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CELLULAR COVERAGE MAPPING IN THE U.S. VIRGIN ISLANDS

by

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14. ABSTRACT

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Wireless mobile telephone service is now a dominant mode of communication throughout the world, with new technologies enabling ever expanding digital services that support commerce, government, and society. A lack of coverage in mobile services is inconvenient under normal conditions, but can exacerbate dangerous situations during emergencies. This report models and measures mobile telephone coverage in the U.S. Virgin Islands, a Caribbean territory that is still recovering from two devastating hurricanes in 2017. We present a physics-based model designed to predict wireless coverage based on characteristics of the transmitting antennae and surrounding topography. We then present the results of ground measurements intended to validate our predictions. Overall, we confirm the anecdotal experience that there are significant "dead zones" in mobile coverage throughout the territory—both through our numerical modeling and primary data collection efforts—which can cause problems for public safety. However, our predicted coverage maps cannot be treated as authoritative at this time, due to incomplete data for transmitting towers. We recommend additional study and identify next steps required to generate authoritative coverage maps, along with the potential benefits of doing so.

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List of Acronyms and Abbreviations

BIT	Bureau of Information Technology
BVI	British Virgin Islands
CAI	Community Anchor Institution
DOD	Department of Defense
FCC	Federal Communications Commission
GIS	Geographical Information System
GVI	Government of the Virgin Islands
NGO	Non-Government Organization
NPS	Naval Postgraduate School
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
STJ	Saint John
STT	Saint Thomas
STX	Saint Croix
TIREM	Terrain Integrated Rough Earth Model
USGS	United States Geological Survey
USVI	United States Virgin Islands
UVI	University of the Virgin Islands
VITEMA	Virgin Islands Territorial Emergency Management Agency

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Executive Summary

More than five years since Hurricanes Irma and Maria struck the U.S. Virgin Islands in 2017, the territory is still recovering. Cellular telephone services remain vital to the ongoing function of life in the territory. But the existence of "dead zones" in service requires residents to work around them. For the most part, this is an inconvenience. But during emergencies, the loss of cellular service creates a potential public safety hazard.

To date, the Government of the Virgin Islands and its components do not have a full accounting of the dead zones, nor do they have a comprehensive understanding of the vulnerability of existing cellular services.

This study takes a first step in providing this understanding. Using limited publicly available data and additional direct observations of cell towers, we use a physics-based model to predict coverage across St. Croix, St. John, and St. Thomas. Our predictions suggest coverage gaps as well as places where coverage is vulnerable to the loss of a single tower. For example, our model predicts that 14% of Community Anchor Institutions (CAIs)—including public safety, medical facilities, and government—across St. Thomas and St. John do not have coverage from any cell tower, while another 19% are covered by only a single tower. For St. Croix, our model predicts that 4% of CAIs do not have any cellular coverage, with another 14% receiving coverage from a single tower. Our results provide an increased understanding for the types of CAIs that could be without service in the event of a cell tower outage.

We additionally conduct limited ground measurements across the three islands. Although not comprehensive, our field measurements confirmed the general notion that (1) cellular coverage is uneven across each of the islands, and (2) cellular service is far less than what is advertised by commercial service providers. We found many areas with poor service (or no signal), even in places that seem relatively close to where people live and work. Our field activities brought us into contact with many residents who shared anecdotes about poor coverage, and the ways in which they regularly "work around" this lack of coverage.

This study has several limitations that potentially affect its results. The primary limitation comes from a lack of access to comprehensive and accurate cell tower information. The ability of our model to generate realistic coverage maps depends critically on the data used as input. Conversations with executives of cellular provider companies has indicated that our inventory of tower locations is incomplete. It stands to reason that our coverage maps are therefore also incomplete. There could be areas being covered by towers not represented in our data. Moreover, it is unlikely that the parameters that we have used to represent the attributes of individual antennae (such as orientation, power, etc) reflect the true operational settings. Discrepancies between our assumed values and reality could also result in significant distortions in our coverage maps.

How should we interpret the results of this study? On the one hand, our model predictions have incomplete cell tower data, suggesting that service could be *better than predicted*. On the other hand, our coverage maps aggregate all service providers, and therefore the experience of a user on a single service network could be *worse than predicted*. Although our model predictions and field measurements do not align perfectly, *they tell a largely consistent story about the presence and location of coverage gaps, and they provide encouragement that our model-based approach can be effective in assessing cell service coverage.*

Developing authoritative coverage maps is possible but will require additional work. Specifically, we believe there is a need (1) to develop a complete database of cell towers and antennae, and (2) to execute a measurement study to validate the predictive coverage. The former seems only possible in partnership with the commercial cellular providers, who otherwise have strong incentive to hide information for competitive purposes. For the latter, the Virgin Islands Bureau of Information Technology (BIT) has previously contracted commercial entities to conduct measurement studies of its emergency radio networks, and it is possible that a similar contract for service could be implemented here.

Working with commercial entities on both fronts would create a new capability in the territory to conduct a number of what-if analyses. In particular, one could better understand:

1. Who is most vulnerable in terms of cellular service, both now and during emergency situations?
2. What does the loss of one (or more) antennae do to the coverage? How critical is each tower? And to whom?
3. How would the placement of additional antennae help to close a coverage gap? Where should additional emergency antennae be placed?

Having authoritative maps would inform a variety of public safety and/or infrastructure recovery and investment decisions for Emergency Support Function (ESF)-2, i.e., communications. This report demonstrates that closing this gap is both possible and prudent.

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Acknowledgments

This report expands on the previous NPS thesis titled, “Analyzing cell phone network resilience in the U.S. Virgin Islands” by William Wine (2020). Some of the material and figures in that report are repeated here.

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1 Introduction

In September 2017, Category-5 Hurricanes Irma and Maria struck the United States Virgin Islands (USVI) within a two-week period and collectively devastated homes, businesses, and infrastructure throughout the territory (for a summary, see USVI Hurricane Recovery and Resilience Task Force 2018; Alderson et al. 2018). Cellular communication infrastructure was extensively disrupted for emergency operations and residents alike: 76.6% of cell sites across the territory were reported down in the weeks after the storms, and the majority of these remained down for over a month (Federal Communications Commission 2017).

Interdependencies across infrastructure systems further impacted the function of cell phone networks that were not directly damaged. For example, large power outages across the territory following the storms contributed to loss of service for cell phone customers, which in turn affected the behavior and function of emergency response teams and local communities. In the aftermath of the storms, it could be difficult to assess who was affected by loss of service, and how to prioritize restoration.

Cellular coverage in the USVI is known to be uneven, with "dead zones" scattered throughout each of the islands. These dead zones are often a nuisance during normal conditions but can exacerbate already dangerous situations during emergencies. Anecdotally, our research team has received first-person accounts of first responders having to leave the scene of an emergency to find cellular service to call for backup support. Additionally, in the aftermath of the 2017 hurricanes, anecdotal reports recounted residents driving on dangerous roads during curfew periods to find cellular coverage so they could communicate with family members.

This report provides an overview of the cell phone infrastructure networks in the USVI and provides a model-based analysis of expected coverage. We use this model to predict coverage gaps related to critical assets and locations across the territory, as well as to assess the potential loss of coverage given possible infrastructure failures in future disasters.

This work extends the previous work of Wine (2020) with new data and results. The techniques presented in this report represent a new capability for stakeholders in the USVI and could become the basis for decisions supporting telecommunication infrastructure in the Territory.

We also report on field experiments conducted in the USVI intended to validate our model predictions. Overall, we confirm the existence of dead zones throughout the Territory through modeling and field data collection. However, our experiments revealed that our predicted coverage maps cannot be treated as authoritative, due to incomplete data for transmitting towers. We conclude this report with additional steps necessary to generate authoritative coverage maps.

1.1 Overview of the U.S. Virgin Islands

The USVI is a territory approximately 1,100 miles southeast from Florida in the Caribbean Sea and primarily comprised of three islands: Saint Thomas (STT), Saint John (STJ), and Saint Croix (STX). The territory is small in both land area and population: The USVI is just 134 square miles with a population of 87,146 as of 2020 (down 18% from the 2010 Census estimate). Nearly all of this population is split evenly across St. Thomas and St. Croix, with only 3,881 residents on the mostly forest-covered St. John (United States Census Bureau 2020). Given it is a small and remote territory, the USVI imports the majority of its goods such as food and fuel (Alderson et al. 2018).

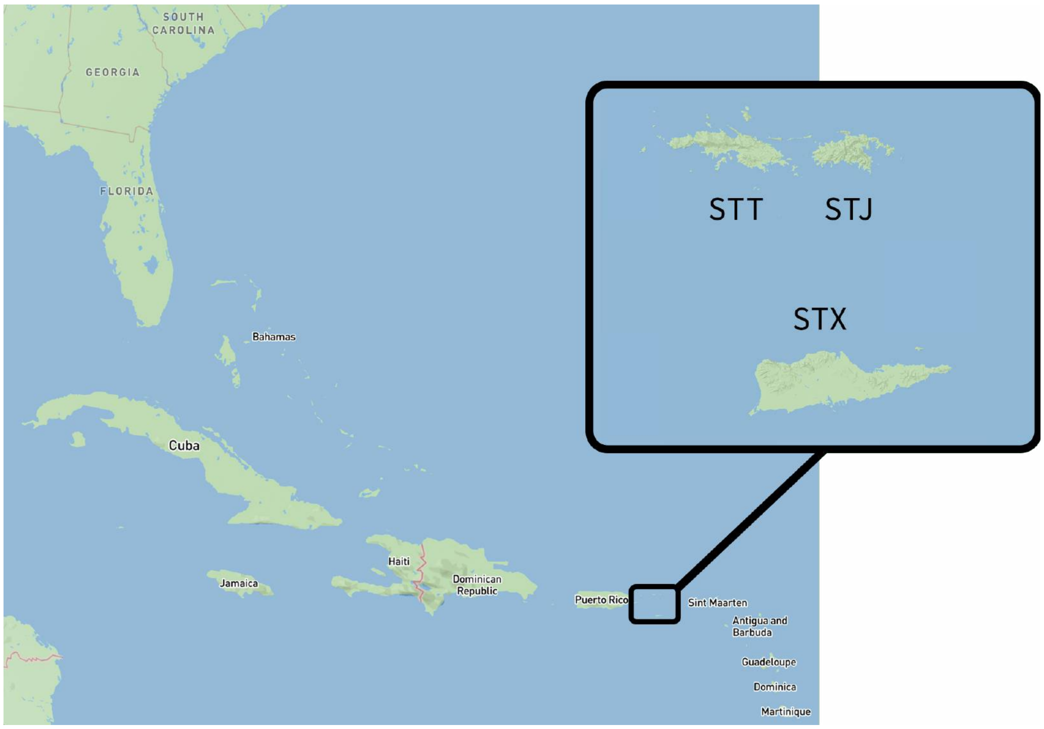

Figure 1. Map showing location of The U.S. Virgin Islands containing St. Thomas (STT), St. John (STJ), and St. Croix (STX).

The islands St. Thomas, St. John, and St. Croix each have a distinctive geography and local communities. St. Thomas has a mountainous topography, with hills and valleys separating many communities on the island. The coastal city of Charlotte Amalie is the capital of both St. Thomas and the USVI, and hosts the majority of tourism activity in the territory.

Just to the east, nearby St. John is the smallest island with only a few secluded communities separated by the large Virgin Islands National Park that accounts for most of the island's land area. The vast majority of St. John's population lives on the west coast closest to St. Thomas, in the tourism hub of Cruz Bay. St. Thomas and St. John are separated by only 3 miles, allowing St. John to depend on St. Thomas for many critical services such as electric power and drinking water (Alderson et al. 2018). It is also common for cell phone service customers on one island to connect to a cell tower located on the other, or even to connect internationally to the nearby British Virgin Islands (BVI). However, the terrain is much more mountainous and covered by vegetation than the other islands, restricting delivery of infrastructure services to many locations on St. John.

The island of St. Croix is 40 miles south of the other two islands and features a flatter topography. Historically, St. Croix contained much of the territory's agriculture and industry, and still retains rum distilleries and an oil refinery, though tourism now makes up the majority of the island's economy.

1.2 Cell Phone Coverage Networks in the USVI

The USVI has a combination of environmental features, physical infrastructure, and infrastructure operators that influence where cell phone coverage is across the islands.

1.2.1 Coverage Areas of Interest

In this report, we consider a number of areas where cellular coverage is important.

Residential areas. The territory of the USVI is divided into residential areas called *estates* that similar to traditional census subdistricts for the purpose of population tracking. Good (2019) and Routley (2020) use geographically defined estates to estimate the demand for roadway vehicular traffic on St. Croix and St. Thomas/St. John respectively.

Work and school zones. Following the convention in Wine (2020), we focus on buildings designated as a Community Anchor Institutions (CAIs) by the Federal Communications Commission (FCC). These include schools, hospitals, and other community installments that are critical locations both during normal daily operations and especially during disasters. Each CAI is given an FCC-designated category code defined in the list below (National Telecommunications and Information Administration 2014):

1. School K-12;
2. Library;
3. Medical/healthcare;
4. Public Safety (includes police, fire stations, and first responders);
5. University College or Post-secondary School;
6. Other community support — governmental; and,
7. Other community support — non-governmental (includes Non-Government Organizations (NGOs) and support organizations).

The list of CAIs for the USVI was developed during the 2010-2014 time period to support federal investment in broadband internet and other telecommunication services throughout the territory.

Tourist zones. Not formally designated in any way, areas in the USVI that support tourism tend to have some of the best cellular coverage. This includes not only shops and restaurants near the areas where cruise ships dock, but also the routes to and from popular remote destinations such a Magen's Bay in St. Thomas. Because telecommunications services are operated as commercial businesses, a reality for coverage is that telecommunication providers have incentive to invest only where market demands exist.

1.2.2 Factors Affecting Cell Phone Coverage

Cell phone coverage in a given area is provided by a network of towers, also called cell sites, each equipped with antennas used to send and receive signal. Cell sites are often thought of as freestanding tall metal towers, but they can also take the form of small additions to preexisting structures like streetlights or buildings, or mobile towers attached to trucks. A cell site typically features its antennas near the peak of the structure, as antenna height is critical for increasing coverage. The following factors are additionally influential in performance of a cell site:

- Generation of network technology (e.g., 3G, 4G/LTE, 5G)
- Elevation profile of surrounding landscape,
- Terrain and vegetation of surrounding landscape (wave reflectivity),
- Weather conditions,
- Signal frequency,
- Power of the transmitter,
- Direction the antenna are facing,
- Antenna bandwidth, and
- Number of nearby devices attempting to connect.

Figure 2 depicts an LTE tower on St. John. The top ring of rectangular shaped boxes are the antennas, facing outward in different directions.

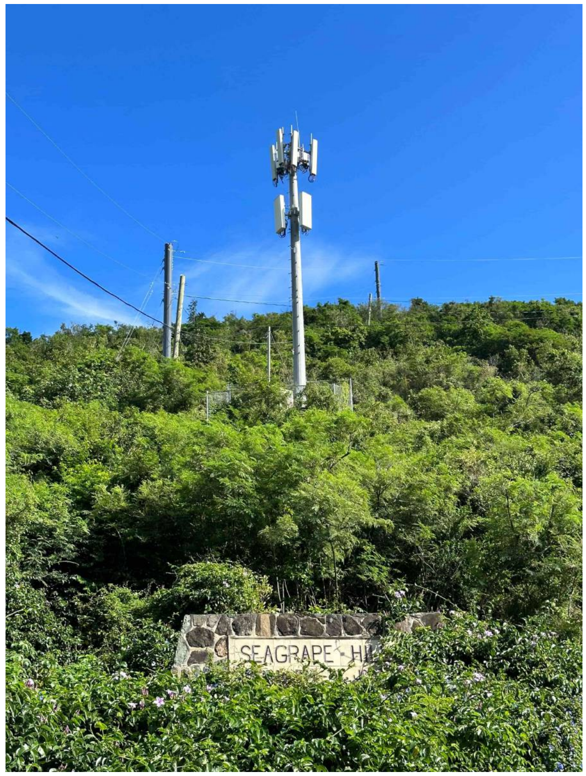

Figure 2. Cell tower at Seagrape Hill on STJ. It is common to place towers at elevated locations to avoid interference from hills, trees, and built structures (Federal Communications Commission 2020).

1.2.3 Differences in Technology Generation

It is important to understand the advancements and limitations of each mobile communication technology generation as multiple generations may coexist and offer service to users in an area.

3G technology was introduced in the early 2000s, offering data speeds of up to 2 Mbps. However, its limited bandwidth and frequencies caused slow data speeds and dropped calls. To overcome these issues, 4G/LTE technology was introduced with speeds up to 100 Mbps and support for a wider range of multimedia services. However, congestion due to increased data usage still remained an issue. The latest network technology, 5G, aims to address these limitations by offering data speeds of up to 20 Gbps among other improvements. However, the technology has yet to be rolled out to many areas.

1.2.4 Cell Phone Providers

Cell phone network assets in the USVI is distributed among three main cell service providers: Liberty, T-Mobile, and Viya.

Liberty has the most physical assets in the territory and provides both 4G and 5G coverage. Liberty began operating in the place of AT&T after completing its purchase of all AT&T assets in the USVI in 2020 (AT&T 2020). It is believed (Price 2018) that the Government of the Virgin Islands (GVI) utilizes Liberty's cables for their primary communication, but this is not verified (Alderson et al. 2018).

T-Mobile also has physical assets in the territory providing 4G and 5G coverage. The provider's coverage is primarily focused around popular tourism areas, leaving gaps in coverage across the territory.

Viya has limited physical assets and offers 4G coverage in the territory. As described previously (in Alderson et al. 2018): "Viya is the USVI communications subsidiary of ATN International, Inc. and the incumbent local exchange carrier (ILEC); Viya has no competitive local exchange carrier. As the ILEC, Viya is the designated wireline provider of dial tone in the territory. With this designation, Viya receives funds from the FCC and other carriers (Liberty and T-Mobile) to maintain lifeline services and provide wireline service capability to everyone in the territory. For wireline services, Viya receives off-island communications through CenturyLink and then provides dial tone through the local exchanges through either copper wire (older infrastructure) or hybrid fiber coaxial (HFC)."

AT&T no longer operates as a cellular provider but remains a presence in the USVI as the contractor selected to build FirstNet, a "network for first responders that uses a new communications spectrum band (digital radios) for public service providers to communicate with one another in the event of another disaster" (Pereira 2017).

Although telecommunications service providers typically own and operate their own equipment, they typically do not own the towers on which they are deployed. Instead, it is common practice to lease space on towers, commercial buildings, or even residences owned by third parties. For example, a majority of the towers in the USVI is owned by SBA Communications Corporation (Alderson et al. 2018). In many cases, a single tower might house equipment from multiple, competing service providers.

The decentralized and competitive nature of telecommunications creates strong incentives for owner-operators to hide or obscure information about their systems (Alderson et al. 2018). Moreover, publicly available information from service providers is often as much a product of marketing as anything else. As a result, the day-to-day service experience of residents in the USVI often differs significantly from the coverage maps advertised by individual service providers.

The net result is many details of the USVI cell phone communications infrastructure are not known, including:

1. where towers are located,
2. which service providers have equipment on a tower,
3. who receives service from a specific tower,
4. who will lose service in the event of a tower failure,
5. which communities are most vulnerable to disruption from one or multiple tower failures, and
6. where any additional tower(s) could be placed to minimize disruption of critical services in the event of a future failure.

Answers to these questions are often revealed only in the aftermath of a service disruption.

1.3 Hurricane Impacts to Cell Phone Networks

Two category-5 storms, Hurricanes Irma and Maria, struck the USVI within a two week period in September 2017, causing major disruptions to the cell phone network of the territory.

1.3.1 Hurricane Irma

Hurricane Irma struck St. Thomas and St. John as a Category-5 storm on September 6-7, 2017 with maximum sustained winds of 180 miles per hour (Alderson et al. 2018). Damage from the storm closed ports and suspended operation of the ferry service from St. Thomas, St. John, and nearby small island, stranding many people on the islands for days. Airports were closed for weeks (USVI Hurricane Recovery and Resilience Task Force 2018). The heavy winds, rain, and flooding resulted in damages to infrastructure across the territory, contributing to some customers being without power for multiple months.

1.3.2 Hurricane Maria

Hurricane Maria charted a course through St. Croix as a Category-5 storm on September 20, 2017, devastating the island while causing additional damage to St. Thomas and St. John. The storm's similarwind speeds, rain, and flooding caused significant damage to structures already weakened from Hurricane Irma, and delayed recovery of infrastructure systems and restoration of service to residents.

1.3.3 Impacts to Cell Phone Networks

There was severe damage to physical assets owned and operated by the three providers during the hurricanes. Vulnerabilities and inter-dependencies of cell phone networks were clear: High winds and power outages resulted in the failure of the vast majority of cell sites in the USVI. Correspondingly communications systems performed poorly both during and immediately after the storms (Alderson et al. 2018), greatly hampering response and recovery efforts. There were widespread cell disruptions across St. Croix and St. Thomas, and a complete loss of cell service across St. John.

There are still concerns over the vulnerability of communications infrastructure to future hazards, leading the GVI and federal agencies to simulate emergency response with degraded communications in their preparation for future hurricanes (Federal Emergency Management Agency 2022).

1.4 Objective and Organization of this Report

This report makes several contributions. First, we present a physics-based model for estimating the cellular coverage for the USVI. We describe past work in this area, and expand on the basic technique presented previously in Wine (2020). This is the focus of Section 2.

Second, we demonstrate how to use this model to answer the following questions:

- who receives service from a specific tower;
- who will lose service in the event of a tower failure;
- which communities are most vulnerable to disruption from one or multiple tower failures; and
- where any additional tower(s) could be placed to minimize disruption of critical services in the event of a future failure.

This is the focus of Section 3.

In Section 4, we summarize recent field experiments to validate the predictions of our model, and describe how incomplete input data about cell towers creates gaps in our analysis.

Finally in Section 5, we describe the additional work needed to close the gap in our analysis, as well as how to use the tools in this report to create a new capability for stakeholders in the USVI.

2 How to Generate Coverage Maps

Wine (2020) outlined the basic technique for estimating the service areas provided by the USVI cell phone network. In this section, we repeat and expand on these methods.

The keystone of our technique is the Terrain Integrated Rough Earth Model (TIREM)—a Department of Defense (DOD) standard model for assessing wireless signal strength over land and water. TIREM inputs include the elevation profile of the area of interest, information on the cell tower (location, height, frequency, polarization), and atmospheric and ground constants such as surface refractivity, humidity, relative permittivity, and conductivity, and then produces estimates of signal loss as output, see Figure 3.

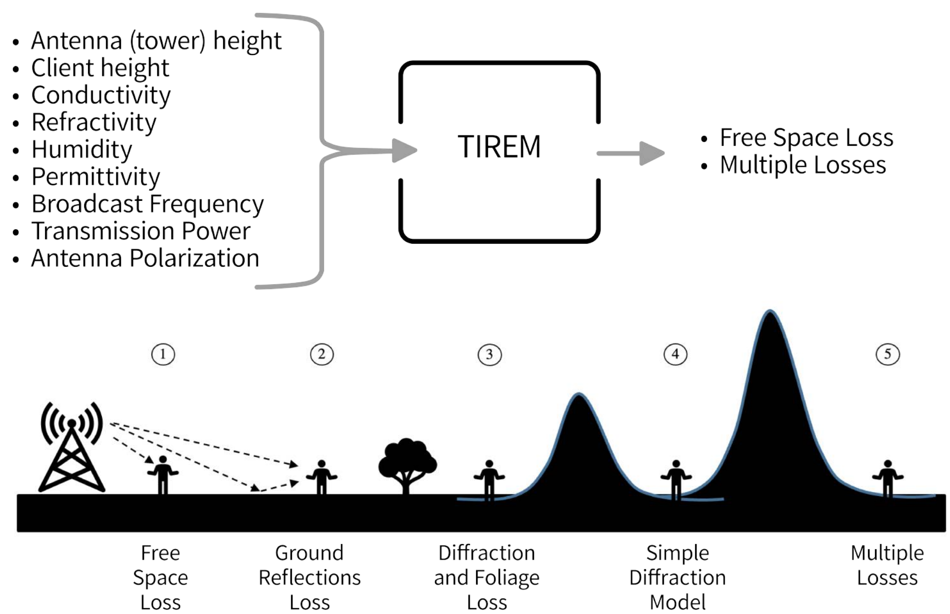

Figure 3. Overview of TIREM, adapted from Wine (2020).

2.1 Input Parameters and Model Assumptions

In order to produce coverage maps, we gathered and pre-processed a variety of input data needed to run TIREM as well as made a number of simplifying assumptions.

Tower Locations and Antenna Heights

Data collection was performed by University of the Virgin Islands (UVI) to gather tower locations and antenna heights. Collection efforts included driving to various locations to verify the existence of a tower. There were:

- 12 tower locations identified on STT,
- 6 tower locations identified on STJ, and,
- 17 tower locations identified on STX.

For each of these locations, antenna heights were recorded with a TruPulse 200L laser rangefinder.

Elevation Data

We use elevation data at 3-meter resolution provided by United States Geological Survey (USGS) in GeoTIFF file format for St. Thomas, St. John, and St. Croix. To capture any signal that propagates across the short water distance between St. Thomas and St. John, we merged their respective GeoTIFF data into one composite raster file. Figures 4, 5, and 6 depict the known tower locations and elevation of St. Thomas, St. John, and St. Croix, respectively.

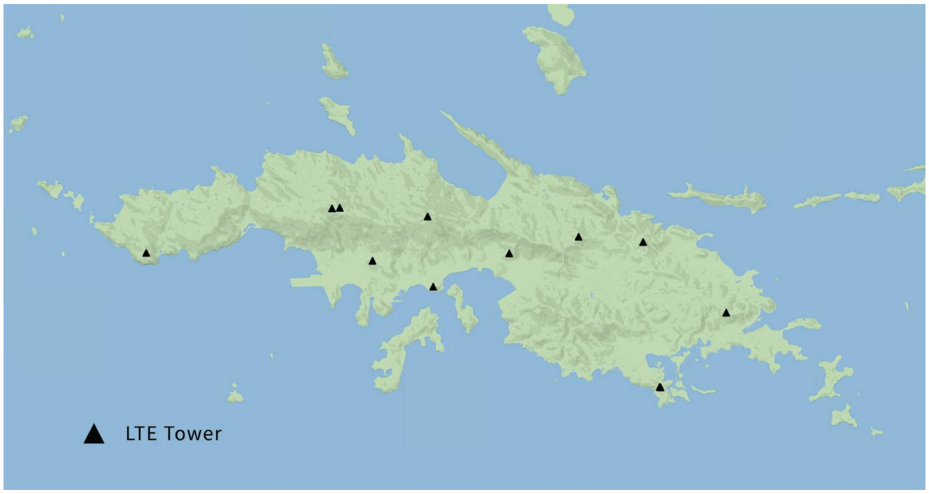

Figure 4. Tower locations and elevation of STT. St. Thomas, the second largest island, features a mountainous terrain with limited flat areas near the island's southern coast.

Figure 5. Tower locations and elevation of STJ. St. John, is the smallest and most mountainous of the three main islands.

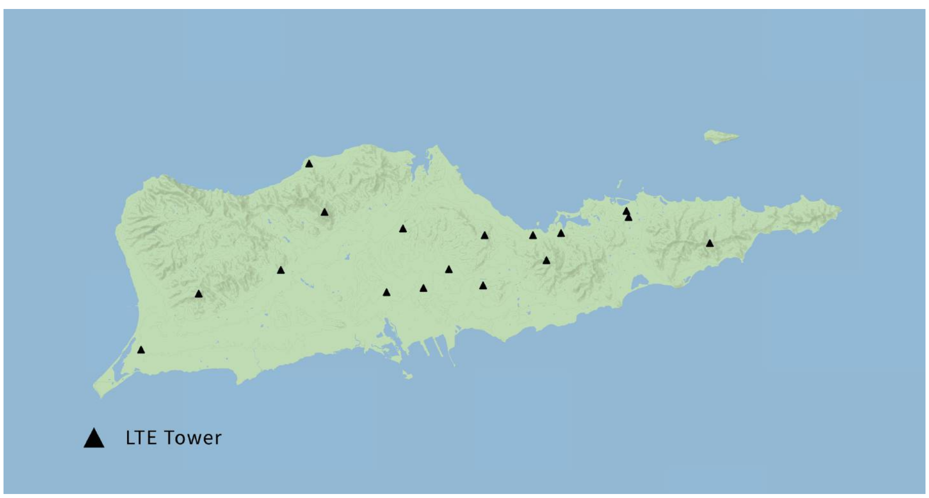

Figure 6. Tower locations and elevation of STX. St. Croix, the largest island, features a predominantly flat terrain across most of its expanse. There are some regions of St. Croix with more rugged topography, such as the island's western region, which features rolling hills and some small mountain ranges.

Additional Assumptions

For the rest of TIREM's inputs, we adopt the convention in Wine (2020) and make the following assumptions for each cellular tower within the USVI :

- antenna gain is assumed to be 2 dBm for all towers;
- transmission power is assumed to be uniform but the most common transmission power for cell tower antennas is between 10 and 20 W (i.e., 40-80 dBm) (Sauter 2013);
- the combination of transmission power and gain is assumed to be 62 dBm for all towers; and,
- the receiver antenna (e.g., customer cell phone) is assumed to be 1.7 m, roughly the height of a person standing up.

Data Processing

Due to memory issues caused by the high fidelity of the elevation data, and an interest in reducing solve times for TIREM, the GeoTIFFs of STT/STJ (composite), and STX were down sampled to a resolution of approximately 61 meters by 61 meters.

The final input for TIREM is the list of coordinates for which to calculate projected signal strength. This list of coordinates was derived from the elevation data by calculating the centroid of each pixel in the input elevation raster. This was done to ensure TIREM's output matched the resolution of the input data.

The full process of signal raster creation is visualized in Figure 7.

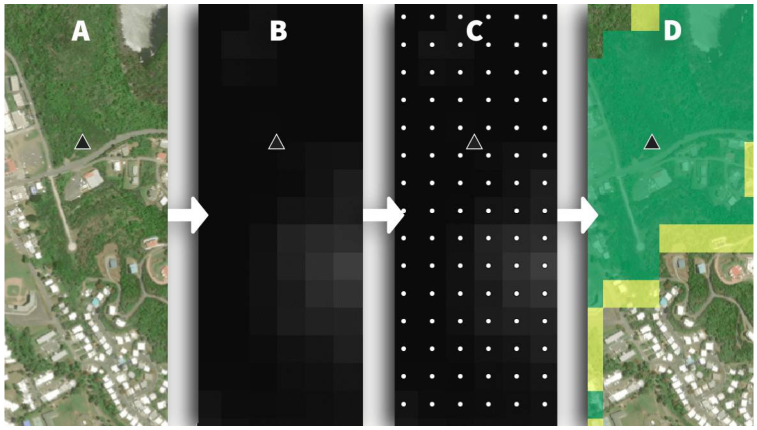

Figure 7. Example of signal raster creation process. A - Identification of tower location, B - elevation raster, C - grid of points created from elevation raster pixel centroids, D - output signal raster with good (green), medium (yellow), and poor (transparent) signal areas identified.

2.2 Model Implementation

TIREM is available as a pair of Dynamic Link Library files (.dll). Dynamic Link Libraries are files compiled using the coding language C, and are only usable within 32-bit Microsoft Windows. A number of steps were taken to enable compatibility with the robust analysis tools available within Python. First, a 32-bit Python environment (in this case the 32-bit Anaconda distribution) was installed on a machine running Microsoft Windows. Next it was ensured that a Microsoft Visual C++ Redistributable package was installed. Finally, code was written to call TIREM functions with the package ctypes, a C wrapper for Python.

2.3 Interpretation of Model Outputs

2.3.1 Signal Strength

There are two common ways 4G (LTE) signal strength is measured: Reference Signal Received Quality (RSRQ) and Reference Signal Received Power (RSRP).

RSRQ more closely measures the real world performance of a single device on a network at the specific time the measurement was taken because it includes network congestion, bandwidth, and resource block allocation by cell providers as inputs.

RSRP measures signal strength in terms of physical constraints (e.g. elevation profile, distance to cell site), and as such is agnostic to the performance of the network on any given day or the variable capabilities of any specific cellular device.

For RSRQ and RSRP, "Good" indicates reliable signal strength for internet, phone calls, and texting. "Medium" indicates signal strength capable of enabling basic connectivity for phone calls and texting, while "Poor" indicates a loss of signal. See Figure 8.

LTE Signal	RSRQ (dB)	RSRP (dB)
Good	0 to -9	0 to -103
Medium	-9 to -12	-103 to -111
Poor	<-12	< -111

Figure 8. LTE signal strength is commonly measured in RSRQ and RSRP.

TIREM produces outputs measured in RSRP. As a result, TIREM results can be interpreted as giving a general assessment of the strength of coverage in an area, while not necessarily being indicative of the connectivity of any one device in that area at a given moment in time.

2.3.2 Example output for a single cell site

Figure 9 shows the TIREM output for a single tower on St. Thomas.

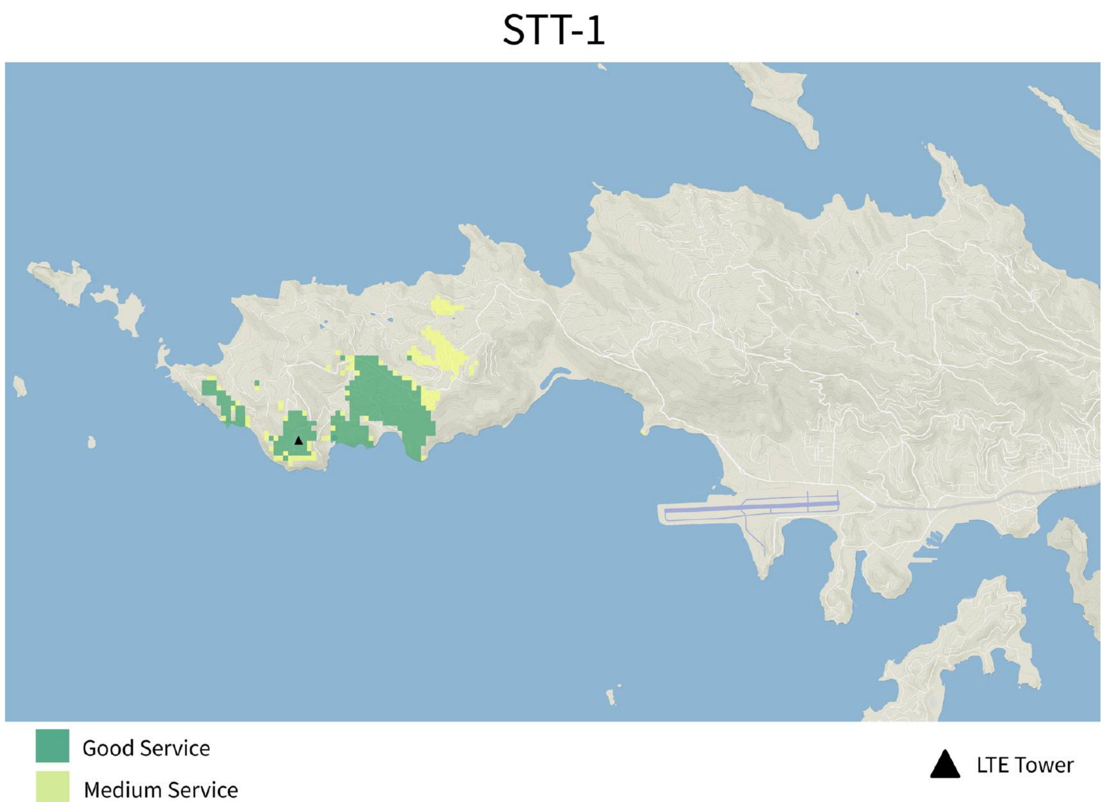

Figure 9. TIREM-Generated LTE Coverage Example for one tower on STT.

The color-coded legend used in the coverage maps indicates that green areas represent good signal strength, characterized by RSRP values greater than -103 dB. Meanwhile, yellow areas indicate medium signal strength, with RSRP values ranging from -103 to -111 dB. Conversely, areas with no color represent locations with poor or non-existent coverage, associated with RSRP values below -111 dB.

3 Predicted Coverage

Given the ability to generate coverage maps that predict signal strength based on tower locations and topography, we consider the question: *How "good" is the coverage in the USVI?*

The question of "goodness" is somewhat complicated, for several reasons:

1. a cellular user connects to only a single tower at a time;
2. a given location can be covered by one or more towers, or none at all;
3. there are multiple providers, each providing separate coverage to their customers; and
4. each provider has strong incentive to obscure the means by which they provide coverage.

In addition, we note three important caveats. First, the coverage maps advertised by each cellular provider are designed for marketing purposes, and therefore seem unlikely to be strictly accurate. Second, our data for cellular antennae does not differentiate individual service providers. Thus, our predicted coverage includes all providers, and this coverage can differ from the experience of an individual user on a single provider's network. Third, our predicted coverage is for LTE technology only, and does not consider 5G service.

Nonetheless, we proceed by comparing our predicted coverage to the advertised coverage maps for each island. The intent is to assess the size and scope of "dead zones."

Then, we consider the coverage at specific locations of interest, defined by the CAIs on each island. The intent is to understand the extent to which critical facilities in the territory have coverage.

3.1 Composite Coverage Maps: Predicted vs. Advertised

We begin by considering the advertised coverage maps for individual service providers. We present the coverage maps for Liberty and T-Mobile below (Viya's coverage maps were not accessible at the time of this report).

Figure 10 depicts the advertised coverage areas for Liberty.

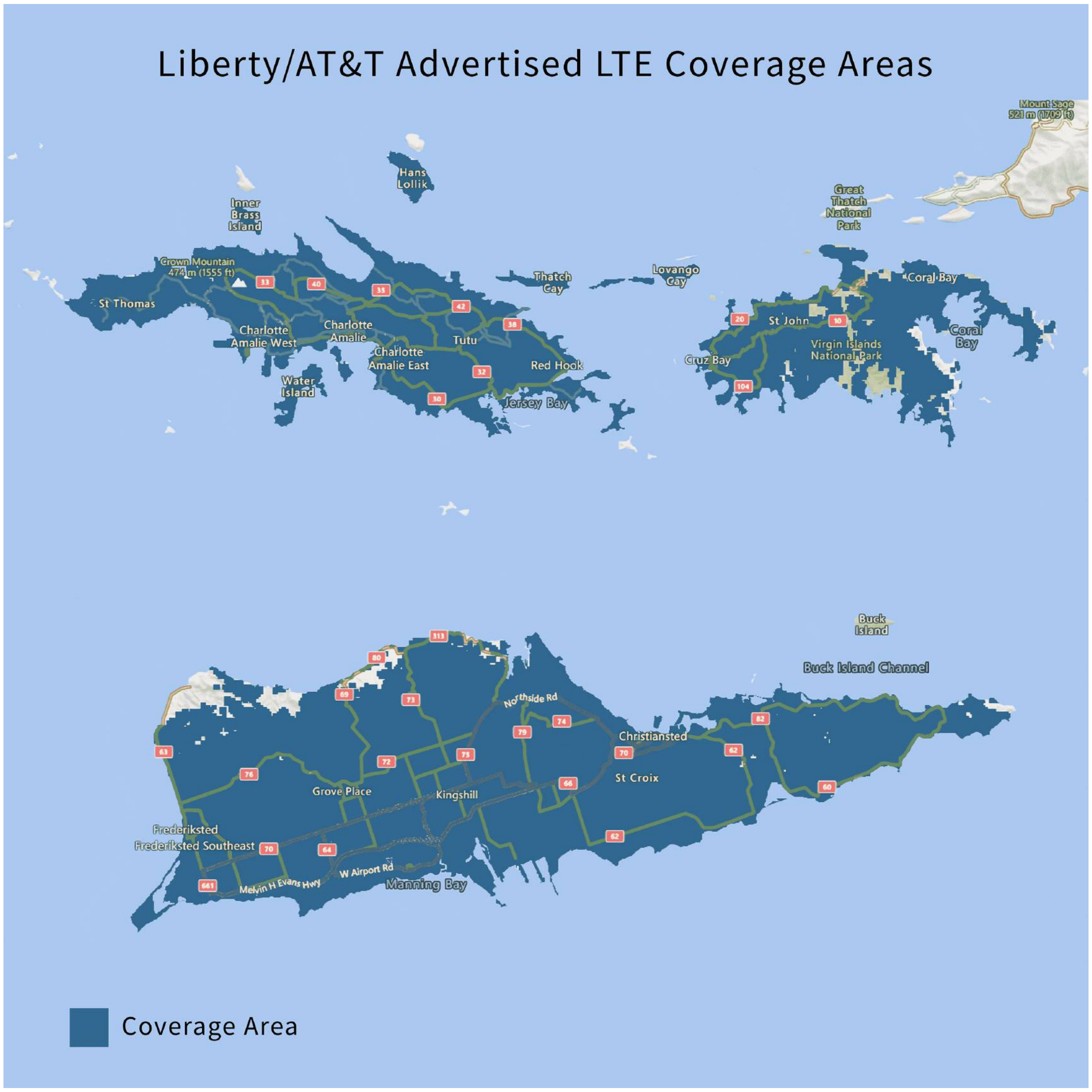

Figure 10. Liberty/AT&T advertised LTE coverage in the USVI. Coverage map obtained from att.com 2/23/2023 (AT&T 2023). Note: Distance between the islands is not to scale.

Figure 11 depicts the advertised coverage areas for T-Mobile.

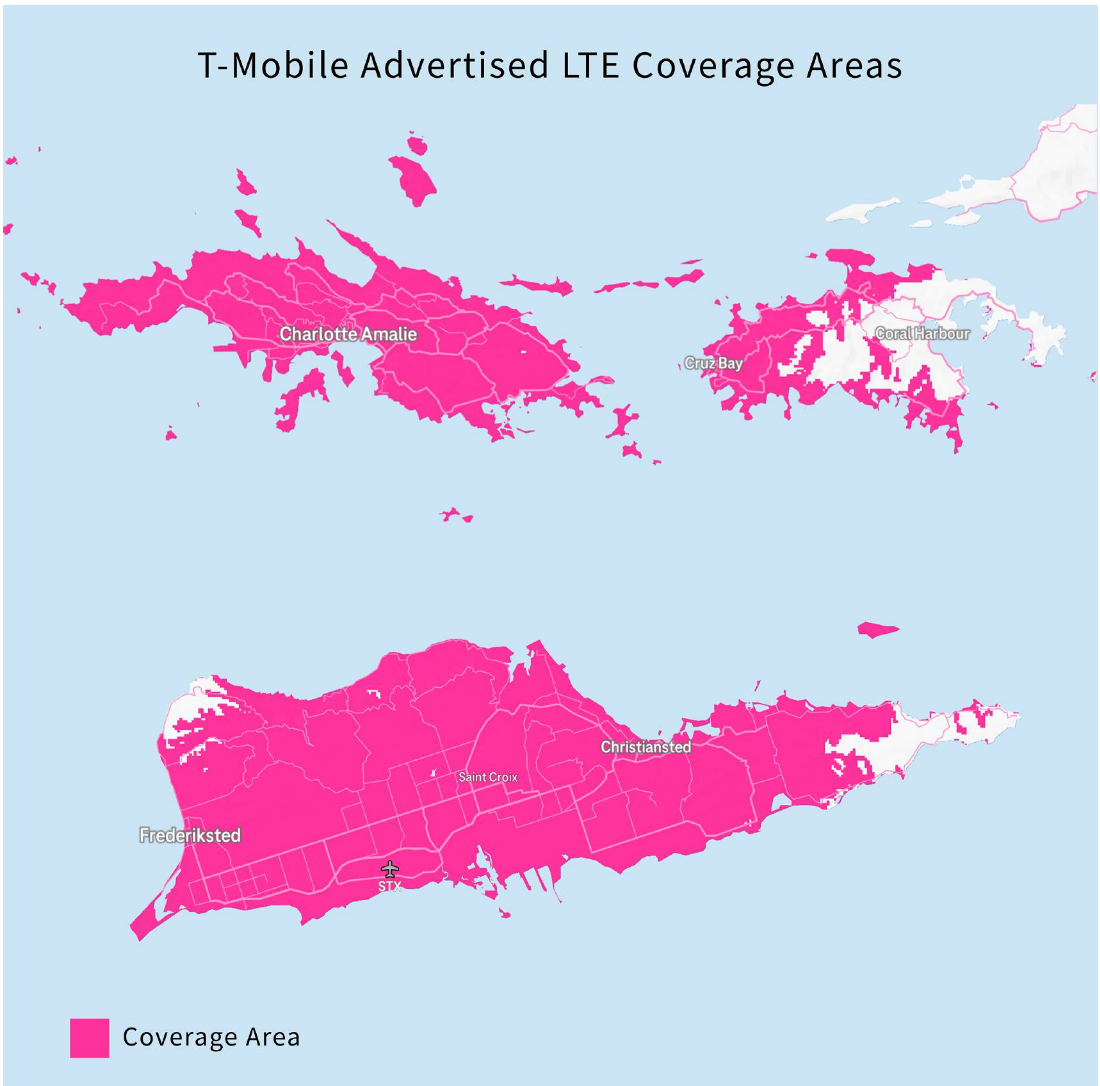

Figure 11. T-Mobile advertised LTE coverage in the USVI. Coverage map obtained from t-mobile.com 2/23/2023 (T-Mobile 2023). Note: Distance between the islands is not to scale.

Figure 12 depicts the model-predicted coverage areas.

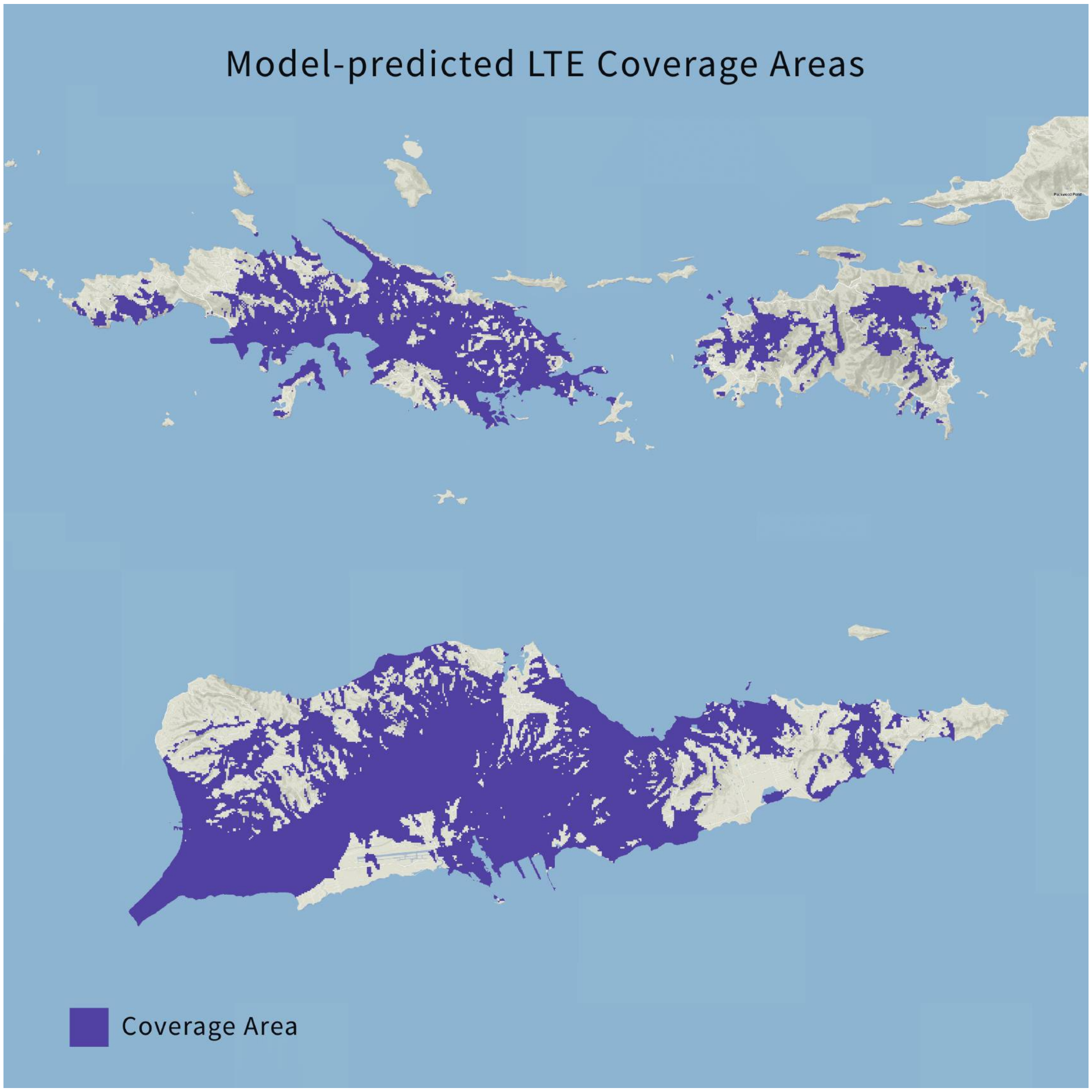

Figure 12. Model-predicted LTE coverage in the USVI. Coverage is defined by an RSRP value of medium service or better. In order to maintain visual consistency with the coverage maps provided by the service providers, any predicted coverage over bodies of water has been omitted from this figure. Note: Distance between the islands is not to scale.

Discussion

Our model predicts LTE coverage areas that are much more fragmented than the coverage areas advertised by individual service providers. This fragmentation is consistent with the experience of "dead zones" in coverage throughout the territory. Notably, the model-predicted LTE coverage areas represent the composite coverage of all service providers. However, real world coverage areas for a person on any single provider is likely be worse than the model predicts, as customers of one service provider typically cannot connect to a cell site operated by a different service provider.

3.2 Coverage of Community Anchor Institutions

Another means of measuring service quality is to consider the ability of specific locations of interest to receive cell phone signal. Here, we consider the model-predicted coverage for predefined CAIs. Of particular interest is the number of towers that cover individual CAIs.

3.2.1 St. Thomas and St. John

Figure 13 depicts the number of CAIs on STT and STJ by type.

CAIs by Type

St. Thomas and St. John

Type	Description	Total CAIs
1	School K-12	39
2	Library	3
3	Medical/Healthcare	14
4	Public Safety	23
5	University, College, Other Postsecondary	1
6	Other Community Support - Government	93
7	Other Community Support - NGO	10
All		183

Figure 13. CAIs by type on STT and STJ.

For each of these CAIs, Figure 14 depicts how many towers on STT and STJ provide coverage. Of note, the model predicts that 26 of 183 CAIs (14%) do not have coverage from any tower and are without service. In addition, the model predicts that another 35 CAIs (19%) have coverage from only a single tower, suggesting that a disruption to that tower would leave them without coverage.

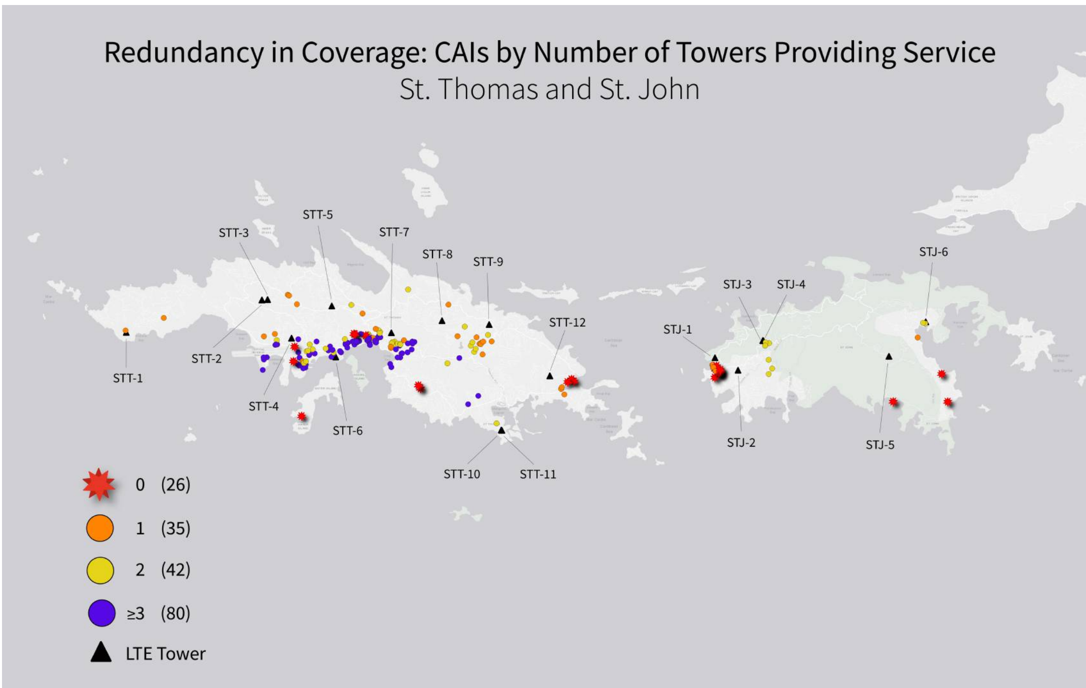

Figure 14. CAI coverage on STT and STJ.

Figure 15 provides additional detail on the types of CAIs covered by only a single tower, along with the tower on which they depend. For example, a disruption to the tower STT-8 would leave 8 CAIs without coverage. (Note: these are not the only CAIs covered by STT-8, just the CAIs that are *only* covered by STT-8.) Similarly, tower STJ-1 is the sole coverage provider for 6 CAIs, and STT-7 is the sole coverage provider for 5 CAIs. These values are useful for understanding the types of CAIs could be without service in the event of a tower outage.

CAIs Relying on Service From Only One Tower

St. Thomas and St. John

	STJ-1	STJ-6	STT-1	STT-3	STT-4	STT-5	STT-6	STT-7	STT-8	STT-9	STT-12
CAI 1	1				1	2		1	4	1	
CAI 2											
CAI 3	1										
CAI 4		1	1	1					1		
CAI 5					1						
CAI 6	4		1	1			3	4	3		1
CAI 7											
Total	6	1	2	2	2	2	3	5	8	1	3

Figure 15. CAIs covered by only a single tower on STT and STJ.

3.2.2 St. Croix

Figure 16 depicts the number of CAIs on STX by type.

CAIs by Type

St. Croix

Type	Description	Total CAIs
1	School K-12	31
2	Library	4
3	Medical/Healthcare	5
4	Public Safety	19
5	University, College, Other Postsecondary	1
6	Other Community Support - Government	64
7	Other Community Support - NGO	9
All		133

Figure 16. CAIs by type on STX.

For each of these CAIs, Figure 17 depicts how many towers on STX provide coverage. Of note, the model predicts that 6 of 133 CAIs (4%) do not have coverage from any tower and are without service. In addition, the model predicts that another 18 CAIs (14%) have coverage from only a single tower, suggesting that a disruption to that tower would leave them without coverage.

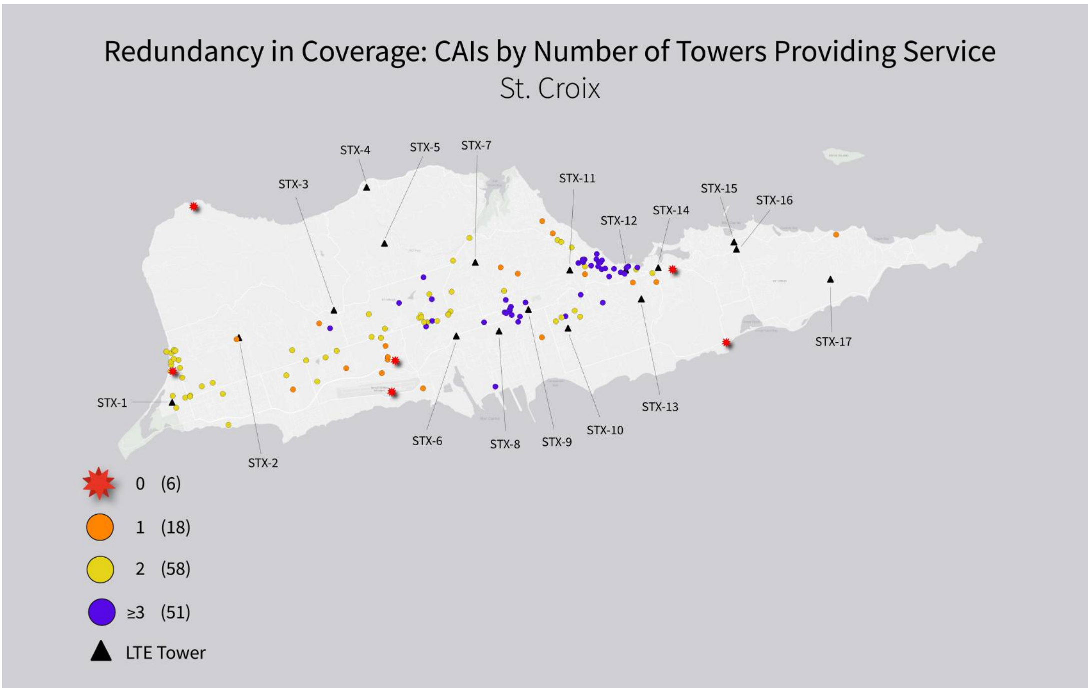

Figure 17. CAI coverage on STX.

Figure 18 provides additional detail on the types of CAIs covered by only a single tower, along with the tower on which they depend. For example, a disruption to the tower STX-3 would leave 6 CAIs without coverage. Overall, STX seems to have fewer CAIs that are solely dependent on a single tower. Nonetheless, the values in Figure 18 are useful for understanding who could be without service in the event of a tower outage.

CAIs Relying on Service From Only One Tower

St. Croix

	STX-2	STX-3	STX-8	STX-10	STX-11	STX-12	STX-14	STX-17
CAI 1	1	1	1		3		1	
CAI 2								
CAI 3								
CAI 4	1	3						1
CAI 5		1						
CAI 6		1	1	1		1		
CAI 7			1					
Total	2	6	3	1	3	1	1	1

Figure 18. CAIs covered by only a single tower on STX.

Discussion

The majority of CAIs on STT and STJ (122/183 = 67%) and on STX (109/133 = 82%) can be covered by more than one tower. This level of redundancy is important in the event of a tower disruption caused by extreme weather, extended power outage, or other mishap. Yet, our model predicts that there are 85 CAIs that either do not have coverage or are solely dependent on a single tower for coverage.

Despite limitations in our model, these results show a potential vulnerability of the CAIs. Even if our results are not 100% correct, this is a warning that perhaps CAI coverage merits closer attention.

The analysis in this section is focused on CAIs but could, in principle, consider any set of fixed locations, such as estates, transportation and shopping centers, or critical infrastructure facilities. Given the ability of our model to generate predicted coverage maps, these can be incorporated into many different tools for geospatial analysis, including Geographical Information System (GIS) tools.

4 Field Measurements

With the assistance of colleagues from UVI, we conducted field measurements during two observation periods in August 2021 and November 2022. To conduct the field cell reception measurements, the research team utilized multiple 5G-capable iPhone devices with service providers Verizon, Viya, and Liberty/AT&T. The measurements were obtained through the internal Field Test Mode of each phone, recording the RSRP values and latitude and longitude coordinates of the phone at the time of measurement.

The original plan was to drive directly towards cell towers from the dataset and take measurements while driving away from them to capture the actual signal strength of each tower. Collecting these measurements would help validate the LTE signal model and improve its accuracy. However, the plan was rendered unfeasible due to the presence of numerous LTE cell sites scattered across the islands that were absent from the dataset. As a result, obtaining more than a few readings from a single tower was unattainable before connecting to an unknown tower location. In view of this challenge, the research team chose to focus on driving throughout each island to obtain signal readings from the broadest area possible. This approach allowed for the collection of an extensive range of measurements, resulting in a more comprehensive understanding of the actual signal strength experienced across the islands.

4.1 St. Thomas

To obtain measurements in both densely populated and rural areas, our team drove around St. Thomas during the first two weeks of August 2021 and the third week of November 2022. Most of the measurements were taken along roadways, in parking lots, or in other areas accessible by automobile. Figure 19 depicts the service quality recorded across St. Thomas overlayed with our model predictions of coverage.

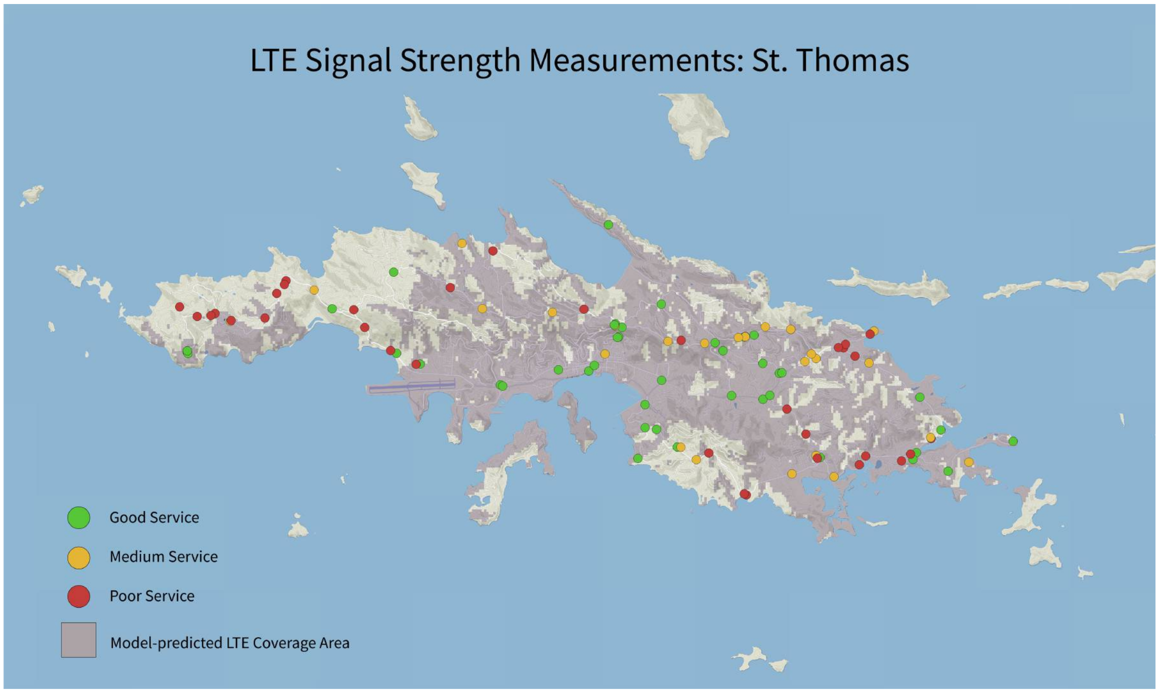

Figure 19. LTE Measurements on STT along with model-predicted coverage. Measurements were taken primarily along major roads and/or places accessible by personal vehicle.

The field measurements indicated that St. Thomas, as a whole, experiences cell reception far below what is advertised by providers. Of the 104 measurements recorded on St. Thomas, 42% indicated good signal, 26% indicated medium signal, and 32% reflected a poor signal. For example, the southern area of the island known as Frenchman's Reef—despite advertised coverage by multiple providers—is locally known to have poor signal quality, and both our model predictions and measurements support this. However, Charlotte Amalie and adjacent areas, along with areas frequently visited by tourists (such as Magen's Bay), exhibited consistently good service.

The juxtaposition of our model-predicted coverage and field measurements in Figure 19 provides some confidence that our model is capturing key features that affect signal quality on the ground. For the most part, we obtain measurements of good service in areas predicted to have coverage from known towers. Similarly, measurements of poor service mostly occur in areas outside or at the boundary of predicted coverage. Measurements of medium service quality often appear at the boundary of predicted coverage areas. However we do observe discrepancies. There are measurements of good quality in areas where we do not predict coverage—this could be evidence that a nearby tower location is missing from our data. There also exist measurements of poor quality in areas predicted to have coverage—this could be the result of local obstructions not reflected in our elevation maps or due to our measurement devices not being able to connect to a specific provider's tower. Overall, these results provide encouragement that our model-based approach can be effective in assessing cell service coverage.

4.2 St. John

In contrast to St. Thomas, St. John exhibited the weakest service of the three islands, with intermittent dead zones observed throughout the island, and most pockets of service being narrowly confined to tourist areas. Figure 20 depicts the service quality recorded across St. John. Of the 69 measurements taken on St. John, only 20% of them reported good signal, 25% indicated medium signal, and a significant 55% indicated poor signal or no connection to a domestic LTE antenna. During the observation periods, there were four instances where an international roaming connection was established, all in the northeast of St. John, near Tortola in the British Virgin Islands. Although our measurements indicate far less coverage than what is advertised by cell phone providers, they are consistent with common experience of residents.

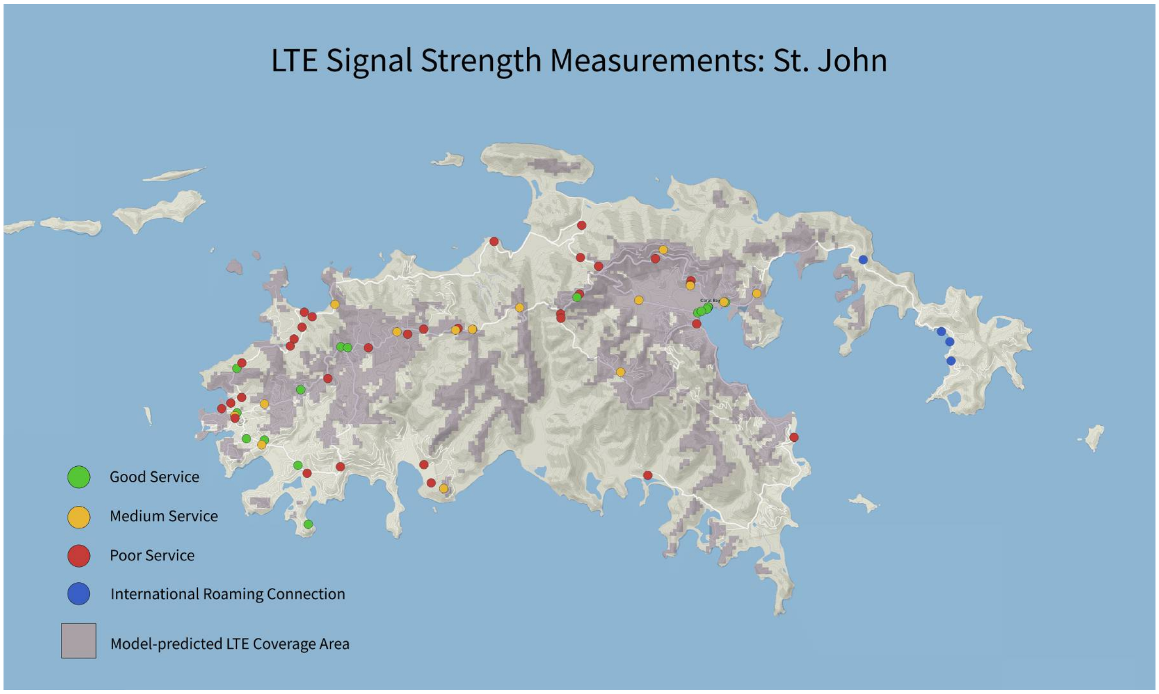

Figure 20. LTE Measurements on STJ along with model-predicted coverage. Measurements were taken primarily along major roads and/or places accessible by personal vehicle.

The juxtaposition of our model-predicted coverage and field measurements in Figure 20 provide additional evidence that our model predictions are reasonable. Based on the tower data available to us, very little of the island should have coverage. For the most part, measurements of good service correspond to areas where we predict coverage; the exception is the southwestern portion of the island near Cruz Bay where we suspect there exists a nearby tower that is missing from our data. The majority of measurements taken outside of our predicted coverage area recorded poor service, and many of the measurements taken on near the boundary of our predicted coverage area recorded medium service. However, we also observe many instances where we record poor or medium service inside regions that are predicted to have coverage. This could be the result of local obstructions (the terrain on St. John is mountainous) or because we do not have the appropriate orientation and/or power attributes for the towers in our data. Not surprisingly, the four instances where we recorded an international roaming connection occurred outside of our model-predicted coverage area.

4.3 St. Croix

As with the other islands, our team drove around St. Croix during the first two weeks of August 2021 and the third week of November 2022. Figure 21 depicts the service quality recorded in these field measurements, along with our model-predicted coverage. The measurements indicate many areas with good service across the flat center of the island, with significant gaps in service for the island's less-populated northwestern and eastern extremities. Of the 88 measurements collected on St. Croix, 38% indicated good signal, 22% indicated medium signal, and 40% reported a poor signal.

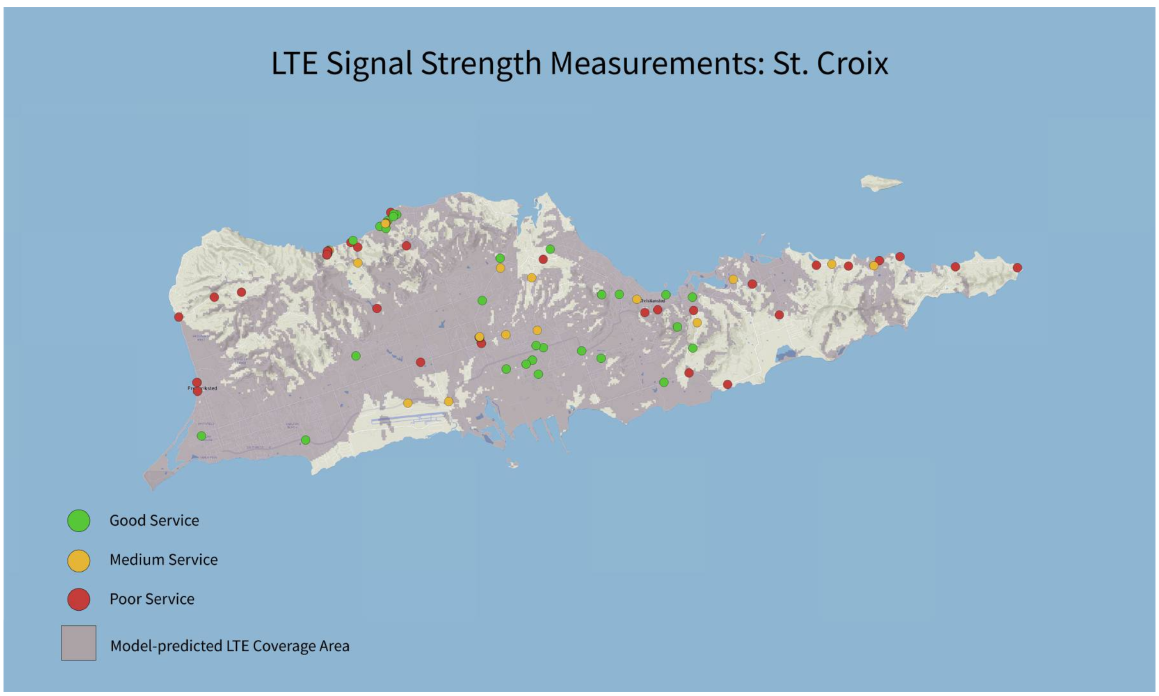

Figure 21. LTE Measurements on STX along with model-predicted coverage. Measurements were taken primarily along major roads and/or places accessible by personal vehicle.

Comparing our model-predicted coverage and field measurements in Figure 21 reveals a pattern similar to what is observed on the other islands. The majority of measurements that were recorded as having good service occur in areas where our model predicts coverage. Measurements recorded as having medium service tend to occur near the boundary of areas predicted to have coverage. Most of the measurements recorded as poor service occur outside areas predicted by our model to have coverage. However, we observe discrepancies here as well. There are a number of places—in Christiansted (in the north), in Fredericksted (in the west), and in the island interior between them—where we recorded poor or medium service despite a prediction of coverage. As noted before, this could be because of local obstructions not accounted for in our data or because our measurement equipment was unable to connect to the specific service provider in that area.

Overall, our measurements and model predictions are consistent in suggesting that cell coverage is significantly less than what is advertised by service providers.

Discussion

Although not comprehensive, our field measurements confirmed the general notion that (1) cellular coverage is uneven across each of the islands, and (2) cellular service is far less than what is advertised by commercial service providers.We found many areas with poor service (or no signal), even in places that seem relatively close to where people live and work. Our field activities brought us into contact with many residents who shared anecdotes about poor coverage, and the ways in which they regularly "work around" this lack of coverage.

One of the most notable takeaways from the field measurements was the absence of 5G service throughout the territory. Despite advertised 5G service and using multiple 5G-capable iPhone devices with service from different providers, not a single measurement indicated any 5G connectivity.

5 Summary and Conclusion

More than five years since the 2017 hurricanes, the USVI is still recovering. Cellular telephone services remain vital to the ongoing function of life in the territory. But the existence of dead zones in service requires residents to work around them. For the most part, this is an inconvenience. But during emergencies, the loss of cellular service creates a potential public safety hazard.

To date, the GVI and its components do not have a full accounting of the dead zones, nor do they have a comprehensive understanding of the vulnerability of existing cellular services.

This study takes a first step in providing this understanding. Using limited publicly available data and additional direct observations of cell towers, we use a physics-based model to predict coverage across St. Croix, St. John, and St. Thomas. We additionally conduct limited ground measurements of cell signal across the three islands.

5.1 Key Findings and Importance

Our predictions suggest coverage gaps as well as places where coverage is vulnerable to the loss of a single tower. Our measurements confirm the existence of coverage gaps, even in places that seem close to where people live and work. These results provide strong evidence for several meaningful conclusions:

- Cellular coverage in the USVI is uneven across each of the islands and also far less than what is advertised by commercial service providers.
- Gaps in cellular coverage are not limited to remote areas, but appear in important locations close to where people live and work. Our model predicts that there are 85 Community Anchor Institutions (CAIs)——including public safety, medical facilities, and government—that either do not have coverage or are solely dependent on a single tower for coverage, meaning that the loss of a single tower could render them without coverage.
- There is a general lack of understanding how government officials and emergency responders routinely "work around" these dead zones under normal conditions. More importantly, it is unknown how a loss of cellular service (e.g., during extreme weather) might create additional vulnerabilities and to whom.

5.2 Limitations in the Current Study

The primary limitation in this study is access to comprehensive and accurate cell tower information. The ability of our model to generate realistic coverage maps depends critically on the data used as input. Conversations with executives of cellular provider companies has indicated that our inventory of tower locations is incomplete. It stands to reason that our coverage maps are therefore also incomplete. There could be areas being covered by towers not represented in our data. Our field measurements support this conjecture.

Moreover, it is unlikely that the parameters that we have used to represent the attributes of individual antennae (such as orientation, power, etc) reflect the true operational settings. Discrepancies between our assumed values and reality could also result in significant distortions in our coverage maps.

What are the implications of these limitations? On the one hand, our model predictions have incomplete cell tower data, suggesting that service could be *better than predicted*. On the other hand, our coverage maps aggregate all service providers, and therefore the experience of a user on a single service network could be *worse than predicted*.

Although our model predictions and field measurements do not align perfectly, they tell a largely consistent story about the presence and location of coverage gaps, and they provide encouragement that our model-based approach can be effective in assessing cell service coverage.

5.3 How to Close the Gap?

In order for our coverage maps to be authoritative it would require (1) a complete set of cell tower and antennae which can only be obtained in partnership with the cellular providers, (2) a measurement study to validate the predictive coverage.

We need more complete tower and antennae information. This is likely going to require co-operation from the providers, which may be challenging given their vested interest in keeping information on their operations hidden from their competitors. However, the local emergency management Virgin Islands Territorial Emergency Management Agency (VITEMA) might be able to coordinate something under the auspices of Emergency Support Function (ESF)-2.

Regarding (1), obtaining the necessary data would enable us to generate updated coverage maps. However, it is important to note that the data will eventually become stale. To ensure the longevity of these maps, it is imperative that local stakeholders develop the capability to maintain and update them as needed. This requires a commitment to ongoing data collection and analysis.

For (2), it makes sense to do a comprehensive study of signal coverage. The Virgin Islands Bureau of Information Technology (BIT) previously contracted a study for its emergency radios ACD Telecom (2021). It is conceivable something similar could be done to understand cell coverage.

5.4 Benefits of Closing the Gap

Having established ground truth related to predictive coverage models and received signal, it becomes possible to conduct a number of what-if analyses. In particular, one could better understand:

1. Who is most vulnerable in terms of cellular service, both now and during emergency situations?
2. What does the loss of one (or more) antennae do to the coverage? How critical is each tower? And to whom?
3. How would the placement of additional antennae help to close a coverage gap? Where should additional emergency antennae be placed?

Having authoritative maps would inform a variety of public safety and/or infrastructure recovery and investment decisions for Emergency Support Function (ESF)-2, i.e., communications. This report demonstrates that closing this gap is both possible and prudent.

6 Appendix

6.1 Tower Locations and Heights Used

St. Thomas and St. John

ID	Name	Height (Meters)	Latitude	Longitude
STT-1	Towers Top Investment	21.1	18.344561	-65.0255
STT-2	Tower Drive	7.3	18.356667	-64.972222
STT-3	Bureau of Information Technology	23.6	18.356831	-64.97
STT-4	AT&T Mobility	11.0	18.342419	-64.9606
STT-5	Government of the Virgin Islands	29.3	18.35445	-64.9448
STT-6	Broad Band VI	47.1	18.335389	-64.9432
STT-7	Thomas Faley	27.6	18.344439	-64.9214
STT-8	SBA tower	32.7	18.34895	-64.9015
STT-9	Insite Towers LLC	11.4	18.347519	-64.883
STT-10	Second Landfill Tower	5.0	18.308121	-64.878257
STT-11	Choice Communication (Landfill)	17.9	18.307989	-64.878
STT-12	Benners Hill	41.5	18.328333	-64.859167
STJ-1	Lind Point	2.5	18.335098	-64.794324
STJ-2	Bethany	5.6	18.330446	-64.785283
STJ-3	Susannaberg	11.4	18.341522	-64.775562
STJ-4	Susannaberg (Mobile)	18.3	18.341466	-64.775315
STJ-5	Bordeaux	45.0	18.335641	-64.72602
STJ-6	Coral Bay	11.3	18.348515	-64.711569

Table 1. Tower locations and heights on STT and STJ used for this study.

St. Croix

ID	Name	Height (Meters)	Latitude	Longitude
STX-1	Sandy Pt	57.3	17.6953	-64.8825
STX-2	St.George	26.2	17.7195	-64.8564
STX-3	Upper Love	14.6	17.7297	-64.8192
STX-4	Cane Bay Tower	17.0	17.7756	-64.8064
STX-5	Blue Mountain 4	13.2	17.7547	-64.7994
STX-6	Fredensborg	7.2	17.7201	-64.7713
STX-7	Mary's Fancy	16.2	17.7476	-64.76389
STX-8	Sunny Isle	51.6	17.7219	-64.7546
STX-9	Sion Farm	14.2	17.73	-64.7431
STX-10	Work/Rest	12.8	17.723	-64.7276
STX-11	Lil Princess	46.2	17.7447	-64.7269
STX-12	Christensted	3.1	17.7447	-64.705
STX-13	Recovery	41.9	17.7339	-64.6989
STX-14	Altona Lagoon	5.8	17.7456	-64.6923
STX-15	Cheeseburger	16.0	17.75518	-64.66267
STX-16	South Gate	17.3	17.7525	-64.6617
STX-17	Cotton Valley	30.4	17.7413	-64.6249

Table 2. Tower locations and heights on STX used for this study.

6.2 Coverage Maps by Tower

We include model-based predictions of coverage for each of the known tower locations. Each map displays the coverage predicted from a single tower only.

- St. Thomas: STT-1 to STT-12
- St. John: STJ-1 to STJ-6
- St. Croix: STX-1 to STX-17

STT-1

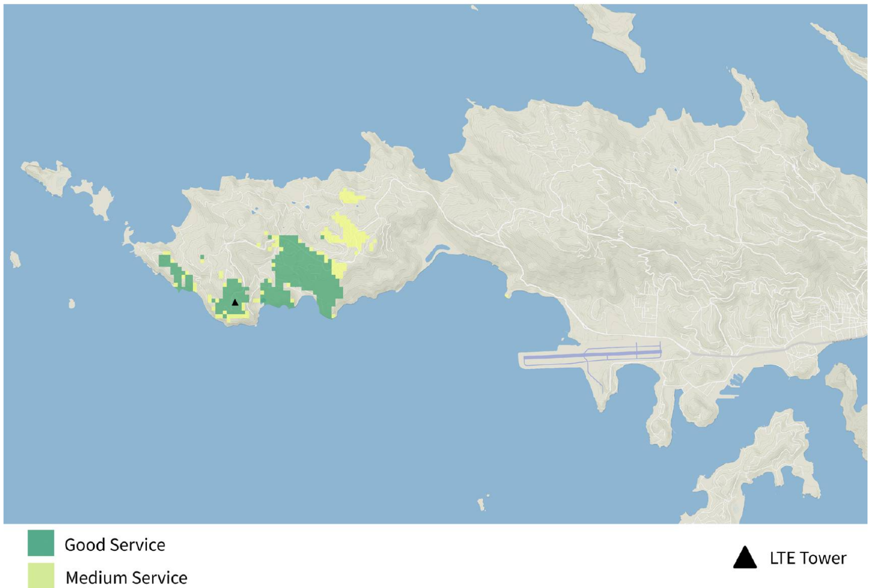

Figure 22. STT-1 TIREM Generated LTE Coverage.

STT-2

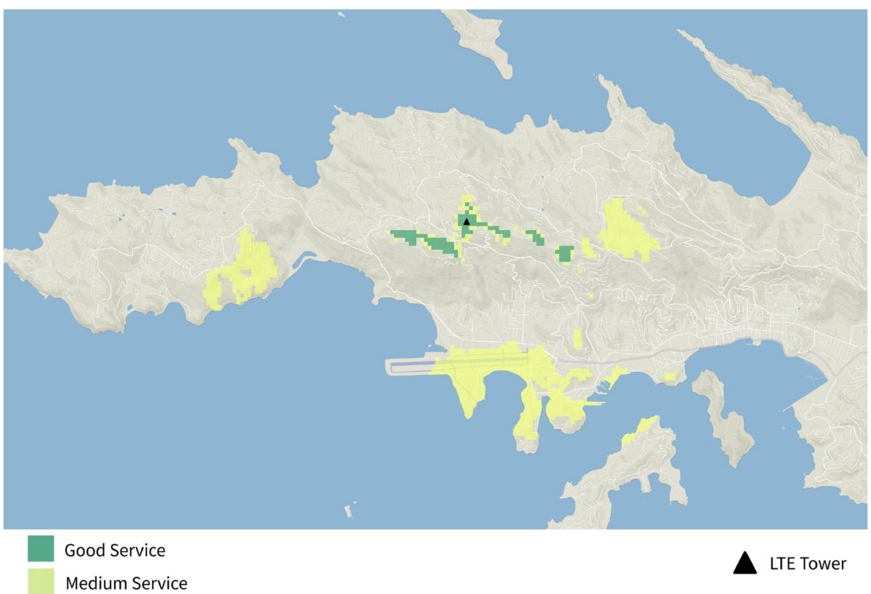

Figure 23. STT-2 TIREM Generated LTE Coverage.

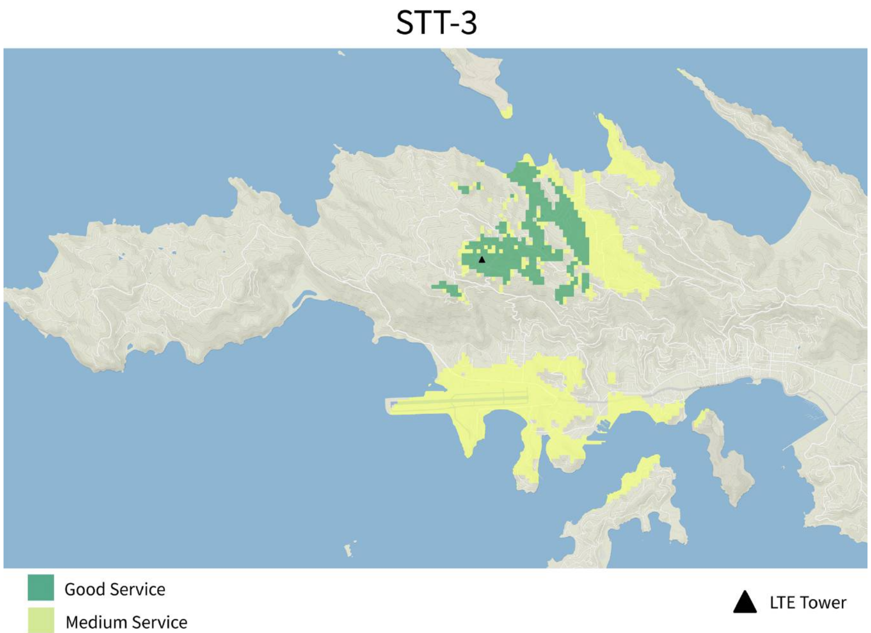

Figure 24. STT-3 TIREM Generated LTE Coverage.

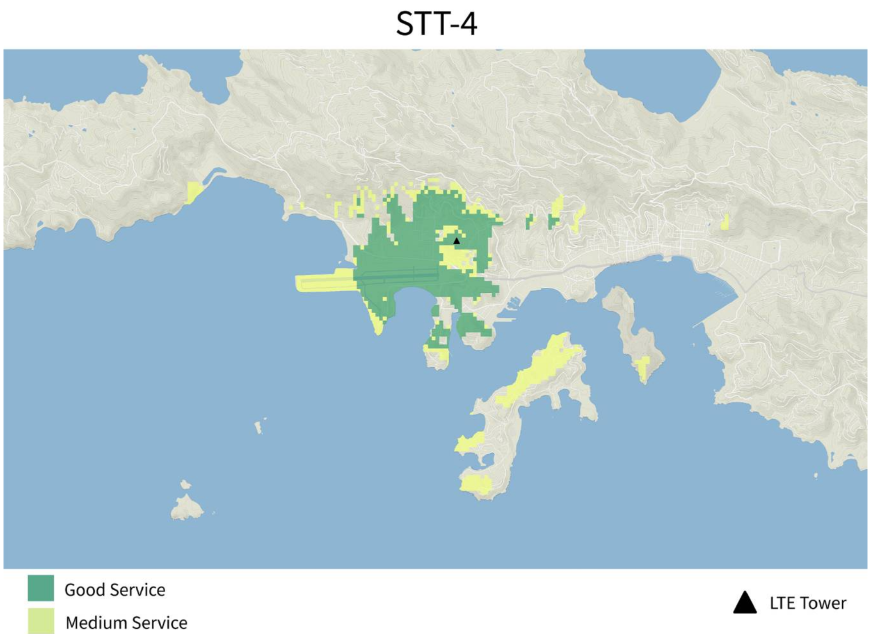

Figure 25. STT-4 TIREM Generated LTE Coverage.

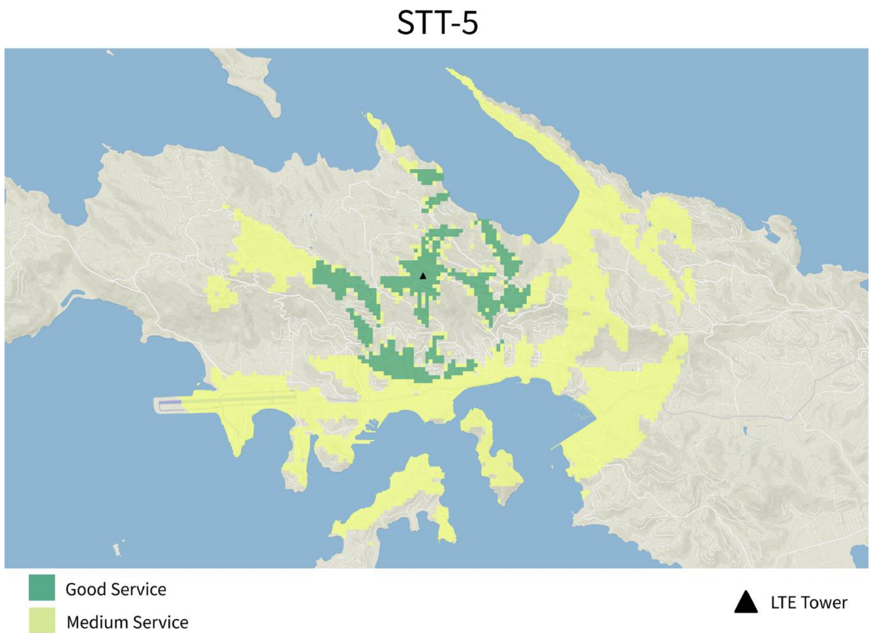

Figure 26. STT-5 TIREM Generated LTE Coverage.

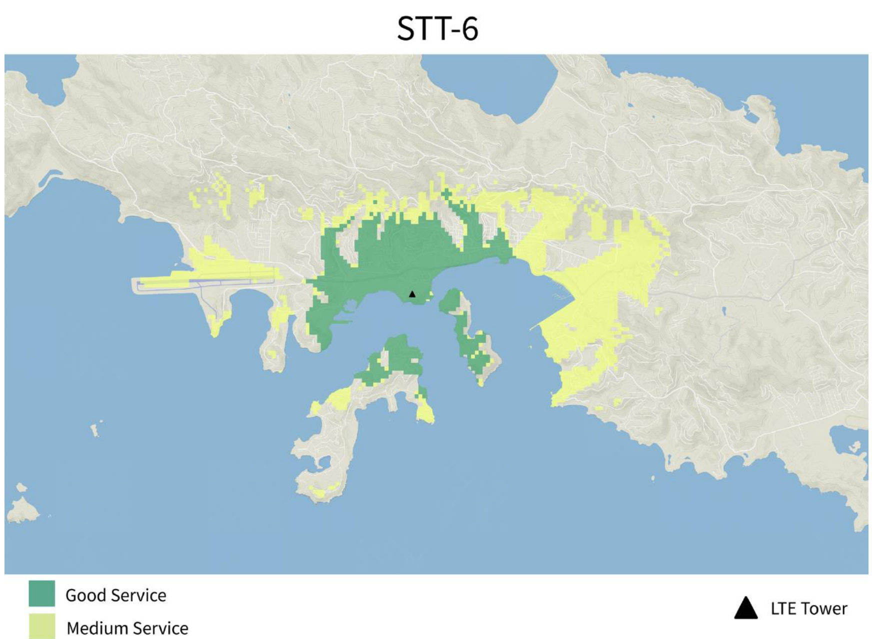

Figure 27. STT-6 TIREM Generated LTE Coverage.

STT-7

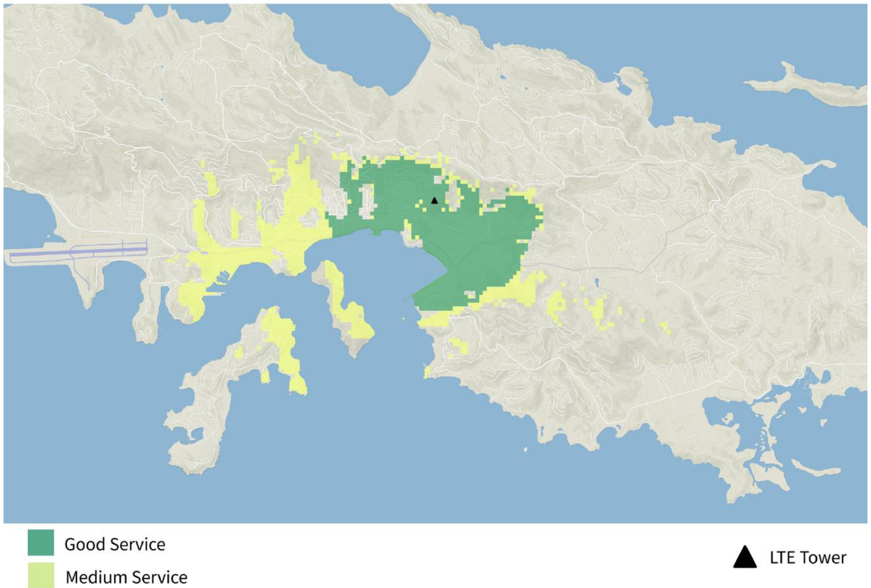

Figure 28. STT-7 TIREM Generated LTE Coverage.

STT-8

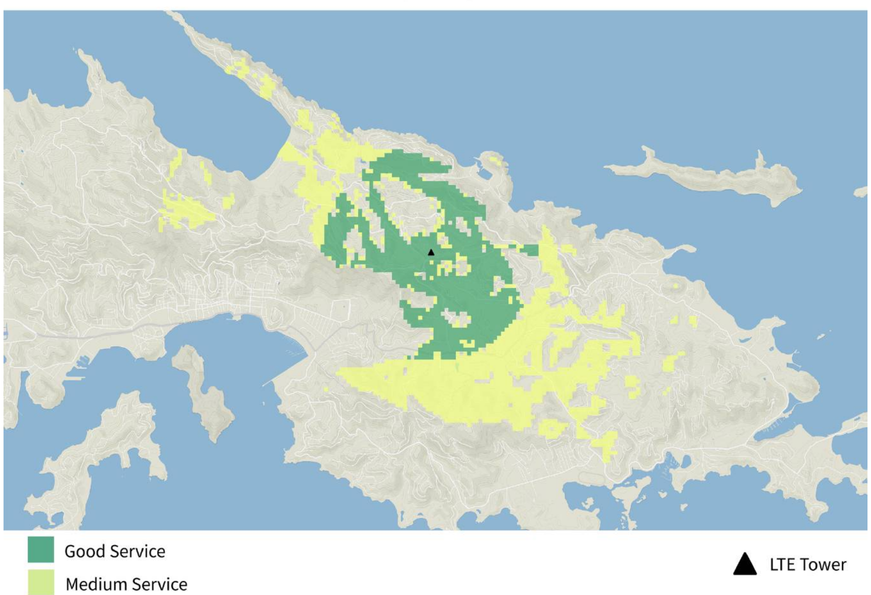

Figure 29. STT-8 TIREM Generated LTE Coverage.

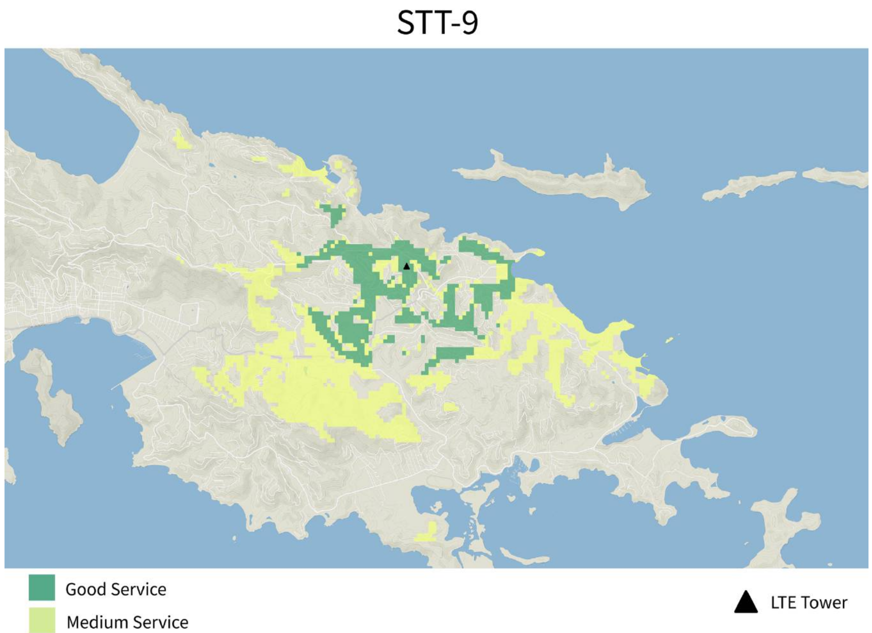

Figure 30. STT-9 TIREM Generated LTE Coverage.

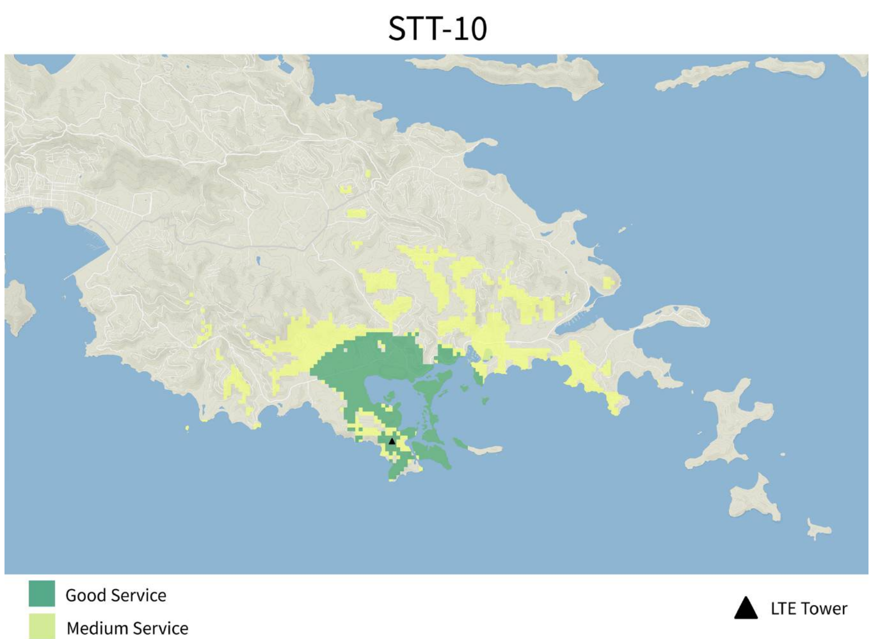

Figure 31. STT-10 TIREM Generated LTE Coverage.

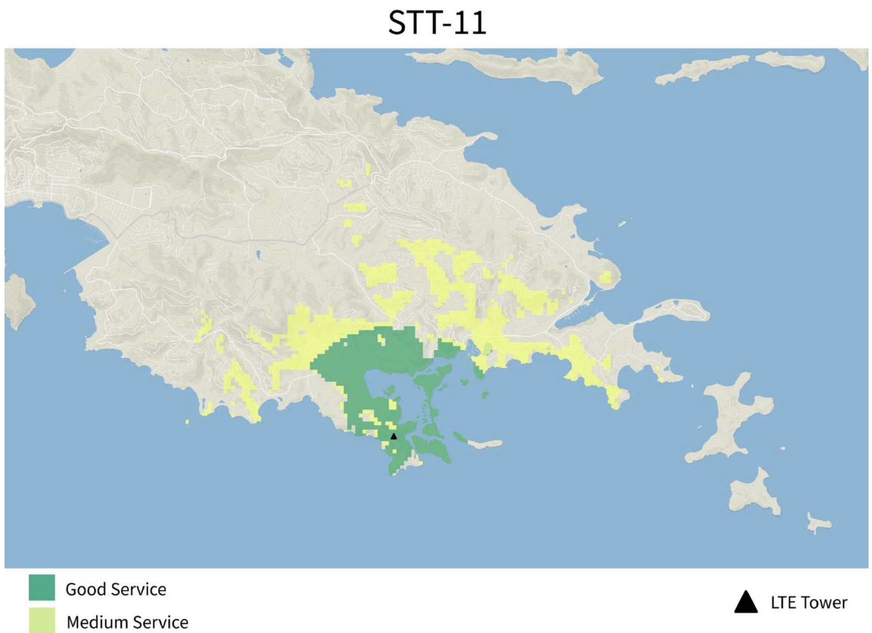

Figure 32. STT-11 TIREM Generated LTE Coverage.

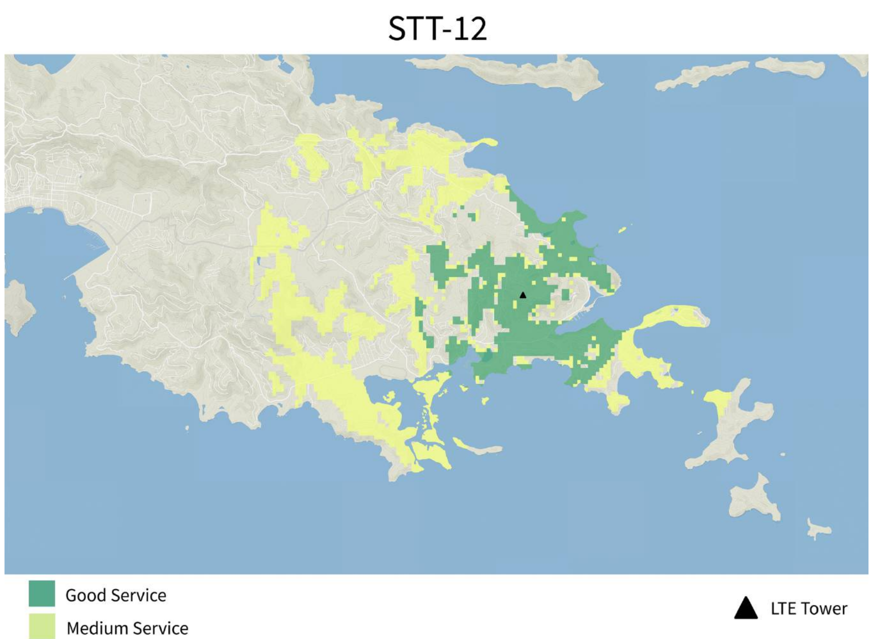

Figure 33. STT-12 TIREM Generated LTE Coverage.

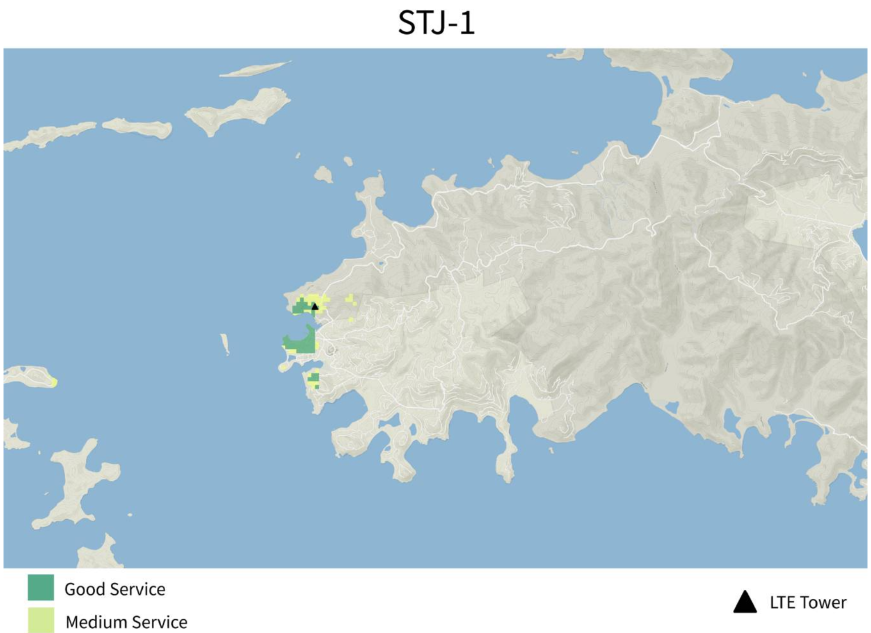

Figure 34. STJ-1 TIREM Generated LTE Coverage.

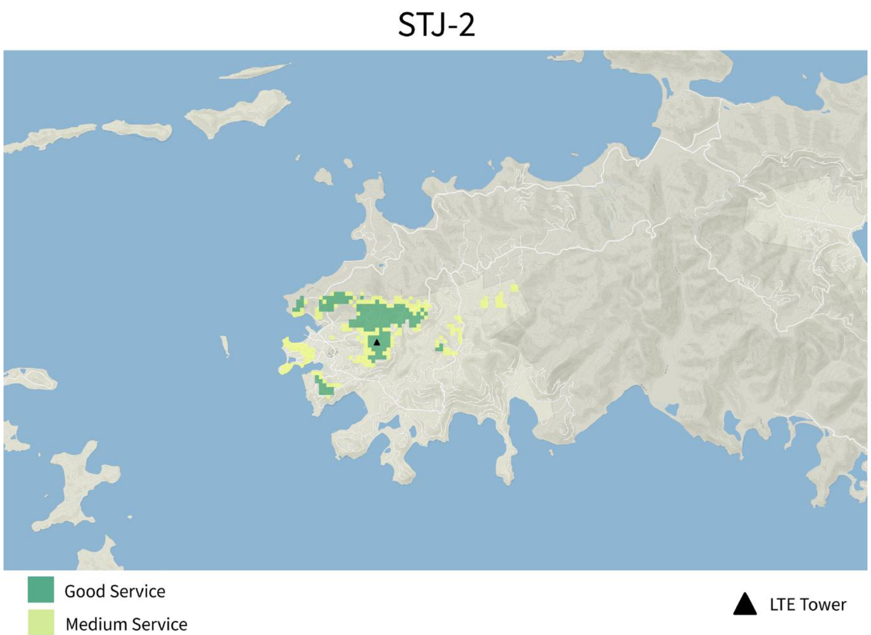

Figure 35. STJ-2 TIREM Generated LTE Coverage.

STJ-3

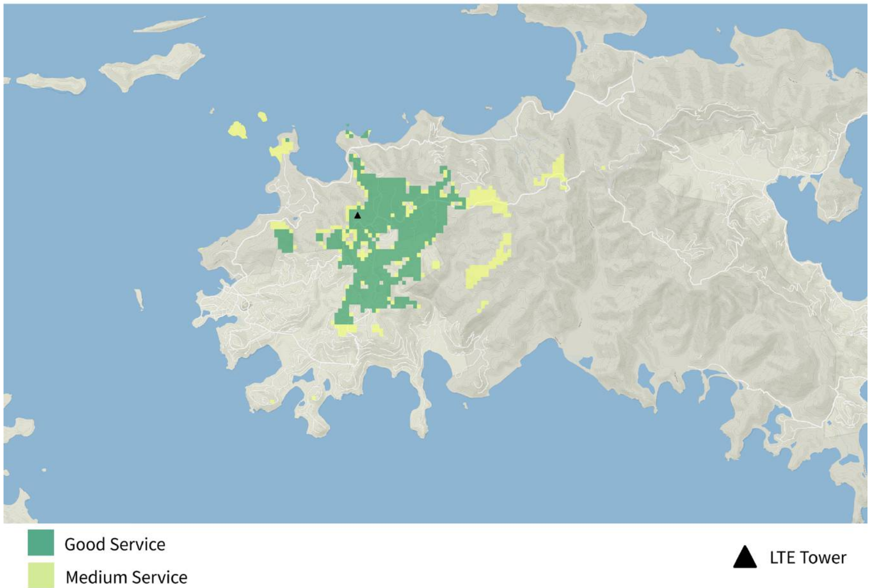

Figure 36. STJ-3 TIREM Generated LTE Coverage.

STJ-4

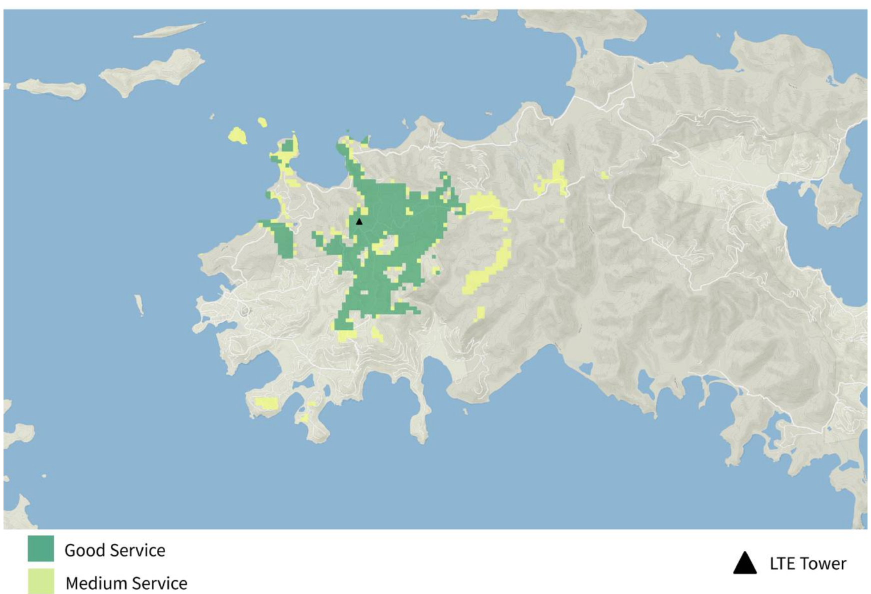

Figure 37. STJ-4 TIREM Generated LTE Coverage.

STJ-5

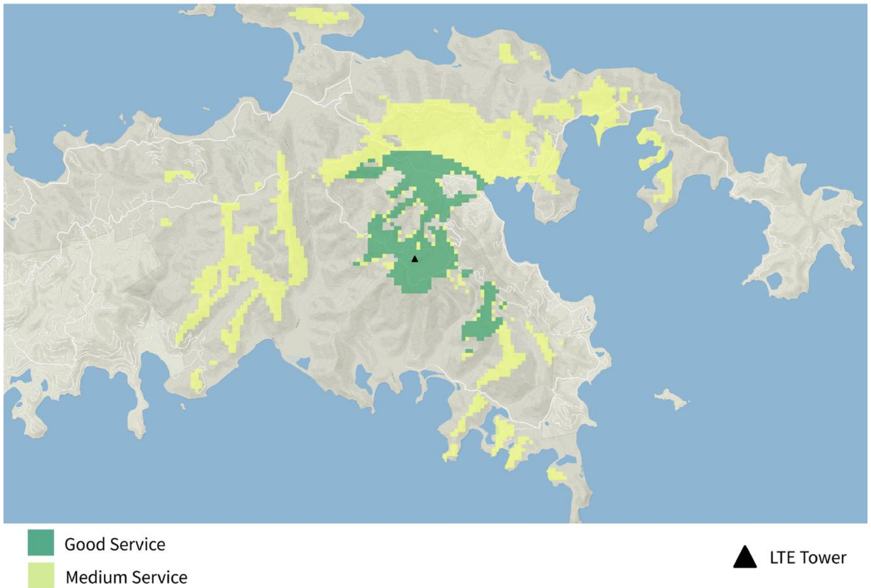

Figure 38. STJ-5 TIREM Generated LTE Coverage.

STJ-6

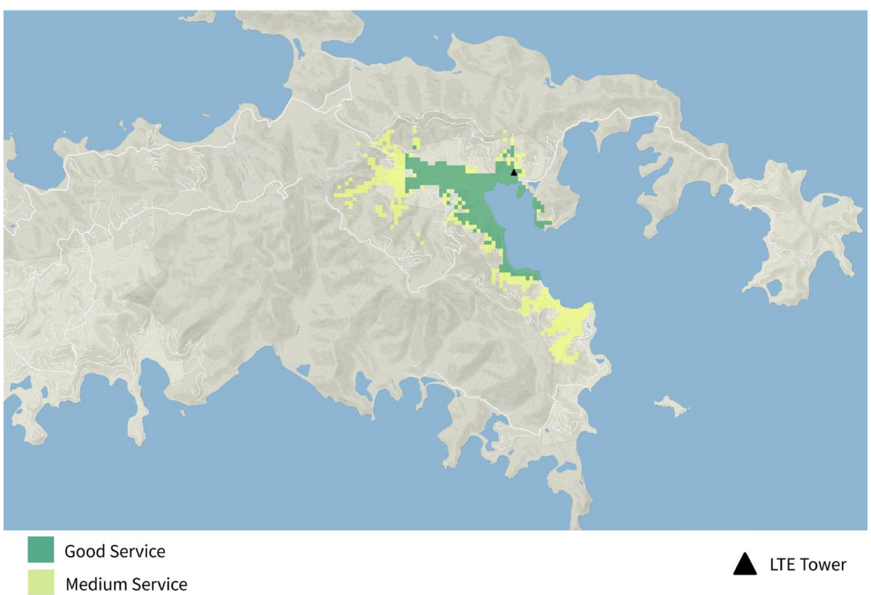

Figure 39. STJ-6 TIREM Generated LTE Coverage.

STX-1

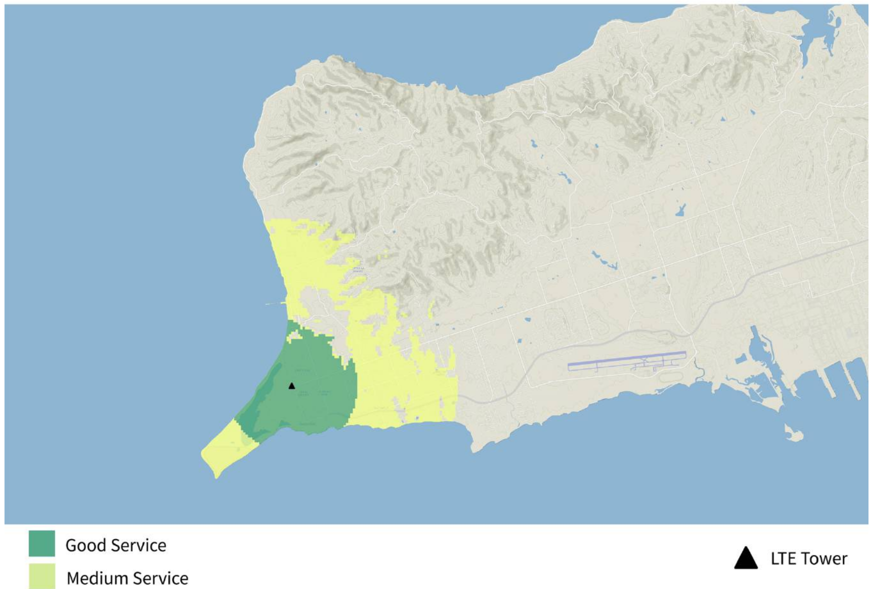

Figure 40. STX-1 TIREM Generated LTE Coverage.

STX-2

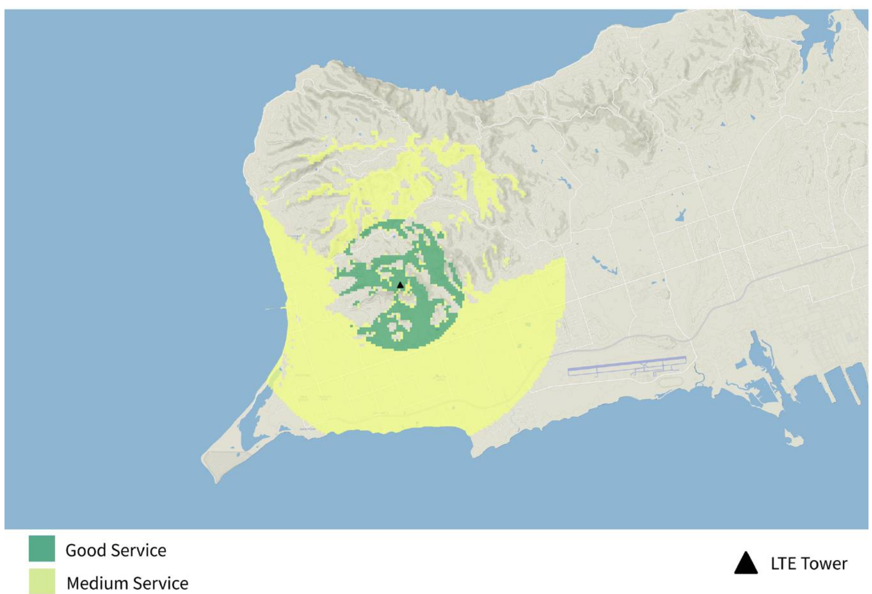

Figure 41. STX-2 TIREM Generated LTE Coverage.

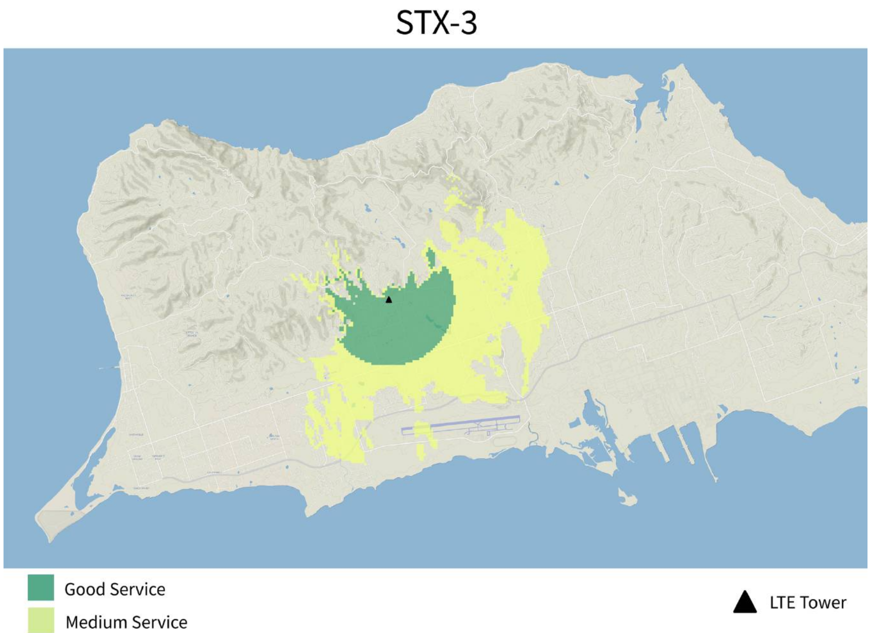

Figure 42. STX-3 TIREM Generated LTE Coverage.

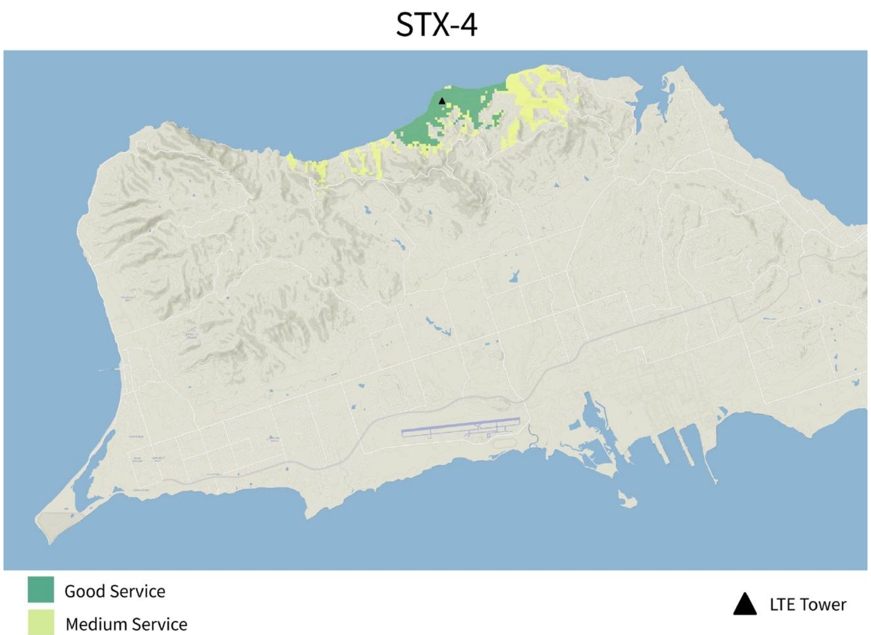

Figure 43. STX-4 TIREM Generated LTE Coverage.

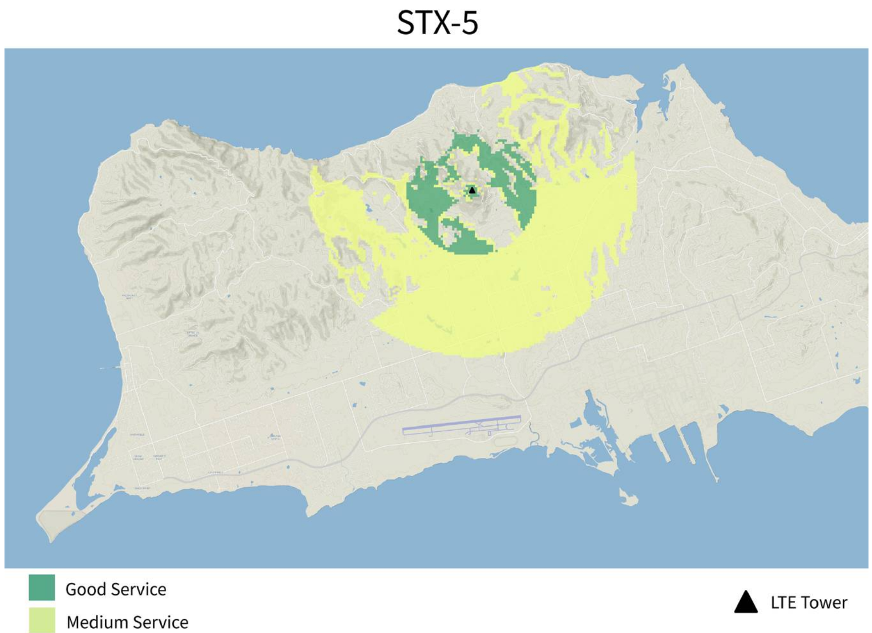

Figure 44. STX-5 TIREM Generated LTE Coverage.

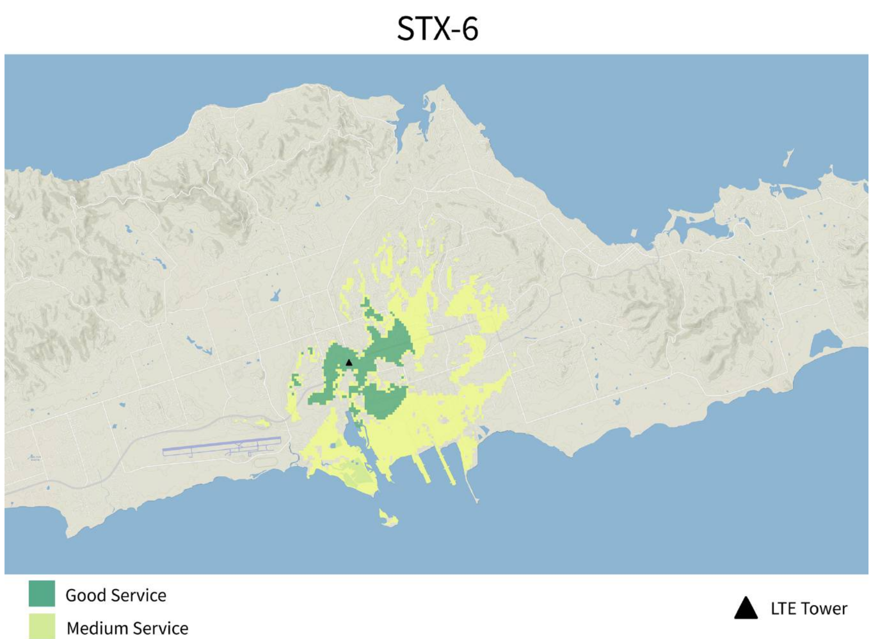

Figure 45. STX-6 TIREM Generated LTE Coverage.

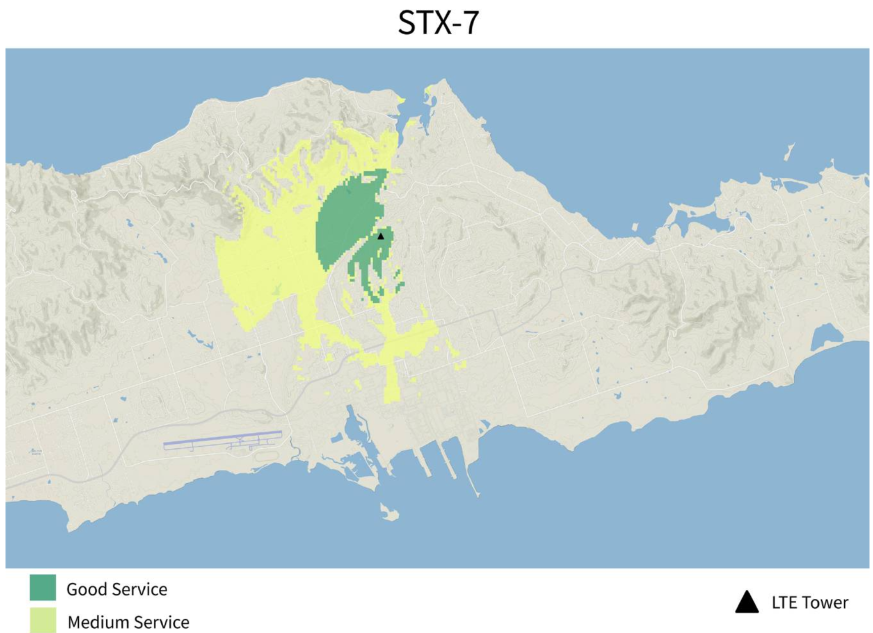

Figure 46. STX-7 TIREM Generated LTE Coverage.

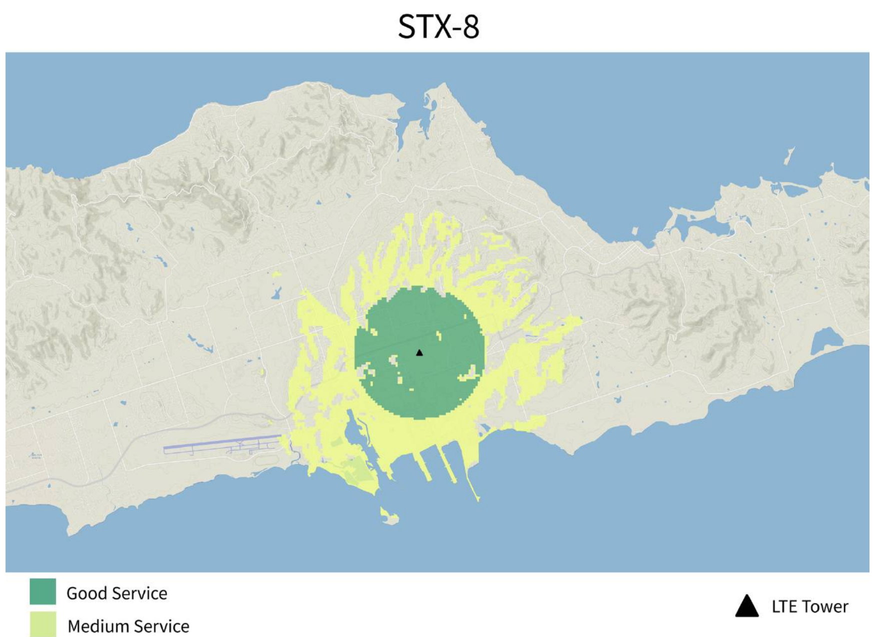

Figure 47. STX-8 TIREM Generated LTE Coverage.

STX-9

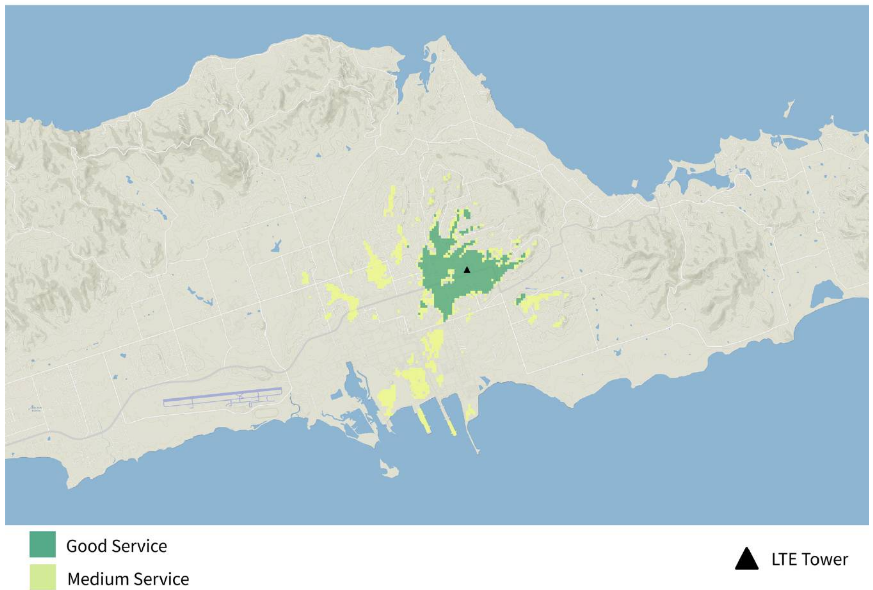

Figure 48. STX-9 TIREM Generated LTE Coverage.

STX-10

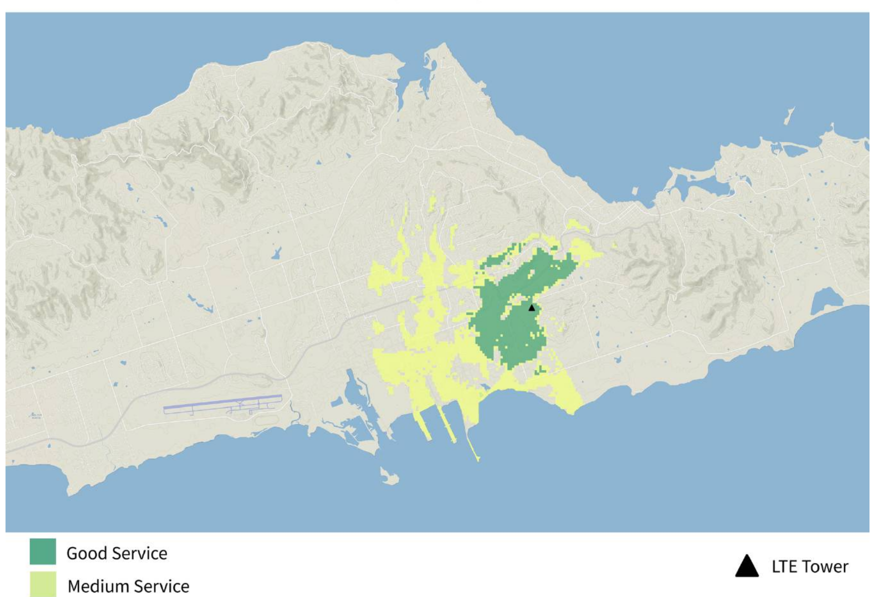

Figure 49. STX-10 TIREM Generated LTE Coverage.

STX-11

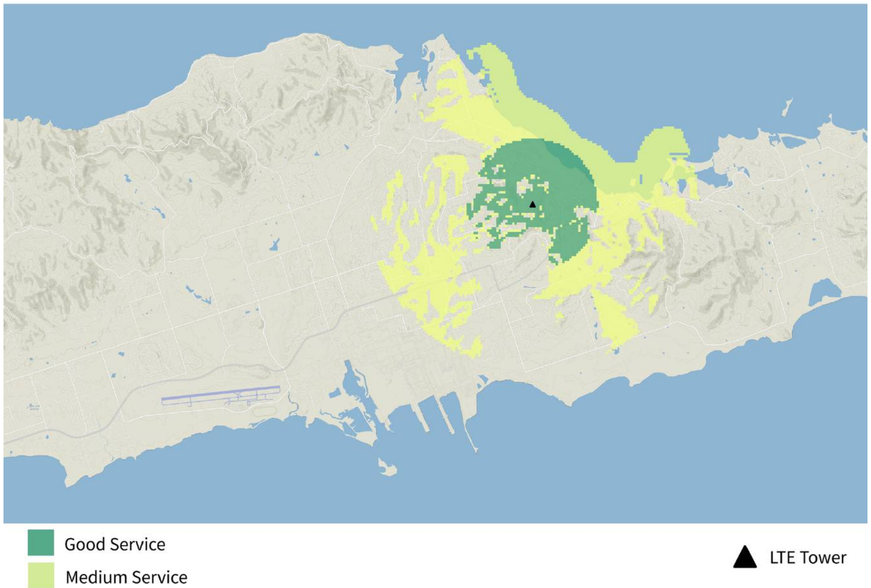

Figure 50. STX-11 TIREM Generated LTE Coverage.

STX-12

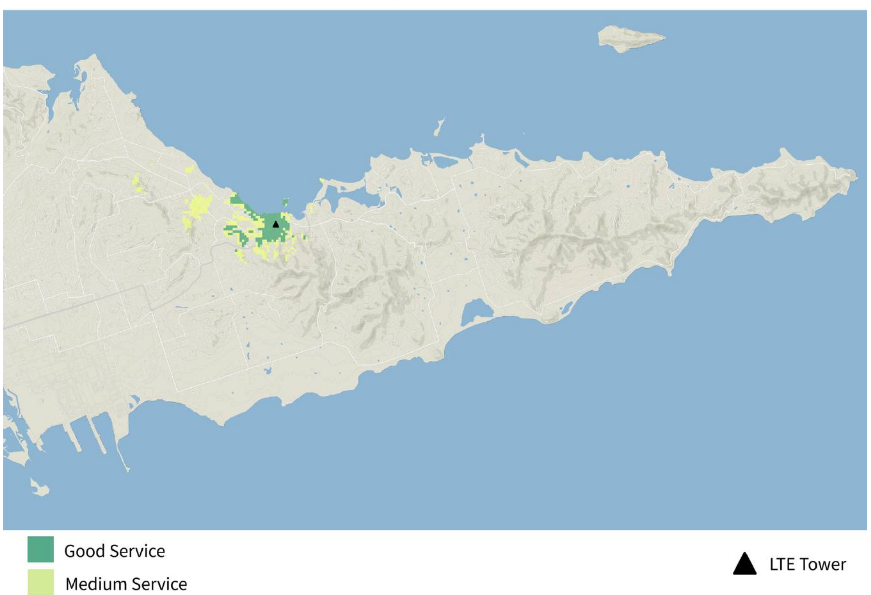

Figure 51. STX-12 TIREM Generated LTE Coverage.

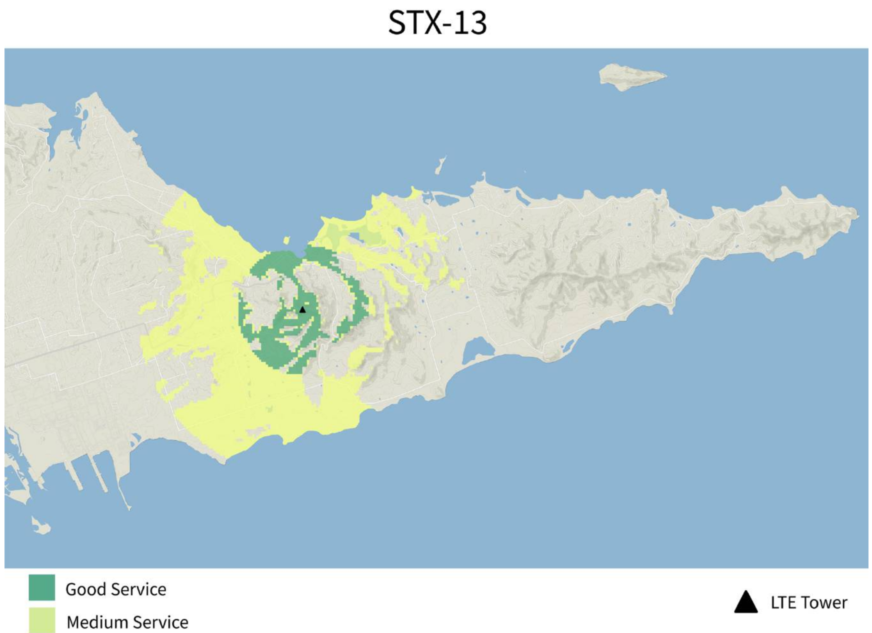

Figure 52. STX-13 TIREM Generated LTE Coverage.

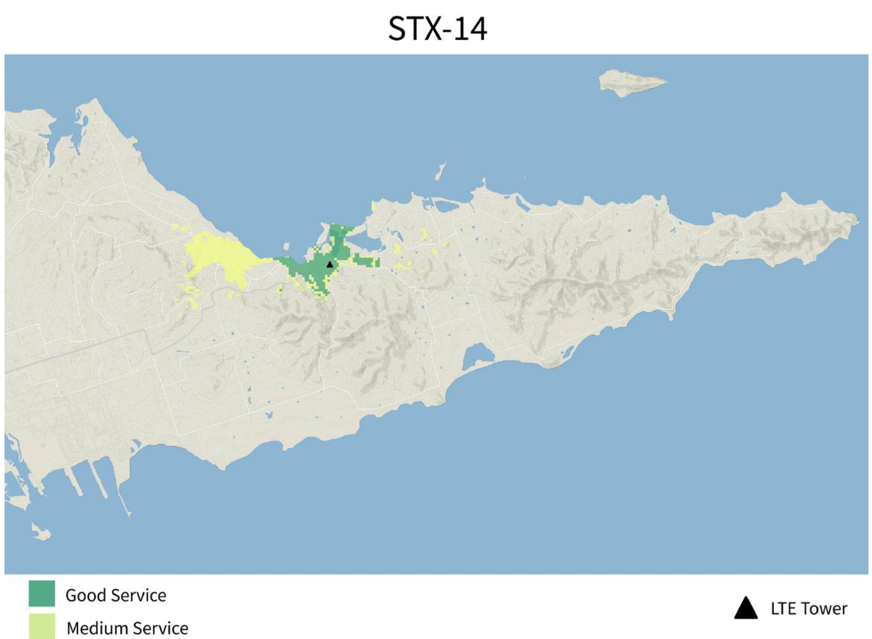

Figure 53. STX-14 TIREM Generated LTE Coverage.

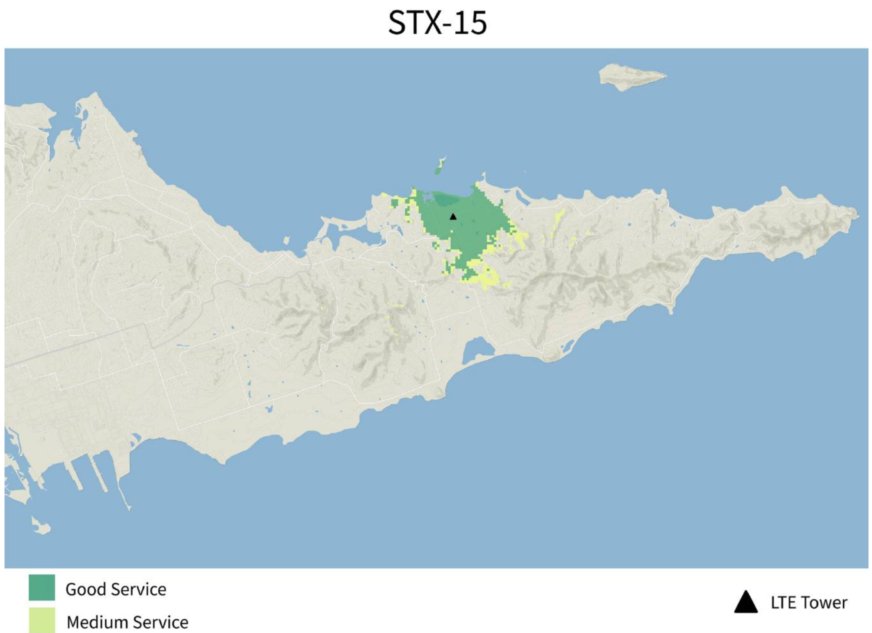

Figure 54. STX-15 TIREM Generated LTE Coverage.

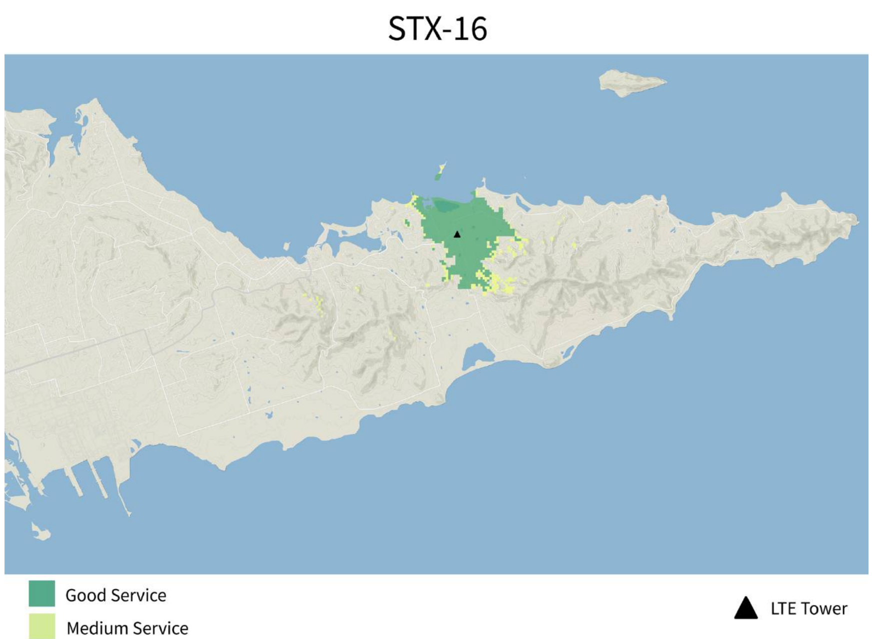

Figure 55. STX-16 TIREM Generated LTE Coverage.

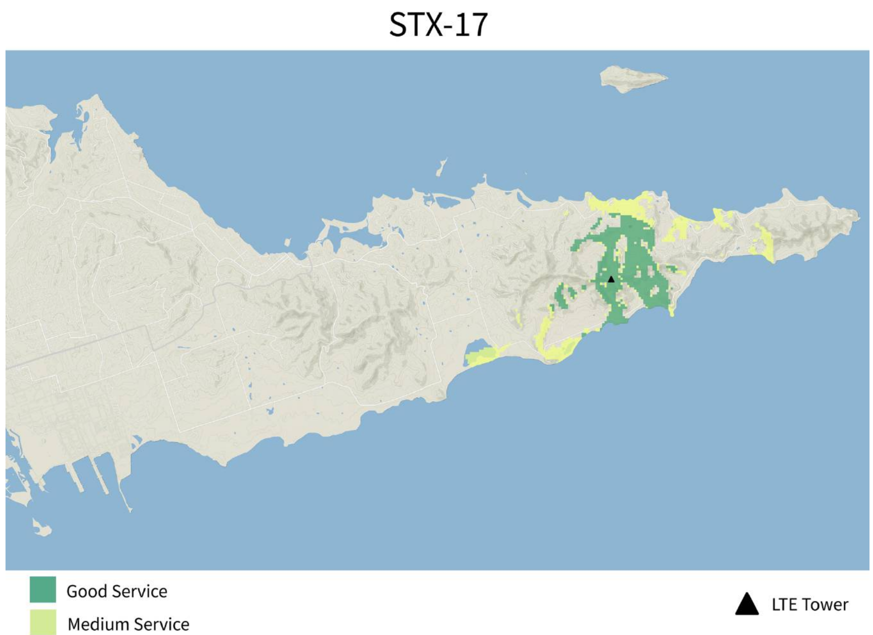

Figure 56. STX-17 TIREM Generated LTE Coverage.

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