute ITS roadside unit (RSU) and on-board unit (OBU) systems.[27] For each census tract, the NLCD area

[24] The fact sheet is available at: https://docs.fcc.gov/public/attachments/DOC-360940A1.pdf.

[25] It should be noted that the transportation community has not accepted that EIRP as a requirement.

[26] *See* MRLC Consortium, https://www.mrlc.gov/index.php.

[27] United States Census Bureau, https://www.census.gov/programs-surveys/decennial-census/data/datasets.2010.html.

classification codes were collected for the entire area of the census tract, and then the census tract was classified by the highest occurring count of NLCD codes: dense urban (24), urban (23), suburban (22), and rural (21).

ITS RSUs and OBUs were placed uniformly along all primary and secondary roads.[28] Table 10 provides the spacing for the RSUs and OBUs.

Table 10. ITS Deployment Parameters

NLCD Classification/Clutter Category	RSU Spacing (km)	OBU Spacing (km)
Urban	0.25	0.1
Suburban	1	0.5
Rural	2	1

Table 11 and Table 12 provide the technical parameters for the RSUs and OBUs. For each RSU and OBU, antenna above ground level (AGL) heights were uniformly distributed based upon the census tract NLCD area classification. To account for RSU and OBU transmissions of a 50%[29] duty cycle, a 3 dB reduction is applied to the EIRP[30] in the tables. Table 11 and Table 12 reflect today's current usage of ITS RSU device parameters. ITS RSUs are permitted EIRP and antenna heights higher than those described in Table 11 and Table 12.[31] Recognizing the ongoing growth and development of ITS, changes to ITS deployment could affect the applicability of results in this report and may warrant revisiting the topic.

[28] United States Census Bureau, 2019 TIGER/Line Shapefiles: Roads, (*Census Shapefiles*), https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2019&layergroup=Roads.

[29] An OBU transmits a BSM in less than 500 usecs, 10 times per second for DSRC and 20 times per second for C-V2X with HARQ. To achieve OBU 50% channel usage would require a large number of vehicles in close proximity.

[30] EIRP values include antenna gain.

[31] *See* 47 CFR § 90.377.

Table 11. RSU Technical Parameters

Parameter	Dense Urban	Urban	Suburban	Rural
DSRC EIRP	18 dBm/10MHz	21 dBm/10MHz	24 dBm/10MHz	27 dBm/10MHz
CV2X EIRP	18 dBm/20MHz	21 dBm/20MHz	24 dBm/20MHz	27 dBm/20MHz
Antenna AGL Height	3-6 m	3-6 m	3-6 m	3-6 m
Sectorization	1 sector			
Downtilt	0 degrees			
Antenna Pattern	Recommendation ITU-R F.1336 omni[32] See **Figure 1** for the antenna patterns			

Table 12. OBU Technical Parameters

Parameter	Dense Urban	Urban	Suburban	Rural
DSRC EIRP	17 dBm/10MHz			
CV2X EIRP	17 dBm/20MHz			
Antenna AGL Height	1-2 m	1-2 m	1-2 m	1-2 m
Sectorization	1 sector			
Downtilt	0 degrees			
Antenna Pattern	Recommendation ITU-R F.1336 omni[33] See **Figure 1** for the antenna patterns			

[32] *See* Recommendation ITU-R F.1336-5, *Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz* (01/2019), https://www.itu.int/dms_pubrec/itu-r/rec/f/R-REC-F.1336-5-201901-I!!PDF-E.pdf.

[33] *Ibid.*

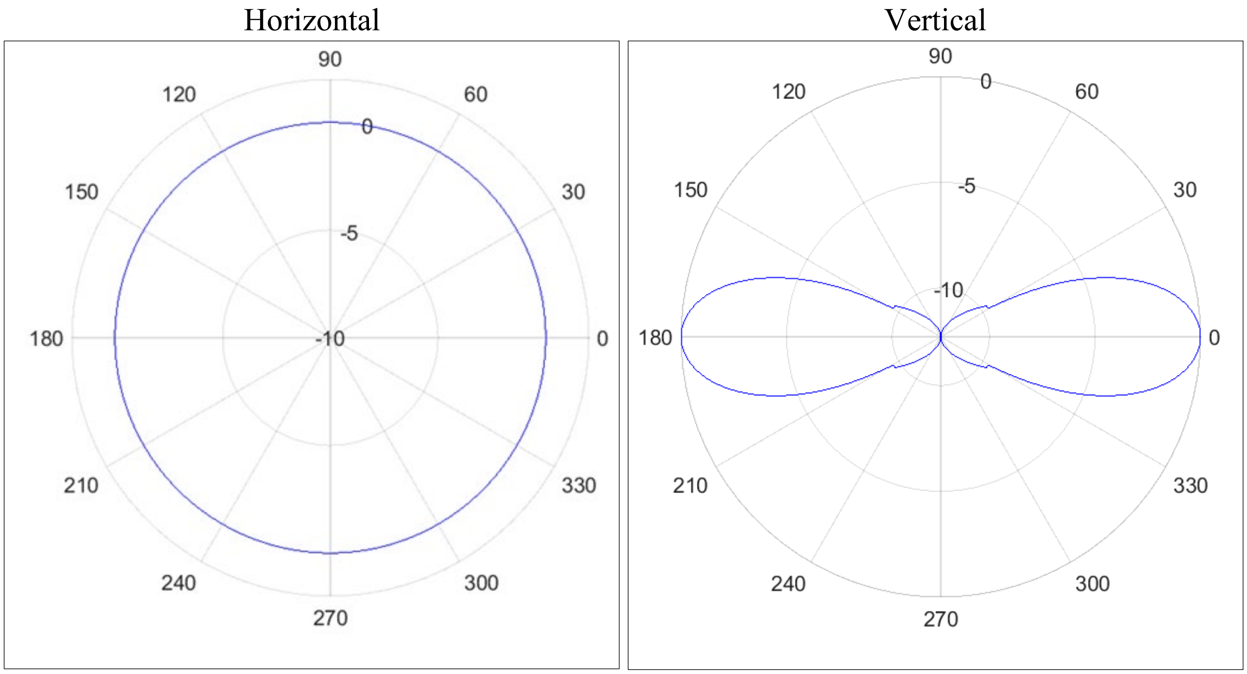

Figure 1. RSU and OBU Antenna Gain Patterns (Polar Plots) Horizontal (Left) and Vertical (Right)

4. U-NII DEPLOYMENT AND TECHNICAL PARAMETERS

4.1 Overview

This section provides the deployment and technical parameters of the outdoor and indoor U-NII devices considered in the analysis.

4.2 Population Based Deployment

The NLCD 2011 data and 2010 U.S. Census population data were used to distribute U-NII devices.[34] For each census tract, the NLCD area classification codes were collected for the entire area of the census tract, and then the census tract was classified by the highest occurring count of NLCD codes: dense urban (24), urban (23), suburban (22), and rural (21).

Assuming a mature deployment phase, a service penetration (SP) factor of 90 percent was assumed. To account for distribution of users across all U-NII bands, a channel scaling (CS) factor of 25 percent was used to determine the number of effective users in the U-NII-4 band. The numbers of outdoor links and indoor access points (AP) were calculated for each census tract, rounding up to the nearest whole number. Table 13 provides the population deployment parameters for outdoor P2MP and indoor APs. Equations (3) and (4) are used to respectively calculate the number of APs and P2MPs per census tract, denoted as $AP_{CensusTract}$ and $P2MP_{CencusTract}$ in that order. In these equations, POP_{CT} is the 2010 population per census tract,[35] $Users_{AP}$ is the quantity of users served per AP (Table 13), and $Users_{P2MP}$ is the quantity of users served per P2MP link (Table 13).

Table 13. Terrestrial Mobile Population Deployment Parameters

NLCD Classification/Clutter Category	Users per AP ($Users_{AP}$)	Users per P2MP ($Users_{P2MP}$)
Urban	50	500
Suburban	20	500
Rural	3	500

$$AP_{CensusTract} = ceiling\left\{\frac{POP_{CT} \times CS \times SP}{Users_{AP}}\right\} \quad (3)$$

$$P2MP_{CensusTract} = ceiling\left\{\frac{POP_{CT} \times CS \times SP}{Users_{P2MP}}\right\} \quad (4)$$

[34] United States Census Bureau, https://www.census.gov/programs-surveys/decennial-census/data/datasets.2010.html.

[35] *See* https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.2010.html.

The locations of the outdoor P2MPs and indoor APs were uniformly distributed within the census tract. Table 14 and Table 15 provide the technical parameters for the outdoor P2MP and indoor APs respectively. For each P2MP and AP, the antenna AGL height was uniformly distributed based upon the census tract NLCD classification. To account for P2MP and AP transmissions of a 50 percent duty cycle, a 3 dB reduction is applied to the EIRP in the tables below. The bandwidth associated with the U-NII EIRP is scaled to be the same as the bandwidth of the federal receivers.

Table 14. Outdoor P2MP Technical Parameters

Parameter	Dense Urban	Urban	Suburban	Rural
EIRP	33 dBm/20MHz			
Antenna AGL Height	6-10 m	6-10 m	6-10 m	6-10 m
Sectorization	1 sector			
Downtilt	0 degrees			
Antenna Pattern	Recommendation ITU-R F.1336 omni[36] See Figure 2 for the antenna patterns			

Table 15. Indoor AP Technical Parameters

Parameter	Dense Urban	Urban	Suburban	Rural
EIRP	33 dBm/20MHz			
Antenna AGL Height	50%: 3-15 m 25%: 18-30 m 25%: 33-60 m	50%: 3 m 50%: 6-18 m	70%: 3 m 30%: 6-12 m	80%: 3 m 20%: 6 m
Sectorization	1 sector			
Downtilt	0 degrees			
Antenna Pattern	Recommendation ITU-R F.1336 omni[37] See Figure 2 for the antenna patterns			

[36] Recommendation ITU-R F.1336-5.

[37] *Ibid.*

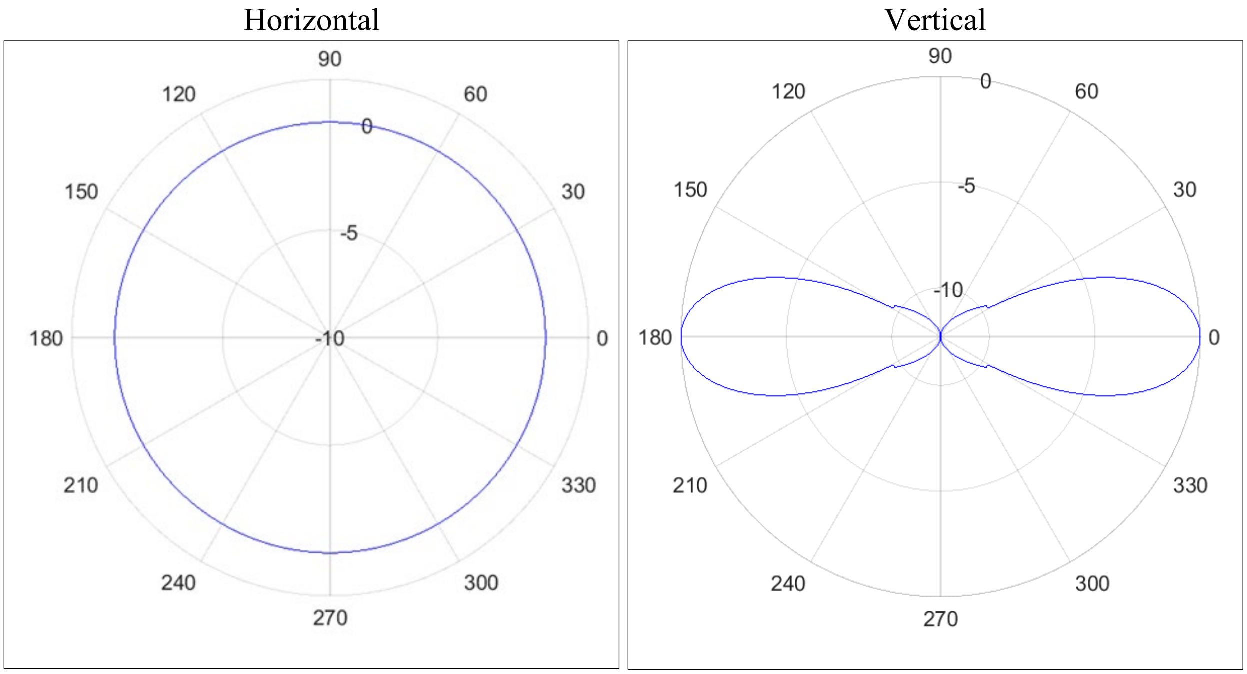

Figure 2. MP2P and AP Antenna Gain Patterns (Polar Plots) Horizontal (Left) and Vertical (Right)

5. ENGINEERING MODELS

5.1 Overview

This section describes the engineering models used in this compatibility study, including each of the losses for basic transmission, clutter, building penetration, and frequency dependent rejection (FDR).

5.2 Radio Frequency Link Budget

The aggregate interference was calculated using a protection Monte Carlo percentile of 95% with a minimum of 1,000 trials. Clutter loss (Section 5.4) and building loss (Section 5.5) were added when applicable. FDR (Section 5.7) was calculated based on the frequency separation between the federal incumbent system and the ITS/U-NII deployment using the federal incumbent receiver selectivity and the RSU, AP, and U-NII transmitter emission masks. The federal incumbent antenna parameters were taken into consideration for the calculation (Section 5.6).

Equations (5)-(9) provide details about the radio frequency (RF) link budget to calculate the aggregate interference.

$$L_{Prop} = L_{ITM/528} + L_{Clutter} + L_{BuildingLoss} \tag{5}$$

where:

$L_{ITM/528}$: path loss (dB) calculated from the Irregular Terrain Model (ITM) or from ITU-R P.528;

$L_{Clutter_{elevation}}$: clutter loss (dB) (Section 5.4); and

$L_{BuildingLoss}$: 15 dB of building loss (Section 5.5).

Using Equation (6), the received power in dBm at the input of an incumbent federal receiver from a single ITS or U-NII transmitter was calculated.

$$P_{R_{dBm}} = EIRP - L_{Prop} + Gain_{FedAnt} - Loss_{TxAnt} + FDR \tag{6}$$

where:

$P_{R_{dBm}}$: received power at the incumbent federal receiver (dBm);

$EIRP$: equivalent isotropically radiated power, in dBm, of the ITS or U-NII transmitter, including antenna gain (dBi);

$Gain_{FedAnt}$: relative gain of the incumbent federal antenna in the direction (azimuth and elevation) of the transmitter (dBi);

$Loss_{TxAnt}$: loss of the ITS or U-NII transmitter antenna in the direction (azimuth and elevation) of the incumbent federal receiver (dBi);

FDR: the frequency dependency rejection loss, in dB, between the federal receiver and the ITS or U-NII transmitter (see section 5.7)

The aggregate interference was calculated by converting each $P_{R_{dBm}}$ into $P_{R_{watts}}$, using Equation (7), and then adding the $P_{R_{watts}}$ from each ITS or U-NII transmitter, using Equation (8), and converting the aggregate power receiver in Watts, $P_{R_{watts_{aggregate}}}$, to dBm/Rx BW MHz, using Equation (9).

$$P_{R_{watts}} = 10^{\left(\frac{P_{R_{dBm}}-30}{10}\right)} \tag{7}$$

$$P_{R_{watts_{aggregate}}} = \sum_{k=1}^{n} P_{R_{watts_k}} \tag{8}$$

$$P_{R_{dBm_{aggregate}}} = 10log_{10}\left(P_{R_{watts_{aggregate}}}\right) + 30 \tag{9}$$

5.3 Basic Transmission Loss

For the ground-based systems, the ITM point-to-point mode was used to calculate the propagation loss using a 1 arc-second terrain database.[38] Additional ITM parameters include:

- Polarization: Vertical
- Dielectric constant: 25
- Conductivity: 0.02 S/m
- Confidence: 50%
- Reliability: 50%
- Mode of Variability: 13 (broadcast point-to-point)
- Surface Refractivity: Value varies by location and was derived by the methods and associated data files in Recommendation ITU-R P.452.[39]
- Climate: Value varies by location and was derived by the methods and associated data files in Recommendation ITU-R P.617.[40]

[38] *See* NTIA Report 82-100, *A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode* (April 1982), https://www.ntia.doc.gov/report/1982/guide-use-its-irregular-terrain-model-area-prediction-mode.

[39] Recommendation ITU-R P.452-16, *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz* (2015), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.452-16-201507-I!!PDF-E.pdf.

[40] Recommendation ITU-R P.617-4, *Propagation prediction techniques and data required for the design of trans-horizon radio-relay systems* (2017), available at: https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.617-4-201712-S!!PDF-E.pdf.

The ITM Area Prediction Mode was used to compute propagation loss to check interference from a single transmitter.[41] Table 16 provides the parameters used in the ITM Area Prediction Mode propagation loss calculations.

Table 16. ITM Area Prediction Mode Parameters

Parameter	**Value**
Surface Refractivity	301 N-units
Conductivity of Ground	0.005 S/M
Dielectric Constant of Ground	15
Terrain Roughness Factor (Delta h)	30 meters
Polarization	Horizontal/vertical
Mode of Variability	Mobile mode
Percent Confidence (Time/Situation/Location Variability)	50%
Frequency	5900 MHz
Site Criteria Transmitter	Careful
Site Criteria Receiver	Random
Radio Climate	Continental temperate

5.4 Clutter Loss

For the ground-based systems, clutter loss, $L_{Clutter}$, was calculated based upon a combination of Recommendation ITU-R P.2108[42] and Recommendation ITU-R P.452,[43] which takes into consideration the transmitter antenna AGL height, and the NLCD classification of the transmitter as a determination of the clutter nominal AGL height, denoted as h_a and clutter nominal distance d_k.

To account for the relationship between the transmitter antenna AGL height and the nominal clutter height, Recommendation ITU-R P.452, Section 5.4, is used. Equation (10) is used to calculate the additional clutter loss A_h in dB.

$$L_{Clutter} = 10.25F_{fc} \cdot e^{-d_k}\left(1 - tanh\left[6\left(\frac{h}{h_a} - 0.625\right)\right]\right) - 0.33 \tag{10}$$

$$F_{fc} = 0.25 + 0.375(1 + tanh[7.5(f - 0.5)]) \tag{11}$$

Where d_k is the nominal distance (km) from nominal clutter point to the antenna, h is the transmitter antenna AGL height (m), h_a is the nominal clutter AGL height (m), and f is the

[41] NTIA Report 82-100.

[42] Recommendation ITU-R P.2108-0, *Prediction of clutter loss* (06/2017), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2108-0-201706-I!!PDF-E.pdf.

[43] Recommendation ITU-R P.452-16.

transmitter operating frequency (GHz). Table 17 has the values for h_a and d_k used in the compatibility study, as provided by Recommendation ITU-R P.452.

Table 17. Recommendation ITU-R P.452[44]

NLCD Classification/Clutter Category	Nominal height h_a (m)	Nominal distance d_k (km)
Rural	4	0.1
Suburban	9	0.025
Urban	20	0.02
Dense Urban	25	0.02

Figure 3 shows the calculated clutter loss as a function of transmitter height, at 5900 MHz for the four NLCD types.

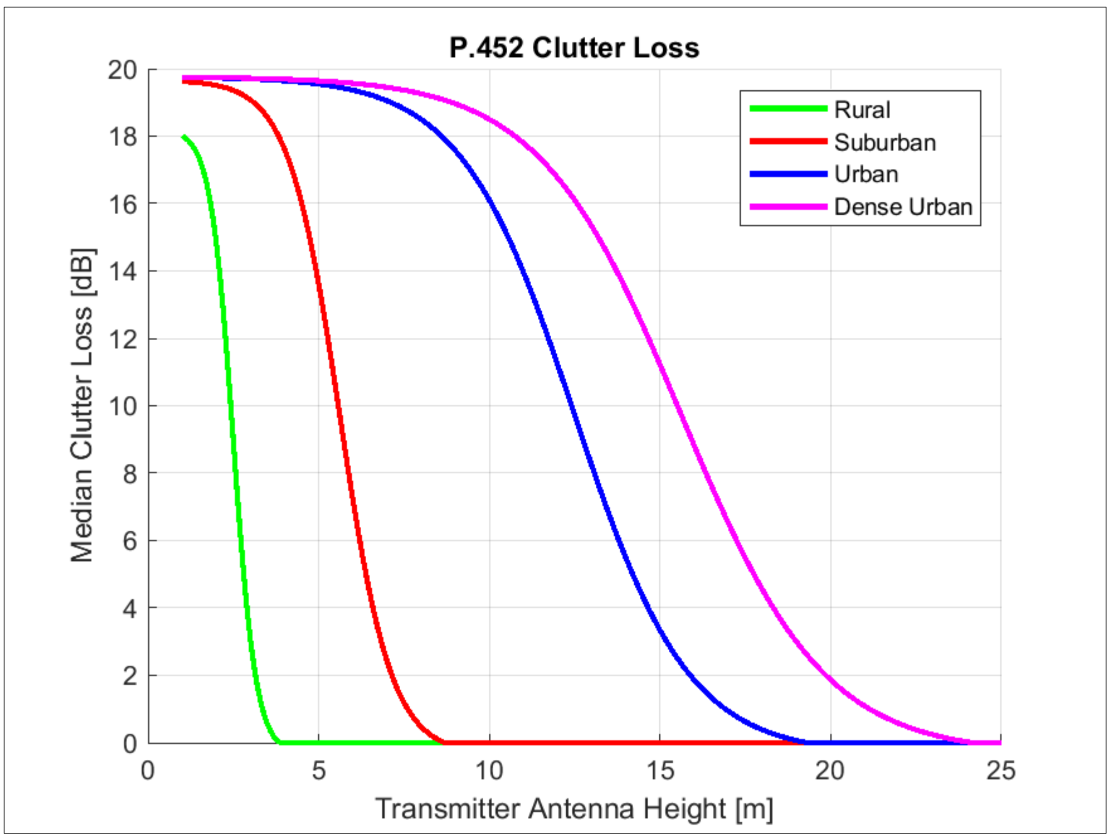

Figure 3. Example Calculated Clutter Loss as a Function of Transmitter Antenna Height

[44] *See* Table 4 of Recommendation ITU-R P.452.

It is noted that the FCC adopted propagation and clutter loss models similar to the models used in NTIA's analysis in a recent rulemaking proceeding:[45]

> *"The Irregular Terrain Model is a propagation model that specifically takes into account the effects of terrain on radio propagation but does not include clutter losses. The model accounts for transmission loss relative to free space loss for distances between 1 km and 2,000 km. For separation distances greater than one kilometer, commenters suggest that the Irregular Terrain Model combined with a clutter model depending on the environment is the most appropriate model. The Commission agrees. Consistent with Commission use of propagation models in other proceedings, the Commission requires use of 1 arc-second digital elevation terrain data and, for locations where such data is not available, the Commission requires use of the most granular digital elevation terrain data available. To account for the effects of clutter, such as from buildings and foliage, the Commission requires that the Irregular Terrain Model be combined with a statistical clutter model ITU-R P.2108 for urban and suburban environments, and ITU-R P.452-16 clutter model for rural environments. The appropriate clutter category that most closely represents the local morphology should be selected when using ITU-R P.452-16. However, if detailed local information is not available, the Commission believes the "Village Centre" clutter category should be used as a default because access points will generally be installed in or on buildings (i.e., in a village) and this category most closely represents that morphology. The Commission specifies the Irregular Terrain Model because it has been widely available and accepted since the early 1980s, has been used by the Commission for interference prediction in other proceedings, is supported by the record, and in its experience has served reliably as a propagation model. The Irregular Terrain Model is the propagation model currently used to determine spectrum availability in the spectrum access systems (SAS) used to manage access to the 3550-3700 MHz band in the Citizens Broadband Radio Service."*

5.5 Building Loss

A building penetration loss of 15 dB was applied to indoor APs according to ITU-R P.2109.[46]

5.6 Federal System Antenna Models

Equation (12) defines the horizontal antenna pattern used for ground-based systems:

$$Gain_{FedAnt}(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right] + Gain_{Ant} \tag{12}$$

where:

[45] *See Unlicensed Use of the 6 GHz Band* Report and Order and Further Notice of Proposed Rulemaking, , 35 FCC Rcd 3852, para. 37 (2020), https://docs.fcc.gov/public/attachments/FCC-20-51A1.pdf.

[46] Report ITU-R P.2109-1, *Prediction of building entry loss* (08/2019), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-1-201908-I!!PDF-E.pdf.

$Gain_{FedAnt}(\theta)$: is the relative antenna gain (dB) in the horizontal direction, $-180° \leq \theta \leq 180°$;

$min[.]$: denotes the minimum function;

θ_{3dB}: is the 3 dB beamwidth (degrees);

θ: off-boresight angle in the direction between incumbent federal system and the transmitter (degrees),

$A_m = 25\ dB$: is the maximum attenuation; and

$Gain_{Ant}$: is the 3 dB mainbeam boresight gain (dBi) of the antenna.[47]

Figure 4 shows an example federal antenna pattern with a 3 dB beamwidth of 20°.

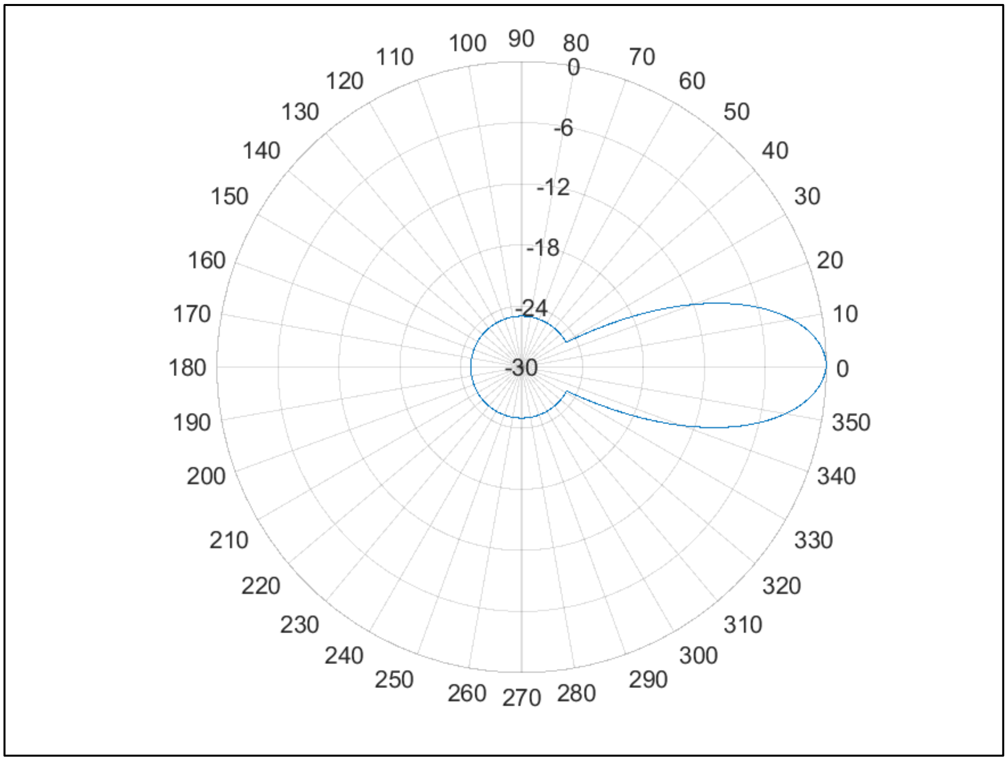

Figure 4. Example Federal Antenna Pattern

5.7 Frequency Dependent Rejection

FDR accounts for the fact that not all of the transmitted energy from a transmitter at the federal receiver location will reach the federal receiver's detector or its signal processing modules. FDR

[47] The mainbeam (boresight) antenna gain $Gain_{Ant}$ is 0 dBi in this equation because the mainbeam (boresight) antenna gain is taken into consideration when calculating the overall interference threshold in Equation (2).

is a calculation of the amount of transmitter energy rejected by a victim receiver due to the IF filtering in the receiver. This FDR attenuation is composed of on-tune rejection (OTR) and off-frequency rejection (OFR). The OTR is the rejection, provided by a receiver's 3 dB bandwidth, to a co-tuned transmitter's 3 dB bandwidth and OFR is calculated using the receiver's IF selectivity and the transmitter emission spectra. The federal receiver IF selectivity and 3 dB bandwidth data for the federal systems was obtained from the agencies. A detailed description of how to compute FDR can be found in Recommendation ITU-R SM.337-4.[48]

For the analysis, it is assumed that DSRC will retain the remaining 10 megahertz (5.895-5.905 GHz) and C-V2X will operate in the upper 20 megahertz of the band (5.905-5.925 GHz) using the emission limits proposed by the FCC.[49]

The frequency dependent rejection was calculated based on the frequency range for each federal incumbent system.

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[48] Recommendation ITU-R SM.337-4, *Frequency and Distance Separations,* https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.337-4-199710-S!!PDF-E.pdf.

[49] *See* FCC Fact Sheet, *Use of the 5.850-5.925 GHz Band* (Nov. 21, 2019), https://docs.fcc.gov/public/attachments/DOC-360940A1.pdf.

6. INTERFERENCE ANALYSIS METHODOLOGY

6.1 Overview

This section describes how the coordination and exclusion zones are calculated to protect the federal systems from interference. A coordination zone is an area in which ITS commercial operators would need to coordinate with the federal incumbent before ITS can deploy in the area. Coordination zones are used for the ITS devices because they are licensed systems, thus enabling coordination to be used as a mechanism to maximize the use of the spectrum. An exclusion zone is an area in which U-NII device deployments are not allowed, and are used for the unlicensed U-NII-4 devices because the devices have no allocation status in the band and are not registered, making coordination impractical. The boundaries of the coordination/exclusion zones are defined as a center point (latitude and longitude) with a radius (to define a circular area) to facilitate the regulator process, or, in very limited cases, as a polygon to optimize deployment areas.

6.1.1 ITS Coordination Zone Methodology

To calculate the ITS coordination zone, the center point was determined by the incumbent's location for fixed incumbent systems or by the centroid of the operational area of transportable incumbent systems. The radius was determined by selecting the largest separation distance required to mitigate potential interference to the federal incumbent operations based on the statistical aggregate interference analysis addressed in section 6.2.

6.1.2 U-NII Exclusion Zone Methodology

To calculate the U-NII exclusion zone, the center point was determined by the incumbent's location for fixed incumbent systems or by the centroid of the operational area of transportable incumbent systems. The radius was determined by selecting the largest of three distance separations required to mitigate potential interference to the federal incumbent operations:

1) distance based on statistical aggregate interference analysis (section 6.2);

2) distance based on single source interference analysis (section 6.3); or

3) distance based on empirical information identifying interference at that location (section 6.4).

The single source analysis was used only for the U-NII devices radius calculation because of the uncertainty associated with the deployment locations, whereas the location of the ITS devices can be better defined along roads.

6.2 Statistical Aggregate Interference Methodology

The following steps were used to calculate the coordination/exclusion zones:

Step 1: For each coordination/exclusion zone of a federal incumbent, a commercial deployment is randomized around the operational area of the federal incumbent. Figure 5 shows the operational area of the federal system in red and an example RSU deployment in blue. In this example, there are more than 38,000 RSUs deployed. OBU deployment is not shown in the figure, but included in the analysis, adding to the aggregate interference. For this example, the federal operational area is MacDill Air Force Base.

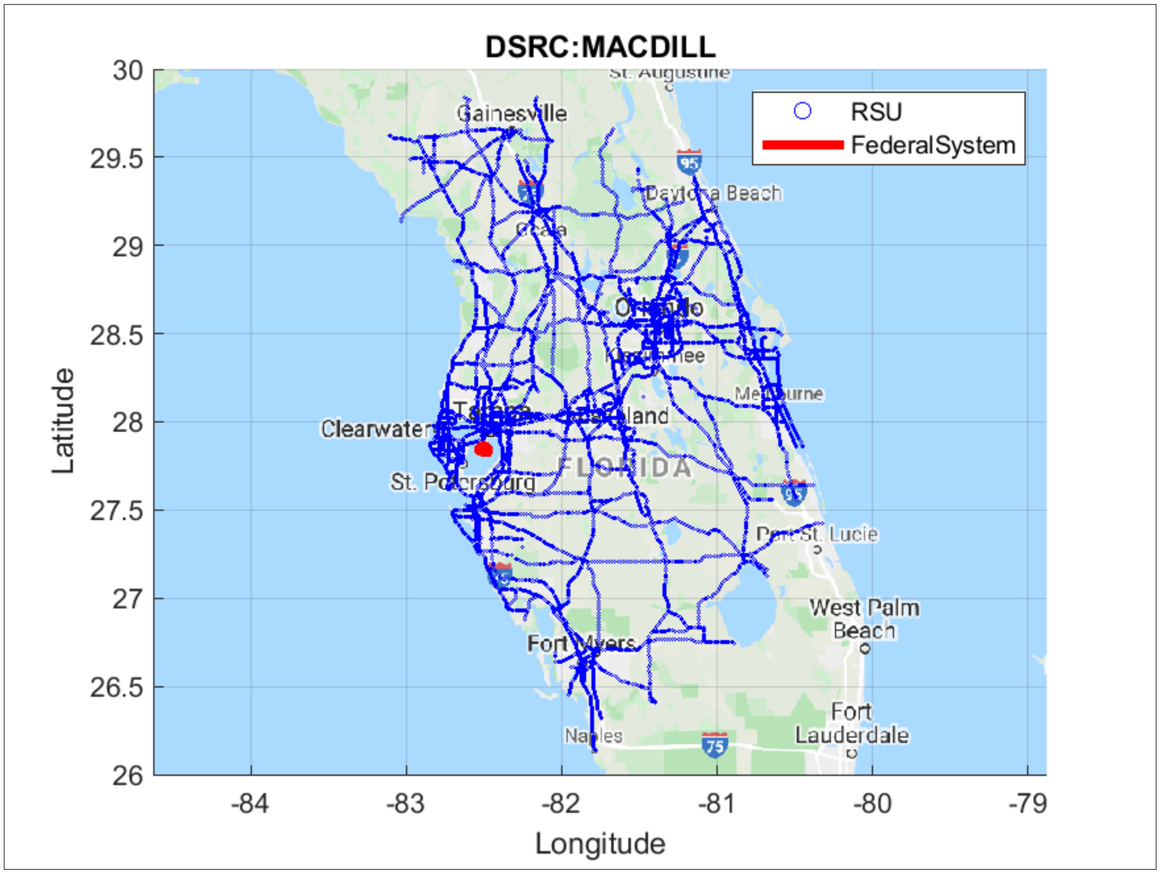

Figure 5. Example RSU Deployment

Step 2: Protection points were generated within the operational area of the federal incumbent.

Step 3: At each protection point, it is determined which commercial deployment transmitters need to be turned off for the aggregate interference to not exceed the protection criteria of the federal incumbent.

Step 4: The union of the commercial deployment transmitters turned off is found for all the protection points. Figure 6 shows, in red, an example of the union of the commercial RSU deployment transmitters turned off, and the RSUs that are allowed to transmit, without causing interference to the federal incumbent, are shown in green.

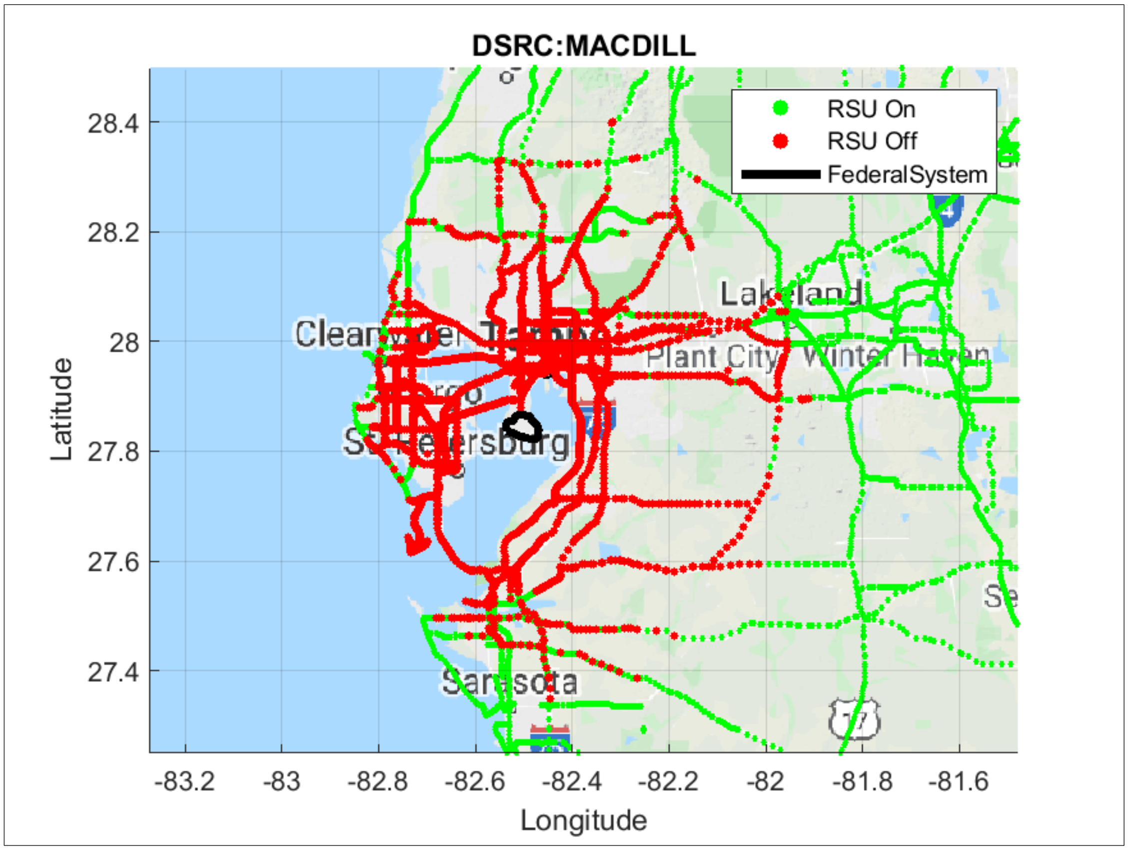

Figure 6. Example of the Union of the Commercial RSU Deployment Turned Off

Figure 7 shows the histogram of the minimum separation distance between each commercial RSU deployment transmitter and the federal incumbent operational area. The red indicates the commercial RSU deployment transmitters turned off, and the RSUs that are allowed to transmit are shown in green.

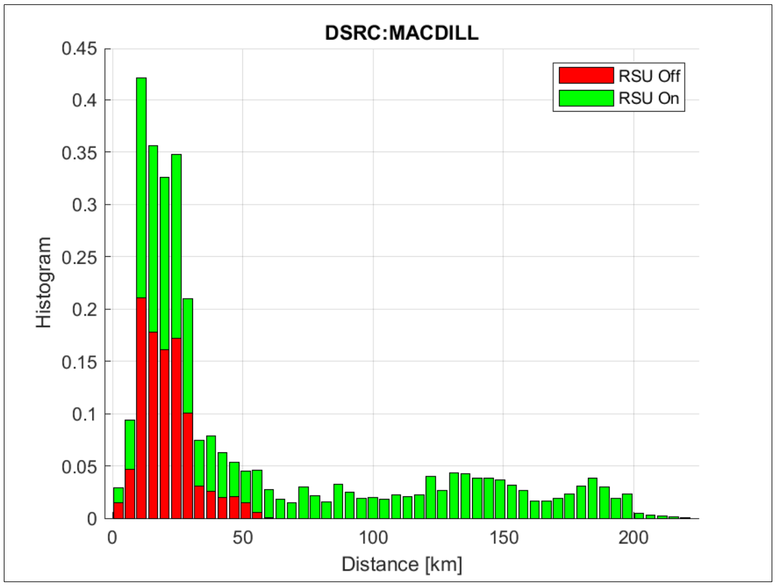

Figure 7. Minimum Separation Distance Between the Commercial RSU Deployment and the Federal Incumbent Operational Area

Step 5: The minimum separation distance is calculated between each commercial deployment transmitter that was turned off and the federal incumbent operational area. Figure 8 shows the histogram of the minimum separation distance for just the commercial RSU deployment transmitters that were turned off, taken from Figure 7.

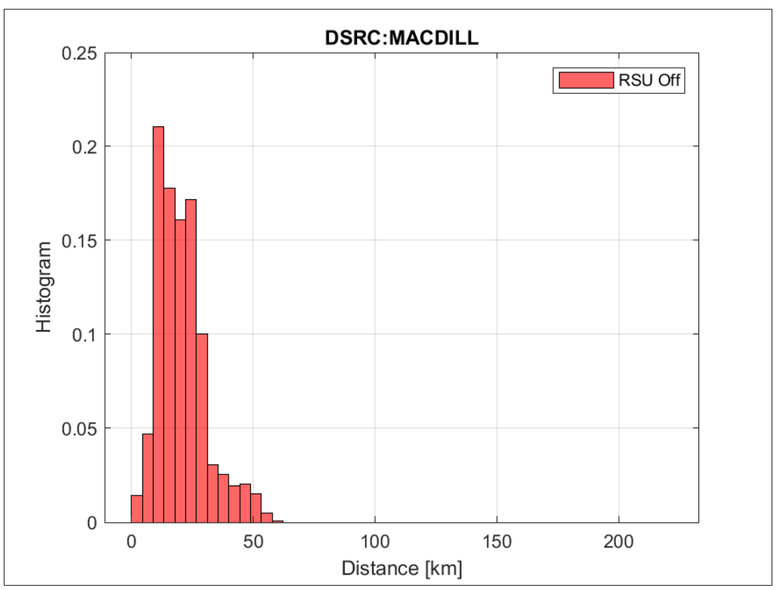

Figure 8. Minimum Separation Distance Between the Commercial RSU Deployment Turn Off and the Federal Incumbent Operational Area

Step 6: The empirical cumulative distribution function (CDF) is found from the histogram of the calculated minimum separation distance between the turned-off commercial deployment transmitters and the federal incumbent operation area. In the example shown in Figure 9, the CDF is calculated from Figure 8.

Step 7: The 95th percentile of the minimum separation distance CDF, calculated in step 6, is found. Figure 9 shows the CDF of the minimum separation distance between the RSU turned off and the federal incumbent operational area with the 95th percentile shown at approximately 42 km.

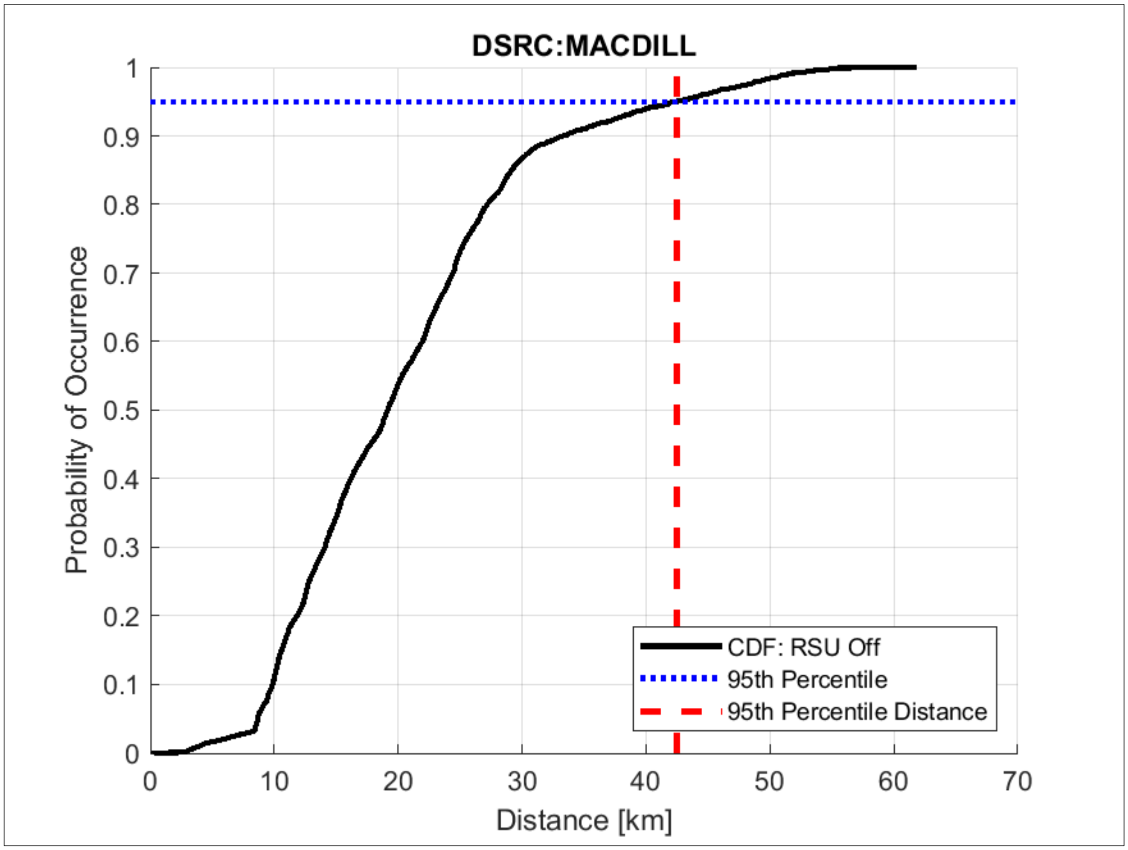

Figure 9. CDF of the Minimum Separation Distance Between the Commercial RSU Deployment and the Federal Incumbent Operational Area

In this example, it should be noted that if the commercial deployment was extended past 200 km, only additional green bars would be added to the histogram in Figure 7. The additional RSUs beyond 200 km would not change the distribution of the Figure 8 histogram and Figure 9 CDF of the RSUs that were turned off, leaving the 95th percentile distance unchanged.

Step 8: A polygon is drawn such that it encompasses all commercial deployment transmitters turned off and within the 95th percentile minimum separation distance in shown in Step 7 (i.e., 42 km). An additional 1 km buffer is drawn around the polygon.

Note: If there are no commercial deployment transmitters turned off, a 1 km coordination zone is drawn around the federal incumbent operational area. Figure 10 shows the 95th percentile polygon plus 1 km (in blue) that encompasses all the commercial RSU deployment transmitters that were turned off (in red) and are within the 95th percentile minimum separation distance of the federal incumbent operational area (in black).

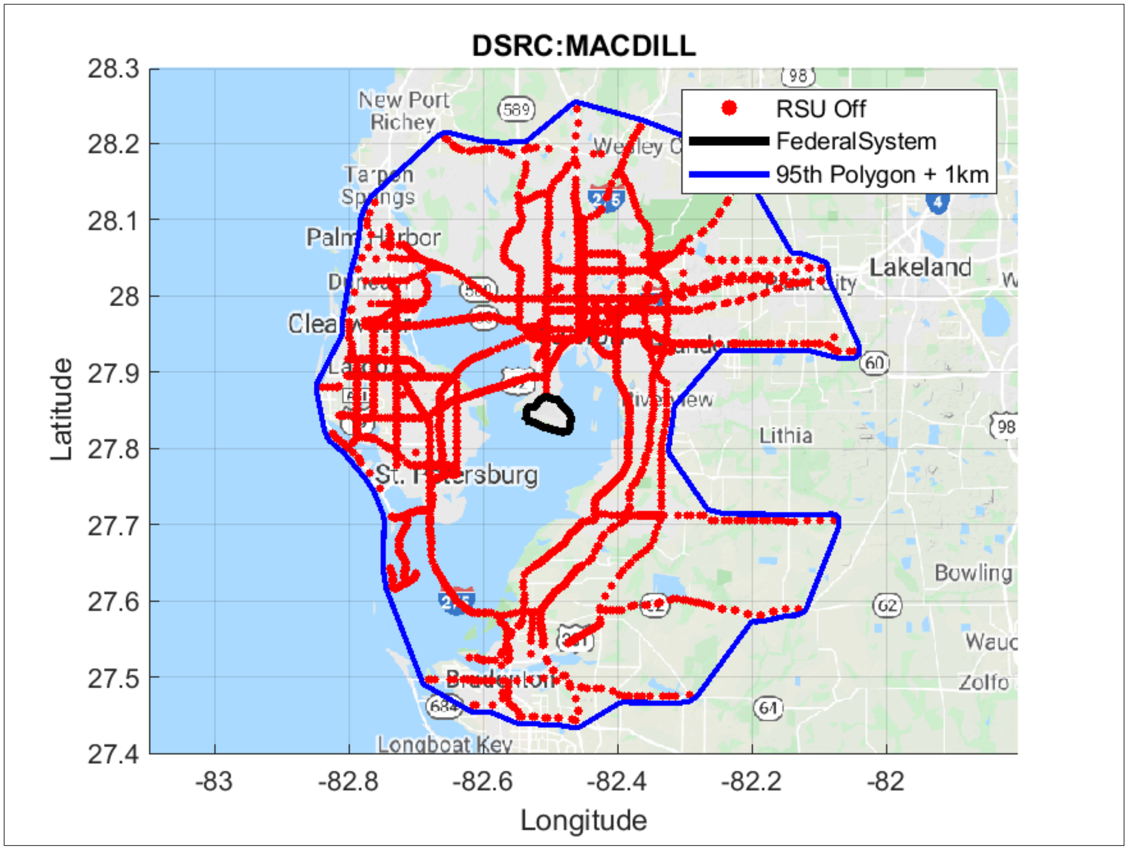

Figure 10. The 95th Percentile Polygon (+1 km)

Step 9: The maximum distance between the centroid of the operational area of the federal incumbent and polygon that encompasses all turned off commercial transmitters within the 95th percentile of the minimum separation distance is calculated and set as the coordination/exclusion zone radius. Figure 11 shows the coordination area (magenta) and the coordination center (red x) that encompasses the 95th percentile polygon.

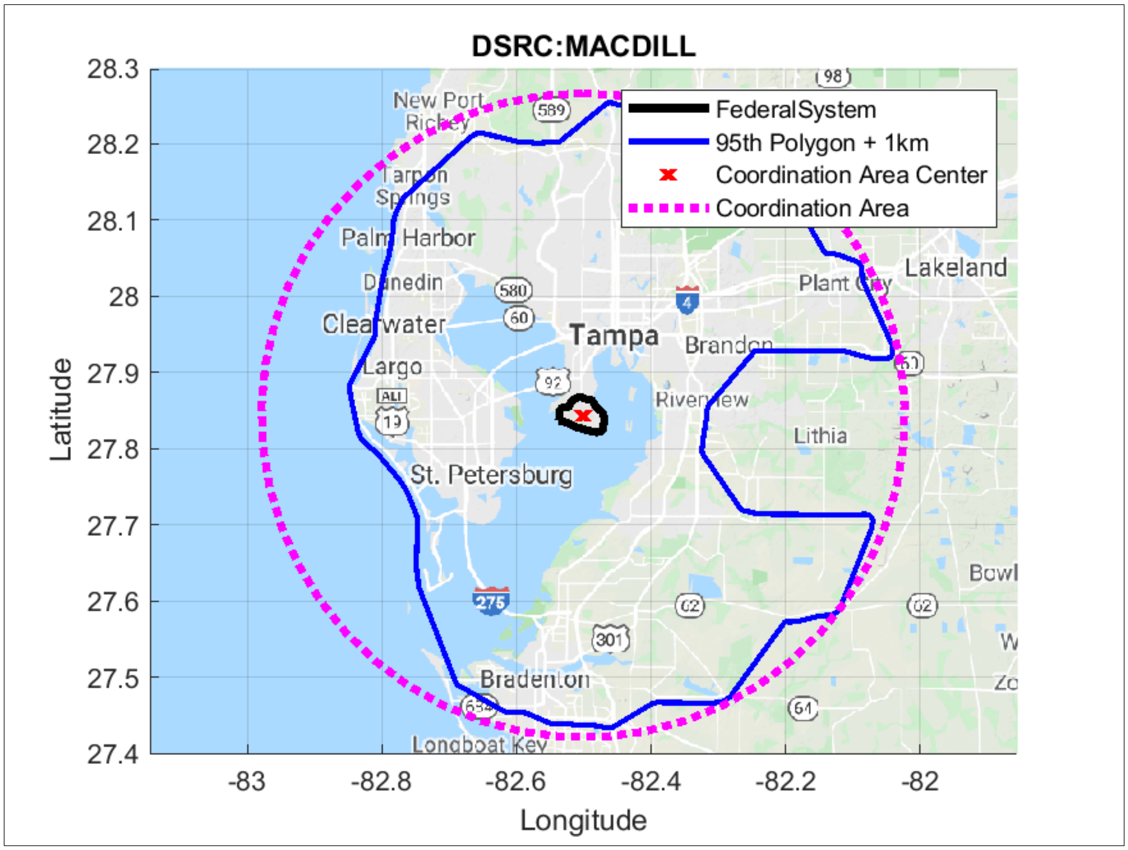

Figure 11. The Coordination Area That Encompasses the 95th Percentile Polygon (+1 Km)

Step 10: For the DSRC and C-V2X simulations, the maximum coordination zone radius was selected as the ITS coordination radius.

6.3 Single Source Interference Methodology

The following steps were used to calculate the exclusion zone distance based on interference from a generic single source.

Step 1: The minimum separation distance is calculated to preclude interference to the federal incumbent in Equation (13) for each federal system. The ITM Area Prediction Mode was used to compute propagation loss.[50] Main-beam to main-beam coupling is assumed.

$$RIT_{\frac{dBm}{RX\,BW\,MHZ}} = EIRP - L_{Prop}(d) + FDR \tag{13}$$

where:

$RIT_{\frac{dBm}{RX\,BW\,MHZ}}$: is the federal system receiver interference threshold, see Equation (2);

[50] *See* NTIA Report 82-100.

$EIRP$: is the equivalent isotropically radiated power (dBm) of the U-NII transmitter, including antenna gain in dBi;

$L_{Prop}(d)$: is the ITM Area Prediction Mode propagation loss (dB) as a function of separation distance;

FDR: is the frequency dependency rejection loss (dB) between the federal receiver and the U-NII transmitter (see Section 5.7).

Step 2: The minimum separation distance, calculated in Step 1, is used to draw a polygon around the operational area of the federal incumbent. Figure 12 shows the polygon for U-NII at MacDill Air Force Base. Please note that the polygon is not a circle since the federal operational area is an irregular polygon.

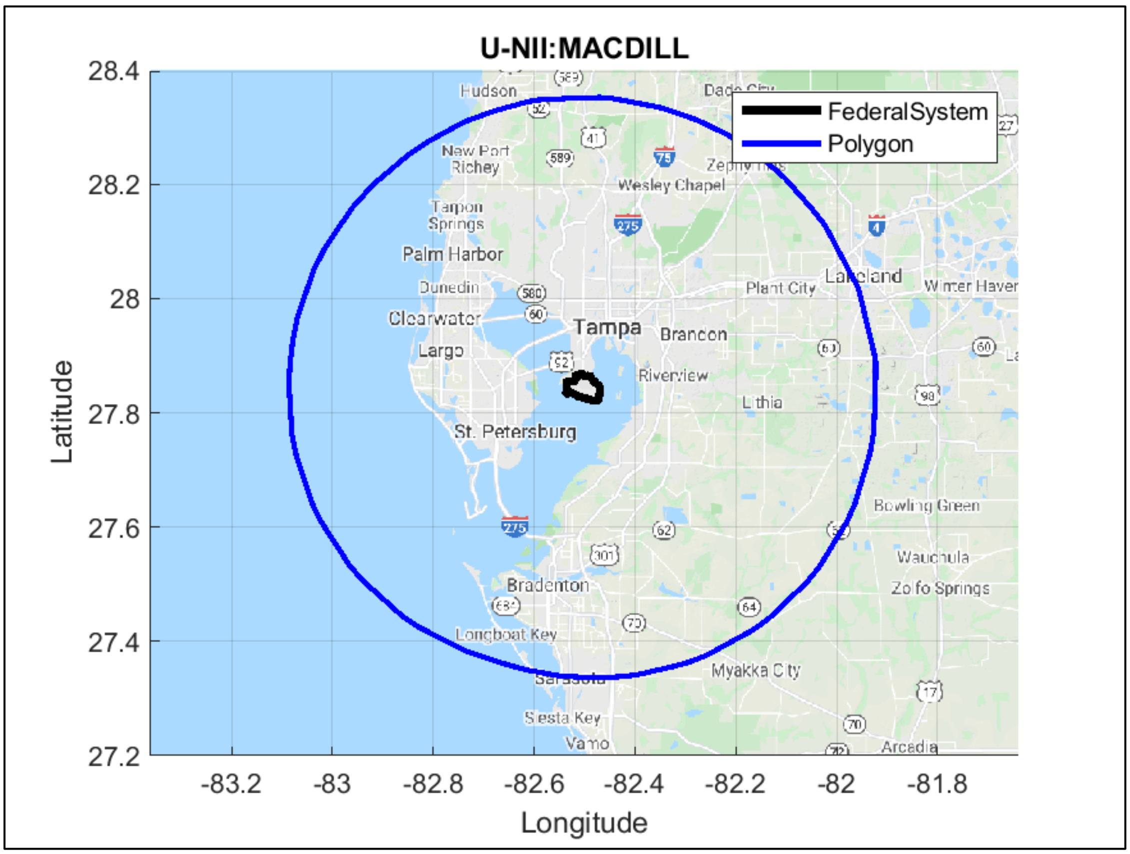

Figure 12. The Polygon Around the Operational Area of the Federal Incumbent

Step 3: The maximum distance between the centroid of the operational area of the federal incumbent and polygon is calculated. Figure 13 shows the polygon (blue line) that is encompassed inside the entire exclusion zone (dashed magenta line) with the center of the circle at the center point (red x).

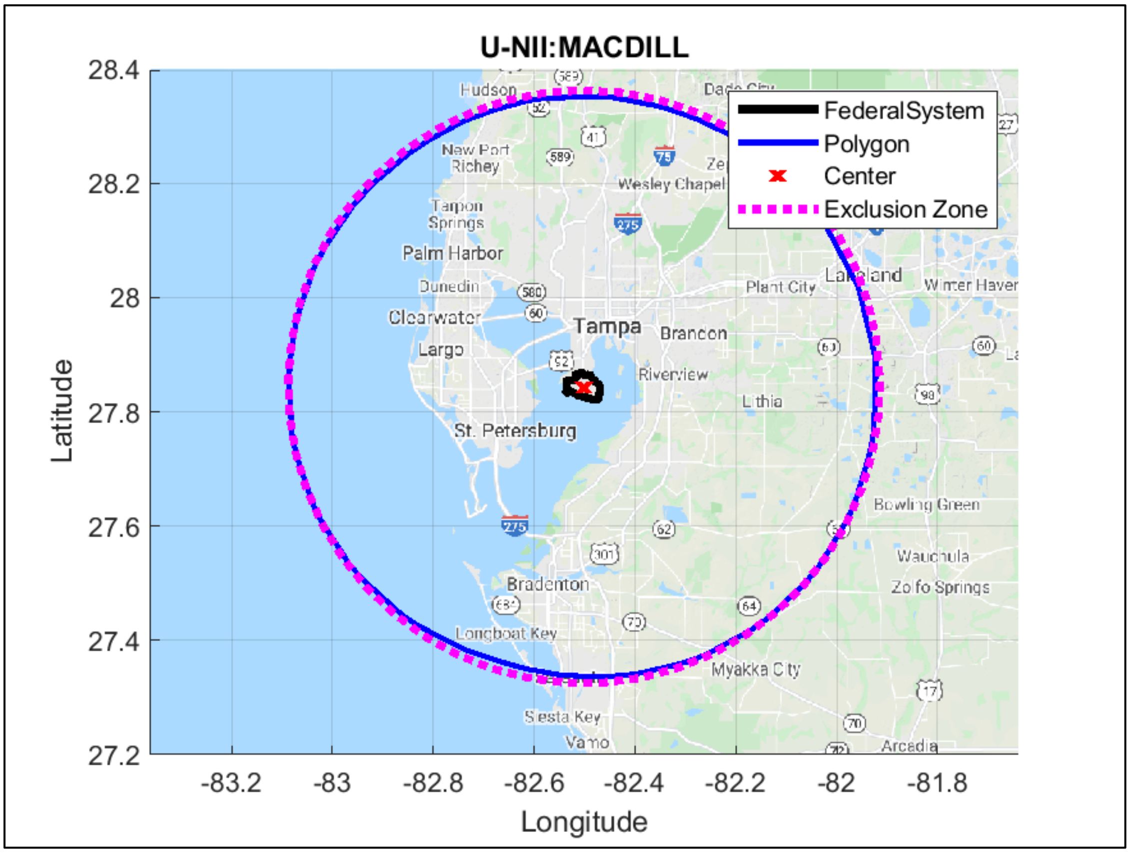

Figure 13. The Exclusion Zone Area (Dashed Magenta Line) That Encompasses the Entire Polygon

6.4 Agency Identified Interference

The following locations were reported to have interference to the federal incumbent from U-NII devices. The distance between the federal incumbent and the U-NII transmitter is also provided.

Facility Name	Interference Distance
Pillar Point, CA	10 km
Vandenberg, CA	74 km

7. RESULTS FOR FEDERAL SYSTEMS

7.1 Overview

Based on the methodology presented in Section 6, the coordination zones for ITS (C-V2X and DSRC) and the exclusion zones for U-NII-4 devices are provided. The boundaries of the coordination/exclusion zones are defined as a center point (latitude and longitude) with a radius (to define a circular area) to facilitate the regulator process of coordination. However, in limited cases where the circular area includes a significant amount of geographic area and/or population not encompassed by the polygon used to generate the circular area, the polygon is used to maximize deployment areas that do not present a potential for interference.

7.1.1 Intelligent Transportation System Results

The analysis results for the coordination zone needed to protect federal operations from RSUs, in terms of center point and radius, are provided for each site in Table 18. A geographical illustration of the coordination zones is provided in subsection A.2 of Appendix A. For the OBUs, the analysis indicates that coordination zones are not necessary to protect federal operations.

Table 18. ITS Coordination Zone Center Point and Radius

Facility Name	Latitude DD-MM-SS North	Longitude DD-MM-SS West	Coordination Zone Radius (km)
Anclote, Florida	28-11-18	82-47-40	45
Cape Canaveral, Florida	28-28-54	80-34-35	47
Cape San Blas, Florida	29-40-31	85-20-48	47
Carabelle Field, Florida	29-50-38	84-39-46	36
Charleston, South Carolina	32-51-48	79-57-48	16
Edwards, California	34-56-43	117-54-50	53
Eglin, Florida	30-37-51	86-24-16	103
Fort Walton Beach, Florida	30-24-53	86-39-58	41
Kennedy Space Center, Florida	28-25-29	80-39-51	47
Key West, Florida	24-33-09	81-48-28	12
Kirtland Air Force Base, New Mexico	34-59-51	106-28-54	15
Kokeepark, Hawaii	22-07-35	159-40-06	5
MacDill, Florida	27-50-37	82-30-04	47
Nevada Test Training Range, Nevada	37-18-27	116-10-24	186
Patuxent River, Maryland	38-16-55	76-25-12	6
Pearl Harbor, Hawaii	21-21-17	157-57-51	16
Pillar Point, California	37-29-52	122-29-59	36
Poker Flat, Alaska	65-07-36	147-29-21	13
Port Canaveral, Florida	28-24-42	80-36-17	19

Port Hueneme, California	34-08-60	119-12-24	24
Point Mugu, California	34-07-17	119-9-01	18
Saddlebunch Keys, Florida	24-38-51	81-36-22	29
San Diego, California	32-43-00	117-11-00	11
San Nicolas Island, California	33-14-47	119-31-07	195
Tonopah Test Range, Nevada	37-44-00	116-43-00	2
Vandenberg, California	34-34-58	120-33-42	55
Venice, Florida	27-04-37	82-27-03	50
Wallops Island, Virginia	37-51-23	75-30-41	48
White Sands Missile Range, New Mexico	32-58-26	106-23-43	158
Yuma, Arizona	32-54-03	114-23-10	2

7.1.2 U-NII 4 Results

The analysis results for the exclusion zone needed to protect federal operations from outdoor U-NII devices, in terms of center point and radius, are provided for each site in Table 19. For cases where a polygon is recommended for the exclusion zone, the annotation "(polygon)" is included next to the numeric entry in the radius column. A geographical illustration of the exclusion zones is provided in subsection A.3 of Appendix A.

For indoor U-NII-4 devices, the analysis indicates that exclusion zones are not necessary to protect federal operations. However, NTIA recommends rules be put in place to help ensure the indoor devices are not deployed outdoors and that expedient and effective corrective measures be in place to eliminate interference should it occur.

Table 19. U-NII-4 Exclusion Zone Center Point and Radius

Facility Name	Latitude DD-MM-SS North	Longitude DD-MM-SS West	Exclusion Zone Radius (km)
Anclote, Florida	28-11-18	82-47-40	54
Cape Canaveral, Florida	28-28-54	80-34-35	53
Cape San Blas, Florida	29-40-31	85-20-48	55
Carabelle Field, Florida	29-50-38	84-39-46	54
Charleston, South Carolina	32-51-48	79-57-48	55
Edwards, California	34-56-43	117-54-50	51
Eglin, Florida	30-37-51	86-24-16	116 (polygon)
Fort Walton Beach, Florida	30-24-53	86-39-58	56
Kennedy Space Center, Florida	28-25-29	80-39-51	98
Key West, Florida	24-33-09	81-48-28	54
Kirtland AFB, New Mexico	34-59-51	106-28-54	15 (polygon)
Kokeepark, Hawaii	22-07-35	159-40-06	49
MacDill, Florida	27-50-37	82-30-04	58

Facility Name	Latitude DD-MM-SS North	Longitude DD-MM-SS West	Exclusion Zone Radius (km)
NV Test Training Range, Nevada	37-18-27	116-10-24	184
Patuxent River, Maryland	38-16-55	76-25-12	7
Pearl Harbor, Hawaii	21-21-17	157-57-51	55
Pillar Point, California	37-29-52	122-29-59	10
Poker Flat, Alaska	65-07-36	147-29-21	58
Port Canaveral, Florida	28-24-42	80-36-17	54
Port Hueneme, California	34-08-60	119-12-24	54
Point Mugu, California	34-07-17	119-9-01	81 (polygon)
Saddlebunch Keys, Florida	24-38-51	81-36-22	54
San Diego, California	32-43-00	117-11-00	54
San Nicolas Island, California	33-14-47	119-31-07	166 (polygon)
Tonopah Test Range, Nevada	37-44-00	116-43-00	48
Vandenberg, California	34-34-58	120-33-42	74
Venice, Florida	27-04-37	82-27-03	54
Wallops Island, Virginia	37-51-23	75-30-41	68
White Sands Missile Range, New Mexico	32-58-26	106-23-43	160 (polygon)
Yuma, Arizona	32-54-03	114-23-10	49

8. DISCUSSION OF RESULTS RELATIVE TO THE FCC NPRM

8.1 Overview

This section summarizes the assessment of the compatibility of ITS C-V2X (RSU and OBU) and U-NII devices (indoor and outdoor) with federal systems operating in the 5.9 GHz band, and provides discussion of these results relative to the technical rules proposed by the FCC in the *NPRM* for C-V2X and U-NII devices.

8.2 Protecting Federal Incumbent from Intelligent Transportation Systems

The *NPRM* proposes that C-V2X equipment would have to comply with existing DSRC rules for protection of the 5.9 GHz band federal radiolocation service with primary allocation.[51] The *NPRM* notes that DSRC RSUs are not protected from harmful interference caused by incumbent federal operations.[52] The existing DSRC rules for the protection of the 5.9 GHz federal radars require that RSU installations within 75 kilometers of 59 specified federal radar locations must be coordinated with NTIA.[53] The *NPRM* states that requiring C-V2X equipment to coordinate installations within the 75-kilometer coordination zones represents "the most straightforward approach for enabling compatibility with federal operations."[54] The *NPRM* seeks comment on this proposal.

NTIA agrees with the Commission's tentative conclusion that requiring ITS RSUs to coordinate installations within a coordination zone is the best approach to facilitate sharing with federal systems. Based upon NTIA's analysis, the coordination zones set forth in Section 90.371(b) of its Rules for DSRC RSUs can equally apply to C-V2X RSUs. In an effort to optimize unencumbered non-federal operations, NTIA also believes the list of coordination zones can be updated to reflect the list shown in Table 18. This would decrease the number of sites from 59 to 30, and would specify the size of each site's coordination zone, most of which have been reduced from the current 75 kilometers.[55] NTIA may, under existing rules, authorize additional federal radiolocation systems.[56] NTIA requests that the rules be clarified to specifically recognize NTIA's authority to amend, modify, or revoke existing assignments[57] that could affect the coordination zones listed in Table 18. Accordingly, NTIA proposes that Section 90.371(b) be

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[51] *See NPRM*, para. 47.

[52] *See NPRM*, para. 47, citing 47 C.F.R. § 90.371(b).

[53] *See* 47 C.F.R. § 90.371(b).

[54] *See NPRM*, para. 47.

[55] The protection requirements contained herein are premised upon the power and out-of-band emission levels contemplated by the Commission. Any deviation from those parameters may result in a change to these requirements.

[56] *See* 47 C.F.R. § 90.371(c).

[57] 47 U.S.C. § 902(b)(2)(A).

revised as follows: "… of the locations listed in the table below, to which NTIA may amend, modify, or revoke locations and associated parameters, must be coordinated through the…"

NTIA also performed an analysis assessing the potential impact of C-V2X OBUs on federal operations. The NTIA analysis, based upon the Commission's proposed rules for C-V2X OBUs, indicates that coordination of these devices would not be necessary to protect federal operations.

8.3 Protecting Federal Incumbent from U-NII Devices

Unlicensed devices in the 5.9 GHz band currently share spectrum with federal radar operations in the adjacent U-NII-3 band (5.725-5.850 GHz). The *NPRM* proposes to adopt the same technical rules (e.g., radiated power, power spectral density, etc.) for 5.850-5.895 GHz (U-NII-4) unlicensed devices as currently applied to U-NII-3 unlicensed devices.[58] The *NPRM* seeks comments on whether or not there are any mitigation measures, such as technical or operational conditions or constraints that it should consider for U-NII-4 operations to protect federal radars in the 5.9 GHz band.[59]

NTIA has determined that, to protect federal radiolocation systems, operation of U-NII-4 outdoor P2MP devices would require the imposition of exclusion zones. The exclusion zones are set forth in Table 19. To enforce the exclusion zones, NTIA believes that interference mitigation techniques such as geo-fencing can be employed to protect federal radiolocation operations. NTIA emphasizes the importance of ensuring that U-NII-4 device operation is not permitted inside of these exclusion zones, especially in light of experience with U-NII devices in the 5 GHz band.[60] NTIA requests that the new rules make clear that NTIA may authorize additional exclusion zones or modify the existing exclusion zones listed in Table 19 as may be necessary to ensure protection of federal radiolocation systems similar to that proposed above for the revised Section 90.371.

To reduce the potential for interference from indoor U-NII-4 devices, NTIA recommends that the rules help ensure the indoor devices are not deployed outdoors and that expedient and effective corrective measures be in place to eliminate interference should it occur, rather than imposing exclusion zones as a first measure to protect the federal systems.[61] Examples of ways to ensure indoor use include having the power for AP devices supplied by a wired connection (not battery powered), having an integrated antenna, and not having a weatherized enclosure.[62] Since it has

[58] *See NPRM*, para. 57.

[59] *See ibid.*

[60] *See* NTIA Technical Report TR 20-544, *Lessons Learned from the Development and Deployment of 5 GHz Unlicensed National Information Infrastructure (U-NII) Dynamic Frequency Selection (DFS) Devices*, available at: https://www.ntia.doc.gov/report/2019/lessons-learned-development-and-deployment-5-ghz-unlicensed-national-information. Section 8 describes interference to a federal radar from a U-NII device.

[61] *See* Report and Order and Further Notice of Proposed Rulemaking, *Unlicensed Use of the 6 GHz Band*, 35 FCC Rcd 3852 (2020), https://docs.fcc.gov/public/attachments/FCC-20-51A1.pdf.

[62] *See*, e.g., 47 C.F.R. §§ 15.257, 15.403, and 15.517.

proven difficult and time consuming to identify and mitigate interference from U-NII devices,[63] the capability of having the U-NII-4 service providers remotely block the interfering device(s) from using certain channels and/or to reduce the operating power of the devices is an important corrective measure. Use of this capability will be imposed based on NTIA and FCC coordination, noting that one of the primary operating conditions under Part 15 is that the operator must correct whatever interference is caused *even if correction of the problem requires ceasing operation*.[64] Service providers and operators should be expected to respond promptly to such FCC directives upon receipt.

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[63] Interference from U-NII devices affected "essential safety systems" at Cape Canaveral and Patrick Air Force Base. *See Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 13-49, Memorandum Opinion and Order, FCC 16-24, 31 FCC Rcd 2317, 2319 n.10 (2016), *citing* Federal Communications Commission, Letter, *5 GHz Interference to Patrick Air Force Base*, (Mar. 10, 2015), https://www.fcc.gov/general/u-nii-and-tdwr-interference-enforcement. *See also* https://www.fcc.gov/eb-fieldadvis.

[64] *See* 47 C.F.R. § 15.5.

APPENDIX A: RESULTS FOR FEDERAL SYSTEMS

A.1 Overview

This appendix provides the geographical areas of the ITS road side unit (RSU) coordination zones (subsection A.2) followed by the geographical area of the outdoor U-NII device exclusion zones (subsection A.3).

A.2 Intelligent Transportation System Results

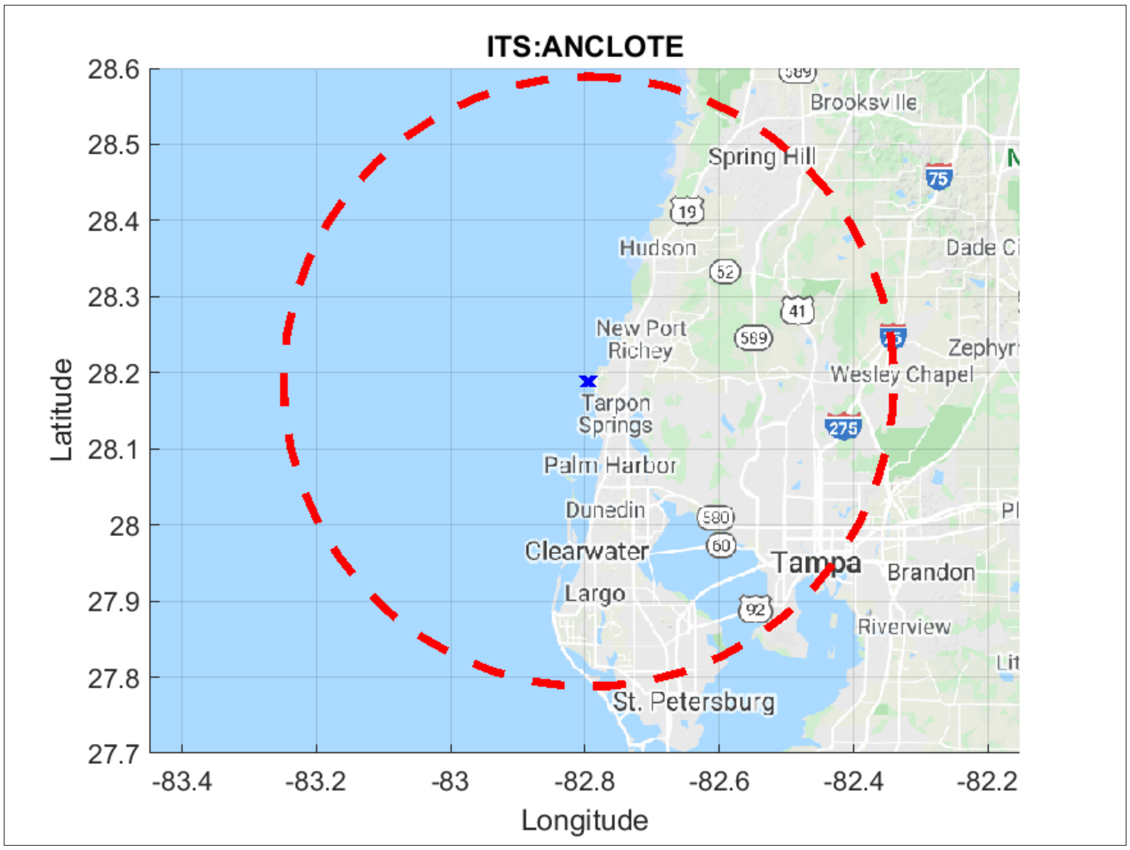

Figure 14. Anclote Intelligent Transportation System Coordination Zone

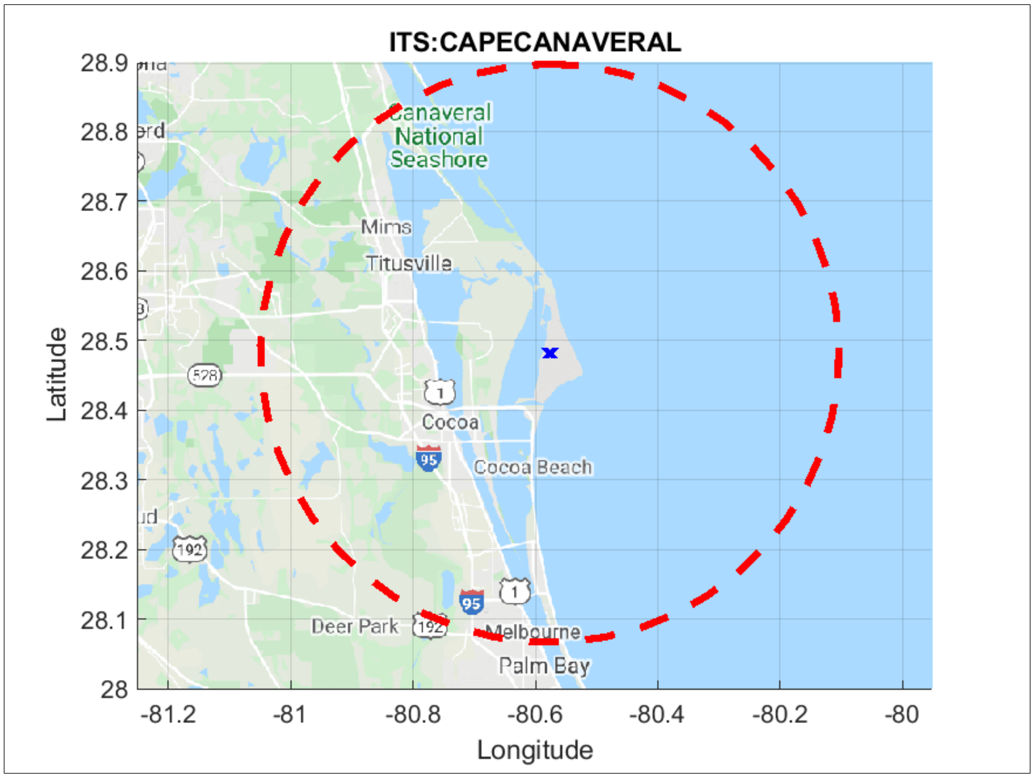

Figure 15. Cape Canaveral Intelligent Transportation System Coordination Zone

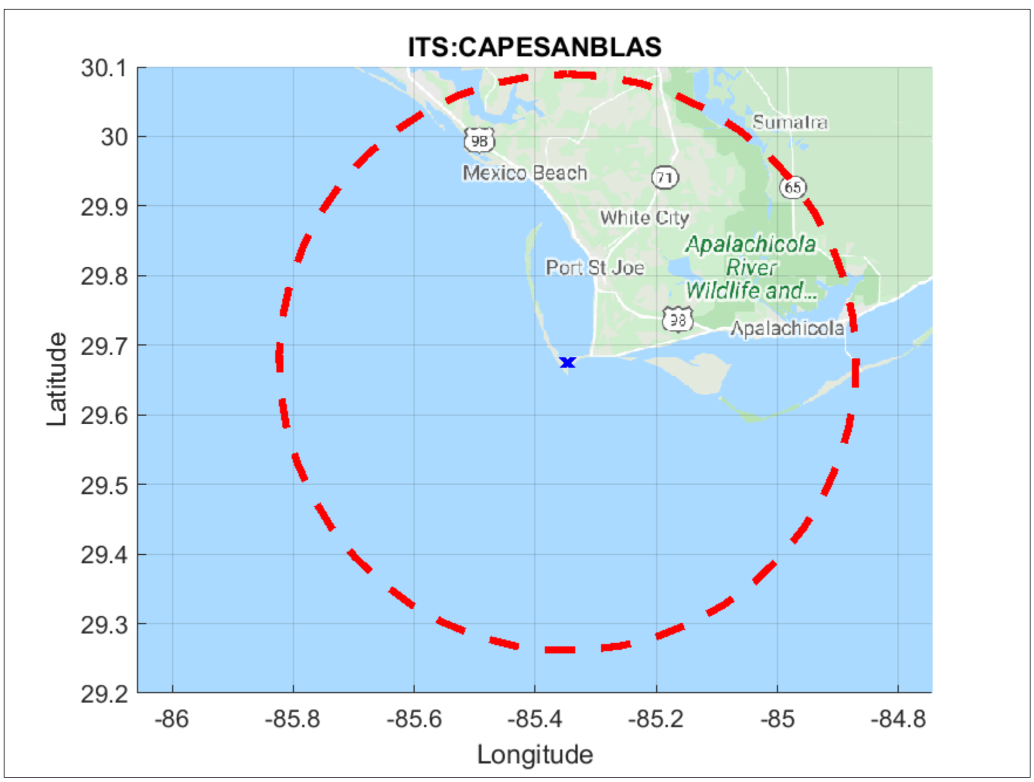

Figure 16. Cape San Blas Intelligent Transportation System Coordination Zone

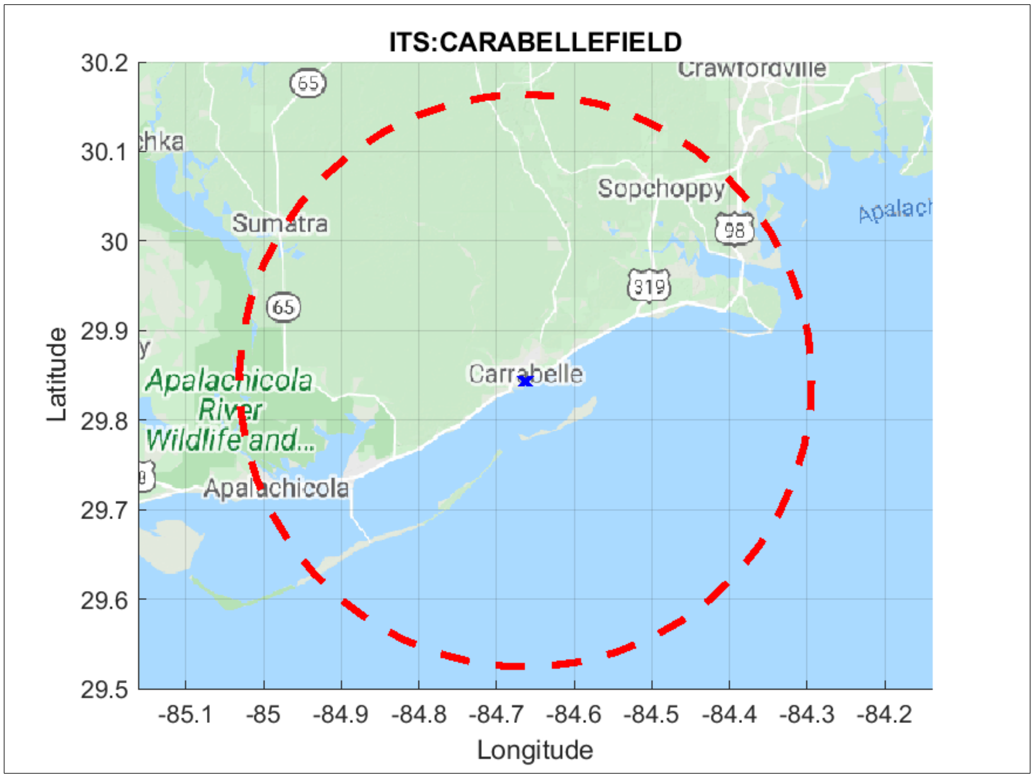

Figure 17. Carabelle Field Intelligent Transportation System Coordination Zone

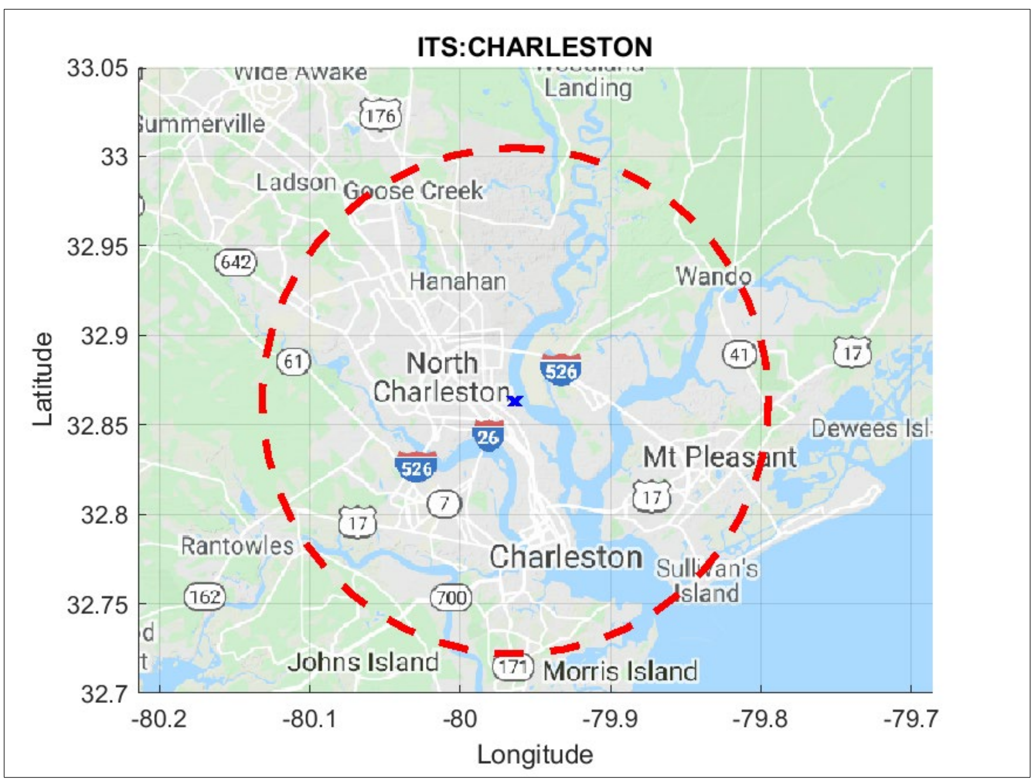

Figure 18. Charleston Intelligent Transportation System Coordination Zone

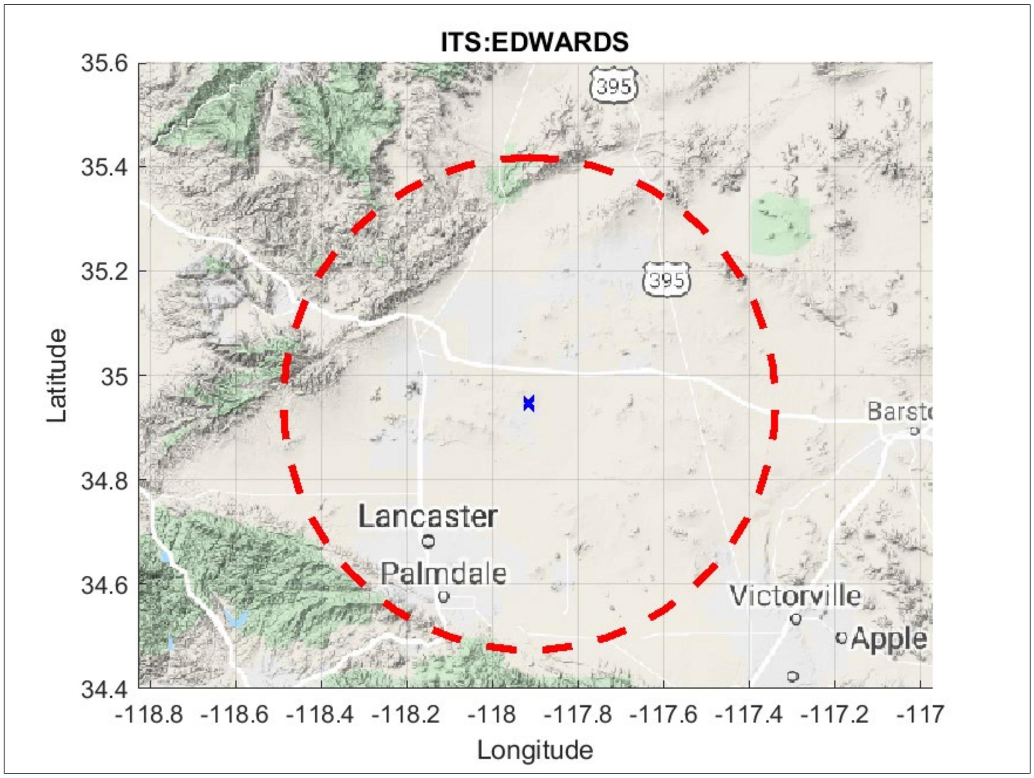

Figure 19. Edwards AFB Intelligent Transportation System Coordination Zone

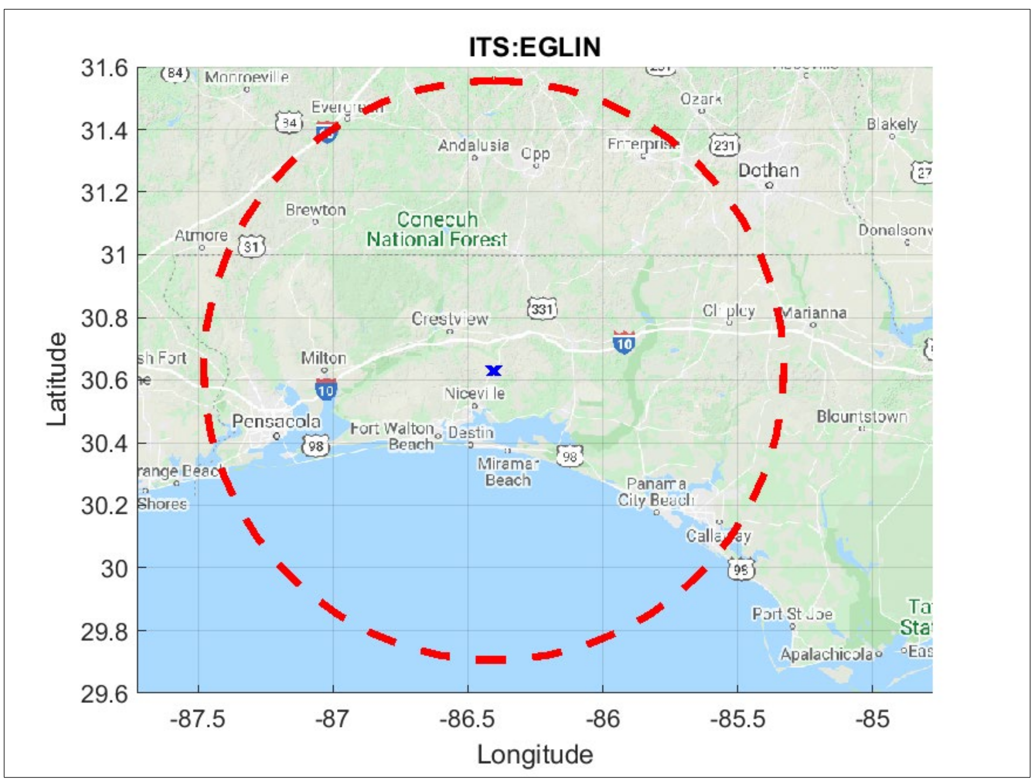

Figure 20. Eglin Intelligent Transportation System Coordination Zone

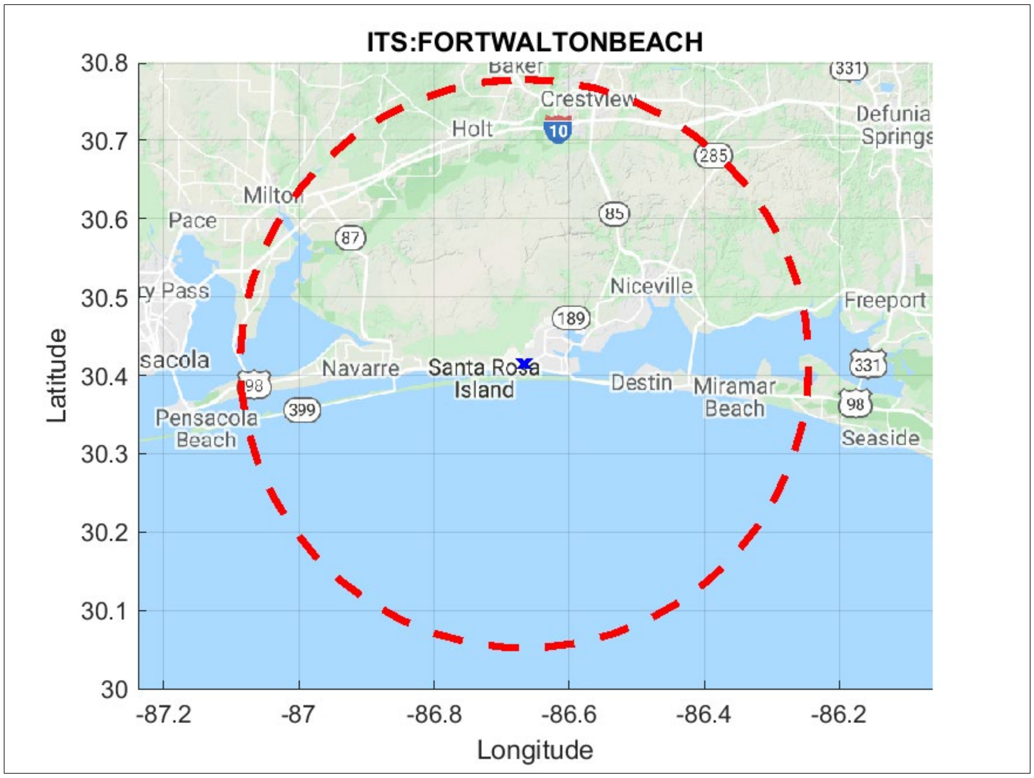

Figure 21. Fort Walton Beach Intelligent Transportation System Coordination Zone

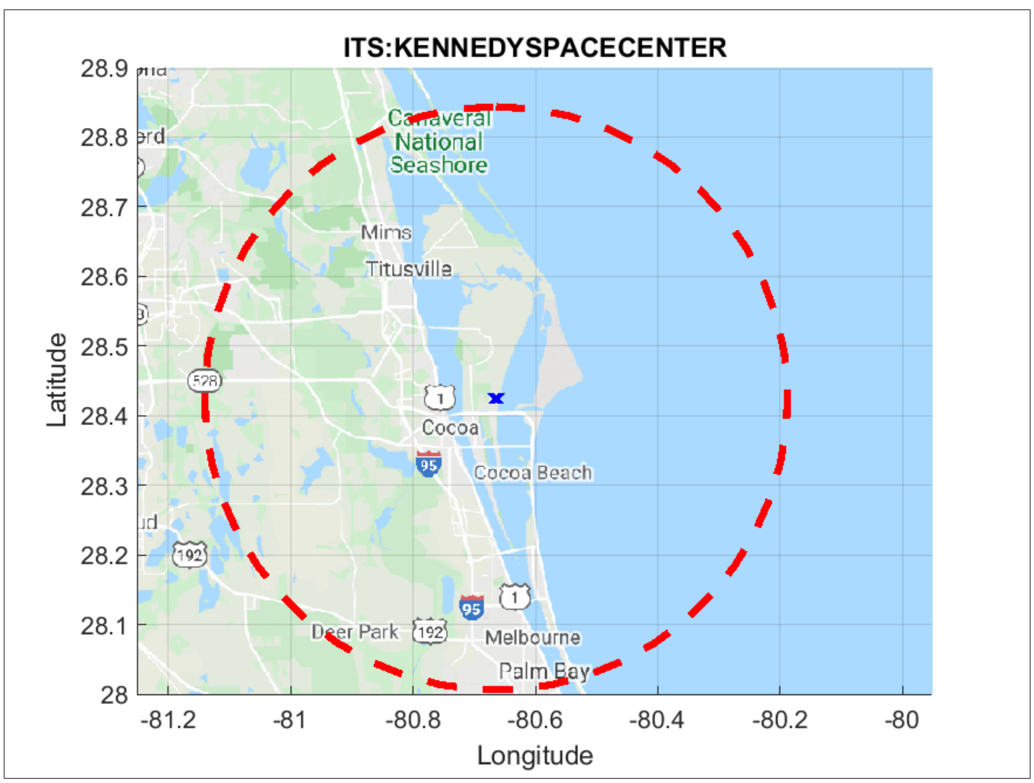

Figure 22. Kennedy Space Center Intelligent Transportation System Coordination Zone

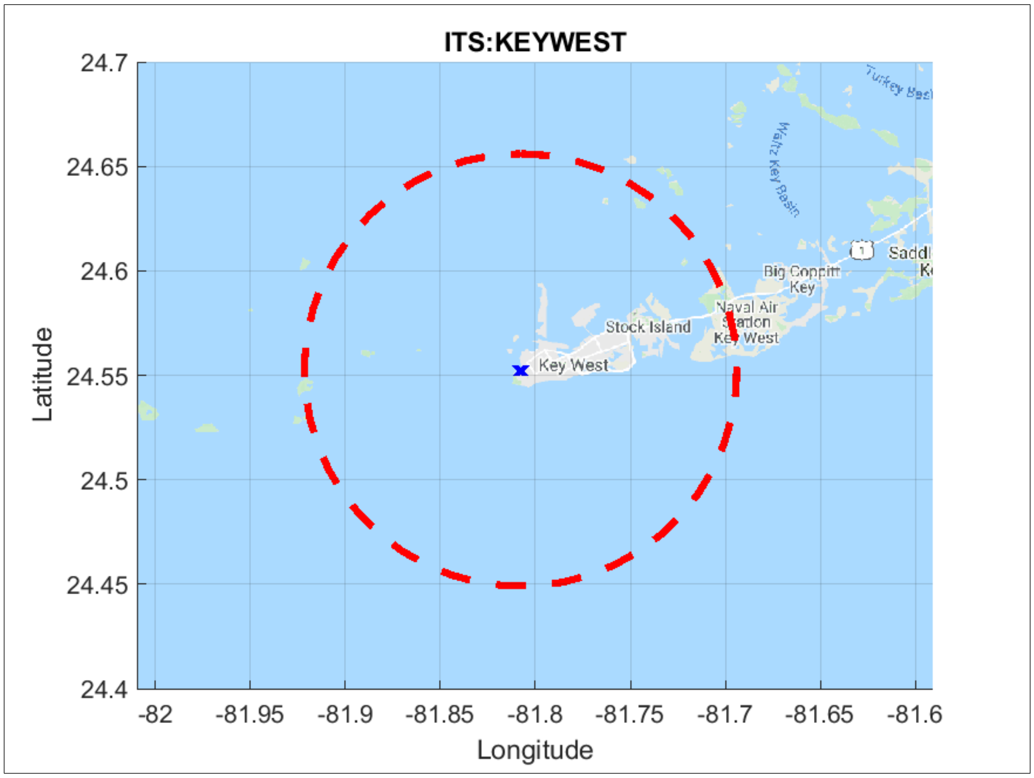

Figure 23. Key West Intelligent Transportation System Coordination Zone

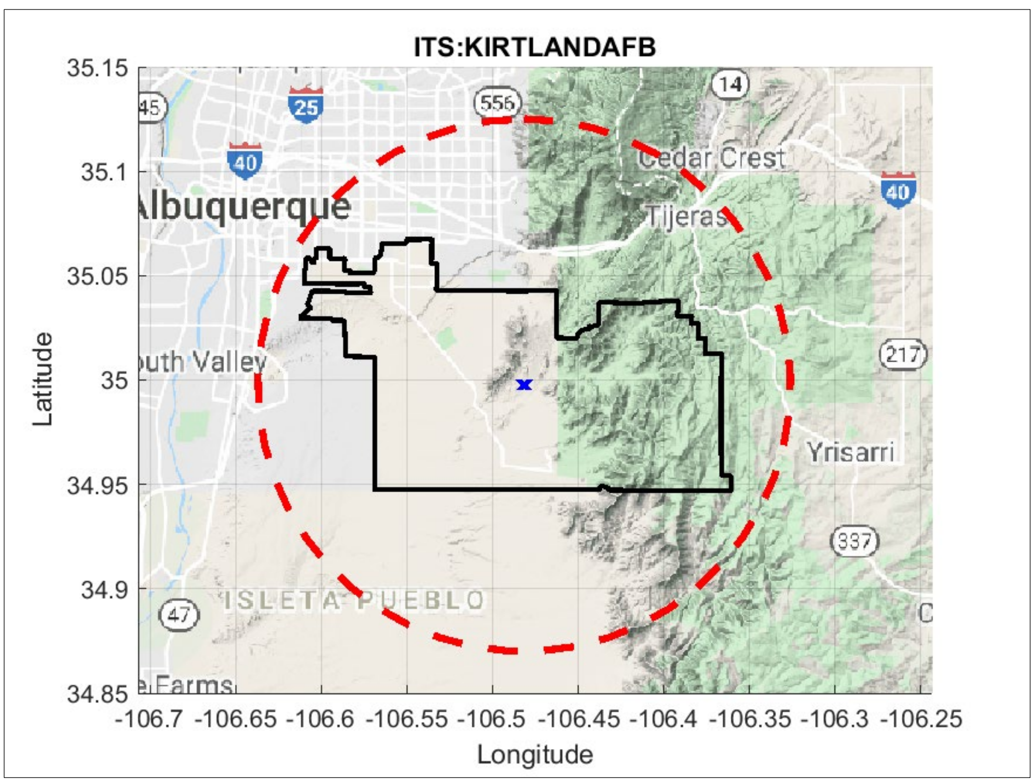

Figure 24. Kirtland AFB Intelligent Transportation System Coordination Zone

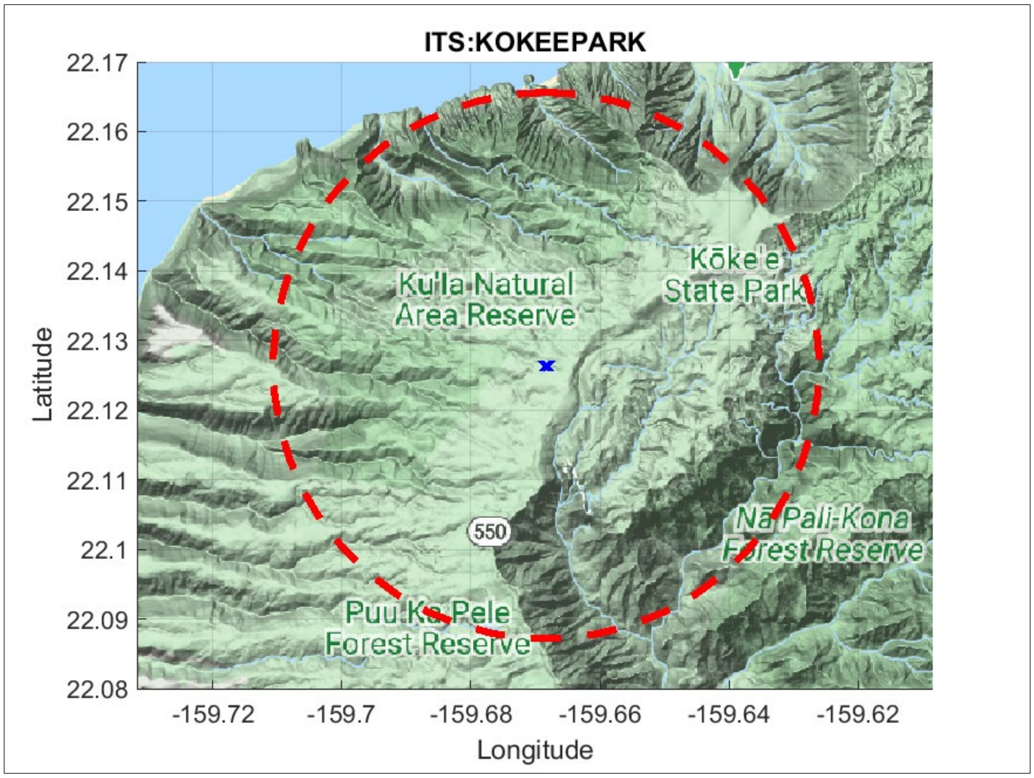

Figure 25. Kokee Park Intelligent Transportation System Coordination Zone

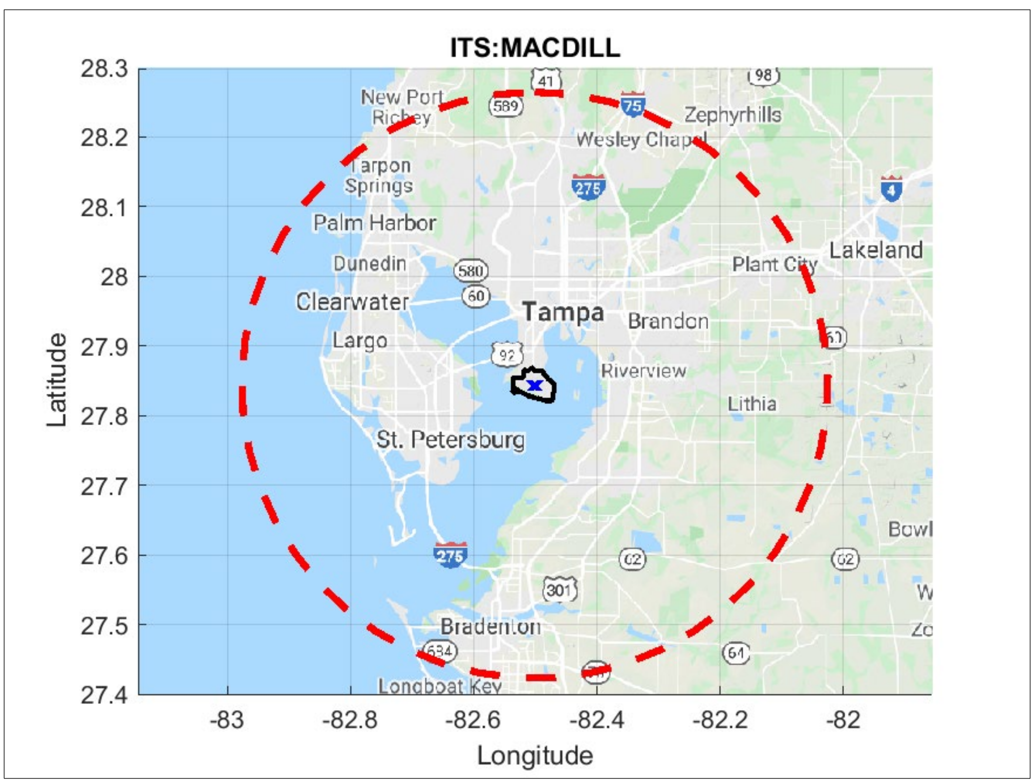

Figure 26. MacDill AFB Intelligent Transportation System Coordination Zone

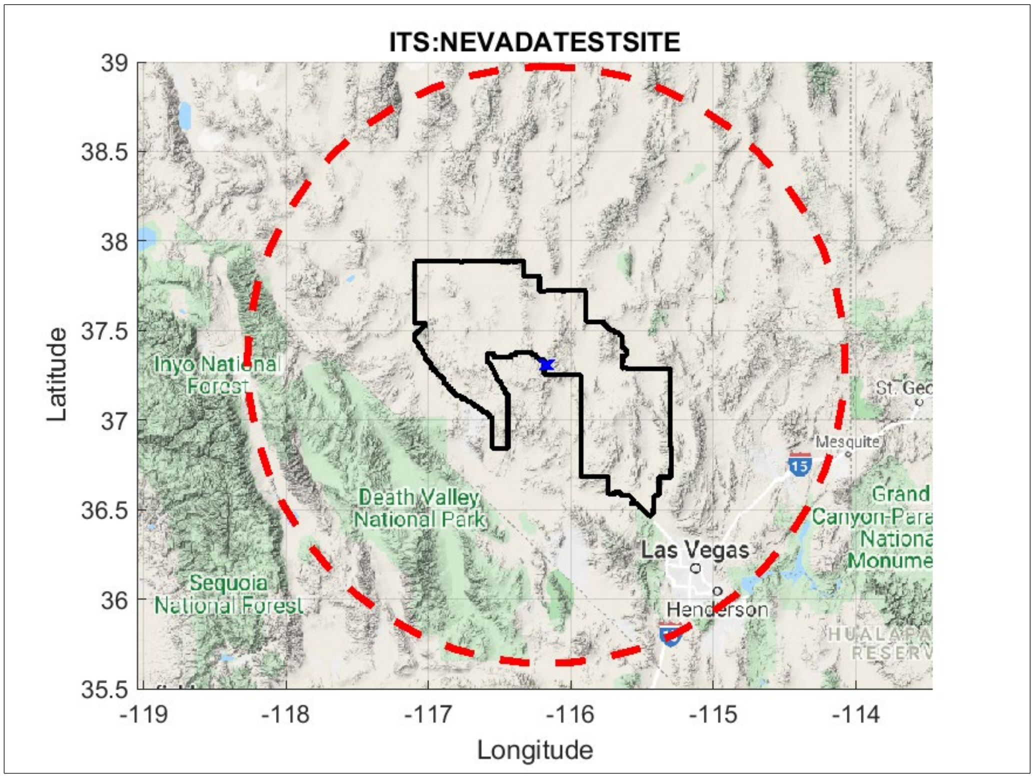

Figure 27. NTTR Intelligent Transportation System Coordination Zone

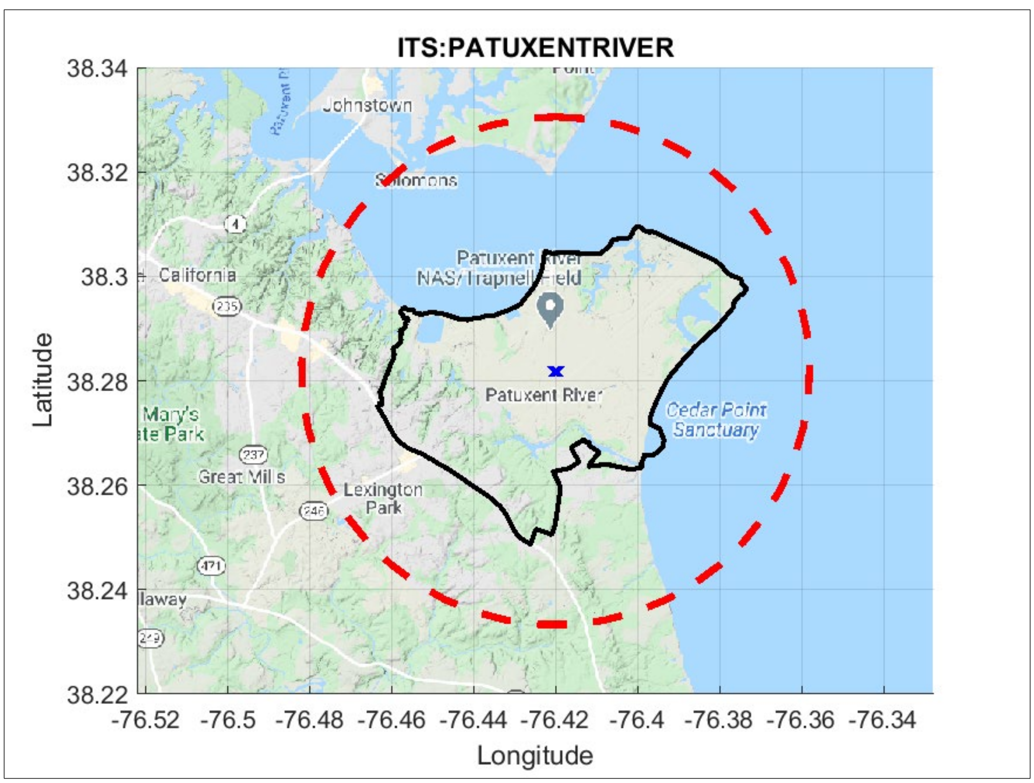

Figure 28. Patuxent River Intelligent Transportation System Coordination Zone

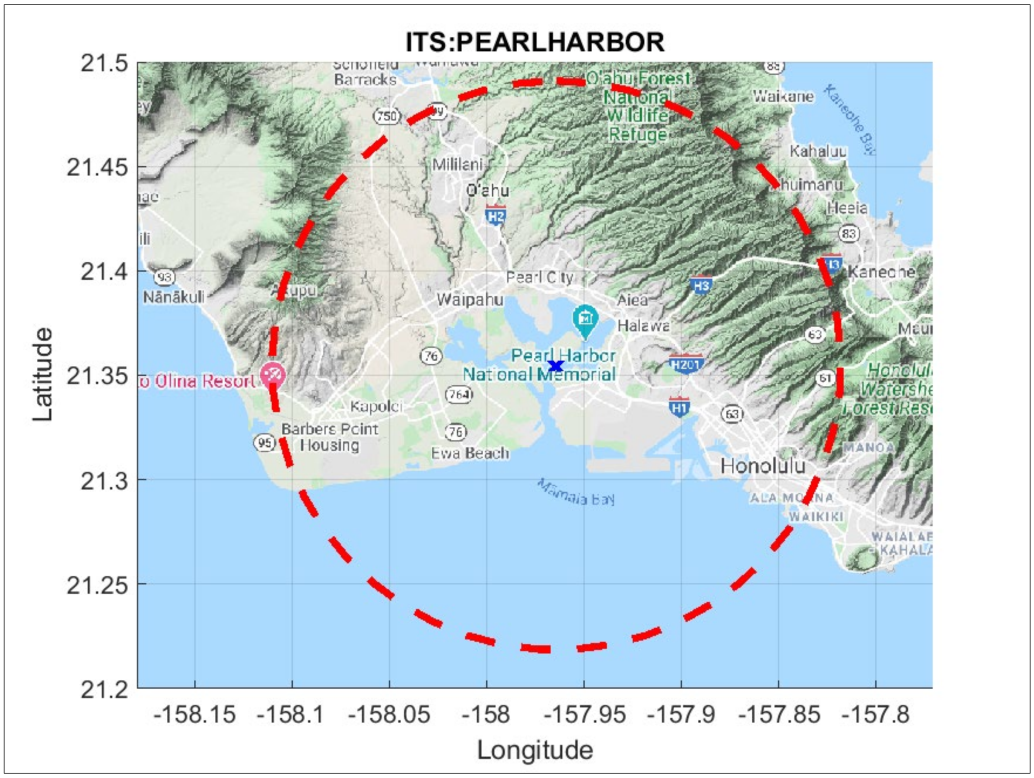

Figure 29. Pearl Harbor Intelligent Transportation System Coordination Zone

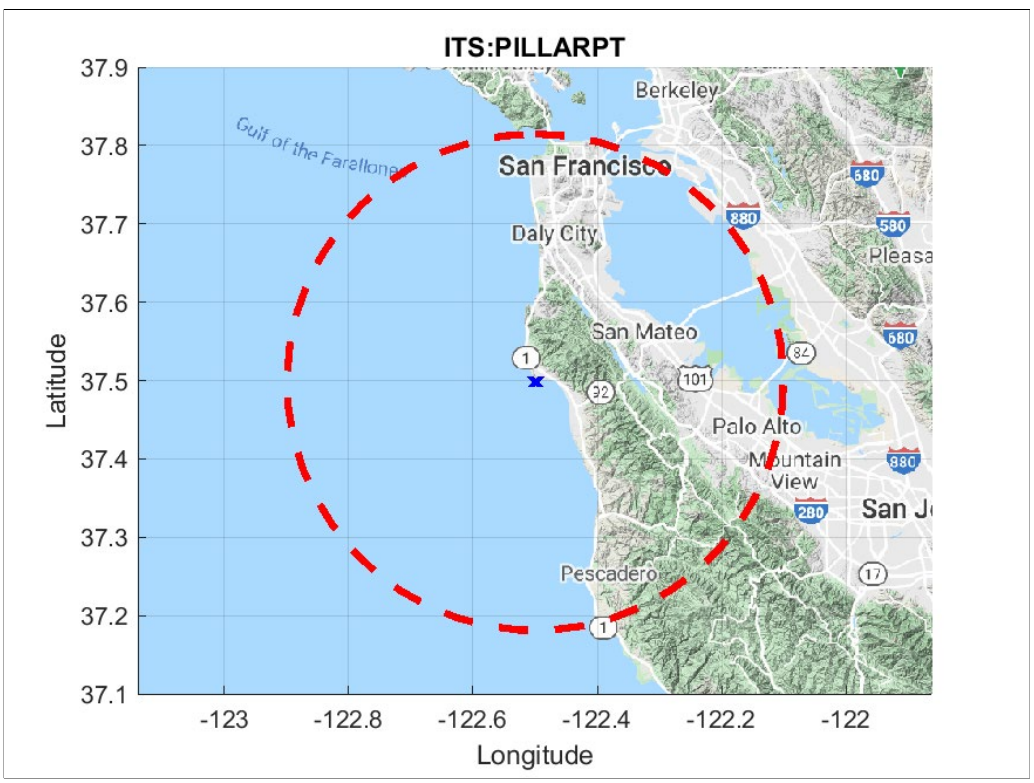

Figure 30. Pillar Point Intelligent Transportation System Coordination Zone

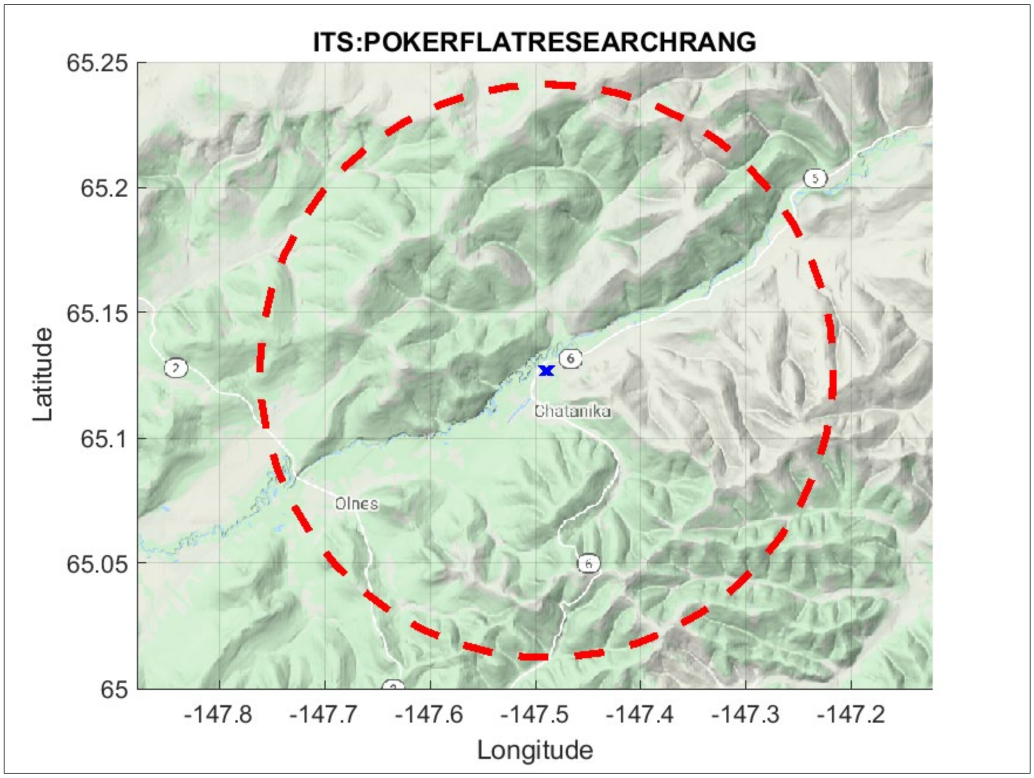

Figure 31. Poker Flat Research Range Intelligent Transportation System Coordination Zone

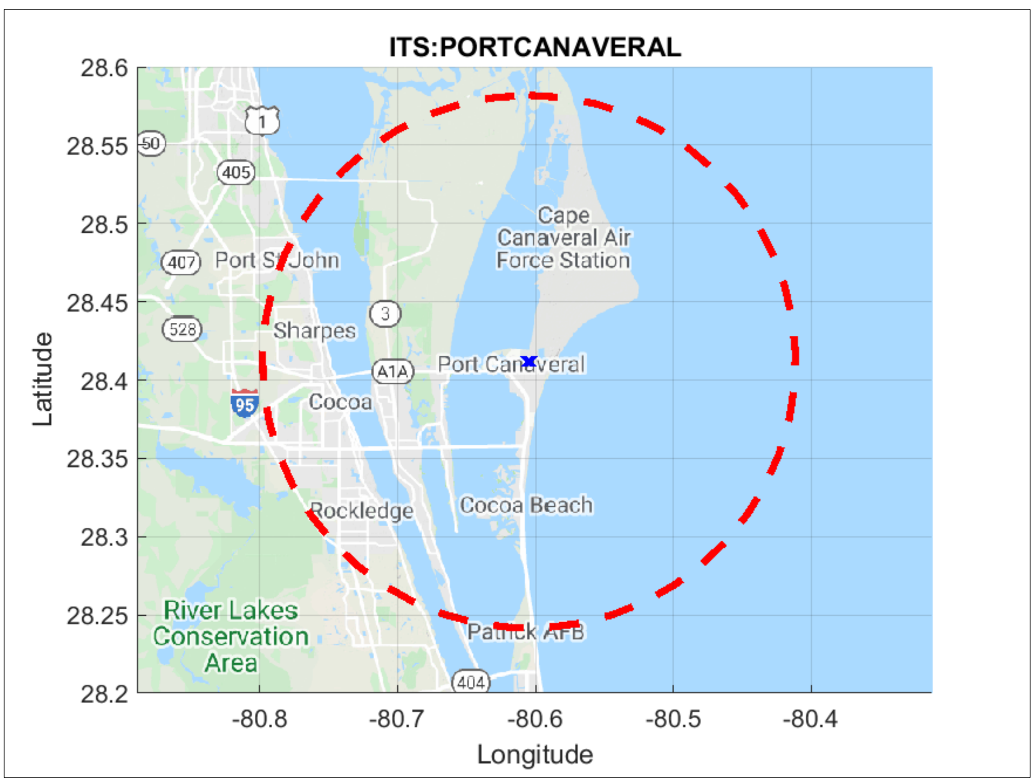

Figure 32. Port Canaveral Intelligent Transportation System Coordination Zone

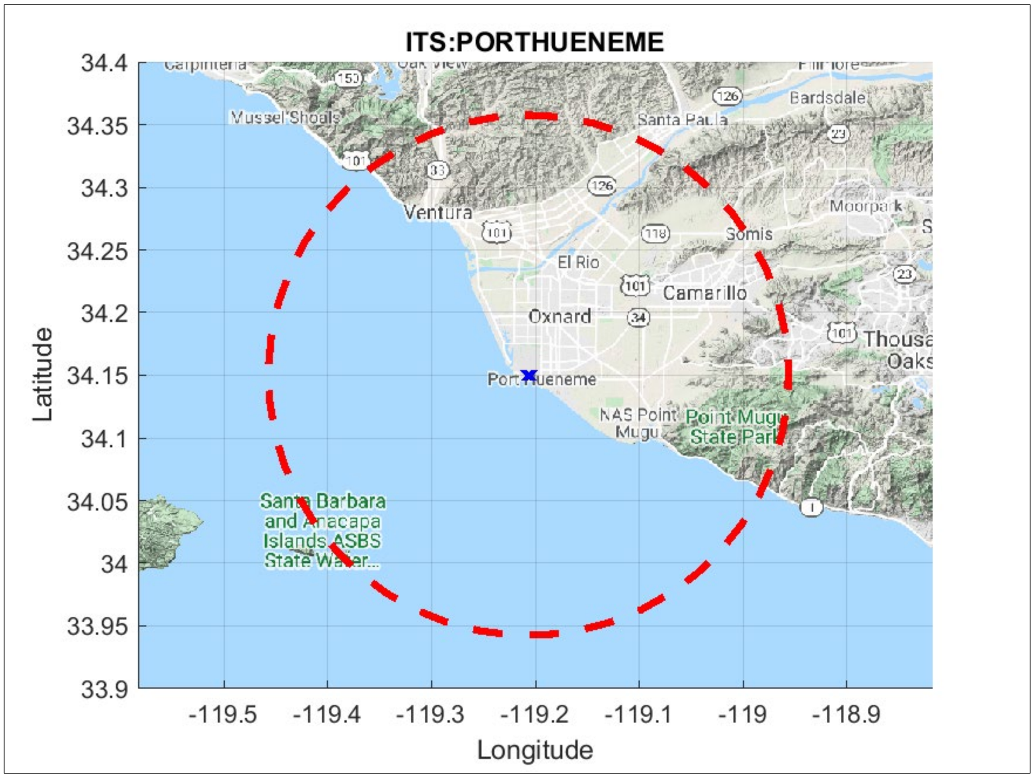

Figure 33. Port Hueneme Intelligent Transportation System Coordination Zone

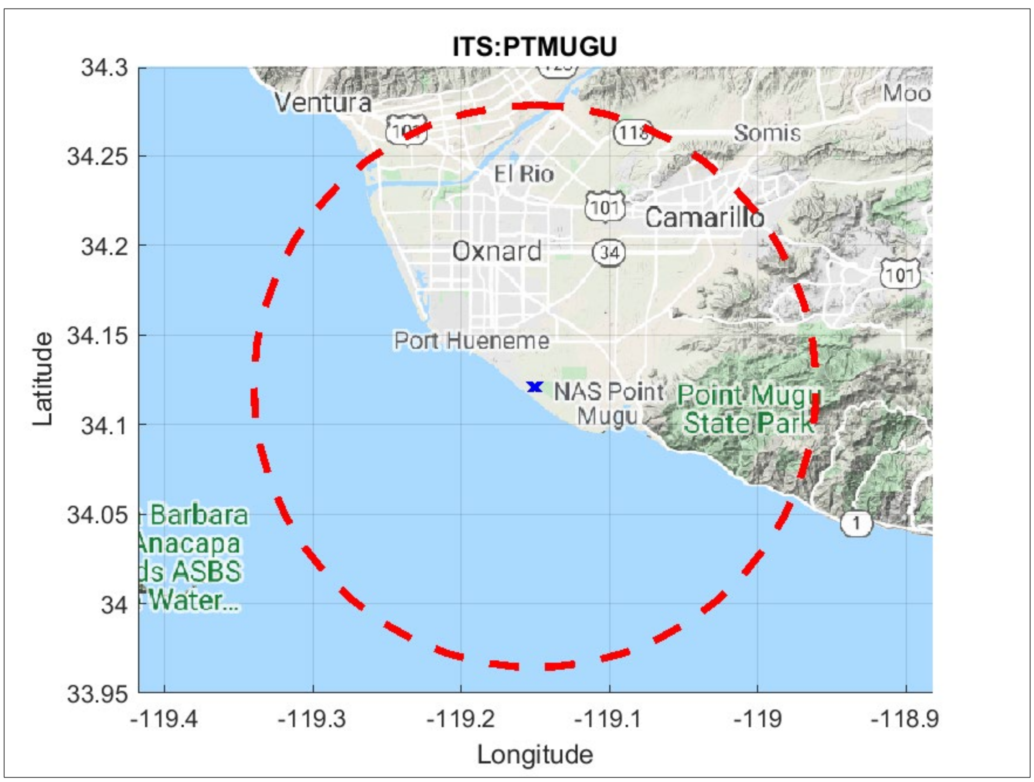

Figure 34. Point Mugu Intelligent Transportation System Coordination Zone

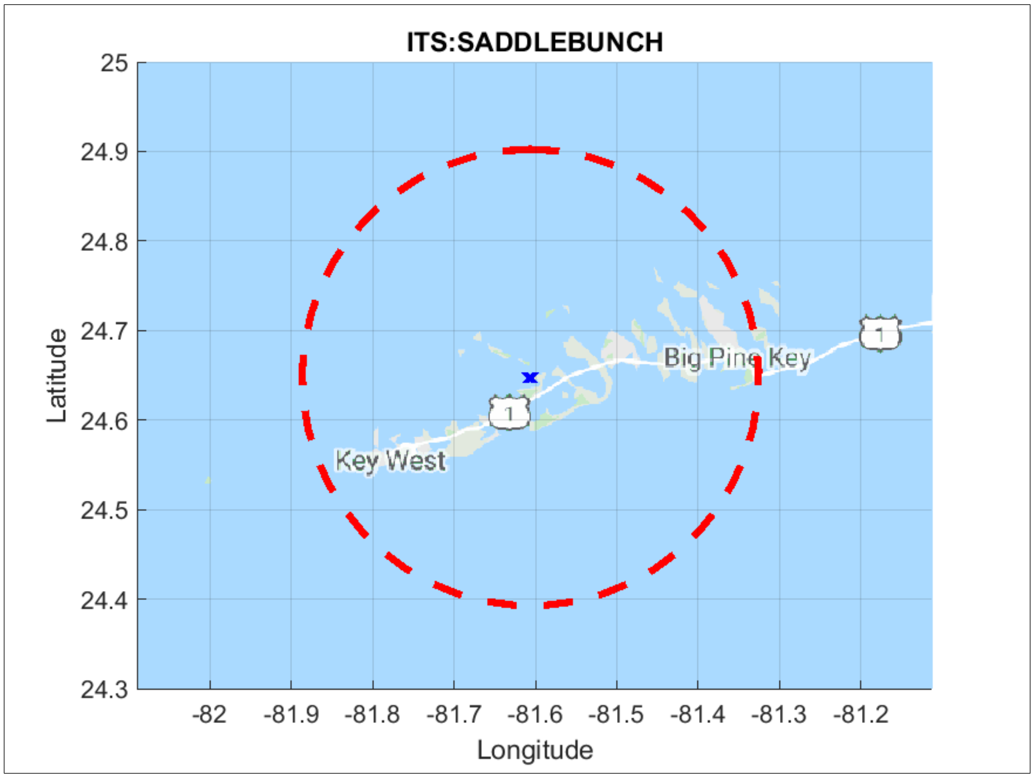

Figure 35. Saddle Bunch Intelligent Transportation System Coordination Zone

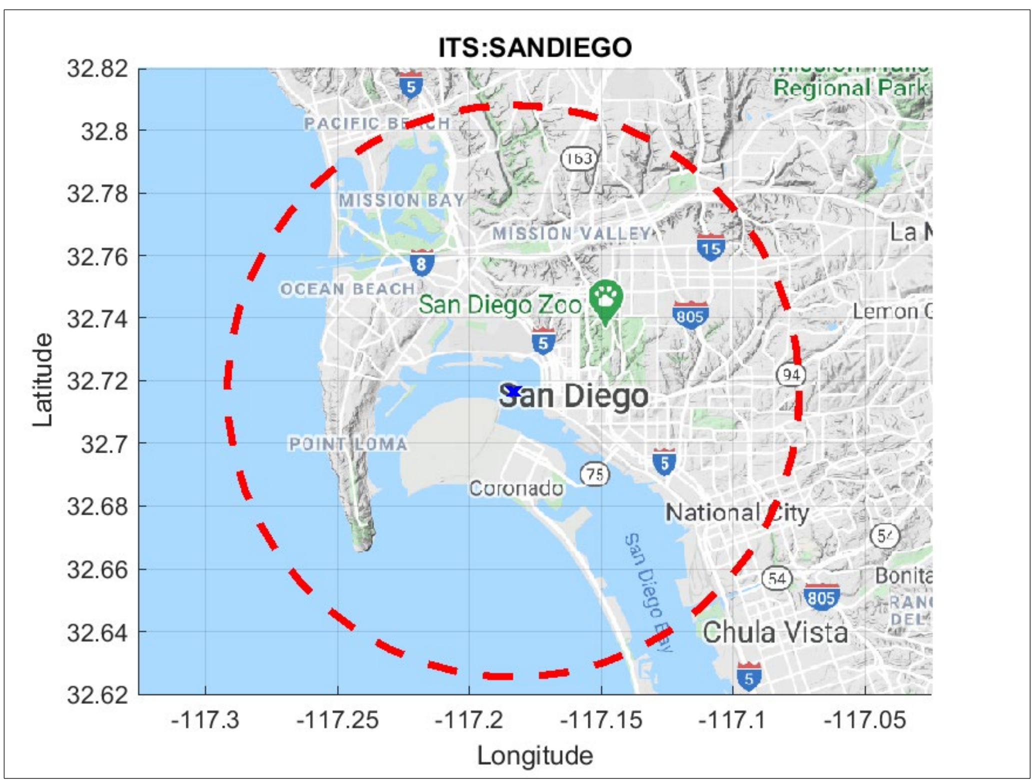

Figure 36. San Diego Intelligent Transportation System Coordination Zone

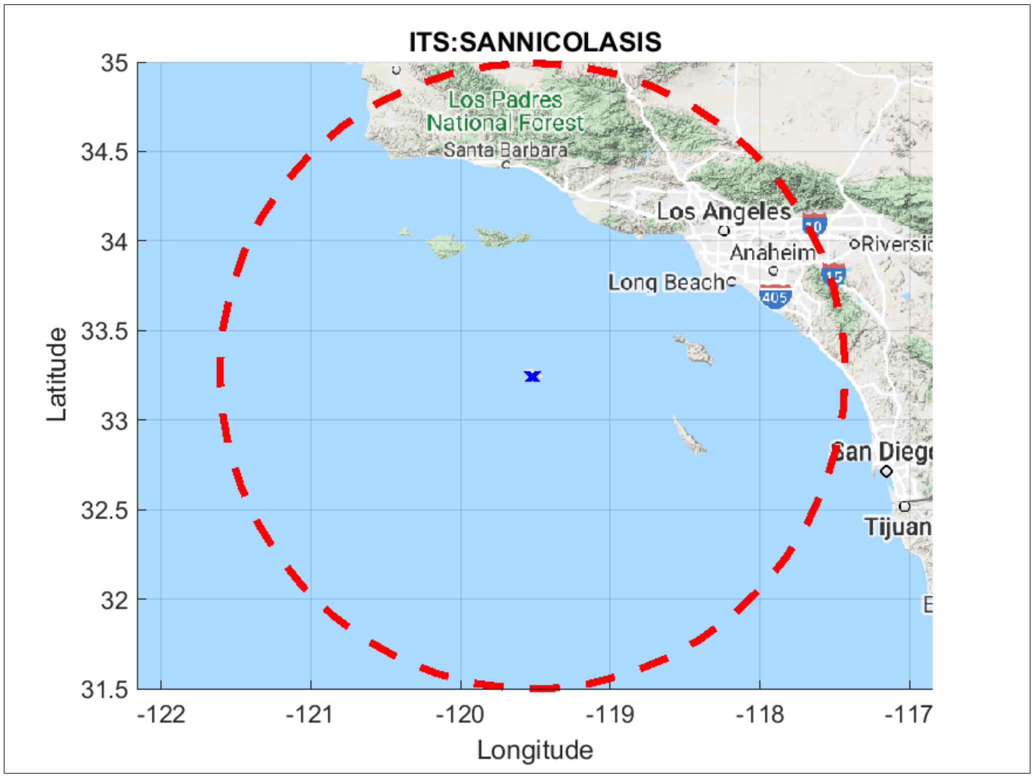

Figure 37. San Nicolas Island Intelligent Transportation System Coordination Zone

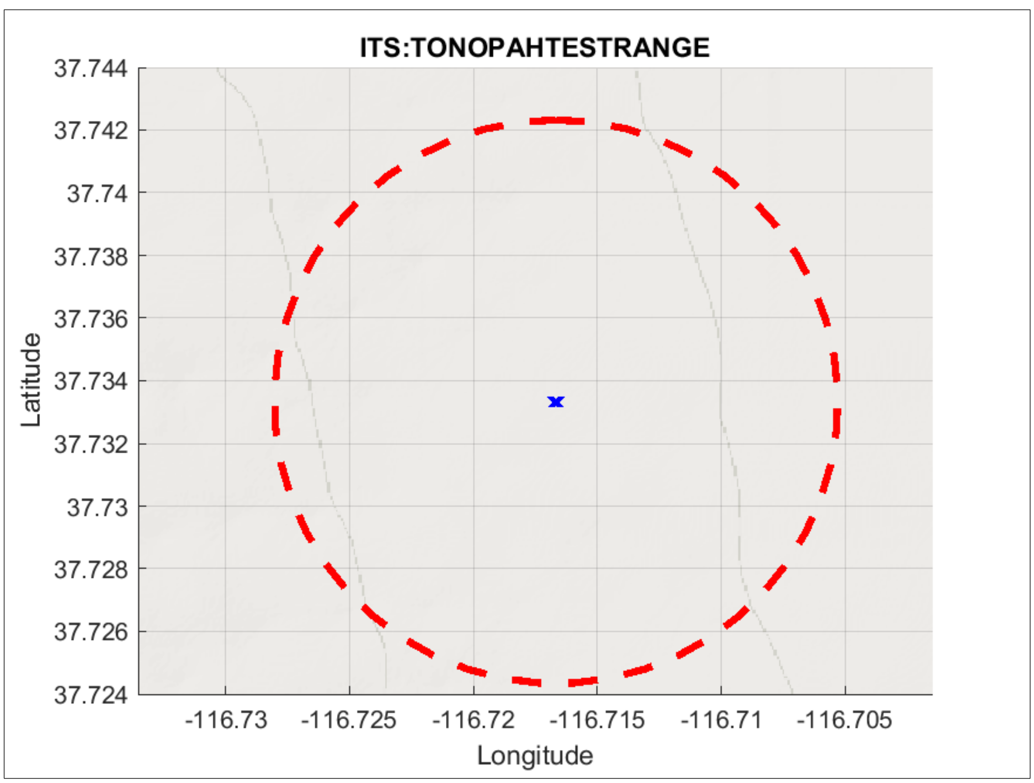

Figure 38. Tonopah Test Range Intelligent Transportation System Coordination Zone

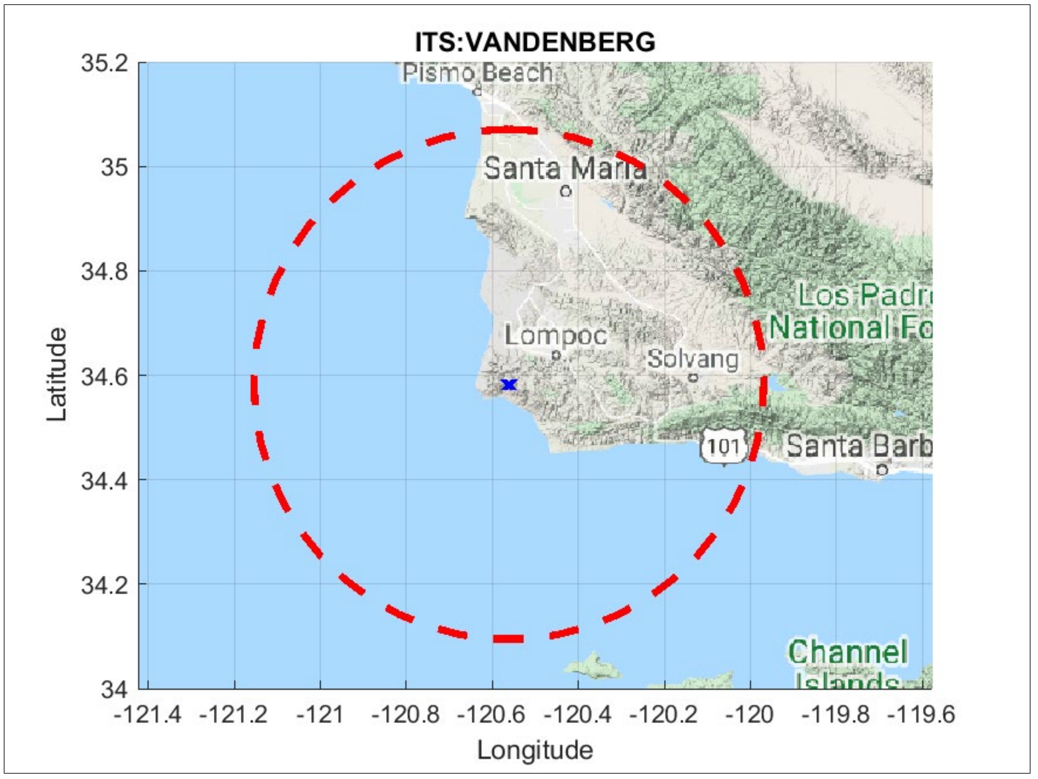

Figure 39. Vandenberg Intelligent Transportation System Coordination Zone

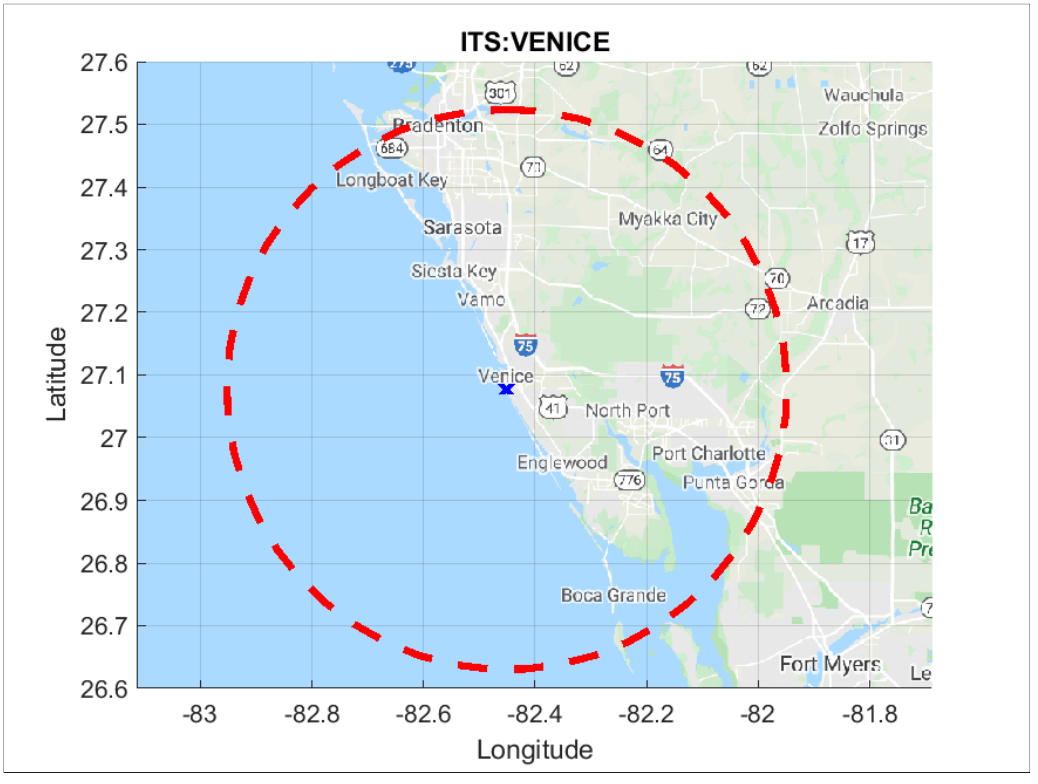

Figure 40. Venice Intelligent Transportation System Coordination Zone

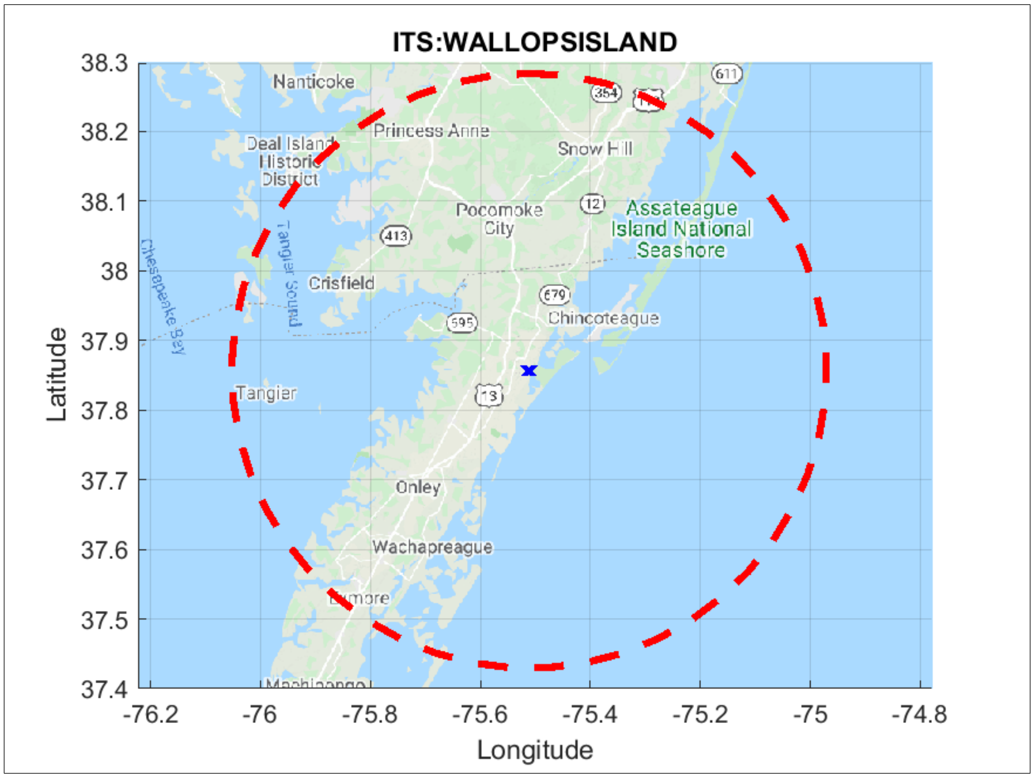

Figure 41. Wallops Island Intelligent Transportation System Coordination Zone

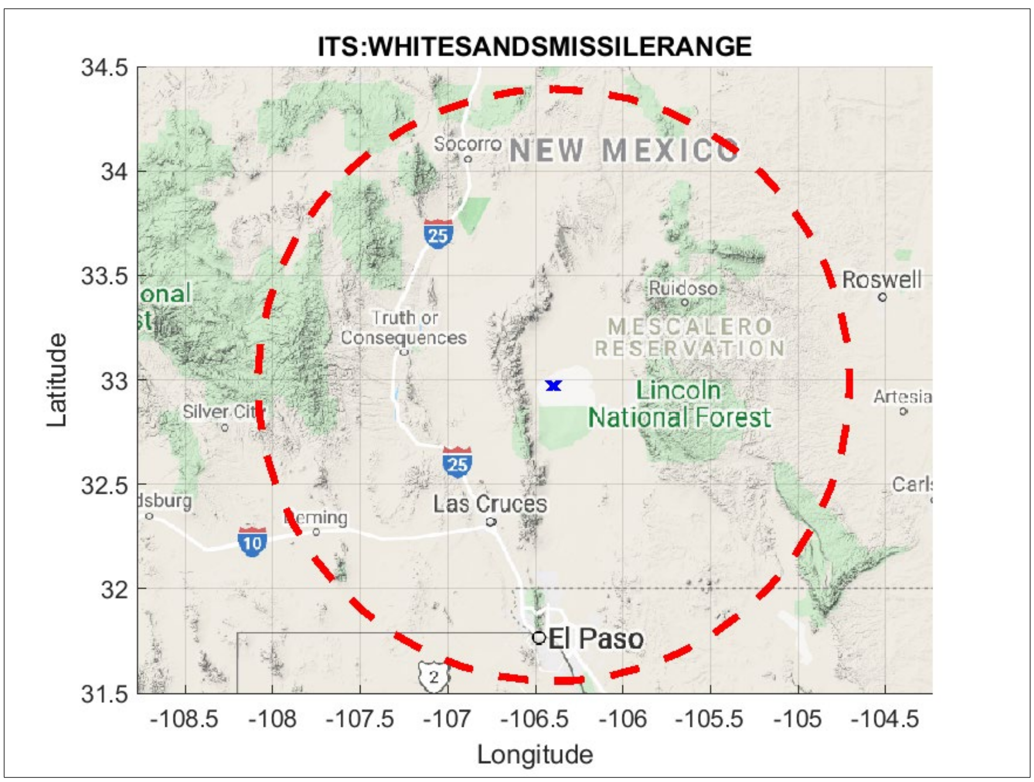

Figure 42. White Sands Intelligent Transportation System Coordination Zone

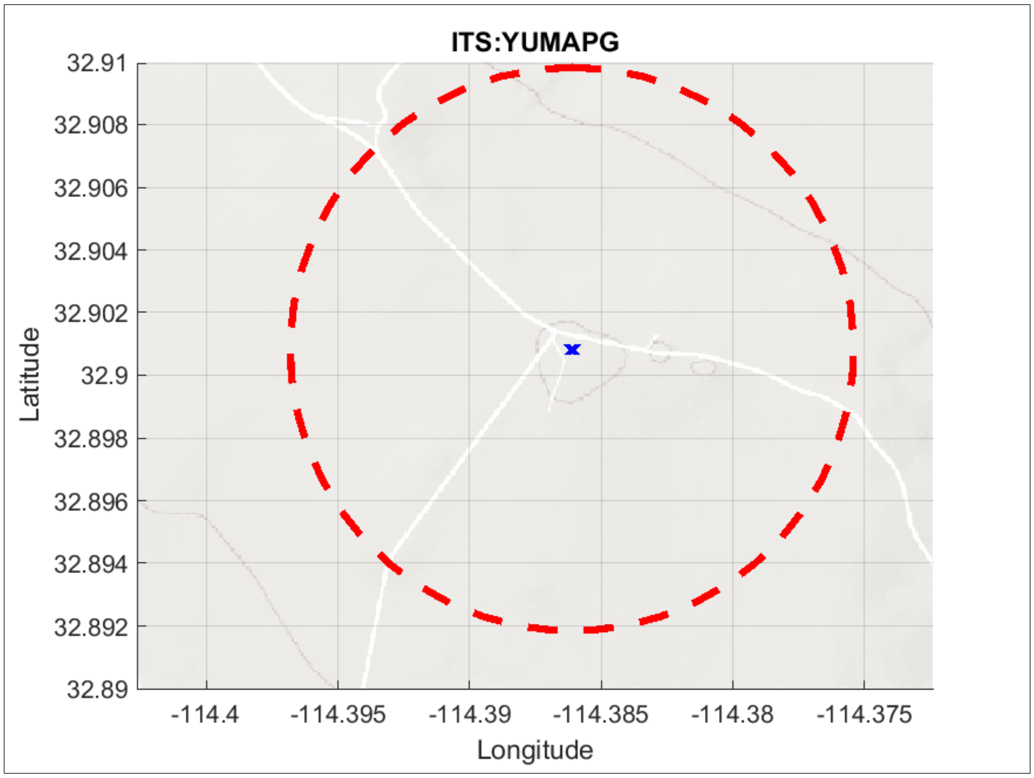

Figure 43. Yuma PG Intelligent Transportation System Coordination Zone

A.3 U-NII-4 Results

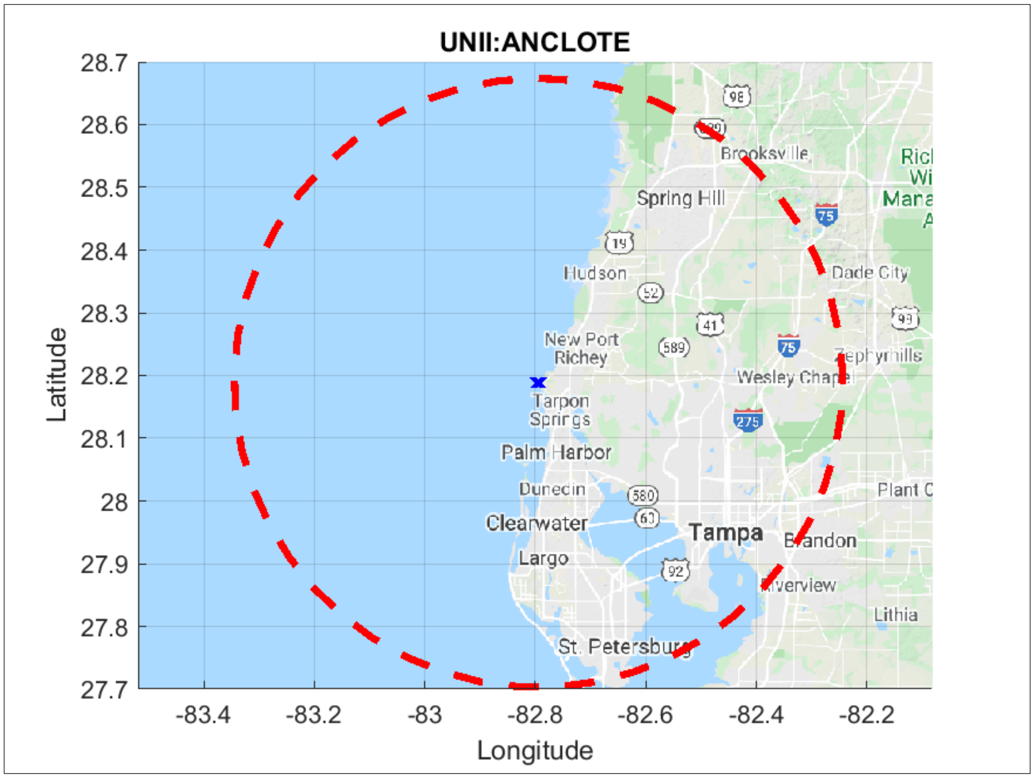

Figure 44. Anclote U-NII-4 Exclusion Zone

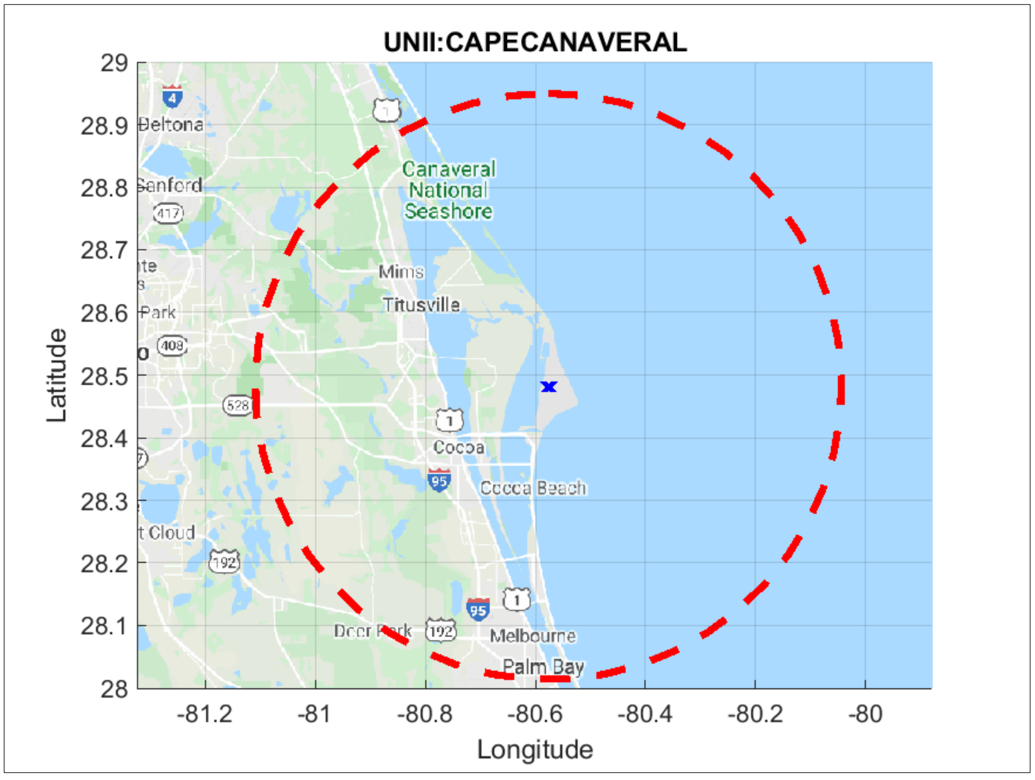

Figure 45. Cape Canaveral U-NII-4 Exclusion Zone

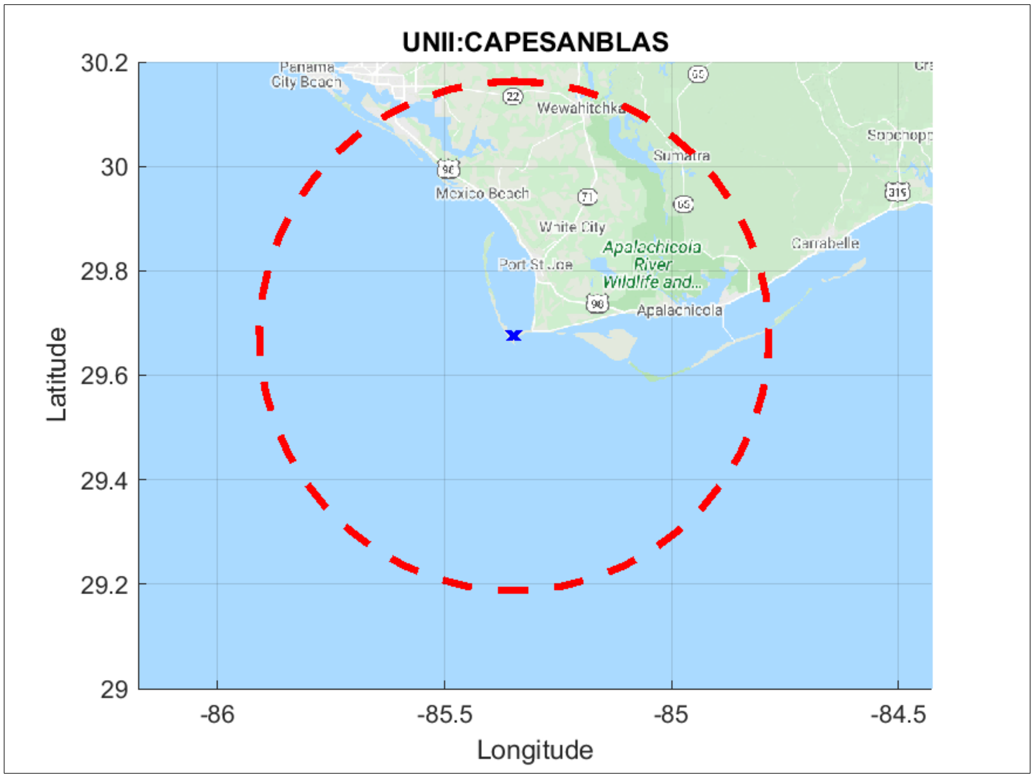

Figure 46. Cape San Blas U-NII-4 Exclusion Zone

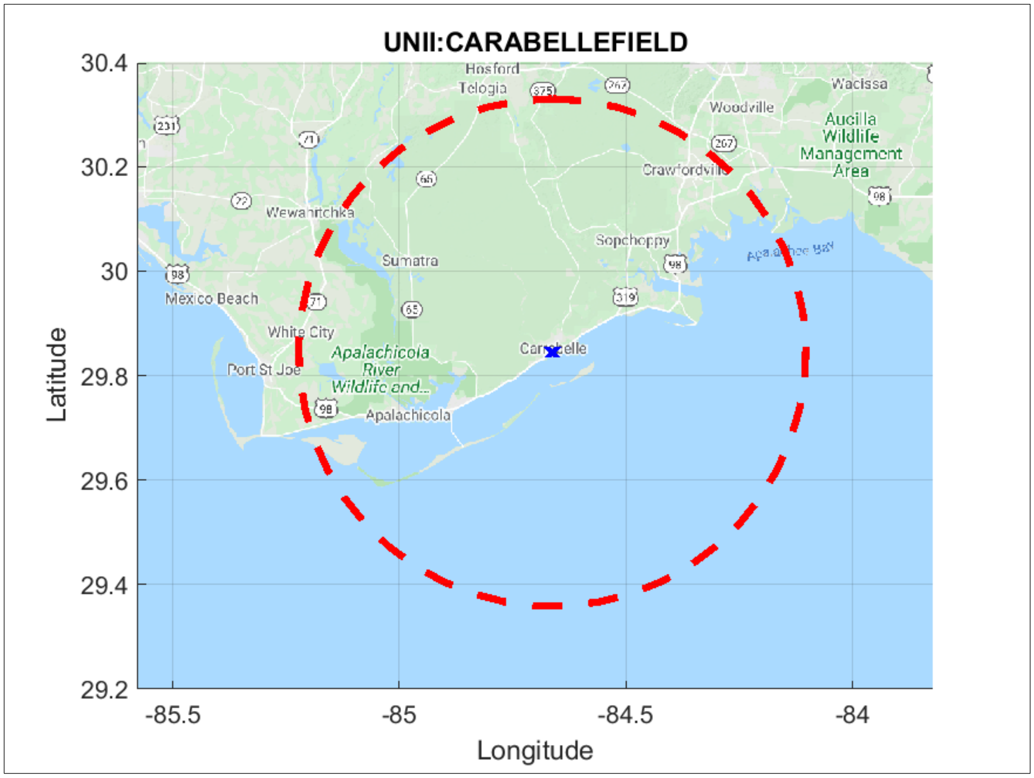

Figure 47. Carabelle Field U-NII-4 Exclusion Zone

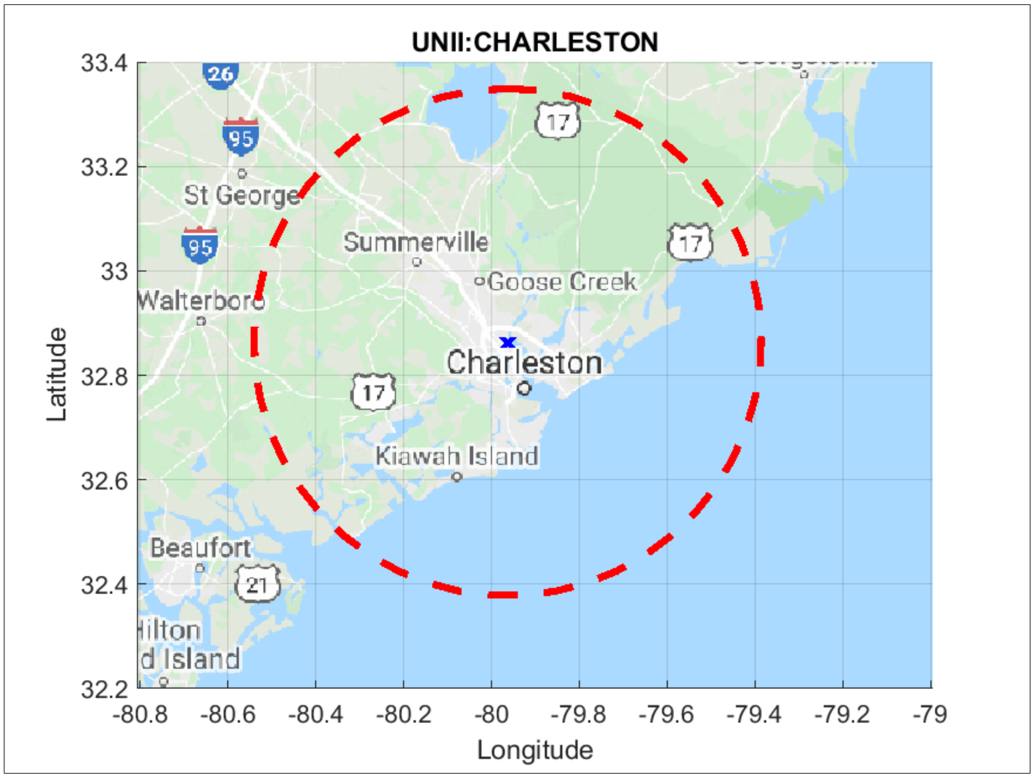

Figure 48. Charleston U-NII-4 Exclusion Zone

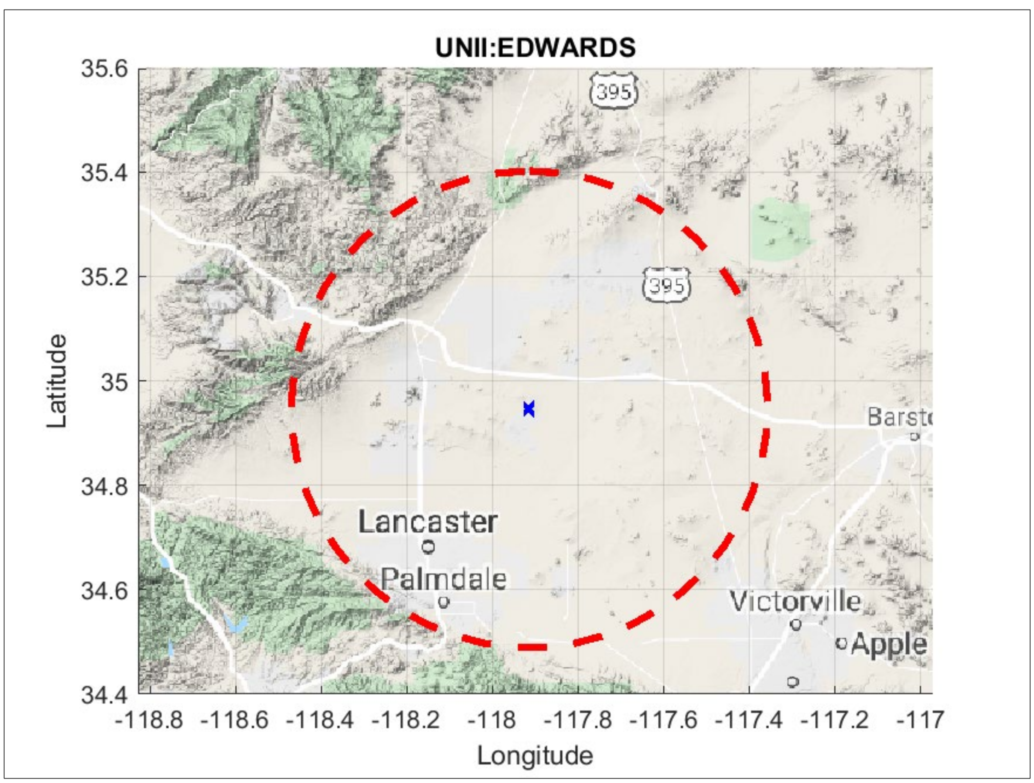

Figure 49. Edwards AFB U-NII-4 Exclusion Zone

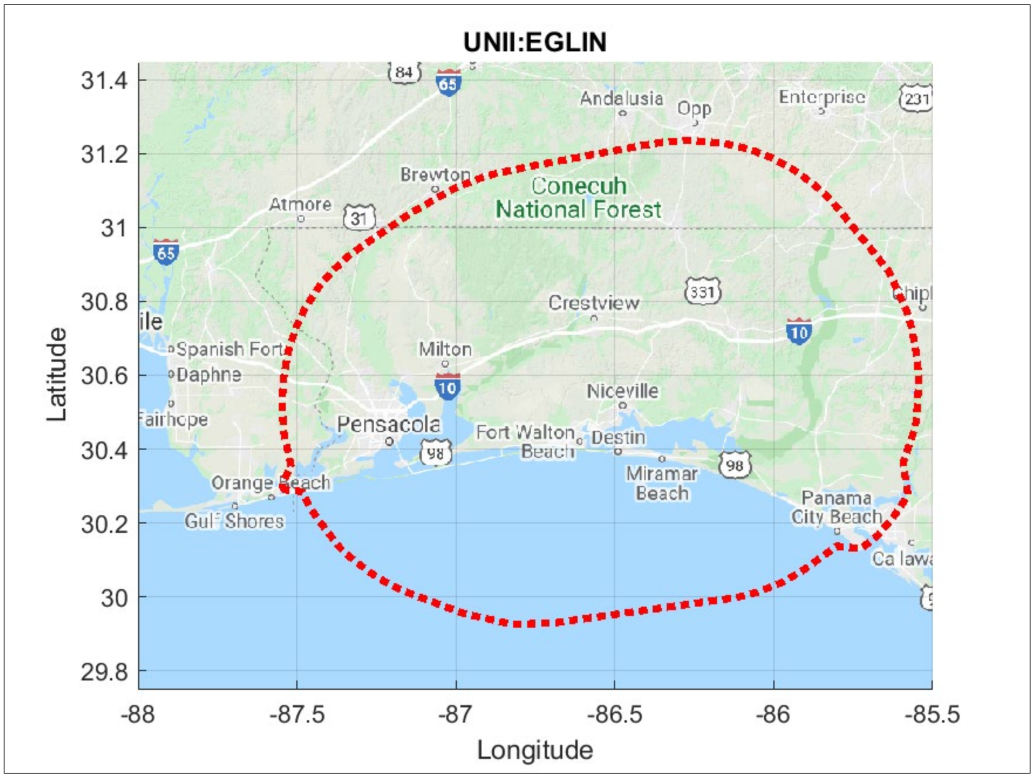

Figure 50. Eglin U-NII-4 Exclusion Zone

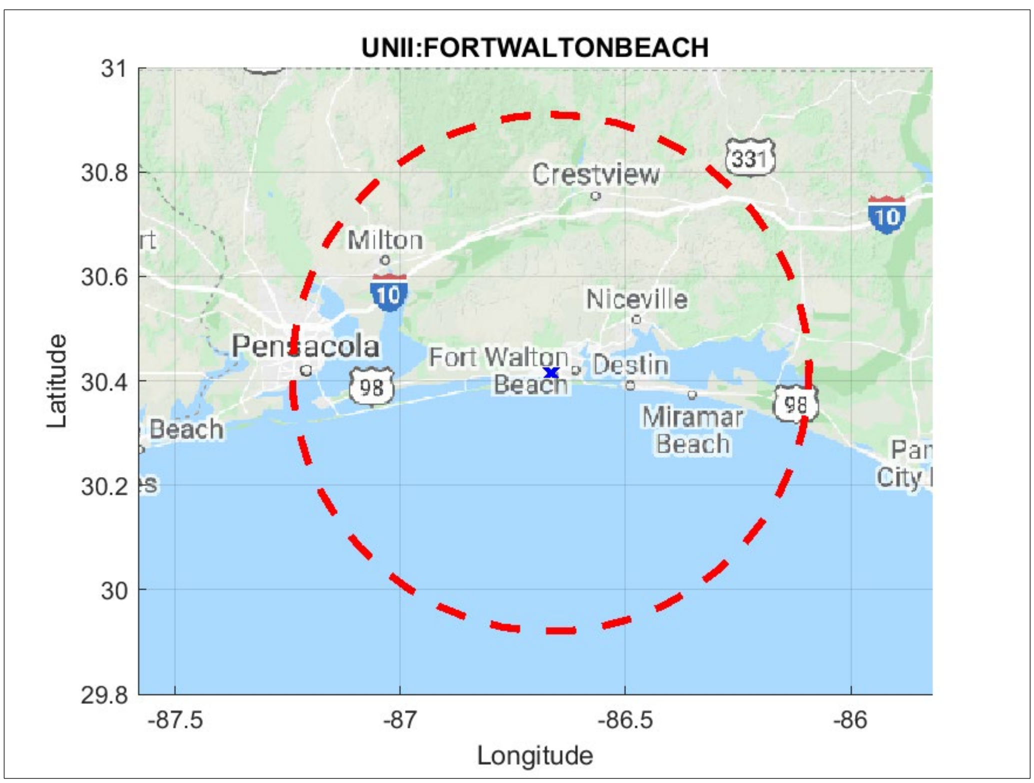

Figure 51. Fort Walton Beach U-NII-4 Exclusion Zone

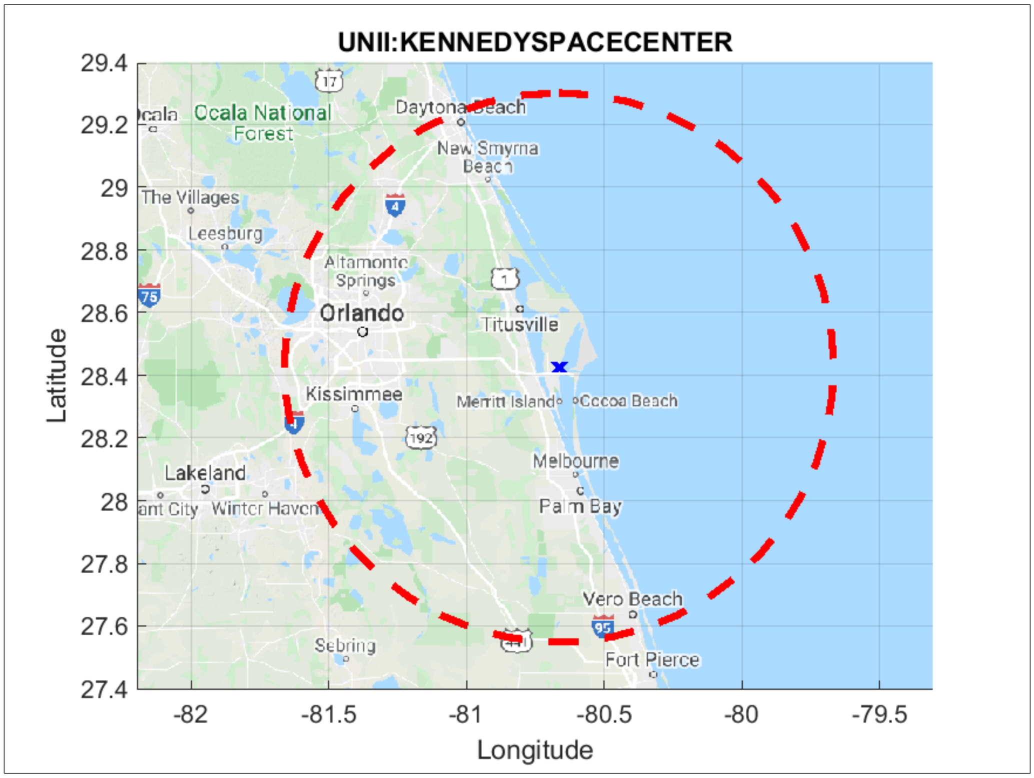

Figure 52. Kennedy Space Center U-NII-4 Exclusion Zone

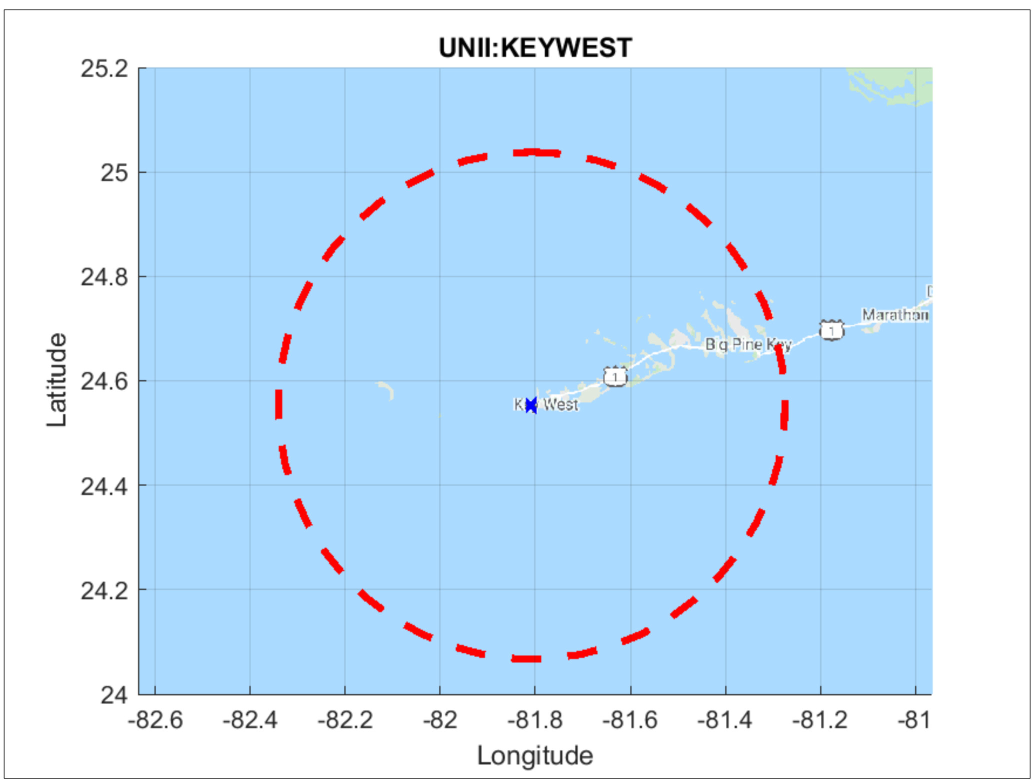

Figure 53. Key West U-NII-4 Exclusion Zone

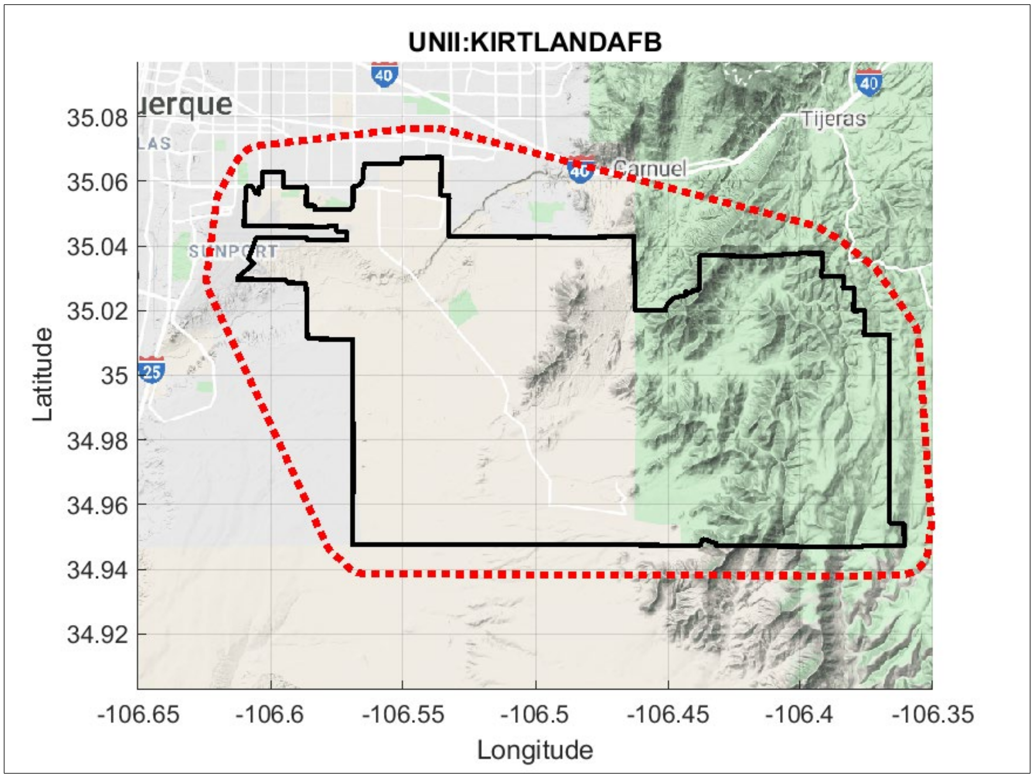

Figure 54. Kirtland AFB U-NII-4 Exclusion Zone

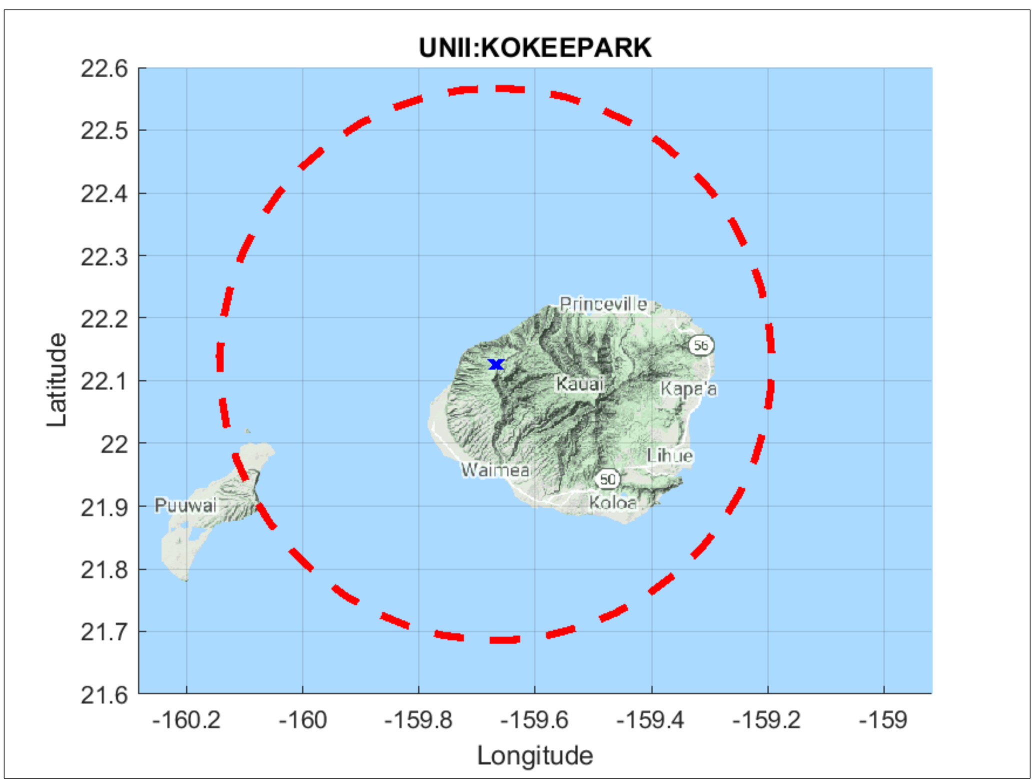

Figure 55. Kokee Park U-NII-4 Exclusion Zone

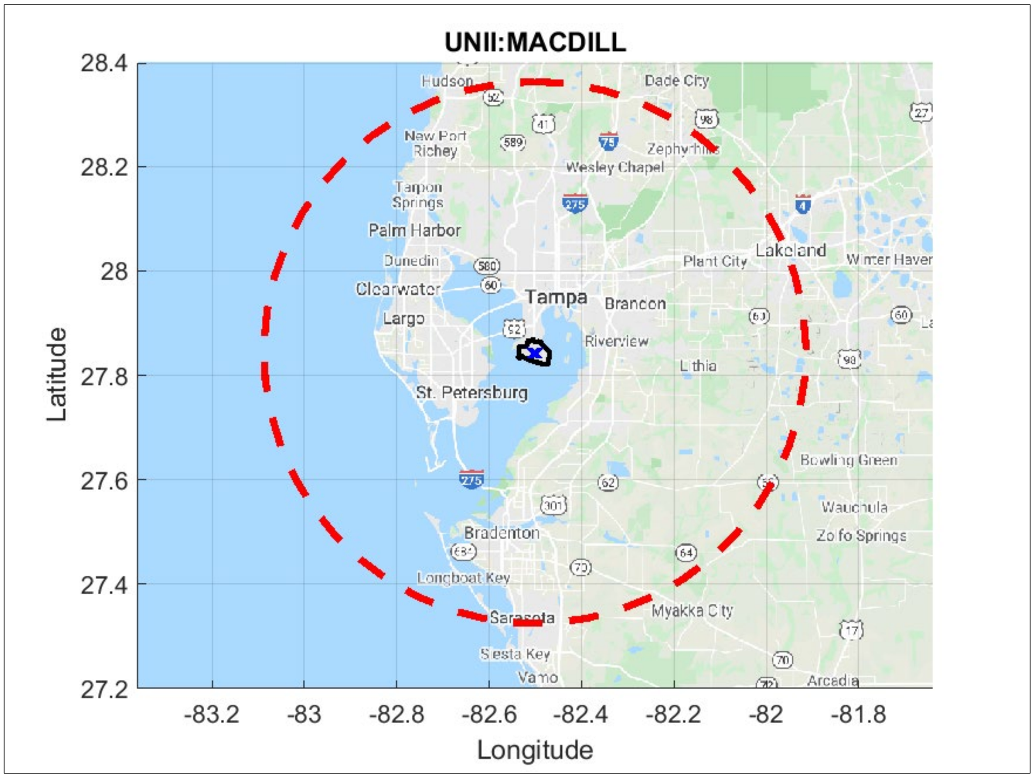

Figure 56. MacDill U-NII-4 Exclusion Zone

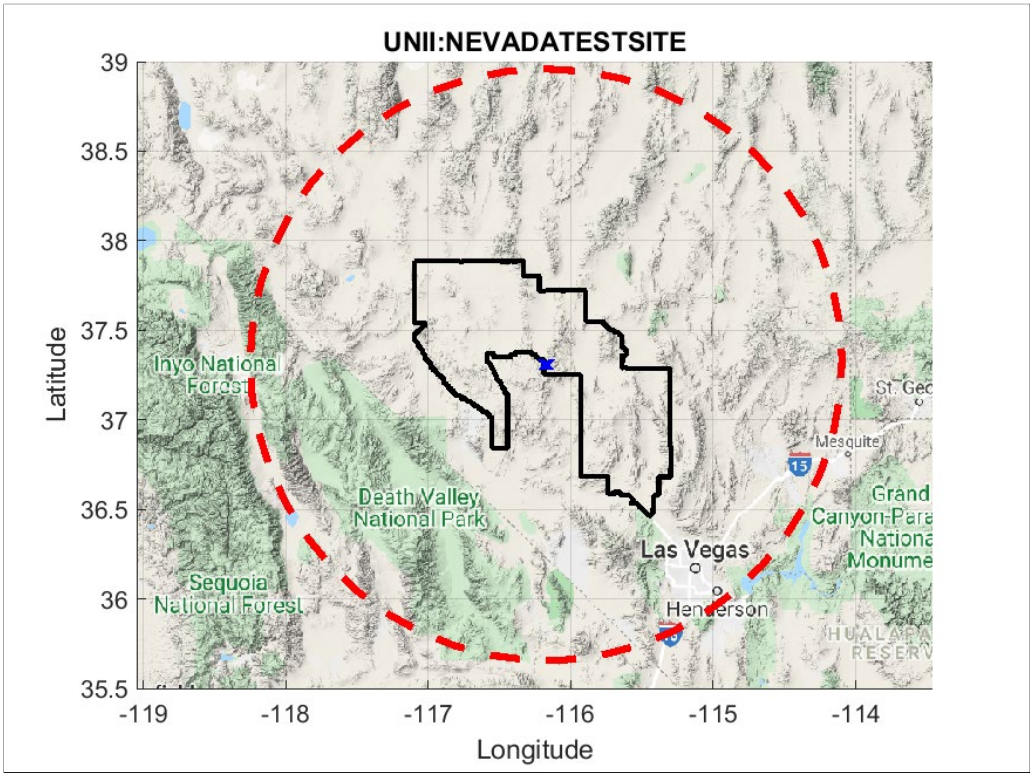

Figure 57. NTTR U-NII-4 Exclusion Zone

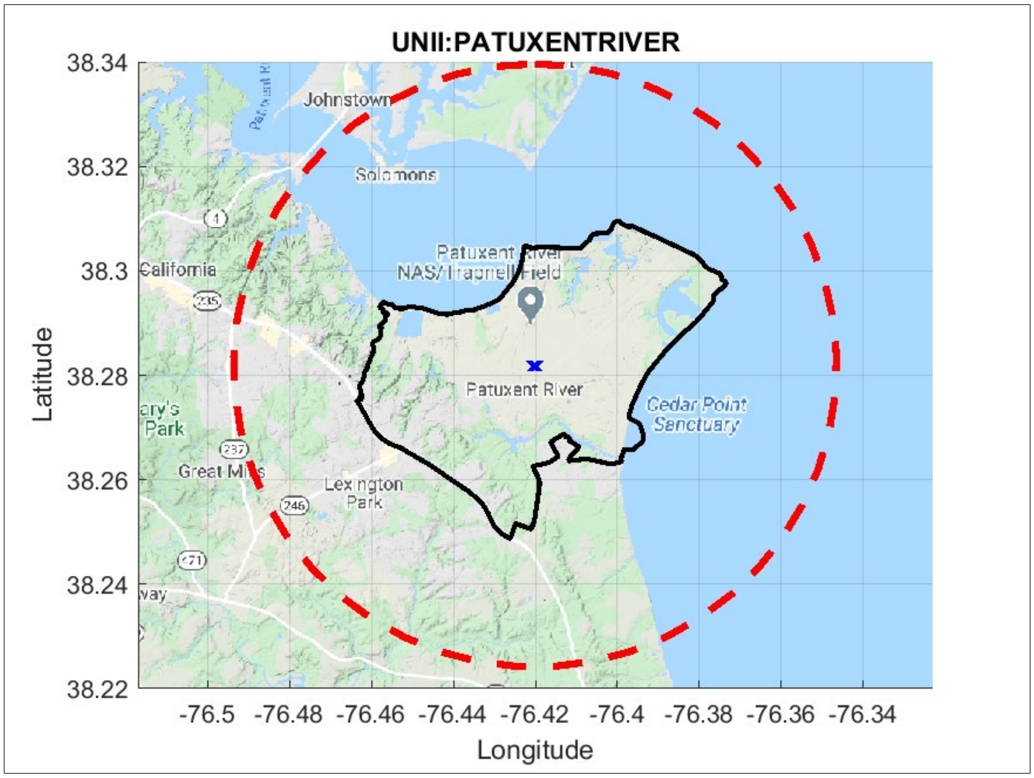

Figure 58. Patuxent River U-NII-4 Exclusion Zone

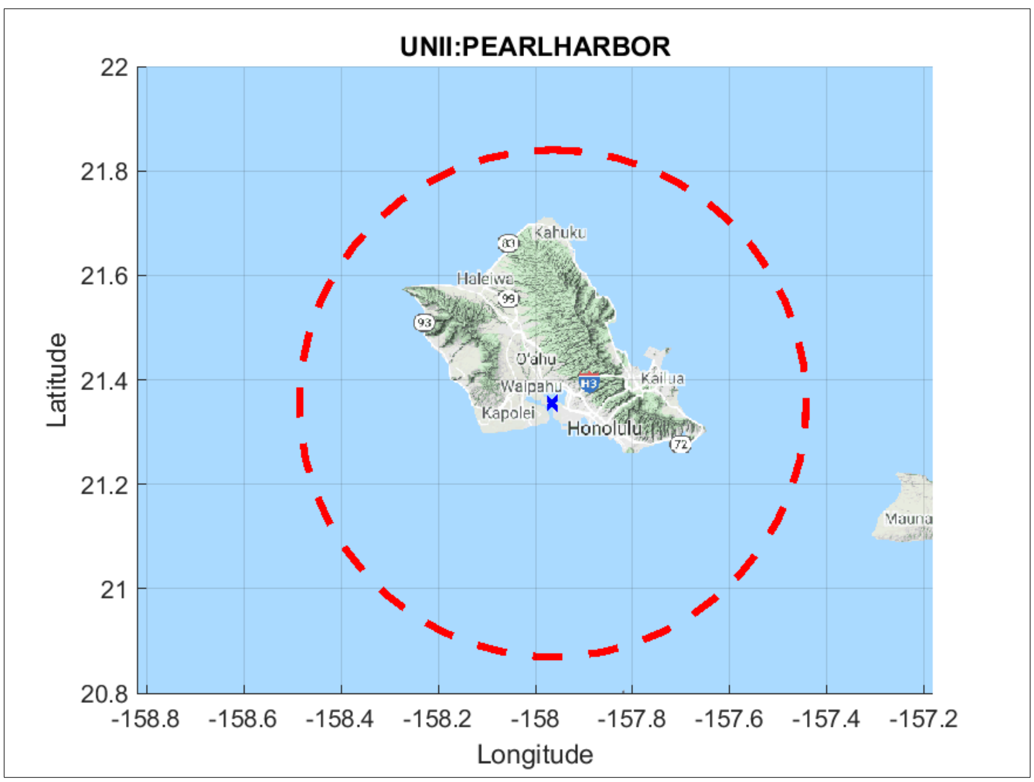

Figure 59. Pearl Harbor U-NII-4 Exclusion Zone

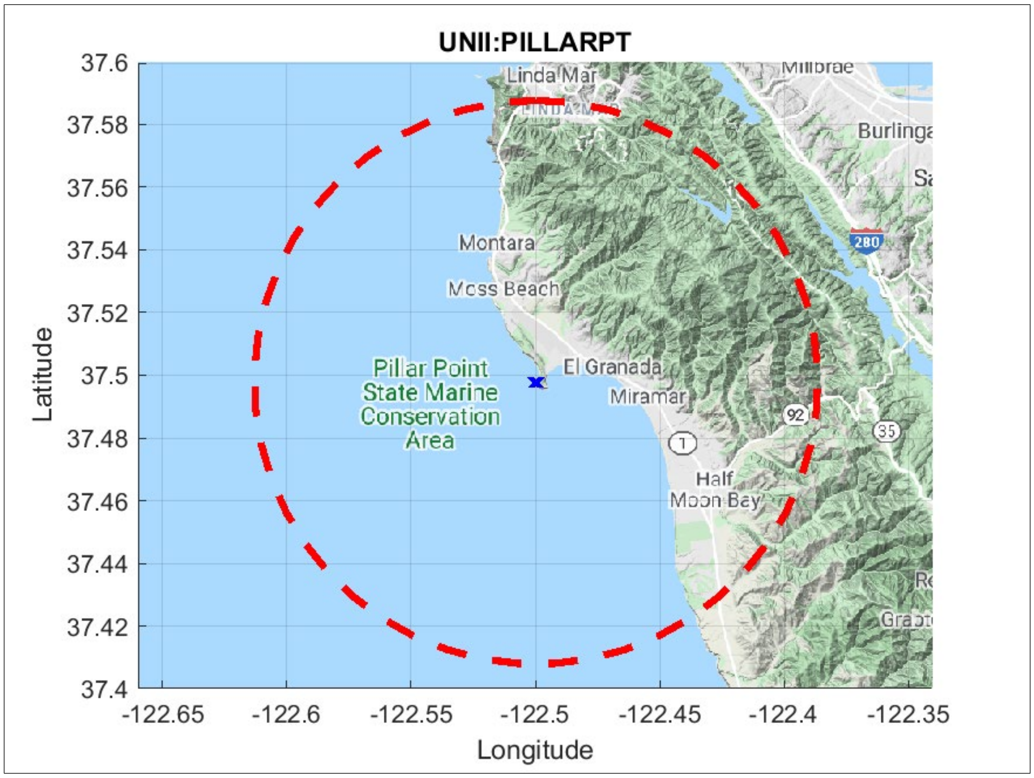

Figure 60. Pillar Point U-NII-4 Exclusion Zone

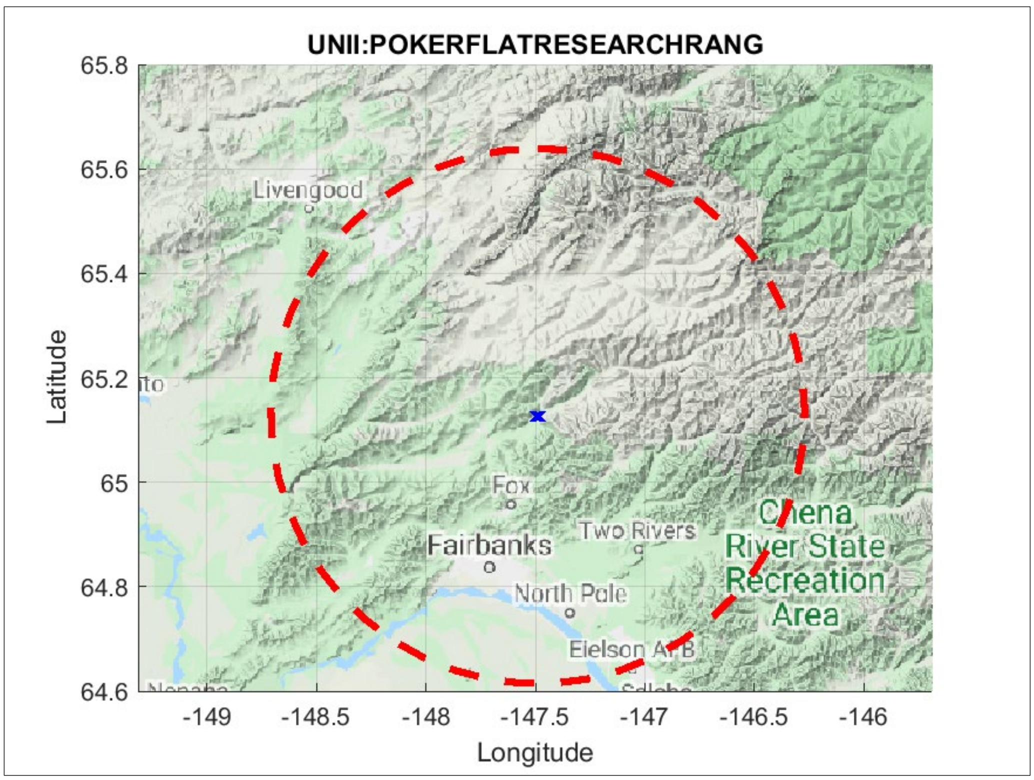

Figure 61. Poker Flat Research Range U-NII-4 Exclusion Zone

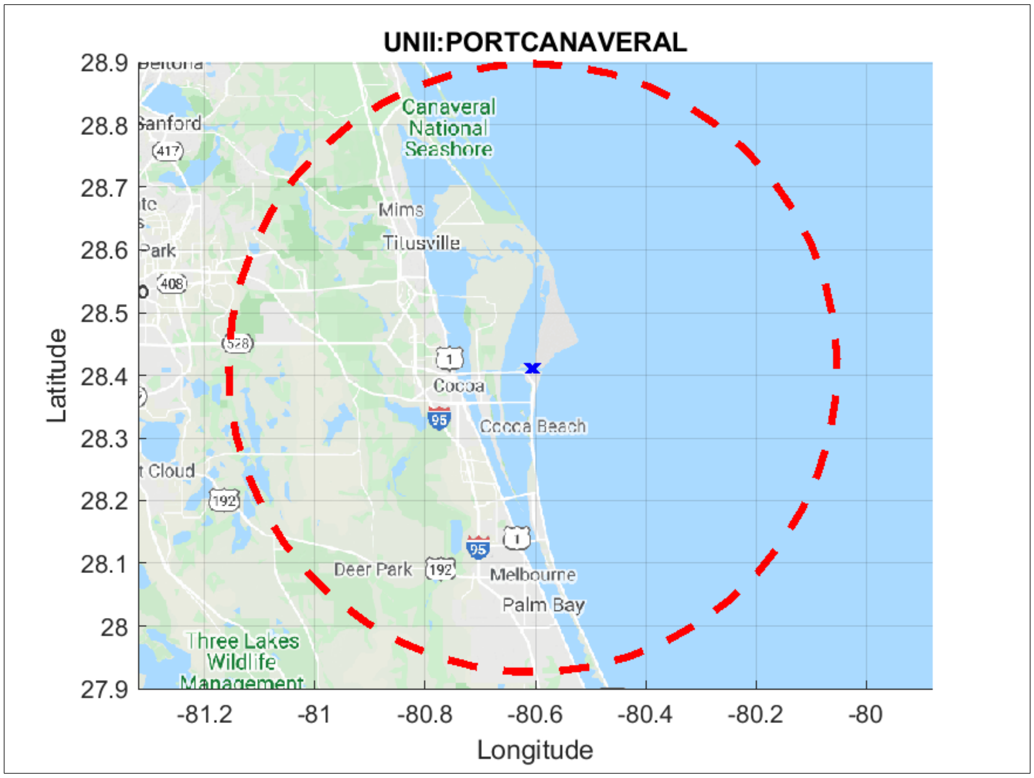

Figure 62. Port Canaveral U-NII-4 Exclusion Zone

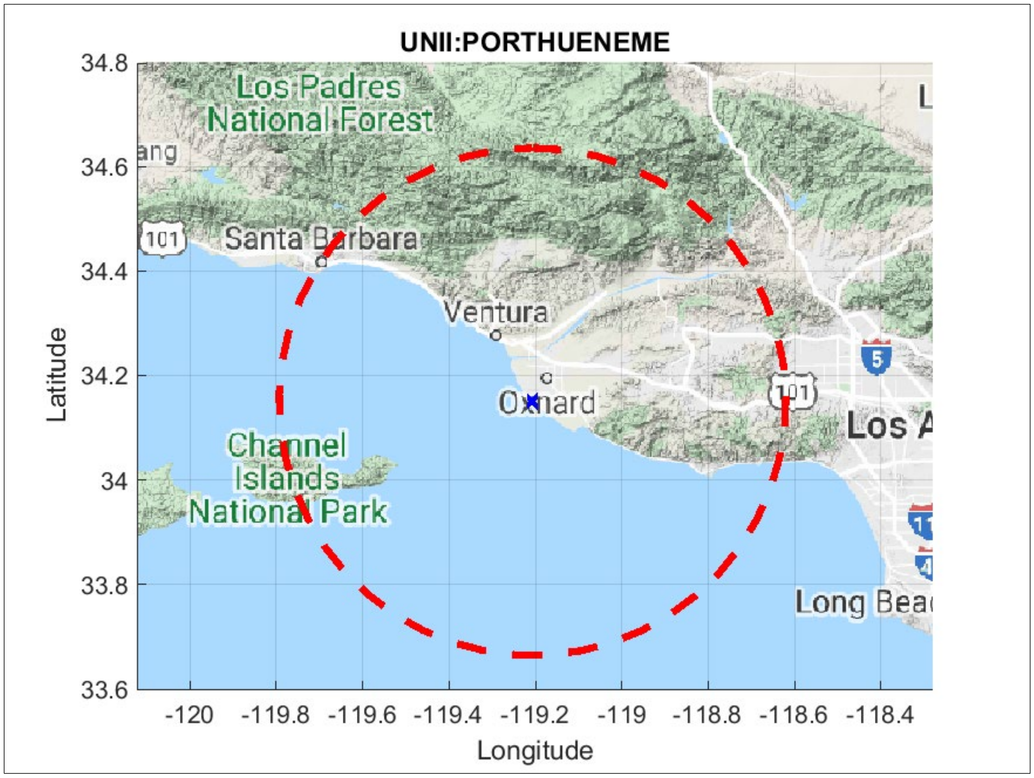

Figure 63. Port Hueneme U-NII-4 Exclusion Zone

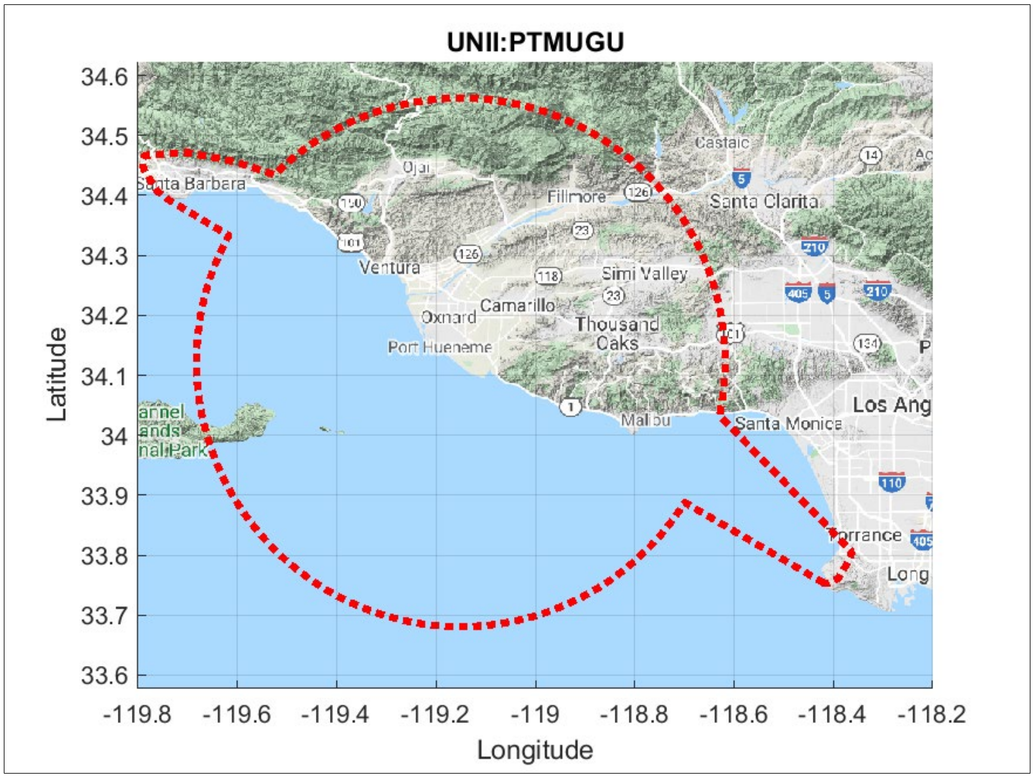

Figure 64. Point Mugu U-NII-4 Exclusion Zone

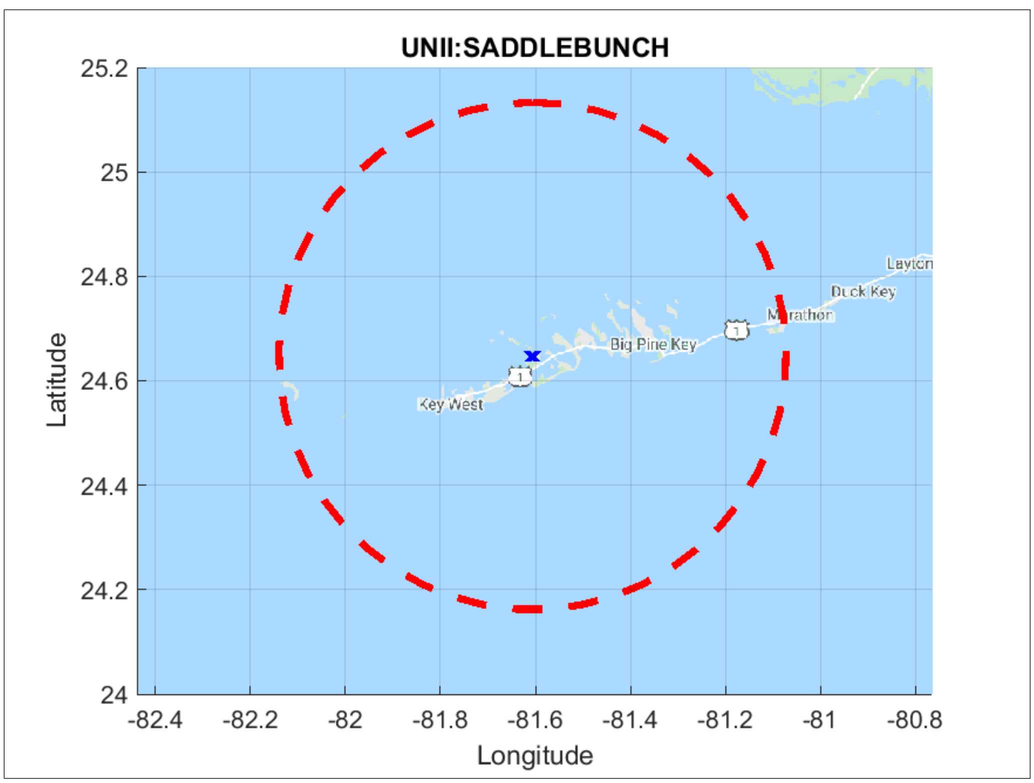

Figure 65. Saddle Bunch U-NII-4 Exclusion Zone

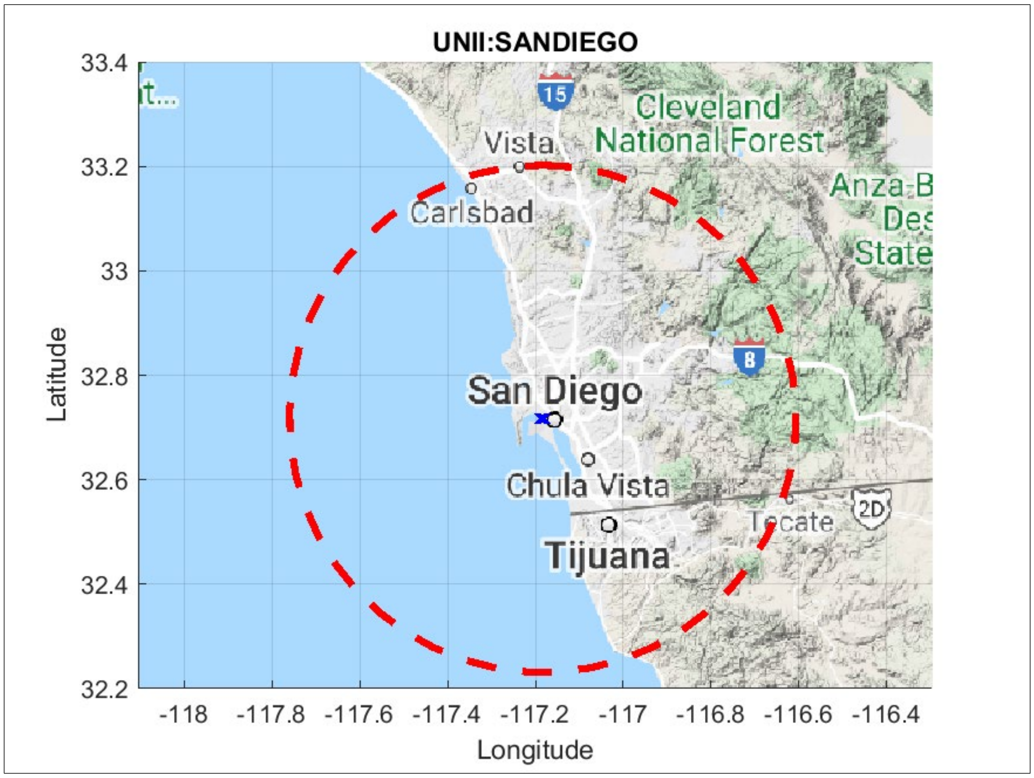

Figure 66. San Diego U-NII-4 Exclusion Zone

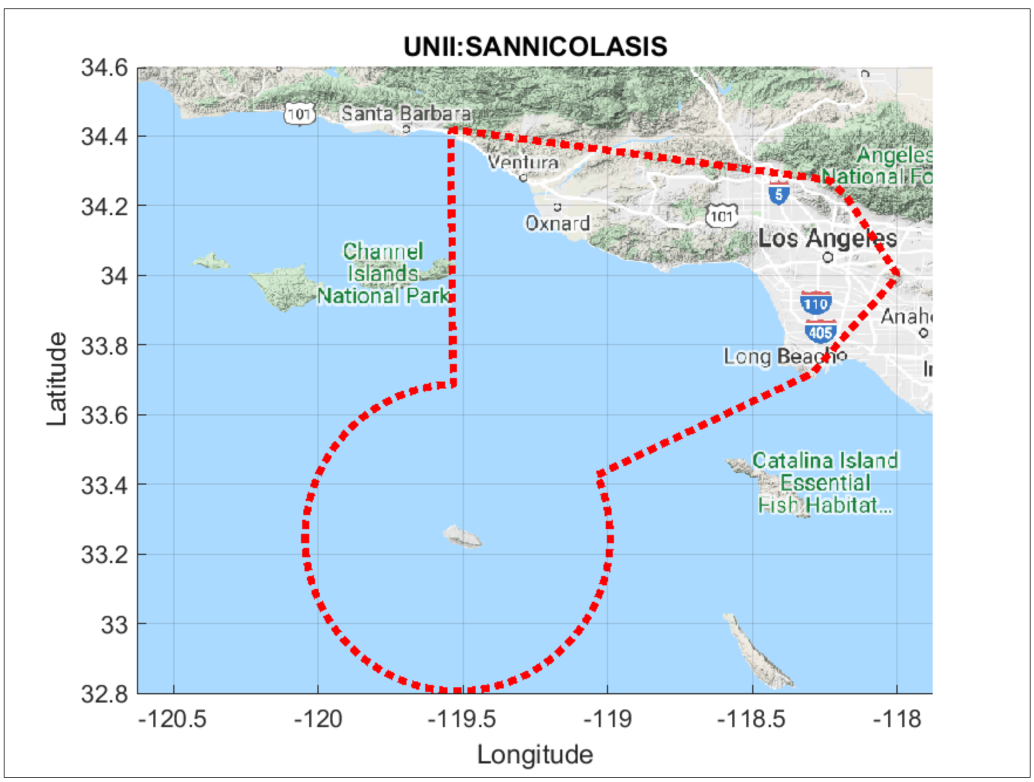

Figure 67. San Nicolas Island U-NII-4 Exclusion Zone

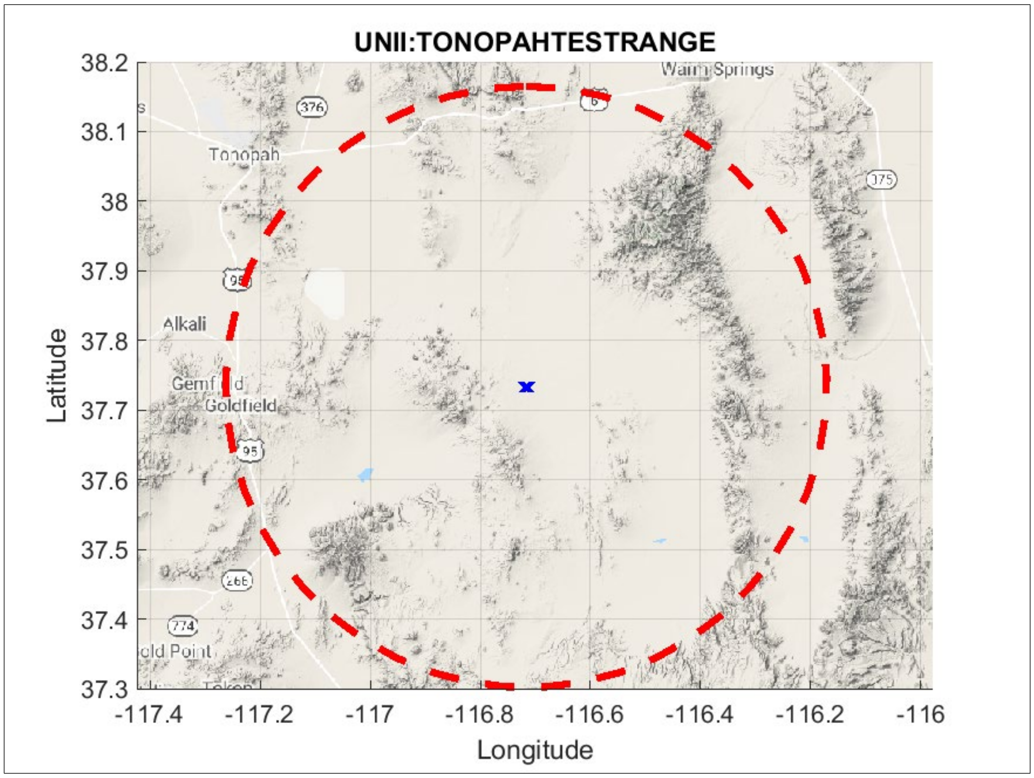

Figure 68. Tonopah Test Range U-NII-4 Exclusion Zone

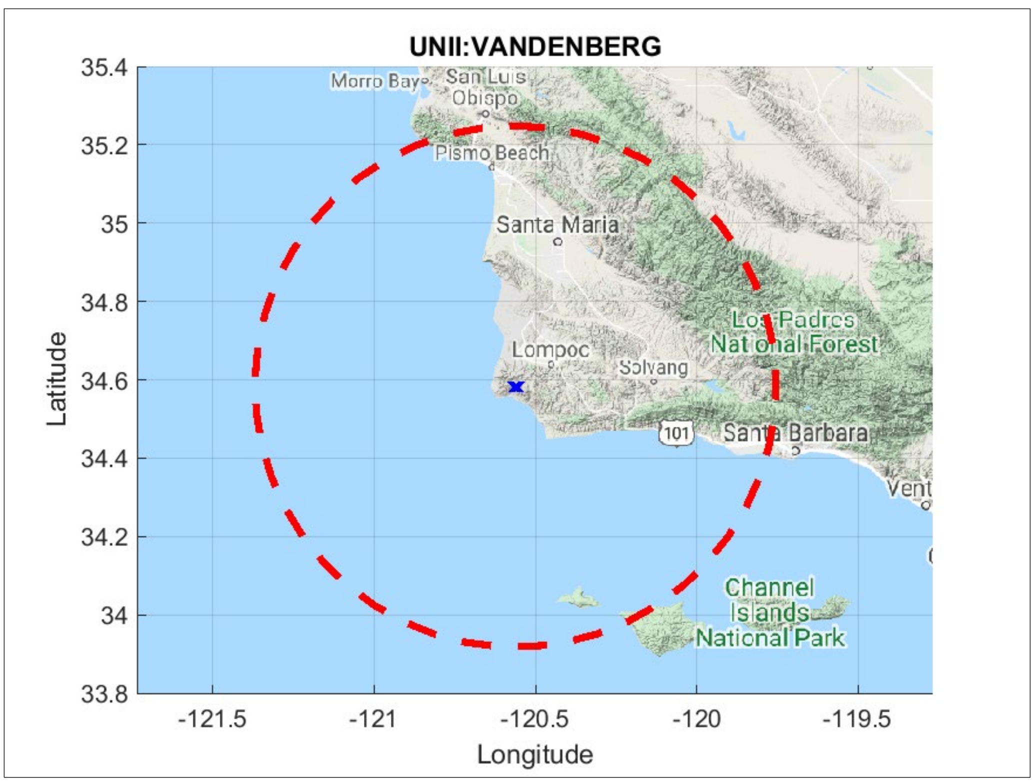

Figure 69. Vandenberg U-NII-4 Exclusion Zone

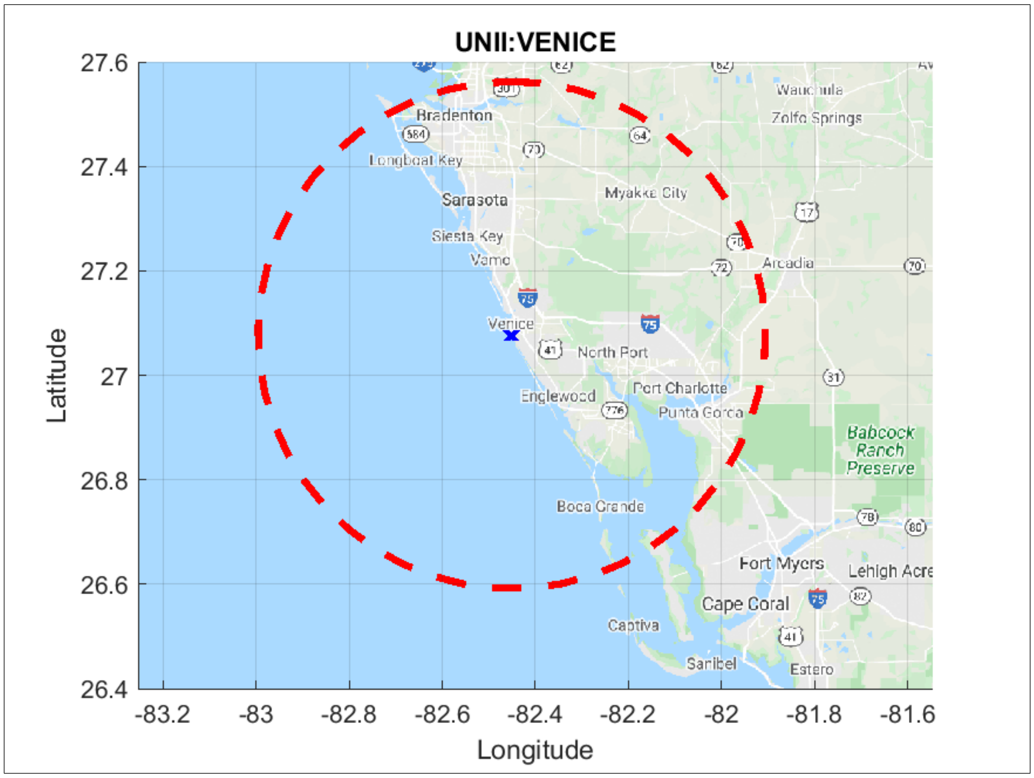

Figure 70. Venice U-NII-4 Exclusion Zone

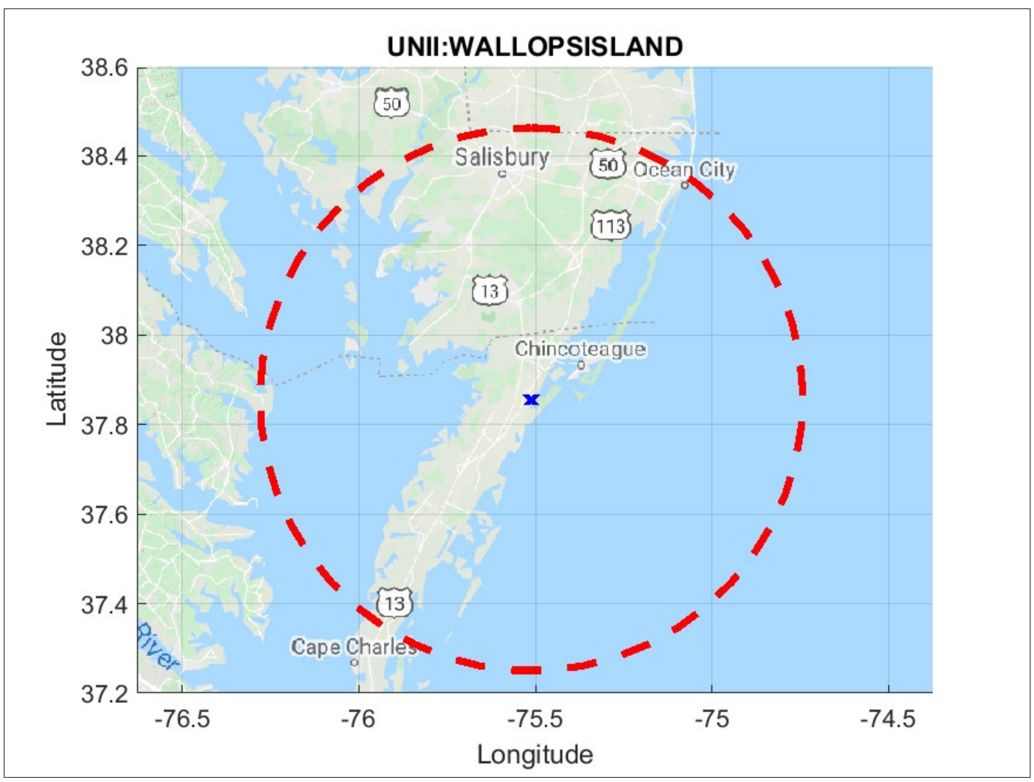

Figure 71. Wallops Island U-NII-4 Exclusion Zone

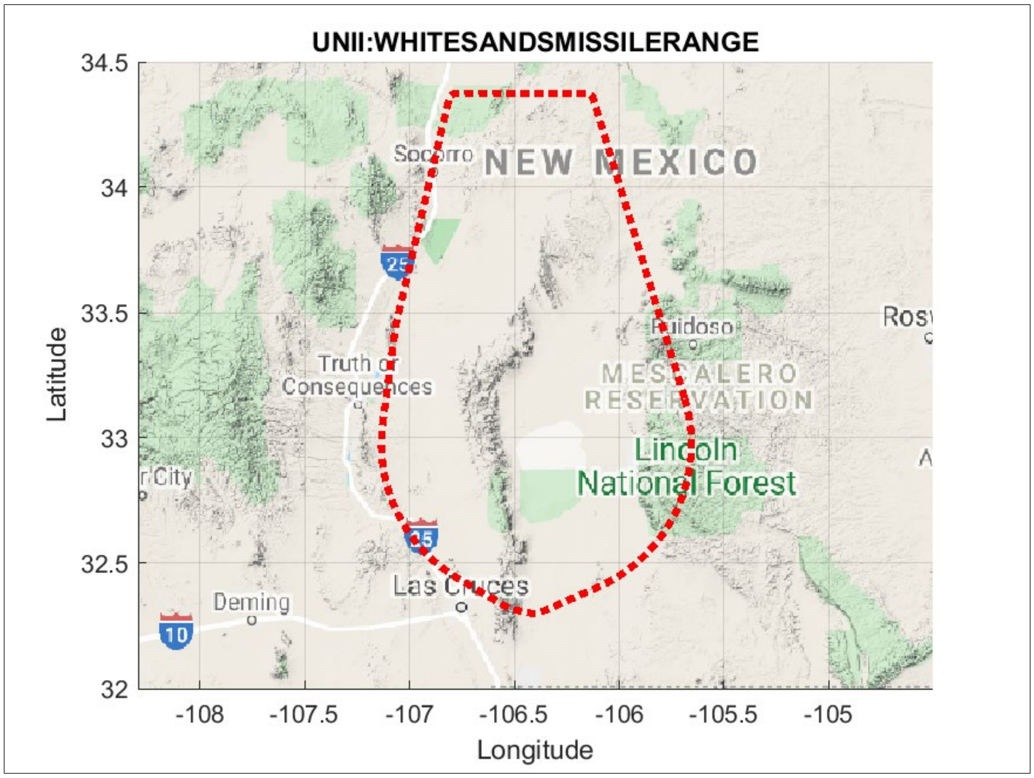

Figure 72. White Sands U-NII-4 Exclusion Zone

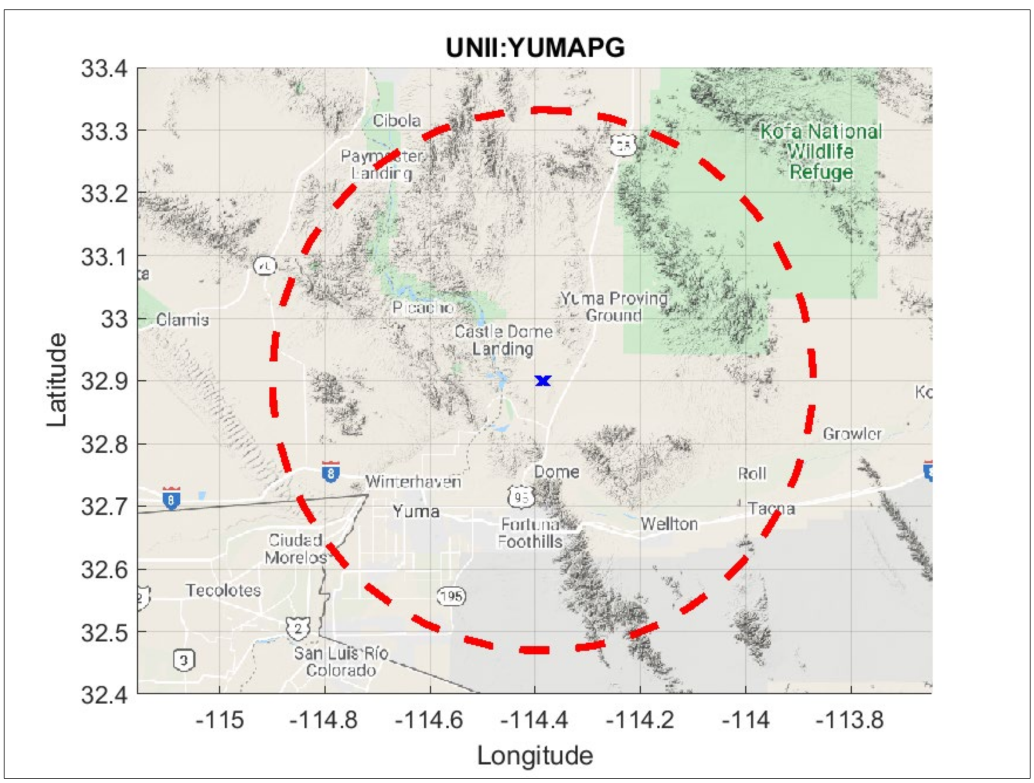

Figure 73. Yuma PG U-NII-4 Exclusion Zone

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This Technical Report provides details about protection of federal operations in the 5.850-5.925 GHz (5.9 GHz) band from new operations considered by the Federal Communications Commission (FCC) as part of the agency's comprehensive review intended to allow for the highest and best use of the band. As part of its ongoing effort to accommodate new commercial wireless services, the National Telecommunications and Information Administration (NTIA) worked with agencies that operate federal systems in the band to determine the protections needed to permit new commercial services to operate without causing impact to incumbent operations. To facilitate the FCC's expeditious review of the record, NTIA already submitted to the FCC a letter setting forth the relevant protection requirements derived from the numerous details provided in this Technical Report.

16. Key Words (Alphabetical order, separated by semicolons)

5.9 GHz, airborne radar, Cellular Vehicle-to-Everything (C-V2X), Dedicated Short Range Communications (DSRC), Intelligent Transportation Systems (ITS), interference mitigation, Part 15, radar, spectrum sharing, Unlicensed National Information Infrastructure (U-NII)

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