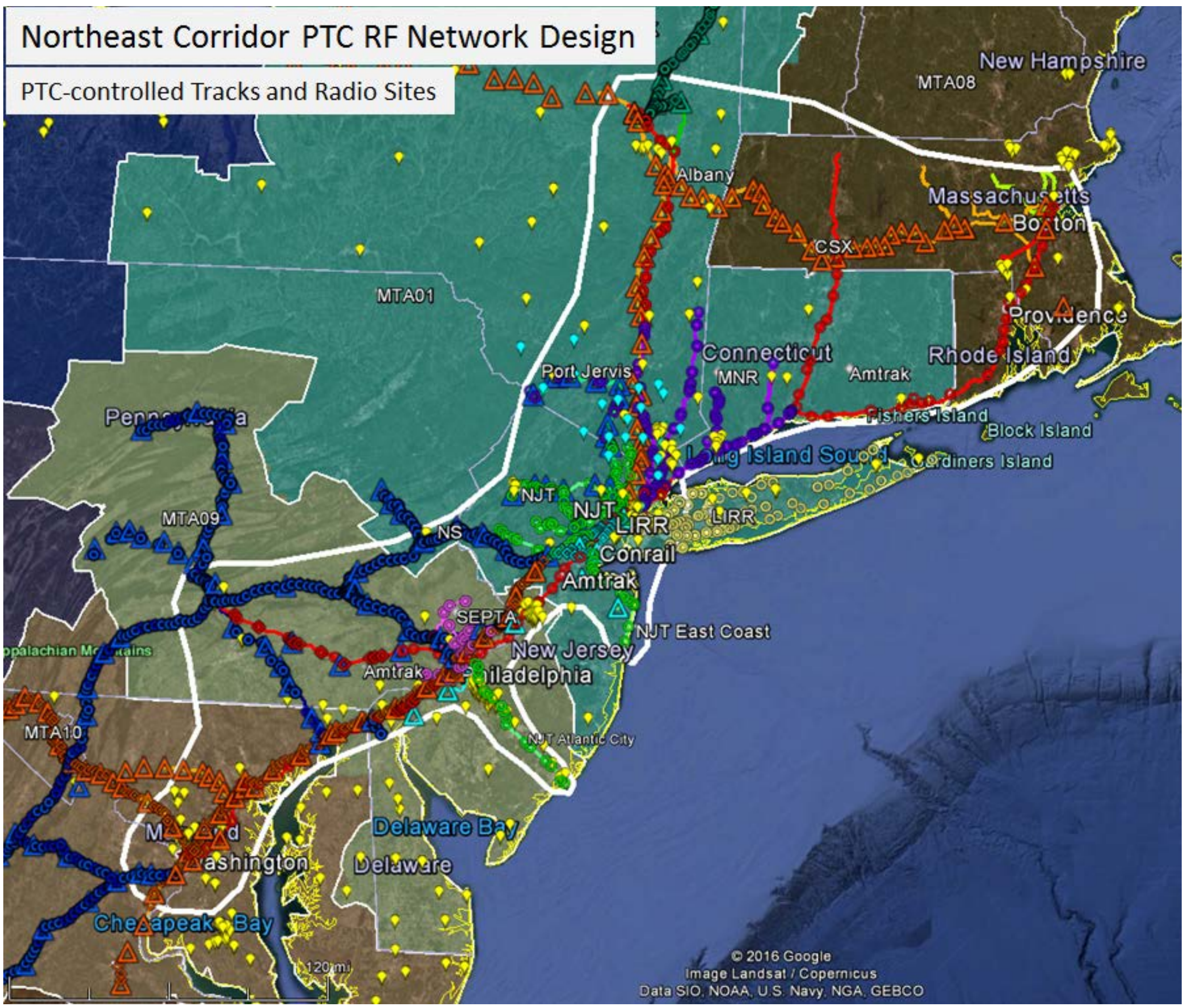
U.S. Department of Transportation

Federal Railroad Administration

Northeast Corridor PTC Radio Frequency Network Design

Office of Research, Development and Technology
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

In 2014, the Federal Railroad Administration (FRA) funded Transportation Technology Center, Inc.'s (TTCI) development of the 220 MHz radio frequency (RF) network design for the Interoperable Train Control (ITC) compliant Positive Train Control (PTC) systems along the Northeast Corridor (NEC), in the area between Boston and Washington, DC. This report describes in detail the work conducted by TTCI to develop the RF network design for the NEC. It also includes a description of the research and development work, as well as the methodology, TTCI applied to support the project.

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1 gallon (gal)	=	3.8 liters (l)			
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°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Executive Summary

In 2014, the Federal Railroad Administration (FRA) funded Transportation Technology Center, Inc.'s (TTCI) development of the 220 MHz radio frequency (RF) network design for the Interoperable Train Control (ITC) compliant Positive Train Control (PTC) systems along the Northeast Corridor (NEC), in the area between Boston and Washington, DC. The NEC is one of the most critical and complex urban areas for PTC radio network deployment because railroads in the area operate dissimilar PTC systems, namely ITC and the Advanced Civil Speed Enforcement System (ACSES), with both concurrently utilizing radio networks in close RF spectrum range due to high rail traffic density.

The 220 MHz PTC radio system used for the ITC system has unique characteristics that require a tailored RF network design. TTCI worked closely with the railroads operating in the area to develop and apply engineering solutions to produce designs that were feasible for deployment. The efforts required several releases of the design, development of software tools, field test validation, and development of special engineering analysis and methods before the RF design plans were ready for field deployment.

In 2017, the RF network designs prepared by TTCI for four dense urban areas (DUA), which are part of the NEC (Boston, New York, Philadelphia, and Washington, DC) were deployed successfully in the field. However, due to individual railroad PTC deployment schedules, the full design had not yet been deployed in the field at the time this report was prepared. Combined, the designs included more than 1,200 route miles of ITC-controlled tracks. TTCI also analyzed the ITC train message traffic among trains and base stations in the busiest areas (New York and Philadelphia), identified peak operation times, and determined the potential for radio network capacity issues.

TTCI modified the unique methodology used to develop RF network designs for PTC systems that had been applied to prior designs (such as Los Angeles, Chicago, and St. Louis) to address and resolve specific issues faced on the NEC. This included the identification and resolution of radio desense issues between all fixed radio sites and between locomotive radios and fixed sites that arise from using dissimilar ITC and ACSES systems along the NEC.

1 Introduction

This report describes in detail the work conducted by Transportation Technology Center, Inc. (TTCI) to develop the radio frequency (RF) network design for the Northeast Corridor (NEC). It also includes a description of the research and development work, as well as the methodology, TTCI applied to support the project.

TTCI configured 133 Interoperable Train Control (ITC) base stations and 167 ITC Wayside Interface Unit (WIU) radio sites, generating frequency/timeslot plans for all ITC radio sites and all 546 Wayside Status Messages (WSMs) broadcast from these sites. More than 1,200 non-railroad incumbent sites operating radios in the same 220 MHz spectrum range were analyzed with respect to frequency interference and radio desense, and all issues found were addressed. TTCI also analyzed 432 ACSES sites to identify and address potential interference and desense issues with ITC radios. Table 1 shows a summary of the number of radio sites, WSMs, channels, incumbents, route miles of the territory in the RF network design, etc. for each of the four DUAs.

Table 1. Summary Counts for Each RF Network Design DUA in the NEC

Item	New York	Philadelphia	Washington, D.C.	Boston	TOTAL
No. of ITC Base Stations	59	33	24	17	133
No. of ITC WIU Radio Sites	48	110	9	N/A (*)	167
No. of ITC WSMs	187	241	118	N/A (*)	546
No. of ACSES Sites	290	114	14	14	432
No. of Channels Used	16	11	13	6	N/A
No. of Incumbents	347	134	28	112	621
ITC Route Miles	393	512	231	126	1,262

(*) Railroads operating in Boston did not provide their WIU data for this study

1.1 Background

In 2008, Congress mandated in the Rail Safety Improvement Act of 2008 (RSIA 08) that railroads implement Positive Train Control (PTC) on all rail lines with regularly-scheduled passenger service or over which certain hazardous materials are transported. PTC systems, as required by RSIA 08, are designed to prevent:

- Train-to-train collisions
- Derailments due to excessive speed
- Unauthorized incursions by trains onto sections of track with established work zones
- Movement of trains through a mainline track switch left in the wrong position

PTC operation is critically dependent upon the underlying data radio network, which must meet unique requirements that are especially challenging in dense urban areas (DUAs). To facilitate PTC implementation and interoperability, the Class I freight railroads formed PTC-220, LLC to secure spectrum in the 220 MHz band for use in a shared, interoperable data radio network for operating the ITC system, also referred to as the Interoperable Electronic Train Management System (I-ETMS®[1]).

The NEC is one of the most critical and complex DUAs for PTC deployment because railroads operate by using dissimilar PTC systems (ITC and ACSES) concurrently, due to high rail traffic density. Along the NEC territory, commuter and passenger railroads are implementing ACSES on their tracks, while freight railroads are implementing ITC on their tracks. When trains from commuter and passenger lines are operating on freight tracks or vice versa (i.e., freight trains operating on commuter and/or passenger lines), there are two possible alternatives to allow interoperability among the railroads:

1. Dual-equip the tracks: In this alternative, the tracks are equipped to support both systems simultaneously. Train locomotives would then have to be equipped with only one of the radio systems to operate on such tracks.
2. Dual-equip the locomotives: In this option, the tracks are equipped with only one of the systems, and the locomotives will have radios from both systems installed. Only one of the locomotive radios would be active at a given moment, depending upon the control system of the tracks they are currently operating on. The exception would be at transition areas from one system to another, when the radios from both systems may be active simultaneously for a short period of time.

The resolution of radio interference between these two systems, including accommodation of incumbents, as well as message traffic loading and resource sharing presents unique challenges that required TTCI to develop new design methods and tools, as well as intensive and detailed engineering analysis that are described in this report.

1.2 Objectives

The objective of this project was to develop a full design of the 220 MHz RF network for the ITC-compliant system used along the NEC, in the area from Boston to Washington, DC.

The design includes all railroads deploying PTC in this area, which consists of:

- Three Class I freight railroads: CSX Transportation (CSX), Norfolk Southern Corporation (NS), and Canadian Pacific Railway (CP)
- One regional freight railroad: Conrail
- One passenger railroad: Amtrak
- Five commuter railroads: Metro-North Railroad (MNR), Long Island Rail Road (LIRR), New Jersey Transit (NJT), Southeastern Pennsylvania Transportation Authority (SEPTA), and Massachusetts Bay Transportation Authority (MBTA)

While the RF network design for the NEC ultimately contains the core methodology and uses the same tools that TTCI previously applied to other PTC RF network design projects, specific

[1] I-ETMS® is a registered trademark of Wabtec Railway Electronics.

methods and tools had to be developed due to specific configuration and, in some cases, requirements as described throughout this report.

1.3 Overall Approach

The development of the 220 MHz RF network for the NEC included the following steps:

- With the use of an RF simulation tool, TTCI configured and simulated the propagation of base station radio sites, which allowed the selection of optimal sites that satisfy coverage and interference requirements.
- With the use of tools and methods developed in-house, TTCI developed the analysis of potential issues with non-railroad incumbents operating in the areas included in the study. Issues found were addressed according to the Federal Communication Commission (FCC) rules and required mitigations were included in the overall design.
- With the use of tools and methods developed in-house, TTCI developed the analysis of radio desense issues between ACSES and ITC radios. The results of the analysis were used to help determine the sites that should not be included in the design (if possible) or would require mitigation techniques to operate without being desensed.
- With the use of an RF simulation tool and a PTC-specific coverage assessment tool, TTCI configured and simulated the propagation of WIU radio signals, which allowed the identification and resolution of coverage gaps, while satisfying interference requirements.
- With the use of unique models and simulators, most of which were developed by TTCI, TTCI simulated the PTC message traffic generated by train operation and analyzed the message traffic loading under each base station, which was used to analyze whether the capacity limits of base station radios were predicted to be exceeded. If capacity limits were predicted to be exceeded, TTCI modified the radio network design to alleviate the issue.
- From the results of the simulations, TTCI identified and resolved issues that did not satisfy RF design criteria.
- TTCI generated an RF network design plan for each of the four DUAs, describing detailed site selections, antenna characteristics, radiated powers, frequency reuse, and timeslot assignment plans for base station and WIU radio sites.

1.4 Scope

This study included the design of the RF network system for ITC operation for the four DUAs that are part of the NEC (Boston, New York, Philadelphia, and Washington, DC), which includes both tracks that will be exclusively ITC controlled as well as tracks that will be dual-equipped. Figure 1 illustrates the approximate boundaries of the territory included in the RF network design for the NEC.

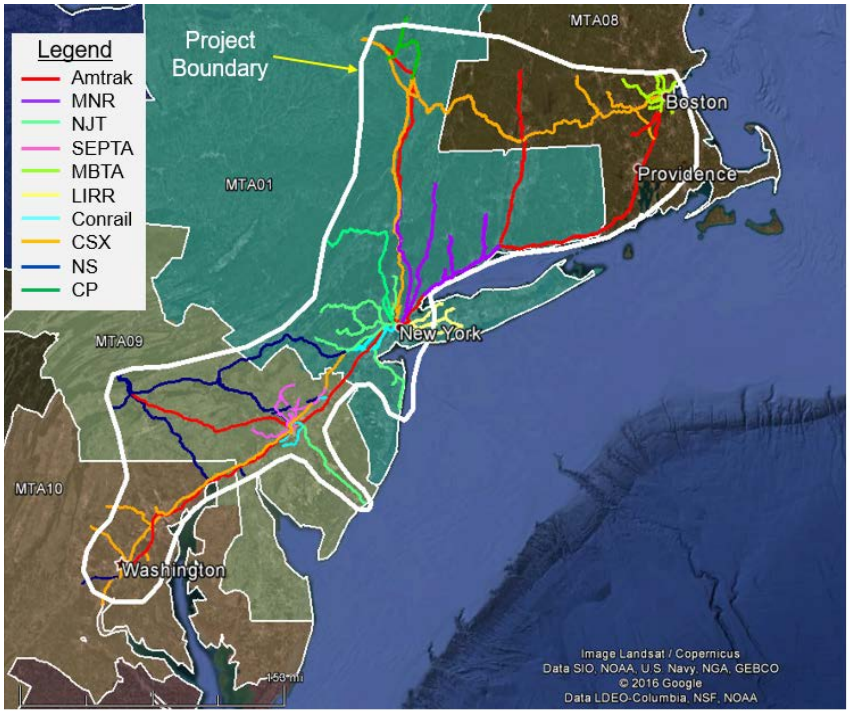

Figure 1. Boundaries of the Project and Railroads Included in the Design

The development of this project presented several unique challenges:

- Coexistence of ACSES and ITC radios in close geographical proximity, which required analysis and resolution of RF interference and desense issues.
- Development of a frequency plan including territories that are being dual-equipped.
- Coordination with incumbents in the 220–222 MHz frequency band.
- Limited availability of 220 MHz spectrum.
- Compliance with specific rules when using non-nationwide PTC-220 LLC channels at certain locations.
- Coordination with the commuter and passenger railroads, which were not at the same stage of development of their PTC projects as the PTC-220 LLC railroad members.
- High complexity of the operating environment (high density of trains, complex track configuration).

The following describes the tasks conducted to meet the project objectives:

- Collection, organization, and quality check reviews of required input data provided by the railroads.
- Generation of an RF network design plan including all railroads that require PTC operations within the boundaries of the study.
- Detailed configuration of sites selected with antenna characteristics, including antenna height and orientation, and effective radiated power (ERP).

- Generation of predicted coverage range of all sites (base stations and WIUs) for the entire study area.
- Determination of sites that were candidates to use regional PTC-220 LLC channels.
- Generation of a frequency reuse plan and Time Domain Multiple Access (TDMA) timeslot assignments for base stations and WIUs.
- Analysis of potential desense issues between ACSES and ITC radios.
- Analysis and resolution of predicted interference levels among all sites (base stations and WIUs).
- Generation of the estimated train message traffic loading per base station for the entire study area.
- Analysis of train message traffic, identification of predicted capacity issues, and proposed resolution.
- Identification of specific solutions required to address issues that failed the criteria for ITC requirements with standard resolution.

Note that the RF designs prepared by TTCI for this study are considered initial and will need to be updated over time, as new railroad deployments are advanced and conditions observed in the field during actual operation require adjustments to achieve expected system performance.

1.5 Organization of the Report

This report is organized in six major sections as outlined below:

1. Project Overview: Provides a description of the project objectives and overview of the work conducted.
2. Technical Foundation Concepts: Describes technical concepts specific to this project that were used for the development of the RF designs.
3. Research and Development: Describes the areas where research and development was needed in order to support either the development of the project or to support analyses and/or decisions required.
4. TTCI's RF Network Design Methodology: Describes the composition of the major tasks developed for each of the four RF design projects.
5. RF Network Design Projects: Describes the details of the RF design for each of the four RF design projects, including scope, results, and deliverables.
6. Conclusion: Provides overall an conclusion of the work conducted and identification of subsequent steps, where applicable.

2 Technical Foundation Concepts

The Class I railroads developed, through an agreement to generate ITC standards, the requirements for their PTC implementations to assure that all railroads can have a single, standard, interoperable system. ITC systems are being adopted by all the Class I railroads and most of the commuter and regional railroads in the United States.

The RF network used for ITC systems consists of multiple endpoints that include base stations, WIUs, and locomotives. The requirements for ITC radios have been derived from railroad operations and safety requirements as well as the need to make efficient use of radio system resources, in order to minimize deployment and operation costs. This section provides an overview of the technical aspects pertaining to PTC, specifically those related to the RF design.

Additional foundation concepts related to specific topics found in the NEC are described below.

2.1 Desense Between Dissimilar PTC Radio Systems

The NEC serves multiple passenger, commuter, and freight rail agencies. As previously mentioned in Section 1.1, two PTC systems are being used in the NEC: ACSES and ITC. Each of the two PTC systems uses a 220 MHz data radio from a different manufacturer, and each system has different communication protocols.

The use of dissimilar radios that operate within the same frequency band introduces the potential for severe communication issues for ACSES and ITC deployments within the NEC. In particular, concurrent use of ACSES and ITC radios within close geographic proximity to one another, even on nonadjacent frequencies, can cause the high level of RF energy from one transmitter to capture the front end of a receiver, thus reducing its RF sensitivity level and, in turn, its performance. This phenomenon is known as "RF desensitization," and will be further referred to as "desense."

There are various scenarios in which desense may occur, i.e., scenarios where an ITC radio may desense an ACSES radio or vice versa. Particularly in the NEC, ACSES and ITC radios are deployed within close proximity to one another. For instance, there are regions where trains controlled by dissimilar PTC systems operate on the same tracks, thus requiring the tracks to be equipped with both ACSES and ITC systems (dual-equipped territory). In other regions, trains need to transition between ITC and ACSES territory. Also, ACSES and ITC radios will both be installed on the same locomotive in order to allow locomotives to seamlessly operate in either ACSES or ITC equipped-territories (dual-equipped locomotives).

If unaddressed, desense would be a major barrier to successful and continuous operation of the railroads in the NEC. The following sections further explain the scenarios where desense could adversely affect railroad operations.

The various scenarios in which desense could occur are listed as follows: (1) fixed site desensing another fixed site, (2) fixed site desensing a locomotive, (3) locomotive desensing a fixed site, (4) locomotive self desense, and (5) locomotive desensing another locomotive.

2.1.1 Fixed Site Desensing Another Fixed Site

When a fixed radio site from one system (ITC or ACSES) is operating in close proximity to another fixed radio site deploying a different PTC system, it could lead to potential desense. To illustrate, consider a scenario when an ITC base station is receiving messages from an ITC locomotive or a wayside. If an ACSES base station is operating in the near vicinity of the ITC base station, the sensitivity of the ITC base station could be reduced. As a result, messages from the ITC locomotive (or wayside) may not be successfully received. This is illustrated in Figure 2.

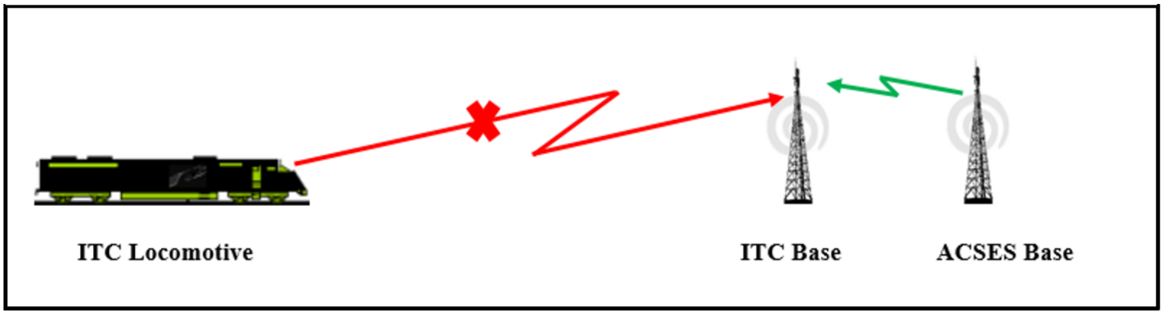

Figure 2. Illustration of a Fixed ACSES Site Desensing a Fixed ITC Site

2.1.2 Fixed Site Desensing a Locomotive Radio

When an ACSES or ITC-equipped locomotive is operating in close proximity to a fixed site radio location (base station or wayside) from a different PTC system, the locomotive may potentially be desensed by this dissimilar fixed site. Consider the case when the ITC locomotive is communicating with the nearby ITC base station and the ITC base station is sending a message to the ITC locomotive. If an ACSES base station is operating in the vicinity of the ITC locomotive, it could reduce its sensitivity, and as a result, the message might not be able to reach the onboard computer of the locomotive, which can have an adverse effect on the PTC system. This is illustrated in Figure 3.

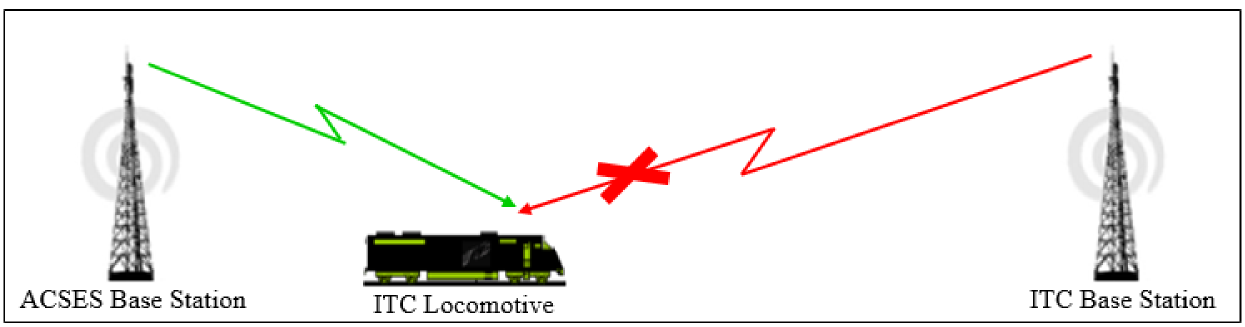

Figure 3. Illustration of a Fixed ACSES Site Desensing an ITC Locomotive

2.1.3 Locomotive Radio Desensing a Fixed Site

When an ACSES or ITC fixed site is communicating with a locomotive with the same onboard PTC system, a locomotive running on an adjacent (or same) track with a dissimilar onboard PTC system may desense the fixed site. Consider the case illustrated in Figure 4 when an ITC locomotive is sending messages to a nearby ITC base station. If an ACSES locomotive is operating near the ITC base station, e.g., on adjacent track, it could potentially desense the ITC base station radio. This could cause messages from the ITC locomotive that would normally be received at the base station to not be received.

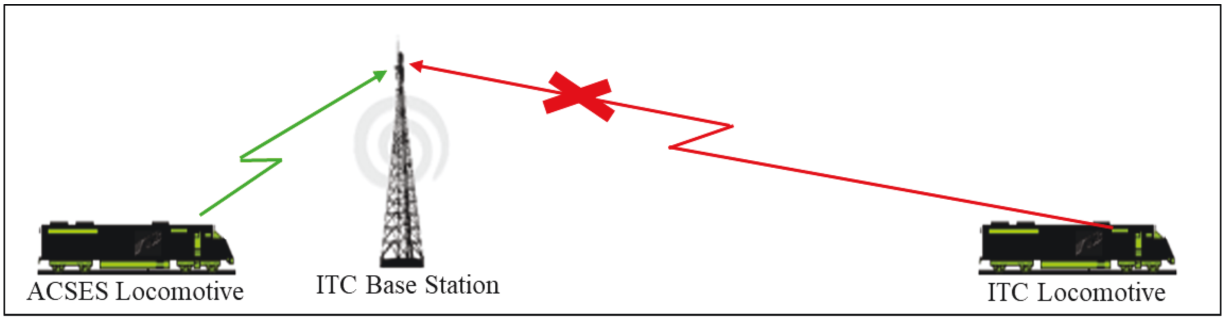

Figure 4. Illustration of an ACSES Locomotive Desensing a Fixed ITC Site

2.1.4 Dual-Equipped Locomotive (Self-Desense)

A locomotive that must operate in territories that are ITC-controlled, as well as on territories that are ACSES-controlled needs to have both ITC and ACSES onboard systems and radios installed. This typically requires installation of two separate antennas for each of the systems on the roof of the locomotive (typically separated between 2 to 5 feet). Whenever one of the radios transmits while the other radio is receiving, desense on the receiving radio may occur. This is known as the "locomotive self-desense" case. The locomotive self-desense case is primarily an issue in areas where the locomotive is transitioning from ITC to ACSES, or vice versa. In these transition zones, dual-equipped locomotives need to simultaneously communicate with both ACSES and ITC base stations as the locomotive prepares to exit territory controlled by one PTC system and enter territory controlled by the other. To illustrate, consider a scenario when the ITC onboard system is receiving messages from the nearby ITC base station. If the onboard ACSES system starts transmitting at the same time, it would reduce the sensitivity of the onboard ITC radio system.

Figure 5 shows such a case when the ACSES system on a dual-equipped locomotive is transmitting as the ITC onboard system is receiving. As a result, messages from the ITC base station may not be successfully received by the ITC radio of the locomotive.

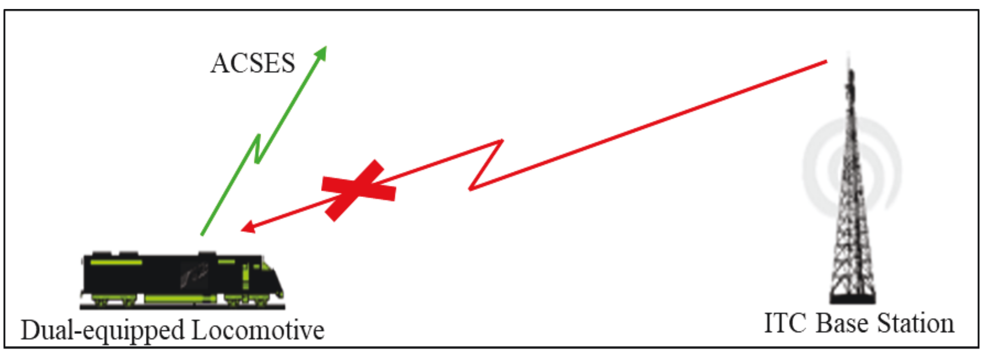

Figure 5. Illustration of a Dual-Equipped Locomotive Self-Desense

2.1.5 Locomotive Radio Desensing Another Locomotive Radio

When two locomotives, one controlled by an ACSES system and another locomotive controlled by an ITC system, are operating on adjacent tracks (as close as 12 feet between track centers) or on the same track, desense of one of the radio systems on the other could occur. This could occur when one of the radio systems is transmitting, while the radio on the other locomotive is simultaneously receiving. To illustrate, consider a scenario when an ITC locomotive and an ACSES locomotive are operating on adjacent tracks. The ITC locomotive is receiving messages from the ITC base station. Operation of the ACSES locomotive in close proximity to the ITC locomotive may reduce its sensitivity. As a result, messages from the ITC base station may not be successfully received, as illustrated in Figure 6.

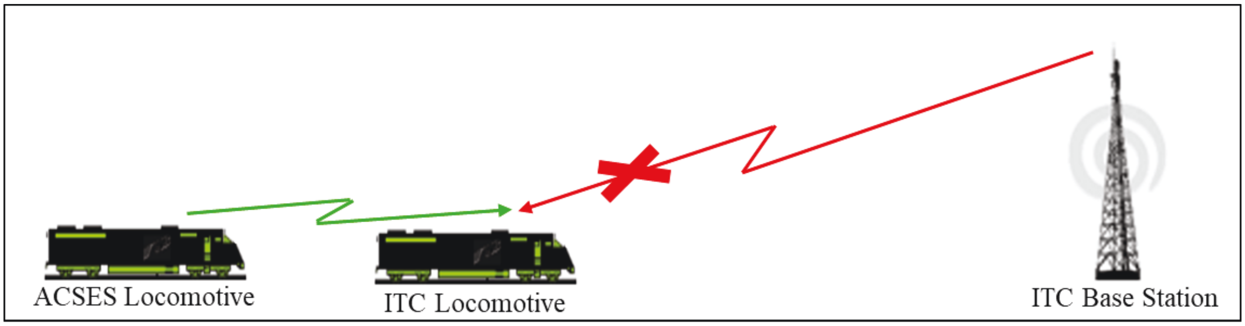

Figure 6. Illustration of an ACSES Locomotive Desensing an ITC Locomotive

Note that per the design of the ACSES system, an ACSES locomotive radio only becomes active when it reaches a transponder placed in the tracks that indicates that the locomotive onboard system needs to obtain the status of the next control point in its route. Typically, ACSES transponders are located 2 miles ahead of the control point it is related to, and ACSES base stations are located near control point locations. This means that ACSES locomotive radios are not expected to cause desense to ITC radios beyond the location of the ACSES transponders, because they will be dormant. Figure 7 illustrates this condition.

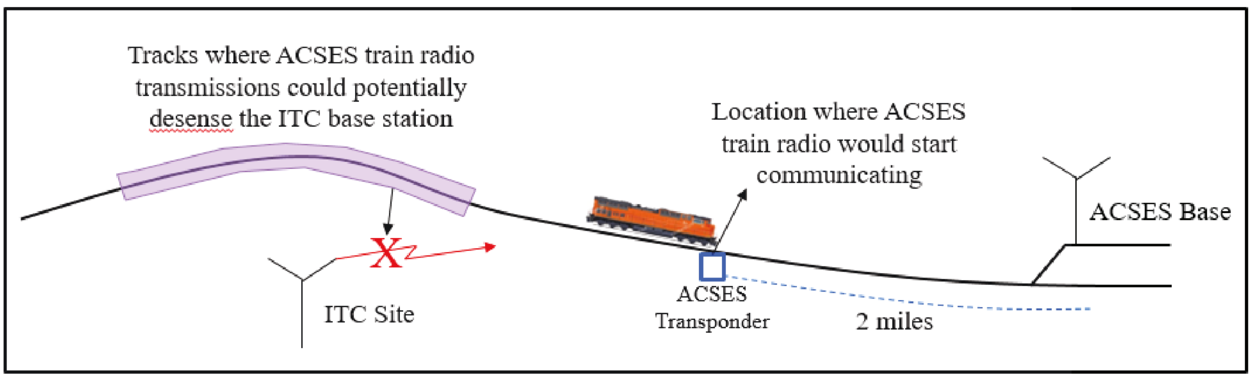

Figure 7. Illustration of the Activation of an ACSES Locomotive Radio Distant from Tracks that Could Potentially be Desensed

2.1.6 Desense Mitigation Options

Due to the coexistence of ACSES and ITC systems, the risk of desense is more prevalent in the NEC than in other areas of the country. Its mitigation is important for successful operation of PTC radios. There are several ways in which desense can be mitigated, such as: reduction of the power of the interferer, use of passive filters, installation of Adaptive Interference Cancellers (AIC), and use of directional antennas with appropriate adjustment of antenna azimuth.

The power of the interfering radio can be reduced by an appropriate amount to ensure desense does not occur. Reducing the power of the radio leads to a reduction in interfering received signal strength (RSS) at the victim radio, which may prevent desense. This has an associated tradeoff, however, as reduction in power may lead to inefficiencies in the system of the interfering radio, due to the associated decrease in base station footprint.

When a directional antenna is used, its azimuth can be changed in order to mitigate desense in some cases. Azimuth of an antenna refers to the rotation of the whole antenna around a vertical axis. Directional antennas focus the RF energy in a particular direction, and can be used to steer the energy away from radios that could potentially be desensed. One of the disadvantages of using directional antennas is their narrower beamwidth, as compared to omnidirectional ones. This reduced beamwidth can cause a reduction in coverage in required areas.

An AIC can also be used at the receiver to mitigate desense. An AIC uses a sample of the interfering signal and generates a real-time anti-interference signal, which is the exact opposite of the signal received at the receiving antenna (same amplitude but 180 degrees out of phase). The AIC then combines the received signal and the anti-interference signal, cancelling each other out. This causes the interference to be subtracted before it is sent to the receiver chain. An AIC generally removes the interferer power as well as some noise and spurious signals, including those which are at the receiver operating frequency, and does not affect the desired signal [8]. The AIC automatically cancels interference when detected, and is able to achieve the high dynamic range required for the PTC interference cancellation application. This would especially be helpful in dual-equipped locomotives. The development and implementation of AICs can be costly, and thus may not be desirable, especially if other mitigation solutions, such as filters, are available and feasible.

Filters can also be used to mitigate desense observed between ITC and ACSES systems, as long as there is enough frequency separation between the signals being used by each system (as is the case in the NEC). Each filter needs to be tuned to a specific pass band that will pass signals on any frequency within this band. Additionally, each filter needs to have a corresponding stop band, in order to reject any signals from the dissimilar system. A filter can be tuned to pass ITC signals and reject ACSES signals while in ITC-controlled territories, or vice versa. ITC and ACSES locomotives can be equipped with filters tuned to their particular pass bands and stop bands. Typically, a frequency separation of 0.5 to 1 MHz or higher is required for the filters to perform efficiently in the 220 MHz band. Physical size and environmental constraints on the filters need to be considered, as they need to withstand operating conditions such as in locomotives and bungalows housing radios.

As part of other Federal Railroad Administration (FRA)-funded efforts, TTCI tested the performance of several filters, some of which proved to be successful in mitigating desense [2]. The railroads in the NEC have indicated that they will be installing filters as-needed in locomotives and fixed radio sites. Thus, for the purposes of this report, it is assumed that filters would be the primary solution for the cases where desense would occur in the NEC.

3 Research and Development

To support the development of the RF network design projects, TTCI dedicated effort to the research of several topics, including resolution of engineering problems, analysis of spectrum use regulations and investigation of available technologies/tools. As a result, TTCI developed custom-made solutions, including methods and software tools.

The following subsection describes the solution that was developed to identify and address possible desense issues between the two distinct radio systems (ACSES and ITC) used in the NEC.

3.1 ACSES and ITC Radio Desense Analysis Tool

3.1.1 Problem Statement

Different railroads are installing different types of PTC systems for their PTC deployments. Co-existence of dissimilar radio types operating in the same frequency band poses a challenge for successful deployment of PTC. One type of PTC radio may cause desense to the other type while operating in the same vicinity.

TTCI used engineering analysis to determine the underlying cause of each desense scenario as described in Section 2.1, except for the cases between locomotive radios, because the railroads in the NEC decided that all locomotives operating in the area would be equipped with filters to mitigate desense in those cases. The process laid out by TTCI to do this analysis is divided into two main categories: desense of a fixed site by another fixed site using a different radio type, and desense between a fixed site and a locomotive using a different radio type. TTCI developed tools to automate the analysis, identification, and report generation of these at-risk areas.

3.1.2 Description of the Solution

To perform an in-depth desense analysis between two different types of PTC radios, TTCI researched several topics, including: analysis of available technologies/tools, analysis of tracks where various railroads deploying different types of PTC systems may operate, identification of potential areas where desense might occur, analysis of the different types of desense scenarios, and analysis of potential mitigation strategies. As a result, TTCI developed a tool that automates most parts of the desense analysis.

The tool determines whether a particular site (base station or WIU site) or portion of a track is predicted to be desensed, or in turn is predicted to cause desense on the basis of various RF parameters, such as effective isotropic radiated power (EIRP) of the transmitter, receiver gains and losses (as provided by the railroads), desense thresholds of the radios used by the ITC and ACSES systems, and the frequency of operation of the radio causing desense. If receiver and transmitter gains and losses values are not provided or are incomplete, TTCI uses analytical methods to approximate the values by taking the average of the gains and losses provided by other railroads. In order to be able to detect as many at-risk scenarios as possible, the tool is built upon the assumption that radio signals propagate in accordance to the free space path loss transmission equation [4].

The parameters are used as inputs to an SQL program, and depending upon the case being analyzed, the output RSS is used to determine whether a site or portion of a track is predicted to be desensed. The outputs obtained from the programs are as follows:

1. Desense radius
2. Distance between the sites and track locations
3. Predicted RSS at the victim site (in decibel-milliwatts (dBm))

The predicted RSS at the site under question is compared against a threshold value to determine whether the site will potentially be desensed. The threshold values for determining whether a site is being desensed depends upon the radio system being used at that particular site (-30 dBm for ACSES radios/ -21 dBm for ITC radios).

Figure 8 shows a snapshot of the output of the desense analysis tool developed by TTCI for desense analysis between ITC and ACSES radios with a subset list of sites predicted to be desensed.

Component Causing Desense				Component Desensed			Predicted RSS at Desensed Site (dBm)	Distance (miles)	Distance (km)
RR	Site ID	Site Description	EIRP (dBm)	RR	Site ID	Site Description			
NS	3550156698	Hackettstown	47.79056	NJT	NJT_71	Cook CP	-22.26	0.5448	0.876768
NS	3550176698	Lake Helen	47.87519	MNR	MNR_138	CP-OV	-28.94	1.7854	2.873316
NS	3550076698	Manville	50.12669	NJT	NJT_103	Brook Int	-29.39	1.1528	1.855247
NS	3550286698	Port_Morris_Jct	47.6784821	NJT	NJT_67	Roxbury Int	-25.62	0.7966	1.282
				NJT	NJT_65	Morris Jct	-25.62	0.7966	1.282
NS	3550256698	Denville	50.29056	NJT	NJT_59	Denville	0.48	0.0533	0.085778
				NJT	NJT_60	Denville Remote S	-26.27	1.2277	1.975787
NS	3550326698	Summit Substation	47.78207	NJT	NJT_53	West Summit	-18.69	0.3844	0.61863
				NJT	NJT_52	Summit Ave	-29.76	1.2977	2.088441

Figure 8. Snapshot of the Desense Analysis Output Generated by TTCI's Desense Tool

4 TTCI's RF Network Design Methodology

TTCI has created a unique methodology with distinct steps to develop an RF network design for the ITC radio system. The methodology is the result of more than four years of continuous work performed by TTCI, not only for the four DUAs included in this report, but also for several other DUA RF designs that TTCI has been developing for PTC-220 LLC.

The methodology, as described in this section, should be seen as a "standard" set of steps that are followed when developing RF network designs, however, specific conditions or requirements may require adjustments to the steps for a specific DUA design. TTCI has indicated whenever adjustments to the standard steps occurred for the four DUA designs included in this project in the specific section for each DUA.

Figure 9 shows the macro steps of TTCI's methodology.

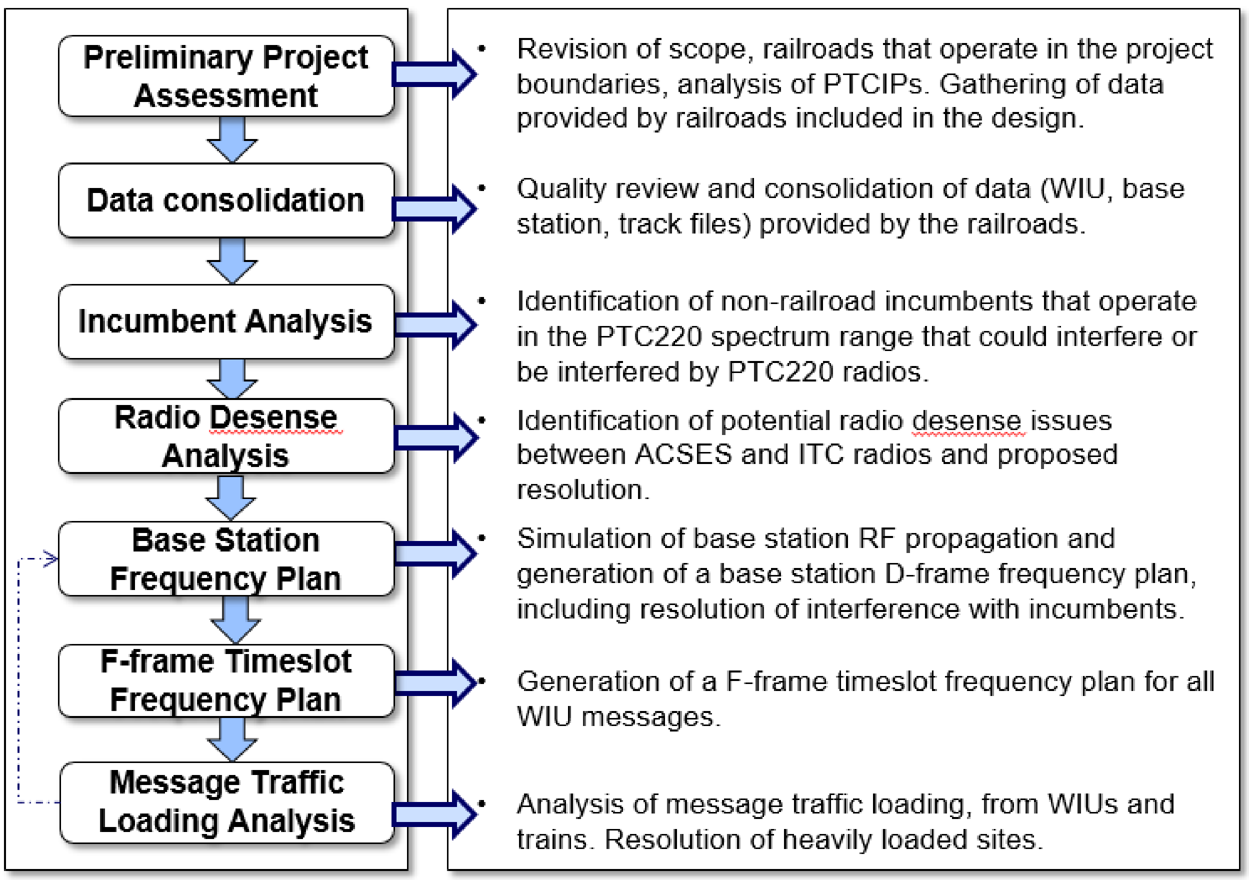

Figure 9. Macro Steps of TTCI's RF Network Design Methodology

The steps under TTCI's methodology are described, except for the steps described in the next subsections, which contains procedures used specifically for the development of the NEC RF design.

4.1 Data Collection from Commuter and Passenger Railroads

For conventional 220 MHz ITC RF network designs, TTCI develops the RF simulations using data uploaded by the PTC-220 LLC railroad members to a hosted server environment that includes detailed information of their ITC systems (tracks, base stations, WIU sites, WSMs) under task Data Consolidation.

For the NEC design, however, there were exceptional cases related to the specific analysis of the ACSES system (that is not present in all other DUA RF designs developed by TTCI) and other aspects of non-PTC-220 LLC railroads that required special handling regarding input data.

TTCI worked with all the commuter and passenger railroads and other non-PTC-220 LLC railroads (such as Conrail) to obtain information of how PTC would be deployed and operated on their tracks for each DUA included in the NEC, including:

- Location (Latitude/Longitude) of all their ACSES base stations
- ERP of each ACSES base station site along with corresponding antenna gains and losses (whenever available)
- ERP and antenna gains and losses of their ACSES locomotive radios on a railroad-by-railroad basis
- Tracks that will be operating under ACSES control only
- Tracks that will be dual equipped (ACSES and ITC)
- Location of ITC WIU sites for the tracks that will be dual-equipped with their WSM configuration
- Historical train movement data for trains operating under ITC control on dual-equipped territory

TTCI reviews the data provided and validates it before conducting any design and analysis. Whenever data is not available from the railroads, TTCI makes assumptions and validates them with the railroads. TTCI uses track charts, timetables, and visual inspection in Geographic Information System (GIS) tools (such as Google Earth Pro™[2]) whenever needed, as tools to prepare or validate data.

TTCI checks WSM data provided for the ACSES dual-equipped territories against track file data to verify they are consistent, formats it to PTC-220 LLC standards and uploads it to the hosted server for the preparation of F-frame timeslot plans. Train movement data is normalized and prepared for train message loading simulation.

4.2 Incumbent Analysis

The possible presence of non-railroad licensees that operate in the 217–222 MHz band and that could operate in the vicinity of ITC radio locations is analyzed in the PTC RF designs. The first phase of the incumbent analysis is focused on identifying PTC base stations that could possibly cause desense or harmful interference issues with non-railroad licensees and vice versa.

The first step of this analysis consists of identifying the incumbents in the area. This is done via the Channel Analysis Tool developed by TTCI [3]. The Channel Analysis Tool contains incumbent locations obtained from the FCC Universal Licensing System (ULS). The tool also

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includes the locations of incumbents of other entities, who have provided their transmitter location information directly to TTCI.

The Channel Analysis Tool generates a list of incumbent locations that could potentially have desense issues caused by the ITC base stations considered in the design. Using this list, TTCI verifies if those base stations are essential for the design, and if not, those ITC base stations are excluded from the list of final base stations to be included in the RF plan. Excluding a base station from the design is only possible when, for instance, there are other base stations in the vicinity that could provide coverage to the tracks, and if the removal of the base station would not cause message loading issues on the remaining railroad assets.

If the base station with possible desense issues cannot be removed from the plan, TTCI informs the owning railroad and, when authorized to do so, TTCI explores additional options such as site configuration changes (power reduction, use of directional antennas, etc.). For the remaining base stations with possible desense issues that need to be included in the plan, TTCI provides a list to the owning railroads so that they can do field tests and/or engage with the incumbents directly.

TTCI also develops the analysis of potential issues with WIU radios, however, no further actions are taken beyond identifying potential issues and informing the railroads, as there are more options to handle potential issues with incumbents, such as the elimination of radios from the WIU sites where desense issues are predicted and broadcast their WSMs through base stations. Railroads typically make those decisions when the design is close to a final configuration, to avoid rework and eventually unnecessary notification and/or request for concurrence with incumbents. It must be also noted that as currently informed, NS is the only railroad in the NEC that will have WIU sites equipped with their own radios, and as WIU radio sites have shorter propagation and are typically oriented just along tracks, the number of potential issues with incumbents is expected to be extremely low.

The Channel Analysis Tool also generates a list of non-preferred channels on a base station-by-base station basis. This list uses the geographic and spectral separation between the incumbents and the ITC base stations being considered. This non-preferred channel list is built in order to comply with the FCC rules pertaining to PTC channels, e.g., the waiver that allows ITC base stations to use frequencies in the 221–222 MHz band. The list can be imported directly into Infovista's Planet® (RF network planning and optimization software simulation tool used in the project) during the base station frequency plan development.

There are cases when developing a base station frequency plan that abides to the list of non-preferred bases is not possible. In such scenarios, the list is overridden for specific sites. This usually results in the need to provide notifications to the incumbents about planned ITC operations in their vicinity. All correspondence with the incumbents is centrally documented by the TTCI's Radio Frequency Coordination Office on behalf of the railroads.

PTC-220 LLC has also made agreements with the National Radio Telecommunication Corporation (NRTC) and with the Potomac Electric Power Company (PEPCO) who owns spectrum in the 220–222 MHz band, in order to prevent potential interference issues between their sites and railroad ITC sites. For ITC sites operating in the 221–222 MHz band, TTCI identifies the potential issues with NRTC and PEPCO sites by running a tool that calculates the Out of Band Emissions (OOBE) of the ITC radios. This is done in order to verify whether the rules and guidelines regarding emission masks outside the frequency band of operation are being met. TTCI notifies NRTC and PEPCO about the results of the analysis, and requests their concurrence on the proposed ITC site locations and frequencies before proceeding with the design.

4.3 Radio Desense Analysis

TTCI uses the ACSES and ITC Radio Desense Analysis Tool (see Section 3.1) to generate the desense analysis results between ITC and ACSES radios for all the Major Trading Areas (MTAs) in the NEC. All In-service, Planned, and Candidate ITC Base stations, WIU radio sites, and ITC-controlled tracks from PTC-220 LLC member railroads are included in the analysis. Track, ACSES radio sites, and ITC WIU locations provided by non-PTC-220 LLC railroads are also included as input to the tool in order to generate the results.

The analysis is developed for each potential desense scenario, per the following:

- For the case of a fixed site desensing another fixed site operating a dissimilar type of PTC system, the EIRP of the transmitter is taken on a case-by-case basis along with the receiver gains and losses of the sites on a per site basis. These values are used as inputs to the tool to determine if the victim radio will potentially be desensed or not.
- For the case of an ITC or ACSES locomotive radio being the victim, the assumptions for overall gains and losses are 2.15 dBi and 1.5 dB, respectively.
- For the case of an ITC locomotive radio being the offender, the EIRP of the locomotive radio is assumed to be 43.45 dBm.
- The ERP of an ACSES locomotive radio is considered on a railroad-by-railroad basis, as per values provided by the various railroads operating an ACSES system, as shown in Table 2.

All these values are used as inputs to the ACSES and ITC Radio Desense Analysis Tool, depending upon the case being analyzed. The tool identifies the radio sites and portions of the tracks that are predicted to cause desense with their corresponding victims and levels of RSS, as described in Section 3.1.

Table 2. ERP Values for ACSES Locomotive Radios Provided by Commuter and Passenger Railroads

Railroad	ERP (Watts)
AMTRAK	25
SEPTA	25
NJT	7
MNR	8

The main purpose of the analysis is to identify the ITC radio sites that are predicted to cause desense or are being desensed, and preferably not use them in the design of the frequency reuse plan of the ITC base stations. If removing an ITC site from the base station frequency plan results in a coverage gap that cannot be resolved by another alternative ITC site, TTCI keeps the site in the plan, assuming that filters would be installed to eliminate the effects of the desense issue.

TTCI also assumes that locomotive radios will be equipped with filters, so the desense analysis is not developed between locomotive radios from each dissimilar system. TTCI, however, develops the analysis between locomotive radios and fixed radio sites from dissimilar systems, in order to identify the fixed radio sites that would require filters to eliminate desense that locomotive radios could cause to them.

The results contain detailed information about all the desense cases identified, along with corresponding RSS, signal-to-track distance, and track points being desensed. The results are shared with all affected railroads to help them decide, based on field verification, whether to install filters at the predicted desensed locations, and be aware of the tracks where the locomotive might potentially be desensed or cause desense to a fixed site (base station or WIU radio site).

5 RF Network Design Projects

5.1 NEC RF Design Overview

Even though the NEC is a continuous territory that extends from Boston to Washington, DC, containing multiple railroads inside its boundaries, the RF design for the NEC was divided into multiple RF design projects, because the RF simulation tool used in the project—Infovista's Planet®—is configured to generate RF designs per pre-determined geographic areas, identified as MTAs. The scope of the NEC includes four MTAs (Boston – MTA08, New York – MTA01, Philadelphia – MTA09, and Washington, DC – MTA10), which required TTCI to develop the RF design for each one of them separately. Notice that MTAs share border areas, and radios near the border propagate their radio signals to neighboring MTAs. To account for this, once the design in one MTA was completed, its results were carried over to the neighboring MTAs. The RF design started with the most complex MTA – New York, and continued to the Philadelphia, Washington, DC, and Boston MTAs.

Figure 10 shows the four MTAs included in the NEC design, each one identified with a different background color. It also indicates the boundaries for the DUAs for each MTA.

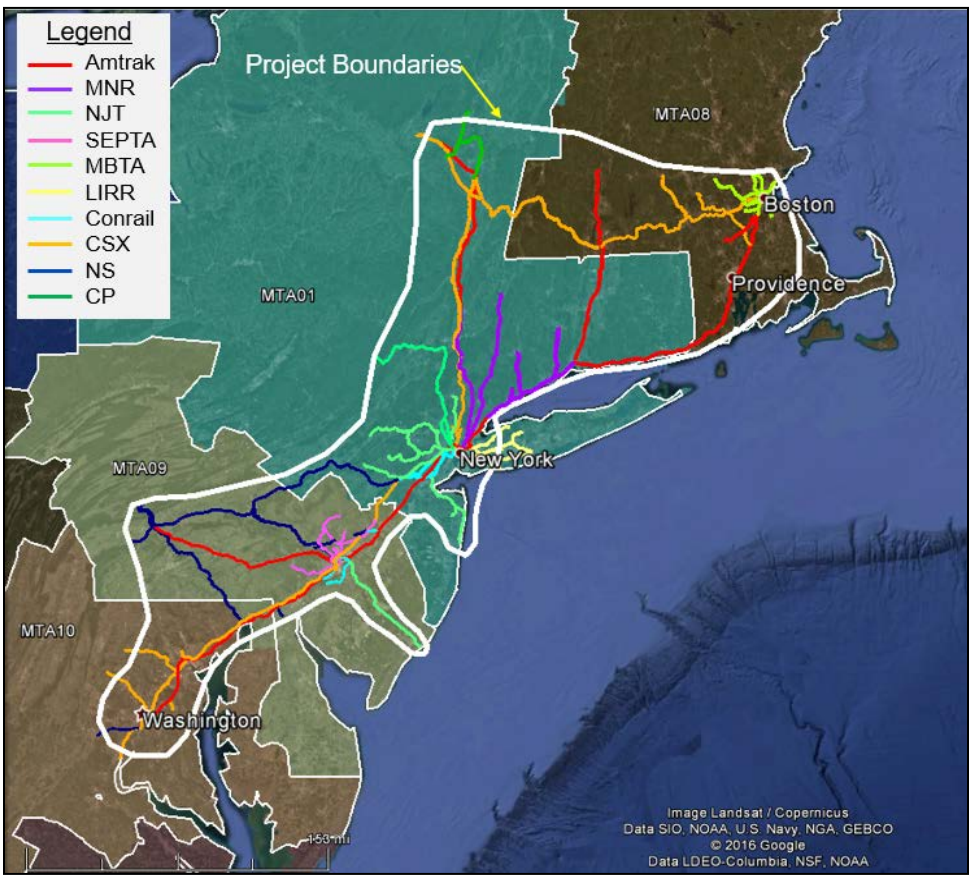

Figure 10. PTC-Controlled Tracks and Project Boundaries Included in the PTC RF Design

The scope of this project was limited to the DUA boundary areas, but as the RF simulation tool generates the RF design for one entire MTA, the results of the base station frequency plan and the F-frame frequency/timeslot plan may encompass the resolution of areas beyond the DUA limits, whenever data was made available by the railroads inside each MTA, which was the case for the New York, Philadelphia, and Washington, DC, areas. This causes a slight impact in the DUA design, for example, when the F-frame frequency/timeslot plan is generated for the MTA, its size may become slightly larger as compared to a design that would include just the DUA limits, which is, in fact, good for the overall NEC RF design.

As stated in the project scope (Section 1.2), the RF design for each of the MTAs in the NEC includes the resolution of dual-equipped territory, meaning that the ITC WIU sites on dual-equipped territories were included in the design of the F-frame timeslot plan. TTCI also developed the desense analysis (between ACSES and ITC radios) per the methodology described in Section 4.1.

Another characteristic specific of the RF design for the NEC regards how WSMs are conveyed to locomotive onboard computers (OBCs). The railroads have decided that on tracks where trains operate with cab-signal control, the status of intermediate signals would be conveyed to locomotive OBCs via the onboard cab-signal system, meaning that WIU sites are not required at intermediate signals for the ITC system. The railroads also decided that along tracks that would be dual-equipped with both systems, WSMs would be broadcast by base stations via wayside status relay service (WSRS), i.e., the WIU locations where WSMs originated are not equipped with ITC radios.

Table 3 lists the type of PTC operation supported by the track configuration and the configuration of ITC WIU locations for all railroads included in the NEC RF design.

Table 3. Type of PTC Operation and Configuration of ITC WIU Locations per Railroad

MTA	Railroad	Subdivision	PTC OPERATION (ITC-compliant or ACSES or DUAL)	ITC WIU CONFIGURATION CONTROL POINT	ITC WIU CONFIGURATION INTERMEDIATE
01-NY-Newark	CSX	ALL	ITC-compliant	WSRS	WSRS
01-NY-Newark	NS	Manville-Bethlehem	ITC-compliant	WITH RADIO	WITH RADIO
01-NY-Newark	AMTRAK	ALL	ACSES	N/A	N/A
01-NY-Newark	Conrail	LEHIGH LINE	DUAL	WSRS	WSRS
01-NY-Newark	Conrail	Other subdivisions	ITC-compliant	WSRS	WSRS
01-NY-Newark	NJT	Selected Tracks	DUAL	WSRS	CAB-SIGNAL
01-NY-Newark	NJT	Port Jervis	DUAL	WSRS	CAB-SIGNAL
01-NY-Newark	NJT	All Other	ACSES	N/A	N/A
01-NY-Newark	MNR	ALL	ACSES	N/A	N/A
01-NY-Newark	LIRR	ALL	ACSES	N/A	N/A
01-NY-Newark	CP	ALL	ITC-compliant	WITH RADIO	WITH RADIO
08-Boston	AMTRAK	ALL	ACSES	N/A	N/A
08-Boston	MBTA		ACSES	N/A	N/A
08-Boston	CSX	ALL	ITC-compliant	WSRS	WSRS
09-Philadelphia	CSX	ALL	ITC-compliant	WSRS	WSRS
09-Philadelphia	NS	Perryville – Harrisburg	ITC-compliant	WITH RADIO	CAB-SIGNAL
09-Philadelphia	NS	ALL Other	ITC-compliant	WITH RADIO	WITH RADIO
09-Philadelphia	AMTRAK	Philadelphia to NY	ACSES	N/A	N/A
09-Philadelphia	AMTRAK	All Other	DUAL	WSRS	CAB-SIGNAL
09-Philadelphia	Conrail	ALL	ITC-compliant	WSRS	WSRS
09-Philadelphia	SEPTA	ALL	ACSES	N/A	N/A
09-Philadelphia	SEPTA	Norristown TC (1 mile long)	DUAL	WSRS	CAB-SIGNAL
09-Philadelphia	NJT	ATLANTIC CITY	ACSES	N/A	NA/

10-Washington, DC	CSX	ALL	ITC-compliant	WSRS	WSRS
10-Washington, DC	NS	ALL	ITC-compliant	WITH RADIO	WITH RADIO
10-Washington, DC	AMTRAK	ALL	DUAL	WSRS	CAB-SIGNAL

Notice that the Port Jervis subdivision is reported under NJT which operates it, however, the tracks are owned by NS and leased to MNR.

Section 5.2 includes topics that are common to all four RF network designs.

Section 5.3 describes the specific analysis developed for the New York and Philadelphia DUAs to identify ITC sites where additional spectrum in the 220 MHz band acquired by PTC-220 LLC could be used.

Sections 5.4 to 5.7 contain the detailed RF design studies prepared for each of the DUAs included in the NEC, following TTCI's methodology, as described in Section 4. It is indicated in each section when exceptions to the methodology had to be made to address specific issues encountered in the RF design.

5.2 List of Requirements, Radio Characteristics, Design Guidelines and Assumptions

The RF design projects used the available data provided by the railroads and obtained from additional documentation sources, including railroad timetables and PTC implementation plans. A series of requirements, assumptions, and design guidelines also guided the execution of this project, as described in the following subsections.

5.2.1 List of Requirements

- Signal strength coverage and carrier-to-interference ratio (C/I) assuming a receiver antenna height of 17 ft. along the tracks where PTC control is required, are designed as targets. RF design results are reviewed with the railroads to determine whether the locations where the targets are not met are acceptable for their operation. The design targets for those are:
    - 95 percent of the +/- 90-meter buffer around the tracks (subsequently referred to as "90-meter buffer") used by the propagation modeling tool should have signal strength coverage of -94.37 dBm or higher from the base stations.
    - 95 percent of the 90-meter track buffer should have a C/I of 11.5 dB or higher for the base station coverage.
- Each WSM being transmitted by a WIU radio site shall be heard by at least one base station site.
- WSMs shall reach locations at least 5 miles along the tracks where there are possible routes connecting to the associated WIU location.
- WSRS messages that are not subscription-based shall be transmitted over the F-frame.
- WSMs from radioless WIU sites shall be broadcast in the F-frame by base stations and satisfy the 5-mile WIU propagation requirement.

- Train message traffic (Locomotive to/from Office messages) shall use at most 80 percent of the D-frame, to allow for future growth.
- Analysis of the message traffic and potential congestion in the Common Channel is not required for this project.

5.2.2 List of Radio Characteristics and Limitations

- ITC locomotive and base radios can receive on up to eight simultaneous channels, one of which is tuned to receive the Common Channel.
- ITC radios can transmit on only one frequency at a time, but can quickly switch to transmit on another frequency, e.g., in the next timeslot, if necessary.
- ITC radios cannot transmit and receive at the same time (i.e., they operate half-duplex).
- The radio handoff algorithm criterion does not use a fixed transition point; therefore, it is not possible to predict what base station a locomotive radio will be registered to when the locomotive is near the handoff point, using RF signal coverage levels.
- The WIU radios have two receive channels, one of which is tuned to receive the Common Channel.
- All ITC radios (wayside, locomotive and base) can transmit at an instantaneous data rate of 16 kbps (half rate). Additionally, base station and locomotive radios also support transmissions at an instantaneous rate of 32 kbps (full rate).

5.2.3 List of Design Guidelines

- The RF simulations were developed using the Interoperable Train Control Network (ITCnet) technology module in Infovista's Planet® tool.
- When developing a fixed F-frame plan using Meteorcomm Communications, LLC's (MCC) ITCnet Planning Module (IPM), it is desirable to:
  - Use the "6+1+1" approach (6 WIU frequencies, 1 Common Channel, and 1 base local channel).
  - Use variable F-frame timeslot sizes, i.e., each timeslot is only allotted enough time to accommodate the payload of its particular WSM.
  - Assume that all WSRS transmissions in the F-frame are done at full rate.
  - Assume that all WSM transmissions via WIU radio sites are done at half rate.
  - Transmit WSMs from radioless WIU sites in the F-frame through at least two different base stations.
- Base stations that are predicted to exceed the F-frame timeslot capacity will be handled per the following priority sequence:
  - Offload WSRS demand and the WIUs that the base station is listening to on neighbor base station sites that also satisfy the 5-mile WSM propagation requirement, if possible.
  - Add base station sites.

- When additional base stations are required, TTCI will use the following priority sequence:
  - Select from candidate sites provided by the railroads.
  - Select sites from the existing FCC ULS database (VHF towers).
  - Propose new sites (new locations or sectored) at existing WIU locations.
- The standard coverage requirement along the railroad tracks is to have coverage from at least one base station at a level of -94.37 dBm or higher.
  - Specific requirements may have to be met on a case-by-case and these are indicated in each design, when applicable.
- The base-to-locomotive links are required to have a minimum Carrier-to-Interference plus Adjacent Channel Interference ratio (C/(I+A)) of 11.5 dB at Carrier-to-Noise ratio (C/N) of at least 15 dB along the PTC-controlled tracks included in the design, including a buffer area with a radius of 90 meters around those tracks.
- Planet®'s Automatic Frequency Planning (AFP) and Iterative Frequency Planning (IFP) are used to optimize the assignment of channels to be used on the D-frame.
- In general, the propagation models are assigned by the owning railroads to their own base station and WIU radio sites. When requested, however, Planet®'s Automatic Propagation Model Assignment (APMA) tool is used by TTCI to assign propagation models.
- Currently, there are 92 base station propagation models available for use in the Planet® Hosted Environment. These models were acquired in different regions of the country.
- The azimuths of the base station and WIU radio antennas can be adjusted in order to provide coverage to the desired areas.
- It is desirable to use base station radio antenna models and heights provided by the railroads, but if necessary, alternative heights or antenna models can be used.
- Predicted train traffic for the year 2020 should be used as a baseline for the D-frame train message traffic analysis.

5.2.4 Assumptions for RF Modeling and Simulations

- Data provided by the railroads about radio sites (WIU and base station), and about tracks and WSMs is accurate and reliable.
- There will be a maximum of one radio per WIU location, due to the potential for desense among radios.
- Coverage is redundant only to a limited extent, given the primary objective to minimize the number of base stations and frequencies needed.
- Link budgets for all the different links have been defined and accepted.
- A 3-dB link budget coverage adjustment is taken on the F-frame at locations where the same WSM is being received via two or more radio locations.

- The propagation studies used clutter and terrain data with a resolution of 30 meters and did not include a "structure data base" (e.g., individual buildings), which would be possible with the Universal Model.
- All RF simulation predictions from Planet® are assumed to have a level of accuracy that will closely resemble the actual values as measured in the field, e.g., during a drive test, locomotive logs, base station logs.
- A 5.19-mile signal strength coverage requirement is used to determine if there is need for WSRS.
- WSMs transmitted by base stations in the F-frame are transmitted at full rate, whereas F-frame transmissions by WIU radio sites are at half rate.
- For ITC locations (tracks or fixed locations, i.e., base stations or WIU radio sites) where it is detected that ITC/I-ETMS radios can experience desense, the following assumptions were taken:
  - Filters will be installed at the affected ITC base stations, WIU radio sites and/or locomotives.
  - The filter insertion losses are already accounted for in the standard link budget. Thus, no changes to the sensitivity thresholds are needed.
- Train traffic loading on the D-frame is determined by a TTCI computer model that estimates the number of simultaneous trains operating at peak hours under each base station, and it uses railroad-provided historical train movements, not Rail Traffic Controller™ (RTC) modeling.
- Coverage inside tunnels is assumed to be reliable and provided by the appropriate equipment (e.g., base station connected to a leaky feeder cable).

5.2.5 Assumptions for Train Message Simulation

In 2011, the design assumptions for simulating PTC messages were developed in a joint effort between TTCI and the PTC-220 Spectrum Management Committee (SMC). Operational aspects and their effects in terms of PTC message traffic were discussed and decisions were made to meet the objectives of the simulation. The discussions also shaped the scope of the simulation to design a more limited, cost effective, and practical implementation.

The train message sizes and duration for the PTC message types were calculated using the ITC specification documents and additional information provided by MCC on the architecture of the radio system [1] [7] [8]. Table 4 lists the messages modeled in TTCI's simulation software. It should be noted, however, that the Bulletin Dataset messages were not used in the simulation performed for this study. The effects of Bulletin Dataset messages in the overall train message traffic loading are verified with analytical methods as explained in Section 5.2.7.

Table 4. List of Train Messages Modeled in TTCI's PTC Message Simulator

Message No.	Message Name	Message Size (bytes)	Message Duration (milliseconds)
1020	Confirmation of Poll Registration	48	25
1021	Office Segment Poll	69	33

1041	Bulletin Dataset (*)	332	130
2020	Poll Registration – Version 1	95	41
2042	Confirmation of Bulletin Dataset (*)	50	25
2080	Locomotive Position Report	123	49

(*) Message Types no included in the PTC Message Simulation

The analysis of the D-frame also has to consider that only 80 percent of the total D-frame size can be used for train message traffic. The remaining 20 percent is reserved for other business messages that railroads will exchange over the D-frame.

5.2.6 Assumptions for Associating Train Messages with Base Stations

It is assumed for this project that train messages can be associated with the train's best server base station when calculating base station train message traffic loading, even though the ITC radio handoff algorithm will not necessarily result in the locomotive handing off to the best server base station exactly at the predicted best server boundary. It is known that MCC's proprietary radio handoff algorithm employs hysteresis and geographical information as part of the criteria for handing off the locomotive radios and these are not included in TTCI's simulation model.

Considering the fact that train operation data comes from probabilistic simulation of train movements, which contributes to imprecision in the exact moment a train would transition from one base station to the next base station in the real world, it is assumed that the association of each train message to its best server base station can provide a sufficient representation of actual message traffic loading.

TTCI also implements a "smoothing" algorithm to determine the association of train messages with base stations that are not necessarily the best server (within a certain signal strength threshold) for short portions of track. Figure 11 illustrates a hypothetical scenario where base station best server areas are indicated by different colors. In this example, there is a short portion of the track best served by base station B (in red), that the algorithm would assume to be best served by base station A (in blue), as it is likely the handoff algorithm would prevent the transition from base station A to base station B.

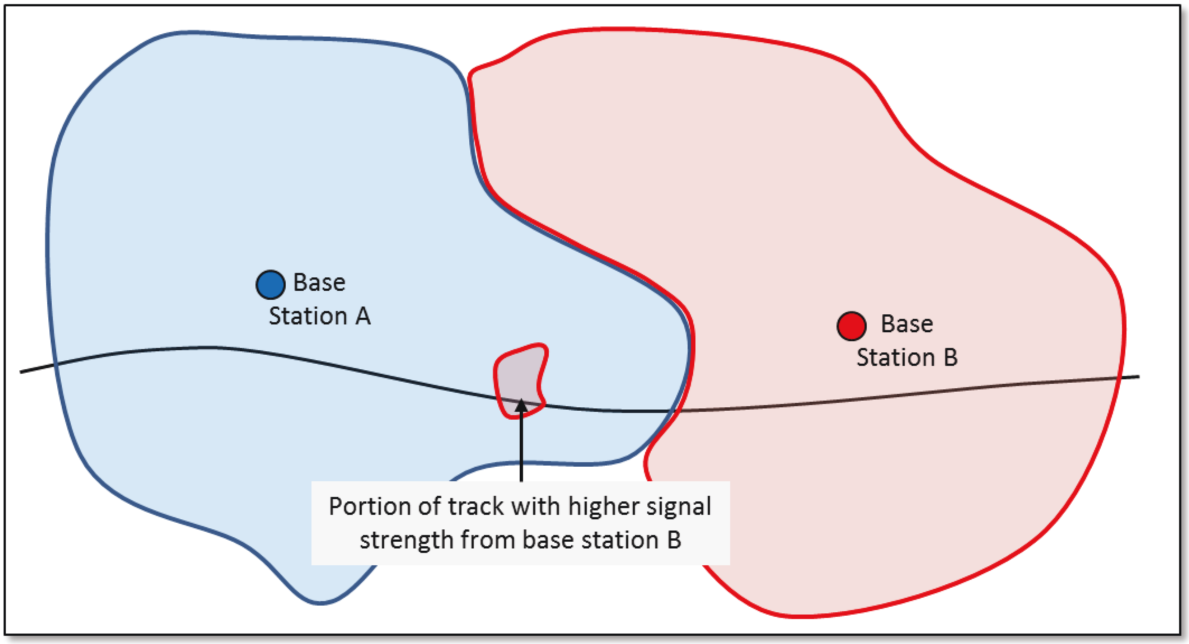

Figure 11. Typical Base Station Coverage Case Handled by TTCI's Smoothing Algorithm

5.2.7 Assumptions for Bulletin Dataset Message Traffic Analysis

The train message simulation developed by TTCI for the RF design projects did not include the simulation of Bulletin Dataset messages. Instead, TTCI investigated the impact that could be caused by Bulletin Dataset messages if they were to coincide with peak train traffic periods.

Bulletin Dataset messages are considered high priority messages sent from the office to trains. If they are handled with the same priority as the PTC messages simulated by TTCI, when they are sent, subsequent messages would be queued. The Bulletin Dataset message (message #1041) is the most frequent Bulletin Dataset message and is sent as a unicast message to trains. It is also the largest Bulletin Dataset message, according to assumptions agreed to with PTC-220 LLC, a Bulletin Dataset message is approximately 330 bytes long (including header size), which corresponds to 130 milliseconds of transmission.

Assuming that, in a worst-case scenario, one Bulletin Dataset message is sent from all railroad Back Office Servers (BOS) to each train registered under a base station at the same time, it would cause queuing (i.e., latency) of subsequent messages until all Bulletin Dataset messages are sent out.

The latency is calculated according to the following:

1. The maximum outbound message duration during the D-frame is used as a limiting factor for the bulletin messages. Note that this limit respects the radio duty cycle and the D-frame size.
2. As Bulletin Dataset messages are unicast, if bulletin data messages are triggered at peak operation times, the system will transmit one message to each train under the base station.
3. Each Bulletin Dataset message is approximately 130 milliseconds, and the number of messages transmitted per D-frame is a multiple of 130 milliseconds.

5.3 NRTC Spectrum Use Analysis

5.3.1 Background

The NRTC made 200 kHz of wireless spectrum available for purchase in specific counties in New Jersey and New York. The spectrum consisted of twenty 5 kHz-wide channel pairs in the J, K, and L blocks of the 220–222 MHz band.

The offer was intended to allow a licensee to use the spectrum within the geographic boundaries shown in Figure 12. The boundaries encompass the following counties in their entirety (see red boundaries in Figure 12): Hunterdon, Mercer, Middlesex, Monmouth, Somerset, Union, Warren (all located in New Jersey) and Richmond County in New York. Additionally, the following New Jersey counties were also part of the offer, albeit only partially (see blue boundaries in Figure 12): Essex, Hudson, Morris, and Sussex.

In order for a fixed location to be able to use a channel in the offered spectrum, the following conditions needed to be met:

- The site needs to be located within the geographic boundaries shown in Figure 12.
- The interference contour (20 decibels above 1 microvolt per meter [dBu] contour) of the base station using the spectrum should not overlap with the service contour (38 dBu contour) of other NRTC sites using the same spectrum outside the offered boundaries.

PTC-220 LLC tasked TTCI with evaluating the extent to which the offered spectrum could be used for ITC purposes. The study involved assessing the number, location, and propagation characteristics of the ITC base stations inside the boundaries in question. TTCI also performed an evaluation of the possible overlap of the interference contour of the candidate ITC base stations with the service contour of any of the NTRC sites outside the offered boundaries, on a base-station-by-base station basis. In particular cases, TTCI also recommended changes to the configuration of certain ITC base stations in order to prevent contour overlap. These changes included power, antenna height, azimuth (for sites using directional antennas), and antenna model.

Figure 12. Boundaries Where NRTC Spectrum was Offered

As stated, the offered NRTC spectrum consisted of twenty 5 kHz channel pairs. The lower half of each pair is in the 220.0–221.0 MHz band, while the upper half is in the 221.0–222.0 MHz band. When continuous 5 kHz channel blocks get aggregated, they translate to eight 25 kHz-wide channels that can be used by the ITC radios for PTC communications, as shown in Table 5.

Table 5. Details of the Spectrum Offered by NRTC

Call Sign	Description	Block	PTC Channel	Center Frequency (MHz)	Description	Number of 25kHz Channels for PTC
WQXL586	**Full Counties:** Hunterdon, NJ; Mercer, NJ; Middlesex, NY; Monmouth, NY; Somerset, NJ; Union, NY; Warren, NJ; Richmond, NY **Partial Counties:** Essex, NJ; Hudson, NJ; Morris, NJ; Sussex, NJ	L	128 168	220.7875 221.7875	5-5 kHz pairs	2
WQXK673	**Full Counties:** Hunterdon, NJ; Mercer, NJ; Middlesex, NY; Monmouth, NY; Somerset, NJ; Union, NY; Warren, NJ; Richmond, NY **Partial Counties:** Essex, NJ; Hudson, NJ; Morris, NJ; Sussex, NJ	J	134 174	220.9375 221.9375	25 kHz pair	2
WQXK674	**Full Counties:** Hunterdon, NJ; Mercer, NJ; Middlesex, NY; Monmouth, NY; Somerset, NJ; Union, NY; Warren, NJ; Richmond, NY **Partial Counties:** Essex, NJ; Hudson, NJ; Morris, NJ; Sussex, NJ	K	107 108 147 148	220.2625 220.2875 221.2625 221.2875	50 kHz	4

5.3.2 Methodology for NRTC Spectrum Use Analysis

The methodology applied by TTCI to evaluate the usability of the offered spectrum was as follows:

- Identify the ITC base stations located in the area where the NRTC spectrum was available.
- For each of the base stations above, determine feasibility of use, based on their interference contours (20 dBu contours):
  - If the interference contour of an ITC base station does not overlap with the boundaries of the area where spectrum was offered, and it does not overlap with any of the NRTC service contours, the ITC base station is determined to be a candidate to use one of the NRTC channels.
  - For cases where there was overlap between the service contours of the ITC base station and the geographic boundaries of Figure 12 (but not with the NRTC service contours), review the results with PTC-220 LLC who then provide direction on whether this is acceptable.
  - If the above fails, TTCI proposes changes to the configuration of ITC base station. The first proposed change is a change in antenna azimuth (for sites using directional antennas), as this would be a relatively simple change for the railroads to perform in the field. If that fails, a reduction in power is proposed. Finally, if necessary, a change in antenna type is evaluated, e.g., changing the antenna pattern from omnidirectional to directional.

– If after making configuration changes, the interference contours of the ITC base stations still fail the tests above, the base station is then classified as not being a candidate for NRTC spectrum use.

TTCI calculated the service and interference contours with ComStudy 2.2 by RadioSoft. The interference contours were calculated using the R-6602 (Carey) Interference feature, while the service contours were calculated using the R-6602 (Carey) Service feature.

5.3.3 Results of NRTC Spectrum Use Analysis

The first step in the process was to identify the ITC base stations that would be qualified to use the offered spectrum. TTCI identified that 18 ITC base stations (17 ITC base stations from the New York MTA and 1 ITC base station from the Philadelphia MTA) were located within the boundary where NRTC spectrum was offered. Table 6 lists all ITC base stations located inside the boundaries of Figure 12.

Table 6. ITC Base Stations Inside the Boundaries Where NRTC Spectrum was Offered

Site ID	Site Name	Railroad	DUA
2190000002	CP Green	Conrail	New York
2190000003	Eport	Conrail	New York
2190000004	Port Reading	Conrail	New York
2190000005	Potter	Conrail	New York
2190000006	Browns Yard	Conrail	New York
2190000007	Jamesburg Road 3	Conrail	New York
2190000008	Red Bank	Conrail	New York
3125201138	Belle Meade	CSX	New York
3125201139	Manville	CSX	New York
3550056698	Bellwood_Pattenburg	NS	New York
3550066698	Stanton	NS	New York
3550076698	Manville	NS	New York
3550086698	Bellwood_Wesst_Portal	NS	New York
3550156698	Hackettstown	NS	New York
3550256698	Denville	NS	New York
3550286698	Port_Morris_Jct	NS	New York
3550296698	Morristown	NS	New York
3550316698	Wharton	NS	New York
3550326698	Summit_Sub	NS	New York

After carrying out the steps outlined in Section 5.3.2, TTCI concluded that four ITC base stations from the New York MTA could use the NRTC channels, whereas none from the Philadelphia MTA were viable candidates. Table 7 lists the ITC sites that were identified as eligible to use the offered spectrum.

Table 7. ITC Base Stations that can Potentially Use NRTC-Offered Spectrum

Site ID	Site Name	Changes required to use NRTC spectrum	Railroad
3125201138	Belle Meade	None	CSX
3550076698	Manville	3 dB power reduction	NS
2190000006	Browns Yard	Azimuth change from 0 to 240°	Conrail
2190000008	Red Bank	Azimuth change from 0 to 180°	Conrail

Table 7 shows that, in some cases, a change of antenna azimuth was sufficient to make the ITC base station comply with the restrictions, such as with the Browns Yard (Site ID 2190000006) and Red Bank (Site ID 2190000008) base stations. For the Manville base station (Site ID 3550076698), however, a 3-dB reduction of power was sufficient to comply. The next set of figures illustrates the details of the analysis for selected cases.

Figure 13 shows the case of the base station with Site ID 2190000008, located inside the boundaries where the spectrum was offered. If the site operated at full power (44.95 dBm from the power amplifier), and with the antenna azimuth at 0 degrees (as originally configured by the owner railroad), it would not be eligible to use NRTC-offered spectrum, because its 20 dBu interference contour (pink outline in Figure 13) would overlap with the service contours of the NRTC sites north of the border (green outlines in Figure 13).

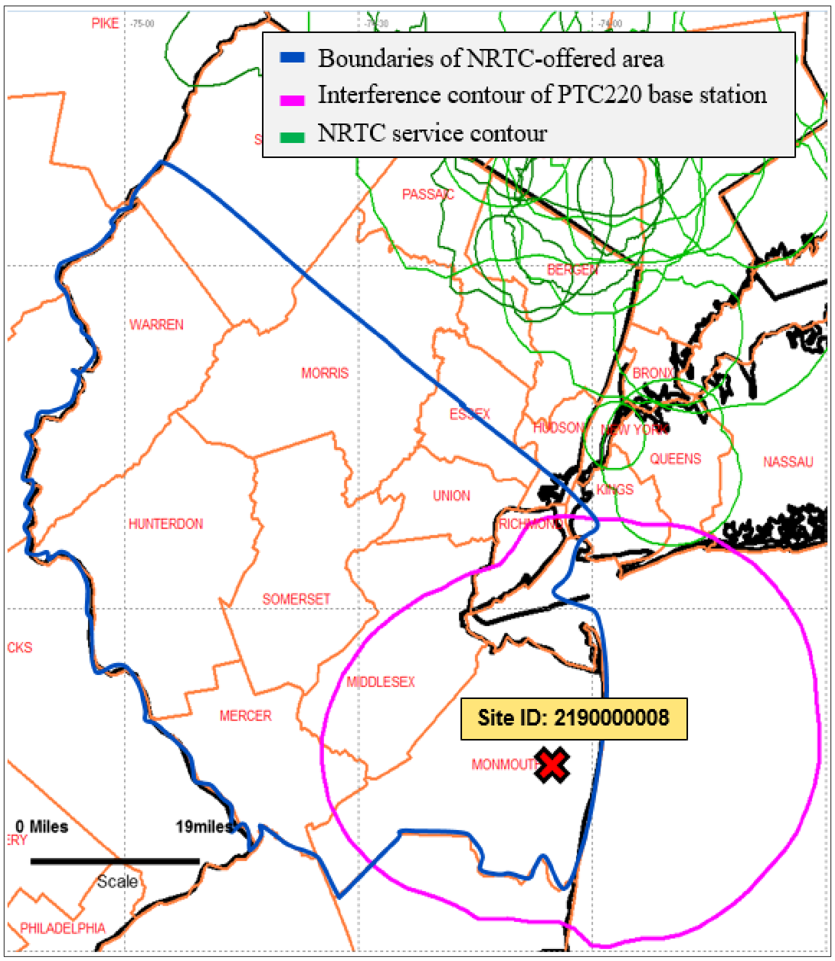

Figure 13. Evaluation of the Usability of NRTC Spectrum for ITC Site 2190000008 with its Original Configuration (Antenna Azimuth at 0 degree)

Figure 14, however, shows how varying the azimuth by 180 degrees would make that base station eligible to use the NRTC spectrum. With this azimuth change, the interference contour no longer overlaps with the service contours of any of the NRTC sites.

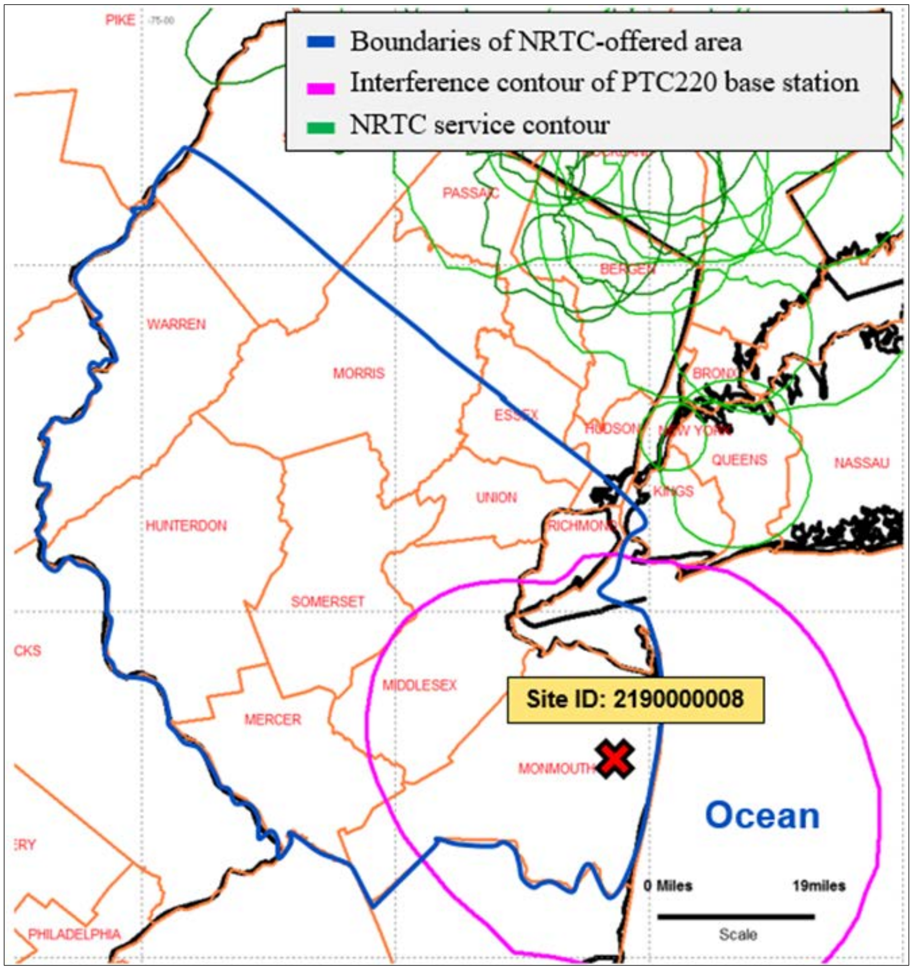

Figure 14. Evaluation of the Usability of NRTC Spectrum for ITC Site 2190000008 with Modified Configuration (Antenna Azimuth at 180 Degrees)

Figure 15 shows the case of base station with Site ID 3125201138, also located inside the boundaries where the spectrum was offered. In this case, the interference contour of the site with its original configuration (output power and antenna azimuth) does not overlap with the service contours of the NRTC sites.

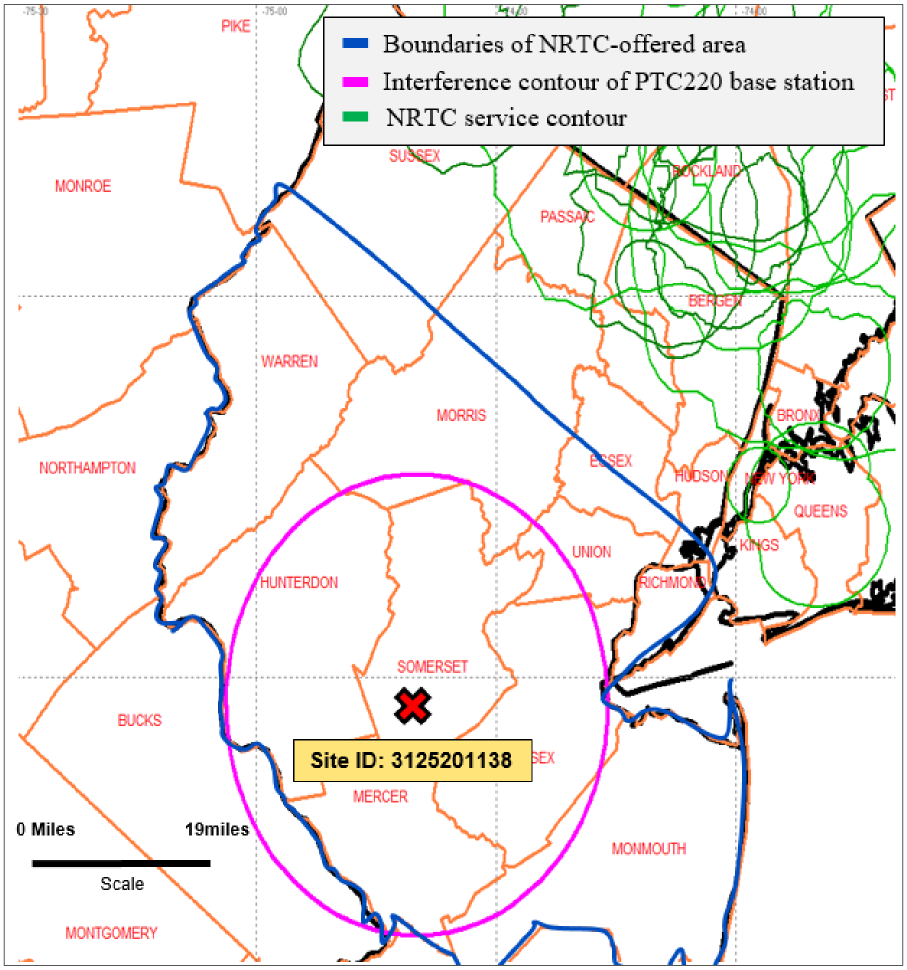

Figure 15. Evaluation of the Usability of NRTC Spectrum for ITC Site ID 3125201138

Figure 16 shows the case of base station with Site ID 3550086698, which is ineligible to use the NRTC spectrum. As shown in Figure 16, its interference contour significantly overlaps the service contours of the NRTC sites. The power and azimuth of the base station cannot be changed without making its footprint impractical for PTC coverage purposes.

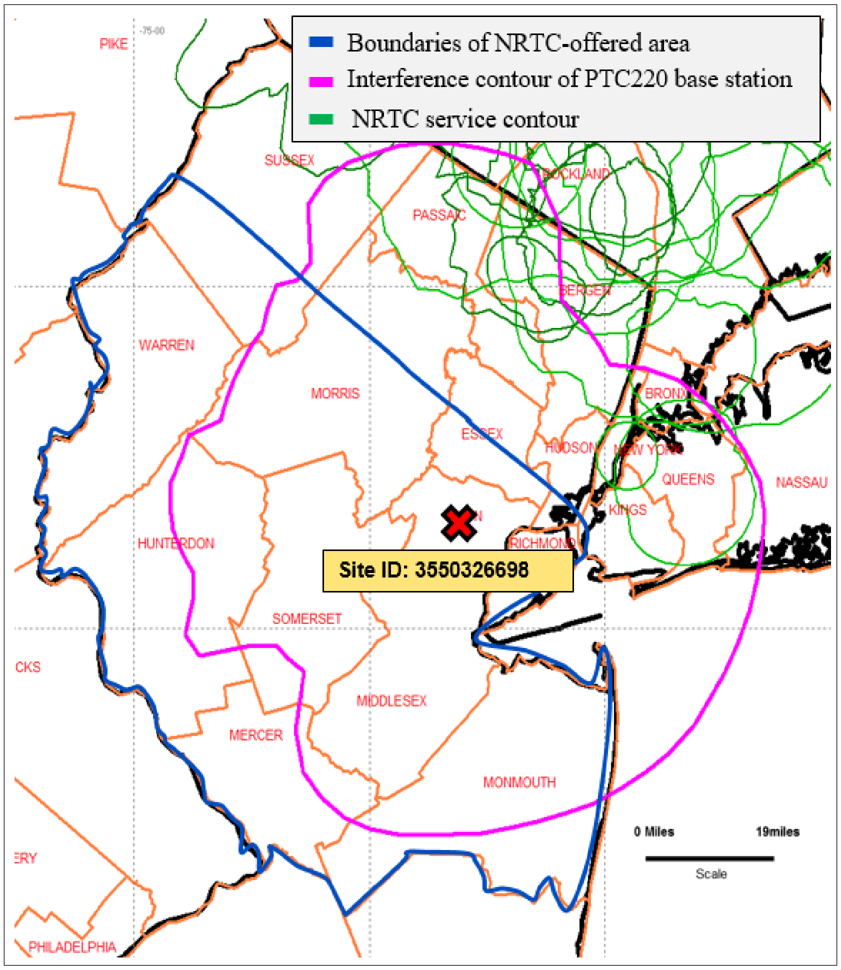

Figure 16. Evaluation of the Usability of NRTC Spectrum for ITC Site ID 3550086698

5.4 RF Network Design for the New York DUA

5.4.1 New York DUA Project Scope

The ITC system RF design project for the New York DUA includes the planned ITC-controlled tracks, base stations and WIU locations from five railroads: CSX, CP, NS, Conrail, and NJT. The design also includes the desense analysis between ITC and ACSES radios for all the fixed radio sites and tracks where PTC-equipped trains from both systems operate. The analysis of train message traffic included all trains operating under the control of an ITC system within the project boundaries.

5.4.2 New York DUA Boundaries

The New York DUA includes all PTC-controlled tracks approximately 25 miles from downtown New York to the east, 180 miles to the north, 95 miles from downtown New York to the west, and 50 miles to the south.

Figure 17 shows the boundaries of the New York study and the PTC-controlled tracks from all the railroads for both ACSES and ITC systems. The design of the ITC system considered all the In-Service, Planned, and Candidate ITC base stations and WIU locations as well as the ACSES sites (required for the radio desense analysis) provided to TTCI for every railroad/subdivision included inside the boundaries.

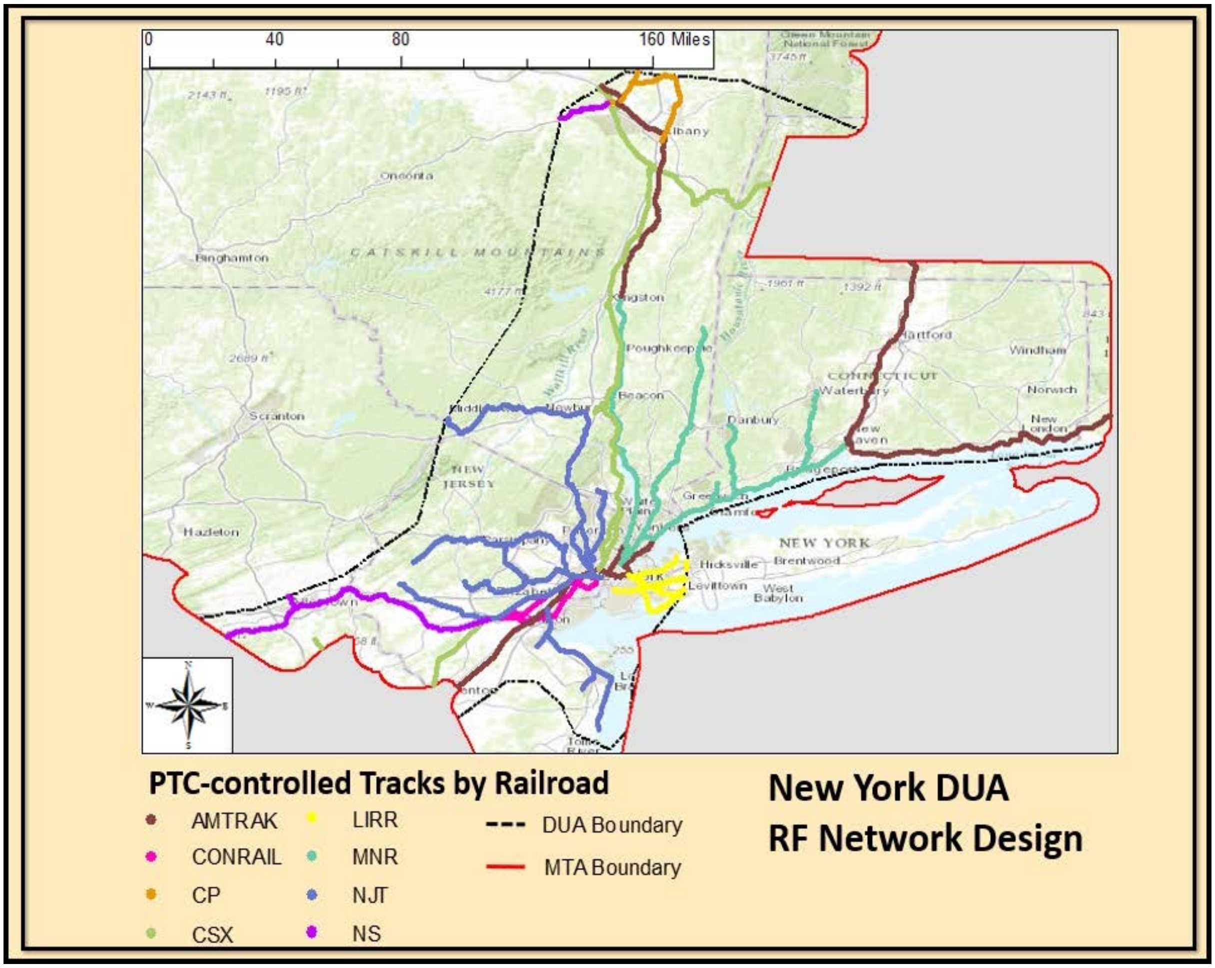

Figure 17. PTC-Controlled Tracks Within the New York DUA Boundaries

PTC-controlled tracks can be configured to support the operation of trains under the control of any of the systems (ACSES or ITC) or both systems simultaneously (dual-equipped), as explained in Section 1.2. Figure 18 displays the PTC-controlled tracks identified by the type of control system in the New York DUA.

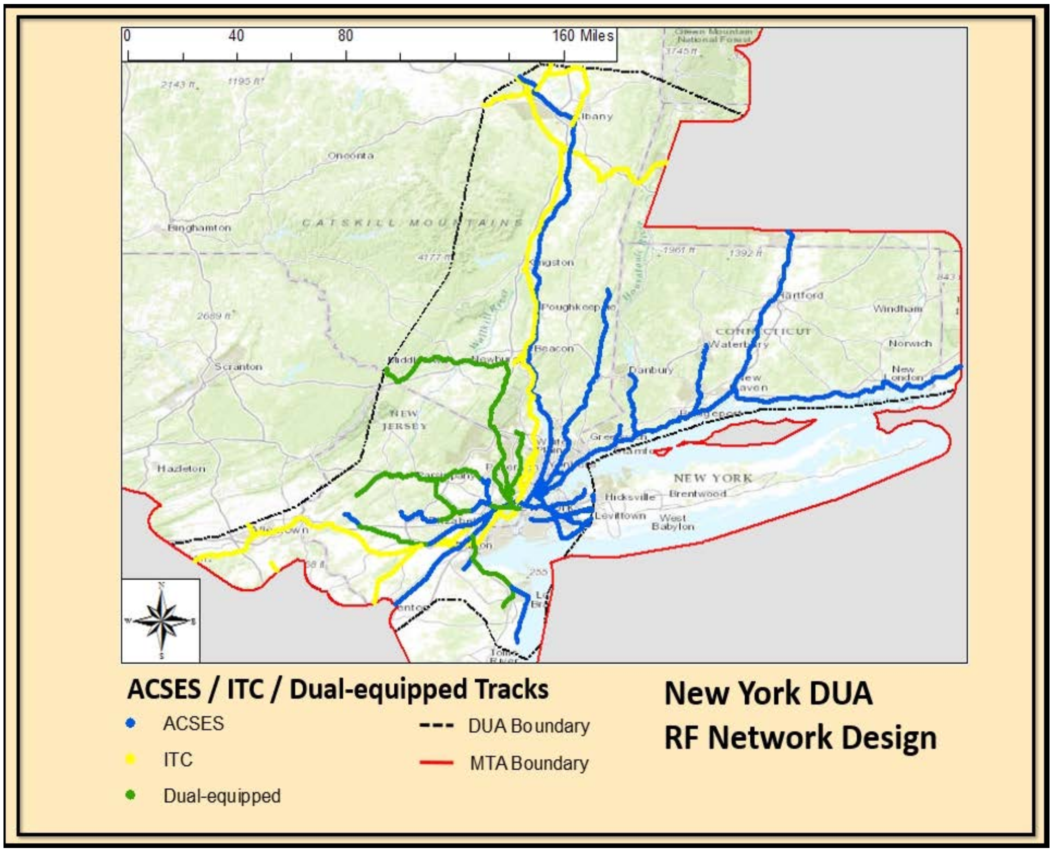

Figure 18. ACSES, ITC and Dual-Equipped Tracks in New York DUA

5.4.3 List of Railroads and Subdivisions Included in the New York DUA

Five different railroads were included in the design of the ITC system for the New York DUA. Table 8 lists the railroads, their subdivisions, and the range of tracks included in the project.

Table 8. Route Miles of ITC-Controlled Tracks per Railroad and Subdivision Included in the New York DUA

Railroad	Subdivision	Start MP	End MP	Route Miles
CP	Canadian	21.7	34.7	13
CP	Freight	467.4	484.7	17.3
Conrail	Lehigh Line	1.6	35.0	33.4
CSX	SELKIRK	168.0	175.5	7.5
CSX	Rotterdam-Boston	13.7	42.3	28.6
CSX	River	0.0	132.0	132.0
CSX	Castleton	8.4	13.7	5.3
CSX	Trenton	44.0	58.0	14.0
NJT	BergenCountyLine	9.8	20.0	10.2
NJT	MainLine	10.5	22.0	11.5
NJT	MainLine	25.5	31.3	5.8
NJT	Montclair	22.0	23.3	1.3
NJT	Port Jervis	31.9	88.9	57.0
NJT	RaritanValley	30.0	36.1	6.1
NS	Lehigh(LB)	84.6	93.0	8.4
NS	Lehigh(LE)	35.0	88.9	53.9
NS	Reading(EN)	88.6	93.0	4.4
NS	Reading(RV)	22.8	36.3	13.5
Total				392.9

5.4.4 New York DUA Data Gathering and Consolidation

5.4.4.1 New York DUA Base Station Input Data

Table 9 contains the list of the 59 ITC base station sites that were considered in the RF design developed by TTCI for the entire New York MTA. The list of sites was obtained from information provided by railroads.

The Status column in Table 9 indicates the status of operation of the base station site, base station sites marked as In-service or Planned were considered preferred sites in the RF design developed. Base station sites marked as Candidate were considered only on an as-needed basis.

Table 9. List of Base Stations Included in the RF Design for the New York MTA

Site ID	Sector ID	Status	Antenna Center of Radiation Height (feet)	Antenna Azimuth (degrees)	Antenna Model
2105151224	Burnt Hill MP 24	Planned	135	110	872F-70(220) Half Wave.pafx
2105151233	Ballston Spa MP 32.99	Planned	135	110	872F-70(220) Half Wave.pafx
2105155667	Mechanicville MP467.4	Planned	135	30	872F-70(220) Half Wave.pafx
2190000001	Croxton	Candidate	100	337.6	SD212-SF3P2SNM_0220.pafx
2190000004	Port Reading	Candidate	100	349.83	SD212-SF3P2SNM_0220.pafx
2190000005	Potter	Candidate	100	316.95	SD212-SF3P2SNM_0220.pafx
2190000006	Browns Yard	Candidate	100	0	SD212-SF3P2SNM_0220.pafx
2190000008	Red Bank	Candidate	100	0	SD212-SF3P2SNM_0220.pafx
3125201025	BOGOTA	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201035	Castleton	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201037	CORNWALL	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201040	EAST CHATHAM	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201053	FORT MONTGOMERY	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201057	GLENVILLE	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201076	MILTON	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201087	ORANGEBURG	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201094	RAVENA	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201126	WEST HAVERSTRAW	In_Service	65	45	SD222-SF6PASNM(OM)_0160.pafx
3125201127	WEST PARK	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201138	Belle Meade	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201147	Lower Gregg	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201148	SCHENECTADY	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201149	FEURA BUSH	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201150	SELKIRK	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201151	Closter Bergen Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201152	Bradley Pkwy	Planned	65	90	SD222-SF6PASNM(OM)_0160.pafx

Site ID	Sector ID	Status	Antenna Center of Radiation Height (feet)	Antenna Azimuth (degrees)	Antenna Model
3125201153	Congers Rockland Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201154	West Point Orange Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201155	Ulster Park Ulster Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201156	Saugerties Ulster Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201157	Catskill Greene Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201158	COXSACKIE	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201159	KINGSTON	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201160	STATE LINE	In_Service	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125201162	Valatie Columbia Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125201163	POST ROAD	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3550046698	Easton	Planned	150	0	PCTEL_BOA2177.pafx
3550056698	Bellwood_Pattenburg	Planned	120	0	PCTEL_BOA2177.pafx
3550066698	Stanton	Planned	135	0	PCTEL_BOA2177.pafx
3550076697	Allentown Disp	Planned	155	0	PCTEL_BOA2177.pafx
3550076698	Manville	Planned	120	0	PCTEL_BOA2177.pafx
3550086698	Bellwood_West_Portal	Planned	65	0	PCTEL_BOA2177.pafx
3550096698	Campbell Hall	Planned	95	0	PCTEL_BOA2177.pafx
3550116697	Lightside_Tower	Planned	55	0	PCTEL_BOA2177.pafx
3550156698	Hackettstown	Planned	55	140	SD212-HF3P2SNM_0207.pafx
3550176698	Lake Helen	Planned	100	130	PCTEL_BOA2177.pafx
3550196698	Salisbury_Mills	Planned	65	0	PCTEL_BOA2177.pafx
3550206698	Woodbury	Planned	100	110	SD212-HF3P2SNM_0207.pafx
3550226698	Southfields	Planned	135	90	PCTEL_BOA2177.pafx
3550236698	Suffern_Yd	Planned	155	0	PCTEL_BOA2177.pafx
3550256698	Denville	Planned	135	0	PCTEL_BOA2177.pafx
3550266698	Paterson_Yd_TBT	Planned	155	90	PCTEL_BOA2177.pafx
3550276698	Mountian_View	Planned	115	0	PCTEL_BOA2177.pafx
3550286698	Port_Morris_Jct	Planned	60	0	PCTEL_BOA2177.pafx
3550316698	Wharton	Planned	65	0	PCTEL_BOA2177.pafx
3550326698	Summit Substation	Planned	155	0	PCTEL_BOA2177.pafx
3550336698	Port Jervis	Planned	140	0	PCTEL_BOA2177.pafx
3550346698	Howells	Planned	135	0	PCTEL_BOA2177.pafx
3550356698	Slostsburg	Planned	64	90	PCTEL_BOA2177.pafx

5.4.4.2 New York DUA WIU Input Data

The WIU data used in the RF design for the New York DUA was provided by the PTC-220 LLC railroad members (CSX, NS, and CP) included in the design. For NJT and Conrail, the data was developed by TTCI and validated by the owning railroads.

NJT, Conrail, and CSX indicated that their WIU devices will not be equipped with WIU radios, meaning that all their WSMs will use WSRS transmission from ITC base stations. Table 10 shows the total number of WIU radio locations and number of WSMs for all the WIU locations from each railroad.

Table 10. Counts of WIU Radio and WIU Device Locations in the New York DUA

Railroad	Number of WIU Radio Locations	Number of WSMs
Conrail	0	58
CSX	0	10
CP	14	15
NJT	0	56
NS	34	48
Total	48	187

Figure 19 illustrates the distribution of all WSM locations along the ITC-controlled tracks per railroad in the New York DUA. Notice that for NS and CP, each WSM location corresponds to the location of a WIU radio site, whereas for the commuter railroads, each location represents a WIU device, but not the location of a WIU radio site. WSM data from CP's Colonie subdivision and CSX's River subdivision were not available and thus were not included in this iteration of the RF design.

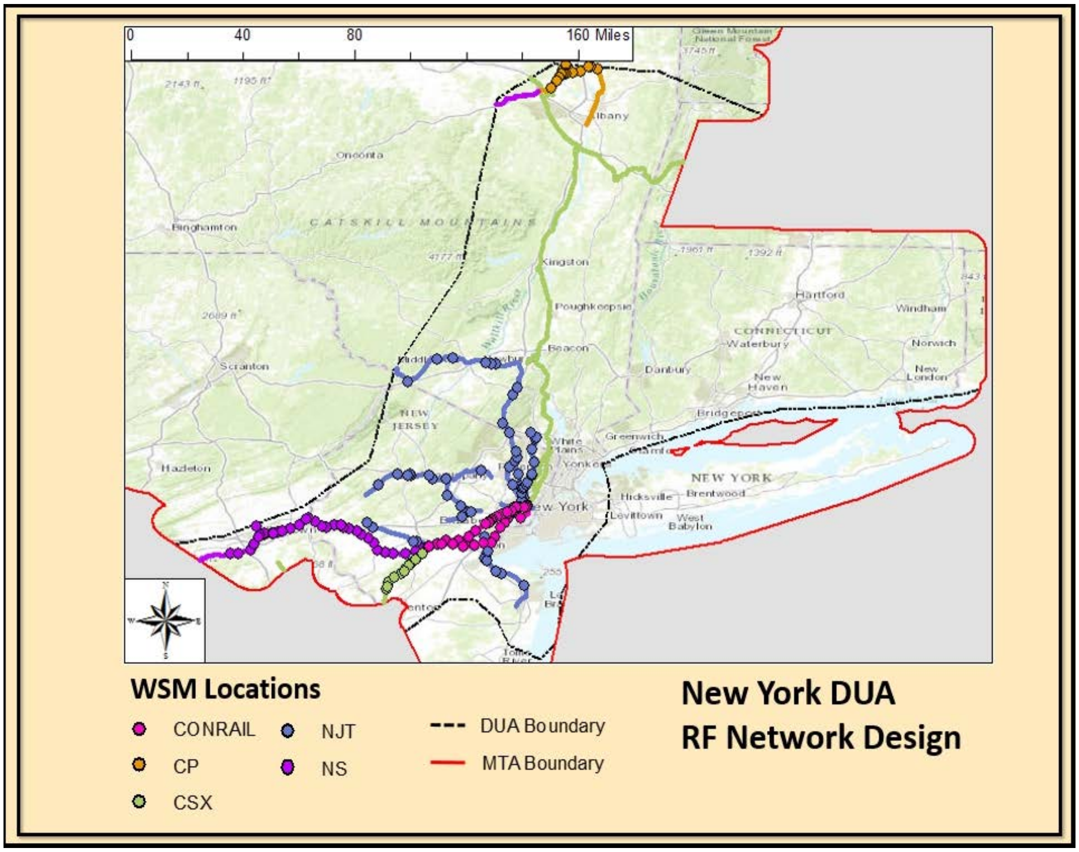

Figure 19. Distribution of WSM Locations Inside the New York DUA

5.4.5 New York DUA Incumbent Analysis

The Incumbent Analysis comprises checking for possible desense scenarios between ITC base stations and fixed non-railroad incumbent sites operating within the 217–222 MHz band, as explained in detail in Section 4.2.

The results of the Incumbent Analysis show 33 non-railroad incumbent licensees inside the New York DUA, operating a total of 347 unique radio locations. Figure 20 shows the location of the ITC base stations inside the New York DUA and all the non-railroad incumbents in the area. It is worth noting that a single location can either have multiple licensees or multiple frequencies in use.

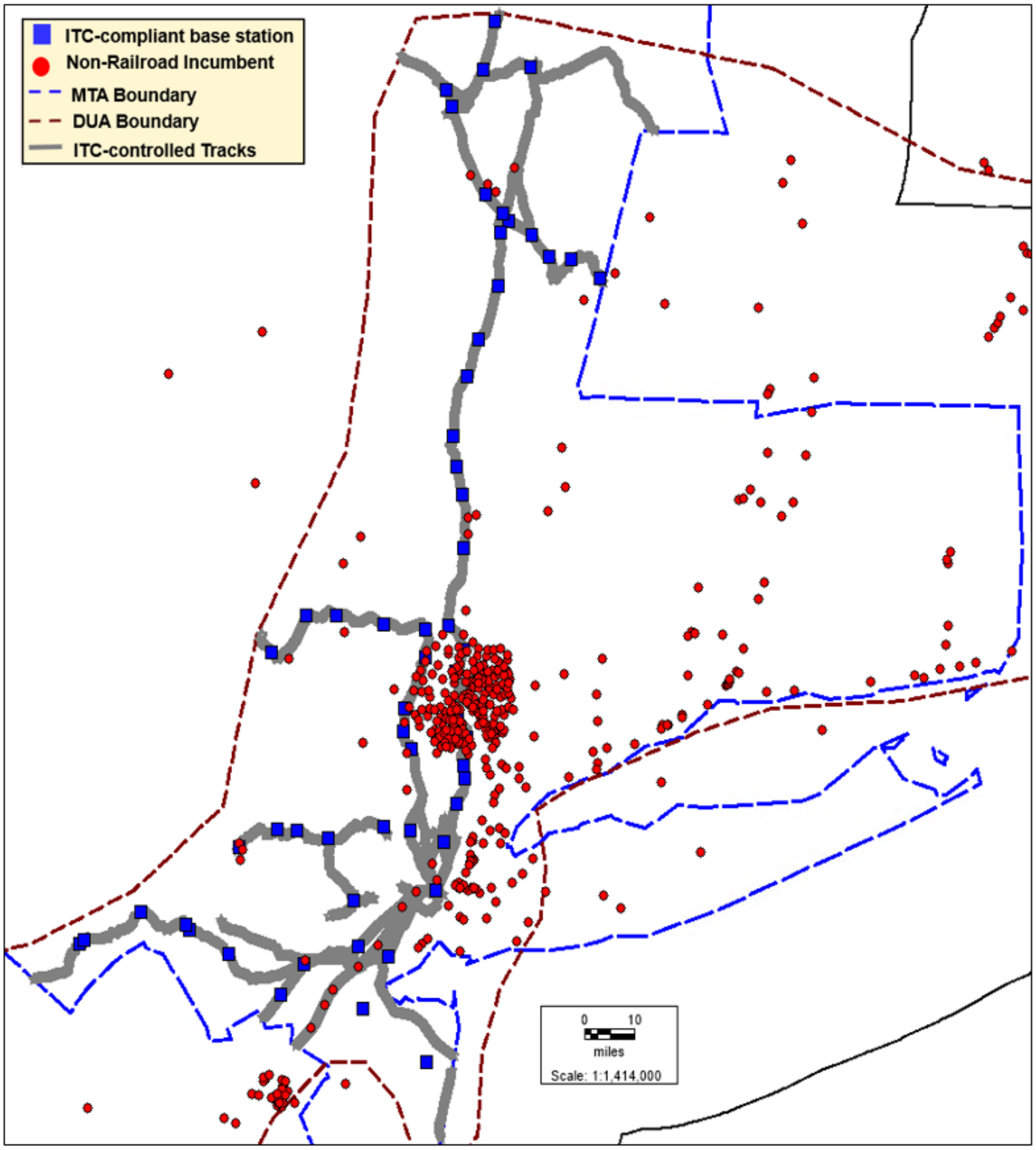

Figure 20. ITC Base Stations and Non-Railroad Incumbent Sites in the New York DUA

It is assumed that the incumbent radios have a desense threshold of -30 dBm when determining whether ITC fixed sites could cause desense issues on non-railroad incumbents as explained in Section 2.1.

TTCI encountered 13 possible cases of desense or interference between NRTC/PEPCO or any other non-railroad incumbent sites and ITC base stations. Waiver notifications were sent to the owners of each of these non-railroad sites before finalizing the D-frame frequency plan. In addition, NRTC sites were notified and asked for their concurrence. Concurrence was obtained from all the non-railroad incumbents and the bases were used as per the initial plan without any additional changes.

TTCI also identified three possible cases of desense or interference between non-railroad incumbents and NS WIU radio sites. TTCI has not taken further actions for these cases, as explained in Section 4.2.

5.4.6 New York DUA ACSES and ITC Radio Desense Analysis

TTCI developed the detailed desense analyses to identify areas where ACSES and ITC radios could be at risk of desensing each other, as explained in Section 4.3. This included:

- Identification and analysis of ACSES radio sites that could desense ITC radio sites and vice versa (see Section 2.1.1).
- Identification and analysis of tracks where locomotives could get desensed by fixed sites from a dissimilar system, i.e., ITC desensing ACSES and vice versa (see Section 2.1.2).
- Identification and analysis of track locations where locomotives could cause desense to fixed sites from the dissimilar system, i.e., ITC desensing ACSES and vice versa (see Section 2.1.3).

The next set of figures and tables shows the results obtained for each of the above listed cases. Appendix A, Section A.3 contains tables with detailed lists of fixed sites that are predicted to either cause desense or be desensed by a dissimilar system.

Figure 21 shows the location of ACSES radio sites and the tracks where ACSES-controlled trains operate inside the New York DUA.

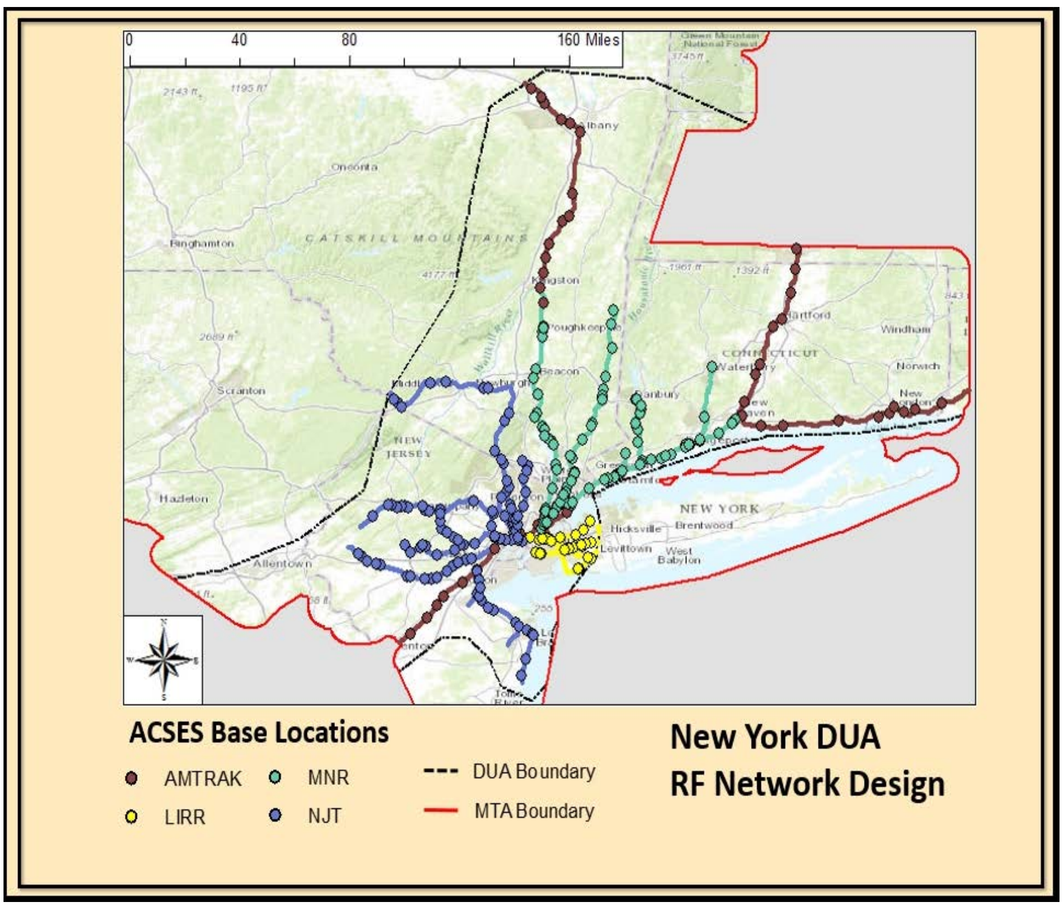

Figure 21. Location of ACSES Base Stations and Tracks in the New York DUA

Table 11 summarizes the results of the desense analysis between ACSES and ITC fixed sites. The column titled "Desensing" shows the number of ACSES or ITC sites that are predicted to be desensed by fixed radios from the dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to radios from the dissimilar system.

Figure 22 shows the locations of the six ITC base stations that are predicted to be desensed by ACSES base stations inside the New York DUA.

Table 11. Desense Results Between Fixed ACSES and ITC Sites Inside the New York DUA

System Type	Desensing	Being Desensed by
ITC Fixed Site	36 ACSES Sites	6 ACSES Sites
ACSES Fixed Site	6 ITC Sites	36 ITC Sites

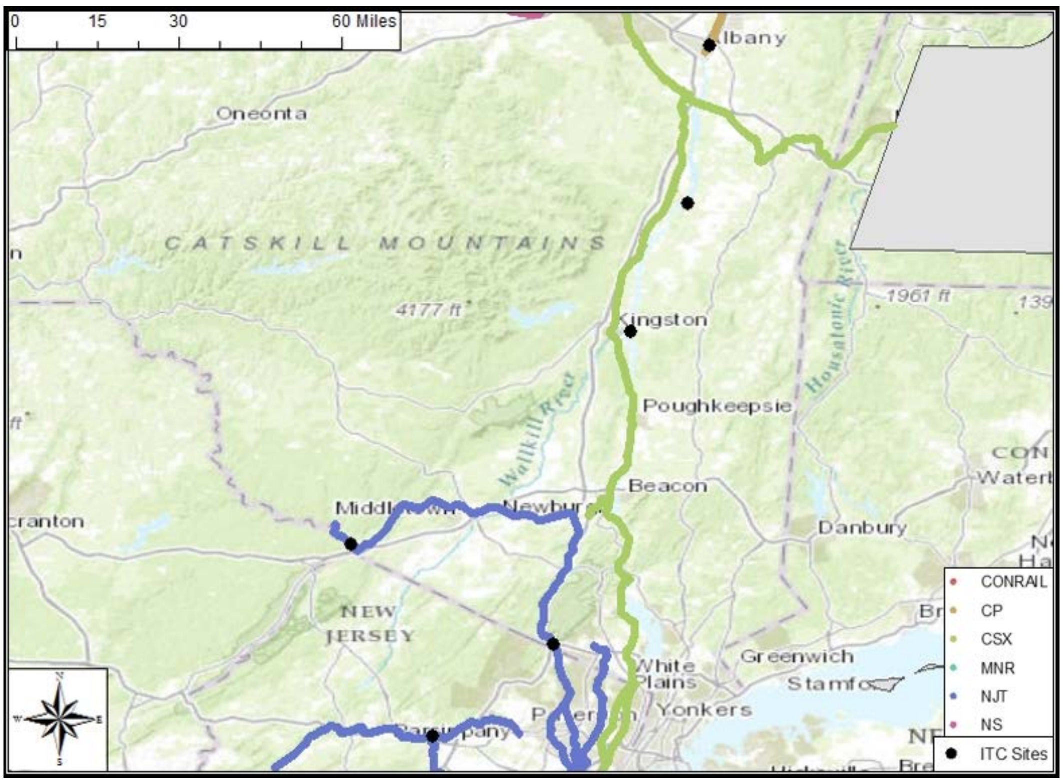

Figure 22. Location of ITC Sites Predicted to be Desensed by ACSES Sites in them New York DUA

Figure 23 shows the locations of 36 ACSES base station sites predicted to be desensed by ITC base stations in the New York DUA. Note that in many cases the location of the sites predicted to be desensed are very close each other, and for those cases one black dot indicates the location of multiple sites.

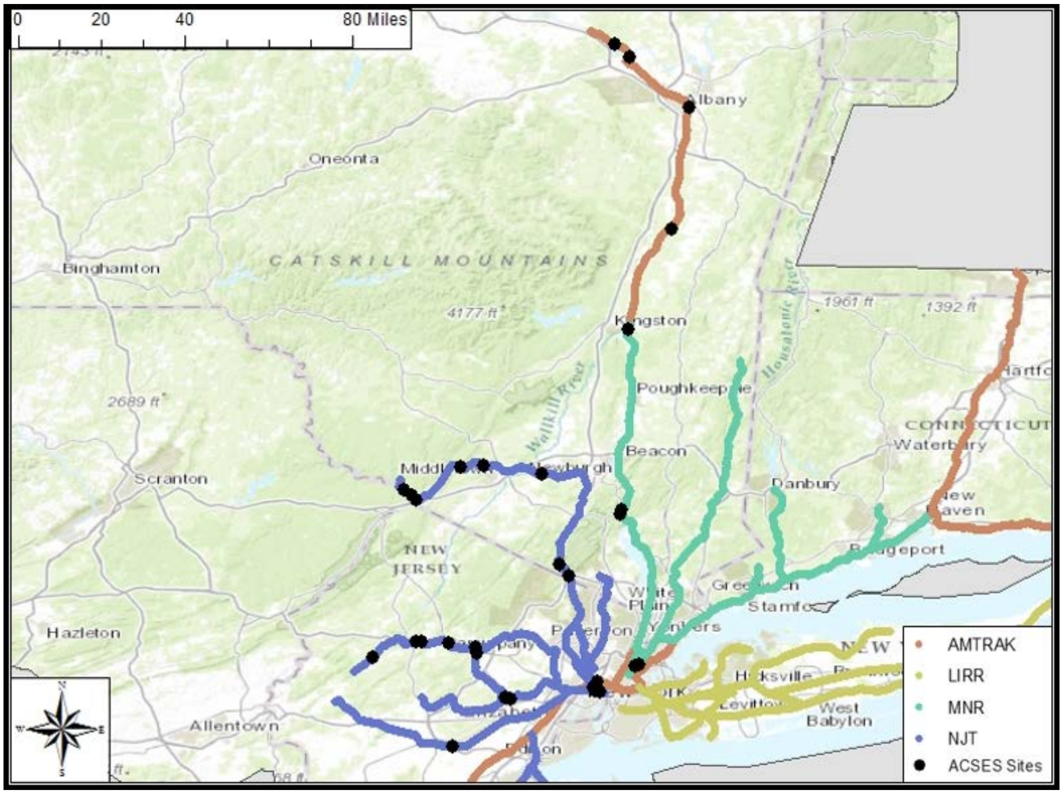

Figure 23. Location of ACSES Sites Predicted to be Desensed by ITC Sites in the New York DUA

TTCI developed the analysis of desense between fixed radio sites and locomotive radios for both systems (ACSES and ITC), as explained in Section 4.3. Table 12 summarizes the results obtained for the New York DUA. The column "Desensing" shows the number of ACSES or ITC fixed radio sites that are predicted to be desensed by locomotive radios from the dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to locomotive radios from the dissimilar system.

Table 12. Desense Results Between Fixed Radio Sites and Locomotive Radios from a Dissimilar System Inside the New York DUA

System Type	Desensing	Being Desensed by
ITC Locomotive	102 ACSES Sites	87 ACSES Sites
ACSES Locomotive	21 ITC Sites	26 ITC Sites

TTCI identified the location of the tracks where locomotive radios could cause desense to fixed radio sites from a dissimilar system, as explained in Section 4.3. Figure 24 shows the location of tracks where ITC locomotive radios are predicted to be desensed by ACSES base stations. Eighty-seven ACSES base stations are predicted to desense ITC-controlled trains along 26.8 miles of tracks.

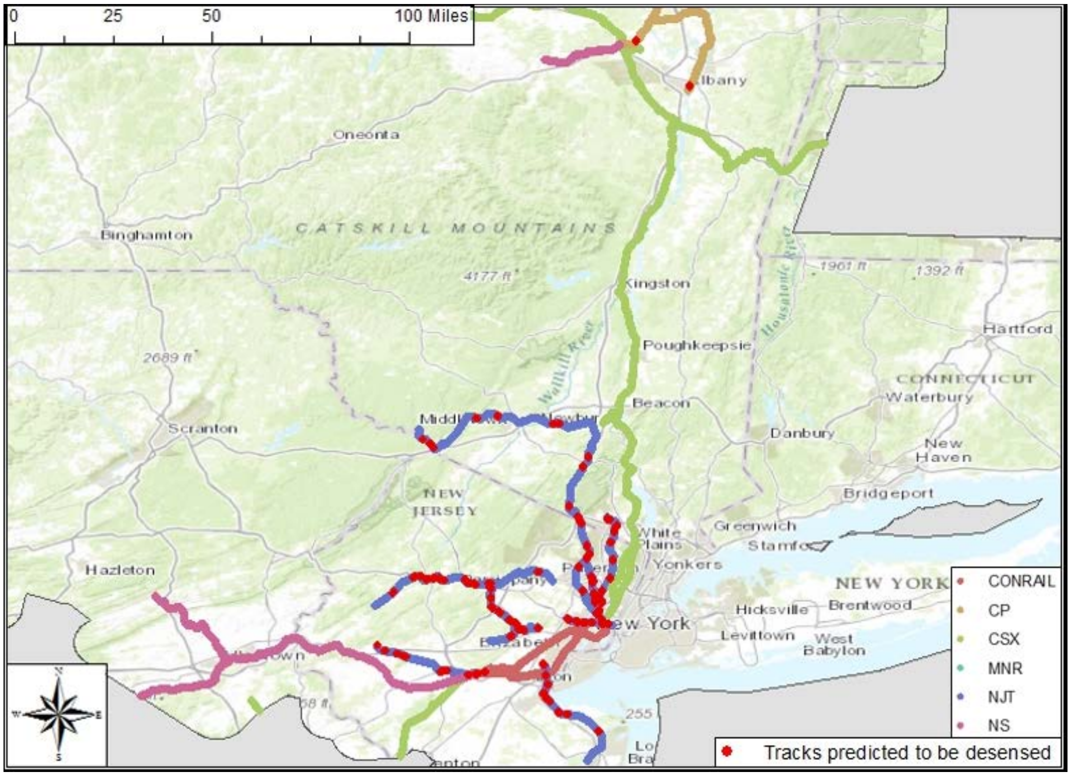

Figure 24. Location of ITC-Controlled Tracks Predicted to be Desensed by ACSES Base Stations in the New York DUA

TTCI developed the desense analysis on the tracks for the opposite direction, i.e., ITC base stations that are predicted to desense ACSES locomotive radios, and identified 26 ITC base stations predicted to potentially desense ACSES-controlled trains along 28.7 miles of tracks. Figure 25 shows the location of ACSES-controlled trains that are predicted to be desensed by ITC base stations in the New York DUA.

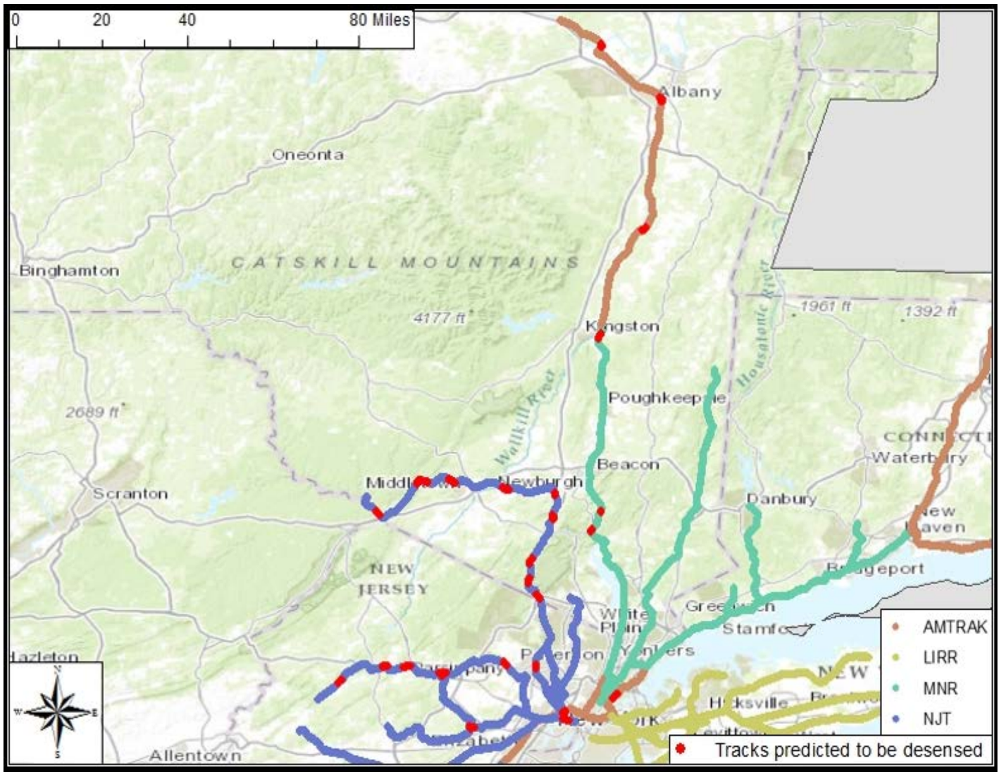

Figure 25. Location of ACSES-Controlled Tracks Predicted to be Desensed by ITC Sites in the New York DUA

The next set of results shows the potential desense that fixed radio sites from one system could suffer from locomotive radios from the dissimilar system. Figure 26 shows the location of the 102 ACSES base stations that are predicted to be potentially desensed by ITC locomotive radios in the New York DUA.

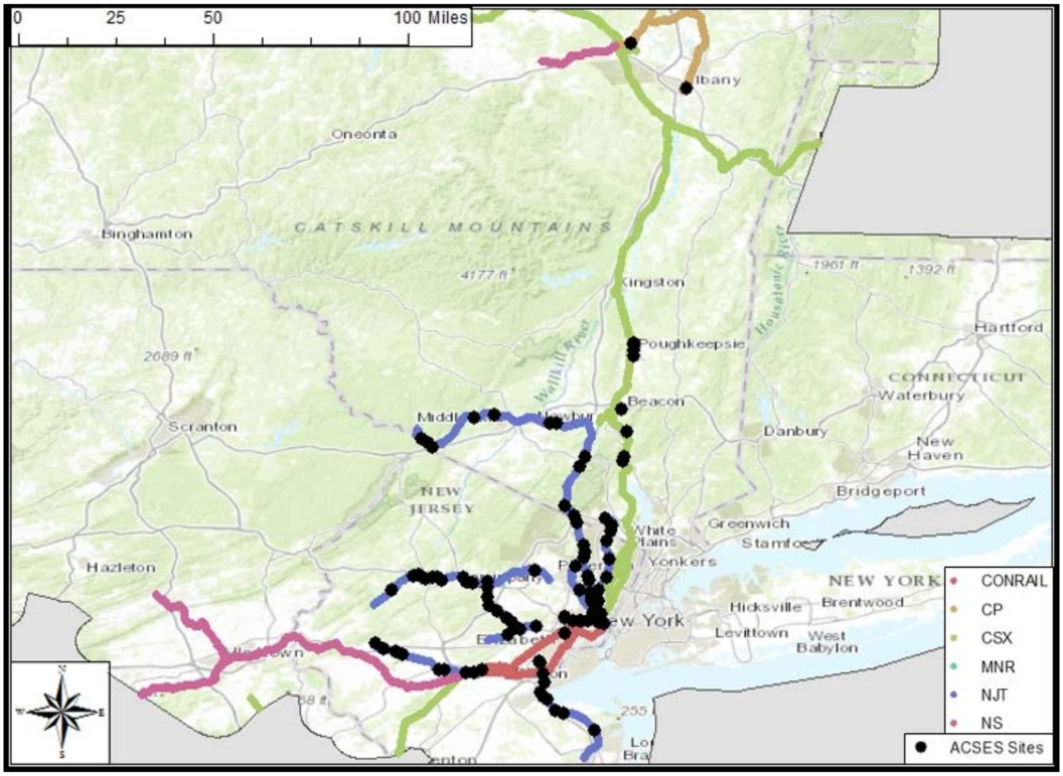

Figure 26. Location of ACSES Sites Predicted to be Desensed by ITC Locomotives in the New York DUA

Figure 27 shows the locations of the 21 ITC base stations that are predicted to be potentially desensed by ACSES locomotive radios in the New York DUA.

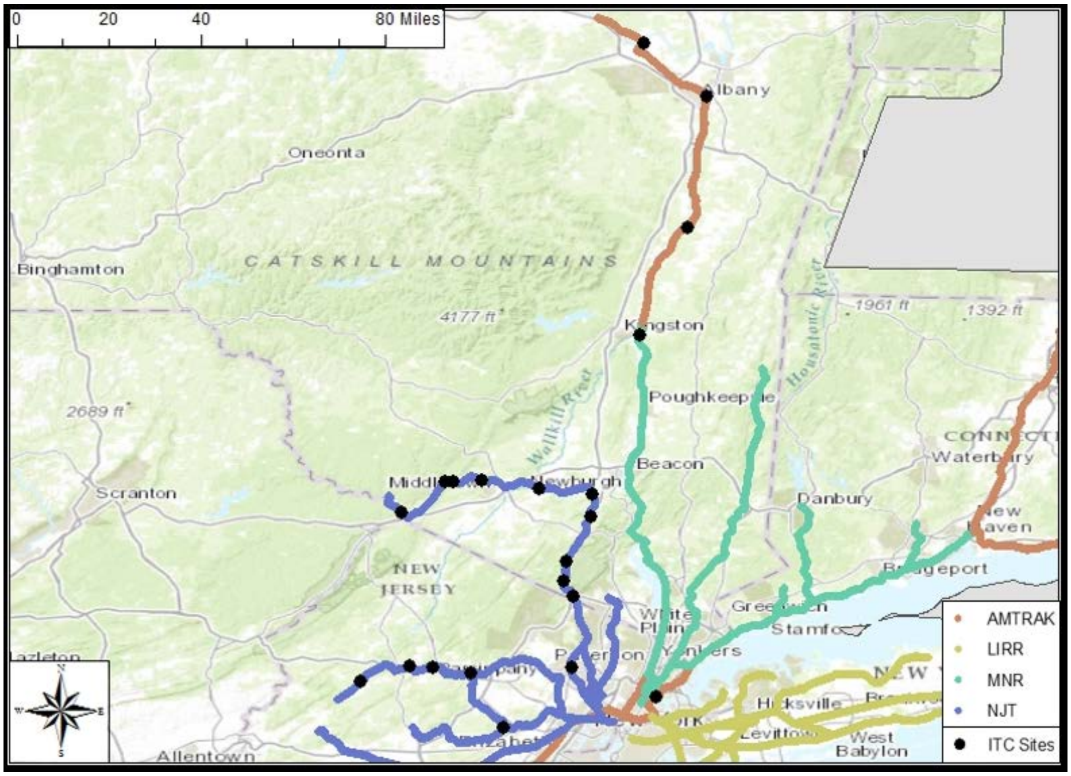

Figure 27. Location of ITC Sites Predicted to be Desensed by ACSES Locomotives in the New York DUA

5.4.7 New York DUA Base Station Coverage Analysis and Frequency Plan

The design requirement along the ITC-controlled tracks for all railroads is to have coverage from at least one ITC base station at a level of -94.37 dBm or higher. The design target along the ITC-controlled tracks for the railroads with radioless WIUs (CSX, Conrail, and NJT) is to have coverage from at least two ITC base stations at -94.37 dBm or higher.

All 59 available In-service, Planned, and Candidate ITC base stations were selected to achieve the coverage requirements over the PTC-controlled tracks in the New York DUA. These 59 base stations were analyzed with Infovista's Planet® software to determine coverage, signal strength, C/I, and other relevant parameters.

As an initial step, the ITC base stations were assigned an RF propagation model. A subset of 19 of the available models in the hosted server was tuned in regions that topographically resemble the New York DUA, as agreed with the railroads.

TTCI considered the results of the analysis of usability of NRTC spectrum described in Section 5.3 and assigned spectrum acquired from NRTC to the eligible sites listed in Table 7. Table 13 shows the selected set of base stations for the New York DUA, including antenna details, propagation models, and channel assignments. The results of the desense analysis (described in Section 5.4.6) were also considered when selecting the sites for the base station frequency plan.

Table 13. ITC Base Station Frequency Plan for the New York DUA

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height (ft)	Antenna Azimuth (degrees)	EIRP (dBm)	Channel
2105151224	Burnt Hill Mp 24	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	135	110	50.4231	153
2105151233	Ballston Spa Mp 32.99	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	135	110	50.4231	165
2105155667	Mechanicville MP467.4	IV_IV_Northeast_RU_1_Cropland_135 ft.pmf	135	30	50.4231	114
2190000001	Croxton	NF_NF_Midwest_RU_1_Cropland_85ft.pmf	100	337.6	49.70644	113
2190000004	Port Reading	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	100	349.83	49.70644	167
2190000005	Potter	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	100	316.95	49.70644	141
2190000006	Browns Yard	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	100	0	49.70644	107
2190000008	Red Bank	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	100	0	49.70644	147
3125201025	Bogota	NF_IV_MidWest-EastNorthCentral_SU_112ft.pmf	65	0	47.37186	154
3125201035	Castleton	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	142
3125201037	Cornwall	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	47.37186	101
3125201040	East Chatham	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	101
3125201053	Fort Montgomery	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	114
3125201057	Glenville	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	101
3125201076	Milton	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	47.37186	153
3125201087	Orangeburg	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	125
3125201094	Ravena	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	47.37186	167
3125201126	West Haverstraw	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	45	47.37186	113
3125201127	West Park	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	141
3125201138	Belle Meade	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	128
3125201147	Lower Gregg	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	125
3125201148	Schenectady	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	47.37186	127
3125201149	Feura Bush	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	141
3125201150	Selkirk	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	113
3125201151	Closter Bergen Cty	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	142
3125201152	Bradley Pkwy	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	90	47.37186	101
3125201153	Congers Rockland Cty	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	114

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height (ft)	Antenna Azimuth (degrees)	EIRP (dBm)	Channel
3125201154	West Point Orange Cty	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	47.37186	125
3125201155	Ulster Park Ulster Cty	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	167
3125201156	Saugerties Ulster Cty	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	127
3125201157	Catskill Greene Cty	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	165
3125201158	Coxsackie	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	65	0	47.37186	153
3125201159	Kingston	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	47.37186	142
3125201160	State Line	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	90	47.37186	125
3125201162	Valatie Columbia Cty	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	114
3125201163	Post Road	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	47.37186	154
3550046698	Easton	IV_IV_ SouthEastSouthCentral_UR_SU_95ft.pmf	150	0	50.0749	167
3550056698	Bellwood_Pattenburg	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	120	0	50.12669	154
3550066698	Stanton	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	135	0	50.12669	165
3550076697	Allentown Disp	NF_NF_Midwest_RU_1_Cropland_186ft.pmf	155	0	50.28207	127
3550076698	Manville	IV_IV_NESouthAtlantic_UR_SU_65ft.pmf	120	0	50.12669	108
3550086698	Bellwood_West_Portal	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.25086	141
3550096698	Campbell Hall	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	95	0	47.87519	127
3550116697	Lightside_Tower	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	55	0	50.28207	142
3550156698	Hackettstown	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	55	140	47.74056	125
3550176698	Lake Helen	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	100	130	47.87519	114
3550196698	Salisbury_Mills	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	42.84056	113
3550206698	Woodbury	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	100	110	47.74056	114
3550226698	Southfields	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	135	90	47.79056	113
3550236698	Suffern_Yd	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	155	0	47.67848	125

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height (ft)	Antenna Azimuth (degrees)	EIRP (dBm)	Channel
3550256698	Denville	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	135	0	50.29056	165
3550266698	Paterson_Yd_Tbt	IV_IV_SouthEastSouthCentral_UR_IND_65ft.pmf	155	90	47.67848	127
3550276698	Mountian_View	PTC220_CRC4_Suburban_16.pmf	115	0	47.78207	114
3550286698	Port_Morris_Jct	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	60	0	47.67848	154
3550316698	Wharton	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	50.29056	153
3550326698	Summit Substation	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	155	0	47.78207	101
3550336698	Port Jervis	IV_IV_NESouthAtlantic_UR_SU_65ft.pmf	140	0	47.79056	125
3550346698	Howells	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	135	0	50.28207	125
3550356698	Slostsburg	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	64	90	47.79056	114

Figure 28 shows the coverage achieved from the 59 selected ITC base stations along the ITC-controlled tracks inside the New York DUA. The base station coverage analysis indicates that 90.49 percent of the 90-meter buffer area around the ITC-controlled tracks has coverage from at least one base station at -94.37 dBm or higher.

The results of the coverage analysis developed by TTCI were reviewed with the railroads, particularly because they did not satisfy the original RF design criteria for coverage. The railroads requested TTCI to proceed with the design with the results as predicted by the RF simulation.

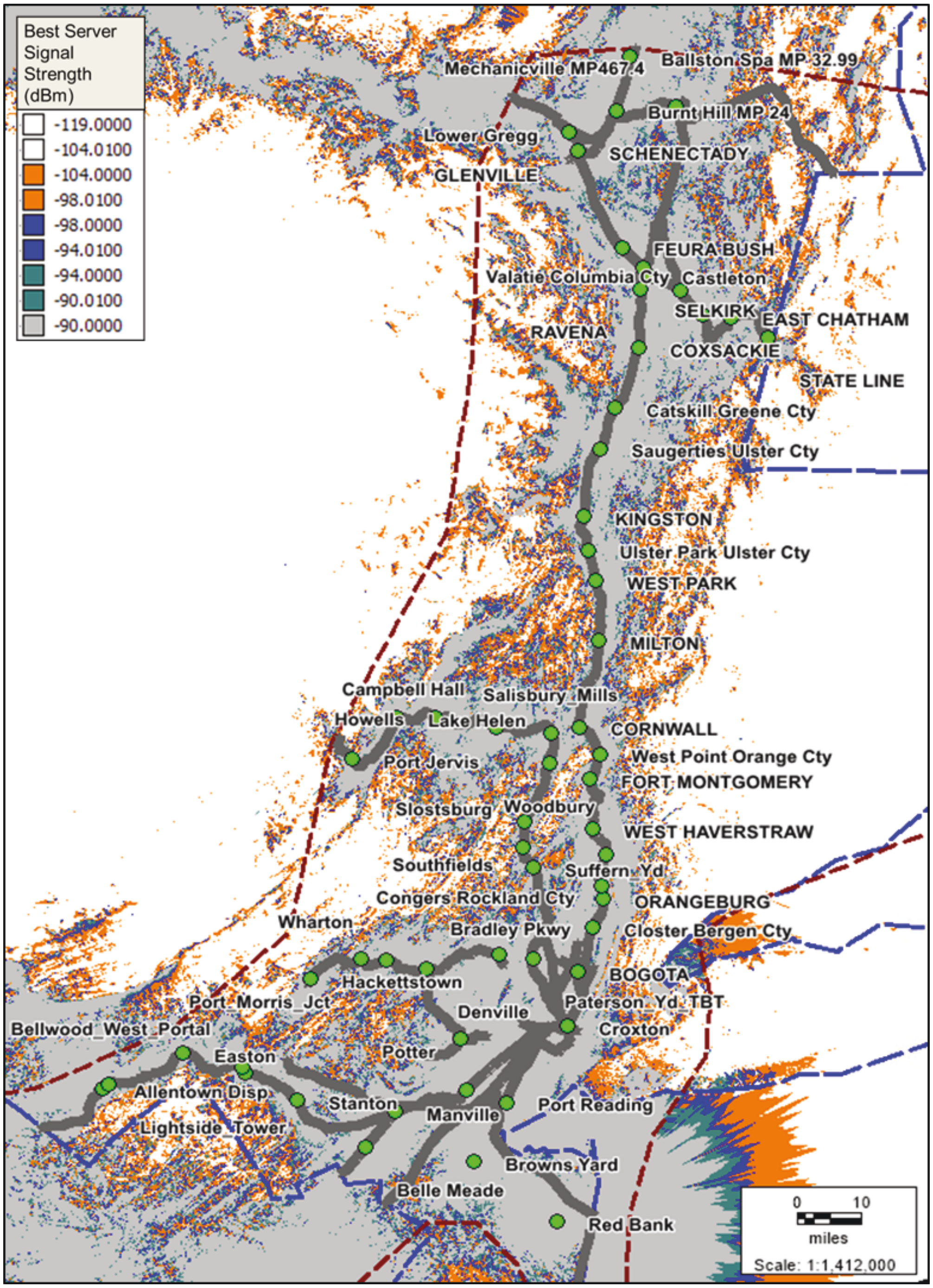

Figure 28. Best Serving ITC Base Station Signal Strength Inside the New York DUA

Propagation modeling using AFP indicates that 15 frequencies are needed to achieve the minimum C/(I+A) requirements. The channel assignments of the 15 available frequencies are shown in the rightmost column of Table 13. One additional frequency is required for the Common Channel, bringing the total to 16 frequencies.

Table 14 shows a summary of the percentage of buffer area with C/(I+A) levels above 18.6 dB and 11.5 dB. The first column in the table represents the C/(I+A) ranges, the second column represents the area in square miles of the 90-meter buffer area with the corresponding C/(I+A) levels, and the third column represents the percentage of the buffer area with the corresponding C/(I+A) levels. Although the radio is designed to handle C/I as low as 11.5 dB, that assumes no fade margin, so a higher analysis threshold is required. A C/I threshold of 18.6 dB is more conservative and thus carries lower risk.

Table 14. Percentage of Buffer Area in the New York DUA Where the Predicted C/(I+A) Levels Exceed the Thresholds of 18.6 dB and 11.5 dB

Ranges	Area (mi^2)	Percentage Sub Area
-50 ~ 0	0	0
0 ~ 11.5	0.00486488361	0.00555679
11.5 ~ 18.6	0.009729767	0.01111358
18.6 ~ 100	85.85755	98.06862

Figure 29 shows the predicted base station best serving sector coverage for the selected 59 ITC base station sites, assuming the use of the 15 available channels. The channels that are reused by multiple ITC base station sites are shown with the same color in Figure 29.

Figure 30 shows the total C/(I+A) that would be received from the best ITC base station server by an ITC locomotive radio at every point throughout the New York DUA for the ITC base station frequency plan prepared for the 59 selected ITC base stations. The objective is for the C/(I+A) to be ≥ 11.5 dB. Green and yellow colors in Figure 30 mean acceptable C/I levels, which, as can be seen, is the case for the majority of ITC-controlled tracks in the New York DUA with the selected base stations and frequencies.

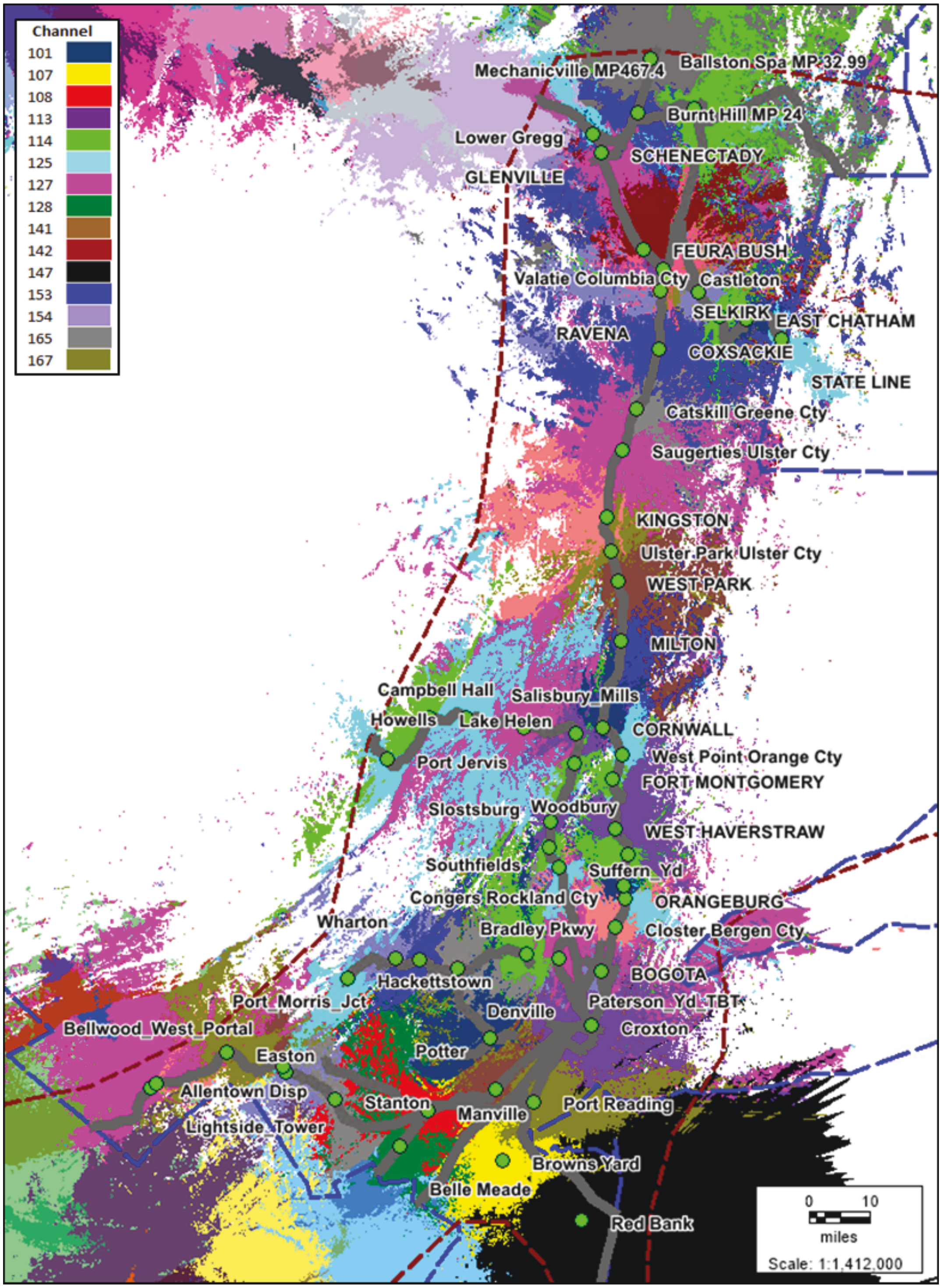

Figure 29. ITC Base Station Best Serving Sectors for the New York DUA

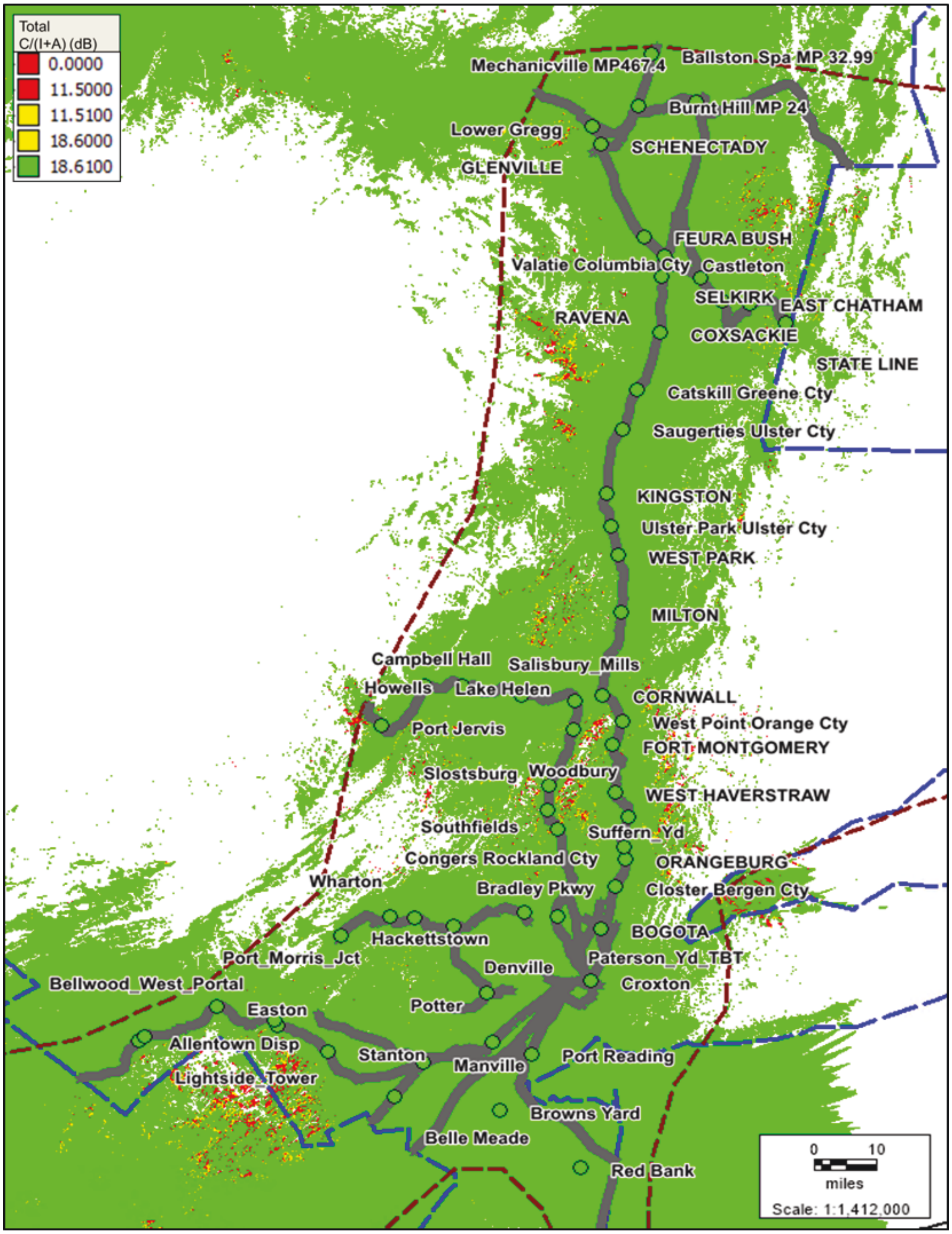

Figure 30. Predicted C/(I+A) Levels of the ITC Base Station Frequency Plan Prepared for the New York DUA

5.4.7.1 Analysis of ITC Base Station Redundancy for the New York DUA

The design target requirement along ITC-controlled tracks with radioless WIUs is to have coverage from at least two ITC base stations at a level of -94.37 dBm or higher, as indicated in Section 5.4.7. The results indicate that there is significant predicted redundancy in the ITC base station coverage along those tracks.

Figure 31 shows the predicted second best ITC base station signal strength along the ITC-controlled tracks inside the New York DUA. The analysis indicates that 54.01 percent of the ITC-controlled tracks are predicted to have coverage satisfying the requirements from at least two base stations. Note that not all of this redundancy is usable, because the C/I levels for second best servers are unknown.

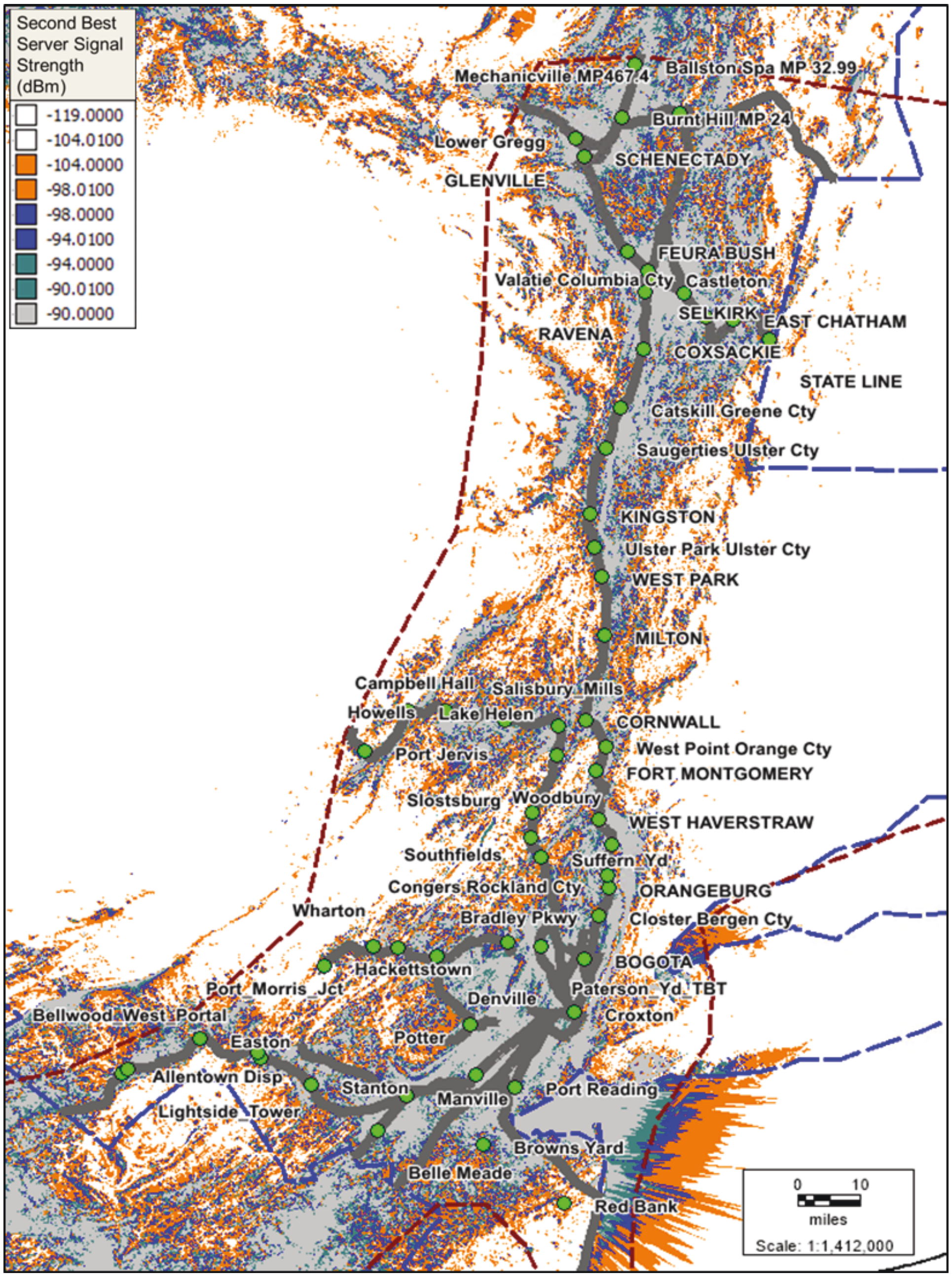

Figure 31. Predicted Second Best ITC Base Station Server Signal Strength for the New York DUA

5.4.8 New York DUA F-frame Timeslot Plan

TTCI used MCC's IPM to generate a fixed F-frame frequency/timeslot plan. As indicated in Section 5.4.4.2, a total of 196 WSM locations and 58 WIU radio sites are present inside the New

York DUA. Figure 32 shows the locations of the WSM locations and WIU radio sites. Notice that, because NJT, CSX, and Conrail are implementing radioless WIUs, their lines only show WSM locations.

Conrail informed TTCI that their base stations are still in the process of being built, and thus, their base stations were not included in the design of the F-frame timeslot plan. If they had been included, there could be a possibility that Conrail base stations would be assigned WSM transmissions via WSRS, which would cause the F-frame timeslot plan to not be immediately implementable by the other railroads in the DUA. Notice, however, that Conrail base stations were included in the D-frame frequency plan, and were assigned a frequency, so that the total demand of spectrum could be correctly determined.

As noted in Section 5.1, the F-frame plan was prepared for the entire MTA, i.e., it was not limited to just the DUA boundary.

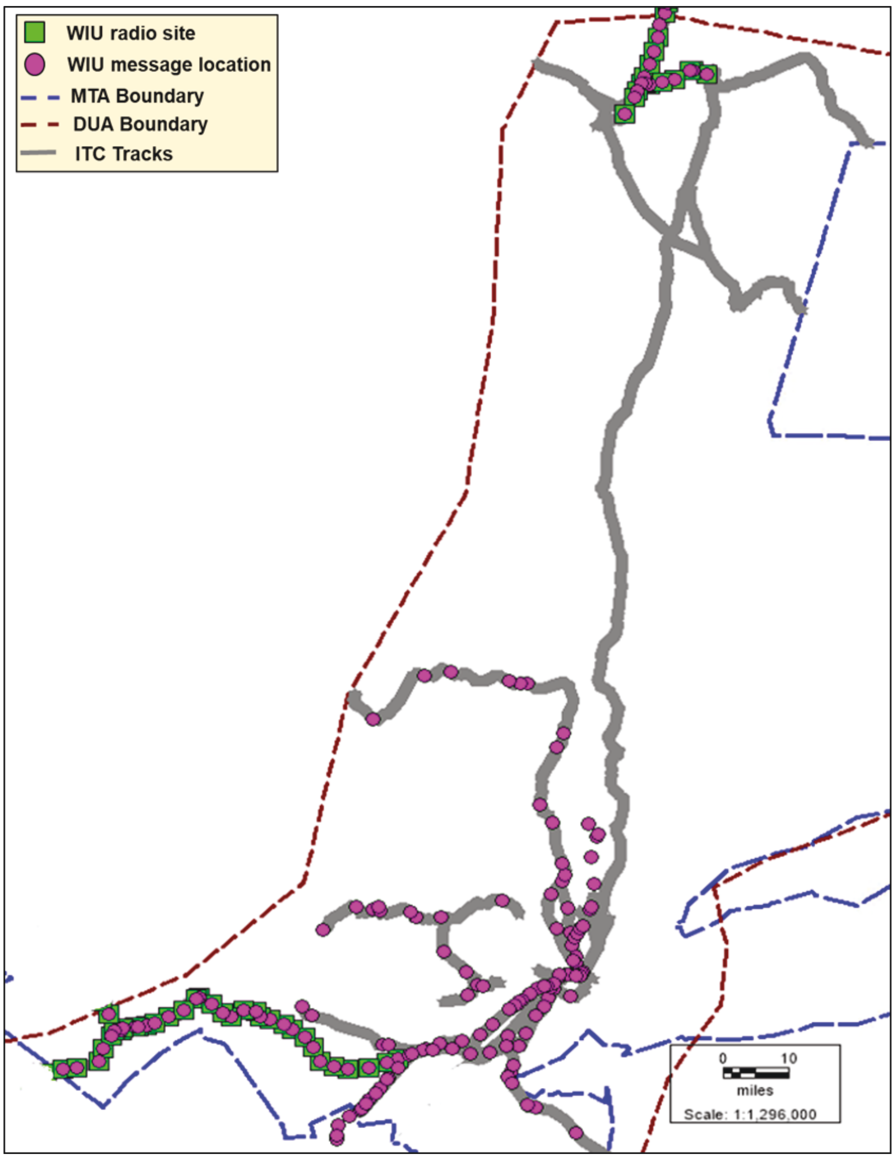

Figure 32. WSM and WIU Radio Locations Inside the New York DUA

For the specific case of the New York DUA, the following PTC Operating Zone end distances were used [3]:

- Zone 1: 0.80 miles
- Zone 2: 1.61 miles
- Zone 3: 5.19 miles

The following IPM configurations were used when generating the F-frame timeslot plan for the New York MTA:

- Zone end distances were determined based on braking distance calculations performed by TTCI [3].
- Dynamic Range Protection was used with a blocking distance of 200 feet and protection distance of 5.5 miles. These values were used on the basis of recommendations from the railroads.
- Variable timeslot lengths were used, as well as the standard duty cycles for WIU and base station radios of 10 percent and 50 percent, respectively.
- Pre-planned timeslots outside the DUA were protected within a distance of 75 miles. A 3-dB coverage adjustment was applied for segments of track where a single WSM is received by two or more radio sites (base station or WIU), effectively reducing the required signal strength for those tracks to -97.37 dBm (as opposed to -94.37 dBm for places where WSMs are only being received by a single site).

The IPM results show that an F-frame size of 1,360 milliseconds with a total of 444 timeslots will be needed for the entire New York MTA. The median offset was 245 milliseconds. All WSMs are predicted to be received by at least one base station.

A total of 382 WSMs are being broadcast by base stations. Of these, 132 are WSRS messages planned to resolve coverage gaps (94 for freight railroads, 38 for NJT), and the rest correspond to WSMs for primary and secondary coverage.

WSM coverage gaps are usually solved via WSRS. However, 157 WSMs were still predicted to have coverage gaps (post-relay gaps), even after exploring all the possible candidate ITC base stations for WSRS. In total, 820 post relay gaps were found, 771 of which correspond to radioless WIU sites, and 391 were located in PTC Operation Zone-3. Most of the post-relay gaps for the radioless WIU sites were due to the poor signal strength of the base stations providing coverage for the secondary path. TTCI provided information on post-relay gaps to the owning railroads, to allow them to verify their existence in the field.

5.4.9 New York DUA Message Traffic Loading Analysis

The message traffic loading for the New York DUA was prepared using historical train operation data provided by the railroads and TTCI's train movement simulation tool that generates train movement data used as input for the train message simulation [3].

The D-frame size for the New York MTA was calculated using the size determined for the fixed F-frame. The F-frame size for the New York MTA is 1,360 milliseconds, as described in Section 5.4.8, which leaves 2,640 milliseconds for the D-frame. As it is required to include a 20 percent provision in the D-frame for other business message traffic, the D-frame size available for PTC train message traffic is 2,112 milliseconds.

Typically, in DUAs, the peak message traffic in the D-frame is driven by passenger trains operating in peak operation times (early mornings and evenings), which will not be the case for the NEC, as all passenger trains in the NEC (from commuter and passenger railroads) will be operating under ACSES control, but not under ITC control.

The following subsections describe how these analyses were developed and the results obtained.

5.4.9.1 Exceptions in Train Operation Data in the New York DUA

Input data for train movement from different railroads varied in format, and were converted to TTCI's standard format before processing for simulations. In cases where the train data was either incomplete or missing, TTCI made some assumptions to either extrapolate the trains or create the train movement data using the information available. It is expected that the areas where some base stations did not see any train traffic due to lack of data would not be of concern in the capacity analysis as they are not expected to experience any capacity issues.

Table 15 summarizes the issues and respective resolution adopted for the exceptions in train operations data provided by the railroads for the New York DUA project.

Table 15. List of Exceptions in Train Operation Data in the New York DUA

Railroad	Subdivision	Observations/Issues	Assumptions/Resolutions
Conrail	Lehigh Line	Information available not enough to generate usable historical movement data	TTCI extrapolated CSX-Trenton trains moving north, and NS-Lehigh(LE) trains moving east all the way through Conrail-Lehigh Line.
CP		Historical data not available for the area of interest	Any bases around the CP tracks were not included in the message traffic loading analysis.
CSX	River	No historical movement data available north of MP QR-90	Trains that reported at MP QR-90 were extrapolated all the way to the north end of the subdivision to MP QR-132
CSX	Trenton	No historical movement data available north of MP QA-36	Trains that reported at MP QA-36 were extrapolated all the way to the north end of the subdivision to MP QA-58 (and onto the Conrail-Lehigh Line for another 28 miles)
NS	Lehigh(LE)	N/A	All trains reporting at MP LE-35 were extrapolated onto all the way through Conrail-Lehigh Line for about 28 miles
NJT	Morris & Essex Line	No historical movement data available	Base Stations serving this line will likely have some more train/ message traffic than shown by the available data
NJT	Atlantic City Line	No historical movement data available	Base Stations serving this line will likely have some more train/ message traffic than shown by the available data

Note that the territories that were not included in the analysis because data was not available, as indicated in Table 15, are outside the core area of the New York DUA. As the F-frame size calculated for the New York DUA (1.360 seconds) leaves a large D-frame size (2.112 seconds), the additional message traffic in the D-frame that was not included in this analysis will unlikely cause any significant impact in the capacity of the ITC base stations.

5.4.9.2 Peak Number of Trains per Base Station in the New York DUA

The first assessment of the load in the D-frame uses the number of simultaneous trains operating under each base station, based on best server base station boundaries.

TTCI determined the base station boundaries for train message association [3]. The boundaries calculated for the New York DUA are listed in the Appendix A, Section A.1.

Using the historical train movement data and the base station boundaries, TTCI calculated the peak number of simultaneous trains under each base station, which is shown in the "Current" column of Table 16. Table 16 also shows the predicted 20 percent increase in train traffic for the year 2020 (column "Year 2020").

Table 16. Peak Number of Simultaneous Trains Under Base Stations in the New York DUA

Base Station Name	Base Station ID	Train Count Current	Train Count Year 2020
Lightside	3550116697	11	14
Croxton	2190000001	9	11
Allentown 1	3550076697	9	11
Bogota	3125201025	8	10
Potter	2190000005	7	9
Easton	3550046698	7	9
Cornwall	3125201037	6	8
Belle Meade	3125201138	6	8
Manville	3550076698	6	8
Milton	3125201076	5	6
West Park	3125201127	5	6
Congers Rockland Cty	3125201153	5	6
West Point Orange Cty	3125201154	5	6
Coxsackie	3125201158	5	6
Kingston	3125201159	5	6
Bellwood East	3550066698	5	6
Paterson	3550266698	5	6
Orangeburg	3125201087	4	5
West Haverstraw	3125201126	4	5
Closter Bergen Cty	3125201151	4	5
Bradley Pkwy	3125201152	4	5
Ulster Park Ulster Cty	3125201155	4	5
Saugerties Ulster Cty	3125201156	4	5
Catskill Greene Cty	3125201157	4	5
Stanton	3550056698	4	5
Suffern_Yd	3550236698	4	5
Fort Montgomery	3125201053	3	4
Ravena	3125201094	3	4
Selkirk	3125201150	3	4
Campbell Hall	3550096698	3	4
Woodbury	3550206698	3	4
Port Reading	2190000004	2	3
Bellwood West	3550086698	2	3
Salisbury_Mills	3550196698	2	3
Southfields	3550226698	2	3
Browns Yard	2190000006	1	2
Red Bank	2190000008	1	2
Lake Helen	3550176698	1	2
Mountain View	3550276698	1	2
Port Jervis	3550336698	1	2

Base Station Name	Base Station ID	Train Count Current	Train Count Year 2020
Otisville	3550346698	1	2
Southfields	3550356698	1	2

The limit of number of simultaneous trains under a base is 24, for a 2,400 milliseconds D-frame size, according to the ITCR 220 MHz Network Design Guidelines, Section 4.2.1 [6]. Assuming that the limit for a 2,400 millisecond D-frame size can be extrapolated for the D-frame size calculated for the New York DUA (2,112 milliseconds), the maximum number of simultaneous trains would be 21 trains. The numbers shown in Table 16 indicate that none of the base stations would exceed this limit. TTCI developed a detailed investigation of the train message traffic loading, as described in the subsequent sections, to further assess any potential capacity issues.

5.4.9.3 Analysis of Base Station Message Loading for the New York DUA

TTCI investigated the peak message traffic periods predicted to be experienced by each site, after having associated the simulated train messages with their best server base station sites [3].

Table 17 shows the peak number of total messages received from (Inbound) and transmitted to (Outbound) trains by each one of the selected base station sites during one minute, at peak train message traffic. TTCI also calculated the total duration of train message transmission (column Total Duration) on the basis of duration of each message type. Figure 33 provides the same information in a bar graph format for the top 20 base stations.

Table 17. Total Duration of Train Messages at Peak Period per Base Station in the New York DUA

Base Station	Total Counts of Message (+20%)				
Name	ID	Inbound	Outbound	Total	Total Duration (milliseconds)
Lightside	3550116697	12	11	23	951
Croxton	2190000001	10	9	19	787
Allentown 1	3550076697	9	9	18	738
Bogota	3125201025	9	8	17	705
Belle Meade	3125201138	6	6	12	492
Easton	3550046698	8	5	13	557
Congers Rockland Cty	3125201153	8	4	12	524
Suffern_Yd	3550236698	8	4	12	524
Paterson	3550266698	6	5	11	459
Potter	2190000005	4	6	10	394
Bellwood East	3550066698	6	4	10	426
Manville	3550076698	6	4	10	426
Cornwall	3125201037	6	3	9	393
Milton	3125201076	6	3	9	393
West Haverstraw	3125201126	6	3	9	393
Selkirk	3125201150	5	4	9	377
Bradley Pkwy	3125201152	5	4	9	377
Coxsackie	3125201158	6	3	9	393
Kingston	3125201159	5	4	9	377
Orangeburg	3125201087	5	3	8	344
Ravena	3125201094	5	3	8	344
Closter Bergen Cty	3125201151	5	3	8	344
Saugerties Ulster Cty	3125201156	5	3	8	344
Catskill Greene Cty	3125201157	5	3	8	344
Stanton	3550056698	4	4	8	328
Fort Montgomery	3125201053	3	4	7	279

Base Station	Total Counts of Message (+20%)				
Name	ID	Inbound	Outbound	Total	Total Duration (milliseconds)
West Park	3125201127	3	4	7	279
West Point Orange Cty	3125201154	4	3	7	295
Ulster Park Ulster Cty	3125201155	4	3	7	295
Bellwood West	3550086698	4	3	7	295
Campbell Hall	3550096698	4	3	7	295
Woodbury	3550206698	4	3	7	295
Port Reading	2190000004	3	3	6	246
Browns Yard	2190000006	3	2	5	213
Red Bank	2190000008	3	2	5	213
Lake Helen	3550176698	3	2	5	213
Salisbury_Mills	3550196698	3	2	5	213
Southfields	3550226698	3	2	5	213
Mountain_View	3550276698	3	2	5	213
Port Jervis	3550336698	3	2	5	213
Southfields	3550356698	3	2	5	213
Otisville	3550346698	2	2	4	164

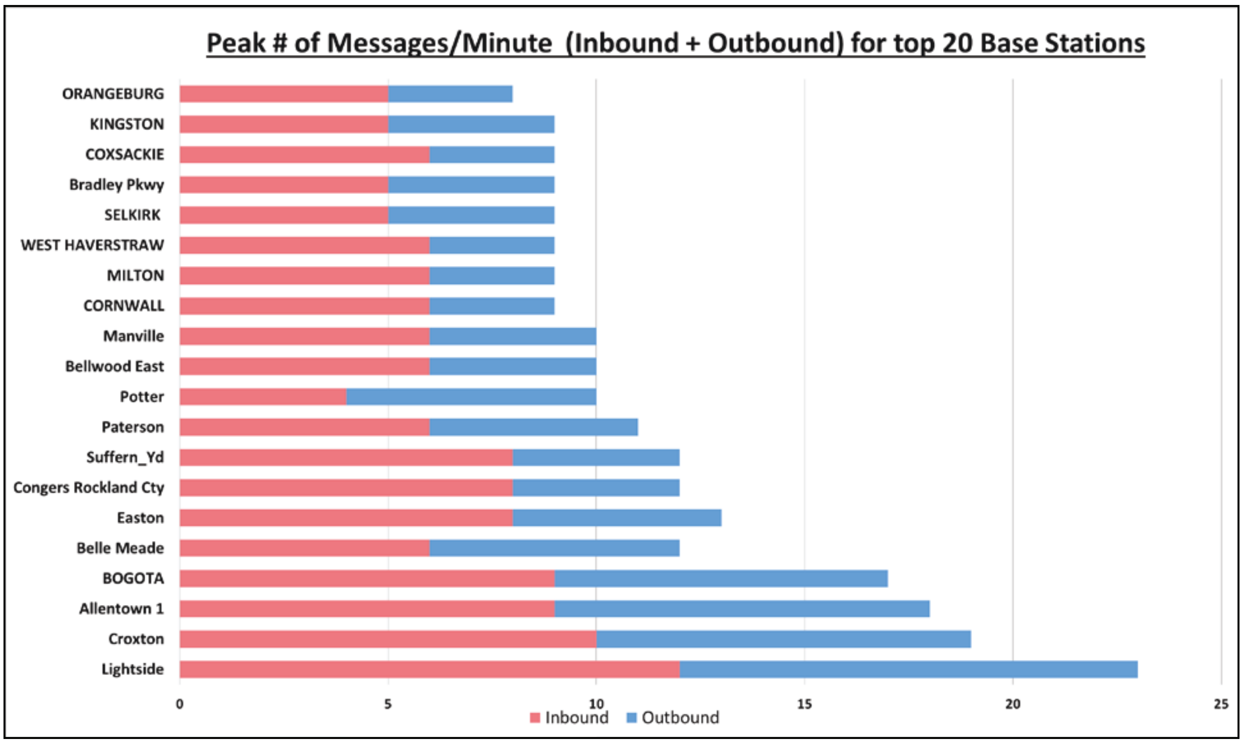

Figure 33. Total Number of Train Messages at Peak Period per Base Station in the New York DUA

The peak number of train messages shown in Figure 33 leads to some initial conclusions:

- Base station Lightside is predicted to experience the highest volume of message traffic while also having had the highest number of simultaneous trains operating under its best server coverage area.
- Base stations Croxton and Allentown are predicted to experience second and third highest message traffic in terms of message counts, respectively, and the highest number of simultaneous trains as well.

- The total number of train messages at peak times (23 messages in a minute), and the total duration of those messages (951 milliseconds), predicted to be experienced by the heaviest loaded site (Lightside) indicates that the predicted D-frame effective loading would not exceed the total D-frame size (2,112 milliseconds).

Note that this analysis was conducted over a 1-minute period instead of the 4-second cycle, in order to provide a better indication of train message traffic loading, as exceptional variation in actual train operation could generate a coincidence of simultaneous messages during the 4-second cycle that could be higher than what was obtained with train movement data provided by the railroads.

TTCI also investigated the message traffic for a 1-hour and a 24-hour window, around the times when the 1-minute peak train messages were observed. The next four figures show the results obtained for base stations Lightside and Croxton. Figure 34 and Figure 35 show the results for the 1-hour period, while Figure 36 and Figure 37 show the results obtained for the 24-hour period.

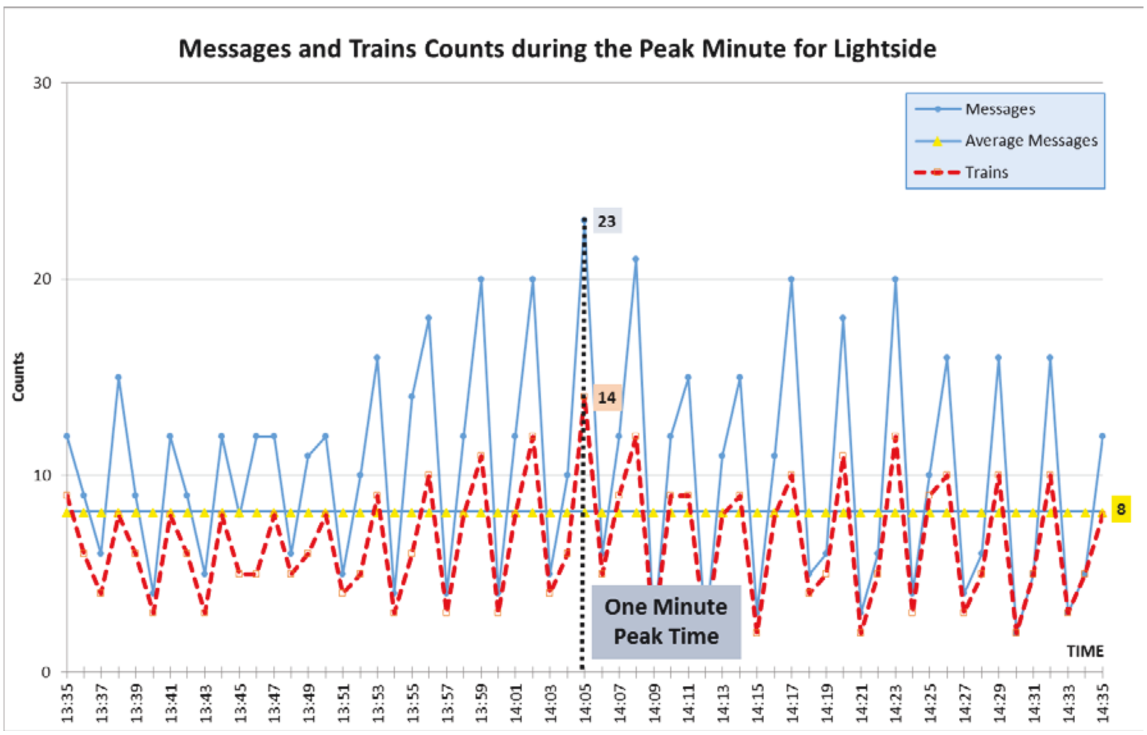

Figure 34. Counts of Train Messages/Minute During the 1-Hour Window Around the Peak Period for Base Station Lightside

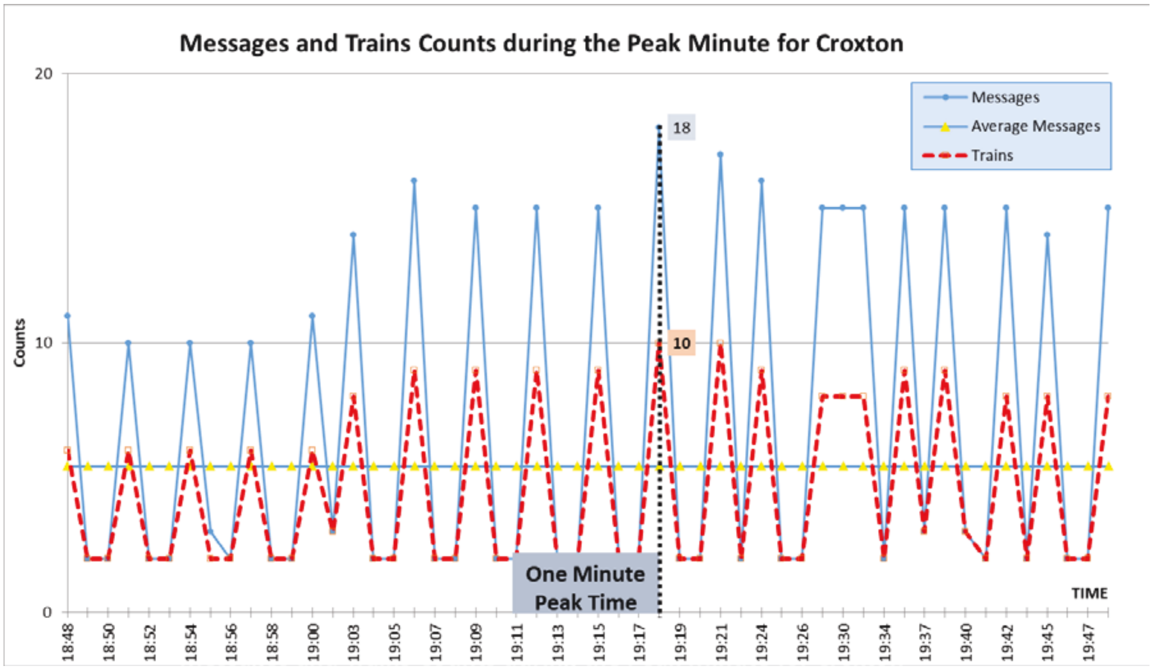

Figure 35. Counts of Train Messages/Minute During the 1-Hour Window Around the Peak Period for Base Station Croxton

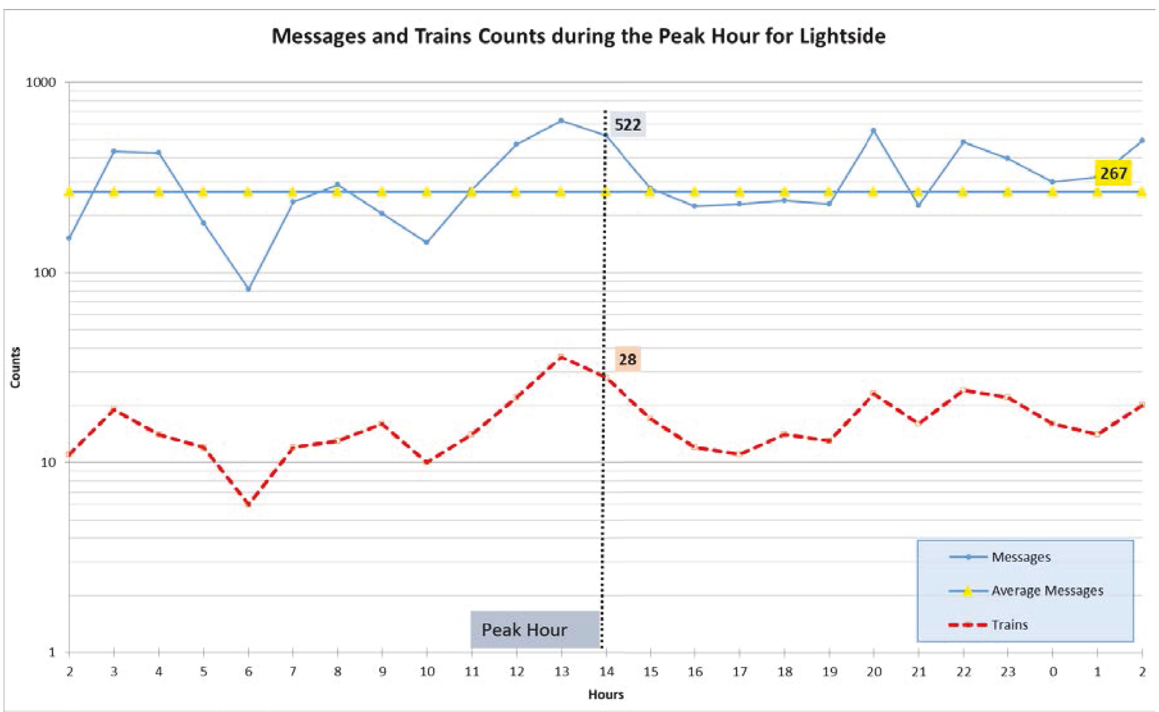

Figure 36. Counts of Train Messages/Minute During the 24-Hour Window Around the Peak Period for Base Station Lightside

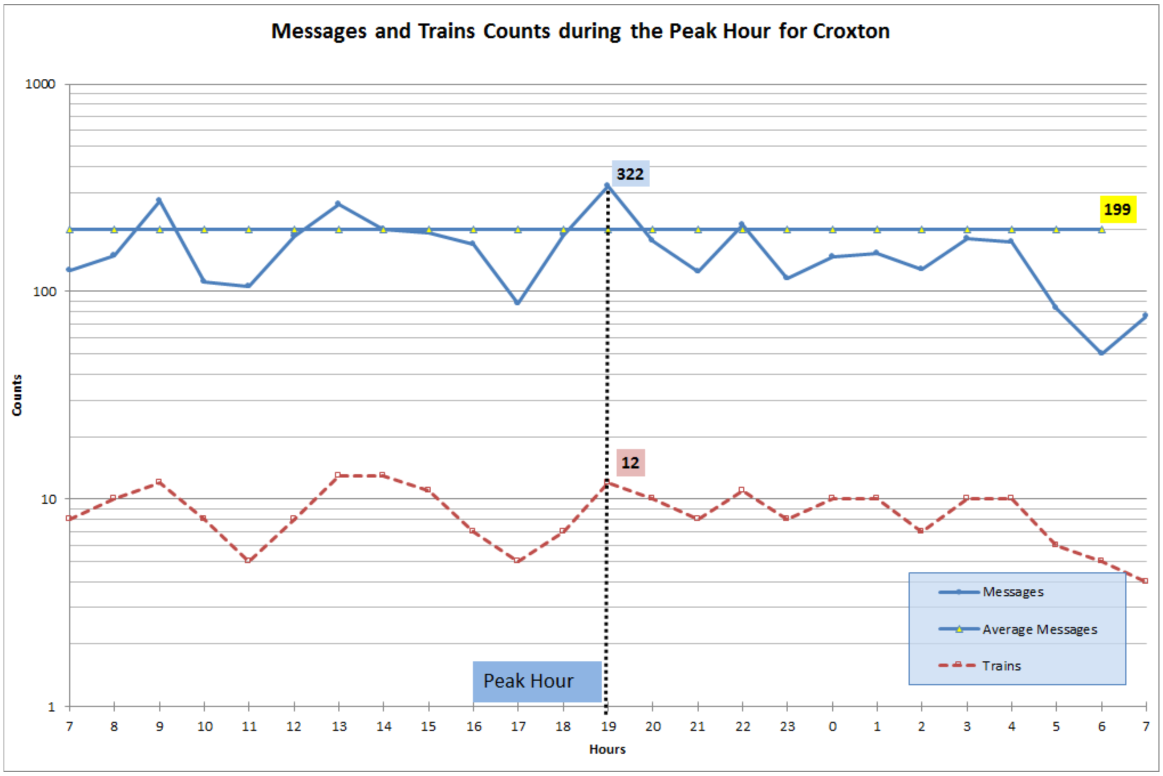

Figure 37. Counts of Train Messages/Minute During the 24-hour Window Around the Peak Period for Base Station Croxton

The graphs shown in Figure 34 and Figure 35 indicate that the peak loading number of train messages per minute does not remain consistent at peak levels, during the 1-hour window when it occurred. Instead, the average total number of train messages per minute for the base station sites would be lower than half the values calculated for the actual 1-minute peak period.

The graphs shown in Figure 36 and Figure 37 also indicate considerable variation of message traffic volumes during the 24-hour window of the day when the 1-minute peak period occurred. Similar to the 1-minute peak period, the average message traffic per hour is also much lower than the 1-hour peak period.

5.4.9.4 Analysis of Base Station Radio Duty Cycle for the New York DUA

TTCI developed the analysis of the base station radio duty cycle [3].

Table 18 shows the total transmission time during the F-frame cycle for each one of the base stations in the New York DUA.

Table 18. Total F-frame Outbound Transmission Time per Base Station in the New York DUA

Base Station Name	Base Station ID	Number of WIU Messages (WSRS)	Transmission Time (milliseconds)
Paterson	3550266698	42	1,260
Bogota	3125201025	37	1,110
Belle Meade	3125201138	37	1,110

Manville	3550076698	34	1,020
Closter Bergen Cty	3125201151	14	420
Easton	3550046698	12	360
Allentown 1	3550076697	12	360
Lightside	3550116697	8	240
Bellwood East	3550066698	6	180
Bellwood West	3550086698	6	180
Stanton	3550056698	5	150
Campbell Hall	3550096698	5	150
Suffern_Yd	3550236698	5	150
Mountian_View	3550276698	5	150
Otisville	3550346698	5	150
Bradley Pkwy	3125201152	4	120
Congers Rockland Cty	3125201153	4	120
Salisbury_Mills	3550196698	3	90
Southfields	3550226698	3	90
Lake Helen	3550176698	2	60
Woodbury	3550206698	2	60
Southfields	3550356698	2	60
Port Jervis	3550336698	1	30

Table 19 shows the maximum allowable outbound train message duration for each base station during the D-frame cycle (column "Maximum Outbound Message Duration (ms)") to not exceed the base station radio duty cycle limit (2 seconds), which is the combination of transmission time at both cycles, F-frame and D-frame. The column "Peak Outbound Message Duration (ms)/ min" shows the total D-frame outbound train message duration that was observed during peak operation at any given 1-minute period.

TTCI analyzed the possible impact on the base station radio duty cycle of a conservative "One Minute Peak" scenario, instead of just one superframe cycle (4 seconds), in which all train messages transmitted by the base station during the 1-minute peak period are transmitted simultaneously. Table 19 shows that even in this coincidental situation, none of the base stations would exceed the base station radio duty cycle limit.

It should be noted that due to very light train message traffic in the New York DUA, "Peak Outbound Message Duration (ms)/ 4 sec" for a superframe were found to be the same as that for the 1-minute period shown in Table 19.

Table 19. Predicted 4-Second and 1-Minute Peak Outbound Message Duration During the D-Frame per Base Station in the New York DUA

Base Station Name	Base Station ID	F-Frame	D-Frame	
		Outbound Message Duration (milliseconds)	Maximum Outbound Message Duration (milliseconds)	Peak Outbound Message Duration (milliseconds)/ minute
Lightside	3550116697	240	1760	363
Croxton	2190000001	0	2000	297

Base Station Name	Base Station ID	F-Frame	D-Frame	
		Outbound Message Duration (milliseconds)	Maximum Outbound Message Duration (milliseconds)	Peak Outbound Message Duration (milliseconds)/ minute
Allentown 1	3550076697	360	1640	297
Bogota	3125201025	1110	890	264
Potter	2190000005	0	2000	198
Belle Meade	3125201138	1110	890	198
Easton	3550046698	360	1640	198
Paterson	3550266698	1260	740	198
Cornwall	3125201037	0	2000	165
Congers Rockland Cty	3125201153	120	1880	165
Coxsackie	3125201158	0	2000	165
Kingston	3125201159	0	2000	165
Bellwood East	3550066698	180	1820	165
Manville	3550076698	1020	980	165
Fort Montgomery	3125201053	0	2000	132
Milton	3125201076	0	2000	132
Orangeburg	3125201087	0	2000	132
Ravena	3125201094	0	2000	132
West Haverstraw	3125201126	0	2000	132
West Park	3125201127	0	2000	132
Selkirk	3125201150	0	2000	132
Closter Bergen Cty	3125201151	420	1580	132
Bradley Pkwy	3125201152	120	1880	132
Saugerties Ulster Cty	3125201156	0	2000	132
Catskill Greene Cty	3125201157	0	2000	132
Stanton	3550056698	150	1850	132
Suffern_Yd	3550236698	150	1850	132
Port Reading	2190000004	0	2000	99
West Point Orange Cty	3125201154	0	2000	99
Ulster Park Ulster Cty	3125201155	0	2000	99
Bellwood West	3550086698	180	1820	99
Campbell Hall	3550096698	150	1850	99
Woodbury	3550206698	60	1940	99
Browns Yard	2190000006	0	2000	66
Red Bank	2190000008	0	2000	66
Lake Helen	3550176698	60	1940	66
Salisbury_Mills	3550196698	90	1910	66
Southfields	3550226698	90	1910	66
Mountian_View	3550276698	150	1850	66
Port Jervis	3550336698	30	1970	66
Otisville	3550346698	150	1850	66
Southfields	3550356698	60	1940	66

5.4.9.5 Analysis of Impact of Bulletin Dataset Messages for the New York DUA

TTCI performed the latency analysis of Bulletin Dataset messages [3].

Table 20 shows the estimated latency that train messages would experience for all the base station sites in the New York DUA, if Bulletin Dataset messages were sent at peak operation time.

Table 20. Predicted Latency Caused by Bulletin Dataset Messages at Peak Train Operation Periods in the New York DUA

Base Station Names	Number of Trains	Maximum Outbound Message Duration (milliseconds)	Maximum Bulletin Messages/D-Frame	No. of D-Frame Cycles Needed for All Bulletin Messages	Maximum Latency (seconds)
Bogota	10	890	6	2	7
Belle Meade	8	890	6	2	7
Manville	8	980	7	2	7
Lightside	14	1760	13	2	6
Paterson	6	740	5	2	6
Croxton	11	2000	15	1	3
Port Reading	3	2000	15	1	3
Potter	9	2000	15	1	3
Browns Yard	2	2000	15	1	3
Red Bank	2	2000	15	1	3
Cornwall	8	2000	15	1	3
Fort Montgomery	4	2000	15	1	3
Milton	6	2000	15	1	3
Orangeburg	5	2000	15	1	3
Ravena	4	2000	15	1	3
West Haverstraw	5	2000	15	1	3
West Park	6	2000	15	1	3
Selkirk	4	2000	15	1	3
Closter Bergen Cty	5	1580	12	1	3
Bradley Pkwy	5	1880	14	1	3
Congers Rockland Cty	6	1880	14	1	3
West Point Orange Cty	6	2000	15	1	3
Ulster Park Ulster Cty	5	2000	15	1	3
Saugerties Ulster Cty	5	2000	15	1	3
Catskill Greene Cty	5	2000	15	1	3
Coxsackie	6	2000	15	1	3
Kingston	6	2000	15	1	3
Easton	9	1640	12	1	3
Stanton	5	1850	14	1	3
Bellwood East	6	1820	14	1	3
Allentown 1	11	1640	12	1	3
Bellwood West	3	1820	14	1	3
Campbell Hall	4	1850	14	1	3
Lake Helen	2	1940	14	1	2
Salisbury_Mills	3	1910	14	1	2

Base Station Names	Number of Trains	Maximum Outbound Message Duration (milliseconds)	Maximum Bulletin Messages/D-Frame	No. of D-Frame Cycles Needed for All Bulletin Messages	Maximum Latency (seconds)
Woodbury	4	1940	14	1	2
Southfields	3	1910	14	1	2
Suffern_Yd	5	1850	14	1	2
Mountian_View	2	1850	14	1	2
Port Jervis	2	1970	15	1	2
Otisville	2	1850	14	1	2
Southfields	2	1940	14	1	2

Note that Bulletin Dataset message transmission at peak operation time is unlikely to occur with high frequency during the railroad operation (a simultaneous transmission typically would occur only once a day). Such message transmission would be noticed as "spikes" in the D-frame traffic and, unless railroads require extremely low message latency requirements for the D-frame, the impact caused by the burst of Bulletin Dataset messages can likely be absorbed by the system without impacting train operations [3].

Still even during those spikes, the maximum predicted latency would not exceed two superframe cycles for the heaviest loaded site, which could be easily absorbed without any impact in train operation.

5.4.9.6 Analysis of Projected Train Traffic Increase for the New York DUA

The train message simulation developed by TTCI used current train operation traffic levels provided by the railroads, i.e., it did not include projection of train traffic for the year 2020. This is due to the fact that the addition of train traffic to the historical train operation data provided by the railroads might lead to unfeasible train traffic, as the additional train traffic cannot be simulated with valid train movements.

For this reason, the analysis of projected train message traffic for this project focused on the portion of the D-frame that is left for an increase in train message traffic, using current train message traffic loading.

The analyses developed in the previous subsections concluded the following:

- The total number of train messages at peak periods for the heaviest loaded base station site, Lightside, is predicted to not exceed 23 train messages total (inbound + outbound) for the projected year of 2020.
- The analysis of total train message traffic over 1-hour and 24-hour periods predicts that peak train message traffic would not be experienced for prolonged periods.
- The analysis of the D-frame capacity indicates that none of the base stations are predicted to exceed the D-frame capacity (i.e., there would be no latency), even in the conservative scenario (One-Minute Peak operation).

- Bulletin Dataset message traffic is predicted to create spikes of transmission that might cause delays of up to 7 seconds for three base stations: BOGOTA, Belle Meade, and Manville. These spikes of Bulletin Dataset message transmission would typically occur once a day and would not cause any significant impact in the D-frame traffic.

These results indicate that the current RF network design for the ITC system in the New York DUA would allow the system to handle substantially more train traffic than is currently operated by the railroads, without causing impacts to the operation of the trains due to additional D-frame train message traffic.

5.4.10 New York DUA RF Network Design Conclusions

The results of the analyses presented in the previous sections lead to the following conclusions:

- A total of 59 base stations are needed to achieve coverage along PTC-controlled tracks in the New York DUA.
  - 90.49 percent of the tracks inside the DUA are predicted to have coverage from at least one base station with an RSS of at least -94.37 dBm.
  - 54.01 percent of the tracks inside the DUA are predicted to have coverage from at least two base stations with an RSS of at least -94.37 dBm.
- The results obtained from the F-frame analysis indicate that a minimum F-frame size of 1,360 milliseconds will be needed to accommodate all the timeslots in the MTA.
  - A total of 48 WIU radio sites and 187 WSMs were planned in the F-frame design of the DUA. The plan includes a frequency/timeslot plan for all of them.
  - A total of 382 WSMs are planned to be broadcast by base stations (via WSRS). One hundred thirty-two of these WSRS messages are planned to solve coverage gaps.
- Radio Desense between ACSES and ITC sites is predicted to occur at multiple locations:
  - Thirty-six ACSES radio sites are predicted to be desensed by fixed ITC radios. One hundred-two ACSES radio sites are predicted to be desensed by ITC locomotive radios. ACSES locomotive radios are predicted to be desensed by 26 ITC radio sites in a total of 28.7 miles of tracks.
  - Six ITC radio sites are predicted to be desensed by ACSES fixed radio sites. Twenty-one ITC radio sites are predicted to be desensed by ACSES locomotives. ITC locomotive radios are predicted to be desensed by 87 ACSES radio sites in a total of 26.8 miles of tracks.
- Thirty-three non-railroad licensees (incumbents) operating in the 217–222 MHz band operating in 347 unique locations were found:
  - Thirteen possible cases of desense or interference with non-railroad incumbents were found.
  - The RF design was adjusted to mitigate potential desense issues by assigning channels to ITC sites that would not cause issues.
  - Notification letters were sent to the non-railroad incumbents and concurrence was obtained from all of them.

- A total of 16 channels will be needed to allow the operation of the ITC radio system inside the New York DUA, including one channel for use as the Common Channel:
  - For D-frame communications, the base stations will need 15 channels as local channels.
  - For F-frame communications, six of the PTC-220 LLC nationwide channels in the 220–221 MHz band will be needed.
- Train message traffic in the D-frame for all base stations is predicted to be relatively low and not cause any impact on train operations
  - At the peak message traffic periods, none of the base station sites are predicted to exceed the total D-frame capacity.
  - The peak number of simultaneous trains under a base station provides an indication about the likely most heavily loaded base stations in terms of train message traffic, but it does not provide an indication of the loading of the D-frame.
  - The results of the duty cycle analysis indicate that, even at peak periods, none of the ITC radios would reach their duty cycle limit.
  - Base stations will operate below the volume calculated for peak periods for the majority of the time. Simultaneous transmission of Bulletin Dataset messages typically occur once a day and can likely be managed to not coincide with peak train operation times. The duty cycle is not predicted to become an issue for the New York DUA base stations.
  - All base stations are predicted to be able to handle substantially more train traffic volumes than currently operated by the railroads that operate in the New York DUA. This spare capacity could be useful for business traffic, Short Message Service (SMS) messages, Network Management messages, and future growth or peaks in train traffic.

Overall, the resources available (220 MHz radio spectrum, base station sites, and WIU radio sites) are sufficient for the normal operation of ITC-controlled trains inside the New York DUA, given that railroads deploy and configure all ITC radio system components per the frequency-timeslot plan prepared by TTCI and that all the desense issues predicted by TTCI between ACSES and ITC radios are properly addressed by the railroads. The predicted redundant coverage (54.01 percent) indicates that trains may experience impact in a degraded mode, such as the failure of a base station. Visual inspection of the second-best server plots shows some continuous extension of tracks without redundant coverage, particularly on CSX tracks west of Hudson River. A detailed analysis of redundant coverage is strongly recommended before full operation of the ITC system commences in the New York DUA.

5.5 RF Network Design for the Philadelphia DUA

5.5.1 Philadelphia DUA Project Scope

The ITC system RF design project for the Philadelphia DUA includes the planned PTC-controlled tracks, base stations, and WIU radio sites from five railroads: CSX, NS, Conrail, SEPTA, and Amtrak.

The design also includes the desense analysis between ITC and ACSES radios for all the fixed sites and tracks where PTC-equipped trains from both systems operate. The analysis of train message traffic included all trains operating under ITC system control within the project boundaries.

5.5.2 Philadelphia DUA Boundaries

The Philadelphia DUA boundary includes all PTC-controlled tracks within approximately 42 miles northeast from downtown Philadelphia, 94 miles to the southwest, 99 miles to the west, and 52 miles to the northwest.

Figure 38 shows the boundaries of the Philadelphia DUA and the PTC-controlled tracks from all the railroads for both ACSES and ITC systems. The design of the ITC system considered all the In-Service, Candidate, and Planned ITC base stations and WIUs provided to TTCI for every railroad/subdivision included inside the boundaries.

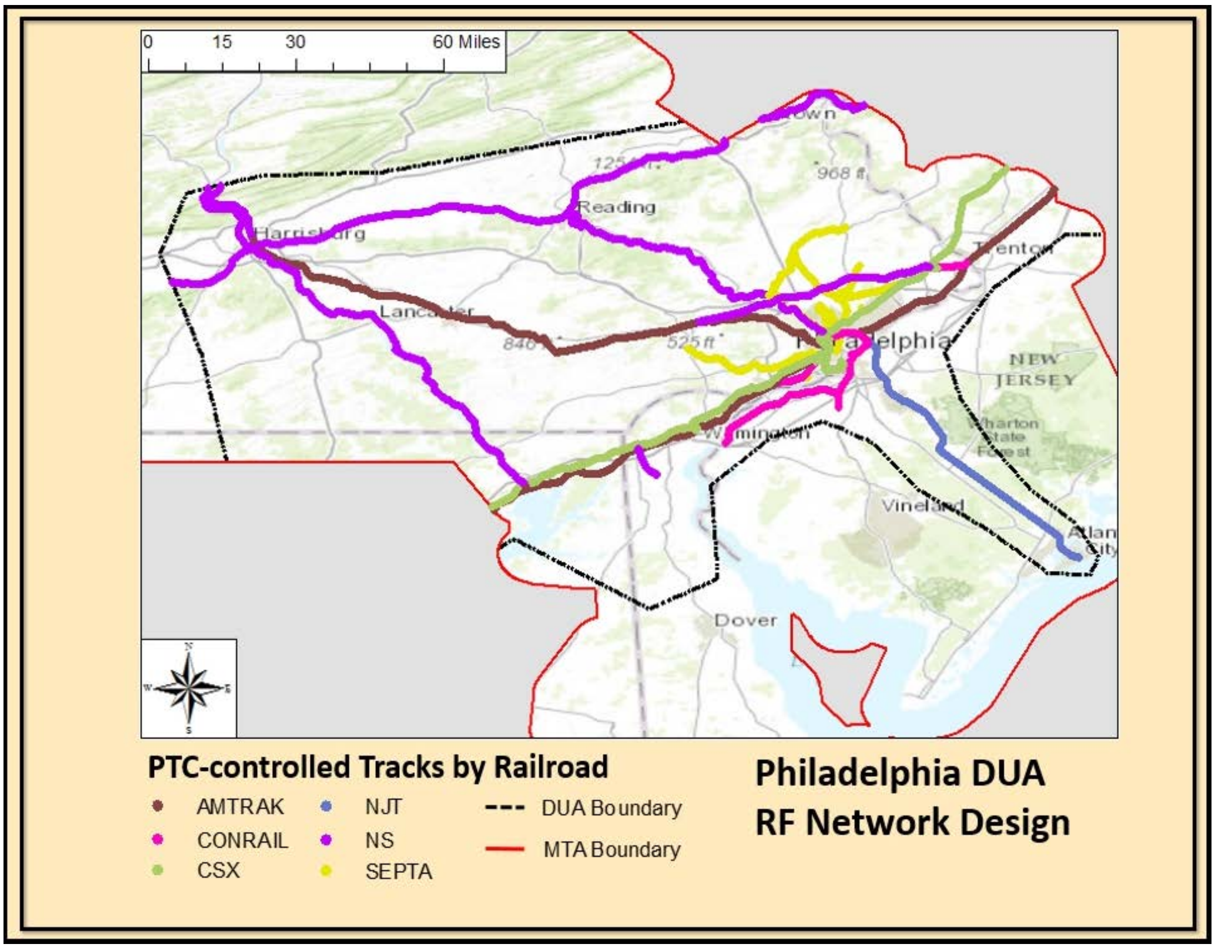

Figure 38. PTC-Controlled Tracks Within the Philadelphia DUA Boundaries

PTC-controlled tracks can be configured to support the operation of trains operating with either of the systems (ACSES or ITC) or both systems simultaneously (dual-equipped), as explained in Section 2.2. Figure 38 displays the PTC-controlled tracks identified by the type of control system in the Philadelphia DUA.

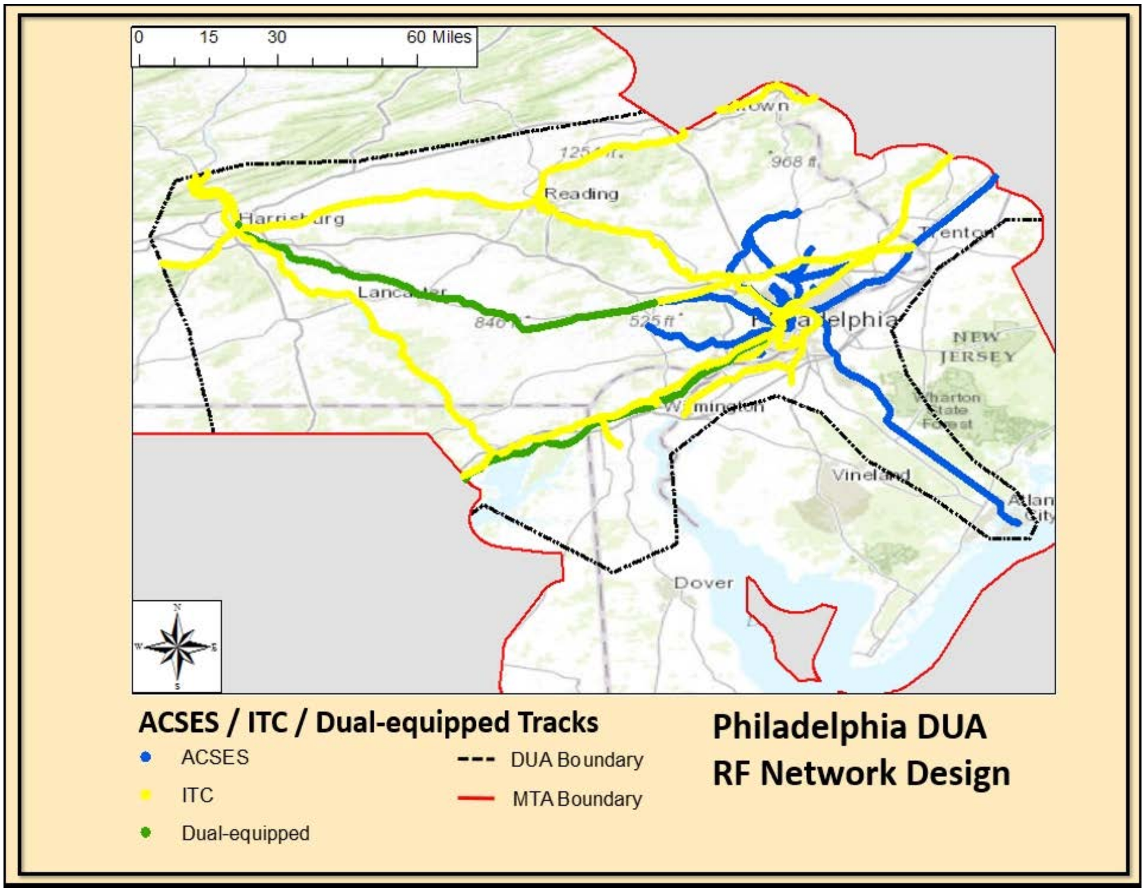

Figure 39. ACSES, ITC and Dual-Equipped Tracks in Philadelphia DUA

5.5.3 List of Railroads and Subdivisions Inside the Philadelphia DUA

Four different railroads were included in the design of the ITC system for the Philadelphia DUA. Table 21 lists the railroads, their subdivisions, and range of route-mile tracks included in the study. Notice that for Amtrak and Conrail, the exact initial and final mileposts (MP) were not provided and TTCI calculated the extension of the tracks based on visual inspection in GIS tools.

Table 21. List of ITC-Controlled Route Miles per Railroad Included in the Philadelphia DUA

Railroad	Subdivision	Start MP	End MP	Route Miles
Amtrak	Philadelphia-Washington, DC	N/A	N/A	58.8
Amtrak	Philadelphia-Harrisburg	N/A	N/A	104
Conrail	Morrisville Line	N/A	N/A	6.11
Conrail	Chester	N/A	N/A	9.6
Conrail	Vineland Secondary	N/A	N/A	11.7
Conrail	Penns Grove	N/A	N/A	7.7
Conrail	Delair	N/A	N/A	9.3
CSX	Philadelphia	0	57.7	57.7
CSX	Trenton	4.7	44	39.3
NS	Harrisburg	5.2	111.5	106.3
NS	Port Road(PD)	0	39.7	39.7
NS	Port Road(EP)	33.7	73	39.3
NS	Reading(RV)	0	22.6	22.6
SEPTA	Norristown	12.6	13.5	0.9
Total				513.01

5.5.4 Philadelphia DUA Data Gathering and Consolidation

5.5.4.1 Philadelphia DUA Base Station Input Data

Table 22 contains the list of the 33 base station sites that were considered in the RF design developed by TTCI. The list of sites was obtained from information provided by the railroads.

The Status column in Table 22 indicates the status of operation of the base station site, base station sites marked as In-service or Planned were considered as preferred sites in the RF design developed. Sites with a status of Candidate were considered only on an as-needed basis.

Table 22. List of Base Stations Included in the RF Design for the Philadelphia DUA

Site ID	Sector ID	Status	Antenna Center of Radiation Height(ft)	Antenna Azimuth (degrees)	Antenna Model
2190000100	Deepwater	Candidate	30	0	SD212-SF3P2SNM_0220.pafx
2190000101	Morrisville	Candidate	90	0	SD212-SF3P2SNM_0220.pafx
2190000102	Paulsboro	Candidate	90	0	SD212-SF3P2SNM_0220.pafx
3125209002	Wilmington	Planned	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125209003	Chester	Planned	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125209005	Rg Tower	In_Service	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125209021	Foys Hill	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125209039	Berry	In_Service	65	40	2-290-70-220_Back_to_Back.pafx
3125209059	Chester Pike	Planned	20	125	SD222-SF6PASNM(OM)_0160.pafx
3125209060	Olney	Planned	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125209061	Woodside	Planned	60	40	SD222-SF6PASNM(OM)_0160.pafx
3125209062	Pennington	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210020	Perryville	Planned	65	80	SD222-SF6PASNM(OM)_0160.pafx
3125210023	Elk Mills	Planned	65	80	SD222-SF6PASNM(OM)_0160.pafx

Site ID	Sector ID	Status	Antenna Center of Radiation Height(ft)	Antenna Azimuth (degrees)	Antenna Model
3550036695	Port Deposit	In_Service	100	0	PCTEL_BOA2177.pafx
3550036696	Frazer	Planned	95	240	SY206-SF11SNM(U)_0225.pafx
3550036697	Mount Penn Mw	Planned	75	270	SD212-SF3P4SNM_0220.pafx
3550046695	Conowingo	In_Service	75	125	445-109 Dual Band.pafx
3550046696	County_Line	Planned	135	340	PCTEL_BOA2177.pafx
3550056695	Holtwood	In_Service	100	0	PCTEL_BOA2177.pafx
3550056697	Balndon	Planned	135	335	PCTEL_BOA2177.pafx
3550056699	Newark	Planned	155	0	PCTEL_BOA2177.pafx
3550066695	Safeharbor	In_Service	90	0	PCTEL_BOA2177.pafx
3550076694	Bluemtn	In_Service	25	90	445-109 Dual Band.pafx
3550076695	Cola	In_Service	90	0	PCTEL_BOA2177.pafx
3550086695	Cly	In_Service	55	50	SD212-SF3P2SNM_0220.pafx
3550136694	Avon_Lebanon	In_Service	125	0	PCTEL_BOA2177.pafx
3550166694	Birdsboro	Planned	95	20	SD212-SF3P2SNM_0220.pafx
3550196694	Phoenixville	In_Service	80	0	PCTEL_BOA2177.pafx
3550226694	Falls	In_Service	55	215	SD212-SF3P2SNM_0220.pafx
3550236694	Ernest	In_Service	115	0	PCTEL_BOA2177.pafx
3550246694	Lancaster	Planned	95	300	SY206-SF11SNM(U)_0225.pafx
3550266694	Atglen	Planned	135	325	PCTEL_BOA2177.pafx

5.5.4.2 Philadelphia DUA WIU Input Data

The WIU data used in the RF design for the Philadelphia DUA was provided by the PTC-220 LLC railroad members (NS and CSX) included in the design. For SEPTA and Amtrak, the data was developed by TTCI and validated by the owning railroads. For Conrail, TTCI developed an initial estimation of WIU site locations based on track charts and visual inspection in GIS tools, however, Conrail was still discussing the details of their design along their territory and it was decided not to include TTCI's estimation in the design.

SEPTA, Amtrak and CSX indicated that their WIU devices will not be equipped with WIU radios, meaning that all their WSMs will use WSRS transmission from ITC base stations. Table 23 shows the total number of WIU radio locations and WIU devices for each railroad.

Table 23. Counts of WIU Radio and WIU Device Locations in the Philadelphia DUA

Railroad	No. of WIU Radio Locations	No. of WSMs
Amtrak	0	31
CSX	0	66
NS	110	142
SEPTA	0	2
Total	110	241

Figure 40 illustrates the distribution of all WSMs along the PTC-controlled tracks per railroad in the Philadelphia DUA. Notice that for NS, a WSM location corresponds to the location of a WIU radio site, whereas for the other railroads, each location represents a WIU device, but not the location of a WIU radio site.

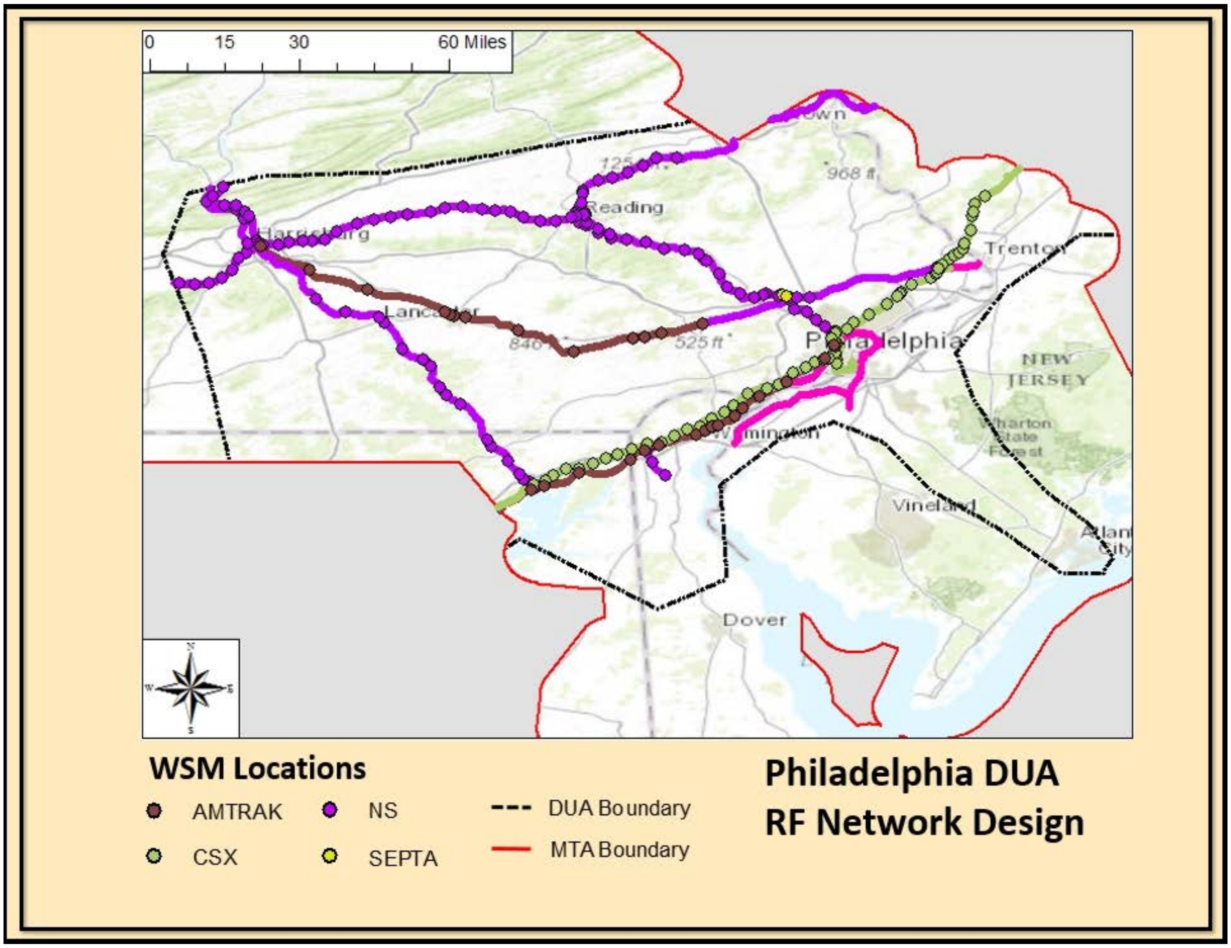

Figure 40. Distribution of WIU Locations Inside the Philadelphia DUA.

5.5.5 Philadelphia DUA Incumbent Analysis

The Incumbent Analysis comprises checking for possible desense scenarios between ITC base stations and fixed non-railroad incumbent sites operating within the 217–222 MHz band, as explained in detail in Section 4.2.

The results of the Phase 1 Incumbent Analysis show 12 non-railroad incumbent licensees inside the Philadelphia DUA, operating a total of 134 unique radio locations. Figure 41 shows the location of the ITC base stations inside the Philadelphia DUA and all the non-railroad incumbents in the area. It is worth noting that a single location can either have multiple licensees or multiple frequencies in use.

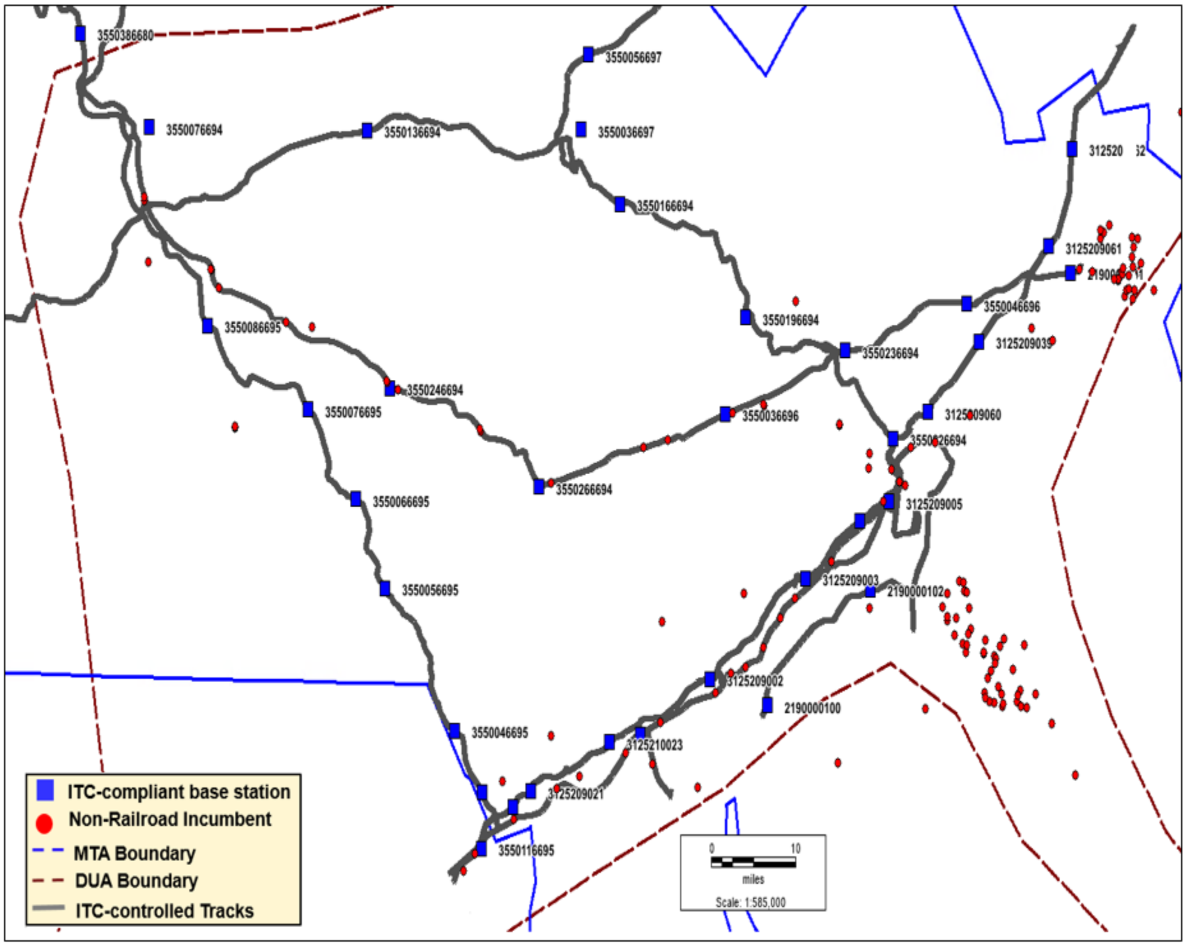

Figure 41. ITC Base Stations and Non-Railroad Incumbent Sites in the Philadelphia DUA

It is assumed that the incumbent radios have a desense threshold of -30 dBm when determining whether an ITC fixed site could cause desense issues on non-railroad incumbents, as explained in Section 2.1.

TTCI encountered eight possible cases of desense or interference with NRTC/PEPCO or any other incumbent sites while preparing the D-frame frequency plan. Waiver notifications were sent to the owners of each of these non-railroad sites before finalizing the frequency plan. In addition, NRTC sites were notified and asked for their concurrence. Concurrence was obtained from all the non-railroad incumbents and the bases were used as per the initial plan without any additional changes.

TTCI also identified seven possible cases of desense or interference between non-railroad incumbents and NS WIU radio sites. TTCI has not taken further actions for these cases, as explained in Section 4.2.

5.5.6 Philadelphia DUA ACSES and ITC Desense Analysis

TTCI developed the detailed desense analyses to identify areas where ACSES and ITC radios could be at risk of desensing each other, as explained in Section 4.3. This included:

- Identification and analysis of ACSES radio sites that could desense ITC radio sites and vice versa (see Section 2.1.1).

- Identification and analysis of tracks where locomotives could get desensed by fixed sites from a dissimilar system (ITC desensing ACSES and vice versa) (see Section 2.1.2).
- Identification and analysis of track locations where locomotives could cause desense to fixed sites from the dissimilar system (ITC desensing ACSES and vice versa) (see Section 2.1.3).

Prior to the development of the desense analysis by TTCI, CSX and SEPTA developed their own analysis of interference/desense between their sites and as a result of that analysis, CSX relocated some of their ITC sites that were close to SEPTA ACSES sites and informed TTCI. Those changes were incorporated in the analysis performed by TTCI.

The next set of figures and tables shows the results obtained for each of the above listed cases. Appendix A, Section A.3 contains tables with detailed lists of fixed sites that are predicted to either desense or be desensed by a dissimilar system.

Figure 42 shows the location of ACSES radio sites and the tracks where ACSES-controlled trains operate inside the Philadelphia DUA.

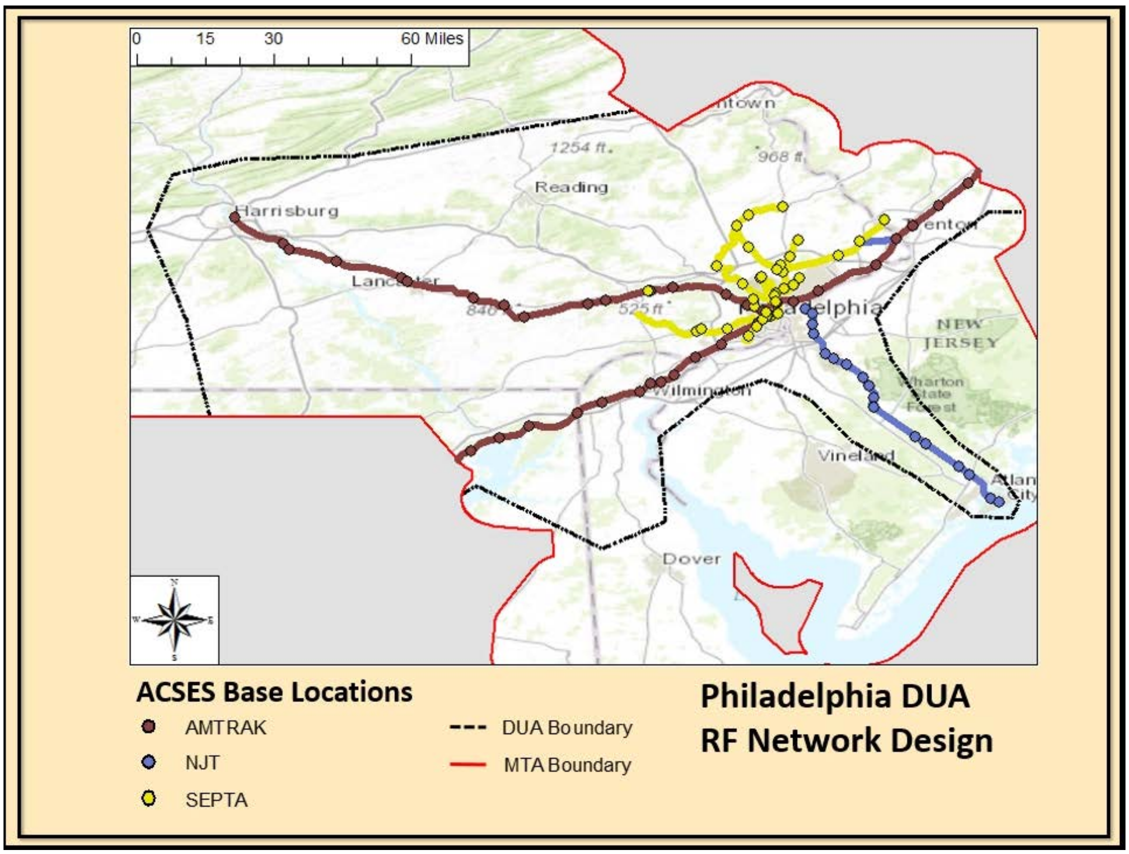

Figure 42. Location of ACSES Base Stations and Tracks in the Philadelphia DUA

Table 24 summarizes the results of the desense analysis between ACSES and ITC fixed sites. The column titled "Desensing" shows the number of ACSES or ITC sites that are predicted to be desensed by fixed radios from a dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to radios from a dissimilar system.

Figure 43 shows the locations of the three ITC base stations that are being desensed by ACSES base stations inside the Philadelphia DUA.

Table 24. Desense Results Between Fixed ACSES and ITC Sites Inside the Philadelphia DUA

System Type	Desensing	Being Desensed by
ITC Fixed Site	11 ACSES Sites	3 ACSES Sites
ACSES Fixed Site	3 ITC Sites	11 ITC Sites

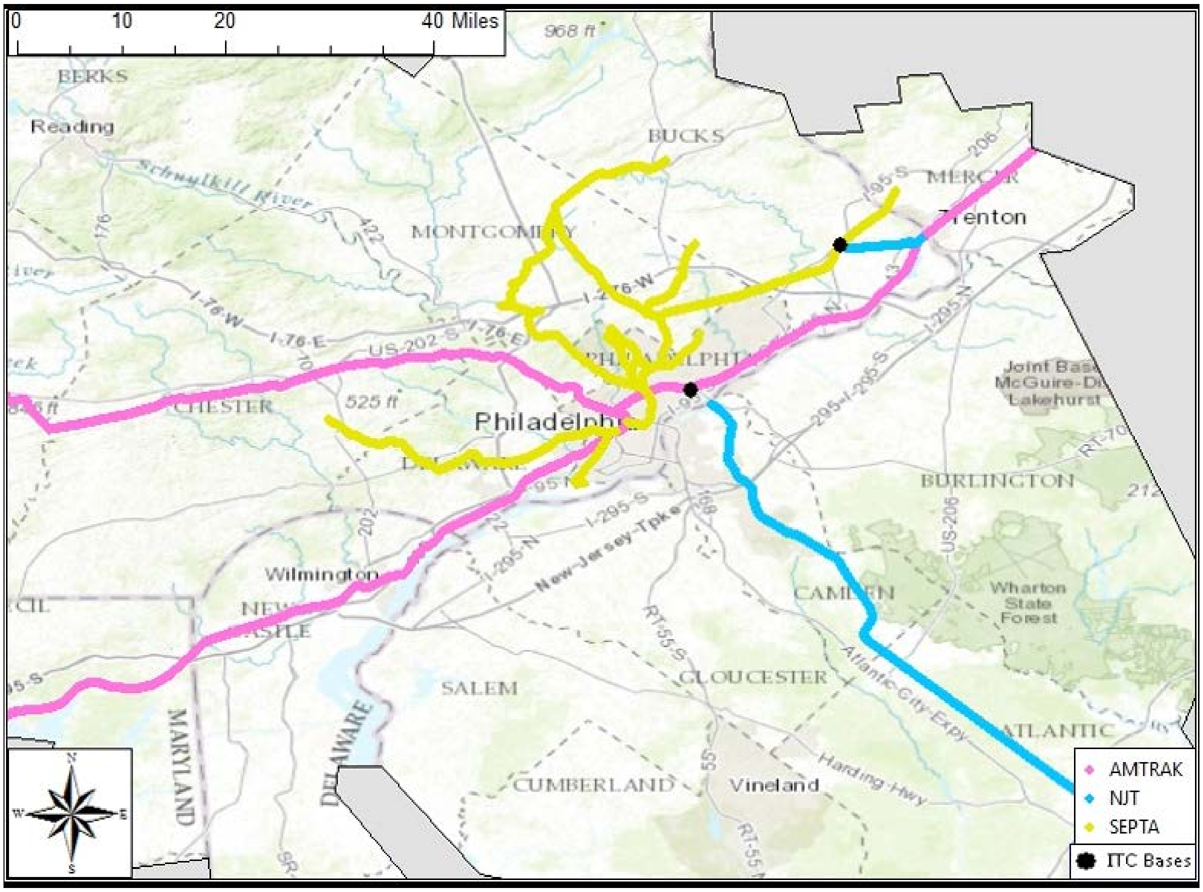

Figure 43. Location of ITC Sites Predicted to be Desensed by ACSES Sites in the Philadelphia DUA

Figure 44 shows the location of the ACSES sites that are predicted to be desensed by ITC base stations in the Philadelphia DUA.

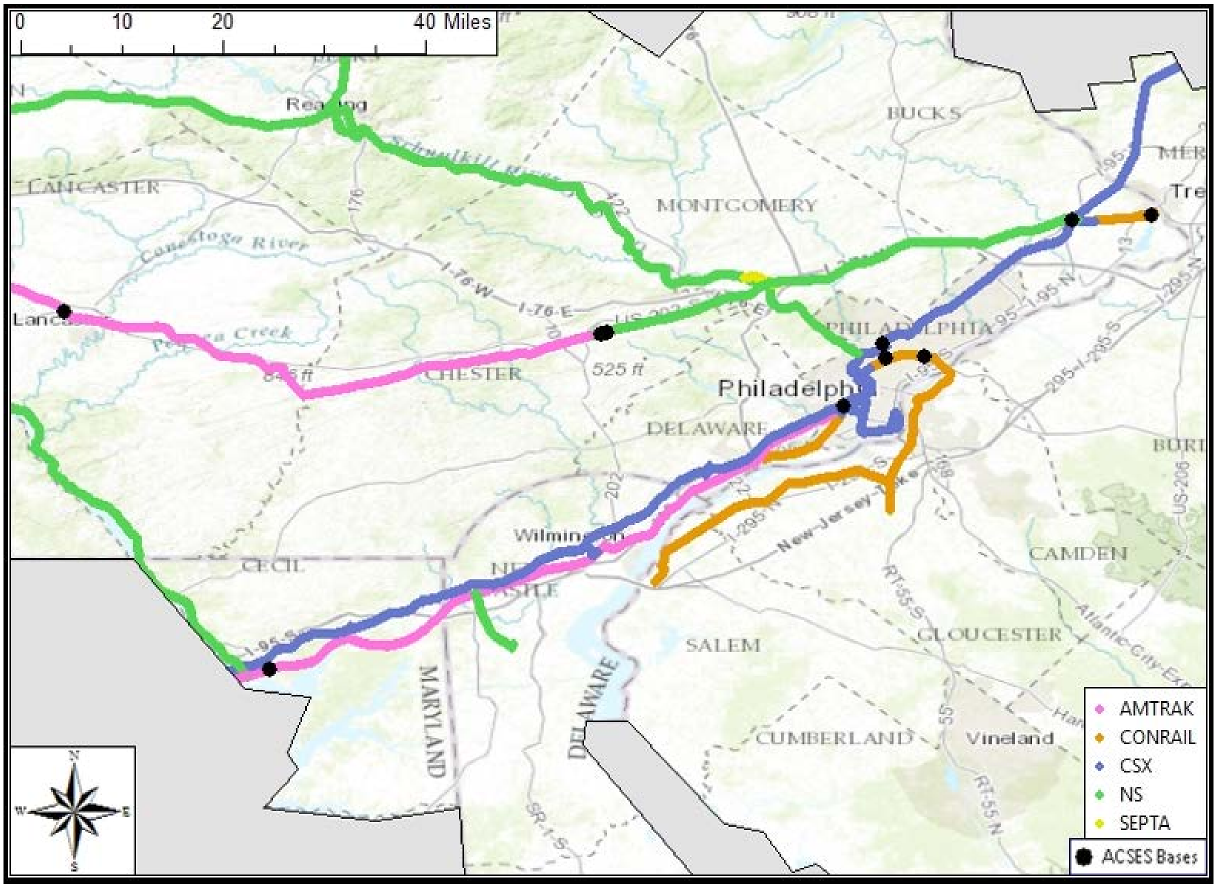

Figure 44. Location of ACSES Sites Predicted to be Desensed by ITC Sites in the Philadelphia DUA

TTCI developed the analysis of desense between fixed radio sites and locomotive radios for both systems (ACSES and ITC), as explained in Section 4.3. Table 25 summarizes the results obtained for the Philadelphia DUA. The column "Desensing" shows the number of ACSES or ITC fixed radio sites that are predicted to be desensed by locomotive radios from a dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to locomotive radios from a dissimilar system.

Table 25. Desense Results Between Fixed Radio Sites and Locomotive Radios from a Dissimilar System Inside the Philadelphia DUA

System Type	Desensing	Being Desensed by
ITC Locomotive	61 ACSES Sites	51 ACSES Sites
ACSES Locomotive	8 ITC Sites	18 ITC Sites

TTCI also identified the location of the tracks where locomotive radios could cause desense to fixed sites from a dissimilar system. Figure 45 shows the location of tracks where ITC locomotive radios are predicted to be desensed by ACSES base stations. A total of 51 ACSES base stations are predicted to desense ITC-controlled trains along 13.2 miles of tracks.

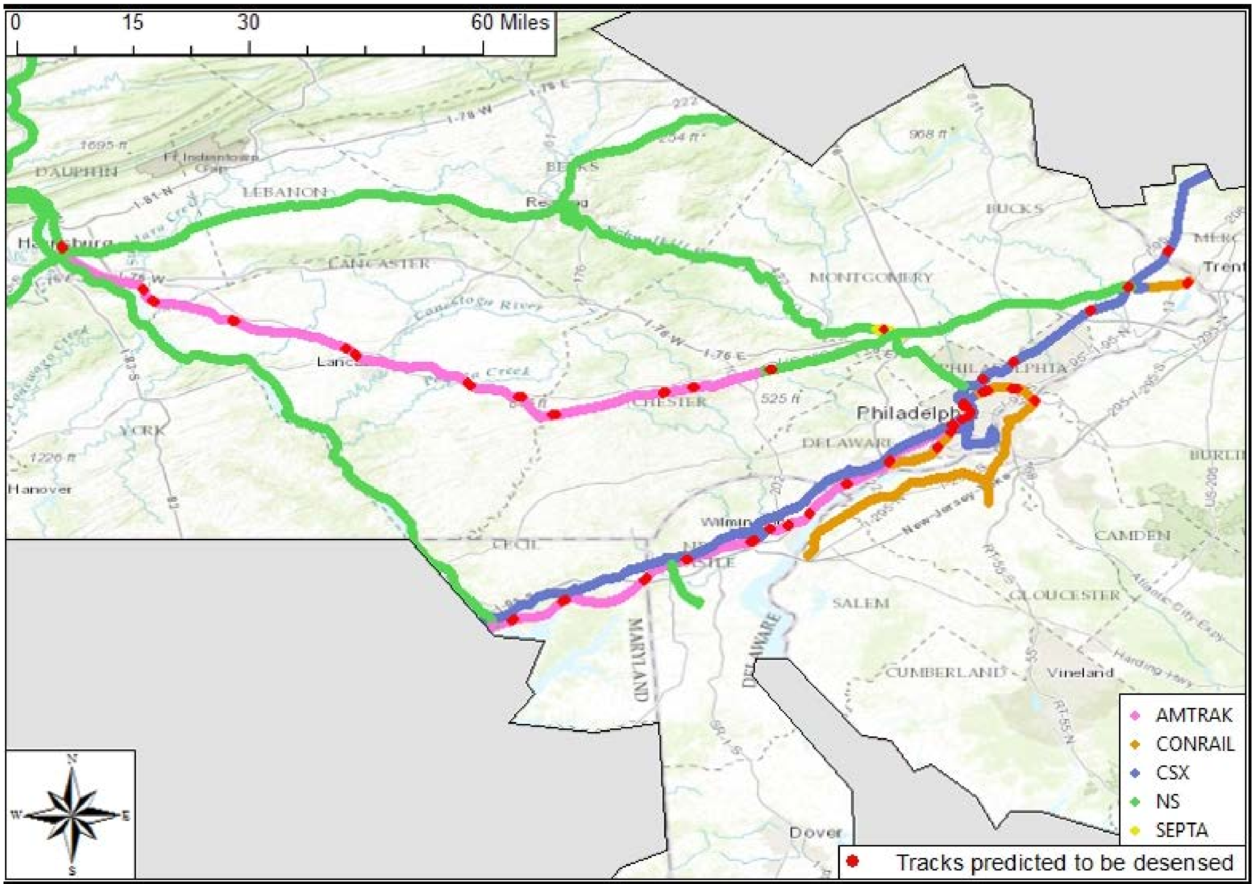

Figure 45. Location of ITC-Controlled Tracks Predicted to be Desensed by ACSES Base Stations in the Philadelphia DUA

TTCI developed the analysis on the tracks for the opposite direction, i.e., ITC base stations that could desense ACSES locomotive radios, and identified 18 ITC base stations predicted to potentially desense ACSES-controlled trains along 20.2 miles of tracks. Figure 46 shows the location of ACSES-controlled territories that are predicted to be desensed by ITC base stations in the Philadelphia DUA.

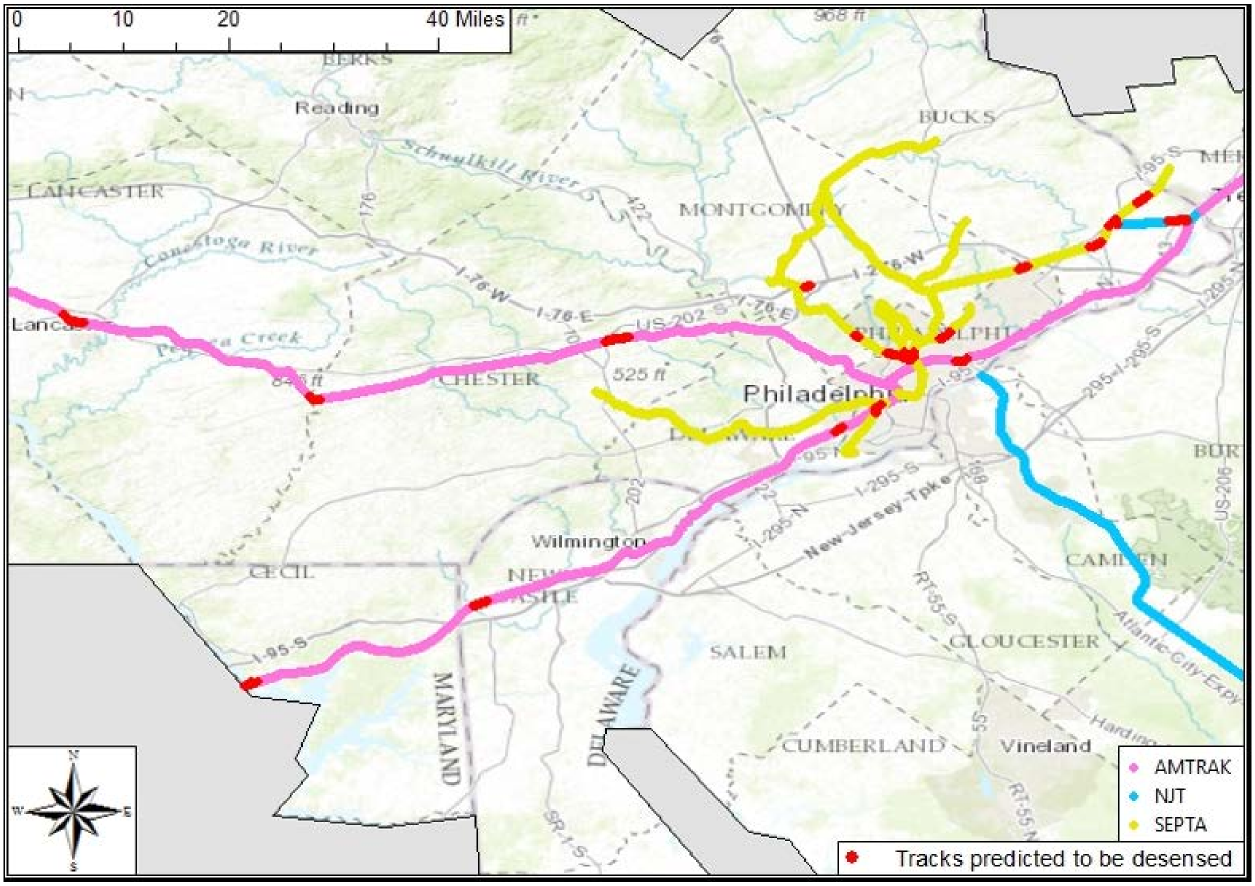

Figure 46. Location of ACSES-Controlled Tracks Predicted to be Desensed by ITC Base Stations in the Philadelphia DUA

The next set of results shows the potential desense that fixed sites from one system could suffer from locomotive radios from a dissimilar system. Figure 47 shows the location of the ACSES base stations that are predicted to be potentially desensed by ITC locomotive radios. Figure 48 shows the locations of the ITC base stations that are predicted to be potentially desensed by ACSES locomotive radios in the Philadelphia DUA.

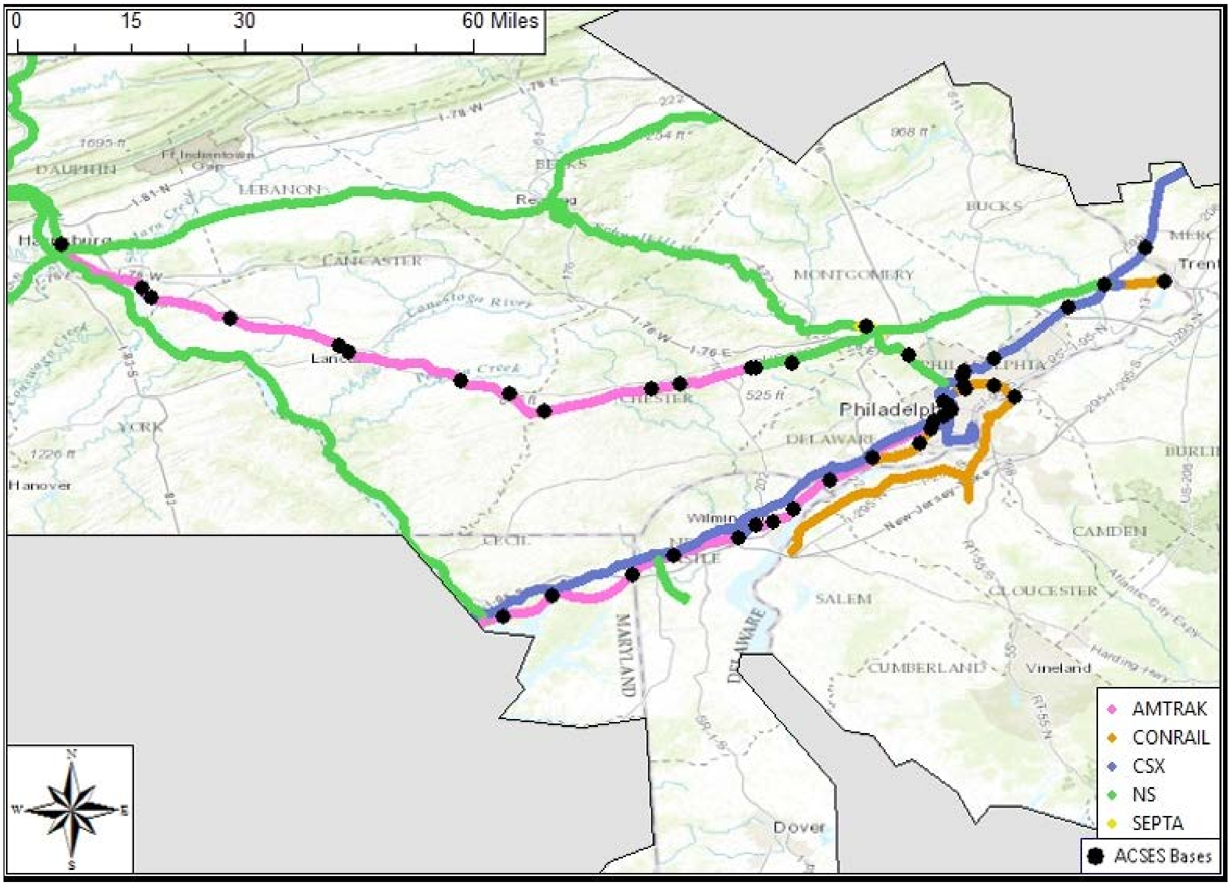

Figure 47. Location of ACSES Base Stations Predicted to be Desensed by ITC Locomotives in the Philadelphia DUA

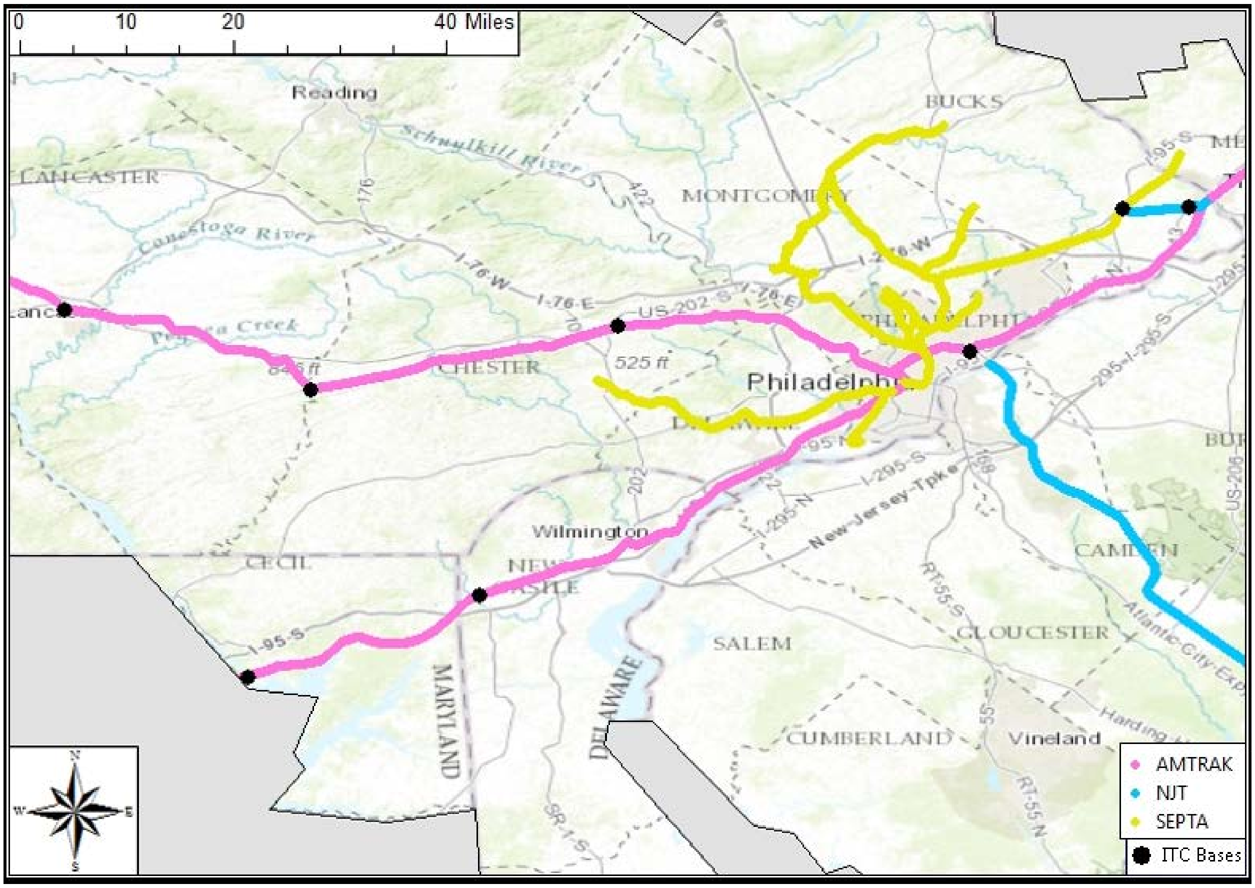

Figure 48. Location of ITC Base Stations Predicted to be Desensed by ACSES Locomotive Radios in the Philadelphia DUA

5.5.7 Philadelphia DUA Base Station Coverage Analysis and Frequency Plan

The design requirement along the ITC-controlled tracks for all railroads is to have coverage from at least one ITC base station at a level of -94.37 dBm or higher. The design target along the ITC-controlled tracks for the railroads with radioless WIUs (CSX, SEPTA, and Amtrak) is to have coverage from at least two ITC base stations at -94.37 dBm or higher.

All 33 available ITC base stations listed in Table 22 were selected to achieve the coverage requirements over the PTC-controlled tracks in the Philadelphia DUA. These 33 base stations were analyzed with Infovista's Planet® software to determine coverage, signal strength, C/I, and other relevant parameters.

As an initial step, the ITC base stations were assigned an RF propagation model. A subset of 19 of the available models in the hosted server was tuned in regions that topographically resemble the Philadelphia DUA, as agreed with the railroads.

Table 26 shows details of the selected set of base stations for the Philadelphia DUA, including antenna and propagation models, and channel assignments. Note that none of the MTA09 base stations are eligible to use the offered NRTC spectrum, as described in Section 5.3, and as result the set of selected base stations were assigned only PTC-220 LLC channels. The results of the desense analysis (described in Section 5.5.6) were also considered when selecting the sites for the base station frequency plan.

Table 26. Base Station Frequency Plan for the Philadelphia DUA

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height(feet)	Antenna Azimuth (degrees)	EIRP (dBm)	Channel
2190000100	Deepwater	NF_NF_Midwest_RU_7_RiverValley_36ft.pmf	30	0	44.95	113
2190000101	Morrisville	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	90	0	44.95	101
2190000102	Paulsboro	NF_NF_Midwest_RU_7_RiverValley_36ft.pmf	90	0	44.95	126
3125209002	Wilmington	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	125	44.95	114
3125209003	Chester	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	125	44.95	153
3125209005	RG Tower	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	125	44.95	114
3125209021	Foys Hill	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	44.95	125
3125209039	Berry	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	40	44.95	153
3125209059	Chester Pike	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	20	125	44.95	125
3125209060	Olney	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	125	44.95	166
3125209061	Woodside	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	60	40	44.95	125
3125209062	Pennington	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	44.95	127
3125210020	Perryville	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	80	44.95	114
3125210023	Elk Mills	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	80	44.95	101
3550036695	Port Deposit	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	100	0	44.95	126
3550036696	Frazer	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	95	240	44.95	113
3550036697	Mount Penn MW	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	75	270	44.95	166
3550046695	Conowingo	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	75	125	44.95	113
3550046696	County_Line	NF_NF_Midwest_RU_7_RiverValley_36ft.pmf	135	340	44.95	114
3550056695	Holtwood	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	100	0	44.95	101
3550056697	Balndon	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	135	335	44.95	125
3550056699	Newark	NF_NF_Midwest_RU_1_Cropland_186ft.pmf	155	0	44.95	127
3550066695	SafeHarbor	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	90	0	44.95	114
3550076694	BlueMtn	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	25	90	44.95	113
3550076695	Cola	IV_IV_Midwest_RiverValley_150ft.pmf	90	0	44.95	153
3550086695	Cly	IV_IV_Midwest_RiverValley_150ft.pmf	55	50	44.95	126
3550136694	Avon_Lebanon	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	125	0	44.95	101
3550166694	Birdsboro	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	95	20	44.95	126
3550196694	Phoenixville	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	80	0	44.95	101
3550226694	Falls	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	55	215	44.95	101
3550236694	Ernest	IV_IV_NESouthAtlantic_UR_SU_65ft.pmf	115	0	44.95	141
3550246694	Lancaster	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	95	300	44.95	125
3550266694	Atglen	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	135	325	44.95	167

Figure 49 shows the coverage achieved from the 33 selected ITC base stations along the ITC-controlled tracks inside the DUA. The base station coverage analysis indicates that 93.67 percent of the 90-meter buffer area around the ITC-controlled tracks has coverage from at least one base station at -94.37 dBm or higher.

The results of the coverage analysis developed by TTCI were reviewed with the railroads, particularly because they would not satisfy the original RF design criteria for coverage. The railroads requested TTCI to proceed with the design using the results as predicted by the RF simulation.

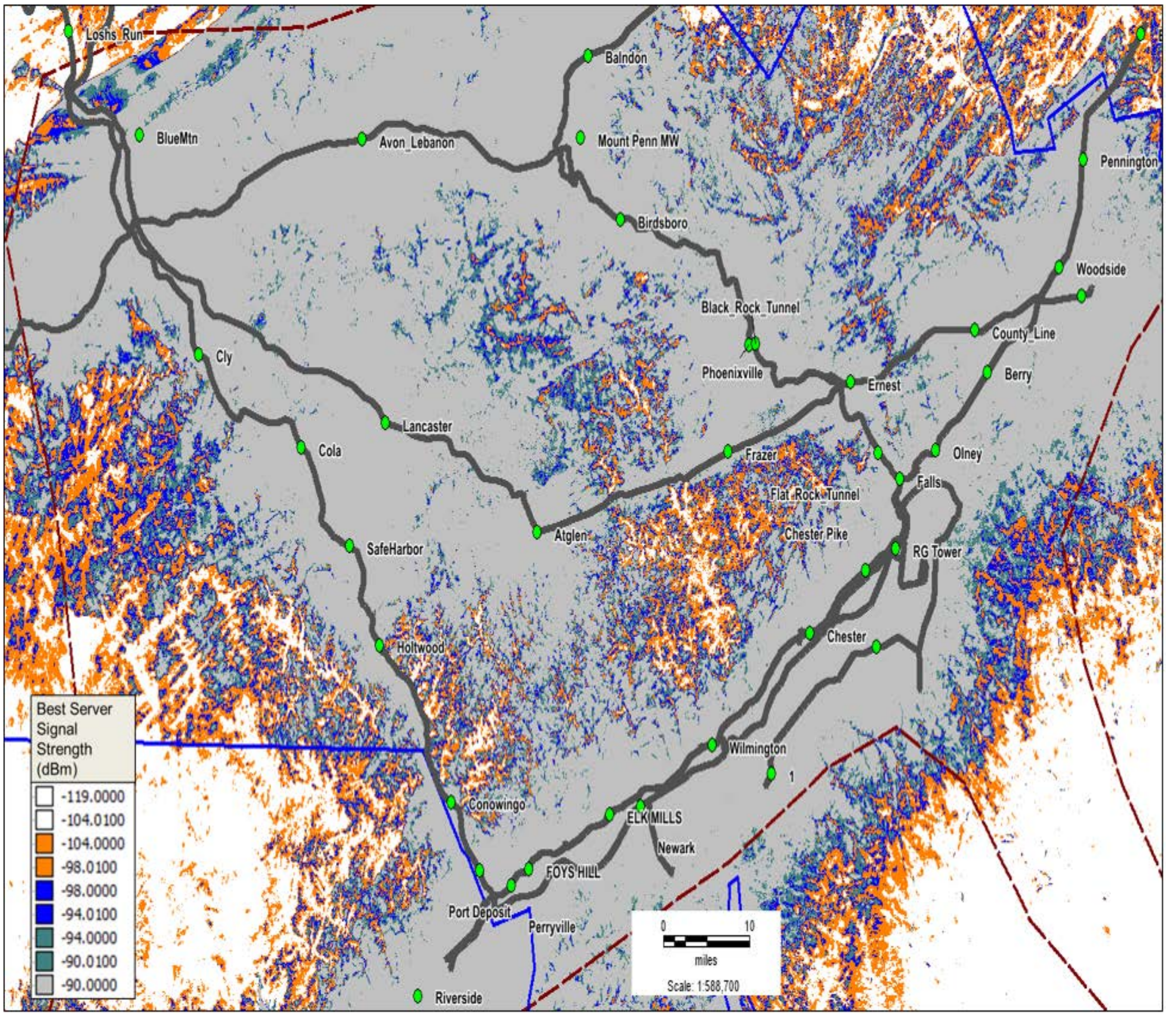

Figure 49. Predicted Best Serving Base Station Signal Strength Inside the Philadelphia DUA

Propagation modeling using AFP indicates that 10 frequencies are needed to achieve the required C/(I+A) requirements. The channel assignments of the 10 available frequencies are shown in the rightmost column of Table 26. One additional frequency is required for the Common Channel, bringing the total to 11 frequencies.

Table 27 shows a summary of the percentage of buffer area with C/(I+A) levels above 18.6 dB and 11.5 dB. The first column in the table represents the C/(I+A) ranges, the second column represents the area in square miles of the 90-meter buffer area with the corresponding C/(I+A) levels, and the third column represents the percentage of the buffer area with the corresponding C/(I+A) levels. Although the radio is designed to handle C/I as low as 11.5 dB, that assumes no fade margin, so a higher analysis threshold is required. A C/I threshold of 18.6 dB is more conservative and thus carries lower risk.

Table 27. Percentage of Buffer Area Where the Predicted C/(I+A) Levels Exceed the Thresholds of 18.6 dB and 11.5 dB in the Philadelphia DUA

Ranges	Area (mi^2)	Percentage Sub Area
-50 ~ 0	0	0
0 ~ 11.5	0.0542087071	0.0630563
11.5 ~ 18.6	0.517762661	0.602268457
18.6 ~ 100	85.39678	99.33468

Figure 50 shows the predicted base station best serving sector coverage for the selected 33 base station sites, assuming the use of the 11 channels. The channels that are reused by multiple base station sites are shown with the same color in Figure 50. Notice that two additional channels (165 and 142) are displayed in Figure 50, but those are being used in neighboring areas to the Philadelphia DUA.

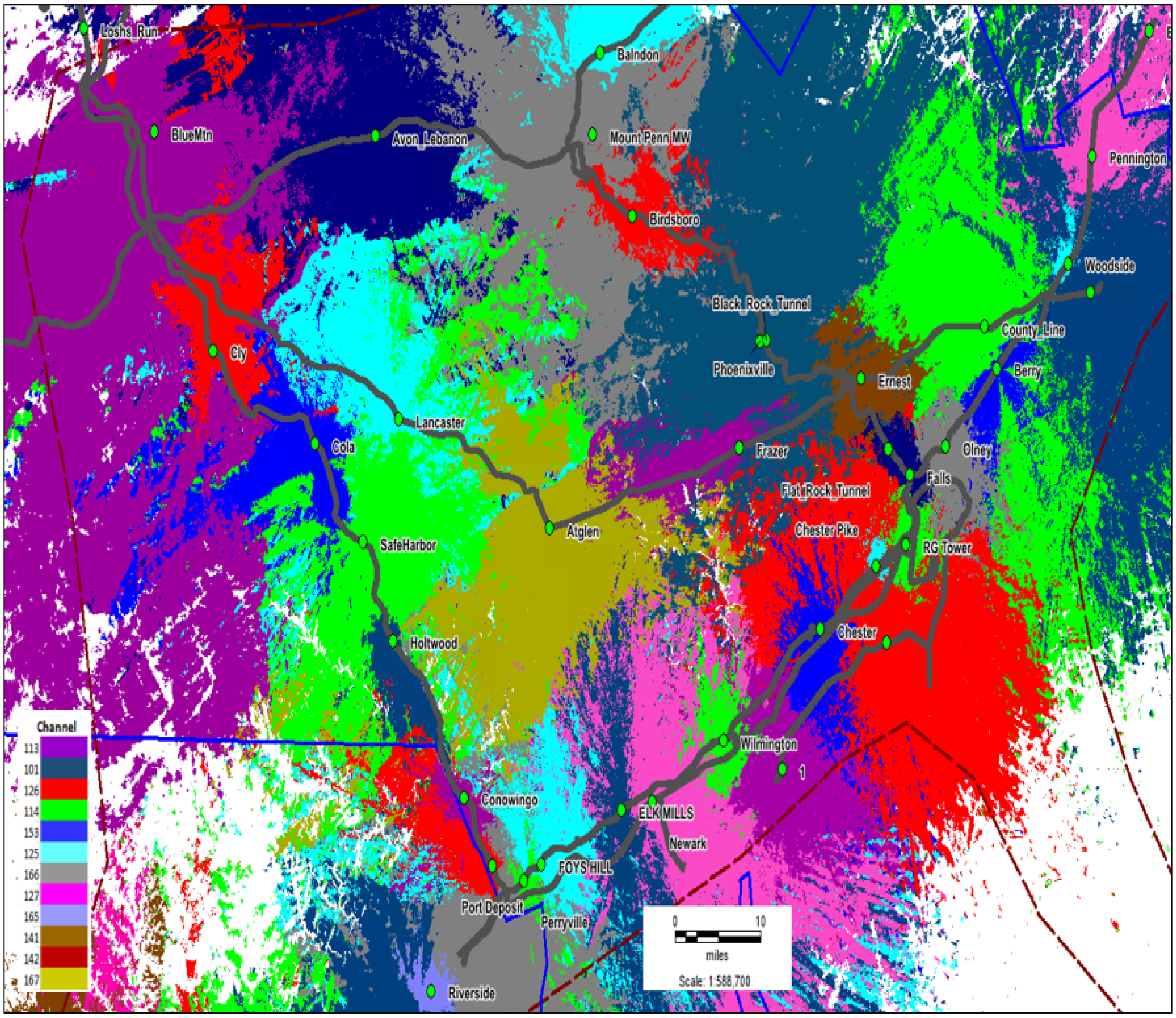

Figure 50. Base Station Best Serving Sectors for the Philadelphia DUA

Figure 51 shows the total C/(I+A) that would be received from the best base station server by a locomotive radio at every point throughout the Philadelphia DUA for the base station frequency plan prepared for the 33 selected sites. The objective is for the C/(I+A) to be ≥ 11.5 dB. The green and yellow colors in Figure 51 mean acceptable C/I levels, which, as can be seen, is the case for the majority of ITC-controlled tracks in the Philadelphia DUA with the selected base stations and frequencies.

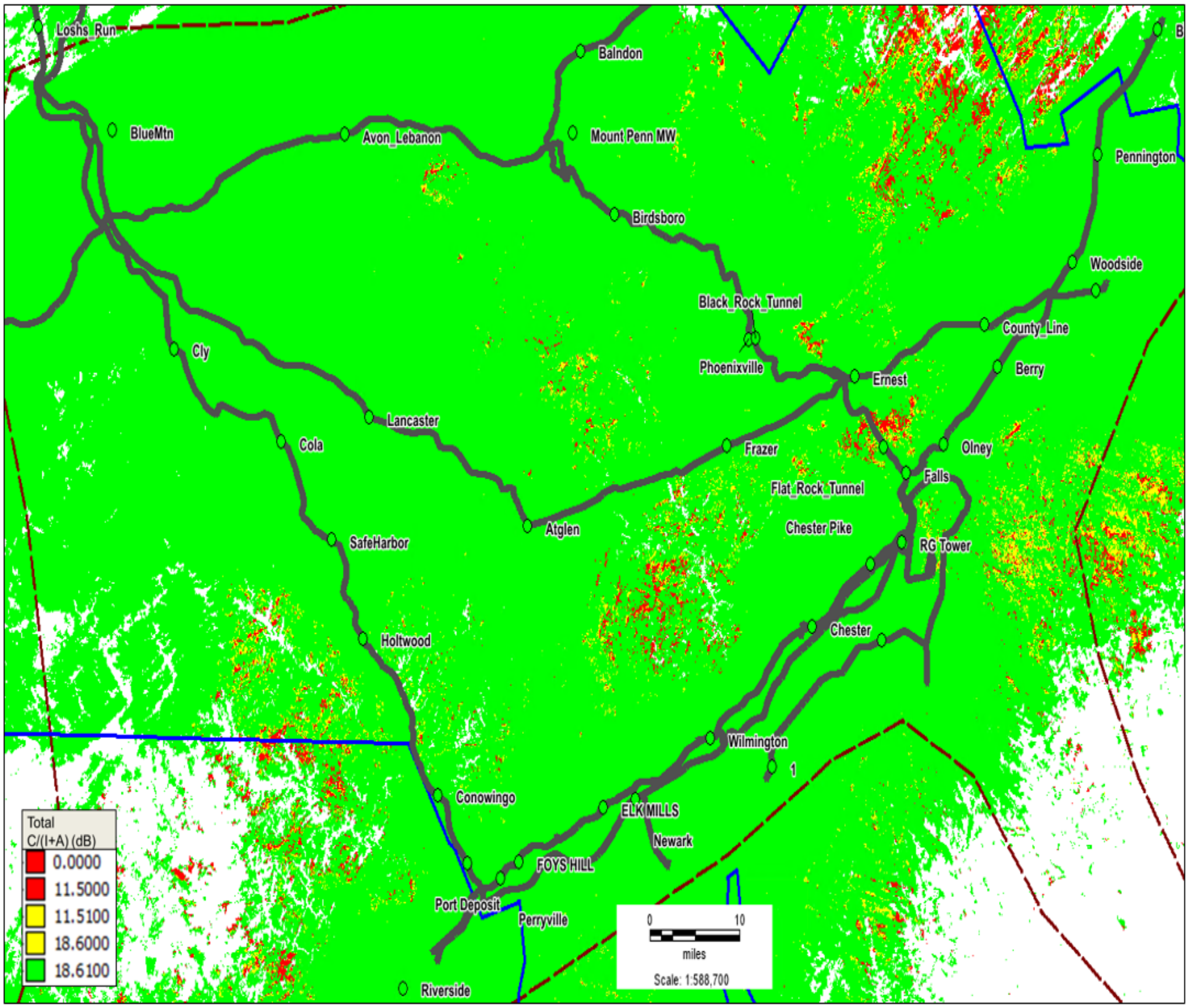

Figure 51. Predicted C/(I+A) Levels of the Base Station Frequency Plan Prepared for the Philadelphia DUA

5.5.7.1 Analysis of Base Station Redundancy for the Philadelphia DUA

The design target requirement along ITC-controlled tracks with radioless WIUs is to have coverage from at least two ITC base stations at a level of -94.37 dBm or higher, as indicated in Section 5.5.7. The results indicate that there is significant predicted redundancy in the ITC base station coverage along those tracks.

The analysis indicates that 71.66 percent of the ITC-controlled tracks are predicted to have coverage satisfying the requirements from at least two base stations, as shown in Figure 52. Note that not all of this redundancy is usable, because the C/I levels for second best servers are unknown.

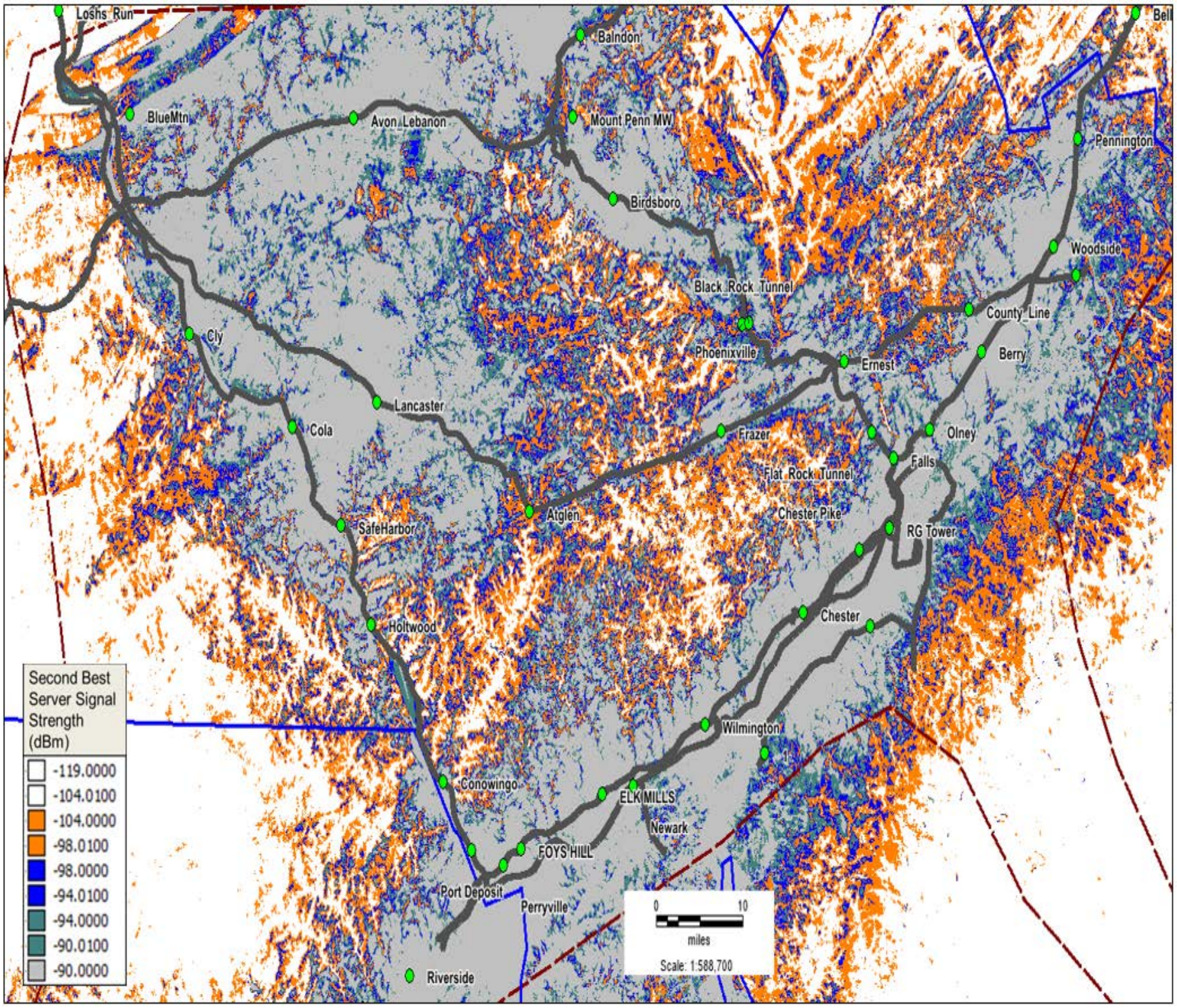

Figure 52. Predicted Second Best Base Station Server Signal Strength Inside the Philadelphia DUA

5.5.8 Philadelphia DUA F-Frame Timeslot Plan

TTCI used the IPM tool to generate a fixed F-frame frequency/timeslot plan. As indicated in Section 5.5.4.2, a total of 241 WSMs and 110 WIU radio sites are present inside the Philadelphia DUA. Figure 53 shows the locations of the WSMs and WIU radio sites. Notice that, because CSX, Amtrak, and SEPTA are implementing radioless WIUs, their lines only show WSM locations, instead of WIU radio sites.

Conrail informed TTCI that their base stations are still in the process of being built, and thus their base stations were not included in the design of the F-frame timeslot plan, because if they had been included, there could be a possibility that Conrail base stations would be assigned WSM transmissions via WSRS, which would cause the F-frame timeslot plan to not be immediately implementable by the other railroads in the DUA. Notice, however, that Conrail base stations were included in the D-frame frequency plan, and were assigned a frequency, so that the total demand of spectrum could be correctly determined.

As noted in Section 5.1, the F-frame plan was prepared for the entire MTA, i.e., it was not limited to just the DUA boundary.

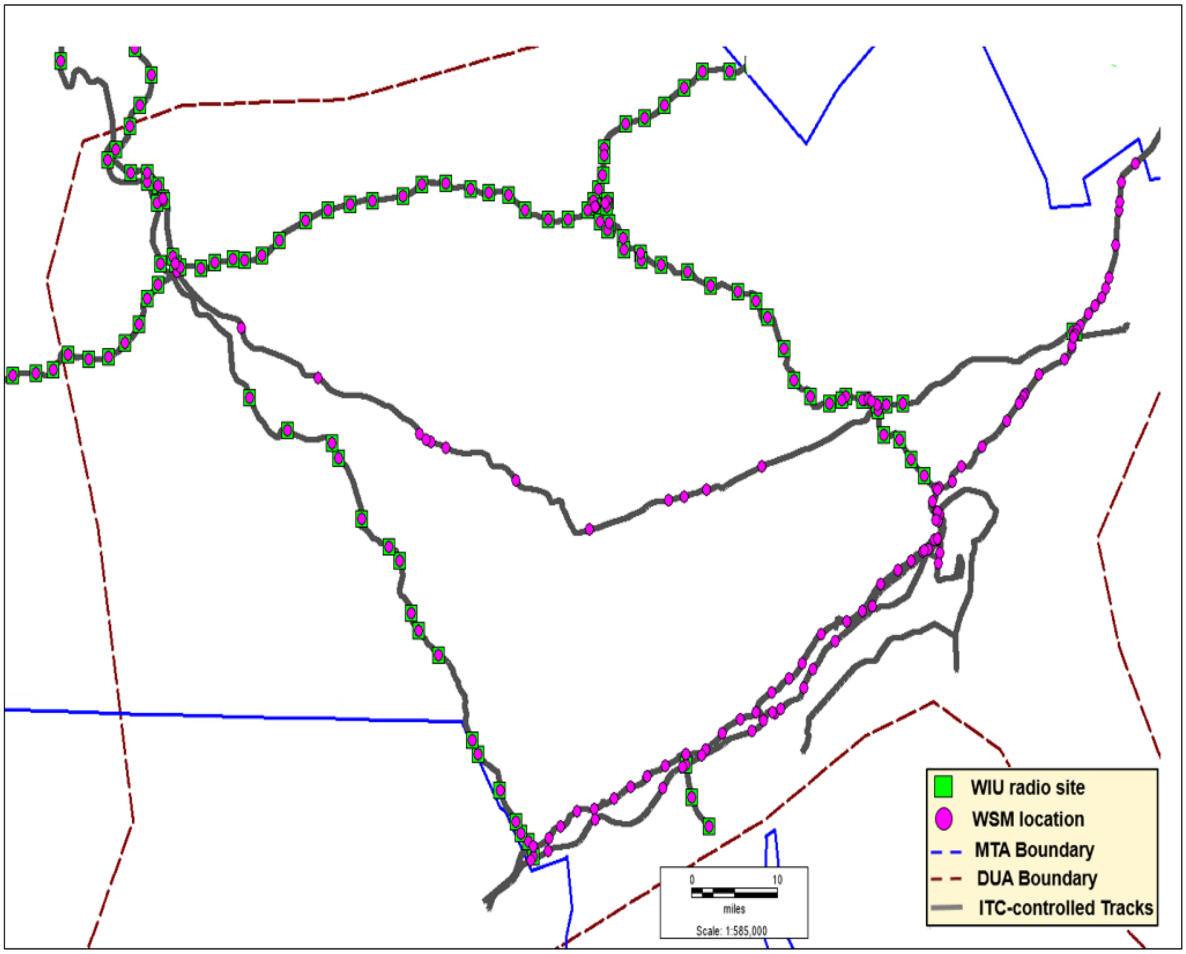

Figure 53. WSM and WIU Radio Locations Inside the Philadelphia DUA

For the specific case of the Philadelphia DUA, the following PTC Operating Zone end distances were used:

- Zone 1: 0.80 miles
- Zone 2: 1.61 miles
- Zone 3: 5.19 miles

The following IPM configuration were used when generating the F-frame timeslot plan for the Philadelphia DUA:

- Zone end distances were determined based on braking distance calculations performed by TTCI [3].
- Dynamic Range Protection was used with a blocking distance of 200 feet and protection distance of 5.5 miles. These values were used on the basis of recommendations from the railroads.

- Variable timeslot lengths were used, as well as the standard duty cycles for WIU and base station radios of 10 percent and 50 percent, respectively.
- Preplanned timeslots outside the DUA were protected within a distance of 100 miles. A 3 dB coverage adjustment was applied for segments of track where a single WSM is received by two or more radio sites (base station or WIU), effectively reducing the required signal strength for those tracks to -97.37 dBm (as opposed to -94.37 dBm for places where WSMs are only being received by a single site).

The IPM results show that an F-frame size of 1,317 milliseconds with a total of 805 timeslots will be needed for the entire Philadelphia MTA. The median offset was 407 milliseconds. All WSMs are predicted to be received by at least one base station.

A total of 307 WSMs are being broadcast by base stations. Of these, 272 are WSRS messages planned to resolve coverage gaps (239 for freight railroads, 2 for SEPTA, 31 for Amtrak), and the rest correspond to WSMs for primary and secondary coverage.

WSM coverage gaps are usually solved via WSRS. However, 141 WSMs were still predicted to have coverage gaps (post-relay gaps), even after exploring all the possible candidate ITC base stations to use for WSRS. In total, 1,008 post relay gaps were found, 906 of which correspond to radioless WIU sites, and 670 were located in PTC Operation Zone-3. Most of the post-relay gaps for the radioless WIU sites were due to the poor signal strength of the base stations providing coverage for the secondary path. TTCI provided information on post-relay gaps to the owning railroads, to allow them to verify their existence in the field.

5.5.9 Philadelphia DUA Message Traffic Loading Analysis

The message traffic loading for the Philadelphia area was prepared using historical train operation data provided by the railroads and TTCI’s train movement simulation tool that generates train movement data used as input for the train message simulation [3].

The D-frame size for the Philadelphia MTA was calculated using the size calculated for the fixed F-frame. The F-frame size for the Philadelphia DUA is 1,317 milliseconds, as described in Section 5.5.8, which leaves 2,683 milliseconds for the D-frame. As it is required to allow for a 20 percent provision in the D-frame for other business message traffic, the D-frame size available for PTC train message traffic is 2,146 milliseconds.

Typically, in DUAs, the peak message traffic in the D-frame is driven by passenger trains operating in peak operation times (early mornings and evenings), which will not be the case for the NEC, as all passenger trains in the NEC (from commuter and passenger railroads) will be operating under ACSES control, not under ITC control.

The following subsections describe how these analyses were developed and the results obtained.

5.5.9.1 Exceptions in Train Operation Data in the Philadelphia DUA

Input data for train movement from different railroads varied in format, and were converted to TTCI’s standard format before processing for simulations. In cases where the train data was either incomplete or missing, TTCI made assumptions to either extrapolate the trains or create the train movement data using the information available. It is expected that the areas where some base stations did not see any train traffic due to lack of data would not be of concern in the capacity analysis, as they are not expected to experience any capacity issues.

Table 28 summarizes the issues and respective resolution adopted for the exceptions in train operations data provided by the railroads for the Philadelphia DUA project.

Table 28. List of Exceptions in Train Operation Data in the Philadelphia DUA

Railroad	Subdivision	Observations/Issues	Assumptions/Resolutions
Amtrak	Keystone (Philly-Harrisburg)	No historical freight movement data available	Base stations providing best server coverage to this subdivision from Philadelphia-Harrisburg would see some more train/ message traffic than shown by the available data
CSX	Trenton	No historical movement data available north of MP QA-36	Trains that reported at MP QA-36 were extrapolated all the way to the north end of the subdivision to MP QA-44, boundary of MTA09
NS	Harrisburg	Historical movement data available only up to MP 28.84	It was assumed that all the trains in the data travel throughout the subdivision to/ from Harrisburg (MP 112.69), and extrapolated accordingly
NS	Reading(RV)	No clarity on where the trains start/end	All trains were extrapolated form MP RV 8.0 all the way to /from Reading, 8 miles

Besides the exceptions listed in Table 28, TTCI also did not include train message traffic from Conrail, as the information provided was not accurate enough to characterize the operation of trains along their tracks. However, based on the information provided, the volume of Conrail trains and consequently the additional PTC message traffic is very low, and it will not change the results from this analysis significantly.

5.5.9.2 Peak Number of Trains per Base Station in the Philadelphia DUA

The first assessment of the train message traffic loading in the D-frame uses the number of simultaneous trains operating under each base station, from the best server base station boundaries.

TTCI determined the base station boundaries for train message association [3]. The boundaries calculated for the Philadelphia DUA are listed in Appendix A, Section A.2.

TTCI calculated the peak number of simultaneous trains operating under each base station site selected for the RF network design, by using the historical train operation data. Table 29 shows the results obtained.

Table 29. Peak Number of Trains Under Base Stations in the Philadelphia DUA

Base Station Name	Base Station ID	Train Count Current	Train Count Year 2020
Schulkill Ave	3125209005	11	14
Paulsboro	2190000102	10	12
Feltonville	3125209003	8	10
Ernest_King	3550236694	8	10
Newark	3550056699	6	8
Falls	3550226694	6	8
Deepwater	2190000100	5	6
Morrisville	2190000101	5	6
Yard Ofc	3125209002	5	6
Byberry Rd	3125209039	5	6
Balndon	3550056697	5	6
BlueMtn	3550076694	5	6
Cola	3550076695	5	6
Phoenixville	3550196694	5	6
Chester Pike	3125209059	4	5

Base Station Name	Base Station ID	Train Count Current	Train Count Year 2020
Holtwood	3550056695	4	5
ClyCh2	3550086695	4	5
Onley Ave	3125209060	3	4
Woodside	3125209061	3	4
Pennington	3125209062	3	4
Safe_Harbor	3550066695	3	4
Black_Rock_Tunnel	3550256694	3	4
Flat_Rock_Tunnel	3550126694	2	3
Mount Penn	3550036697	1	2
Lebanon_Avon	3550136694	1	2
Birdsboro	3550166694	1	2

The limit for number of simultaneous trains under a base is 24, for a 2,400-millisecond D-frame size, according to Section 3.1.2 (Application Traffic) of MCC's Network Design Principles document [6]. Assuming that the limit for a 2,400-millisecond D-frame size can be extrapolated for the D-frame size calculated for the Philadelphia DUA (2,146 milliseconds), the maximum number of simultaneous trains would be 21 trains. The numbers shown in Table 29 indicate that none of the base stations in the Philadelphia DUA would exceed this limit. TTCI developed a detailed investigation of the train message traffic loading, as described in the subsequent sections, to further assess any potential capacity issues.

5.5.9.3 Analysis of Base Station Message Loading for the Philadelphia DUA

TTCI investigated the peak message traffic periods predicted to be experienced by each site, after having associated the simulated train messages with their best server base station sites [3].

Table 30 shows the peak number of total messages received from (Inbound) and transmitted to (Outbound) trains by each one of the selected base station sites during one-minute, at peak train message traffic. TTCI also calculated the total duration of message transmission (column Total Duration) on the basis of duration of each message type. Figure 54 provides the same information in a bar graph format.

Table 30. Total Message Duration at Peak Period per Base Station for the Philadelphia DUA

Base Station	Total Counts of Messages (+20%)				
Name	ID	Inbound	Outbound	Total	Total Duration (milliseconds)
Schulkill Ave	3125209005	11	18	29	1,133
Paulsboro	2190000102	11	10	21	869
Feltonville	3125209003	10	9	19	787
Newark	3550056699	10	6	16	688
Falls	3550226694	9	6	15	639
Ernest_King	3550236694	6	9	15	591
Yard Ofc	3125209002	6	6	12	492
Cola	3550076695	6	6	12	492
Deepwater	2190000100	6	5	11	459
BlueMtn	3550076694	8	4	12	524
Morrisville	2190000101	5	5	10	410
Chester Pike	3125209059	5	5	10	410
Balndon	3550056697	5	5	10	410
Phoenixville	3550196694	5	5	10	410
Byberry Rd	3125209039	5	4	9	377
ClyCh2	3550086695	4	5	9	361

Base Station	Total Counts of Messages (+20%)				
Name	ID	Inbound	Outbound	Total	Total Duration (milliseconds)
Holtwood	3550056695	4	4	8	328
Safe_Harbor	3550066695	4	4	8	328
Black_Rock_Tunnel	3550256694	4	4	8	328
Onley Ave	3125209060	4	3	7	295
Woodside	3125209061	4	3	7	295
Pennington	3125209062	3	4	7	279
Flat_Rock_Tunnel	3550126694	3	3	6	246
Mount Penn	3550036697	3	2	5	213
Lebanon_Avon	3550136694	3	2	5	213
Birdsboro	3550166694	2	2	4	164

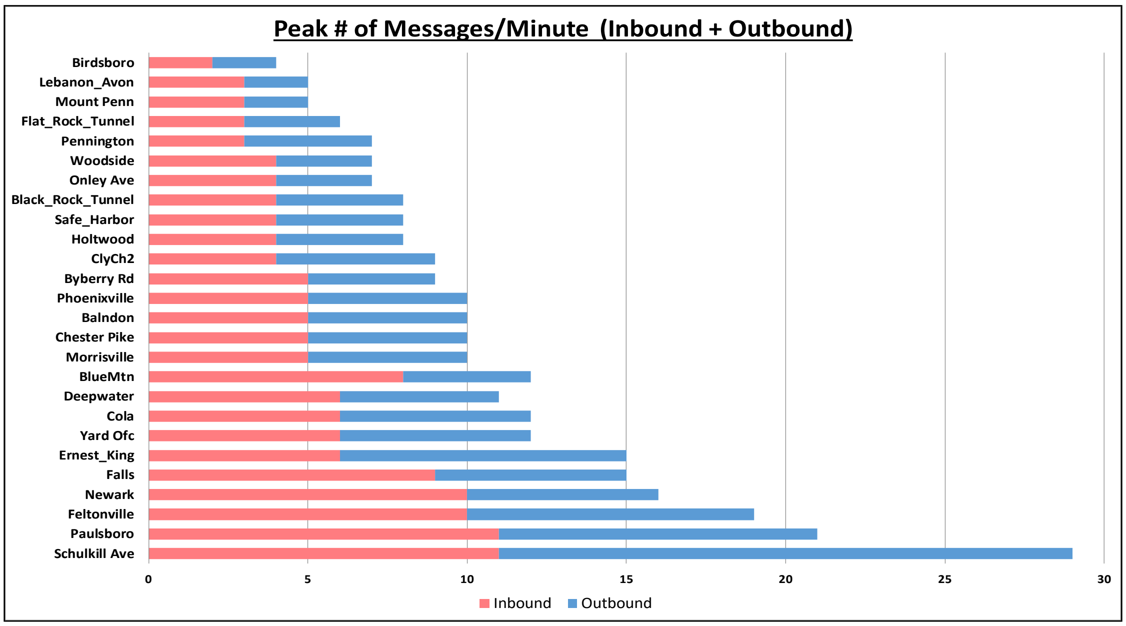

Figure 54. Total Number of Train Messages at Peak Period per Base Stations in the Philadelphia DUA

The peak number of train messages shown in Figure 54 lead to some initial conclusions:

- Base station Schulkill Ave is predicted to experience the highest volume of train message traffic, while also having had the highest number of simultaneous trains operating under its best server coverage area.
- Base station Paulsboro is predicted to experience the second highest train message traffic in terms of message counts, while also having the second highest number of simultaneous trains operating under its best server coverage area.
- The total number of train messages at peak times (29 messages in a minute), and the total duration of those messages (1,133 milliseconds), predicted to be experienced by the heaviest loaded site (Schulkill Ave) indicates that the predicted D-frame effective loading would not exceed the total D-frame size (2,146 milliseconds).

Note that this analysis was conducted over a 1-minute period instead of the 4-second cycle, in order to provide a better indication of train message traffic loading, as exceptional variation in actual train operation could generate a coincidence of simultaneous messages during the 4-second cycle that could be higher than what was obtained with historical train movement data provided by the railroads.

TTCI also investigated the message traffic for a 1-hour window and a 24-hour window, around the times when the 1-minute peak train messages were observed. The next four figures show the results obtained for base stations Schulkill Ave and Paulsboro. Figure 55 and Figure 56 show the results for the 1-hour period, while Figure 57 and Figure 58 show the results obtained for the 24-hour period. Note that the train counts include only the trains that were actively exchanging messages during the period indicated, i.e., there could be more trains under the base, but if they have not exchanged messages during that period, they are not included in the counts.

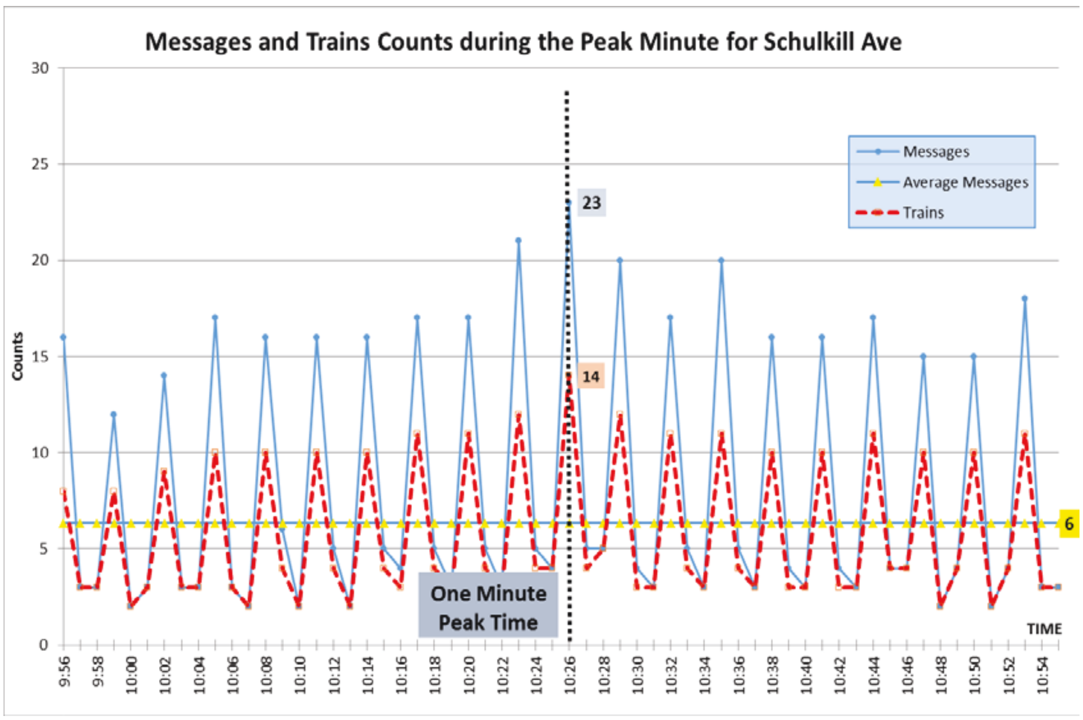

Figure 55. Counts of Train Messages/Minute During the One-Hour Around the Peak Period for Base Station Schulkill Ave

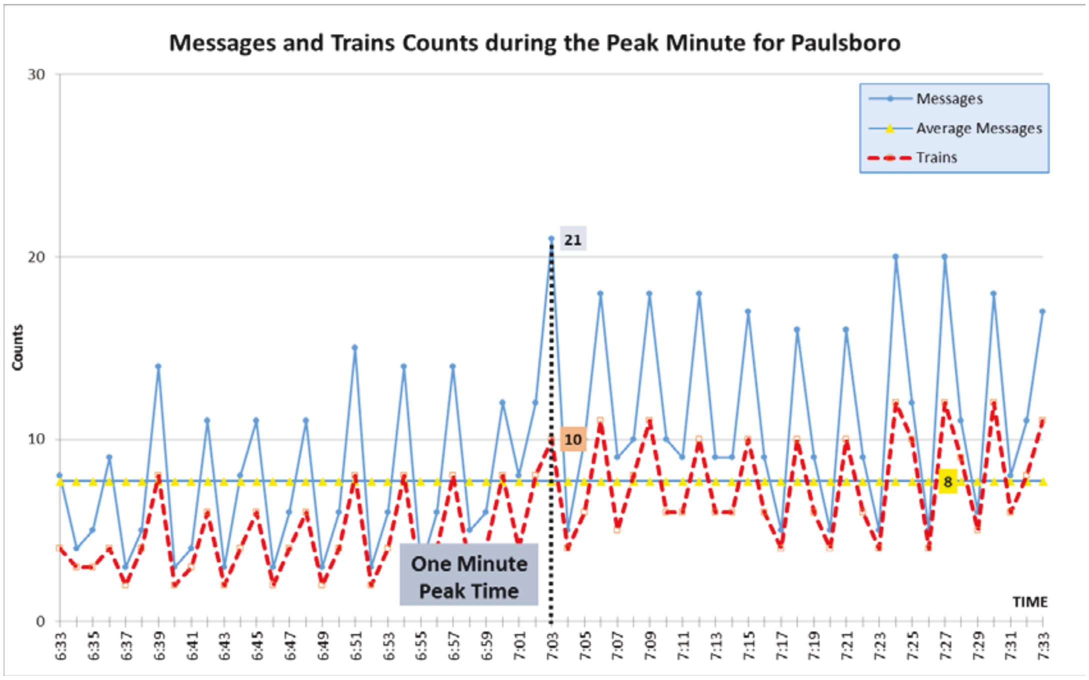

Figure 56. Counts of Train Messages/Minutes During the One-Hour Around the Peak Period for Base Station Paulsboro

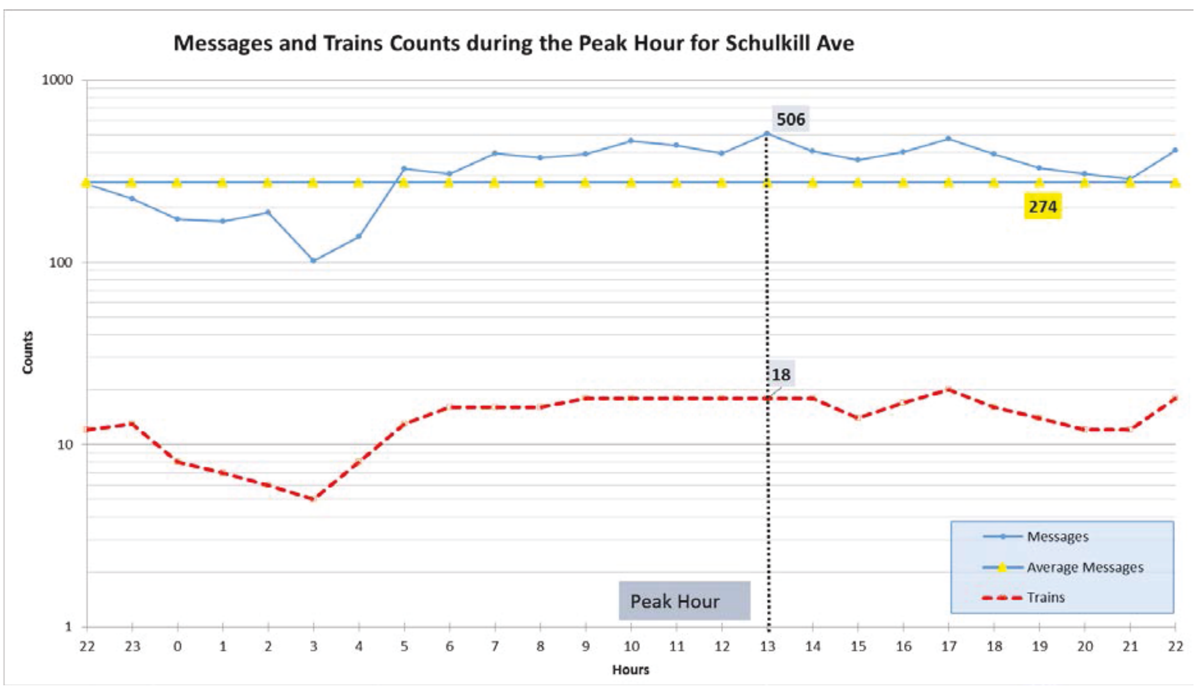

Figure 57. Counts of Train Messages/Minute During the 24-Hour Around the Peak Period for Base Station Schulkill Ave

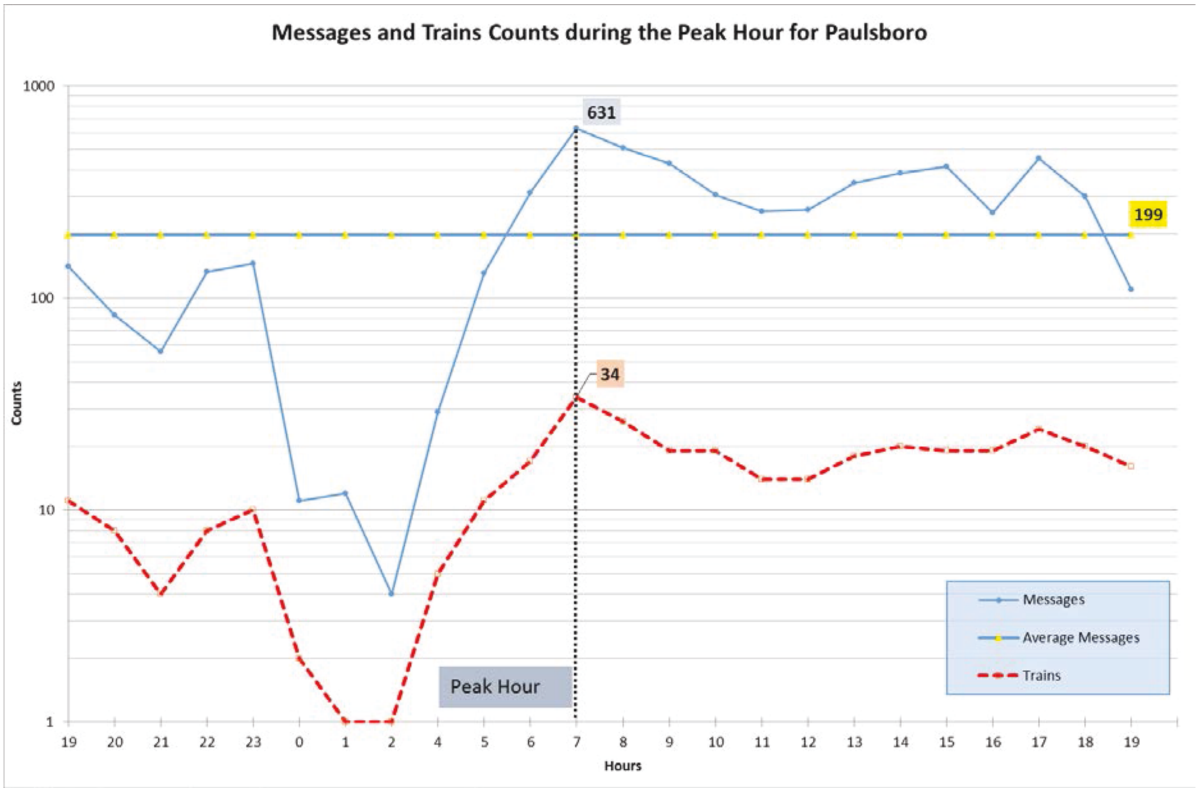

Figure 58. Counts of Train Messages/Minute During the 24-Hour Around the Peak Period for Base Station Paulsboro

The graphs shown in Figure 55 and Figure 56 indicate that the peak number of train messages per minute does not remain consistent at peak levels during the 1-hour window when it occurs, but, instead, the average total number of train messages per minute is predicted to be lower than half the values calculated for the actual 1-minute peak period.

The graphs shown in Figure 57 and Figure 58 indicate that the train traffic dips late at night and picks up early in the morning in Philadelphia. Similar to the 1-minute peak period, the average message traffic per hour is also lower than the 1-hour peak period.

As a note, it is also seen that for base station Schulkill Ave, the 1-minute peak period does not coincide with the 1-hour peak period. This does not indicate any anomaly or special concern.

5.5.9.4 Analysis of Base Station Radio Duty Cycle for the Philadelphia DUA

TTCI developed the analysis of the base station radio duty cycle [3]. Table 31 shows the total transmission time during the F-frame cycle for each of the base stations in the Philadelphia DUA.

Table 31. Total F-Frame Outbound Transmission Time per Base Station in the Philadelphia DUA

Site Name	ID	No. of WIU Messages (WSRS)	Transmission Time (milliseconds)
Onley Ave	3125209060	33	990
BlueMtn	3550076694	30	900

Schulkill Ave	3125209005	28	840
Newark	3550056699	28	840
Byberry Rd	3125209039	26	780
Chester Pike	3125209059	26	780
Mount Penn	3550036697	25	750
Falls	3550226694	24	720
Feltonville	3125209003	23	690
Ernest_King	3550236694	22	660
Flat_Rock_Tunnel	3550126694	21	630
Yard Ofc	3125209002	19	570
Phoenixville	3550196694	19	570
Birdsboro	3550166694	18	540
Woodside	3125209061	17	510
Pennington	3125209062	10	300
Safe_Harbor	3550066695	9	270
Black_Rock_Tunnel	3550256694	8	240
Balndon	3550056697	7	210
Lebanon_Avon	3550136694	6	180
Holtwood	3550056695	5	150
Cola	3550076695	3	90
ClyCh2	3550086695	3	90

Table 32 shows the maximum allowable outbound train message duration for each base station during the D-frame cycle (column "Maximum Outbound Message Duration (ms)") to not exceed the base station radio duty cycle limit (2 seconds), which is the combination of transmission time at both cycles, F-frame and D-frame. The column "Peak Outbound Message Duration (ms)/ min" shows the total D-frame outbound train message duration that was observed during peak operation at any given 1-minute period.

TTCI analyzed the possible impact on the base station radio duty cycle using a conservative "One Minute Peak" scenario, instead of just one superframe cycle (4 seconds), in which all train messages transmitted by the base station during the 1-minute peak period are transmitted simultaneously. Table 32 shows that even in this coincidental situation, none of the base stations would exceed the base station radio duty cycle limit. It should be noted that due to very light train message traffic in the Philadelphia DUA, "Peak Outbound Message Duarion (ms)/ 4 sec" for a superframe were found to be the same as that for 1-minute period shown in Table 32.

Table 32. Predicted 4-Second and 1-Minute Peak Outbound Message Durations in the Philadelphia DUA

Base Station Name	Base Station ID	F-Frame	D-Frame	
		Outbound Message Duration (ms)	Maximum Outbound Message Duration (ms)	Peak Outbound Message Duration (ms)/ min
Schulkill Ave	3125209005	840	1160	363
Paulsboro	2190000102	0	2000	363
Feltonville	3125209003	690	1310	297
Ernest_King	3550236694	660	1340	297
Newark	3550056699	840	1160	264
BlueMtn	3550076694	900	1100	198
Falls	3550226694	720	1280	198
Yard Ofc	3125209002	570	1430	198
Cola	3550076695	90	1910	198
Morrisville	2190000101	0	2000	198
Byberry Rd	3125209039	780	1220	165
Chester Pike	3125209059	780	1220	165
Phoenixville	3550196694	570	1430	165
Balndon	3550056697	210	1790	165
ClyCh2	3550086695	90	1910	165
Deepwater	2190000100	0	2000	165
Onley Ave	3125209060	990	1010	132
Pennington	3125209062	300	1700	132
Safe_Harbor	3550066695	270	1730	132
Black_Rock_Tunnel	3550256694	240	1760	132
Holtwood	3550056695	150	1850	132
Flat_Rock_Tunnel	3550126694	630	1370	99
Woodside	3125209061	510	1490	99
Mount Penn	3550036697	750	1250	66
Birdsboro	3550166694	540	1460	66
Lebanon_Avon	3550136694	180	1820	66

5.5.9.5 Analysis of Impact of Bulletin Dataset Message for the Philadelphia DUA

TTCI performed the latency analysis of Bulletin Dataset messages [3].

Table 33 shows the estimated latency that train messages would experience for all the base station sites in the Philadelphia DUA if Bulletin Dataset messages were sent at peak operation time.

Table 33. Predicted Latency Caused by Bulletin Dataset at Peak Train Operation Periods

Base Station Names	Number of Trains	Maximum Outbound Message Duration (ms)	Maximum Bulletin Messages/D-Frame	#D-Frame Cycles Needed for All Bulletin Messages	Maximum Latency (sec)
Schulkill Ave	14	1160	8	2	7
Morrisville	6	2000	15	1	3
Paulsboro	12	2000	15	1	3
Yard Ofc	6	1430	11	1	3
Feltonville	10	1310	10	1	3
Byberry Rd	6	1220	9	1	3
Chester Pike	5	1220	9	1	3
Onley Ave	4	1010	7	1	3
Woodside	4	1490	11	1	3
Pennington	4	1700	13	1	3
Mount Penn	2	1250	9	1	3
Holtwood	5	1850	14	1	3
Balndon	6	1790	13	1	3
Newark	8	1160	8	1	3
Safe_Harbor	4	1730	13	1	3
BlueMtn	6	1100	8	1	3
Cola	6	1910	14	1	3
ClyCh2	5	1910	14	1	3
Deepwater	6	2000	15	1	2
Flat_Rock_Tunnel	3	1370	10	1	2
Lebanon_Avon	2	1820	14	1	2
Birdsboro	2	1460	11	1	2
Phoenixville	6	1430	11	1	2
Falls	8	1280	9	1	2
Ernest_King	10	1340	10	1	2
Black_Rock_Tunnel	4	1760	13	1	2

Note that Bulletin Dataset message transmission at peak operation time is unlikely to occur with high frequency during the railroad operation (a simultaneous transmission typically would occur only once a day). Such message transmission would be noticed as “spikes” in the D-frame traffic and, unless railroads require extremely low message latency requirements for the D-frame, the impact caused by the burst of Bulletin Dataset messages can likely be absorbed by the system without impacting train operations [3].

Still, even during those spikes, the maximum predicted latency would not exceed two superframe cycles for the heaviest loaded site, which could be easily absorbed without any impact on train operation.

5.5.9.6 Analysis of Projected Train Traffic Increase for the Philadelphia DUA

The train message simulation developed by TTCI used current train operation traffic levels provided by the railroads, i.e., it did not include projection of train traffic for the year 2020. This is due to the fact that the addition of train traffic to the historical train operation data provided by the railroads might lead to unfeasible train traffic, as the additional train traffic cannot be simulated with valid train movements.

For this reason, the analysis of projected train message traffic for this project focused on the portion of the D-frame that is left for an increase in train message traffic, using current train message traffic loading.

The analyses developed in the previous subsections concluded the following:

- The total number of train messages at peak periods for the heaviest loaded base station site, Schulkill Ave, is predicted to not exceed 29 train messages total (inbound + outbound) for the projected year of 2020.
- The analysis of total train message traffic over 1-hour and 24-hour periods predicts that peak train message traffic would not be experienced for prolonged periods.
- The analysis of the D-frame capacity indicates that none of the base stations are predicted to exceed the D-frame capacity (i.e., there would be no latency), even in the conservative scenario (1-Minute Peak operation).
- Bulletin Dataset message traffic is predicted to create spikes of transmission that might cause delays of up to 7 seconds for base stations Schulkill Ave. These spikes of Bulletin Dataset message transmission would typically occur once a day and would not cause any significant impact on the D-frame traffic.

These results indicate that the current RF network design for the ITC system in the Philadelphia DUA would allow the system to handle substantially more train traffic than currently operated by the railroads, without causing impacts to the operation of the trains due to additional D-frame train message traffic.

5.5.10 Philadelphia DUA RF Network Design Conclusions

The results of the analyses presented in the previous sections lead to the following conclusions:

- A total of 48 base stations are used in the base station frequency plan for the Philadelphia DUA
- A total of 33 base stations are needed to achieve coverage along PTC-controlled tracks in the Philadelphia DUA.
  - 93.67 percent of the tracks inside the DUA are predicted to have coverage from at least one base station with an RSS of at least -94.37 dBm.
  - 71.66 percent of the tracks inside the DUA are predicted to have coverage from at least two base stations with an RSS of at least -94.37 dBm.
- The results obtained from the F-frame analysis indicate that a minimum F-frame size of 1,317 milliseconds will be needed to accommodate all the timeslots in the MTA.

- A total of 110 WIU radio sites and 241 WSMs were planned in the F-frame design of the DUA. The plan includes a frequency/timeslot plan for all of them.
- A total of 307 WSMs are planned to be broadcast by base stations (via WSRS). Two hundred seventy-two of these WSRS messages are planned to solve coverage gaps.

- Radio Desense between ACSES and ITC sites is predicted to occur at multiple locations:
  - Eleven ACSES radio sites are predicted to be desensed by fixed ITC radios. Sixty-one ACSES radio sites are predicted to be desensed by ITC locomotive radios. ACSES locomotive radios are predicted to be desensed by 18 ITC radio sites in a total of 20.2 miles of tracks.
  - Three ITC radio sites are predicted to be desensed by ACSES fixed radio sites. Eight ITC radio sites are predicted to be desensed by ACSES locomotives. ITC locomotive radios are predicted to be desensed by 51 ACSES radio sites in a total of 13.2 miles of tracks
- Twelve non-railroad licensees (incumbents) operating in the 217–222 MHz band operating in 134 unique locations were found:
  - Eight possible cases of desense or interference with non-railroad incumbents were found.
  - TTCI adjusted the RF design to mitigate potential desense issues by assigning channels to ITC sites that would not cause issues.
  - TTCI sent notification letters to the non-railroad incumbents and concurrence was obtained from all of them.
- A total of 11 channels will be needed to allow for the operation of the ITC radio system inside the Philadelphia DUA, including one channel for use as the Common Channel:
  - For D-frame communications, the base stations will need 10 channels as local channels.
  - For F-frame communications, six of the PTC-220 LLC nationwide channels in the 220–221 MHz band will be needed.
- Train message traffic in the D-frame for all base stations is predicted to be relatively low and not cause any impact in train operations
  - At the peak message traffic periods, none of the base station sites are predicted to exceed the total D-frame capacity.
  - The peak number of simultaneous trains under a base station provides an indication about the likely most heavily loaded base stations in terms of train message traffic, but it does not provide an indication of the loading of the D-frame.
  - The results of the duty cycle analysis indicate that, even at peak periods, none of the ITC radios would reach their duty cycle limit.
  - The base stations will operate below the volume calculated for peak periods for the majority of the time. Simultaneous transmission of Bulletin Dataset messages typically occur once a day and can likely be managed to not coincide with peak train

operation times. The duty cycle is not predicted to become an issue for the Philadelphia DUA base stations.

- All base stations are predicted to be able to handle substantially more train traffic volumes than currently operated by the railroads that operate in the Philadelphia DUA. This spare capacity could be useful for business traffic, SMS messages, Network Management messages, and future growth or peaks in train traffic.

Overall, the resources available (220 MHz radio spectrum, base station and WIU radio sites) are sufficient for the normal operation of ITC-controlled trains inside the Philadelphia DUA, given that railroads deploy and configure all ITC radio system components per the frequency-timeslot plan prepared by TTCI and that all the desense issues predicted by TTCI between ACSES and ITC radios are properly addressed by the railroads. While the overall redundant coverage is not very high (71.66 percent), visual inspection indicates that most of the ITC-controlled tracks are predicted to have good redundant coverage, except for long extensions of tracks along Amtrak's Harrisburg subdivision. A detailed analysis of redundant coverage is also strongly recommended for this DUA before full operation of the ITC system commences.

5.6 RF Network Design for the Washington, D.C. DUA

5.6.1 Washington, D.C. DUA Project Scope

The ITC system RF design project for the Washington, D.C. DUA includes the planned PTC-controlled tracks, base stations and WIU radio sites from three railroads: CSX, NS, and Amtrak. The design also includes the desense analysis between ITC and ACSES radios for all the fixed sites and tracks where PTC-equipped trains from both systems operate.

The design did not include the analysis of train message traffic loading because the volume of ITC-controlled trains in this DUA is very small (only CSX and NS freight trains), and as observed in the designs completed for the New York and Philadelphia DUAs that also have very low ITC-controlled train traffic volume, the D-frame message traffic is not expected to reach any significant volume as compared to the capacity of the system.

5.6.2 Washington, D.C. DUA Boundaries

The Washington, D.C. DUA includes all PTC-controlled tracks within a distance of approximately 63 miles northeast from downtown Washington, DC, 23 miles to the southwest, 23 miles to the northwest, and 20 miles to the southeast.

Figure 59 shows the boundaries of the Washington, DC, study and the PTC-controlled tracks from all the railroads for both ACSES and ITC systems. The design of the ITC system considered all the In-Service, Planned, and Candidate ITC base stations and WIU locations as well as the ACSES sites (required for the radio desense analysis) provided to TTCI for every railroad/subdivision included inside the boundaries.

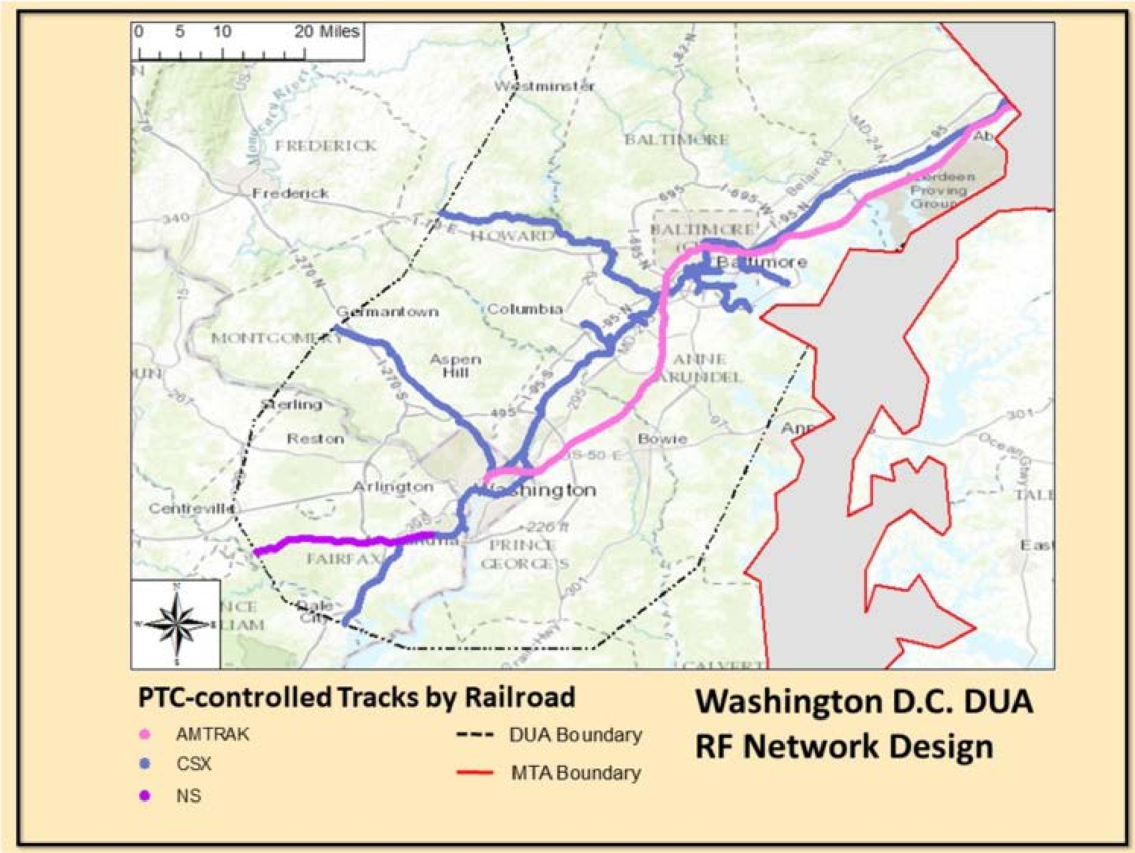

Figure 59. PTC-Controlled Tracks Within the Washington, D.C. DUA Boundaries

PTC-controlled tracks can be configured to support trains operating with either of the systems (ACSES or ITC) or both systems simultaneously (dual-equipped), as explained in Section 1.2. Figure 60 displays the PTC-controlled tracks identified by the type of control system in the Washington, D.C. DUA. Note that in the Washington, DC, area, all the ACSES-controlled tracks from Amtrak are also equipped to support the operation of ITC-controlled trains from freight railroads, therefore, there are no tracks that are exclusively ACSES-controlled.

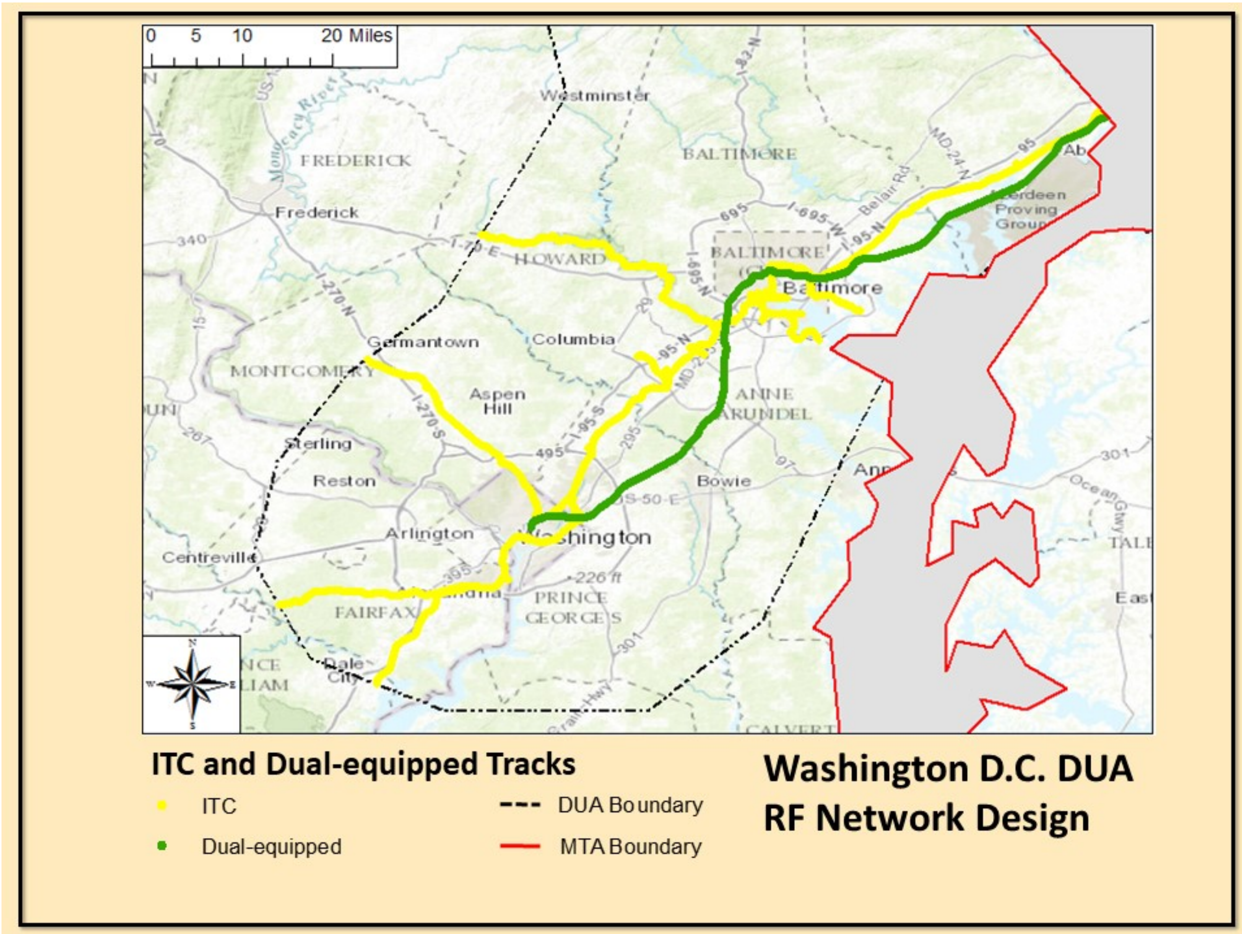

Figure 60. Visualization of ITC and Dual-Equipped Tracks in the Washington, D.C. DUA

5.6.3 List of Railroads and Subdivisions Inside the Washington, D.C. DUA

Three railroads were included in the design of the ITC system for the Washington DUA. Table 34 lists the railroads, their subdivisions, and the range of route-mile tracks included in the study. Note that in some cases the exact MPs were not provided, and TTCI calculated the estimated length of the tracks based on visual inspection using GIS tools.

Table 34. Route Miles of ITC-Controlled Tracks per Railroad and Subdivision Included in the Washington, D.C. DUA

Railroad	Subdivision	Start MP	End MP	Route Miles
Amtrak	Philadelphia–Washington, DC	N/A	N/A	73.6
CSX	RFP	88	110	34.1
CSX	Metropolitan	1	26	26
CSX	Capital	0	37	29.2
CSX	Baltimore	N/A	6	12.8
CSX	Philadelphia	58	94	36
NS	Washington, DC	8.2	27.9	19.7
	Total			**231.4**

5.6.4 Washington, D.C. DUA Data Gathering and Consolidation

5.6.4.1 Washington, D.C. DUA Base Station Input Data

Table 35 contains the list of the 24 base station sites that were considered in the RF design developed by TTCI. The list of sites was obtained from information provided by the railroads.

The Status column in Table 35 indicates the status of operation of the base station site, base station sites marked as In-service or Planned were considered as preferred sites in the RF design developed. Sites with a status of Candidate were considered only on an as-needed basis.

Table 35. List of ITC Base Stations Included in the RF Design for the Washington, D.C. DUA

Site ID	Sector ID	Status	Antenna Centre of Radiation Height(ft)	Antenna Azimuth (degrees)	Antenna Model
3125210006	Potomac Yard	In_Service	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125210019	Howard St. Tunnel	Planned	15	0	SD222-SF6PASNM(OM)_0160.pafx
3125210022	White Marsh	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210024	Jessup	Planned	85	90	SD222-SF6PASNM(OM)_0160.pafx
3125210025	Riverside	Planned	65	80	SD222-SF6PASNM(OM)_0160.pafx
3125210026	Beltsville	Planned	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125210027	Woodbine	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210045	Bayview	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210046	Halethorpe	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210066	Bowie	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210133	Henryton	Planned	65	20	SD222-SF6PASNM(OM)_0160.pafx
3125210134	Hollofield	Planned	65	40	SD222-SF6PASNM(OM)_0160.pafx
3125210143	Ilchester	Planned	65	40	SD222-SF6PASNM(OM)_0160.pafx
3125210145	Jessup	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210147	Joppa	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210183	Rockville	Planned	65	60	SD222-SF6PASNM(OM)_0160.pafx
3125210204	Bennings	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125210206	Washington	Planned	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125210220	Woodstock	Planned	65	35	SD222-SF6PASNM(OM)_0160.pafx
3125210239	Lorton	Planned	65	125	SD222-SF6PASNM(OM)_0160.pafx
3125210254	Charles St	In_Service	10	90	SD222-SF6PASNM(OM)_0160.pafx
3550116695	Old Bay	Candidate	155	0	PCTEL_BOA2177.pafx
3550156609	Fairfax	Planned	110	0	PCTEL_BOA2177.pafx
3550166609	Burke	In_Service	120	0	PCTEL_BOA2177.pafx

5.6.4.2 Washington, D.C. DUA WIU Input Data

The WIU data used in the RF design for the Washington, D.C. DUA was provided by the PTC-220, LLC railroad members (NS and CSX) included in the design. For Amtrak, the data was developed by TTCI and validated with the railroad.

Amtrak and CSX indicated that their WIU devices will not be equipped with WIU radios, meaning that all their WSMs will use WSRS transmission from ITC base stations. Table 36 shows the total number of WIU radio locations and WSMs for each railroad.

Table 36. Counts of WIU Radio Locations and WSMs in the Washington, D.C. DUA

Railroad	No. of WIU Radio Locations	No. of WSMs
Amtrak	0	22
CSX	0	87
NS	9	9
Total	9	118

Figure 61 illustrates the distribution of all WSMs along the PTC-controlled tracks per railroad in the Washington, D.C. DUA. Notice that for NS, WSM location corresponds to the location of a WIU radio site, whereas for the commuter railroads, each location represents a WIU device, but not the location of a WIU radio site. CSX was unable to provide WSM data for their tracks along the Old Main Line subdivision, and thus, this subdivision was included only in the base station frequency plan design, but not in the F-frame plan.

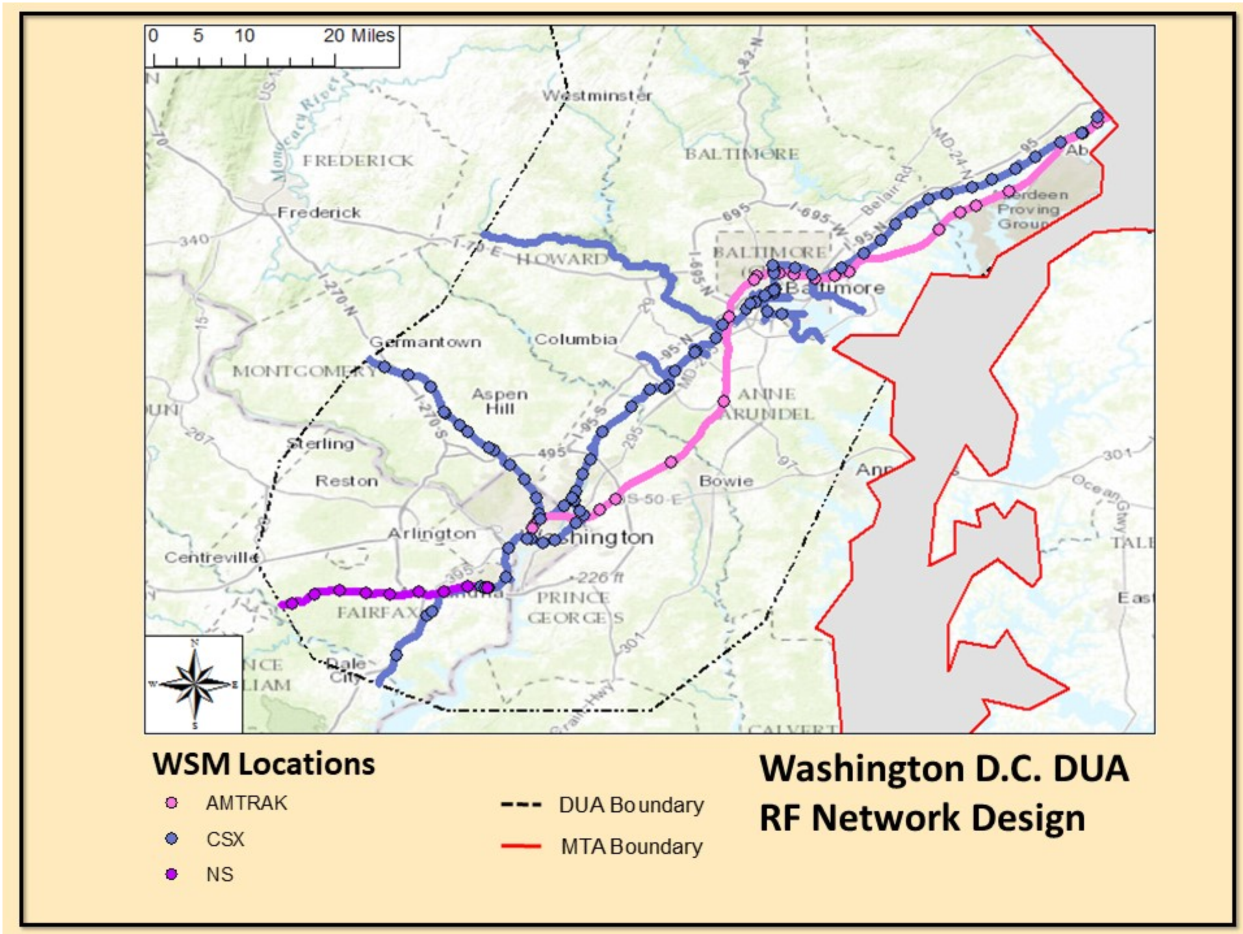

Figure 61. Distribution of WIU Locations Inside the Washington, D.C. DUA

5.6.5 Washington, D.C. DUA Incumbent Analysis

The Incumbent Analysis comprises checking for possible desense scenarios between ITC base stations and fixed non-railroad incumbent sites operating within the 217–222 MHz band, as explained in detail in Section 4.2.

The results of the Phase 1 Incumbent Analysis show nine non-railroad incumbent licensees inside the Washington, D.C. DUA, operating a total of 28 unique radio locations. Figure 62 shows the location of the ITC base stations inside the Washington, D.C. DUA and all the non-railroad incumbents in the area. It is worth noting that a single location can either have multiple licensees or multiple frequencies in use.

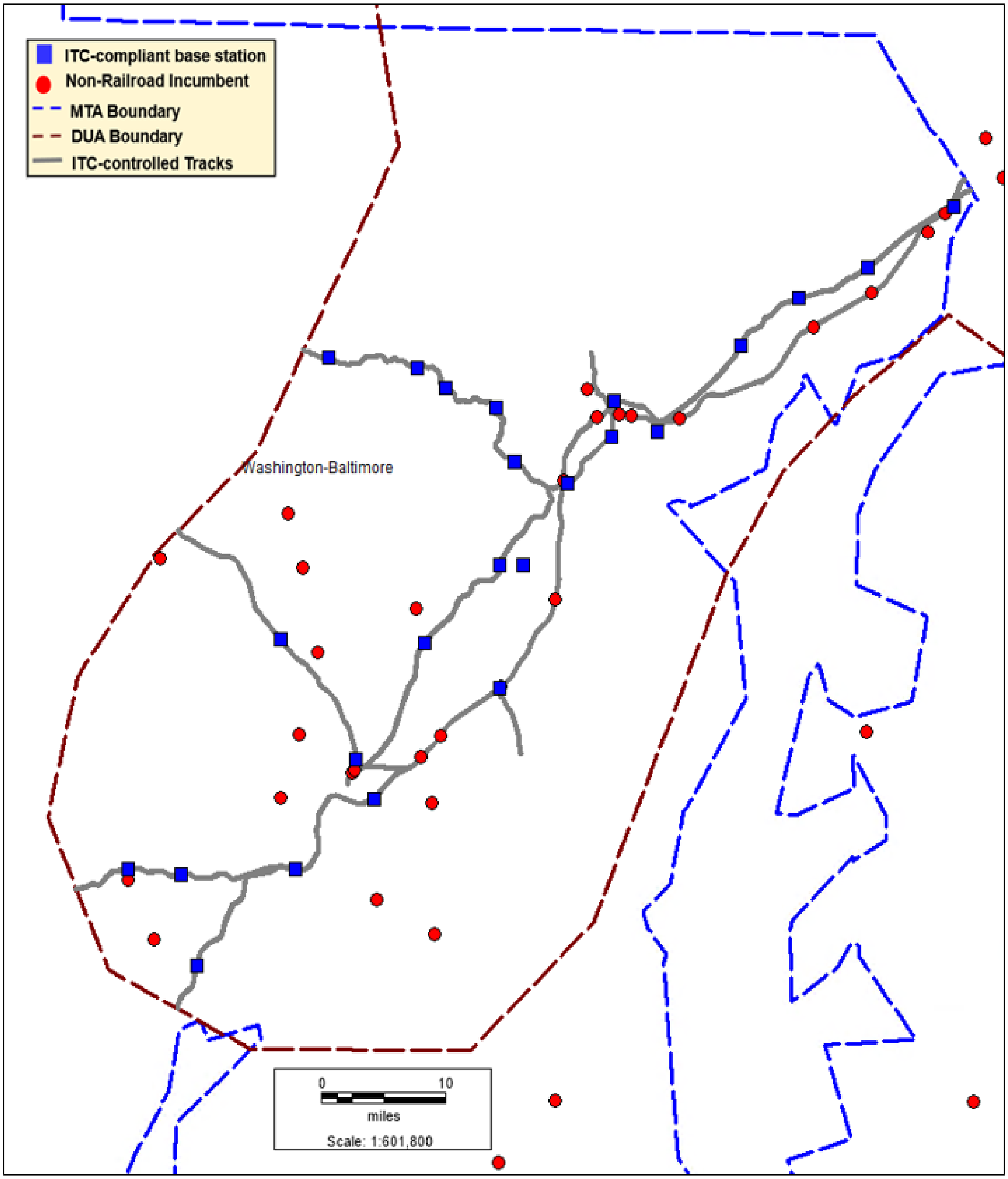

Figure 62. ITC Base Stations and Non-Railroad Incumbent Sites in the Washington, D.C. DUA

It is assumed that the incumbent radios have a desense threshold of -30 dBm when determining whether an ITC fixed site could cause desense issues on non-railroad incumbents as explained in Section 2.1.

TTCI encountered seven possible cases of desense or interference with NRTC or any other incumbent sites while preparing the D-frame frequency plan. Waiver notifications were sent to the owners of each of these non-railroad sites before finalizing the frequency plan. In addition, NRTC sites were notified and asked for their concurrence. Concurrence was obtained from all the non-railroad incumbents and the bases were used as per the initial plan without any additional changes.

TTCI also identified three possible cases of desense or interference between non-railroad incumbents and NS WIU radio sites. TTCI has not taken further actions for these cases, as explained in Section 4.2.

5.6.6 Washington, D.C. DUA ACSES and ITC Desense Analysis

TTCI developed the detailed desense analyses to identify areas where ACSES and ITC radios could be at risk of desensing each other, as explained in Section 4.3. This included:

- Identification and analysis of ACSES radio sites that could desense ITC radio sites and vice versa (see Section 2.1.1).
- Identification and analysis of tracks where locomotives could get desensed by fixed sites from a dissimilar system (ITC desensing ACSES and vice versa) (see Section 2.1.2).
- Identification and analysis of track locations where locomotives could cause desense to fixed sites from the dissimilar system (ITC desensing ACSES and vice versa) (see Section 2.1.3).

The next set of figures and tables shows the results obtained for each of the above listed cases. Appendix A, Section A.3 contains tables with detailed lists of fixed sites that are predicted to either desense or be desensed by a dissimilar system.

Figure 63 shows the location of ACSES radio sites and the tracks where ACSES-controlled trains operate inside the Washington, D.C. DUA.

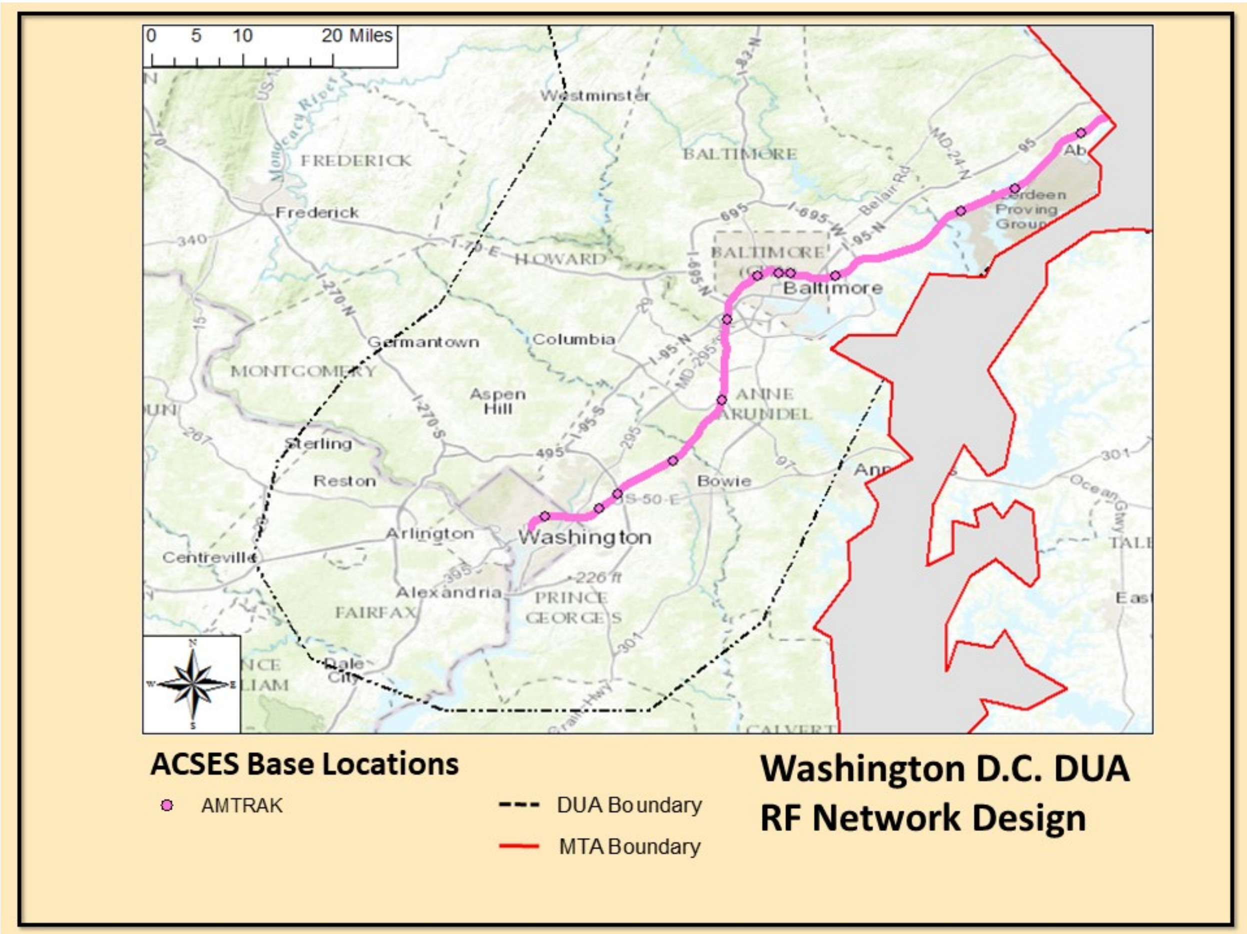

Figure 63. Location of ACSES Base Stations and ACSES-Controlled Tracks in the Washington, D.C. DUA

Table 37 summarizes the results of the desense analysis between ACSES and ITC fixed sites. The column titled "Desensing" shows the number of ACSES or ITC sites that are predicted to be desensed by fixed radios from a dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to radios from a dissimilar system.

Figure 64 shows the locations of the ITC base stations that are predicted to be desensed by ACSES base stations inside the Washington, D.C. DUA.

Table 37. Desense Results Between Fixed ACSES and ITC Sites in the Washington, D.C. DUA

System Type	Desensing	Being Desensed by
ITC Fixed Site	3 ACSES Sites	1 ACSES Site
ACSES Fixed Site	1 ITC Site	3 ITC Sites

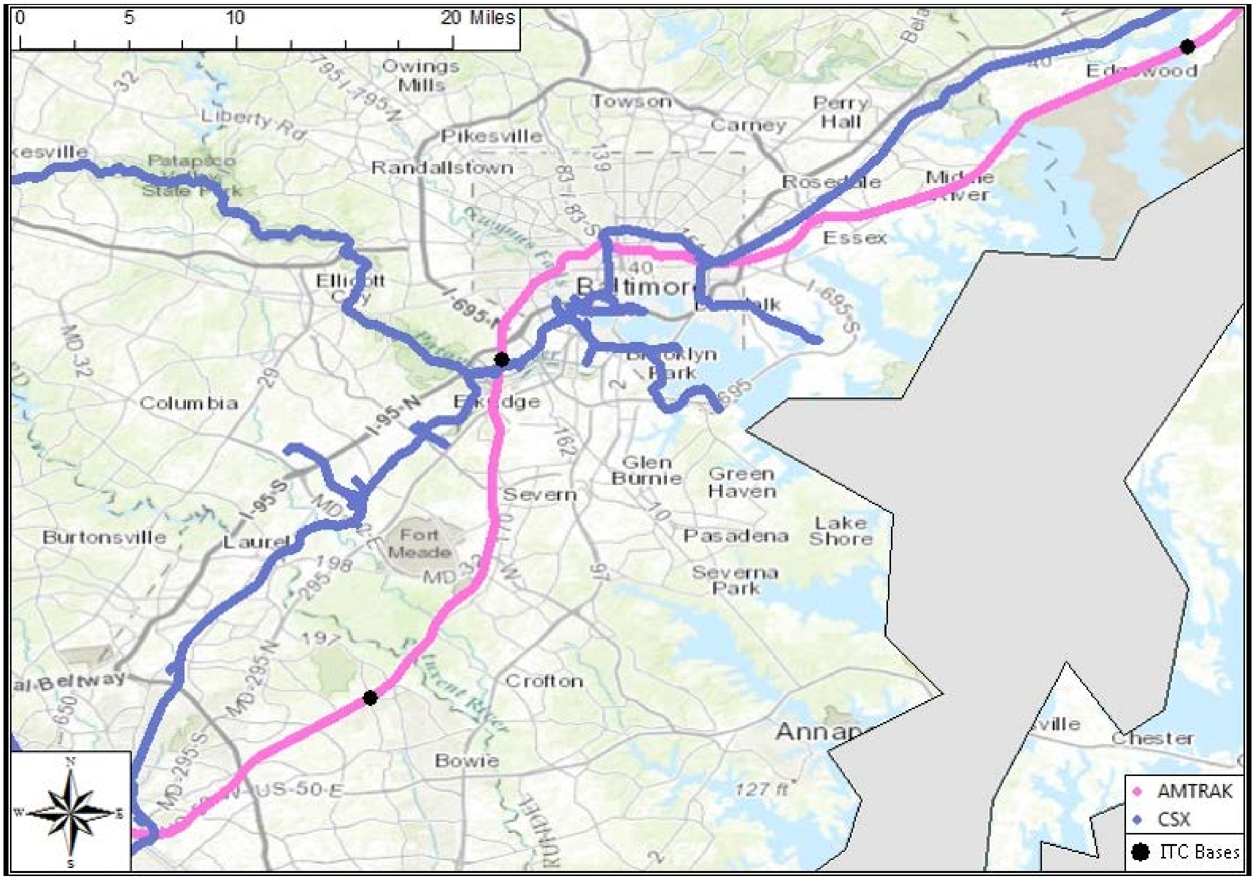

Figure 64. Location of ITC Base Stations Predicted to be Desensed by ACSES Base Stations in the Washington, D.C. DUA

Figure 65 shows the locations of ACSES base station sites predicted to be desensed by ITC base stations in the Washington, D.C. DUA. Note that in many cases the desensed sites are very close to each other, and for those cases one black dot indicates the location of multiple sites.

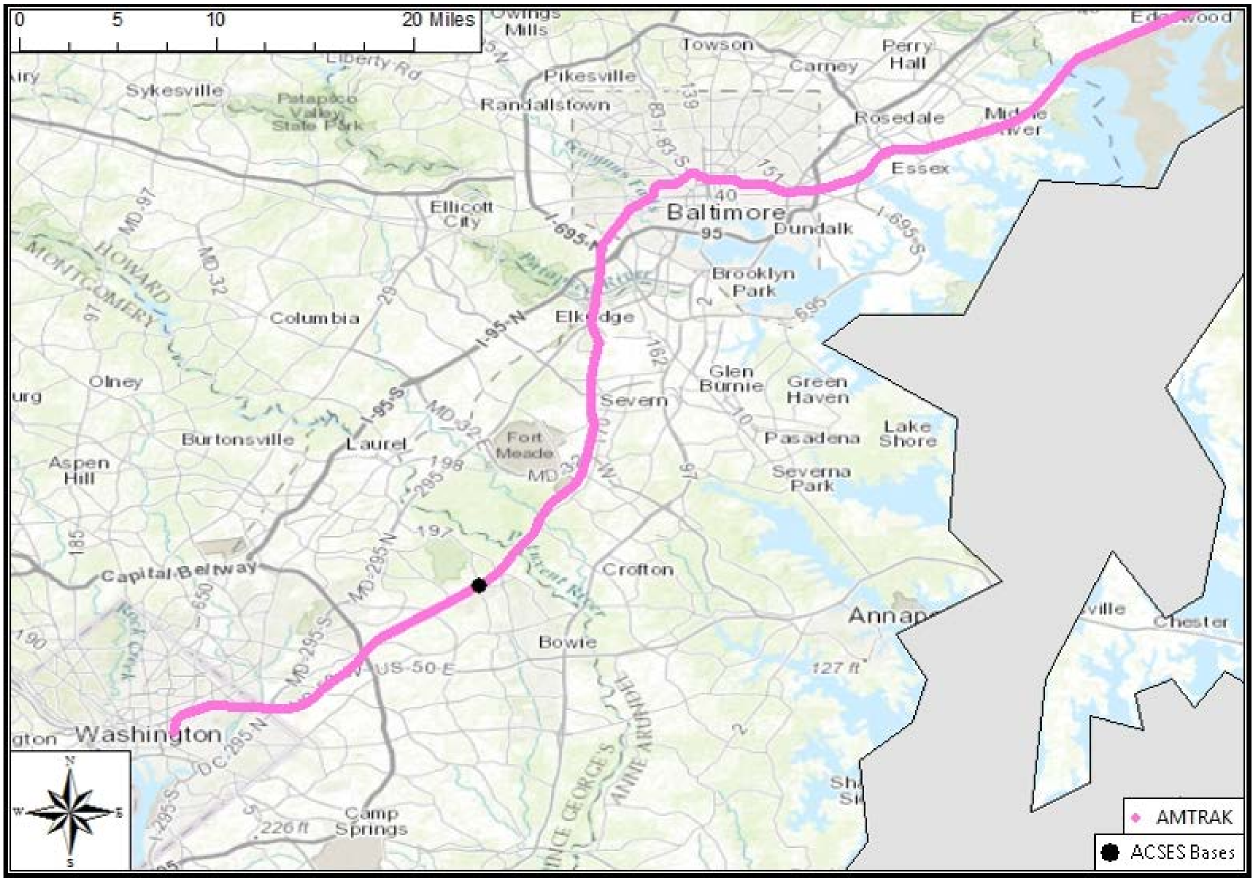

Figure 65. Location of ACSES Base Stations Being Desensed by ITC Base Stations in the Washington, D.C. DUA

TTCI developed the analysis of desense between fixed radio sites and locomotive radios for both systems (ACSES and ITC), as explained in Section 4.3. Table 38 summarizes the results obtained for the Washington, D.C. DUA. The column "Desensing" shows the number of ACSES or ITC fixed radio sites that are predicted to be desensed by locomotive radios from the dissimilar system, while the column "Being Desensed by" shows the number of sites that are predicted to potentially cause desense to locomotive radios from the dissimilar system.

Table 38. Desense Results Between Fixed Radio Sites and Locomotive Radios from a Dissimilar System Inside the Washington, D.C. DUA

System Type	Desensing	Being Desensed by
ITC Locomotive	15 ACSES Sites	15 ACSES Sites
ACSES Locomotive	4 ITC Sites	5 ITC Sites

TTCI identified the location of the tracks where locomotive radios could cause desense to fixed radio sites from a dissimilar system, as explained in Section 4.3. Figure 66 shows the location of tracks where ITC locomotive radios are predicted to be desensed by ACSES base stations. Fifteen ACSES sites are predicted to desense ITC-controlled trains along 5.6 miles of tracks.

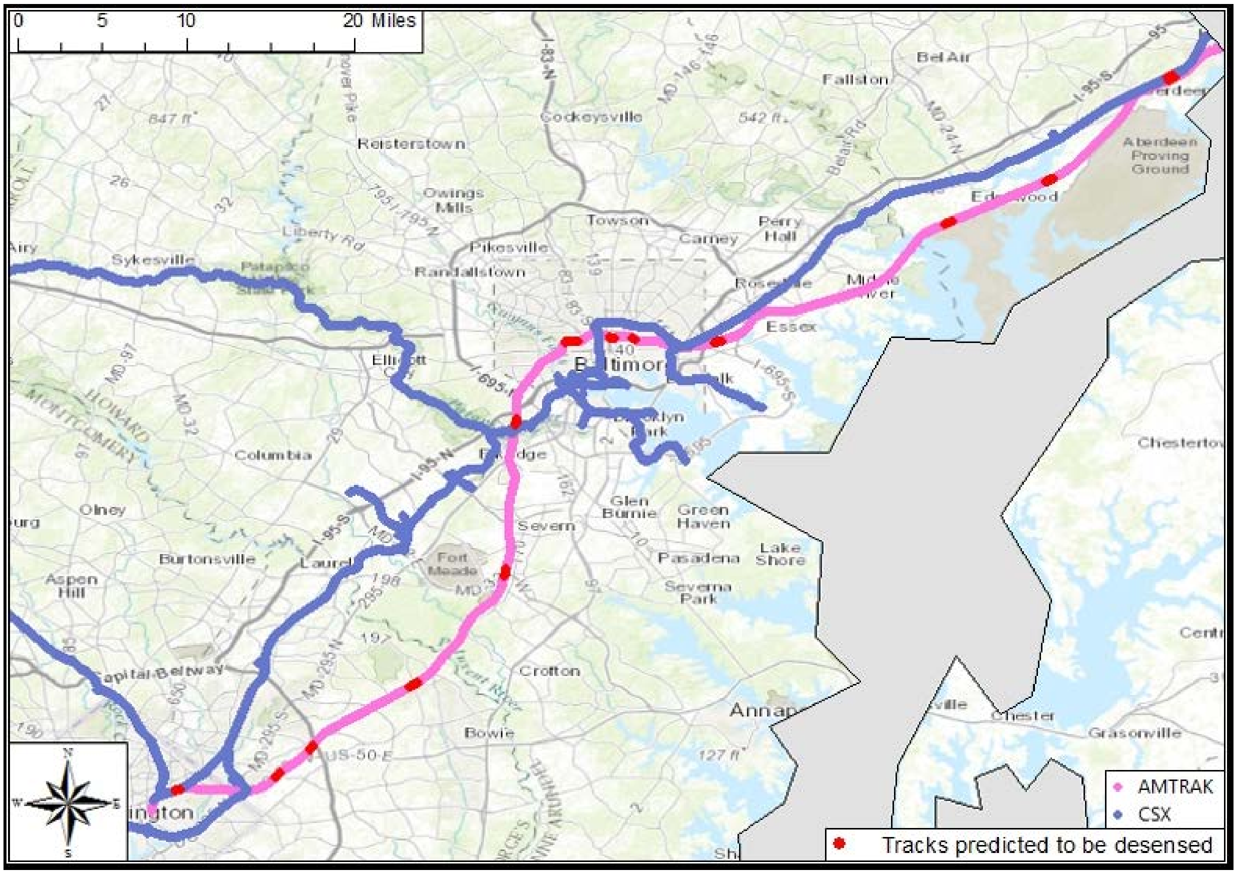

Figure 66. Location of ITC-Controlled Tracks Predicted to be Desensed by ACSES Base Stations in the Washington, D.C. DUA

TTCI developed the desense analysis on the tracks for the opposite direction, i.e., ITC base stations that are predicted to desense ACSES locomotive radios. Five ITC sites are predicted to desense ACSES-controlled trains along 5.5 miles of tracks. Figure 67 shows the location of the tracks where ACSES-controlled trains are predicted to be desensed by ITC base stations in the Washington, D.C. DUA.

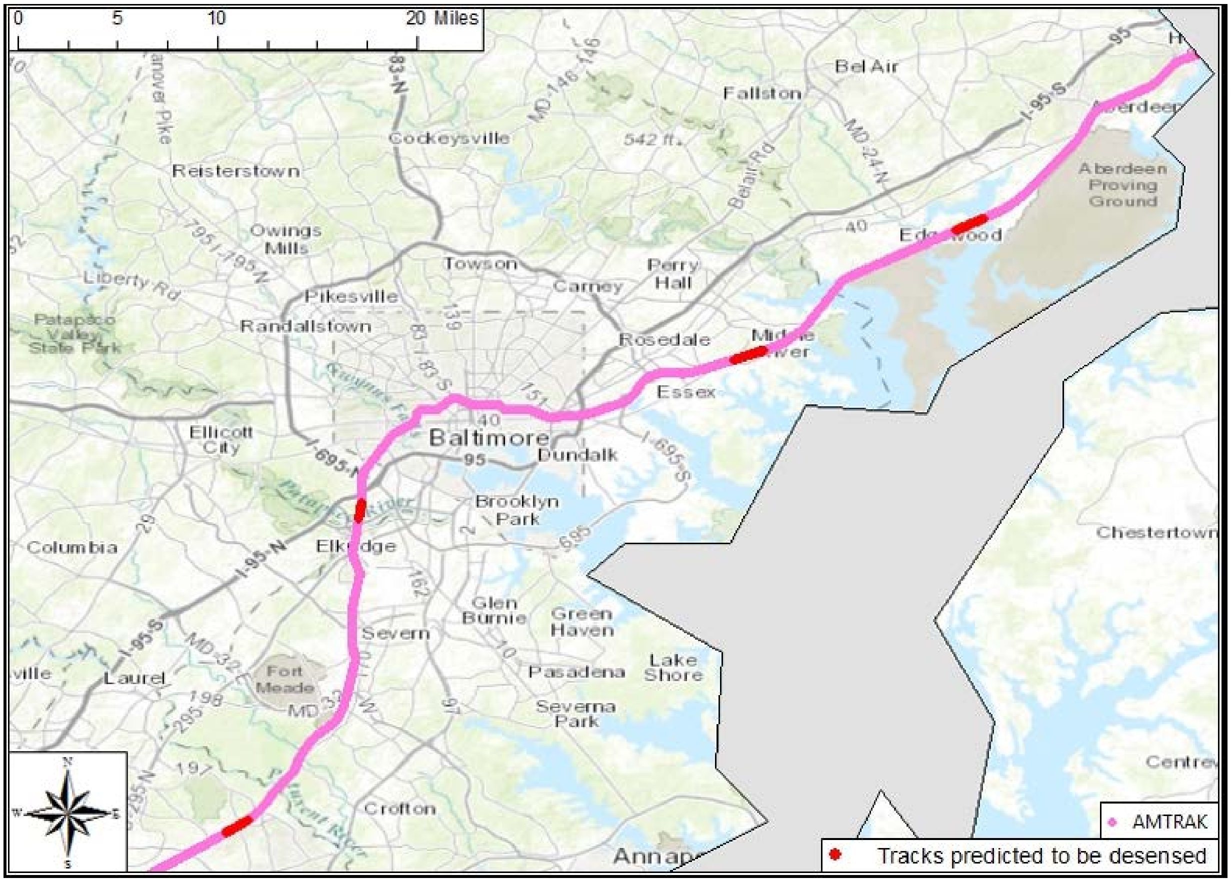

Figure 67. Location of ACSES-Controlled Tracks Predicted to be Desensed by ITC Base Stations in the Washington, D.C. DUA

The next set of results shows the potential desense that fixed radio sites from one system could suffer from locomotive radios from the dissimilar system. Figure 68 shows the location of the 15 ACSES base stations that are predicted to be potentially desensed by ITC locomotive radios in the Washington, D.C. DUA.

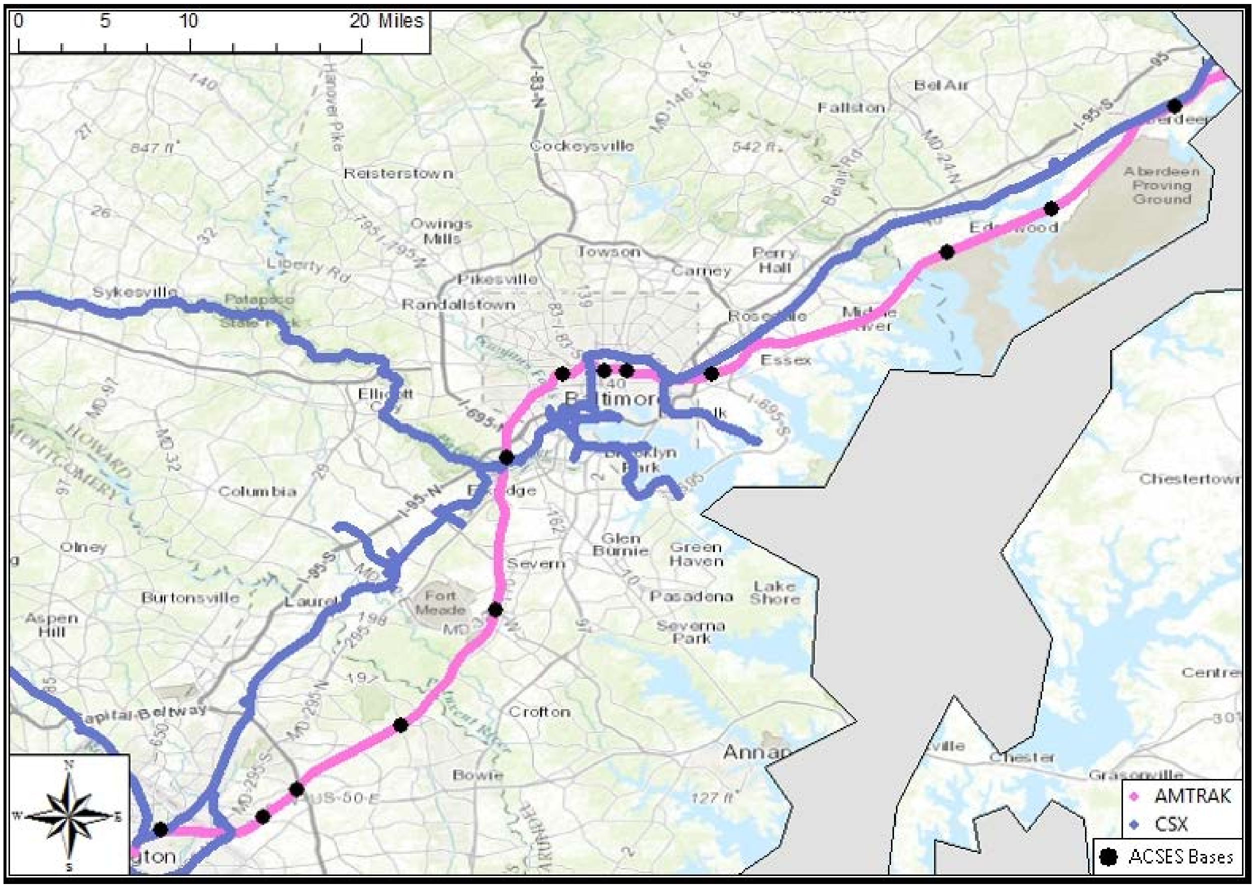

Figure 68. Location of ACSES Base Stations Predicted to be Desensed by ITC Locomotives in the Washington, D.C. DUA

Figure 69 shows the locations of the four ITC base stations that are predicted to be potentially desensed by ACSES locomotive radios in the Washington, D.C. DUA.

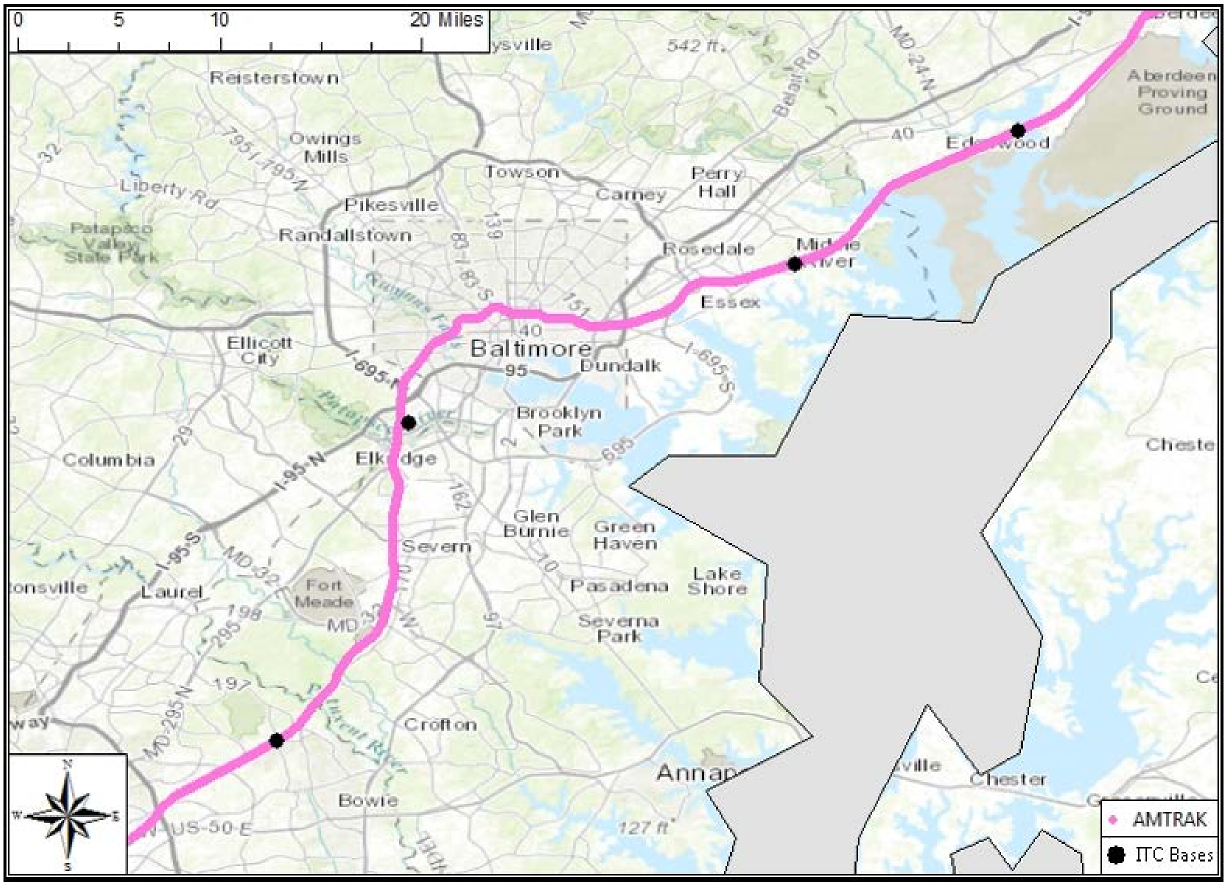

Figure 69. Location of ITC Base Stations Predicted to be Desensed by ACSES Locomotive Radios in the Washington, D.C. DUA

5.6.7 Washington, D.C. DUA Base Station Coverage Analysis and Frequency Plan

The design requirement along the ITC-controlled tracks for all railroads is to have coverage from at least one ITC base station at a level of -94.37 dBm or higher. The design target along the ITC-controlled tracks for the railroads with radioless WIUs (CSX and Amtrak) is to have coverage from at least two ITC base stations at -94.37 dBm or higher.

All 24 available ITC base stations listed in Table 35 were selected to achieve the coverage requirements over the ITC-controlled tracks in the Washington, D.C. DUA. These 23 base stations were analyzed with Infovista's Planet® software to determine coverage, signal strength, C/I, and other relevant parameters.

As an initial step, the ITC base stations were assigned an RF propagation model. A subset of 19 of the available models in the hosted server was tuned in regions that topographically resemble the Washington, D.C. DUA, as agreed with the railroads.

Table 39 shows details of the selected set of base stations for the Washington, D.C. DUA, including the antenna and propagation models, and channel assignments. The results of the desense analysis (described in Section 5.6.6) were also considered when selecting the sites for the base station frequency plan.

Table 39. ITC Base Station Frequency Plan for the Washington, D.C. DUA

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height (ft)	Antenna Aximuth (degrees)	EIRP (dBm)	Channel
3125210006	Potomac Yard	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	125	44.95	101
3125210019	Howard St. Tunnel	IV_IV_NESouthAtlantic_UR_SU_82ft.pmf	15	0	44.95	126
3125210022	White Marsh	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	44.95	125
3125210024	Jessup	NF_NF_Midwest_RU_8_Grassland_130ft.pmf	85	90	44.95	153
3125210025	Riverside	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	80	44.95	165
3125210026	Beltsville	IV_IV_NESouthAtlantic_UR_SU_82ft.pmf	65	90	44.95	125
3125210027	Woodbine	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	44.95	141
3125210045	Bayview	NF_NF_Midwest_RU_1_Cropland_85ft.pmf	65	0	44.95	114
3125210046	Halethorpe	IV_IV_NESouthAtlantic_UR_SU_65ft.pmf	65	0	44.95	127
3125210066	Bowie	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	44.95	114
3125210133	Henryton	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	65	20	44.95	142
3125210134	Hollofield	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	40	44.95	126
3125210143	Ilchester	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	40	44.95	114
3125210145	Jessup	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	0	44.95	154
3125210147	Joppa	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	65	0	44.95	101
3125210183	Rockville	IV_IV_NESouthAtlantic_UR_SU_82ft.pmf	65	60	44.95	101
3125210204	Bennings	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	0	44.95	113
3125210206	Washington	IV_IV_NEMiddleAtlantic_UR_SU_65ft.pmf	65	90	44.95	126
3125210220	Woodstock	NF_NF_Midwest_RU_8_Grassland_126ft.pmf	65	35	44.95	127
3125210239	Lorton	IV_IV_NESouthAtlantic_UR_SU_65ft.pmf	65	125	44.95	126
3125210254	Charles St	NF_NF_Midwest_RU_7_RiverValley_40ft.pmf	1	270	34.95	127
3550116695	Old Bay	IV_IV_Northeast_RU_1_Cropland_113 ft avg.pmf	155	0	44.95	166
3550156609	Fairfax	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	110	0	44.95	127
3550166609	Burke	IV_IV_Northeast_RU_1Cropland_135 ft.pmf	120	0	44.95	125

Figure 70 shows the coverage achieved from the 24 selected ITC base stations along the ITC-controlled tracks inside the Washington, D.C. DUA. The base station coverage analysis indicates that 93.77 percent of the 90-meter buffer area around the ITC-controlled tracks has coverage from at least one base station at -94.37 dBm or higher.

The results of the coverage analysis developed by TTCI were reviewed with the railroads, particularly because they did not satisfy the original RF design criteria for coverage. The railroads requested TTCI to proceed with the design with the results as predicted by the RF simulation.

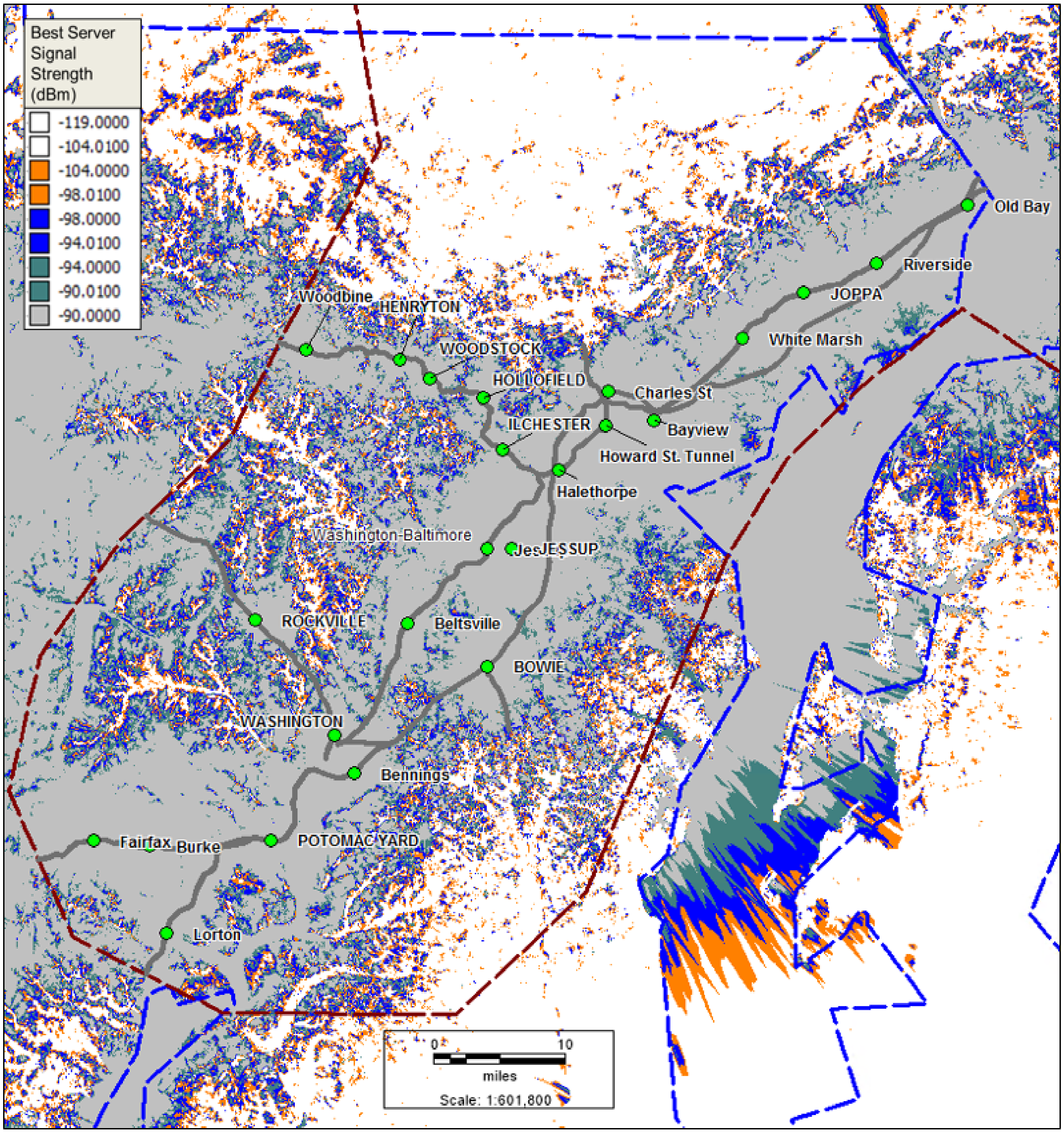

Figure 70. Best Serving ITC Base Station Signal Strength Inside the Washington, D.C. DUA

Propagation modeling using AFP indicates that 12 frequencies are needed to achieve the required C/(I+A) requirements. The channel assignments of the 12 available frequencies are shown in the rightmost column of Table 39. One additional frequency is required for the Common Channel, bringing the total to 13 frequencies. Table 40 shows a summary of the percentage of buffer area with C/(I+A) levels above 18.6 dB and 11.5 dB. The first column in the table represents the C/(I+A) ranges, the second column represents the area in square miles of the 90-meter buffer area with the corresponding C/(I+A) levels, and the third column represents the percentage of the buffer area with the corresponding C/(I+A) levels. Although the radio is designed to handle C/I as low as 11.5 dB, that assumes no fade margin, so a higher analysis threshold is required. A C/I threshold of 18.6 dB is more conservative and thus carries lower risk.

Table 40. Percentage of Buffer Area in the Washington, D.C. DUA Where the Predicted C/(I+A) Levels Exceed the Thresholds of 18.6 dB and 11.5 dB

Ranges	**Area (mi^2)**	**Percentage Sub Area**
-50 ~ 0	0	0
0 ~ 11.5	0.00451739226	0.0160751827
11.5 ~ 18.6	0.207800046	0.739458442
18.6 ~ 100	27.8893375	99.24447

Figure 71 shows the predicted base station best serving sector coverage for the selected 24 ITC base station sites, assuming the use of the 12 available channels. The channels that are reused by multiple ITC base station sites are shown with the same color in Figure 71.

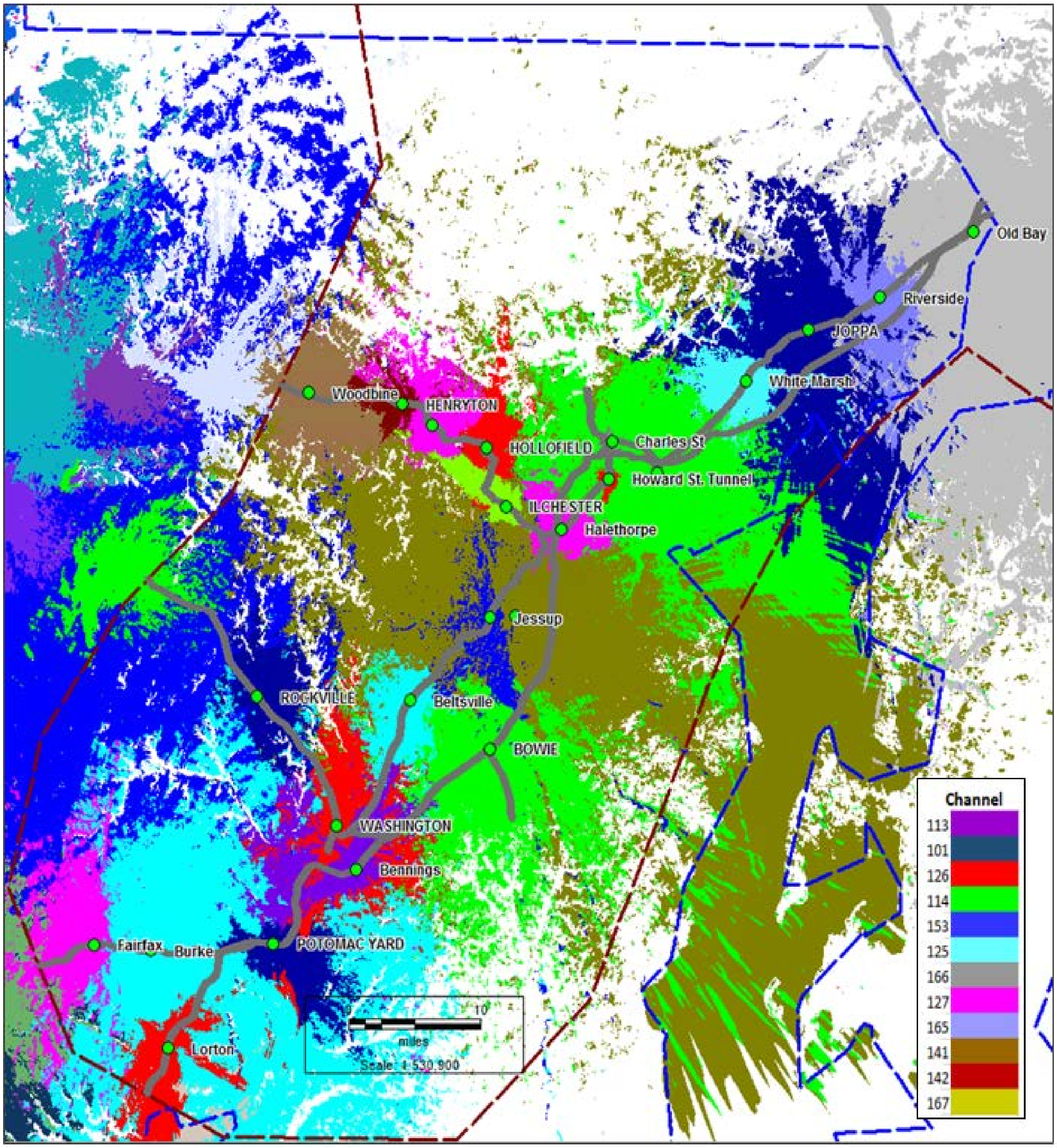

Figure 71. ITC Base Station Best Serving Sectors for the Washington, D.C. DUA

Figure 72 shows the total C/(I+A) that would be received from the best ITC base station server by an ITC locomotive radio at every point throughout the Washington, D.C. DUA for the ITC base station frequency plan prepared for the 24 selected ITC base stations. The objective is for the C/(I+A) to be ≥ 11.5 dB. Green and yellow colors in Figure 72 means acceptable C/I levels, which, as can be seen, is the case for the majority of ITC-controlled tracks in the Washington, D.C. DUA with the selected base stations and frequencies.

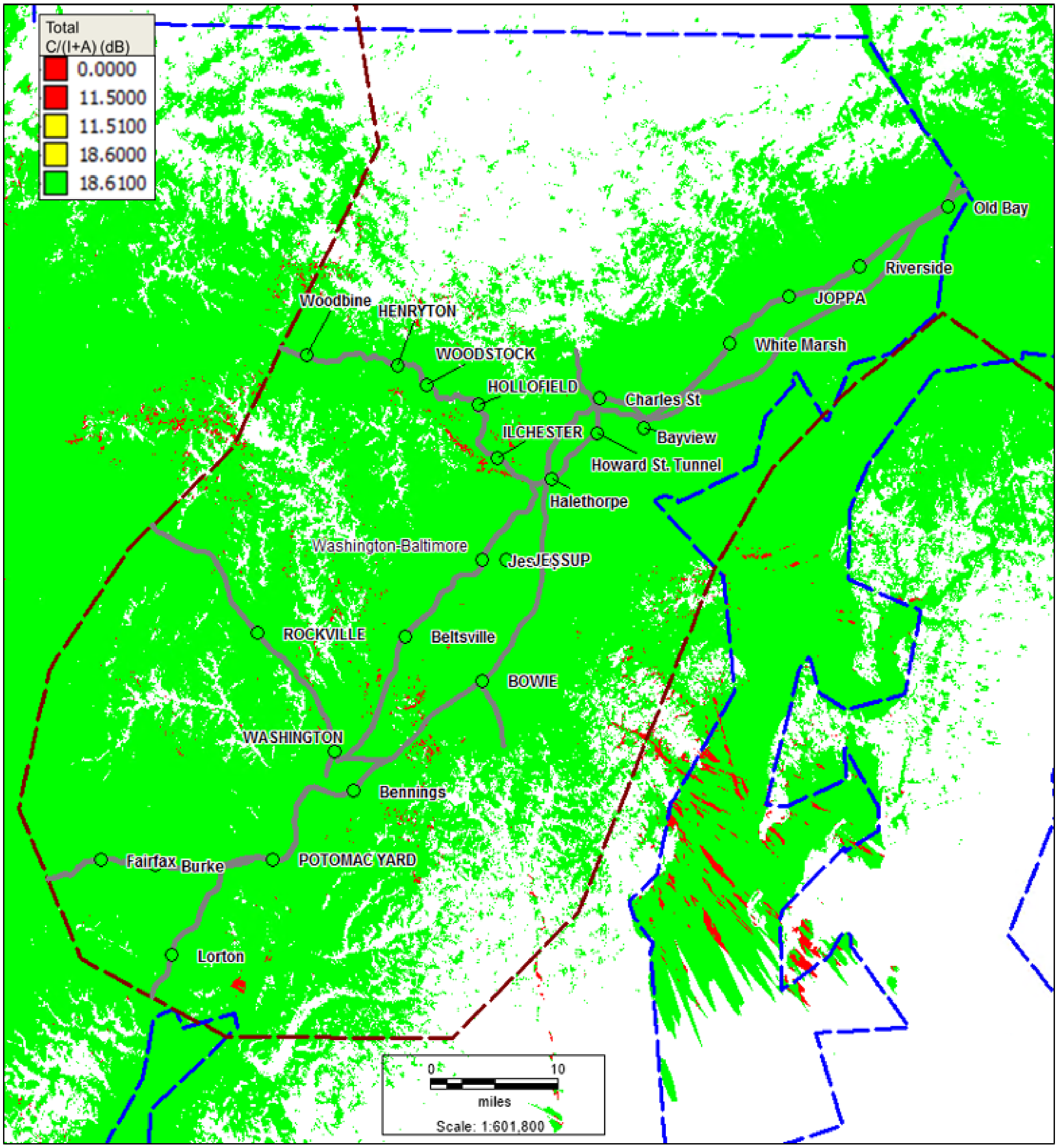

Figure 72. Predicted C/(I+A) Levels of the ITC Base Station Frequency Plan Prepared for the Washington, D.C. DUA

5.6.7.1 Analysis of Base Station Redundancy for the Washington, D.C. DUA

The design target requirement along ITC-controlled tracks with radioless WIUs is to have coverage from at least two ITC base stations at a level of -94.37 dBm or higher, as indicated in Section 5.6.7.

Figure 73 shows the predicted second best ITC base station signal strength along the ITC-controlled tracks inside the Washington, D.C. DUA. The analysis indicates that 61.08 percent of the ITC-controlled tracks are predicted to have coverage satisfying the requirements from at least two base stations. Note that not all of this redundancy is usable, because the C/I levels for second best servers are unknown.

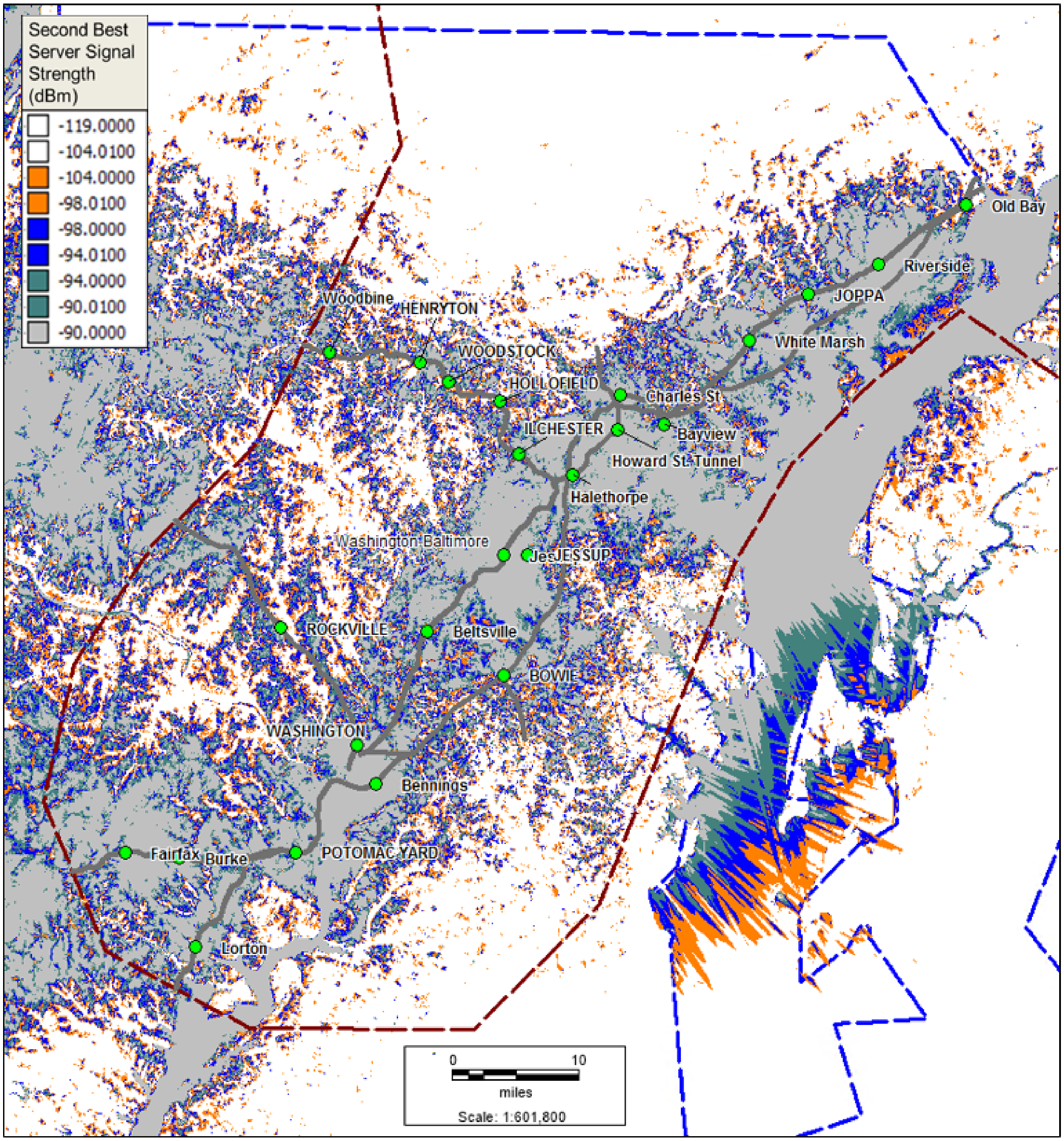

Figure 73. Predicted Second Best ITC Base Station Server Signal Strength for the Washington, D.C. DUA

5.6.8 Washington, D.C. DUA F-Frame Timeslot Plan

TTCI used the IPM tool to generate a fixed F-frame frequency/timeslot plan. As indicated in Table 36, a total of 118 WSM locations and 9 WIU radio sites are present inside the DUA. Figure 74 shows the locations of the WSM locations and WIU radio sites. Notice that, because CSX and Amtrak are implementing radioless WIUs, their lines only show WSM locations.

As noted in Section 5.1, the F-frame plan was prepared for the entire MTA, i.e., it was not limited to just the DUA boundary.

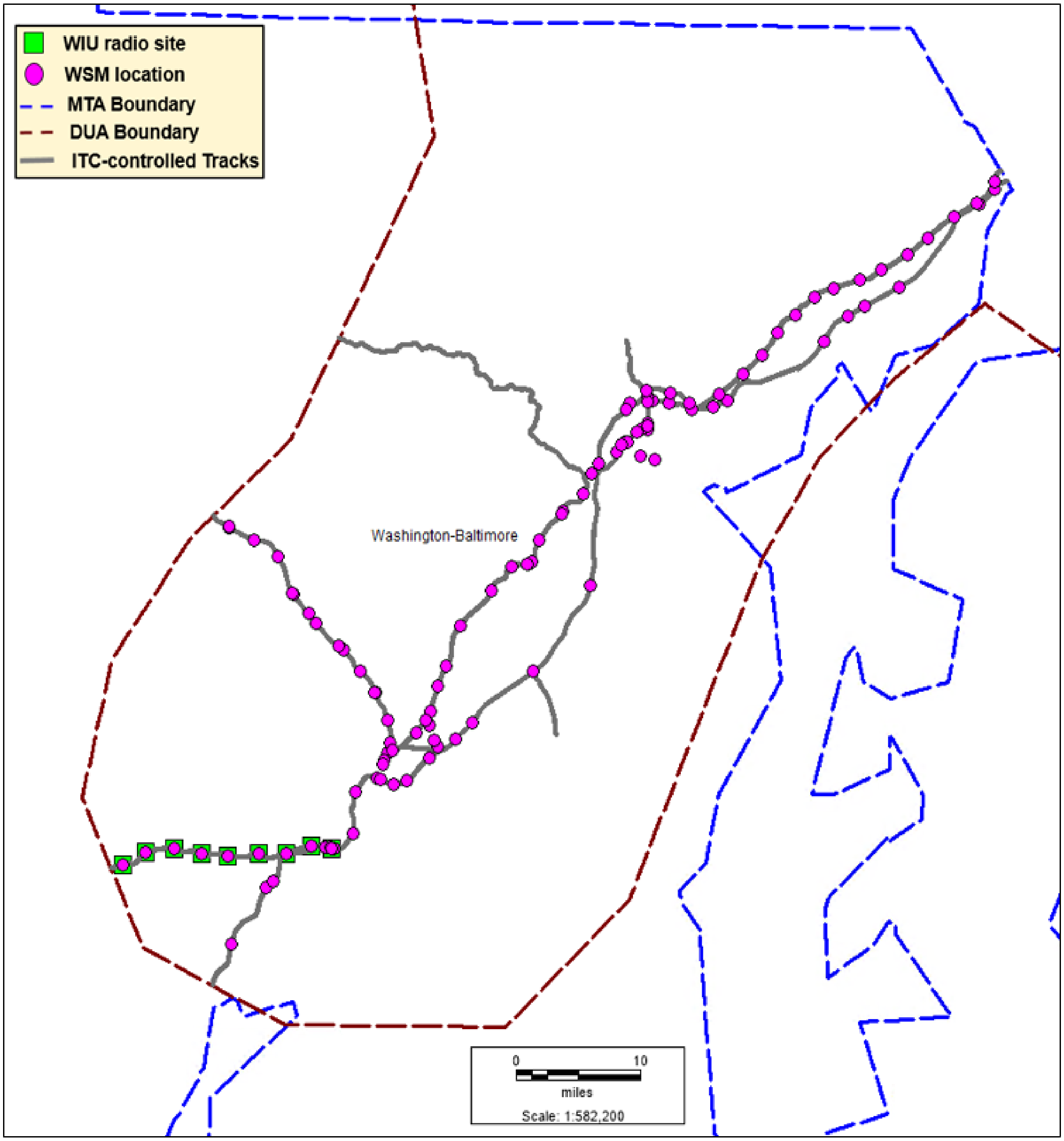

Figure 74. WSM and WIU Radio Locations Inside the Washington, D.C. DUA

For the specific case of the Washington, DC, MTA, the following PTC Operating Zone end distances were used:

- Zone 1: 0.80 miles
- Zone 2: 1.61 miles
- Zone 3: 5.19 miles

The following IPM configurations were used when generating the F-frame timeslot plan for the Washington, D.C. DUA:

- Zone end distances were determined based on braking distance calculations performed by TTCI [3].
- Dynamic Range Protection was used with a blocking distance of 200 feet and protection distance of 5.5 miles. These values were used on the basis of recommendations from the railroads.
- Variable timeslot lengths were used, as well as the standard duty cycles for WIU and base station radios of 10 percent and 50 percent, respectively.
- Preplanned timeslots outside the DUA were protected within a distance of 100 miles. A 3 dB coverage adjustment was applied for segments of track where a single WSM is received by two or more radio sites (base station or WIU), effectively reducing the required signal strength for those tracks to -97.37 dBm (as opposed to -94.37 dBm for places where WSMs are only being received by a single site).

The IPM results show that an F-frame size of 1,592 milliseconds with a total of 1,238 timeslots will be needed for the entire Washington, DC, MTA. The median offset was 294 milliseconds. All WSMs are predicted to be received by at least one base station.

A total of 382 WSMs are being broadcast by base stations. Of these, 209 are WSRS messages planned to resolve coverage gaps (192 for freight railroads, 17 for Amtrak).

WSM coverage gaps are usually solved via WSRS. However, 244 WSMs were still predicted to have coverage gaps (post-relay gaps), even after exploring all the possible candidate ITC base stations to be used for WSRS. In total, 1,441 post relay gaps were found, 1,357 of which correspond to radioless WIU sites, and 921 were located in PTC Operation Zone 3. Most of the post-relay gaps for the radioless WIU sites were due to the poor signal strength of the base stations providing coverage for the secondary path. TTCI provided information on post-relay gaps to the owning railroads, to allow them to verify their existence in the field.

5.6.9 Washington, D.C. DUA RF Network Design Conclusions

The results of the analyses presented in the previous sections lead to the following conclusions:

- A total of 24 base stations are needed to achieve coverage along PTC-controlled tracks in the Washington, D.C. DUA.
  - 93.77 percent of the tracks inside the DUA are predicted to have coverage from at least one base station with an RSS of at least -94.37 dBm.
  - 61.08 percent of the tracks inside the DUA are predicted to have coverage from at least two base stations with an RSS of at least -94.37 dBm.

- The results obtained from the F-frame analysis indicate that a minimum F-frame size of 1,592 milliseconds will be needed to accommodate all the timeslots in the MTA.
  - A total of 9 WIU radio sites and 118 WSMs were planned in the F-frame design of the DUA. The plan includes a frequency/timeslot plan for all of them.
  - A total of 382 WSMs are planned to be broadcast by base stations (via WSRS). Two hundred nine of these WSRS messages are planned to solve coverage gaps.
- Radio Desense between ACSES and ITC sites is predicted to occur at multiple locations:
  - Three ACSES radio sites are predicted to be desensed by fixed ITC radios. Fifteen ACSES radio sites are predicted to be desensed by ITC locomotive radios. ACSES locomotive radios are predicted to be desensed by 5 ITC radio sites in a total of 5.5 miles of tracks.
  - One ITC radio site is predicted to be desensed by ACSES fixed radio sites. Four ITC radio sites are predicted to be desensed by ACSES locomotives. ITC locomotive radios are predicted to be desensed by 15 ACSES radio sites in a total of 5.6 miles of tracks.
- Nine non-railroad licensees (incumbents) operating in the 217–222 MHz band operating in 28 unique locations were found:
  - Seven possible cases of desense or interference with non-railroad incumbents were found.
  - TTCI adjusted the RF design to mitigate potential desense issues by assigning channels to ITC sites that would not cause issues.
  - TTCI sent notification letters to the non-railroad incumbents and concurrence was obtained from all of them.
- A total of 13 channels will be needed to allow the operation of ITC radio system inside the Washington, D.C. DUA, including one channel for use as the Common Channel:
- For D-frame communications, the base stations will need 12 channels as local channels.
- For F-frame communications, six of the PTC-220 LLC nationwide channels in the 220–221 MHz band will be needed.

Overall, the resources available (220 MHz radio spectrum, base station and WIU radio sites) are sufficient for the normal operation of ITC-controlled trains inside the Washington, D.C. DUA, given that railroads deploy and configure all ITC radio system components per the frequency-timeslot plan prepared by TTCI, and that all the desense issues predicted by TTCI between ACSES and ITC radios are properly addressed by the railroads. The predicted redundant coverage (61.08 percent) indicates that trains may experience impact in a degraded mode, such as the failure of a base station. Visual inspection of the second-best server plots, however, does not show any long continuous extension of tracks without coverage, which is a good indication. A detailed analysis of redundant coverage is also strongly recommended for this DUA before full operation of the ITC system commences.

5.7 RF Network Design for the Boston DUA

5.7.1 Boston DUA Project Scope

The ITC system RF design project for the Boston DUA includes the planned PTC-controlled tracks and base stations from CSX. The design also includes the desense analysis between ITC and ACSES radios for all the fixed radio sites and tracks where PTC-equipped trains from both systems operate.

The design did not include the analysis of train message traffic loading, because the volume of ITC-controlled trains in this DUA is very small (only two CSX subdivisions) and as observed in the designs completed for the New York and Philadelphia DUAs that also have very low ITC-controlled train traffic volume, the D-frame message traffic is not expected to reach any significant volume as compared to the capacity of the system.

Due to schedule priorities, CSX was unable to prepare WSM data for the Boston area, and as CSX is the only railroad with ITC-controlled tracks inside this area, TTCI developed only the D-Frame plan for the Boston DUA.

MBTA was also unable to provide details of their ACSES sites to TTCI, except for a short portion of track where CSX and MBTA tracks meet, by MBTA's Worcester Union Station, referred to as CP45. The analysis of ACSES and ITC desense between CSX and MBTA sites was restricted to the CP45 area.

5.7.2 Boston DUA Boundaries

The Boston DUA includes all PTC-controlled tracks approximately 120 miles from Boston to the west, 80 miles to the southwest, and 13 miles to the north.

Figure 75 shows the boundaries of the Boston study and the PTC-controlled tracks from all the railroads for both ACSES and ITC systems. The design of the ITC system considered all the In-Service, Planned, and Candidate ITC base stations and WIU locations provided by CSX, as well as the ACSES sites (required for the radio desense analysis) provided to TTCI by Amtrak and MBTA.

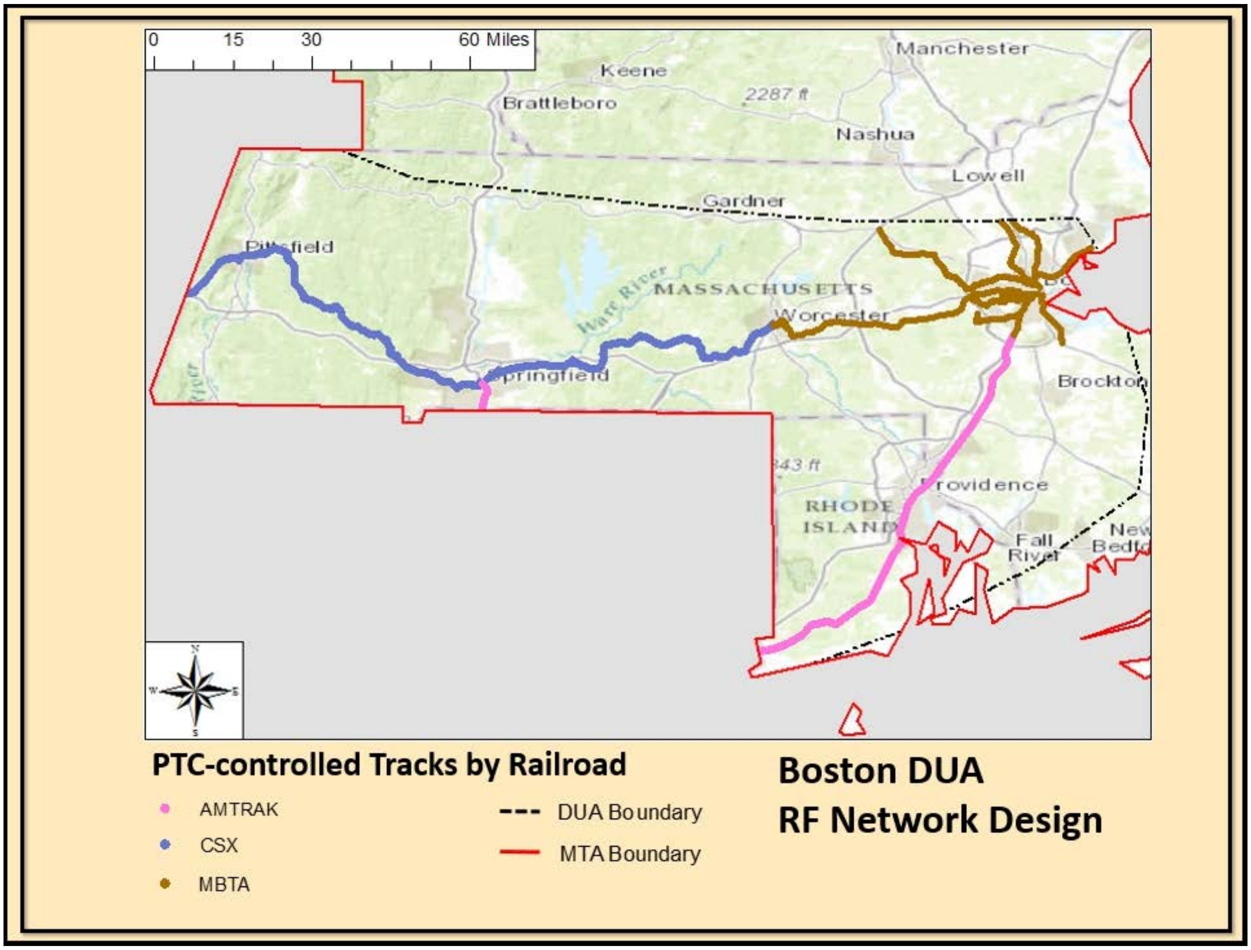

Figure 75. PTC-Controlled Tracks Within the Boston DUA

PTC-controlled tracks can be configured to support the operation of trains under the control of either of the systems (ACSES or ITC). Notice that, unlike the other DUAs in the NEC, in Boston there are no dual-equipped tracks. Figure 77 displays the PTC-controlled tracks identified by the type of control system in the Boston DUA.

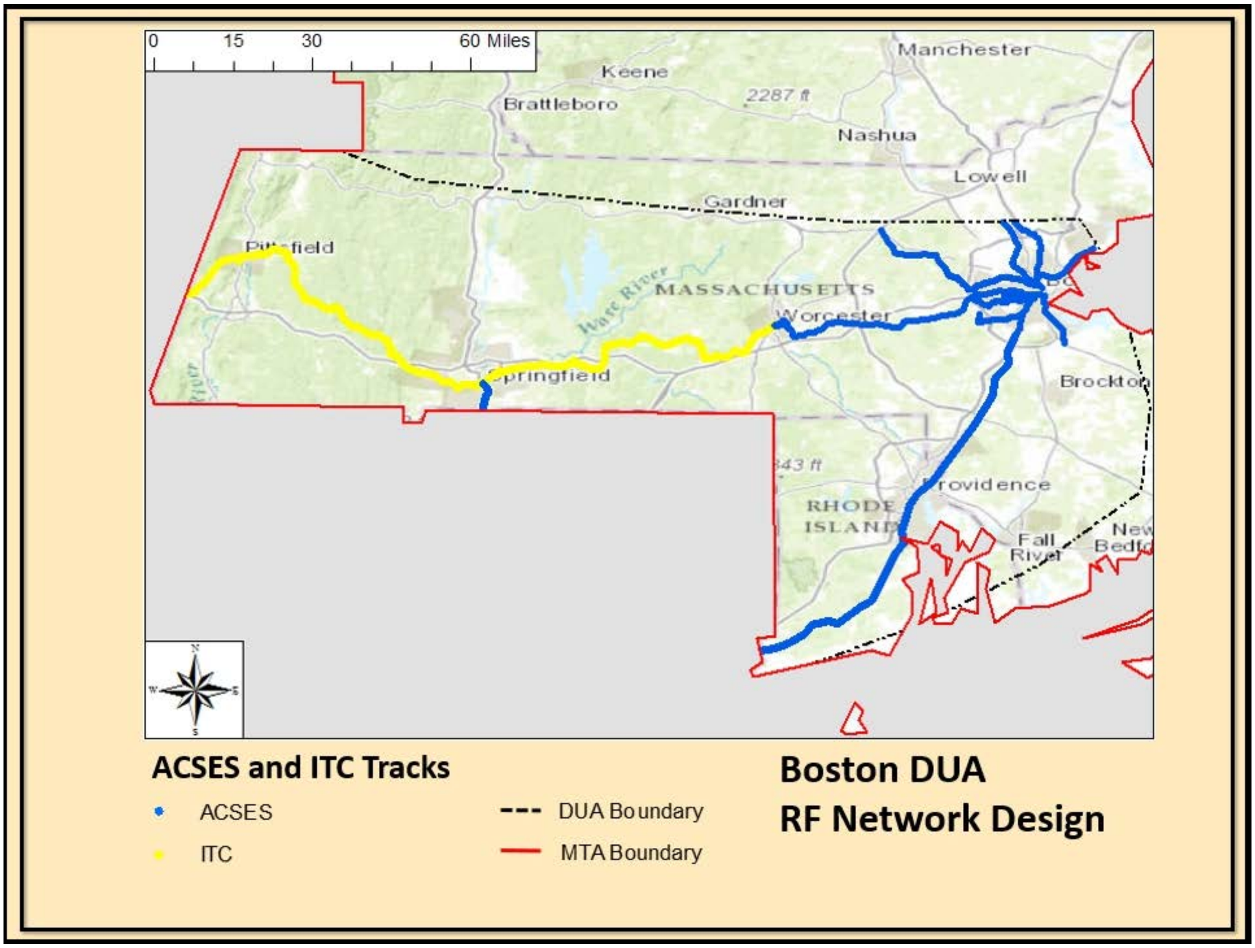

Figure 76. ACSES and ITC Tracks in Boston DUA

5.7.3 List of Railroads and Subdivisions Inside the Boston DUA

CSX was the only freight railroad included in the RF Network design of the ITC system for the Boston DUA. Table 41 lists the CSX subdivisions included in the study with their range of route-mile tracks.

Table 41. List of CSX ITC-Controlled Subdivisions in the Boston DUA

Railroad	Subdivision	Start MP	End MP	Route Miles
CSX	Rotterdam–Boston	N/A	N/A	60.4
CSX	Worcester–Springfield			66
	Total			**126.4**

5.7.4 Boston DUA Data Gathering and Consolidation

5.7.4.1 Boston DUA Base Station Input Data

Table 42 contains the list of the 17 ITC base station sites that were considered in the RF design developed by TTCI. The list of sites was obtained from information provided by CSX.

The “Status” column in Table 42 indicates the status of operation of the base station site, base station sites marked as “In-service” or “Planned” were considered preferred sites in the RF design developed.

Table 42. List of Base Stations Included in the RF Design for the Boston DUA

Site ID	Sector ID	Status	Antenna Center of Radiation Height (ft)	Antenna Azimuth (degrees)	Antenna Model
3125208006	Charlton	In_Service	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125208009	Chester	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208012	East Brookfield	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208023	Palmer	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208044	Wilbraham	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208045	Westfield	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208046	Russell	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208047	Washington, DC	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208048	Middlefield Hampshire Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208049	Hinsdale Berkshire Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208050	Dalton	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208051	Pittsfield Berkshire Cty	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208052	Worcester Near Stafford St	Planned	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125208053	W Brookfield Worcester Cty	Planned	65	90	SD222-SF6PASNM(OM)_0160.pafx
3125208054	W Warren Near 1698 Main St	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208055	West Warren	In_Service	65	0	SD222-SF6PASNM(OM)_0160.pafx
3125208056	Wilbraham Near 71 Silver St	Planned	65	0	SD222-SF6PASNM(OM)_0160.pafx

5.7.5 Boston DUA Incumbent Analysis

The Incumbent Analysis comprises checking for possible desense scenarios between ITC base stations and fixed non-railroad incumbent sites operating within the 217–222 MHz band, as explained in detail in Section 5.2.

The results of the Phase 1 Incumbent Analysis show 43 non-railroad incumbent licensees inside the Boston DUA, operating a total of 112 unique radio locations. Figure 77 shows the location of the ITC base stations inside the Boston DUA and all the non-railroad incumbents in the area. Note that a single location can either have multiple licensees or multiple frequencies in use.

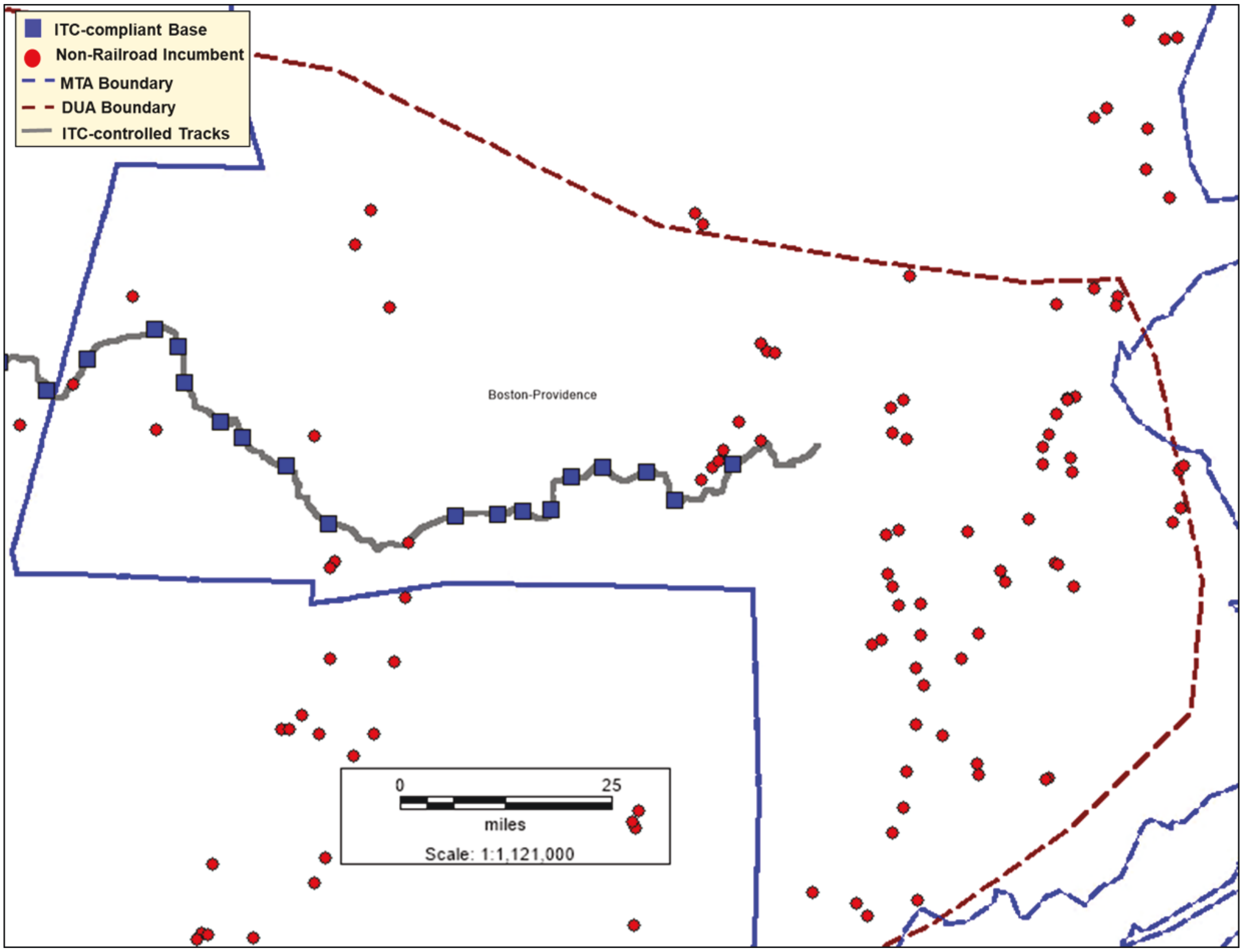

Figure 77. ITC Base Stations and Non-Railroad Incumbent Sites in the Boston DUA

It is assumed that the incumbent radios have a desense threshold of -30 dBm when determining whether an ITC fixed site could cause desense issues on non-railroad incumbents as explained in Section 2.1.

TTCI was able to assign only non-waivered channels, i.e., channels in the 220–221 MHz range, when preparing the frequency plan for the ITC sites from CSX while avoiding any potential desense issues with non-railroad incumbents, which eliminated the need to send notification/concurrence letters.

5.7.6 Boston DUA ACSES and ITC Desense Analysis

TTCI developed the detailed desense analyses to identify areas where ACSES and ITC radios could be at risk of desensing each other, as explained in Section 4.3. This included:

- Identification and analysis of ACSES radio sites that could desense ITC radio sites and vice versa (see Section 2.1.1).
- Identification and analysis of tracks where locomotives could get desensed by fixed sites from a dissimilar system, i.e., ITC desensing ACSES and vice versa (see Section 2.1.2).

- Identification and analysis of track locations where locomotives could cause desense to fixed sites from the dissimilar system, i.e., ITC desensing ACSES and vice versa (see Section 2.1.3).

The next set of figures and tables shows the results obtained for each of the above listed cases.

Figure 78 shows the location of ACSES radio sites and the tracks where ACSES-controlled trains operate inside the Boston DUA.

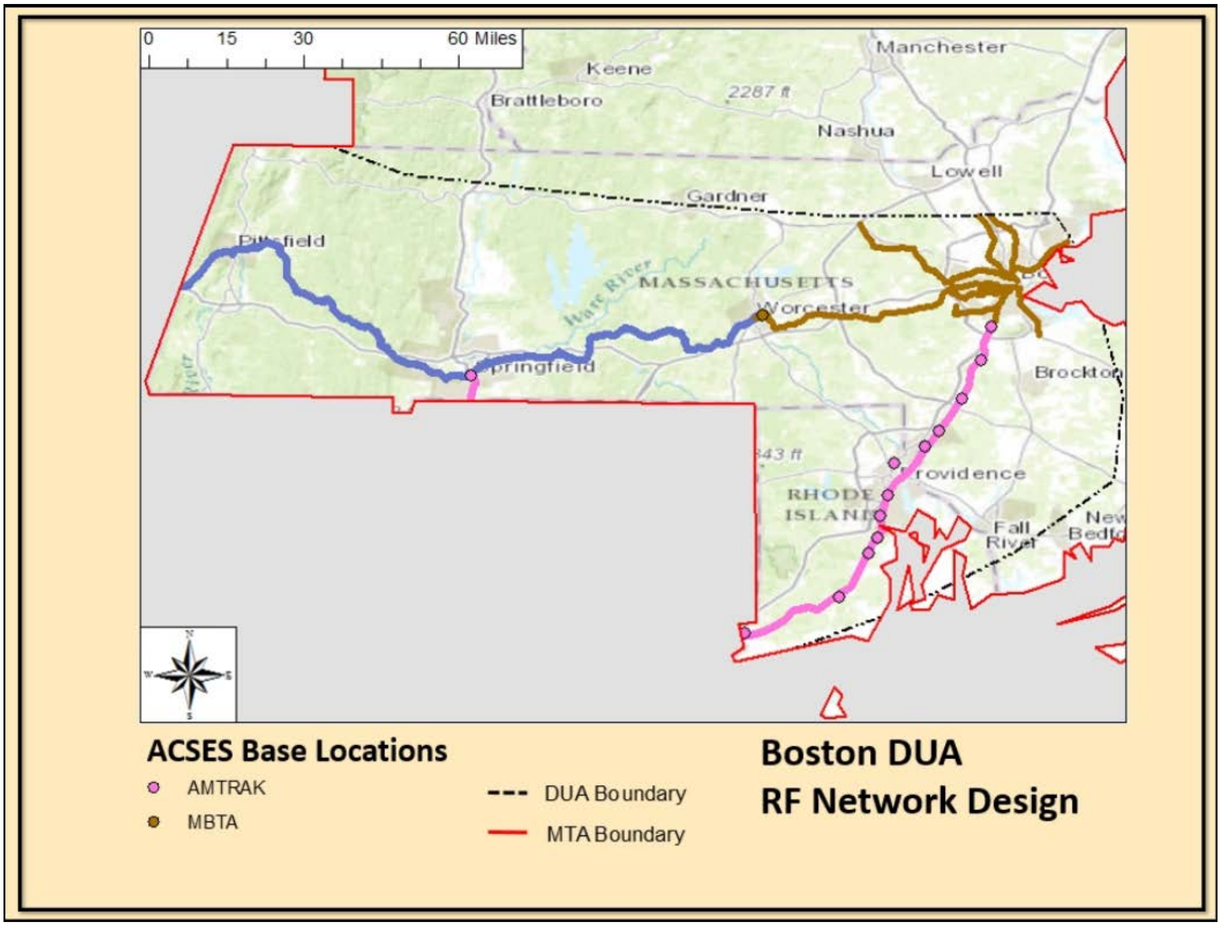

Figure 78. Location of ACSES Base Stations and Tracks in the Boston DUA

The desense analysis has not predicted any potential issues between ACSES and ITC fixed sites in the Boston DUA.

TTCI developed the analysis of desense between fixed radio sites and locomotive radios for both systems (ACSES and ITC), as explained in Section 4.3, and encountered four cases for the Boston DUA.

The first two cases were encountered in the CP45 area, where CSX and MBTA tracks meet and trains from CSX and Amtrak transition to operate on MBTA tracks. Figure 79 shows the details of the area, illustrating how the operation of trains occurs.

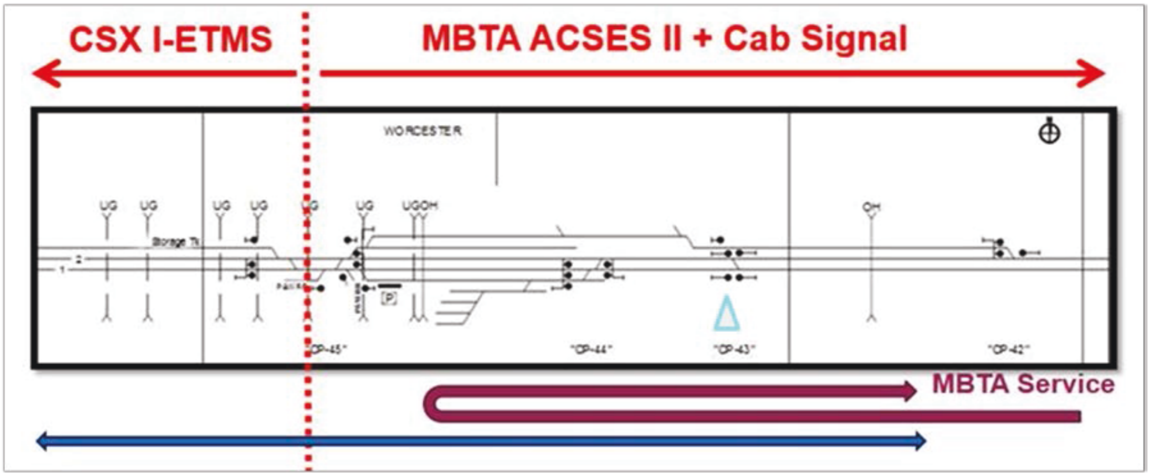

Figure 79. Illustration of the Transition Area Between CSX and MBTA at CP45

From information provided by CSX and MBTA, trains in the CP45 transition area operate as follows:

1. MBTA trains heading west operate until the Worcester Union Station and return, under ACSES control at all times.
2. CSX and Amtrak heading east operate under ITC control until control point CP45 and transition to ACSES control from that point on. CSX and Amtrak trains will be dual-equipped with radios from both systems.
3. CSX and Amtrak trains heading west, operate under ACSES control until control point CP45 and transition to ITC control from that point on.

Note that in order to transition to ITC control, CSX and Amtrak trains need to start communicating with the ITC WIU at CP45 5 miles ahead of that location, meaning that these trains will have their radios active for both systems when moving west towards CP45.

MBTA also informed TTCI that an ACSES base station will be installed at location CP43 to support ACSES operation for all trains in the CP45 area.

Figure 81provides additional details, including the location of the nearest CSX base station to the CP45 area with its predicted coverage levels.

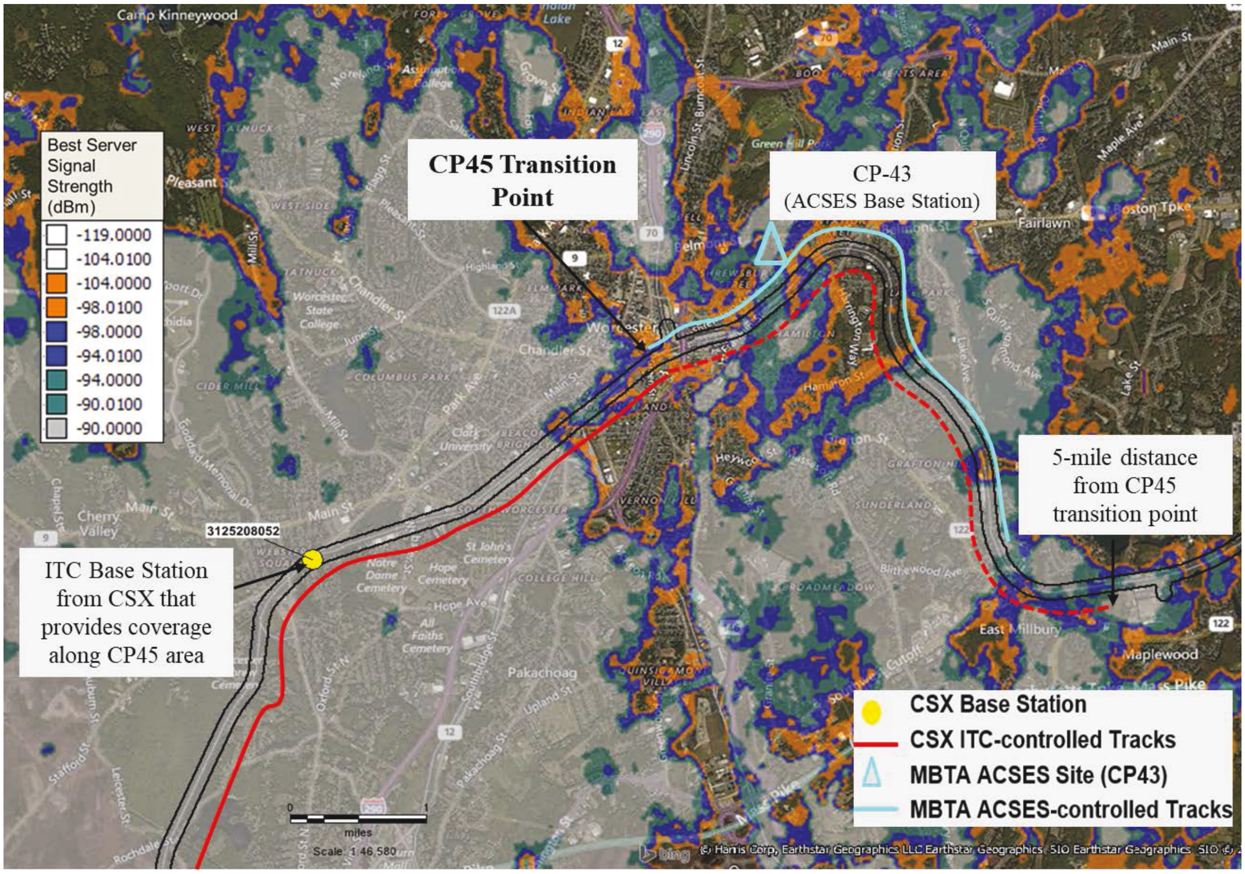

Figure 80. Details of CP45 Transition Area Including Coverage Predictions for CSX Base Station

The desense analysis for this area indicates that MBTA's ACSES site CP-43 is predicted to desense ITC locomotive radios from CSX and Amtrak operating in its proximity, and ITC-controlled trains from CSX and Amtrak are predicted to cause desense to that site.

TTCI also identified another area of potential desense around Springfield, where ACSES-controlled tracks from Amtrak meet ITC-controlled tracks from CSX. Figure 81 shows 0.8 miles of ITC-controlled tracks from CSX that are predicted to be desensed by one Amtrak ACSES base station.

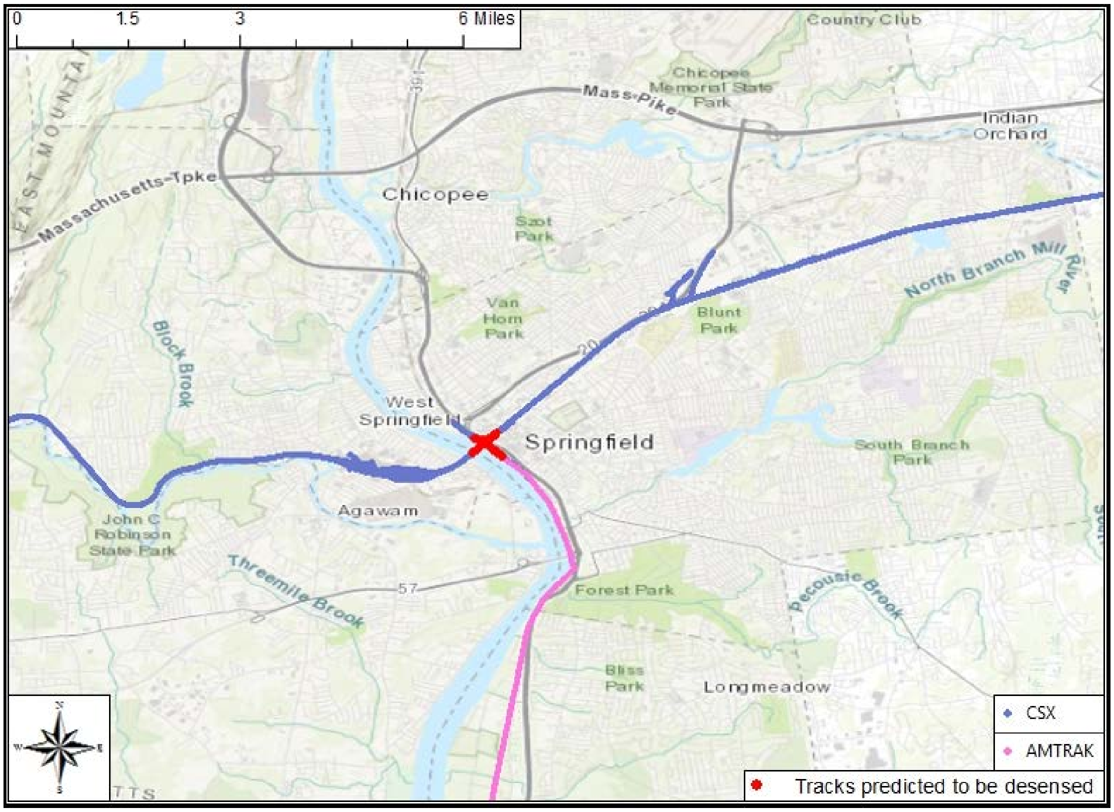

Figure 81. ITC-Controlled Tracks from CXS Predicted to be Desensed by Amtrak ACSES Base Station Near Springfield

The analysis also indicates that one Amtrak ACSES base station is predicted to be desensed by ITC-controlled trains operating on CSX tracks near Springfield, as shown in Figure 82.

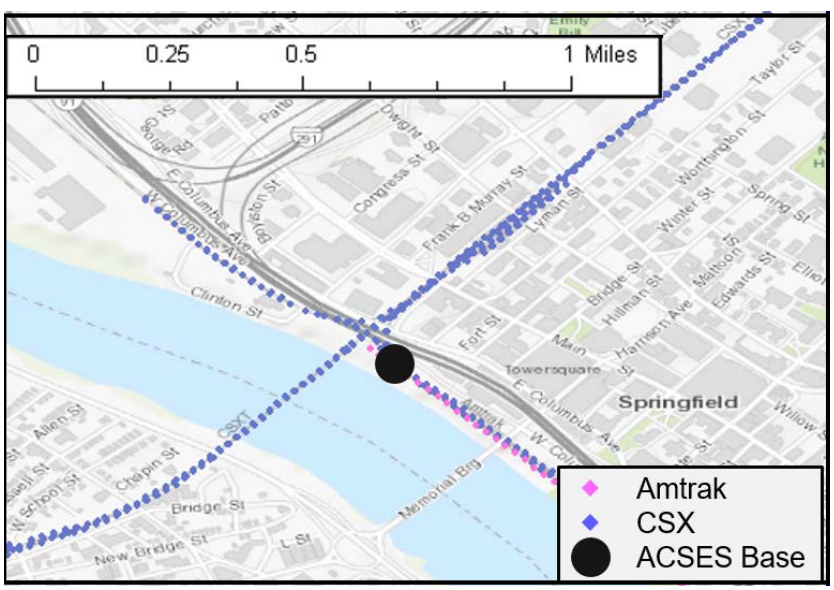

Figure 82. Location of the ACSES Base Station from Amtrak Predicted to be Desensed by ITC Locomotive Radios near Springfield

5.7.7 Boston DUA Base Station Frequency Plan

The design requirement along the ITC-controlled tracks for CSX is to have coverage from at least one ITC base station at a level of -94.37 dBm or higher.

All 17 available ITC base stations listed in Table 42 were selected to achieve the coverage requirements over the ITC-controlled tracks in the Boston DUA. These 17 base stations were analyzed with Infovista's Planet® software to determine coverage, signal strength, C/I, and other relevant parameters.

As an initial step, the ITC base stations were assigned an RF propagation model. A subset of 19 of the available models in the hosted server was tuned in regions that topographically resemble the Boston DUA, as agreed with the railroads. Table 43 shows the selected set of base stations for the Boston DUA, including antenna details, propagation models, and channel assignments. The results of the desense analysis (described in Section 5.7.6) were also considered when selecting the sites for the base station frequency plan.

Table 43. ITC Base Station Frequency Plan for the Boston DUA

Site ID	Sector ID	Propagation Model	Antenna Center of Radiation Height (feet)	Antenna Aximuth (degrees)	EIRP (dBm)	Channel
3125208006	Charlton	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	90	47.37186	101
3125208009	Chester	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	127
3125208012	East Brookfield	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	127
3125208023	Palmer	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	113
3125208044	Wilbraham	IV_IV_Northeast_RU_1_Croplan_113 ft avg.pmf	65	0	47.37186	101
3125208045	Westfield	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	125
3125208046	Russell	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	113
3125208047	Washington, DC	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	125
3125208048	Middlefield Hampshire Cty	NF_NF_Midwest_RU_8_Grassland_110ft.pmf	65	0	47.37186	114
3125208049	Hinsdale Berkshire Cty	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	113
3125208050	Dalton	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	114
3125208051	Pittsfield Berkshire Cty	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	127
3125208052	Worcester Near Stafford St	NF_IV_MidWest-EastNorthCentral_SU_112ft.pmf	65	90	47.37186	114
3125208053	W Brookfield Worcester Cty	IV_IV_Northeast_RU_1_Croplan_113 ft avg.pmf	65	90	47.37186	113
3125208054	W Warren Near 1698 Main St	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	114
3125208055	West Warren	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	125

3125208056	Wilbraham Near 71 Silver St	NF_NF_South-SouthAtlantic_RU_2_Forest1_80ft_avg.pmf	65	0	47.37186	127

Figure 83 shows the coverage achieved from the 17 selected ITC base stations along the ITC-controlled tracks inside the Boston DUA. The base station coverage analysis indicates that 84.76 percent of the 90-meter buffer area around the ITC-controlled tracks has coverage from at least one base station at -94.37 dBm or higher.

Most of the coverage gaps along ITC-controlled tracks were located around the CP45 area, particularly where trains from CSX and Amtrak operating on MBTA tracks, i.e., still under ACSES control, and heading west towards CP45, start communications with the nearest ITC base station from CSX. This situation was discussed with CSX, who requested TTCI to proceed with the design, while CSX performs field tests to verify whether the predicted gaps could cause any impact in the operation of CSX and Amtrak trains in that area.

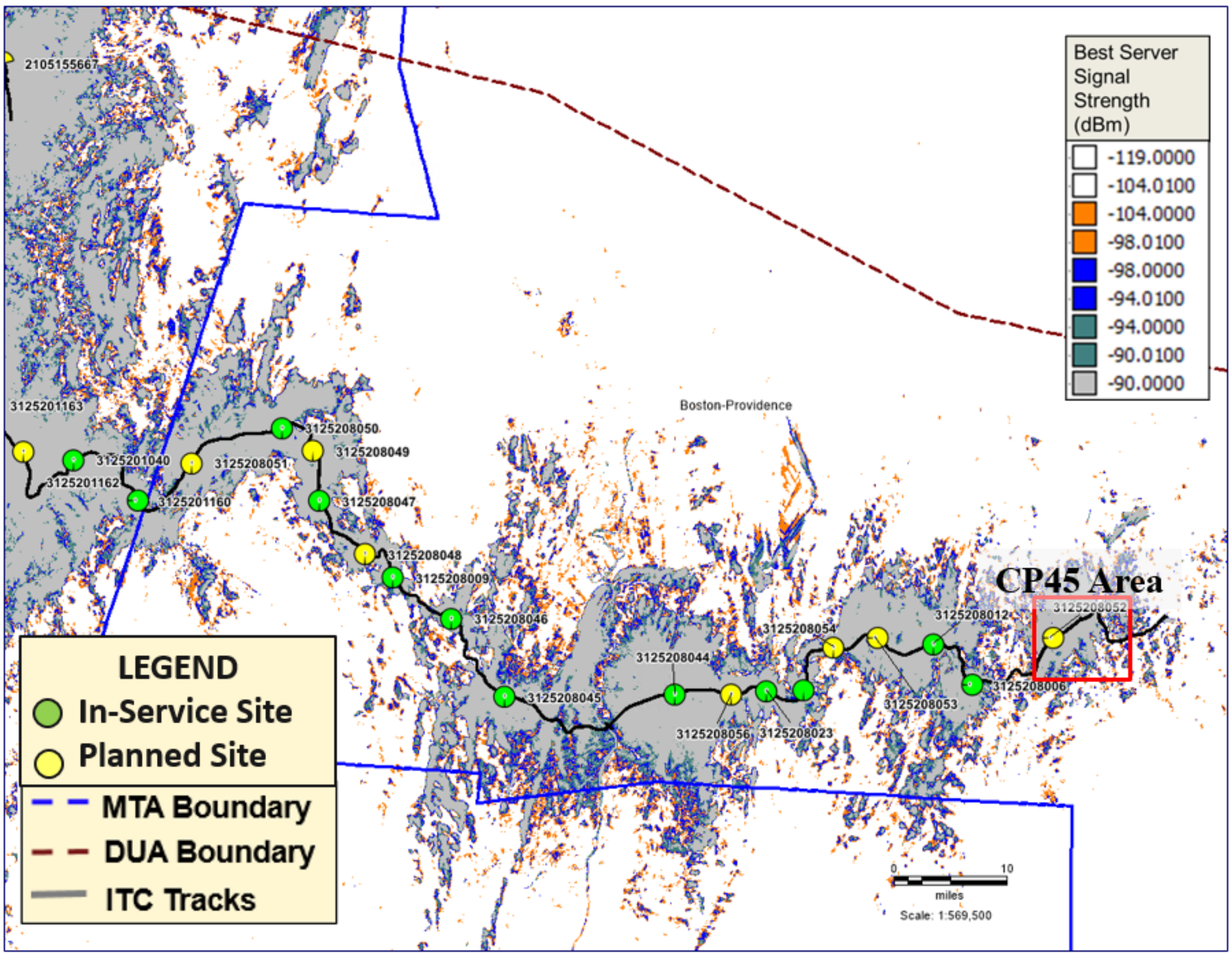

Figure 83. Best Serving ITC Base Station Signal Strength Inside the Boston DUA

Table 44 shows a summary of the percentage of buffer area with C/(I+A) levels above 18.6 dB and 11.5 dB. The first column in the table represents the C/(I+A) ranges, the second column represents the area in square miles of the 90-meter buffer area with the corresponding C/(I+A) levels, and the third column represents the percentage of the buffer area with the corresponding

C/(I+A) levels. Although the radio is designed to handle C/I as low as 11.5 dB, that assumes no fade margin, so a higher analysis threshold is required. A C/I threshold of 18.6 dB is more conservative, and thus carries lower risk.

Table 44. Percentage of Buffer Area in the Boston DUA Where the Predicted C/(I+A) Levels Exceed the Thresholds of 18.6 dB and 11.5 dB

Ranges	Area (mi^2)	Percentage Sub Area
-50 ~ 0	0	0
0 ~ 11.5	0.0566411465	0.0460111462
11.5 ~ 18.6	0.3304646	0.2684454
18.6 ~ 100	122.716	99.68555
Outside range	0	0

Propagation modeling using AFP indicates that five frequencies are needed to achieve the required C/(I+A) requirements. The channel assignments of the five available frequencies are shown in the rightmost column of Table 43. One additional frequency is required for the Common Channel, bringing the total to six frequencies.

Figure 84 shows the predicted base station best serving sector coverage for the selected 17 ITC base station sites, assuming the use of 5 of the 14 available channels for the Boston DUA. The channels that are reused by multiple ITC base station sites are shown with the same color in Figure 84.

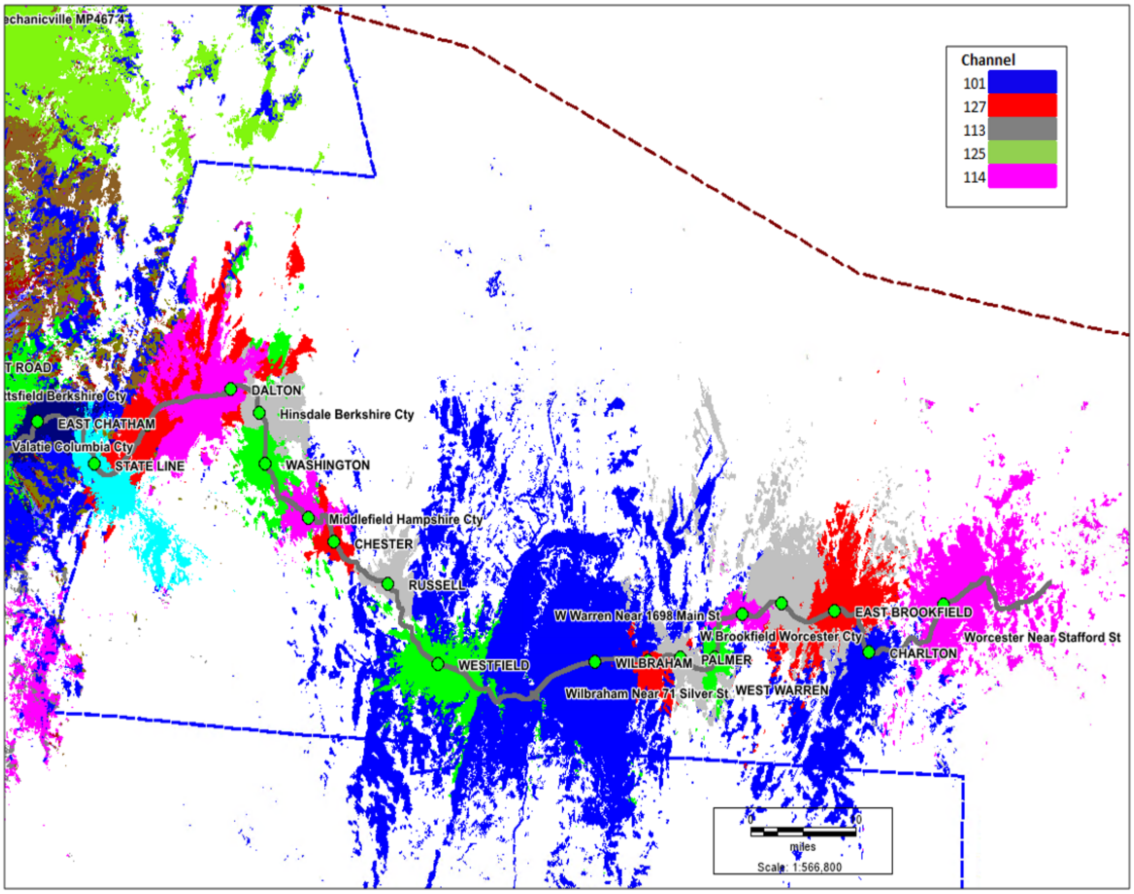

Figure 84. ITC Base Station Best Serving Sectors for the Boston DUA

Figure 85 shows the total C/(I+A) that would be received from the best ITC base station server by an ITC locomotive radio at every point throughout the Boston DUA for the ITC base station frequency plan prepared for the 17 selected ITC base stations. The objective is for the C/(I+A) to be ≥ 11.5 dB. Green and yellow colors in Figure 85 mean acceptable C/I levels, which is the case for the majority of ITC-controlled tracks in the Boston DUA with the selected base stations and frequencies.

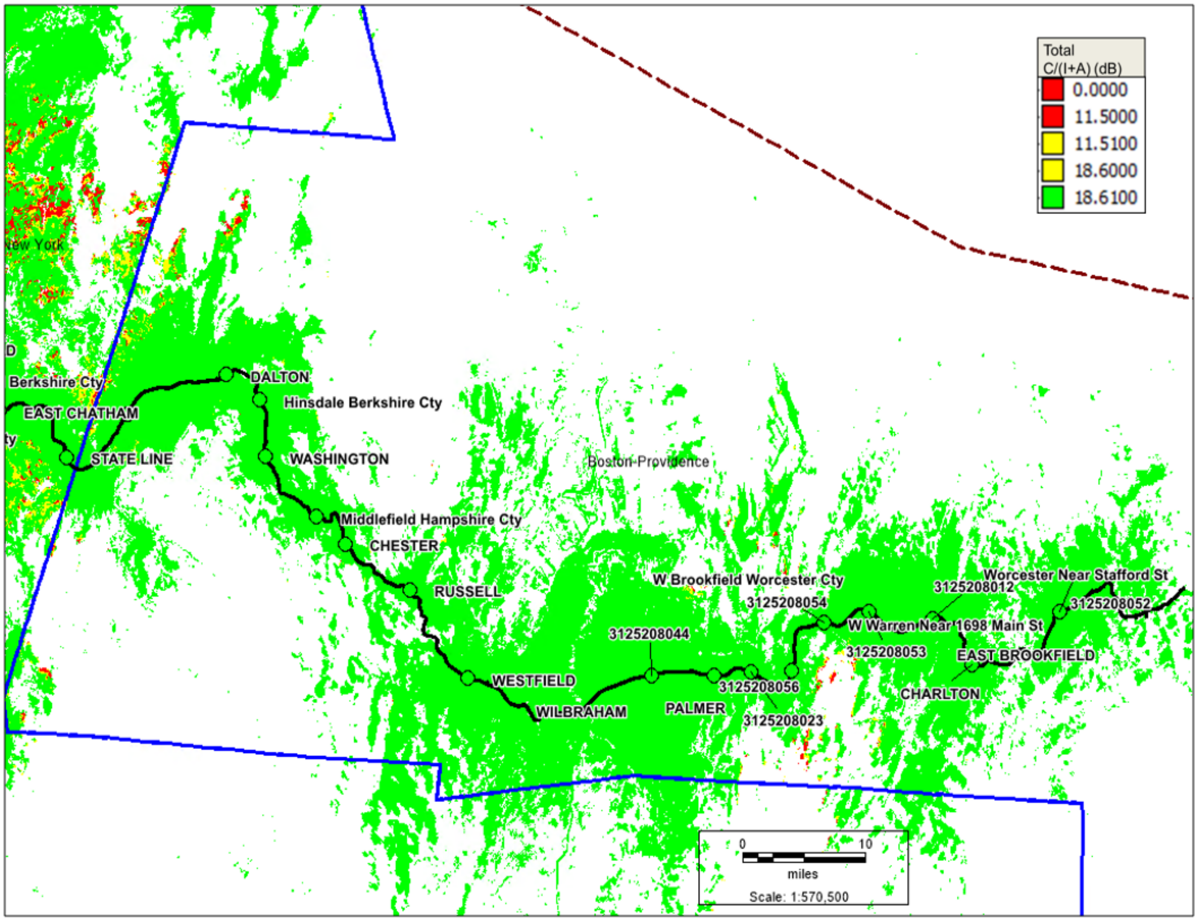

Figure 85. Predicted C/(I+A) Levels of the ITC Base Station Frequency Plan Prepared for the Boston DUA

5.7.7.1 Analysis of Base Station Redundancy for the Boston DUA

The design target requirement along ITC-controlled tracks with radioless WIUs is to have coverage from at least two ITC base stations at a level of -94.37 dBm or higher, as indicated in Section 5.7.7.

Figure 73 shows the predicted second best ITC base station signal strength along the ITC-controlled tracks inside the Boston DUA. The analysis indicates that only 33.09 percent of the ITC-controlled tracks are predicted to have coverage satisfying the requirements from at least two base stations. Note that not all of this redundancy is usable, because the C/I levels for second best servers are unknown.

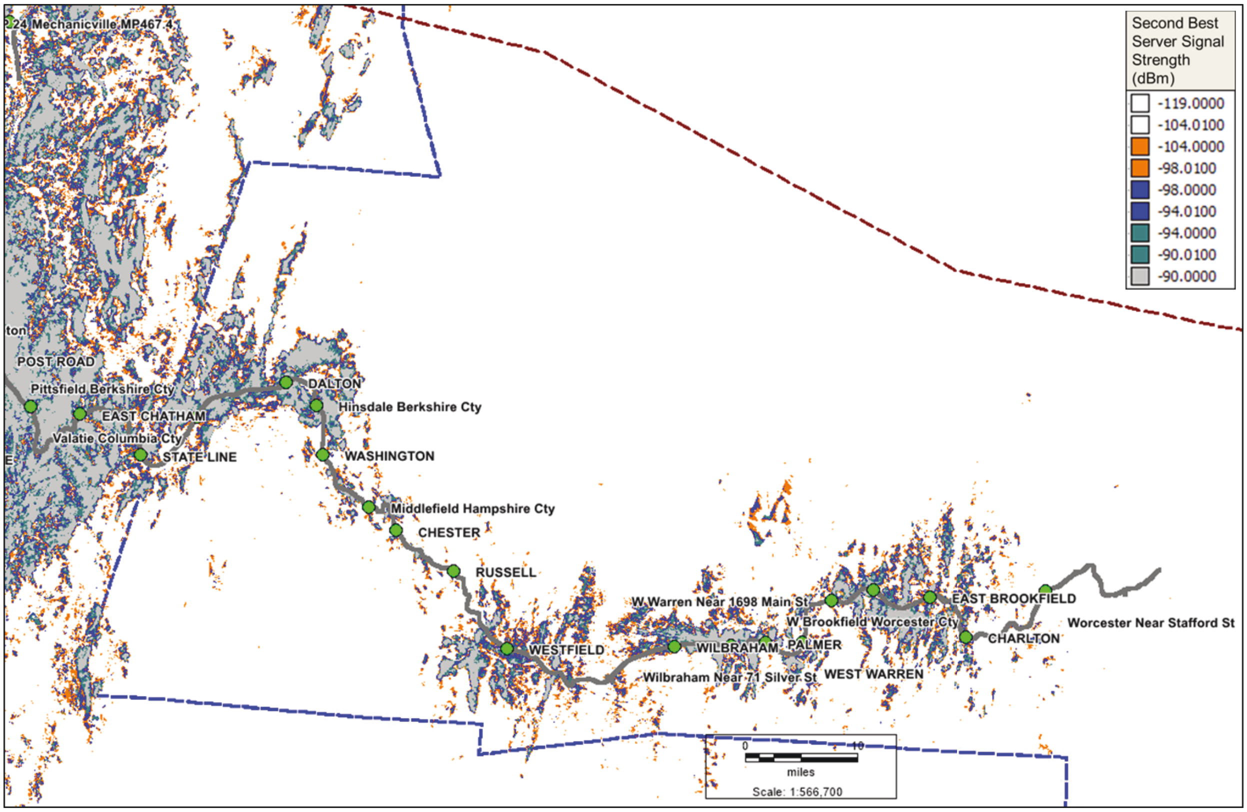

Figure 86. Predicted Second Best ITC Base Station Server Signal Strength for the Boston DUA

5.7.8 Boston DUA RF Network Design Conclusions

The results of the analyses presented in the previous sections lead to the following conclusions:

- A total of 17 base stations are needed to achieve coverage along PTC-controlled tracks in the Boston DUA.
  - 84.76 percent of the tracks inside the DUA are predicted to have coverage from at least one base station with an RSS of at least -94.37 dBm.
  - 33.09 percent of the tracks inside the DUA are predicted to have coverage from at least two base stations with an RSS of at least -94.37 dBm.
- Radio Desense between ACSES and ITC sites is predicted to occur at two locations:
  - Near the CP45 area, where ITC-controlled trains from CSX and Amtrak are predicted to desense and get desensed by an MBTA ACSES site at CP-43.
  - Near Springfield where CSX and Amtrak tracks connect and desense is predicted to occur between one Amtrak ACSES site and ITC-controlled locomotives operating nearby.
- 44 non-railroad licensees (incumbents) operating in the 217–222 MHz band operating in 113 unique locations were found, and potential issues with ITC sites were resolved without requiring notification to incumbents.

- A total of six channels will be needed to allow the operation of the ITC radio system inside the Boston DUA, including one channel for use as the Common Channel. For D-frame communications, the base stations will need five channels as local channels.

The design of the ITC radio system for the Boston DUA is not complex; only CSX has ITC-controlled tracks in this area. Even though an F-frame plan was not prepared in this study, it is extremely unlikely that it will be a complex task or require additional resources to be implemented. The volume of messages to be exchanged between trains and ITC base stations along CSX tracks is also unlikely to cause any impact to the D-frame message traffic. The main resolution topic was the analysis of potential desense issues between ACSES and ITC radios, particularly around the CP45 transitional area, which was extensively addressed and reviewed with the railroads. The number of available resources (RF spectrum and base stations) is sufficient for the normal operation of ITC-controlled trains, but not for a degraded situation such as failure of one base station, because there are long stretches of CSX tracks without redundant coverage, which would significantly affect train operations. Similar to conclusions for the other DUAs, it is also strongly recommended that a detailed analysis of redundant coverage is done for this DUA before full operation of the ITC system commences.

6 Conclusion

TTCI successfully developed full RF network designs for the ITC-compliant system being deployed by railroads on the NEC. In late 2016, the RF network designs that TTCI prepared for the Boston, New York, Philadelphia, and Washington, DC DUAs were partially deployed successfully in the field by most of the railroads, with minor adjustments. Typically, these adjustments were to accommodate field or data discrepancies, which is normal in these types of projects, e.g., due to inaccuracies in the simulation of RF propagation.

Combined, the designs included more than 1,200 route miles of track. TTCI configured 133 ITC base stations and 167 WIU radio sites, and generated frequency/timeslot reuse plans including all 546 WSMs. TTCI analyzed and addressed potential radio desense issues between ITC and ACSES radios, including the analysis of 432 ACSES sites and all ACSES and ITC-controlled tracks inside the NEC. TTCI also analyzed train message traffic for the New York and Philadelphia areas, verifying whether capacity issues might occur.

The results of the project indicate that the existing resources (220 MHz radio spectrum, base station, and WIU radio sites) can support the normal operation of the ITC system with high confidence, given that potential radio desense issues between ACSES and ITC radios as well as between ITC and non-railroad incumbents are properly addressed by the railroads, as proposed by TTCI in technical reports from this project and spin-off projects that were shared with railroads. The results of the analysis also indicate that base station coverage needs to be improved at several locations along the NEC to support failure scenarios without impact on train operations. It is strongly recommended that a detailed analysis of redundant coverage be developed before full operation of the ITC system commences.

During the development of the RF designs, TTCI faced several technical challenges that required TTCI to work closely with the railroads and other engineering companies to design and apply engineering solutions to produce designs that were feasible for deployment. It took several releases of the designs, development of software tools, field test validation, and development of special engineering analyses and methods to successfully develop the RF design plans ready for field deployment. It is expected that these plans will continue to be improved and optimized as railroads progress with their deployments.

The work developed within this project not only made it possible to achieve feasible RF network designs for the NEC, but produced methods, tools, and results that can be applied in similar areas of the country, which is a major benefit for overall PTC deployment in the US. TTCI successfully developed methodologies and tools to identify and address potential interference and desense issues between ITC and ACSES radios. Based on the results obtained, spin-off projects were also created to investigate specific issues and develop solutions, such as the *PTC Radio Desense Mitigation Research, Phase 2: Filter Identification and Testing* project and the *PTC Radio Frequency Network Design for Dense Urban Areas* project funded by FRA [2] [3].

7 References

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Appendix A.
Base Station Boundaries

A.1 New York Base Station Boundaries for Train Message Association

Table C1shows the coverage boundaries calculated for each of the selected base station sites for the New York DUA project from Infovista's Planet® software predicted best server coverage results, matched with the Geographic Information System (GIS) track point data provided by the railroads that relates to railroad subdivisions and mileposts (MP).

Table A1. Base Station Best Server Boundaries in the New York DUA

Base Station Name	Base Station ID	Subdivision	lowMP	highMP
Croxton	2190000001	CSX-River	0	4.5
Croxton	2190000001	CSX-Trenton	75.4	86
Croxton	2190000001	NJT-BergenCountyLine	0	9.8
Croxton	2190000001	NJT-MainLine	0	10.5
Croxton	2190000001	NJT-PascackValley	7.6	9.6
Croxton	2190000001	NS-Lehigh(LE)	2.34	11.34
Port Reading	2190000004	NJT-NorthJerseyCoast	-1.5	3
Potter	2190000005	CSX-Trenton	60.7	75.4
Potter	2190000005	NS-Lehigh(LE)	11.34	25.56
Browns Yard	2190000006	NJT-NorthJerseyCoast	3	10.6
Red Bank	2190000008	NJT-NorthJerseyCoast	10.6	15.9
Bogota	3125201025	CSX-River	4.5	10.5
Bogota	3125201025	NJT-PascackValley	9.6	15
Cornwall	3125201037	CSX-River	49.5	62.7
Fort Montgomery	3125201053	CSX-River	39.5	44
Milton	3125201076	CSX-River	62.7	71
Orangeburg	3125201087	CSX-River	18.5	21.8
Ravena	3125201094	CSX-River	125.5	130.5
West Haverstraw	3125201126	CSX-River	30	39.5
West Part	3125201127	CSX-River	71	80
Belle Meade	3125201138	CSX-Trenton	43	54
Belle Meade	3125201138	NS-Lehigh(LE)	35.7	46.5
Selkirk	3125201150	CSX-River	130.5	132
Closter Bergen Cty	3125201151	CSX-River	13	18.5
Closter Bergen Cty	3125201151	NJT-MainLine	22	25.5
Bradley Pkwy	3125201152	CSX-River	21.8	25.5
Congers Rockland Cty	3125201153	CSX-River	25.5	30
West Point Organe Cty	3125201154	CSX-River	44	49.5
Ulster Park Ulster Cty	3125201155	CSX-River	80	85.7
Saugerties Ulster Cty	3125201156	CSX-River	95	103
Catskill Greene Cty	3125201157	CSX-River	103	112
Coxsackie	3125201158	CSX-River	112	125.5
Kingston	3125201159	CSX-River	85.7	95
Easton	3550046698	NS-Lehigh(LE)	67	82.85
Stanton	3550056698	NS-Lehigh(LE)	60	65
Bellwood East	3550066698	NS-Lehigh(LE)	46.5	60
Allentown 1	3550076697	NS-Lehigh(LB)	87	93
Allentown 1	3550076697	NS-Reading(EN)	91.1	93
Allentown 1	3550076697	NS-Reading(RV)	19	36.3
Manville	3550076698	CSX-Trenton	54	60.7

Base Station Name	Base Station ID	Subdivision	lowMP	highMP
Manville	3550076698	NJT-RaritanValley	30	36.1
Manville	3550076698	NS-Lehigh(LE)	25.56	35.7
Bellwood West	3550086698	NS-Lehigh(LE)	65	67
Campbell Hall	3550096698	NS-SouthernTier	60.5	72.2
Lightside	3550116697	NS-Lehigh (LB)	84.6	87
Lightside	3550116697	NS-Lehigh (LE)	82.85	88.9
Lightside	3550116697	NS-Reading (EN)	88.6	91.1
Lake Helen	3550176698	NS-SouthernTier	74.7	83
Salisbury_Mills	3550196698	NS-SouthernTier	53.8	60.5
Woodbury	3550206698	NS-SouthernTier	45	53.8
Southfields	3550226698	NS-SouthernTier	36.8	45
Suffern_Yd	3550236698	NJT-MainLine	25.5	31.3
Suffern_Yd	3550236698	NS-SouthernTier	31.9	33.1
Paterson	3550266698	CSX-River	10.5	13
Paterson	3550266698	NJT-BergenCountyLine	9.8	20
Paterson	3550266698	NJT-MainLine	10.5	22
Mountian_View	3550276698	NJT-Montclair	22	23.3
Port Jervis	3550336698	NS-SouthernTier	83	88.9
Otisville	3550346698	NS-SouthernTier	72.2	74.7
Southfields	3550356698	NS-SouthernTier	33.1	36.8

A.2 Philadelphia Base Station Boundaries for Train Message Association

Table A2 shows the coverage boundaries calculated for each of the selected base station sites for the Philadelphia DUA project from Infovista's Planet® software predicted best server coverage results, matched with the GIS track point data provided by the railroads that relates to railroad subdivisions and MPs.

Table A2. Base Station Best Server Boundaries in the Philadelphia DUA

Base Station Name	Base Station ID	Subdivision	lowMP	highMP
Balndon	3550056697	NS-Reading(RV)	5.7	19
Birdsboro	3550166694	NS-Harrisburg	39.5	57.1
Black_Rock_Tunnel	3550256694	NS-Harrisburg	26.42	29
Bluemtn	3550076694	NS-Harrisburg	95	111.5
Bluemtn	3550076694	NS-PortRoad(EP)	46.9	51.29
Bluemtn	3550076694	NS-PortRoad(EP)	53.69	73
Byberry Rd	3125209039	CSX-Trenton	10.7	23.5
Chester Pike	3125209059	Amtrak-Philly	4.6	7.3
Chester Pike	3125209059	CSX-Philadelphia	4	7
Clych2	3550086695	NS-PortRoad(EP)	51.29	53.69
Cola	3550076695	NS-PortRoad(EP)	33.7	46.9
Cola	3550076695	NS-PortRoad(PD)	37.2	39.7
Conowingo	3550046695	NS-PortRoad(PD)	7.1	10.21
Deepwater	2190000100	Amtrak-Philly	19.4	25.4
Deepwater	2190000100	CSX-Philadelphia	20	25
Elk Mills	3125210023	Amtrak-Philly	41.5	47.2
Elk Mills	3125210023	CSX-Philadelphia	40	45
Ernest_King	3550236694	NS-Harrisburg	11.7	20.2
Falls	3550226694	NS-Harrisburg	5.2	7.7
Falls	3550226694	NS-Harrisburg	9	11.7
Feltonville	3125209003	Amtrak-Philly	13.3	19.4
Feltonville	3125209003	CSX-Philadelphia	12	20

Base Station Name	Base Station ID	Subdivision	lowMP	highMP
Flat_Rock_Tunnel	3550126694	NS-Harrisburg	7.7	9
Foys Hill	3125209021	Amtrak-Philly	47.2	54.6
Foys Hill	3125209021	CSX-Philadelphia	45	53
Gonce Rd	3125210020	Amtrak-Philly	54.6	57.7
Gonce Rd	3125210020	CSX-Philadelphia	53	55.5
Holtwood	3550556695	NS-PortRoad(PD)	10.21	27.72
Lebanon_Avon	3550136694	NS-Harrisburg	72	95
Morrisville	2190000101	CSX-Trenton	23.5	27.5
Morrisville	2190000101	CSX-Trenton	31	35.5
Mount Penn	3550036697	NS-Harrisburg	27.1	72
Mount Penn	3550036697	NS-Reading(RV)	0	5.7
Newark	3550056699	Amtrak-Philly	31.6	41.5
Newark	3550056699	CSX-Philadelphia	31	40
Old Bay	3550116695	Amtrak-Philly	57.7	68.7
Old Bay	3550116695	CSX-Philadelphia	55.5	65.5
Old Bay	3550116695	NS-PortRoad(PD)	0	2.8
Onley Ave	3125209060	CSX-Trenton	4.7	10.7
Paulsboro	2190000102	Amtrak-Philly	7.3	13.3
Paulsboro	2190000102	CSX-Philadelphia	7	12
Pennington	3125209062	CSX-Trenton	35.5	43
Phoenixville	3550196694	NS-Harrisburg	20.2	26.42
Phoenixville	3550196694	NS-Harrisburg	29	39.5
Port Deposit	3550036695	NS-PortRoad(PD)	2.8	7.1
Safe_Harbor	3550066695	NS-PortRoad(PD)	27.72	37.2
Shulkill Ave	3125209005	Amtrak-Philly	1	4.6
Shulkill Ave	3125209005	CSX-Philadelphia	0	4
Woodside	3125209061	CSX-Trenton	27.5	31
Yard Ofc	3125209002	Amtrak-Philly	25.4	31.6
Yard Ofc	3125209002	CSX-Philadelphia	25	31

A.3 ACSES and ITC Radio Desense Results

The next set of tables contains the details of sites from both ACSES and ITC systems that are predicted to be desensed by the other PTC system. Table A3, Table A4, and Table A5 show the list of ITC sites that are predicted to be desensed by either ACSES fixed sites or ACSES locomotive radios in the New York, Philadelphia and Washington, D.C. DUAs respectively. Notice that some ITC sites may not necessarily be desensed by ACSES locomotive radios, as explained in Section 2.1.5. These cases are indicated with an asterisk in these tables.

Table A6, Table A7, and Table A8 show the list of ACSES sites predicted to be desensed by either ITC fixed sites or ITC locomotive radios in the New York DUA.

The coordinates of the site locations have been redacted as requested by the railroads. The identification of Amtrak sites has also been redacted as requested by Amtrak.

Table A3. ITC Sites Predicted to be Desensed by ACSES Radios in the New York DUA

ITC Sites Predicted to Be Desensed				Desensed by:	
Railroad	Site ID	Latitude	Longitude	ACSES Fixed site	ACSES Locomotive
NS	3550256698	Redacted	Redacted	Yes	Yes
NS	3550236698	Redacted	Redacted	Yes	Yes
NS	3550336698	Redacted	Redacted	Yes	Yes
CSX	3125201097	Redacted	Redacted	Yes	Yes
CSX	3125201062	Redacted	Redacted	Yes	Yes (*)
CSX	3125201001	Redacted	Redacted	Yes	Yes
CSX	3125201081	Redacted	Redacted	No	Yes (*)
CP	7105155684	Redacted	Redacted	No	Yes
NS	3550156698	Redacted	Redacted	No	Yes
NS	3550266698	Redacted	Redacted	No	Yes (*)
NS	3550286698	Redacted	Redacted	No	Yes
NS	3550316698	Redacted	Redacted	No	Yes
NS	3550326698	Redacted	Redacted	No	Yes
NS	3550096698	Redacted	Redacted	No	Yes
NS	3550176698	Redacted	Redacted	No	Yes
NS	3550196698	Redacted	Redacted	No	Yes (*)
NS	3550206698	Redacted	Redacted	No	Yes (*)
NS	3550226698	Redacted	Redacted	No	Yes (*)
NS	3550276694	Redacted	Redacted	No	Yes
NS	3550346698	Redacted	Redacted	No	Yes
NS	3550356698	Redacted	Redacted	No	Yes

(*) These are the cases where predicted desensing tracks are more than two miles away from the nearest ACSES base station and ACSES locomotive radios may not desense the ITC site in such condition. Railroads need to check actual field configuration (such as location of ACSES transponders) and any other exceptional cases to determine whether or not desense from ACSES locomotives could potentially occur.

Table A4. ITC Sites Predicted to be Desensed by ACSES Radios in the Philadelphia DUA

ITC Sites Predicted to be Desensed				Desensed by:	
Railroad	Site ID	Latitude	Longitude	ACSES Fixed site	ACSES Locomotive
CSX	3125209038	Redacted	Redacted	Yes	Yes
NS	3550056696	Redacted	Redacted	Yes	Yes (*)
NS	2891001003	Redacted	Redacted	No	Yes
NS	3550036696	Redacted	Redacted	No	Yes
NS	3550056699	Redacted	Redacted	No	Yes (*)
NS	3550246694	Redacted	Redacted	No	Yes
NS	3550266694	Redacted	Redacted	No	Yes
Conrail	2190000101	Redacted	Redacted	No	Yes
(*) These are the cases where predicted desensing tracks are more than 2 miles away from the nearest ACSES base station and ACSES locomotive radios may not desense the ITC site in such condition. Railroads need to check actual field configuration (such as location of ACSES transponders) and any other exceptional cases to determine whether or not desense from ACSES locomotives could potentially occur.					

Table A5. ITC Sites Predicted to be Desensed by ACSES Radios in the Washington, D.C. DUA

ITC/I-ETMS Sites predicted to need filter				Desensed by:	
Railroad	Site ID	Latitude	Longitude	ACSES Fixed site	ACSES Locomotive
CSX	3125210066	Redacted	Redacted	Yes	Yes
NS	2891001001	Redacted	Redacted	No	Yes (*)
NS	2891001002	Redacted	Redacted	No	Yes
CSX	3125210046	Redacted	Redacted	No	Yes
(*) These are the cases where predicted desensing tracks are more than 2 miles away from the nearest ACSES base station and ACSES locomotive radios may not desense the ITC site in such condition. Railroads need to check actual field configuration (such as location of ACSES transponders) and any other exceptional cases to determine whether or not desense from ACSES locomotives could potentially occur.					

Table A6. ACSES Sites Predicted to be Desensed by ITC Radios in the New York DUA

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	Site	Latitude	Longitude	ITC Fixed site	ITC Locomotive Radio
NJT	Cook CP	Redacted	Redacted	Yes	Yes
MNR	CP-OV	Redacted	Redacted	Yes	Yes
NJT	Brook Int	Redacted	Redacted	Yes	Yes
NJT	Roxbury Int	Redacted	Redacted	Yes	Yes
NJT	Morris Jct	Redacted	Redacted	Yes	Yes
NJT	Denville	Redacted	Redacted	Yes	No
NJT	Denville Remote S	Redacted	Redacted	Yes	Yes

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
NJT	West Summit	Redacted	Redacted	Yes	Yes
NJT	Summit Ave	Redacted	Redacted	Yes	Yes
NJT	West End Satellite	Redacted	Redacted	Yes	Yes
NJT	West End	Redacted	Redacted	Yes	Yes
NJT	Suffern Yard	Redacted	Redacted	Yes	Yes
MNR	CP-HOWELL	Redacted	Redacted	Yes	Yes
MNR	CP-HALL	Redacted	Redacted	Yes	Yes
NJT	Wharton CP	Redacted	Redacted	Yes	Yes
MNR	CP-STERLING	Redacted	Redacted	Yes	Yes
MNR	CP-BC	Redacted	Redacted	Yes	Yes
MNR	CP-WX	Redacted	Redacted	Yes	Yes
MNR	CP-PA	Redacted	Redacted	Yes	Yes
MNR	CP-106	Redacted	Redacted	Yes	No
MNR	CP-6	Redacted	Redacted	Yes	No
MNR	CP-6	Redacted	Redacted	Yes	No
MNR	CP-46 North	Redacted	Redacted	Yes	Yes
MNR	CP-46 South	Redacted	Redacted	Yes	Yes
NJT	Bergen Tunnel East	Redacted	Redacted	Yes	Yes
NJT	Olive CP	Redacted	Redacted	No	Yes
MNR	POUGHKEEPSIE	Redacted	Redacted	No	Yes
MNR	CP-58	Redacted	Redacted	No	Yes
NJT	West Pond	Redacted	Redacted	No	Yes
NJT	Spring CP	Redacted	Redacted	No	Yes
NJT	Sport	Redacted	Redacted	No	Yes
NJT	Stadium	Redacted	Redacted	No	Yes
NJT	Boyd	Redacted	Redacted	No	Yes
NJT	Brad	Redacted	Redacted	No	Yes
NJT	Cush-Tunk Comm. Hut	Redacted	Redacted	No	Yes
NJT	Clinton Int	Redacted	Redacted	No	Yes
NJT	Highbridge Station	Redacted	Redacted	No	Yes
NJT	Kearny Jct	Redacted	Redacted	No	Yes
NJT	ROC MW Tower	Redacted	Redacted	No	Yes
NJT	Graw	Redacted	Redacted	No	Yes
NJT	Bank	Redacted	Redacted	No	Yes
NJT	Hx	Redacted	Redacted	No	Yes
NJT	West Secaucus	Redacted	Redacted	No	Yes
NJT	Denville Twr Bld	Redacted	Redacted	No	Yes
NJT	Pascack Jct	Redacted	Redacted	No	Yes
NJT	West Bj	Redacted	Redacted	No	Yes

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
NJT	Bt	Redacted	Redacted	No	Yes
NJT	Ridgewood	Redacted	Redacted	No	Yes
NJT	Mill	Redacted	Redacted	No	Yes
MNR	CP-HARRIMAN	Redacted	Redacted	No	Yes
MNR	CP-VALLEY	Redacted	Redacted	No	Yes
Amtrak	Wood	Redacted	Redacted	No	Yes
NJT	Essay	Redacted	Redacted	No	Yes
NJT	Rare	Redacted	Redacted	No	Yes
NJT	Morgan	Redacted	Redacted	No	Yes
NJT	East Matawan Station	Redacted	Redacted	No	Yes
NJT	Lloyd	Redacted	Redacted	No	Yes
NJT	Harrison	Redacted	Redacted	No	Yes
NJT	Roseville Split	Redacted	Redacted	No	Yes
NJT	Ampere	Redacted	Redacted	No	Yes
NJT	Millburn	Redacted	Redacted	No	Yes
NJT	Drew	Redacted	Redacted	No	Yes
NJT	Suscun	Redacted	Redacted	No	Yes
NJT	Camerons	Redacted	Redacted	No	Yes
NJT	Waldwick	Redacted	Redacted	No	Yes
NJT	Seamans	Redacted	Redacted	No	Yes
NJT	East Sack	Redacted	Redacted	No	Yes
NJT	East Cole	Redacted	Redacted	No	Yes
NJT	Golf	Redacted	Redacted	No	Yes
Amtrak	Park	Redacted	Redacted	No	Yes
MNR	CP-HUDSON	Redacted	Redacted	No	Yes
NJT	Murray Hill	Redacted	Redacted	No	Yes
NJT	Lincoln Park Station	Redacted	Redacted	No	Yes
MNR	CP-75	Redacted	Redacted	No	Yes
MNR	CP-53	Redacted	Redacted	No	Yes
MNR	CP-72	Redacted	Redacted	No	Yes
NJT	Morristown Remote S	Redacted	Redacted	No	Yes
NJT	Morristown Station	Redacted	Redacted	No	Yes
NJT	Morristown Remote N	Redacted	Redacted	No	Yes
NJT	West Dover	Redacted	Redacted	No	Yes
NJT	Dover	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	No
AMTRAK	Redacted	Redacted	Redacted	Yes	No
AMTRAK	Redacted	Redacted	Redacted	Yes	No
AMTRAK	Redacted	Redacted	Redacted	Yes	No

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes

Table A7. ACSES Sites Predicted to be Desensed by ITC Radios in the Philadelphia DUA

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
SEPTA	16th Street Antenna	Redacted	Redacted	Yes	Yes
SEPTA	Wayne Junction Antenna	Redacted	Redacted	Yes	Yes
SEPTA	Frazer Yard Antenna	Redacted	Redacted	Yes	Yes
SEPTA	Wood Antenna	Redacted	Redacted	Yes	Yes
SEPTA	Grays Ferry Antenna	Redacted	Redacted	No	Yes
SEPTA	Powelton Antenna	Redacted	Redacted	No	Yes
SEPTA	60th Street South Antenna	Redacted	Redacted	No	Yes
SEPTA	Walnut Antenna	Redacted	Redacted	No	Yes
SEPTA	Asneral Antenna	Redacted	Redacted	No	Yes
SEPTA	Kalb New	Redacted	Redacted	No	Yes
SEPTA	Kay Antenna	Redacted	Redacted	No	Yes
SEPTA	Wind New	Redacted	Redacted	No	Yes
SEPTA	River New	Redacted	Redacted	No	Yes
SEPTA	Neshaminy Antenna	Redacted	Redacted	No	Yes
SEPTA	Lawndale Antenna	Redacted	Redacted	No	Yes
SEPTA	Eastwick Antenna	Redacted	Redacted	No	Yes
SEPTA	Trent Antenna	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
NJT	Jersey	Redacted	Redacted	No	Yes

Table A8. ACSES Sites Predicted to be Desensed by ITC Radios in the Washington, D.C. DUA

ACSES Sites Predicted to be Desensed				Desensed by:	
Railroad	**Site**	**Latitude**	**Longitude**	**ITC Fixed site**	**ITC Locomotive Radio**
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	Yes	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes
AMTRAK	Redacted	Redacted	Redacted	No	Yes

Abbreviations and Acronyms

AIC	Adaptive Interference Cancellers
ACSES	Advanced Civil Speed Enforcement System
AFP	Automatic Frequency Planning
APMA	Automatic Propagation Model Assignment
BOS	Back Office Server
BNSF	Burlington Northern Santa Fe Railway
CP	Canadian Pacific Railway
C/(I+A)	Carrier-to-Interference plus Adjacent Channel Interference Ratio
C/I	Carrier-to-Interference Ratio
C/N	Carrier-to-Noise ratio
CSX	CSX Transportation
dB	Decibel
dBu	Decibels Above One Microvolt per Meter
dBm	Decibel-Milliwatts
DUA	Dense Urban Area
EIRP	Effective Isotropic Radiated Power
ERP	Effective Radiated Power
FCC	Federal Communication Commission
FRA	Federal Railroad Administration
GIS	Geographic Information System
IT	Information Technology
I-ETMS™	Interoperable-Electronic Train Management System
IP	Internet Protocol
ITC	Interoperable Train Control
ITCnet	Interoperable Train Control Network
IFP	Iterative Frequency Planning
IPM	ITCnet Planning Module
kbps	Kilobits per Second
LIRR	Long Island Railroad
MTA	Major Trading Area
MBTA	Massachusetts Bay Transportation Authority

MCC	Meteorcomm Communications, LLC
MNR	Metro-North Railroad
MP	Milepost
NRTC	National Rural Telecommunications Cooperative
NJT	New Jersey Transit
NEC	Northeast Corridor
NS	Norfolk Southern Corporation
OCM	Office Communications Manager
OBC	Onboard Computer
OOBE	Out of Band Emissions
PTC	Positive Train Control
PEPCO	Potomac Electric Power Company
RF	Radio Frequency
RSIA	Rail Safety Improvement Act
RTC™	Rail Traffic Controller
RSS	Received Signal Strength
SMS	Short Message Service
SEPTA	Southeastern Pennsylvania Transportation Authority
SMC	Spectrum Management Committee
TDMA	Time Domain Multiple Access
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
ULS	Universal Licensing System
WSM	Wayside Status Message
WIU	Wayside Interface Unit
WSRS	Wayside Status Relay Service