State of Vermont

FirstNet Coverage Test Report

TELEVATE

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Executive Summary

The State of Vermont authorized coverage and performance testing of the FirstNet wireless broadband network. This comprehensive coverage test was performed using typical smartphones and with cellular industry standard network engineering measurement tools to capture the actual network performance experienced by Public Safety end users. As detailed throughout the report, the test results provide important insight into the variance of network coverage mapping and field validated coverage. Network coverage testing underscores the need for the first responder community to verify and validate the availability and quality of broadband wireless coverage in making the decision to subscribe to the FirstNet service, and for confirming and documenting coverage reliability for current FirstNet subscribers. Predictable communication is essential for public safety to support their respective agency response requirements; however, FirstNet's coverage maps do not provide sufficient network coverage and performance assurance for public safety.

Over the course of the 1,200 miles driven along pre-determined routes, an equivalent of 326 square miles of area was tested. A variety of FirstNet 4G-LTE and other wireless technology data was captured to best represent the depth and breadth of network coverage and performance. This data is carefully detailed and analyzed within the report and includes a variety of findings and recommendations to assist State of Vermont Public Safety evaluators of, and subscribers to, FirstNet.

One of the most critical findings of the coverage testing that should be of mutual interest to the Vermont public safety community and FirstNet, is that the broadband radio frequency (RF) signal strengths and quality of service within the test areas detailed in the FirstNet coverage maps available at www.firstnet.com tend to overestimate the actual coverage delivered to standard commercial smartphones that will be used by Public Safety to communicate over FirstNet. The ability for Public Safety to reference coverage maps that accurately reflect actual coverage in various coverage environments (in-building, in-vehicle, on-street) is a common expectation that they now have with their land mobile radio (LMR) networks. First Responders and the communities they support will be best served if Public Safety has accurate and consistent coverage performance information from FirstNet.

Coverage mapping has a much higher level of urgency for Public Safety than for the general commercial network subscriber and we encourage FirstNet to investigate and implement corrective and innovative activities to improve the quality of predicted, measured and map-illustrated coverage. Certainly, the quality and accuracy of the maps can be regularly enhanced through crowd sourced data delivered directly from Public Safety over the end user devices they use to communicate. More comprehensive coverage propagation and prediction tools and methods can also be incorporated along with a variety of best practices promoted throughout the wireless broadband communications industry.

The following table summarizes the results for each route and the key performance indicators of the FirstNet service.

Table 1: Summary of FirstNet Drive Test Coverage Statistics

	Route 1	Route 2	Route 3	Route 4
Equivalent Area (square miles)[1]	120	88	77	41
Good Service Availability (% total area)[2]	44	52	58	56
Spotty Service (% total area)[3]	28	20	25	18
No/Limited Service (% total area)[4]	28	28	17	26
LTE Technology Available (% total area)	51	65	85	83
Ping Performance (% area served)[5]	42	61	76	74
Target Download Performance (% area served)[6]	44	62	83	90
Target Upload Performance (% area served)[7]	32	59	75	86

The FirstNet wireless broadband service can provide important next generation communications capabilities for Public Safety, and there are various actions that FirstNet can undertake to improve the detail and reliability of the network coverage prediction and propagation mapping. Additional information regarding the various on-street, in-vehicle and in-building coverage service environments should be added to the maps. The coverage reliability of the mapping can also be improved by incorporating drive test data to improve the reliability of the coverage prediction modeling. Higher resolution maps can also be provided, and the coverage predictions can be displayed based on smaller grid sizing. These and other actions by the FirstNet system engineers would provide operational benefits to Public Safety and to the communities they serve.

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[1] The sum total of the area of all grids traversed on the route.
[2] Percentage of all grids per route that have service availability of 90% or higher
[3] Percentage of all grids per route that have service availability between 10% and 90%
[4] Percentage of all grids per route that have service availability of 10% or less
[5] Percentage of all grids that achieve an average ping loss of less than 10%
[6] Percentage of all grids that achieve average download speed of 768 kbps or higher. Note some users might expect download speeds of 5,000 kbps (5 megabits per second) for broadband service.
[7] Percentage of all grids that achieve average upload speed of 256 kbps or higher. Note some users might expect upload speeds of 2,000 kbps (2 megabits per second) for broadband service.

Introduction

On behalf of its statewide Public Safety stakeholder community, the State of Vermont retained Televate, LLC, a Public Safety communications and information technology firm with extensive public safety wireless broadband experience and capabilities, to conduct an independent field study of the Nationwide Public Safety Broadband Network (NPSBN), also referred to as the FirstNet – Built with AT&T (“FirstNet”) commercial broadband cellular network. This report describes the coverage testing methodology undertaken and presents the results of the network field measurements and data collection conducted to identify and document FirstNet coverage capabilities and gaps within specific geographic areas of Vermont.

Coverage validation is critical to the public safety community. First responders rely on mission critical voice and data communications to support public safety objectives to serve and protect their communities and to ensure their own wellbeing. Public safety must have greater assurance that FirstNet coverage depictions are accurate. While there are arguably vital justifications and incentives for public safety to subscribe to the FirstNet service, nothing is more important to the public safety community than the delivery of reliable network coverage and performance over FirstNet.

The FirstNet coverage testing was performed within geographic regions determined by members of the local Public Safety community that operate FirstNet’s Initial Operational Capability (IOC 1 & 2) areas. As verified within the coverage test results and further illustrated in coverage maps and other graphics incorporated into the report, the broadband network coverage maps as depicted by AT&T do not accurately depict the actual coverage measured and documented within various areas of the drive test study environment. The broadband radio frequency (RF) signal strengths and quality of service within the test areas that are shown in FirstNet’s coverage maps (available at www.firstnet.com) tend to overestimate the actual coverage delivered to the standard commercial smartphones that Public Safety will use to communicate. FirstNet coverage maps *do* reflect accurate coverage in some geographic areas; however, the FirstNet network did not provide reliable coverage in a significant percentage of the test areas where the coverage maps indicated service.

Although FirstNet does briefly mention the methodology in which the projected coverage was determined and further qualifies the potential inaccuracy of the coverage maps through a broad explanation, the actual coverage available to users under normal usage scenarios was determined to be less than depicted. As the test results will illustrate, FirstNet coverage is insufficient in various coverage test route service environments where public safety requires reliable service delivery.

Description of Test Environment

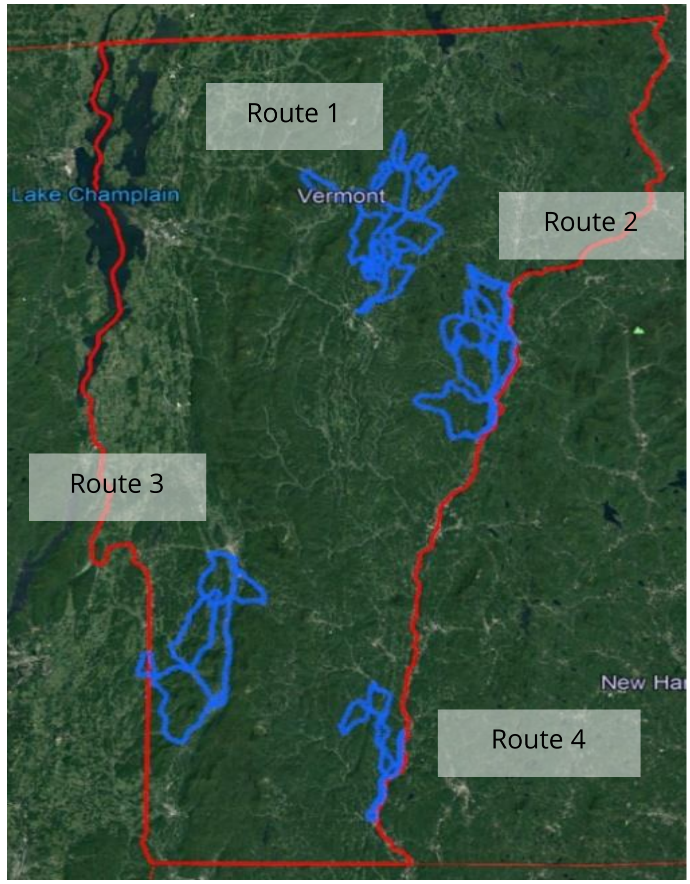

Figure 1: Vermont Drive Test Routes

In preparation for the FirstNet coverage testing, vehicle drive test routes were created based on local Vermont first responder agency's reports of service issues in areas where FirstNet data represented that coverage was available. The test coverage areas conformed with the FirstNet IOC 1 & 2 coverage maps as reported by AT&T to the State of Vermont. Four (4) distinct drive test areas were derived from this information and, working with the State and local agencies, drive routes were identified to traverse key highway routes, populations centers and various points of interest within the test areas, along with secondary roads of interest to the local responders. Considerable time was expended preparing the maps and coordinating with State and local public safety agencies to ensure accuracy and relevance to Vermont's public safety agencies operating within the test coverage areas.

The drive tests were performed between September and October 2019, well before the start of the fall season and the annual shedding of leaves from deciduous trees and plants.

Therefore, the timing of the test represents the typical FirstNet service that public safety subscribers can expect from the current constellation of cell sites in the areas identified.[8] Of additional relevance to the coverage analysis, the weather conditions were clear throughout the drive testing timeframe. Figure 1 details the four tested areas with the pre-planned drive routes indicated in blue.

The drive test team employed Televate's Pinpoint™ software application to collect data on the coverage and performance of the FirstNet network. The Pinpoint application operates on most Android commercial smartphone devices and therefore, the coverage data reported from these typical Public Safety subscriber devices provide the best representation of the actual FirstNet coverage and performance experienced. Quantifying the Public Safety user experience with typical commercial devices is essential for providing accurate information regarding the broadband data communications coverage and user expectations. The State's first responders rely on the availability

[8] Please note the seasonal loss deciduous tree leaves will likely cause coverage improvements within the test areas. However, the determination and testing of reliable FirstNet coverage must be based on full leaf seasons.

of critical broadband data and communications and need to have reliable insight into where and how FirstNet will perform. Prior to each drive test, Televate calibrated the Pinpoint application with signal testing and data processing solutions commonly used by the commercial cellular community. Televate employed the Infovista TEMS[9] measurement system combined with PCTel's MxFlex scanning receiver[10] to collect signals received from a roof-mounted antenna.[11] This test configuration was also considered to better mimic the AT&T's outdoor coverage maps. With an underlying goal of validating the FirstNet coverage maps, which are based on outdoor coverage to what appears to be a smartphone, and to provide the Vermont Public Safety community with better insight into the actual coverage experience, Televate conducted coverage with indoor smartphone devices that were then calibrated to outdoor coverage.[12] Please see Appendices A and B for additional insights into how the Pinpoint calibration and the results of the commercial measurement tools were integrated.

Pinpoint is a crowd-sourced application that automatically collects over 50 unique data elements—including service availability, device location, signal strength, signal quality, cell information, network latency and data speeds—then uploads (in the uplink direction) the test results onto a secure cloud-based data server (see www.televate.com/pinpoint for additional information). The frequency of data collection points varies depending on the speed of the vehicle, typically, every 5 to 60 seconds, with the later coverage measurement being performed when the vehicle is stopped or very slowly moving.

In support of the coverage testing, the State of Vermont provided two (2) identical Samsung S9+ smartphones, with FirstNet subscriptions. The in-vehicles devices were mounted on the dashboard of the vehicle. The dashboard mounting provided the most optimal FirstNet in-vehicles coverage scenario in attempting to conduct an unbiased coverage test; however, it is expected that Public Safety, similar to typical commercial users, will have their smartphone in pants pockets, the vehicle cupholder, on the car seat, in pocketbooks, and in other locations within the vehicles that will not typically provide the reliability of coverage from dashboard-mounted devices.

The test device details are as follows:

Wireless Carrier	Device Model	Pinpoint Version	Operating System
AT&T/FirstNet	Samsung Galaxy S9+	0.9.97	Android 9.0

[9] https://www.infovista.com/resources/tems/the-evolution-of-the-tems-network-testing-portfolio
[10] https://www.pctel.com/wp-content/uploads/2017/09/SeeGull-MXflex-Brochure.pdf
[11] Televate has considerable experience designing, implementing, testing and operating 4G-LTE wireless networks incorporating Band 14. Televate is and has provided these services to the Public Safety Early Builders under the Broadband Technology Opportunities Program (BTOP) for the Los Angeles Regional Interoperable Communications Network Authority (LA-RICS), the State of New Jersey and the State of New Mexico.
[12] Televate highly recommends that FirstNet depict maps illustrating in-vehicle smartphone coverage, which is likely to be the most common usage scenario for Public Safety.

The Pinpoint application was set to run continuously in background mode, automatically capturing data without user intervention. The location of the device is determined based on its connectivity to the Global Positioning Satellite (GPS) network. One of the smartphones was placed in throughput testing mode for each route. In throughput testing mode, the application attempts to transfer as much data as the network will accommodate from the device to the Internet (upload) and from the Internet to the device (download). The data collected by these devices, across the four drive test areas, has been assessed, analyzed and graphically represented within the maps and statistics of this report.

Pinpoint post-processing software aggregates the raw data points into variable grid dimensions. For the Vermont FirstNet coverage tests, the measurement data was process based on quarter mile hexagonal grids to present "area based" test results. If multiple data samples are collected in a grid, which is quite common based on the vehicle speed, the data is aggregated to represent the average performance in the grid. This approach of capturing multiple tests points, summing and averaging the radio frequency (RF) signal data on both the uplink and down link RF signals is a common wireless industry network testing methodology. This collection of multiple data samples within a geographic gridded area provides a more realistic representation of the cellular network's performance and the associated subscriber experience.

Test Results

During the drive test period, more than 1,000 road miles in Vermont were driven over a period of six days. Hundreds of thousands of FirstNet cellular network test points were collected over this coverage testing timeframe. The RF uplink and downlink signal data were then processed to aggregate the measurements over a total of 3,699 distinct hexagonal grids representing roughly 998 square miles. The following sections provide a high-level view of coverage signal and performance quality, strengths, gaps and other service degradation findings for the data collected.

Service Availability

The Service Availability measurements reflect the percentage of RF signal test samples collected within a given geographic test grid when the device is either "Connected" or is "Unavailable" ("no service" or "out of service") to the FirstNet broadband wireless network. Network availability is fundamental for the delivery of reliable FirstNet broadband data communications and is an important network coverage measurement variable. When performing cellular network coverage data collection, the Pinpoint application routinely collects Service Availability data samples including when the service state changes from "unavailable to available," from "available to unavailable" and reports availability from 0-to-100%.

In a grid where there is 100% service availability, the device was connected to the FirstNet network 100% of the time and is highly capable of sending and receiving data. In a grid with 0% service availability, the device was not connected to the cell network; however, the device would have been connected to the GPS satellite unless the view to the satellite was blocked by obstacles local to the device. In the presence of GPS data, Pinpoint records the device location data even if the device is not connected to the cellular network. Once the device reconnects to the network, the stored recorded data downloads to the Pinpoint server. This capability facilitates the ability to illustrate where the network is not "Available."

The following maps and graphics illustrate the Service Availability test results from within the four FirstNet coverage test areas. As detailed below, there are distinct tests areas with highly available service and areas with no available service. However, the FirstNet coverage map, when zoomed into the highest map resolution possible on the online map portal indicates that coverage should be available within many of the coverage test service environment where it was not available. The discrepancies between the FirstNet coverage map and field measured coverage results is a source of concerns for public safety that is further assessed below. The variance between the coverage maps and drive test results does provide an opportunity to articulate actionable recommendations that FirstNet could consider for improving the quality and accuracy of the coverage maps. Such observations are documented throughout the Vermont FirstNet coverage report.

Service Availability Overlaid on FirstNet Service Map

The maps in this section illustrate an overlay of the service availability results derived from the Vermont FirstNet coverage measurements with the published FirstNet coverage or area of service.[13] The FirstNet maps were exported directly from the commercially-available FirstNet website (www.firstnet.com). The technical parameters that underpin the FirstNet coverage map and the level of service predicted are not specifically provided other than to say that the maps depict outdoor coverage. FirstNet states that the:

> "*Maps provide a predicted high-level approximation of wireless coverage. There are gaps in coverage that are not shown by this high-level approximation. Actual coverage may differ from map graphics and may be affected by terrain, weather, network changes, foliage, buildings, construction, signal strength, high-usage periods, customer equipment, and other factors.*"

FirstNet network coverage statements, while reasonably meaningful and likely more meaningful to commercial service subscribers who are not using the network to support mission critical communications, are still quite broad and do not provide sufficient clarity for public safety subscribers for making coverage service reliability determinations. In responding to mission critical calls for service, public safety must have greater certainty about their ability to reliably communicate over the FirstNet broadband network. As currently structured, the statement is also very difficult to interpret for the average FirstNet network subscriber. The maps do not accurately depict service availability in all environments and tend to be too generous in depicting coverage. Coverage is overestimated in various geographies and as such can be a source of discontent for perspective subscribers.

The FirstNet coverage testing identified numerous locations where the FirstNet coverage maps did not accurately illustrate the lack of coverage. The coverage maps are generally accurate in many tested areas; however, there are too many variations between the maps and actual network performance for it to be a reliable source of coverage and performance information for public safety. In Televate's opinion and based on our collective team engineering experience of over 100 years in designing public safety land mobile radio (LMR) networks along with a similar number of collective years designing, engineering and operating commercial cellular and public safety 4G-LTE broadband networks, the FirstNet coverage maps could, and should include multiple coverage service environments. The FirstNet maps could include projected coverage for in-vehicle, in-building and on-street coverage for handheld devices. Additional detail regarding how these coverage environments were computed, including the underlying RF propagation model variables could be provided. FirstNet coverage mapping should be less conservative than the methodology employed to develop the commercial AT&T coverage maps. Illustrating coverage where it is not available can be counterproductive for FirstNet to attract network subscribers and to properly inform existing subscribers. Public safety is accustomed to this level of detail from their LMR coverage mapping. We encourage AT&T to consider and act on this recommendation to provide this additional detail.

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[13] FirstNet coverage as published online at https://www.firstnet.com/coverage on 22 October 2019. It is presumed that the map represents the then current Interim Operating Capability (IOC) service area.

The following maps overlay the Service Availability test results with the FirstNet coverage maps as extracted from the www.firstnet.com website.

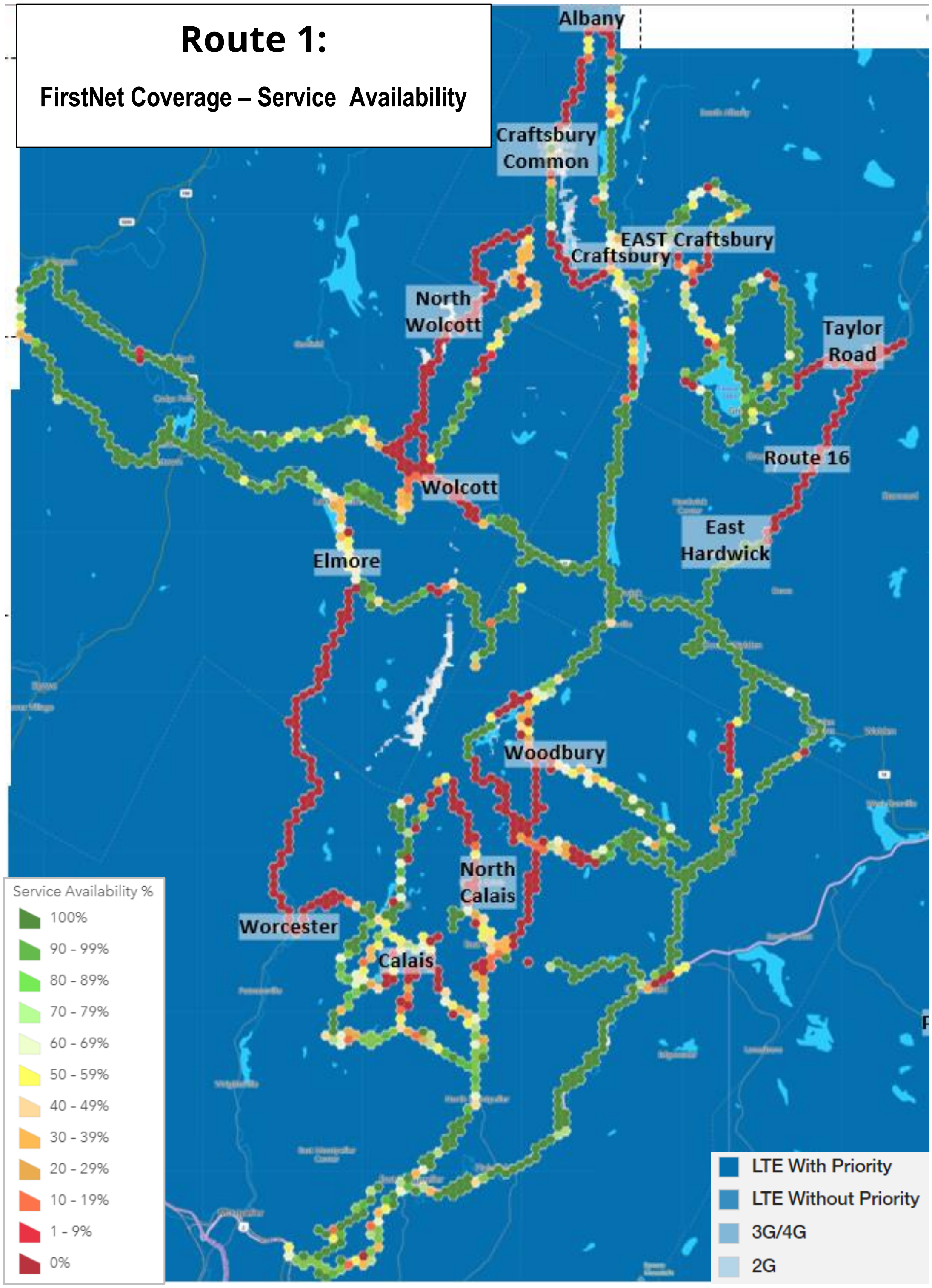

Figure 2: Route 1 Network Availability Map

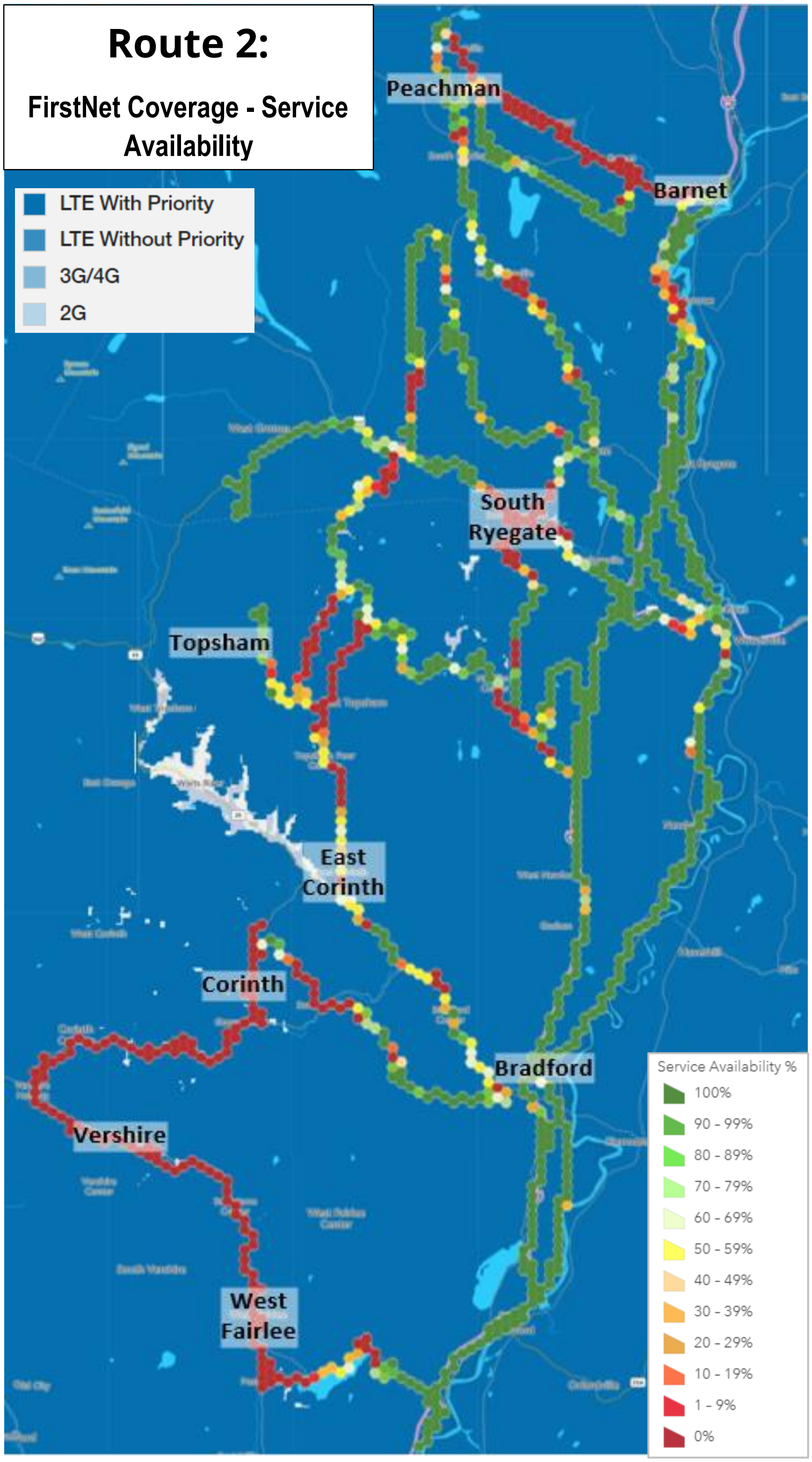

Figure 3: Route 2 Network Availability Map

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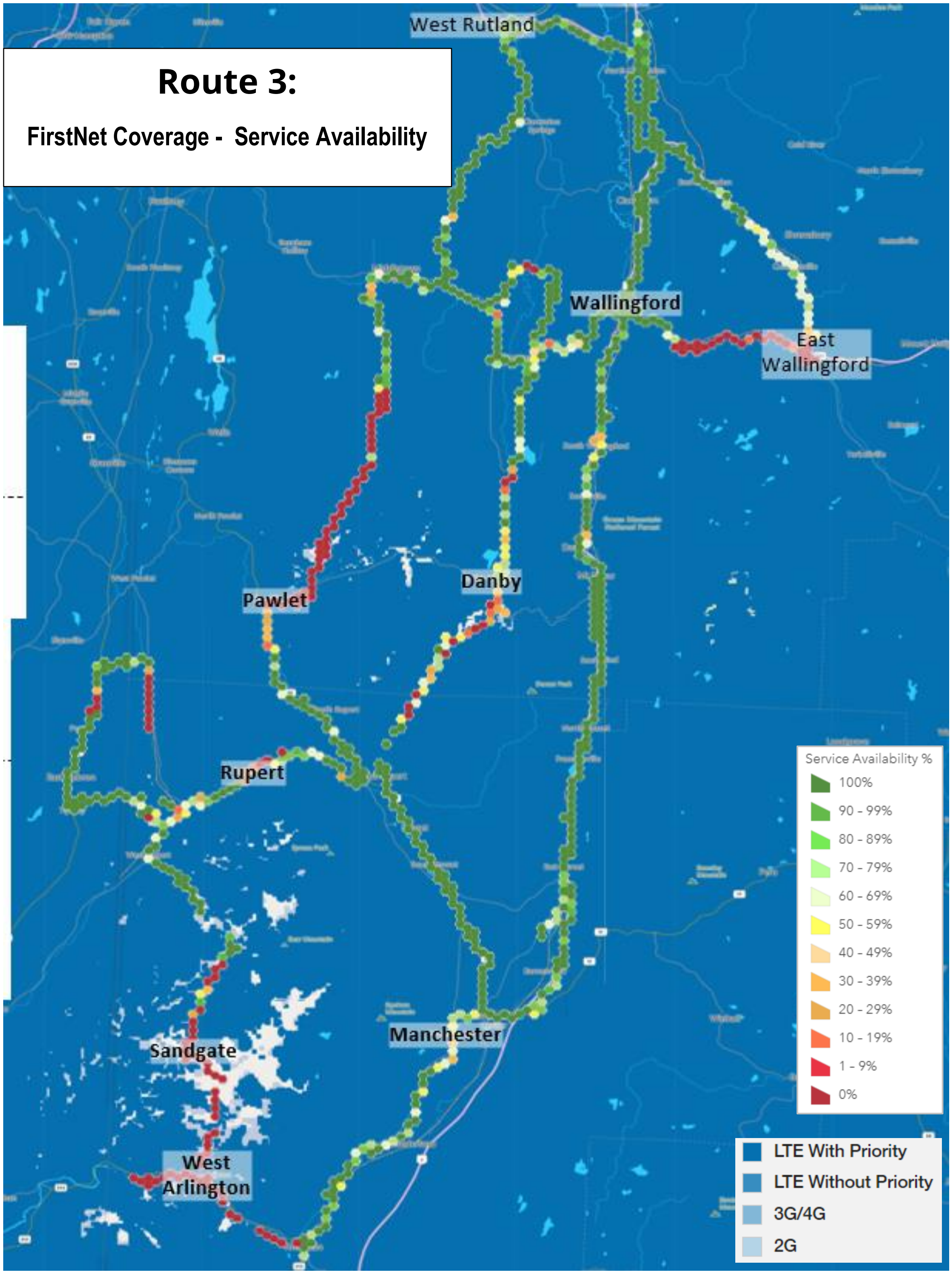


Figure 4: Route 3 Network Availability Map

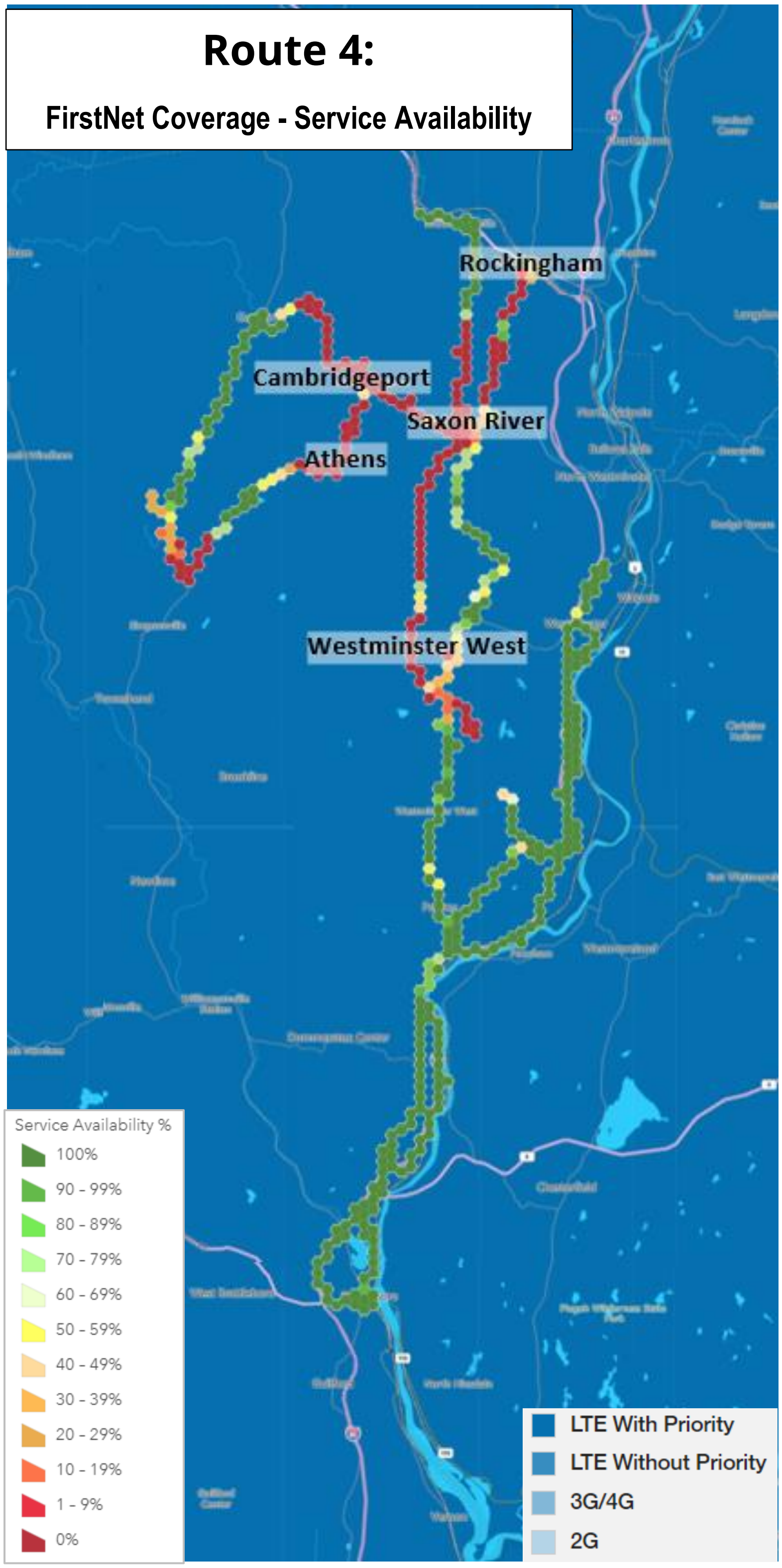
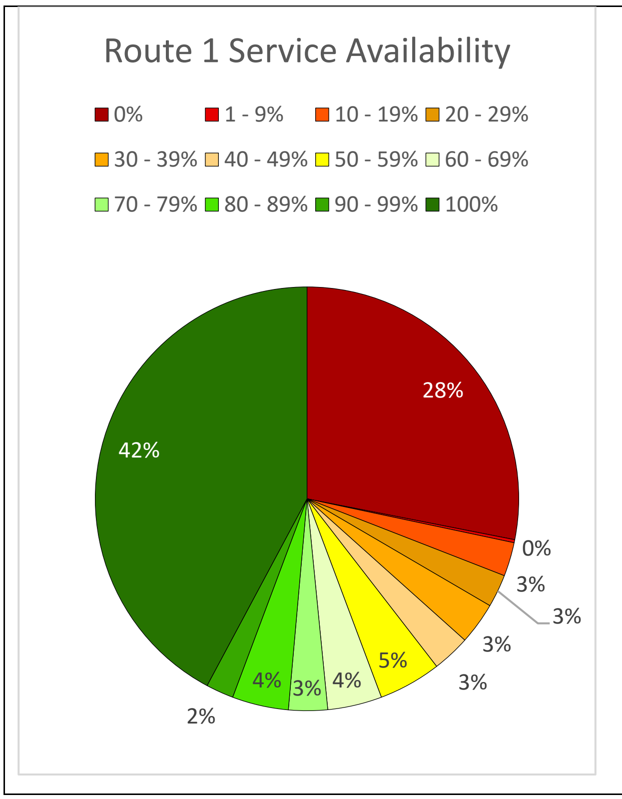
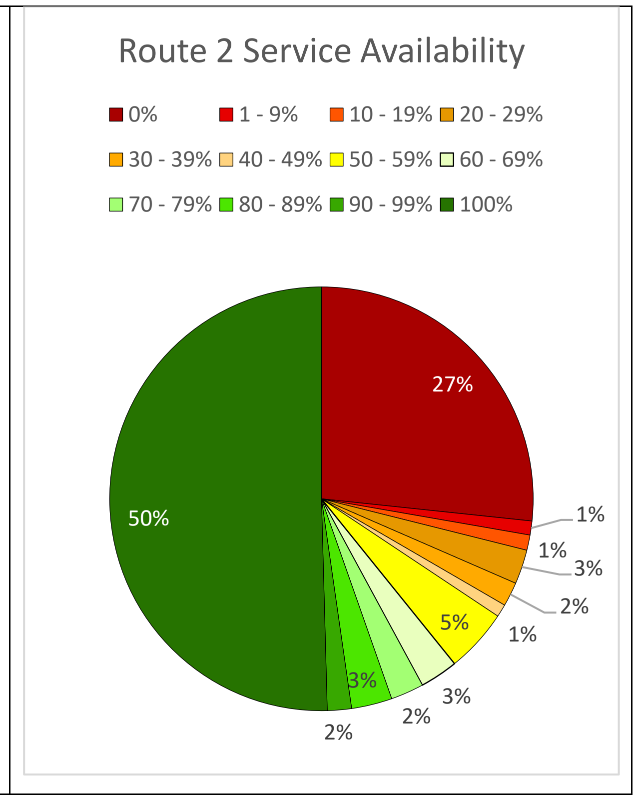


Figure 5: Route 4 Network Availability Map

FirstNet Service Availability Drive Test Statistics

The following charts detail the percentage of hexagonal test grids that fall within various categories of service availability for each of the drive routes. **It represents the overall reliability of service in the general area of each route.** Figure 6 shows that Service Availability for Route #3 had the best results for the FirstNet network. Roughly 58% of Route 3 had Service Availability of 90% or greater resulting in access to the FirstNet service being very reliable in 58% of the area tested. There was no service available in roughly 17% of the area tested for Route 3. The remaining 25% of Route 3 was "spotty," where access to FirstNet service was intermittent. Drive Routes 1, 2, and 4 had excellent service availability for 44%, 52%, and 56% of their respective areas. More than a quarter of each coverage test routes, Routes 1, 2 and 4, 28%, 27%, and 26% respectively, had no FirstNet service available.





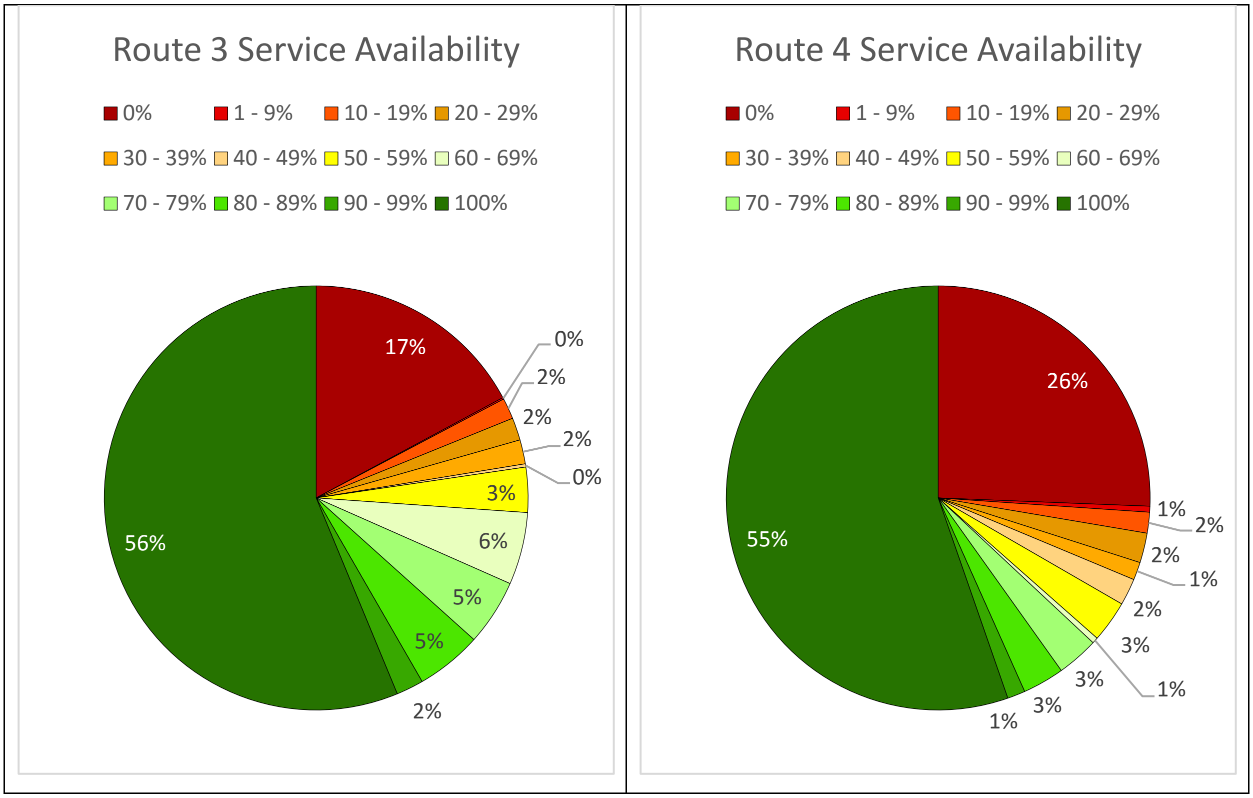


Figure 6: Percentage of FirstNet Drive Test Area Service Availability

Signal Level

The radio frequency (RF) signal level data measured and processed represents the relative strength of the FirstNet signal received by the subscriber device in decibels referenced to one milliwatt (dBm). Higher signal levels generally translate to more reliable, high-bandwidth connections that better penetrate buildings.[14] However, it is important to note that while higher signal strength is a reliable indicator of network performance, the corresponding broadband data throughput does not necessarily directly correlate to the RF signal strength. Data throughput will additionally be affected by network capacity and usage, and while the FirstNet priority and preemption offering for public safety will ensure network access when the network is available, data throughput speeds could be affected even in higher RF signal strength areas.

The Pinpoint application collects signal levels where service is available and creates one unified map that represents the net coverage footprint over the entire service area, normalizing other wireless technologies to LTE signal levels. See Appendix A for additional information regarding RF signal level computation and analysis. Because the Pinpoint data was collected using a smartphone located inside a vehicle,[15] other environments can be computed or imputed based on standard loss or gain factors as discussed in Appendix A. For example, residential indoor coverage can be computed based on the differences in losses between the cell site and the device for in-vehicle versus indoor device environments.

Televate conducted specialized "calibration" analysis in Vermont to determine the signal level thresholds where "reliable" broadband data throughput speeds were achieved. In addition, Televate conducted calibration of "mobile outdoor coverage" against "in-vehicle smartphone coverage" with the objective of both calibrating Pinpoint to commonly employed cellular engineering measurement tools, and to better fit the coverage results to outdoor coverage which appear to be reflected on the FirstNet coverage maps. Those results are documented in Appendix B, and the calibration thresholds for signal levels are reflected in the signal level maps and statistics below.

Please note that there are various areas on the map where service availability data was not collected due to insufficient network coverage. In those cases, data grids are not depicted, and the underlying map is illustrated. In these cases, the background color of the map is displayed. Similarly, in the subsequent maps representing signal level, data throughout, technology and ping loss, wherever data was not collected, the background color of the maps is displayed.

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[14] Please note that a -94 dBm signal level is significantly stronger than a -115 dBm by a factor of 21 dB. When computing RF signal strength logarithmically, every +3 dB reflects a doubling of the RF power. Therefore, a RF signal that is 21 dB stronger is actually seven times (7X) stronger.

[15] The test smartphones were positioned on dashboard mounts to provide the best possible measurements results.

Route 1

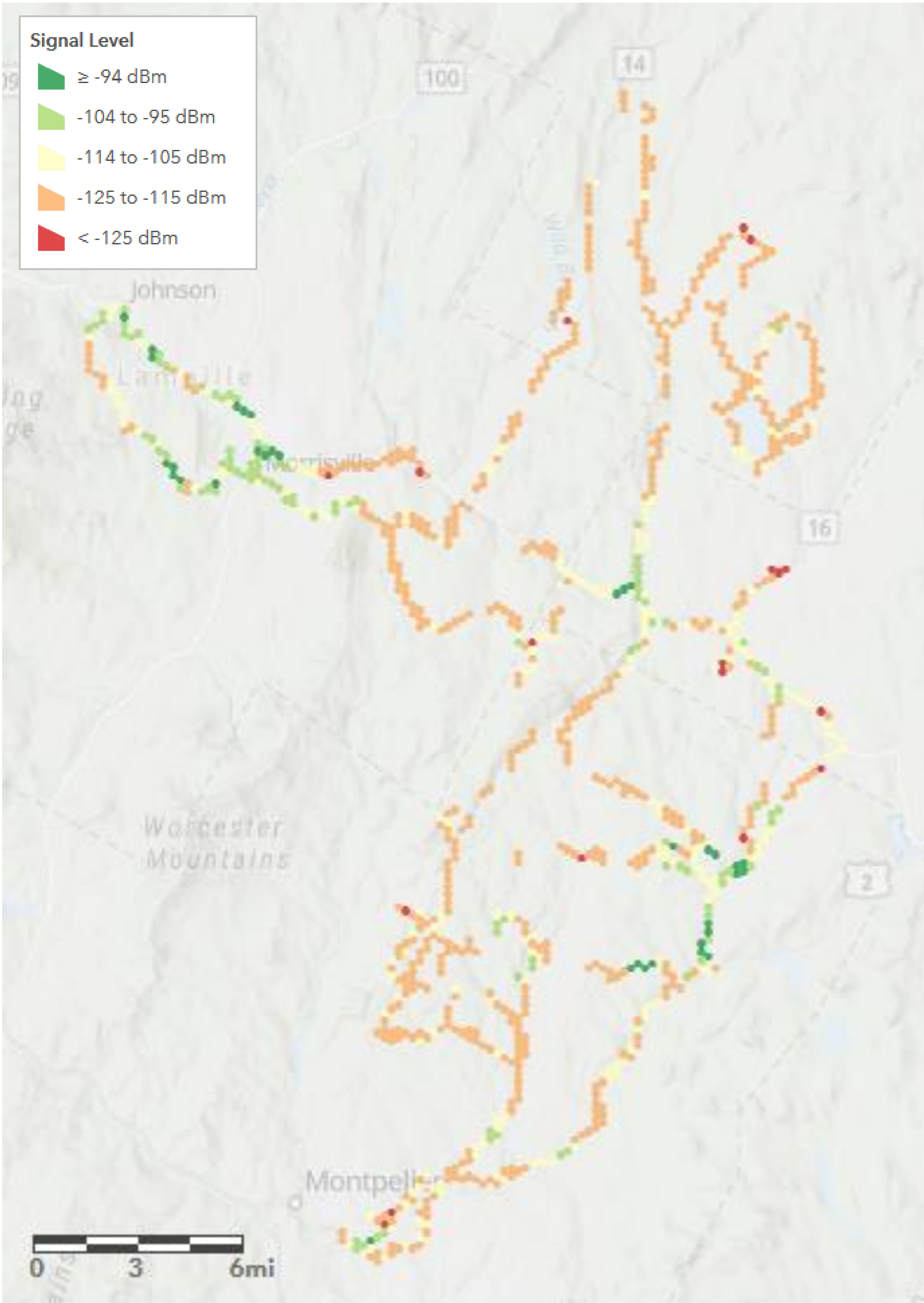


Figure 7: Route 1 Signal Level Map

Route 2

Figure 8: Route 2 Signal Level Map

Route 3

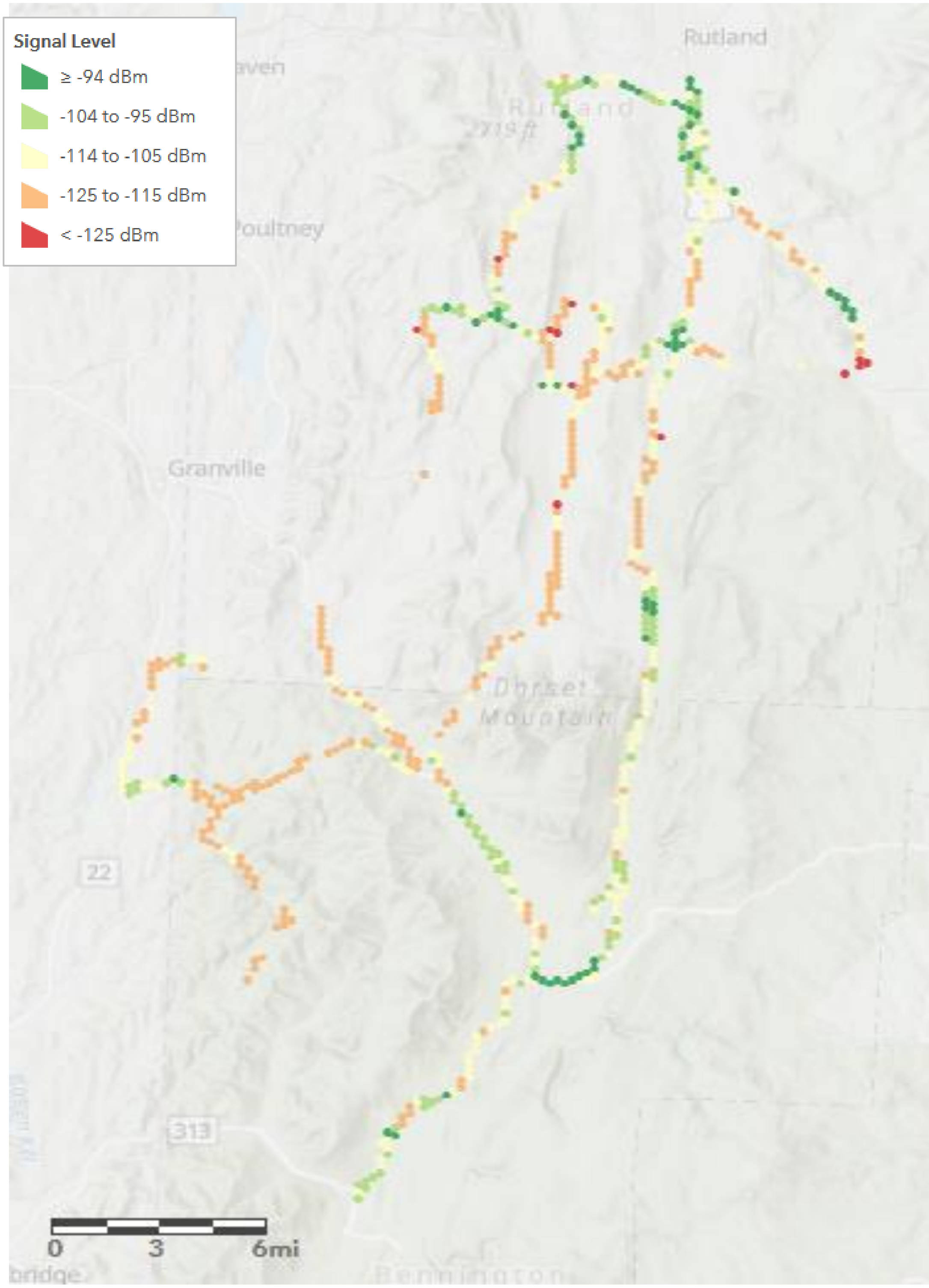


Figure 9: Route 3 Signal Level Map

Route 4

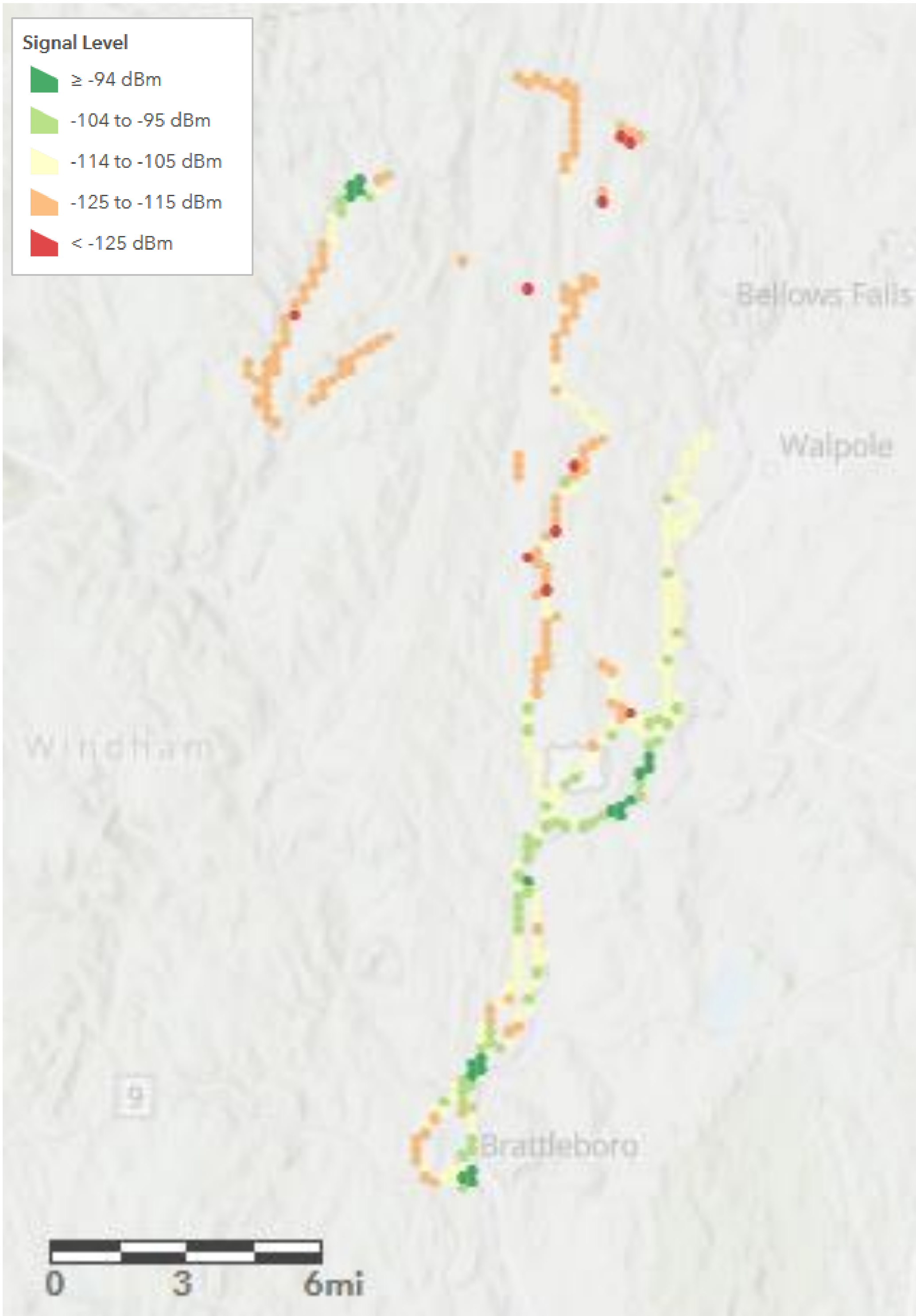
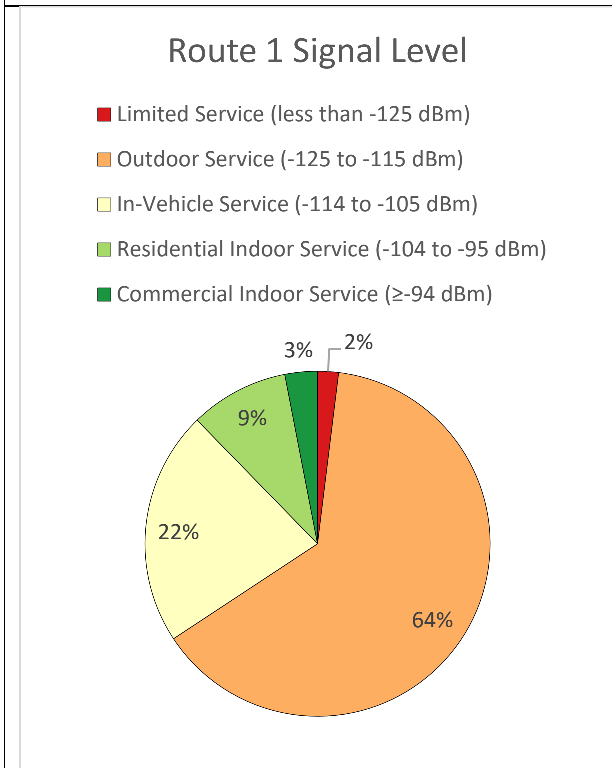
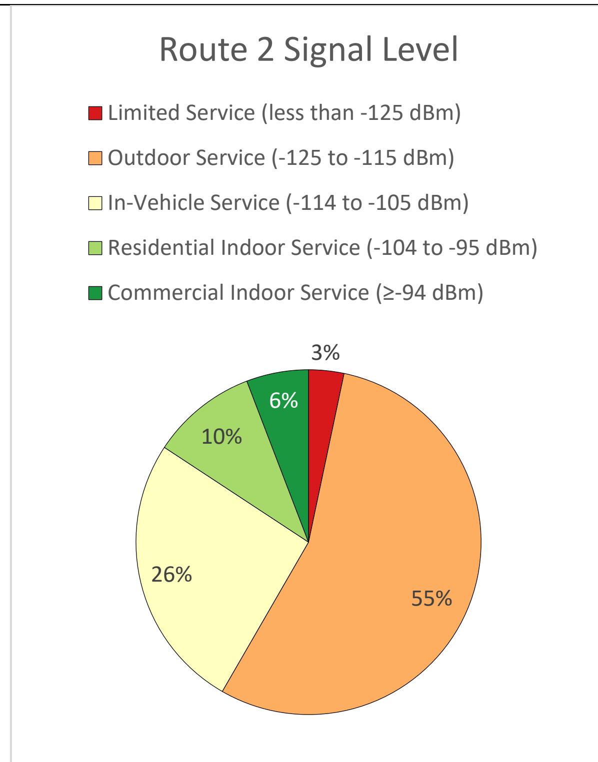


Figure 10: Route 4 Signal Level Map

Notes on Signal Level:

- *Pie charts only represent the areas on the map where the phone was in service and receiving a signal. Periods of no service or signal reception are not represented in the charts below.*
- *Outdoor service can be achieved at -125 dBm and any greater signal strength, which includes in-vehicle service, residential indoor service, and commercial indoor service.*





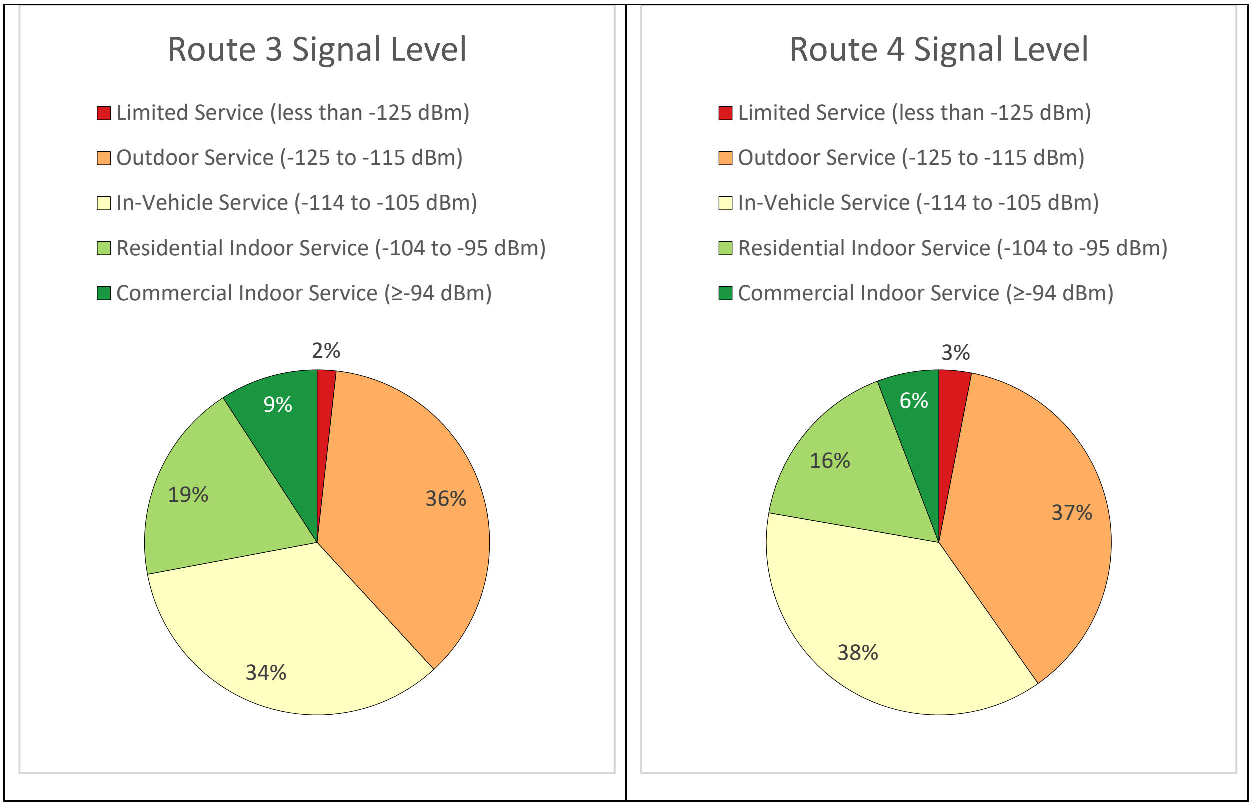


Figure 11: FirstNet Signal Strength Percentage Per Drive Test Area

The results indicate that indoor coverage levels are rarely achieved along these drive test routes, as would be expected in a generally rural area. Where service was available, the outdoor signal levels represents the most frequent level of service. Route #3 had an in-vehicle or greater signal level 62% of the time followed by Route #4 at 60%, Route #2 at 42% and Route #1 at 34% of the time.

Technology

The technology represents the high-level technology type used by the subscriber test device for every sample. **It indicates whether the device uses 4G-LTE, including FirstNet Band 14, or one of the various 3G wireless technologies offered by AT&T.** This measurement is important because, at the same signal level, the performance of the mobile network may differ depending on the network wireless technology type. For example, a carrier may not offer public safety quality of service over 3G technologies. In addition, 3G technologies tend to have far greater latency, affecting applications like push-to-talk. Some 3G technologies also have far lower throughput capabilities than 4G-LTE technologies.

Please note that there are various areas on the maps where no technology or signal was detected. In these cases, data grids are not depicted, and the underlying map is illustrated. In these cases, the background color of the map is displayed.

Route 1

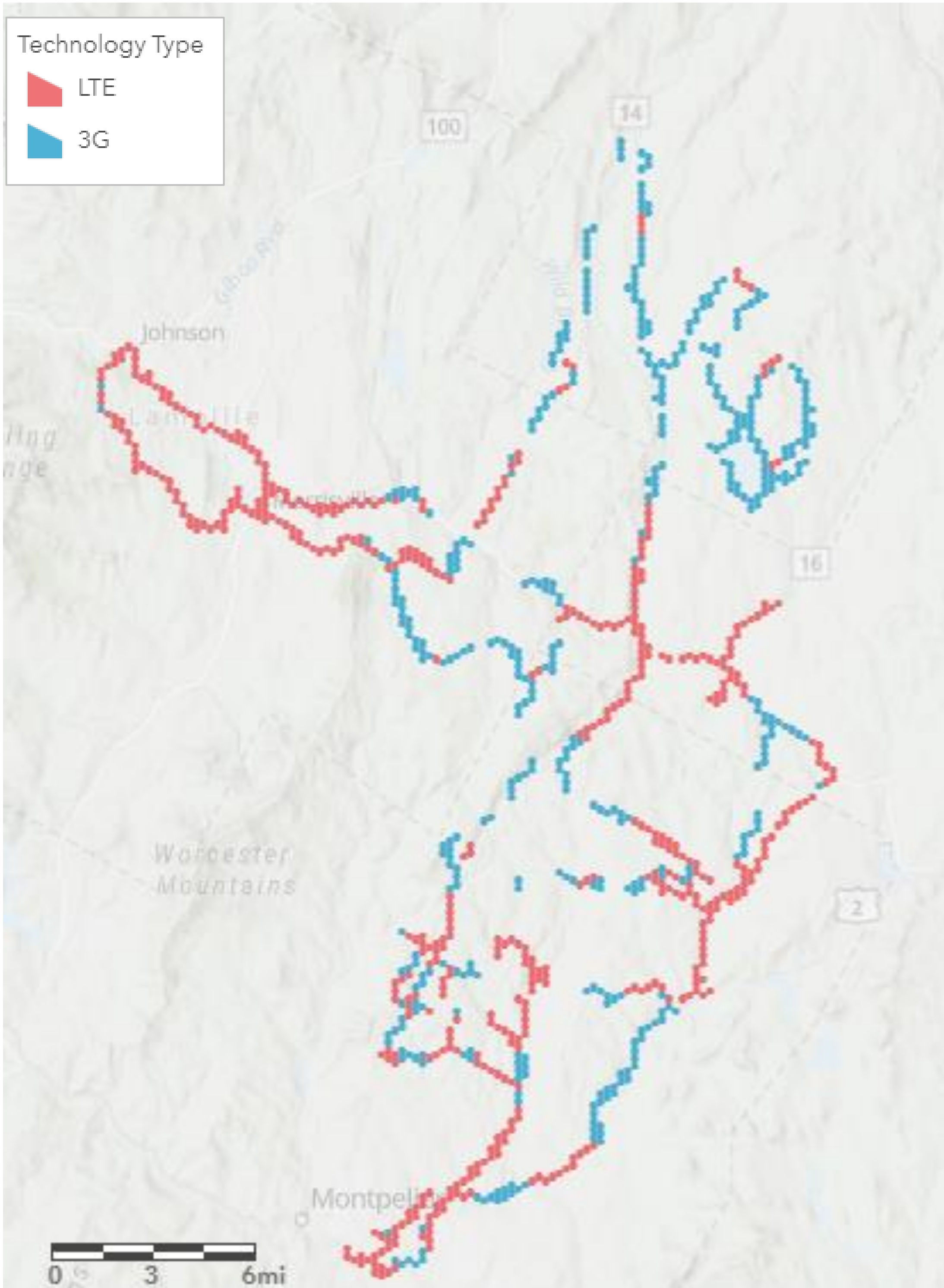


Figure 12: Route 1 Technology Type Map

Route 2

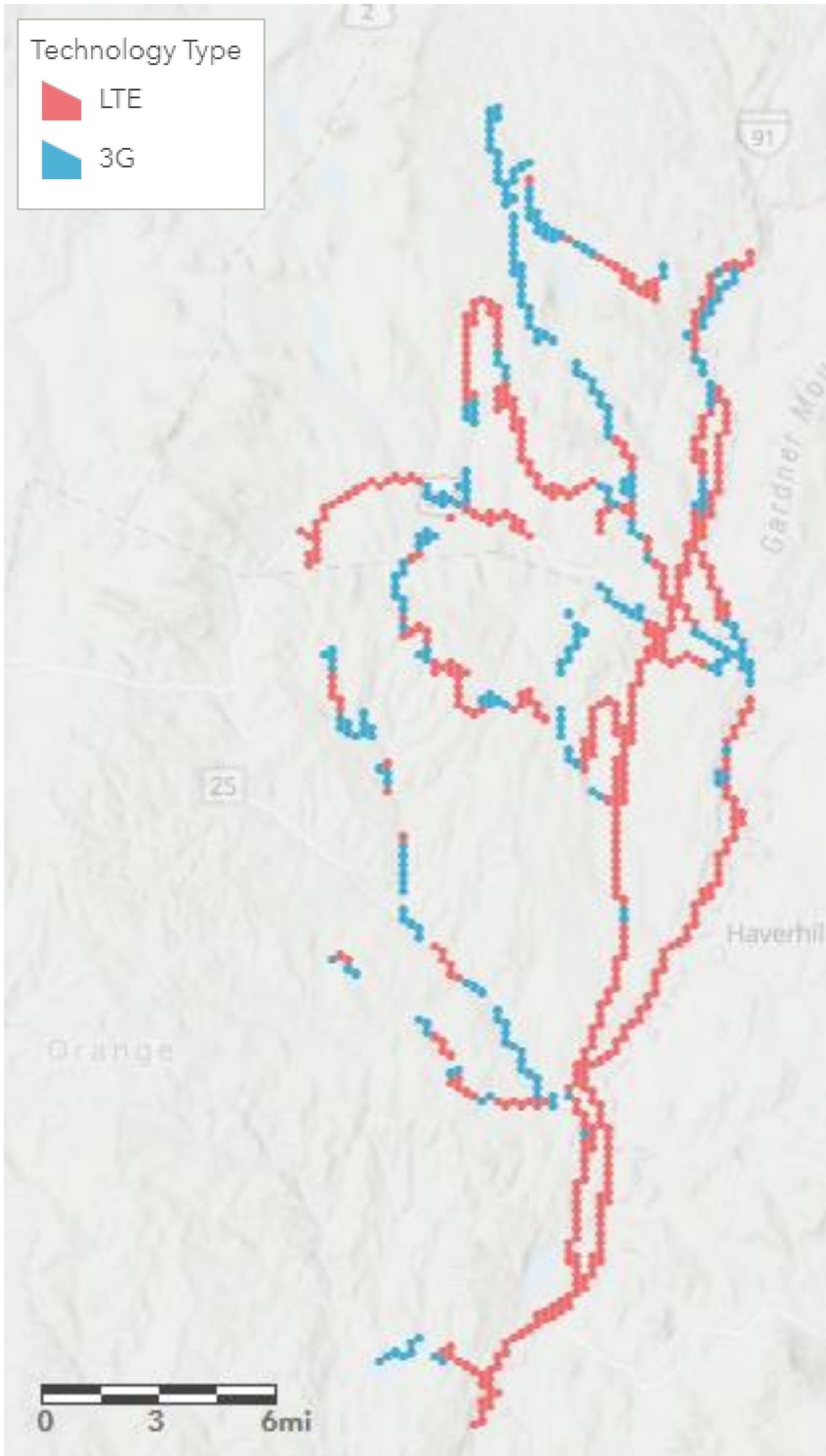


Figure 13: Route 2 Technology Type Map

Route 3

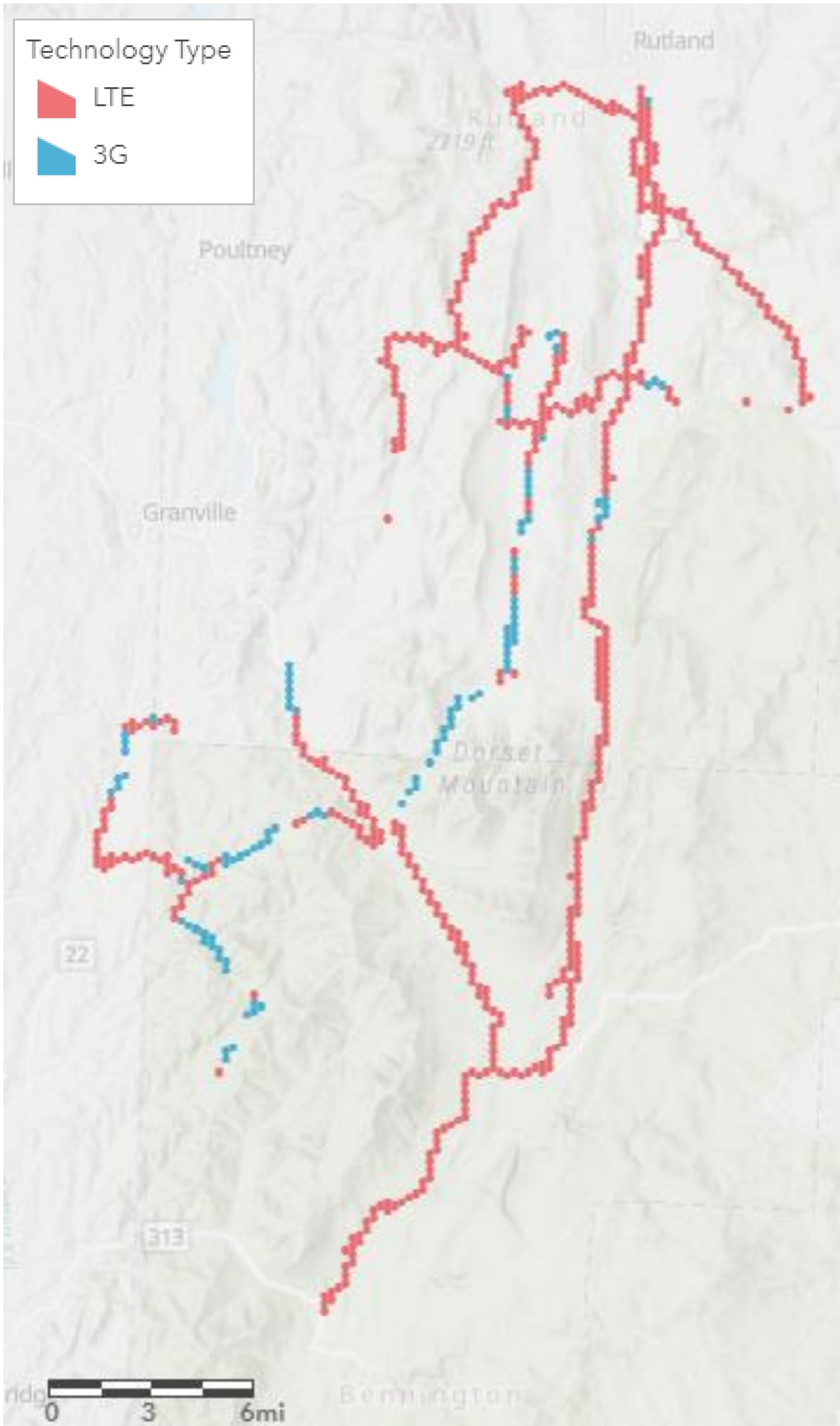


Figure 14: Route 3 Technology Type Map

Route 4

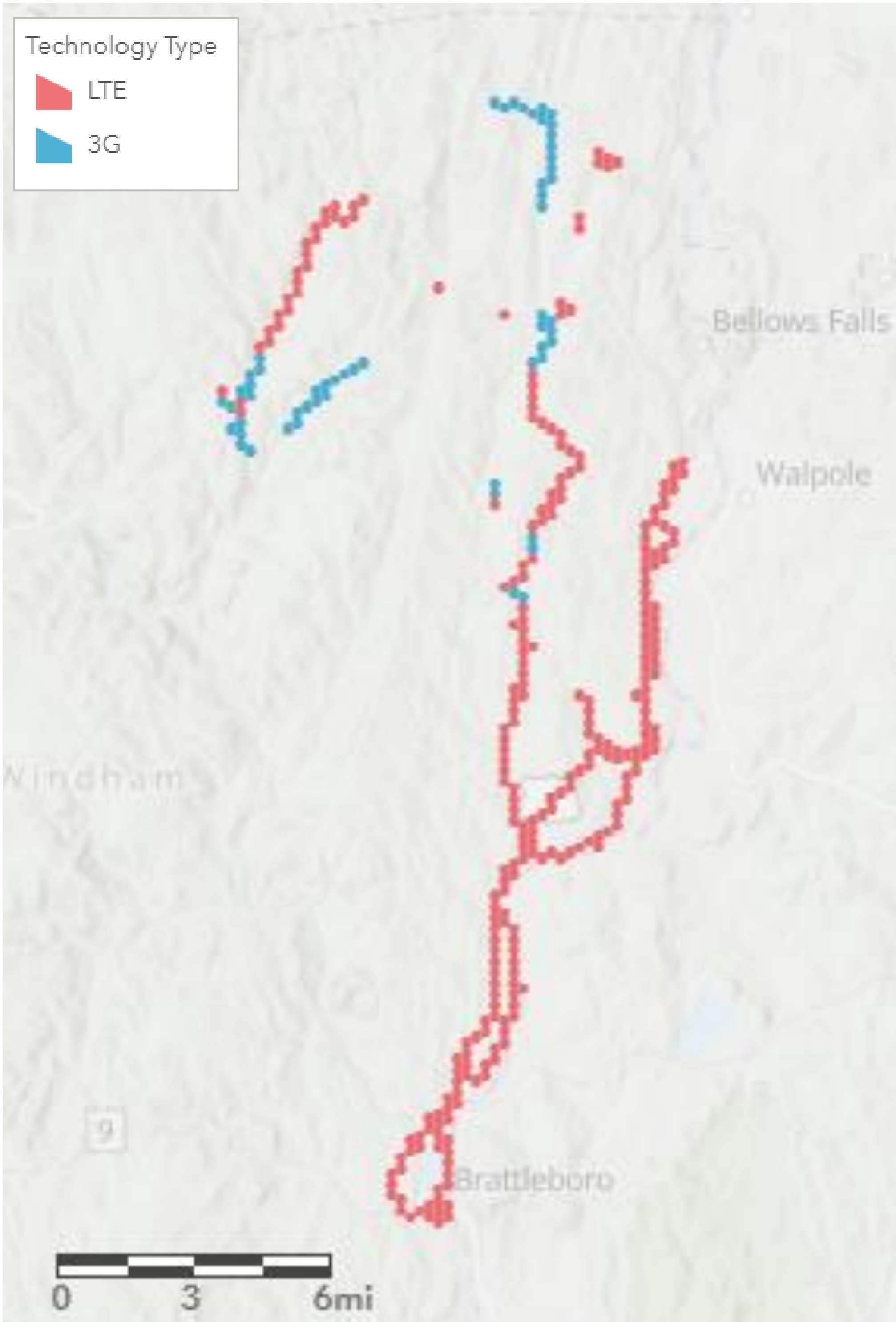


Figure 15: Route 4 Technology Type Map

Note on Technology:

- *Pie charts only represent the areas on the map where the phone was in service and receiving a signal and reported each technology type. Periods of no service or signal reception are not represented in the charts below. It may be noted that the FirstNet coverage maps generally reported 4G-LTE technology over the majority of the test areas.*

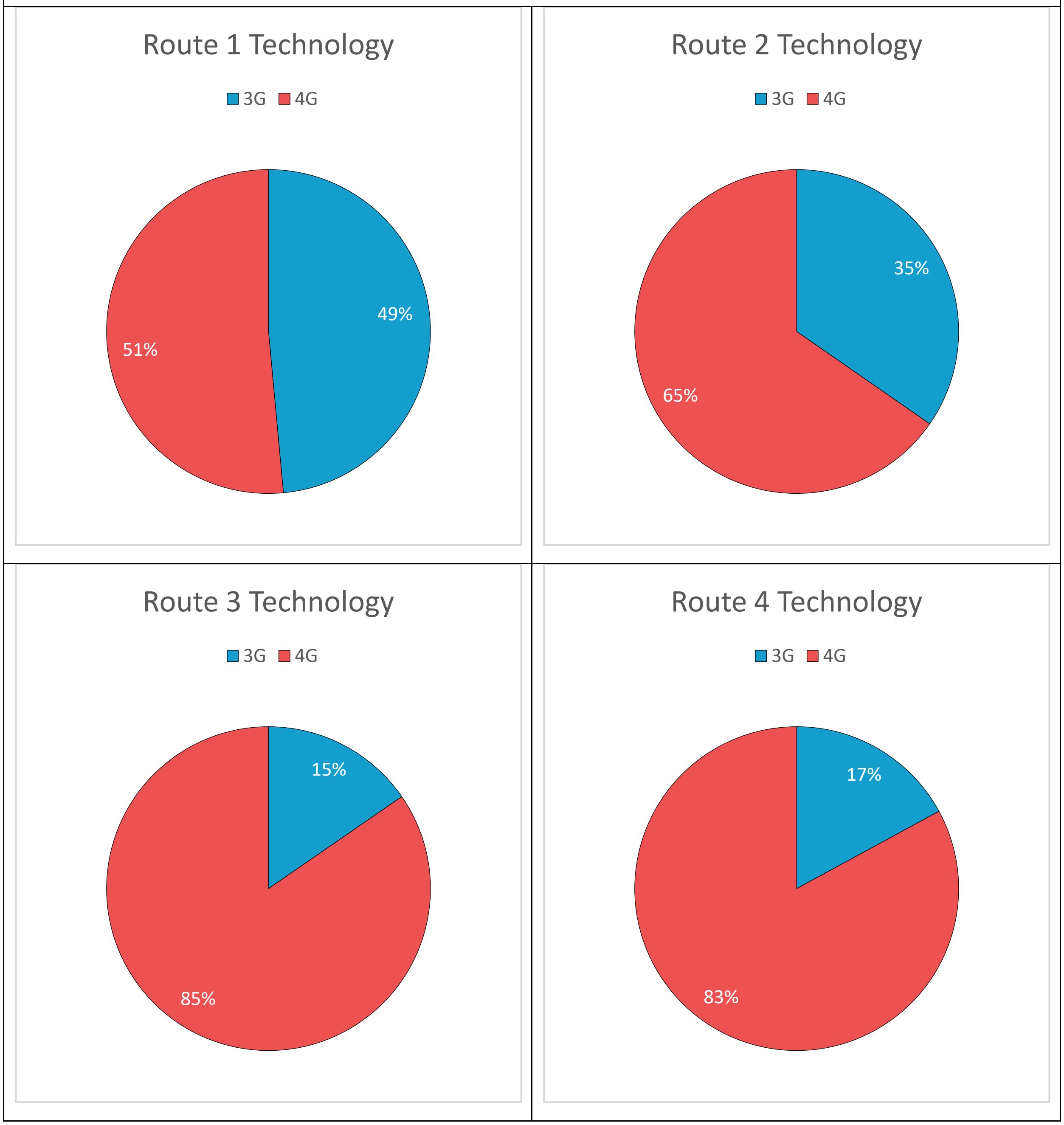


Figure 16: Wireless Technology Percentage Per Drive Test Area

For areas where service was available, 4G-LTE was available the majority of the time. Drive Route #3 had the highest amount of 4G-LTE service with 85% of the total service area served by 4G-LTE, followed by Route #4 at 83%, Route #2 at 65% and Route #1 at 51%.

Data Throughput

The Test Mode function enables Pinpoint to conduct periodic data throughput tests to determine the data speeds available in any given network location at the specific time the throughout test is conducted. Data throughput will vary based on signal strength, RF network interference, and general network traffic and usage at the time broadband data is requested by network subscribers. Data throughput is fundamental for public safety to assess the types of applications, such as streaming video , which requires substantial data throughput, that could be reliably used at a particular network location.

The throughput tests push the network to the limit to determine the full capacity that is available to the device. At the pre-defined measurement reporting interval, Pinpoint makes a request to download a sample file from Televate's cloud service. The test is designed to download as much data as it can in one second, measure the data throughout in Megabits Per Second (Mbps) and record the results. After the download test is complete, Pinpoint conducts an upload test in a similar manner. The throughput test runs continuously in the background throughout the drive test. The following figures present the download (data speed to the device from the Internet) and upload (data speed from the device to the Internet). Examples of typical services that can be supported by different throughput data rates are given by the FCC.[16]

There are several factors that contribute to the data speed of any one test. Network saturation, traveling speed, signal levels, noise levels, device performance, and others contribute to the amount of data that can be transferred by a device. Areas served by 4G-LTE will see significantly better throughput on both the uplink (the user sending data to the network) and downlink (the user requesting data from the network such as a file or video) due various factors. Because of the significant gains in the technology, the throughput results can easily be correlated with whether the given drive test area had access to 4G-LTE service or not.

The following figures depict the maps and statistics regarding the throughput results for the four drive test routes. Please note that there are various areas on the maps where uplink and downlink throughput data was not collected due to insufficient network coverage or a delay on the throughput data transmission or reception. In these cases, data grids are not depicted, and the underlying map is illustrated. In these cases, the background color of the map is displayed.

[16] See FCC's Household Broadband Guide: https://www.fcc.gov/research-reports/guides/household-broadband-guide and Broadband Speed Guide: https://www.fcc.gov/reports-research/guides/broadband-speed-guide

Route 1: Uplink Throughput

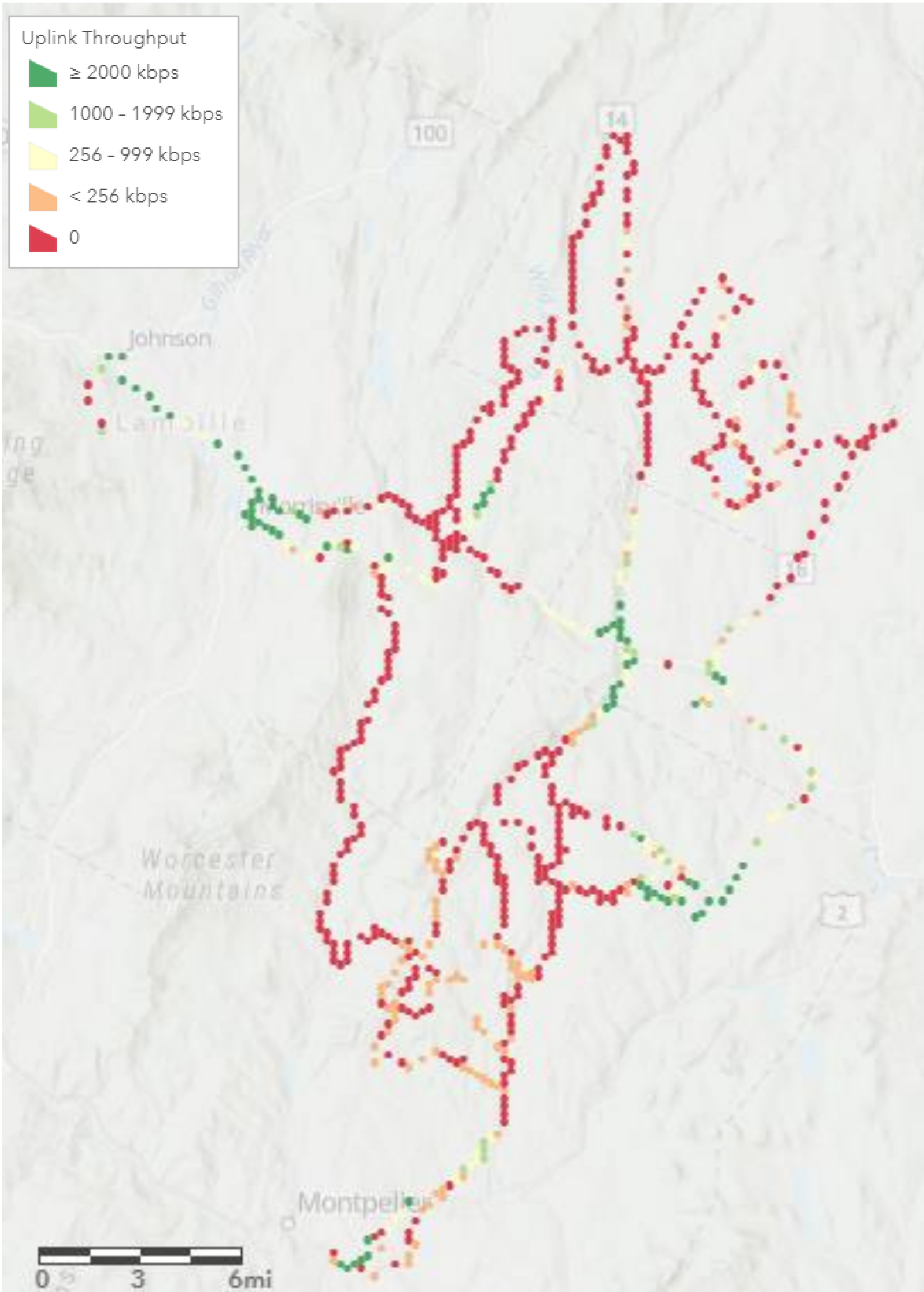


Figure 17: Route 1 Uplink Throughput Map

Route 1: Downlink Throughput

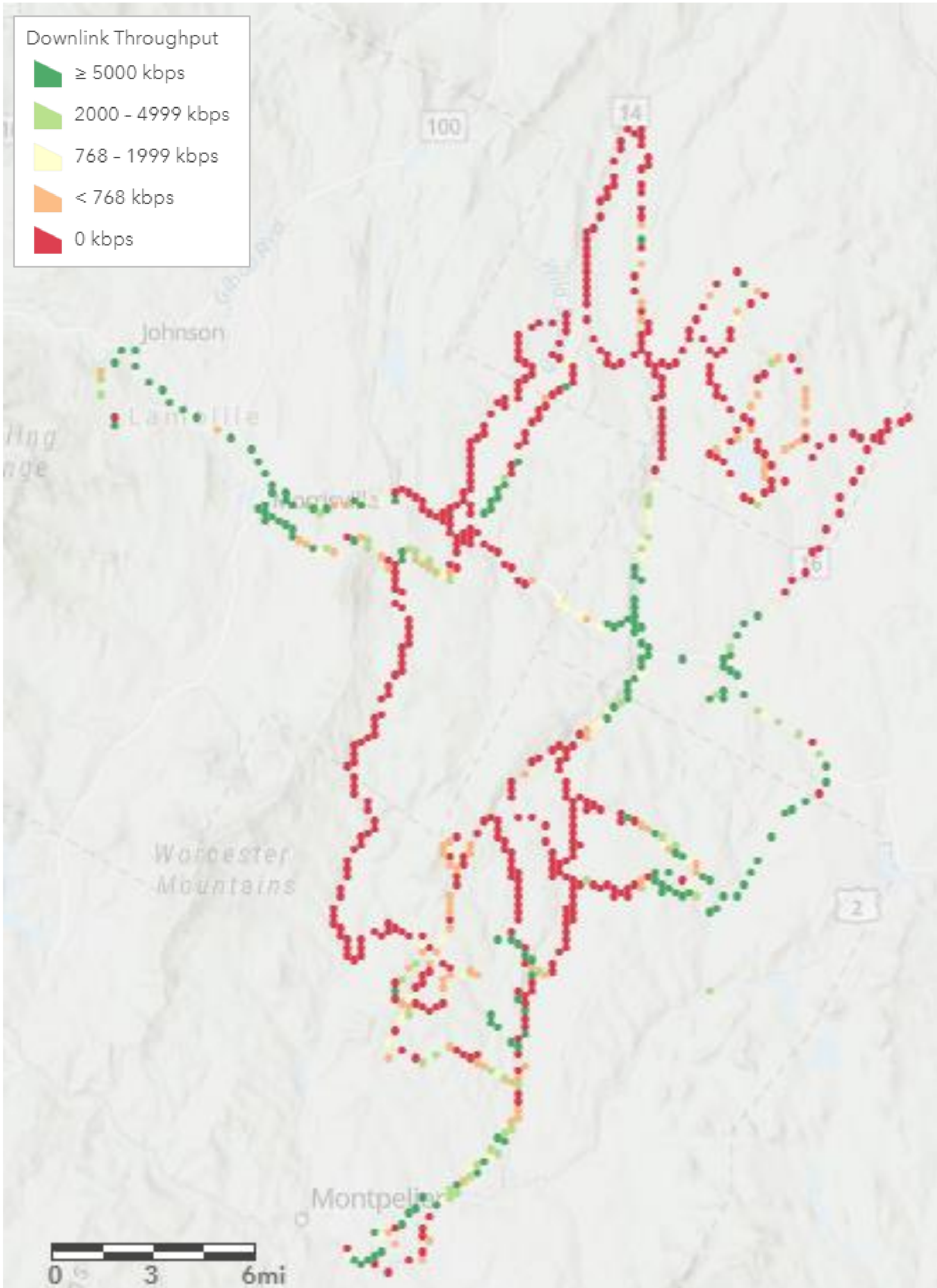


Figure 18: Route1 Downlink Throughput Map

Route 2: Uplink Throughput

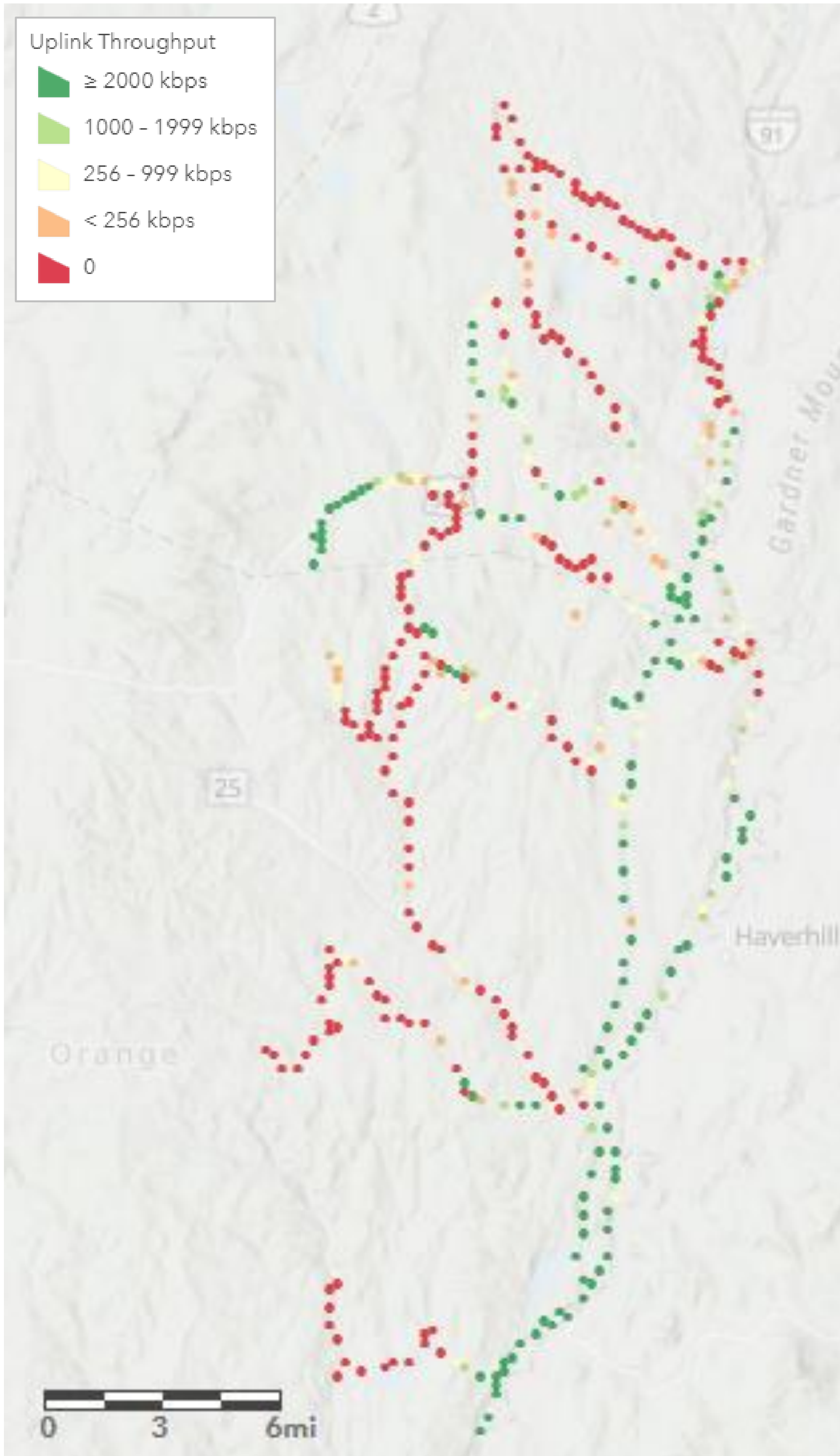


Figure 19: Route 2 Uplink Throughput Map

Route 2: Downlink Throughput

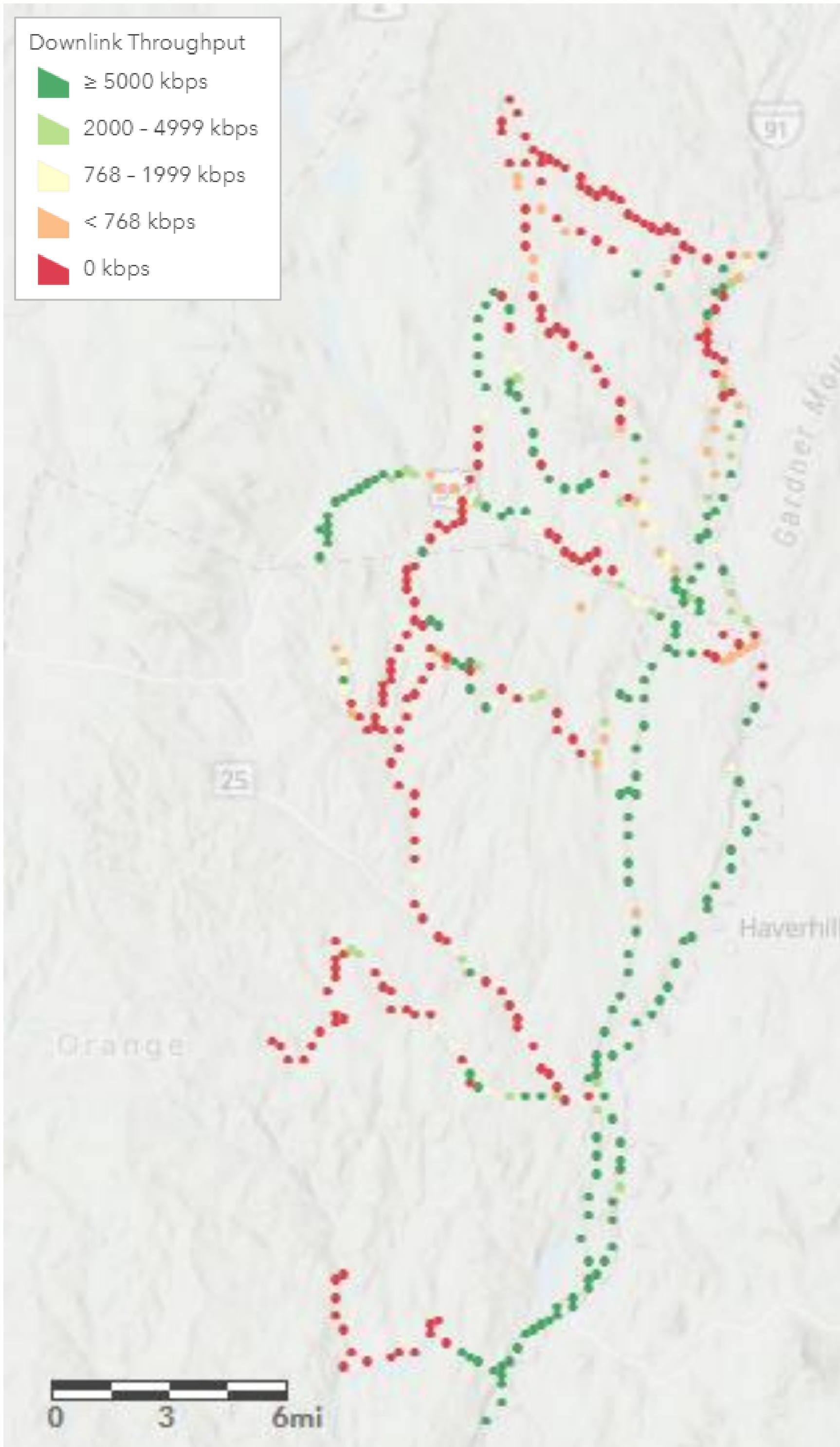


Figure 20: Route 2 Downlink Throughput Map

Route 3: Uplink Throughput

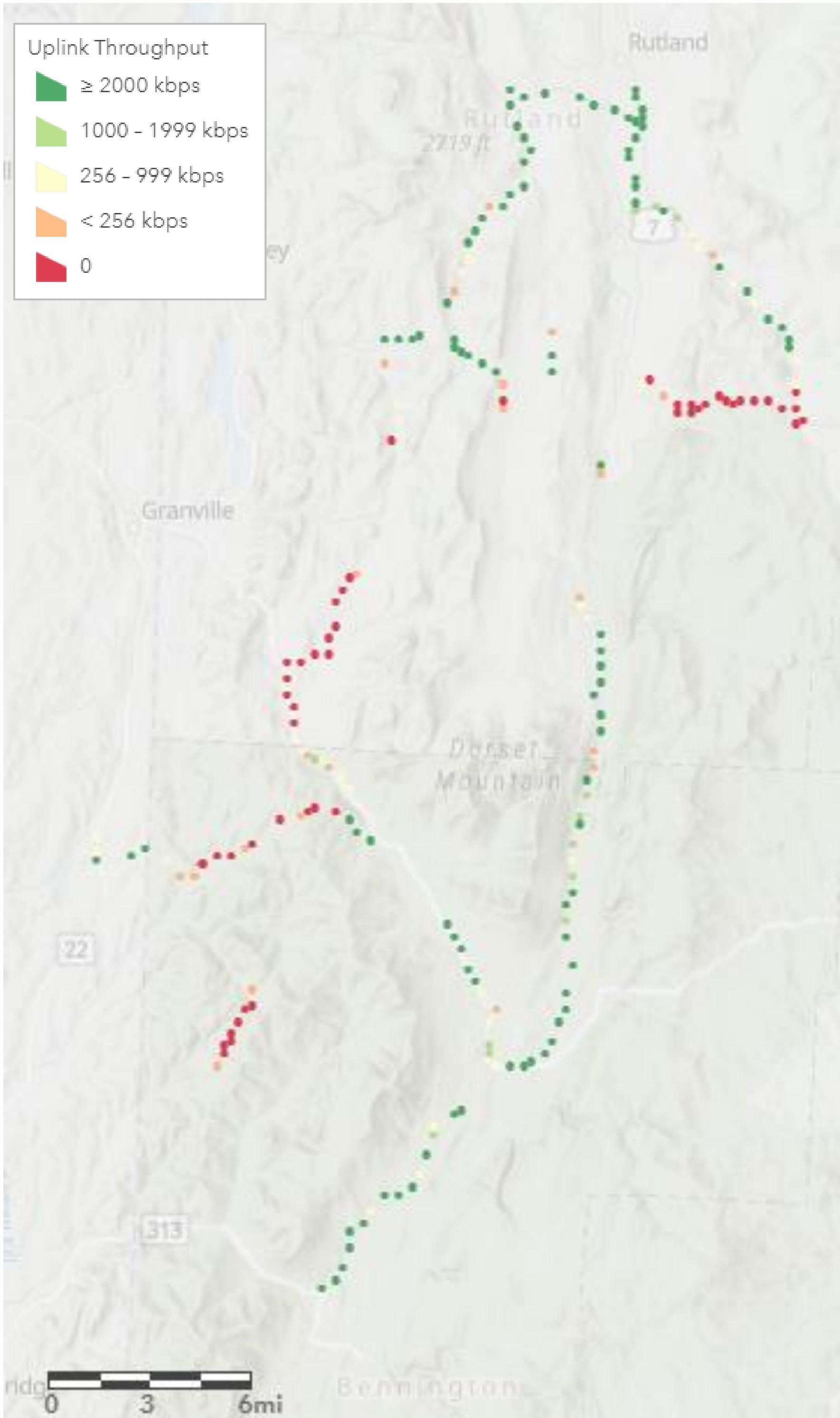


Figure 21: Route 3 Uplink Throughput Map

Route 3: Downlink Throughput

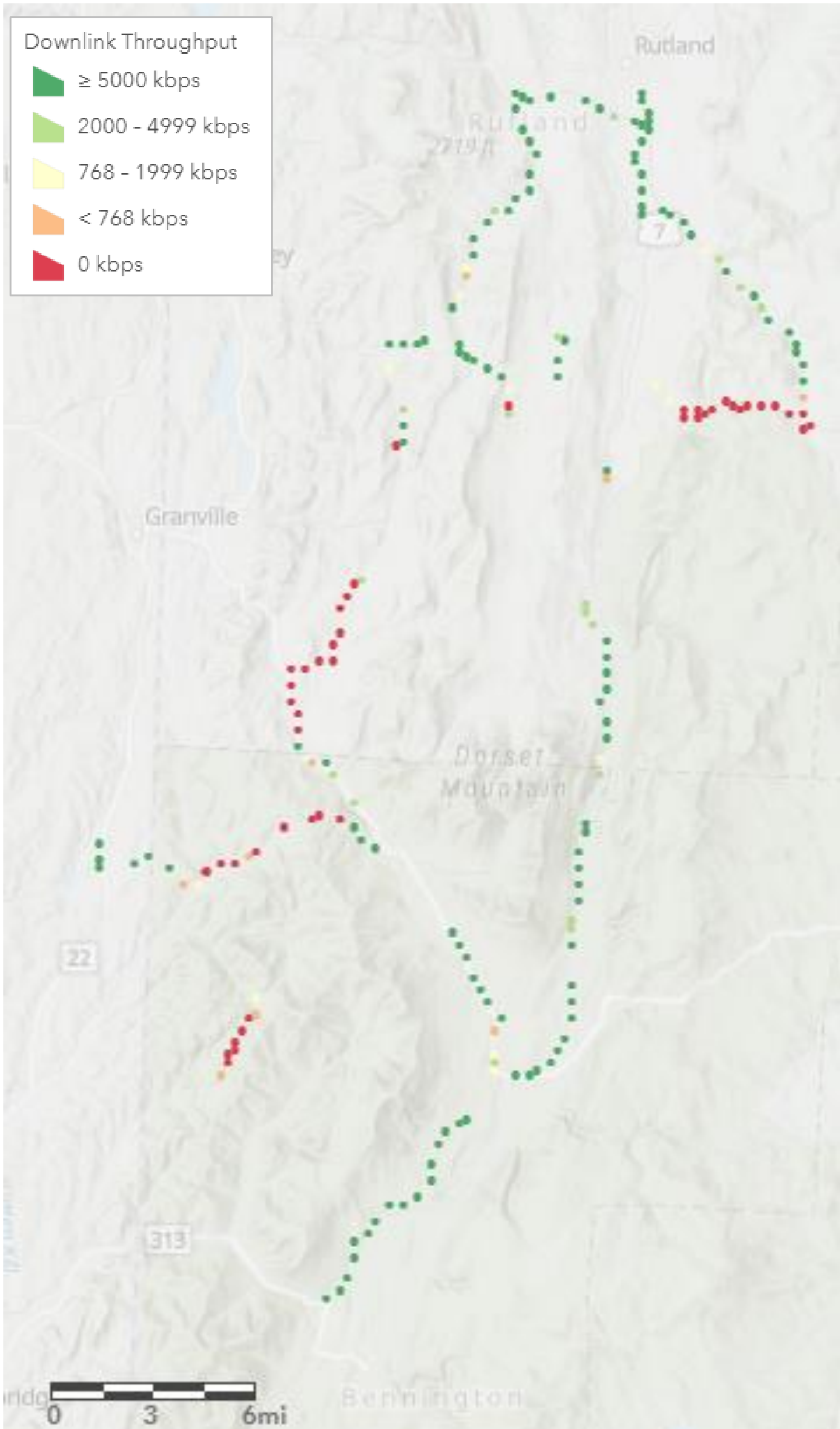


Figure 22: Route 3 Downlink Throughput Map

Route 4: Uplink Throughput

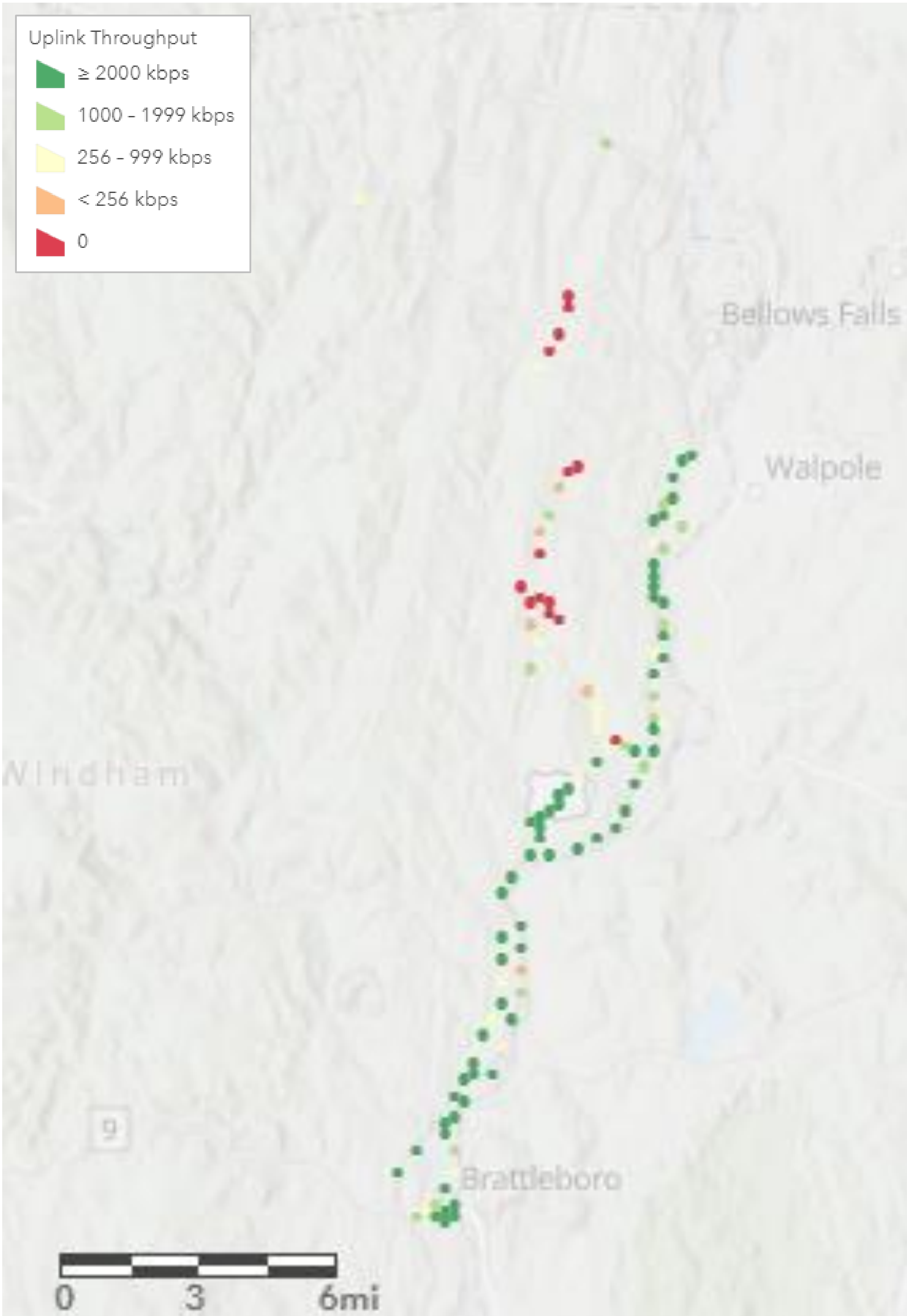


Figure 23: Route 4 Uplink Throughput Map

Route 4: Downlink Throughput

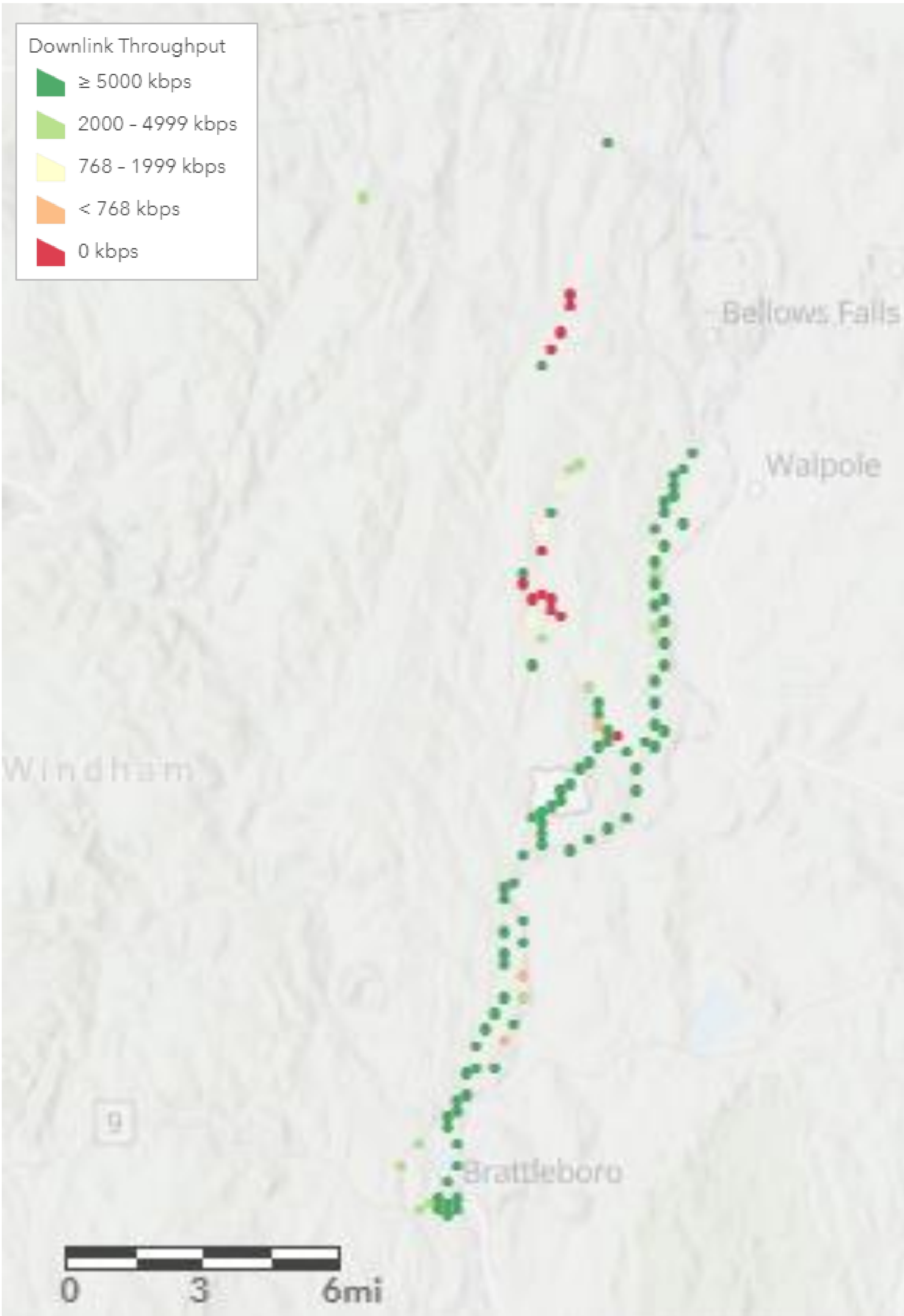


Figure 24: Route 4 Downlink Throughput Map

Note on Throughput:

- *Pie charts only represent the percentage of the time the phone was both in service and reported each throughput speed. Periods of no service or signal reception are not represented in the charts below.*

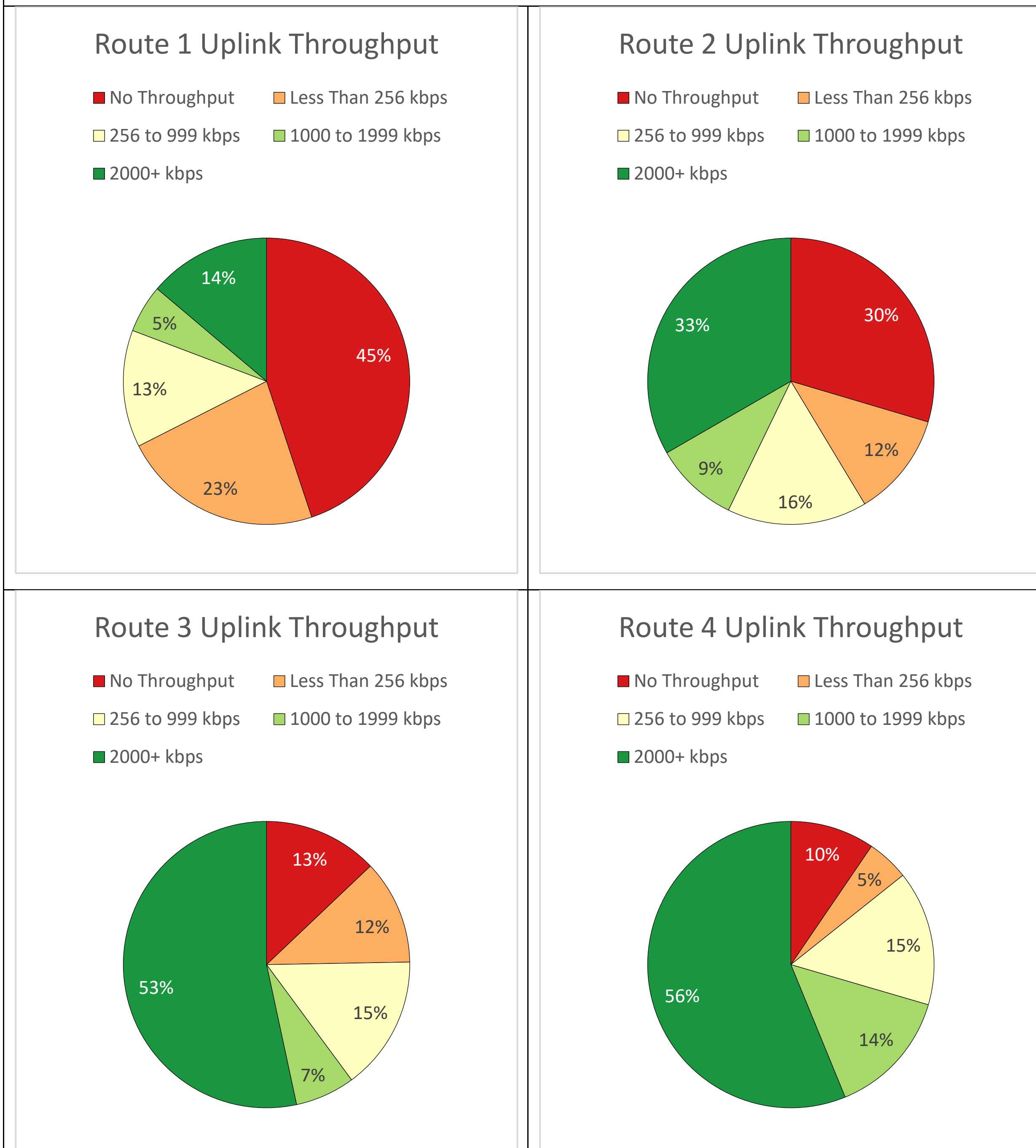


Figure 25: Uplink Data Throughput Percentage Per Drive Test Area

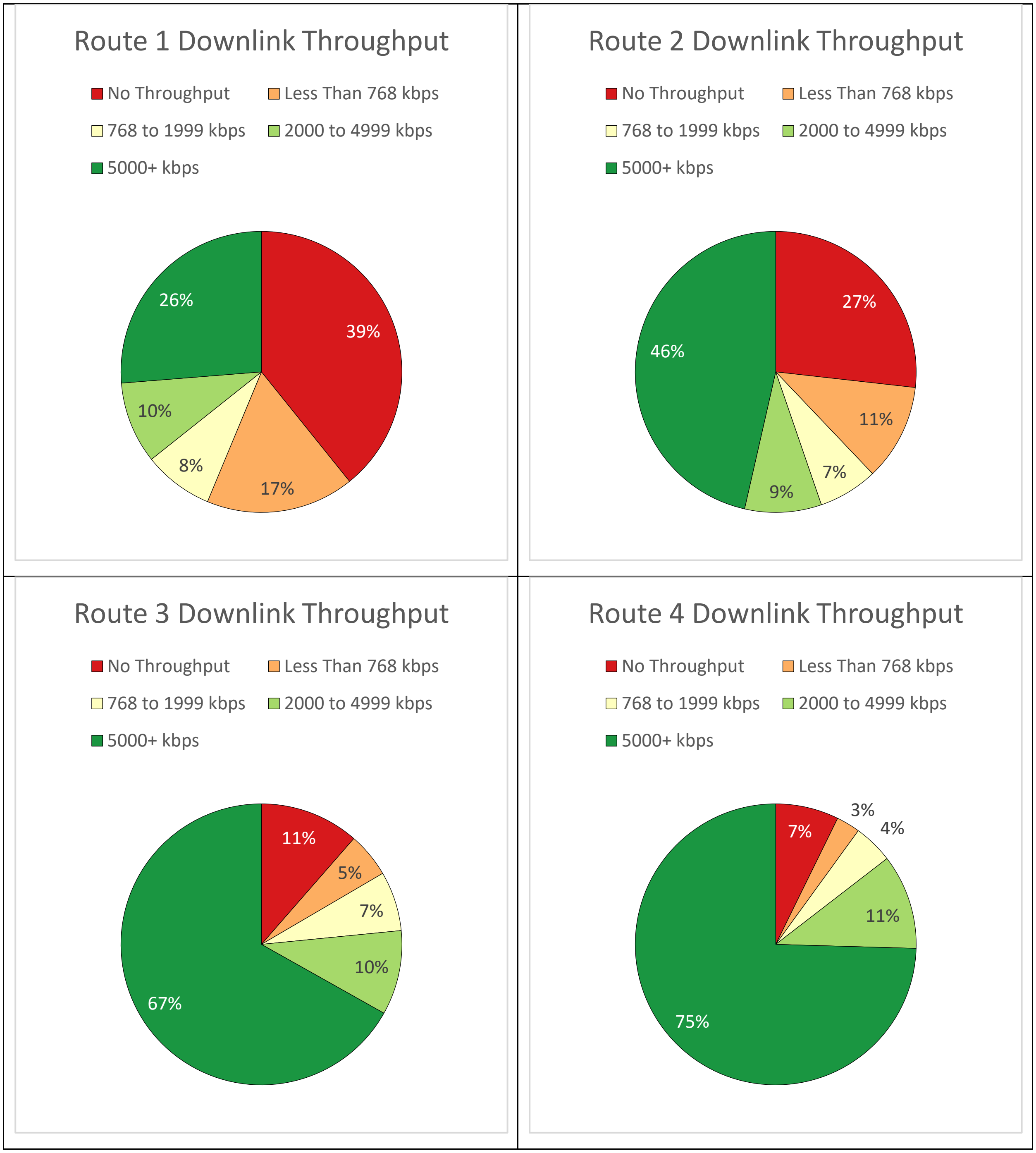


Figure 26: Downlink Data Throughput Per Drive Test Area

As a result of the additional coverage and percentage of 4G-LTE service on Routes 3 and 4, the data speeds were far better on those routes. Where service was available, the data speeds of those routes exceeded 5 megabits per second (Mbps) downloads and 2 Mbps uploads for more than 50% of the areas tested. In the national RFP for network services, the FirstNet Authority established data speeds of 768 kbps download and 256 kbps upload as the required network standard the chosen vendor must provide. AT&T was selected to deploy and operate the Nationwide Public Safety Broadband Network (NPSBN). While higher data throughput speeds will frequently be delivered across the network, the 768 kbps download, and 256 kbps upload data throughput speeds are the AT&T contractual data speeds. The drive testing verified that where FirstNet service was available, these data speeds were achieved more than 75% of the time on those routes. However, data speeds were far lower on Routes 1 and 2. In the case of Route 1, 768 kbps was achieved only 44% of the time for downloads, and 256 kbps was achieved for only 32% of uploads. On Route 2, 768 kbps was achieved 62% of the time for downloads, and 256 kbps or greater was achieved 59% of the time for uploads.

Ping Loss

The ping loss represents the loss of useful connectivity with the network. A ping test sends a small amount of data to the server and that server automatically replies. A successful ping is one in which the return data is received. Therefore, it represents roundtrip successful transmission. In the case of Pinpoint, the ping message is sent to a server in the Internet. Generally, a ping test is a reflection of reliable service, but it can also be an indicator of network congestion. When congestion levels in the network rise, public safety subscribers may experience problems or difficulties securing resources to transmit or receive data. A ping loss of zero percent indicates that all the tests were successfully transmitted, and a return message is received by the device. Ping loss of 100% indicates that all the tests failed.

As previously noted, that there are various areas on the map where service availability data was not collected due to insufficient network coverage. In those cases, data grids are not depicted, and the underlying map is illustrated. In these cases, the background color of the map is displayed. Similarly, in the subsequent maps representing signal level, data throughout, technology and ping loss, wherever data was not collected, the background color of the maps is displayed.

Route 1

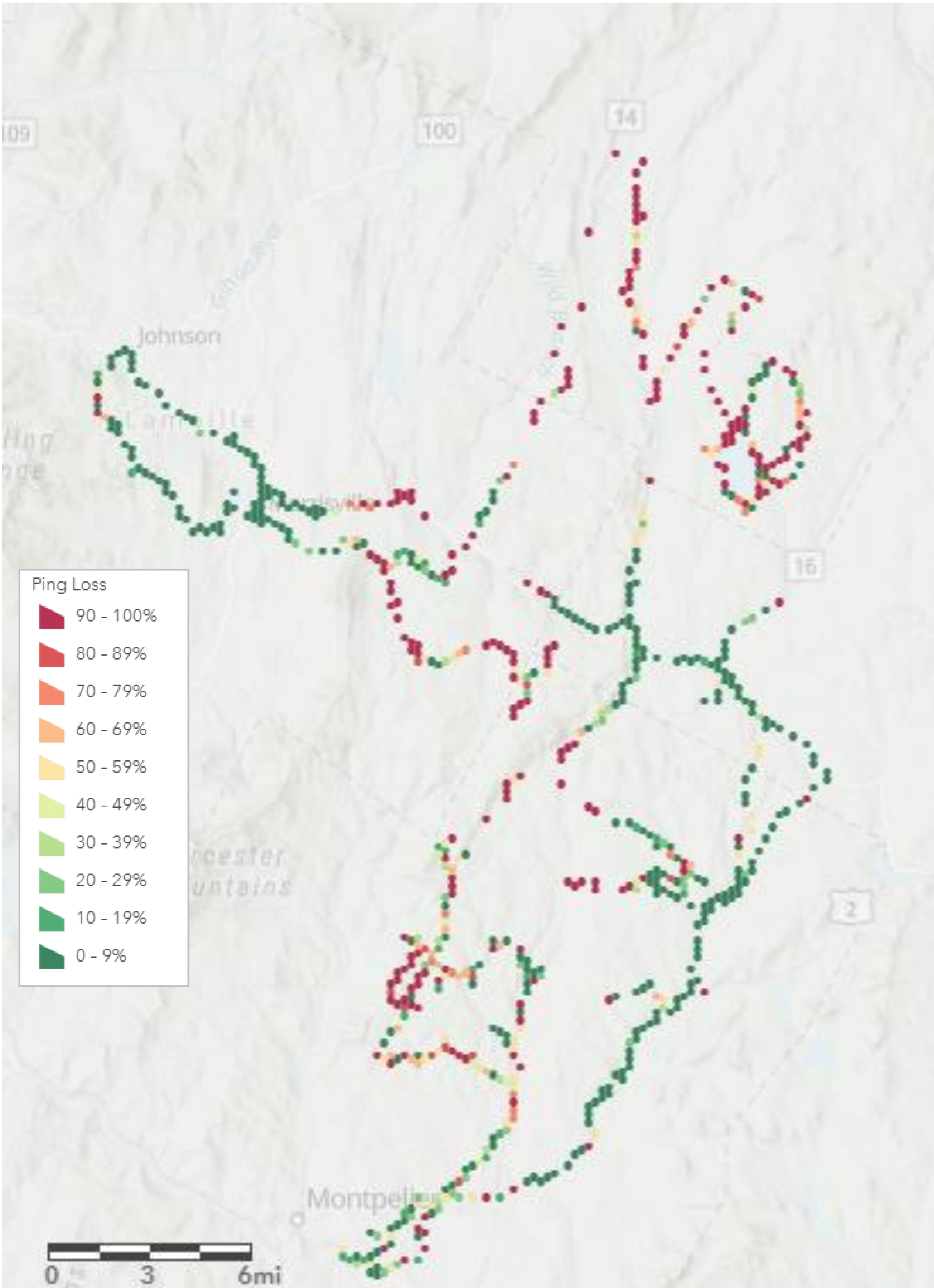


Figure 27: Route 1 Ping Loss Map

Route 2

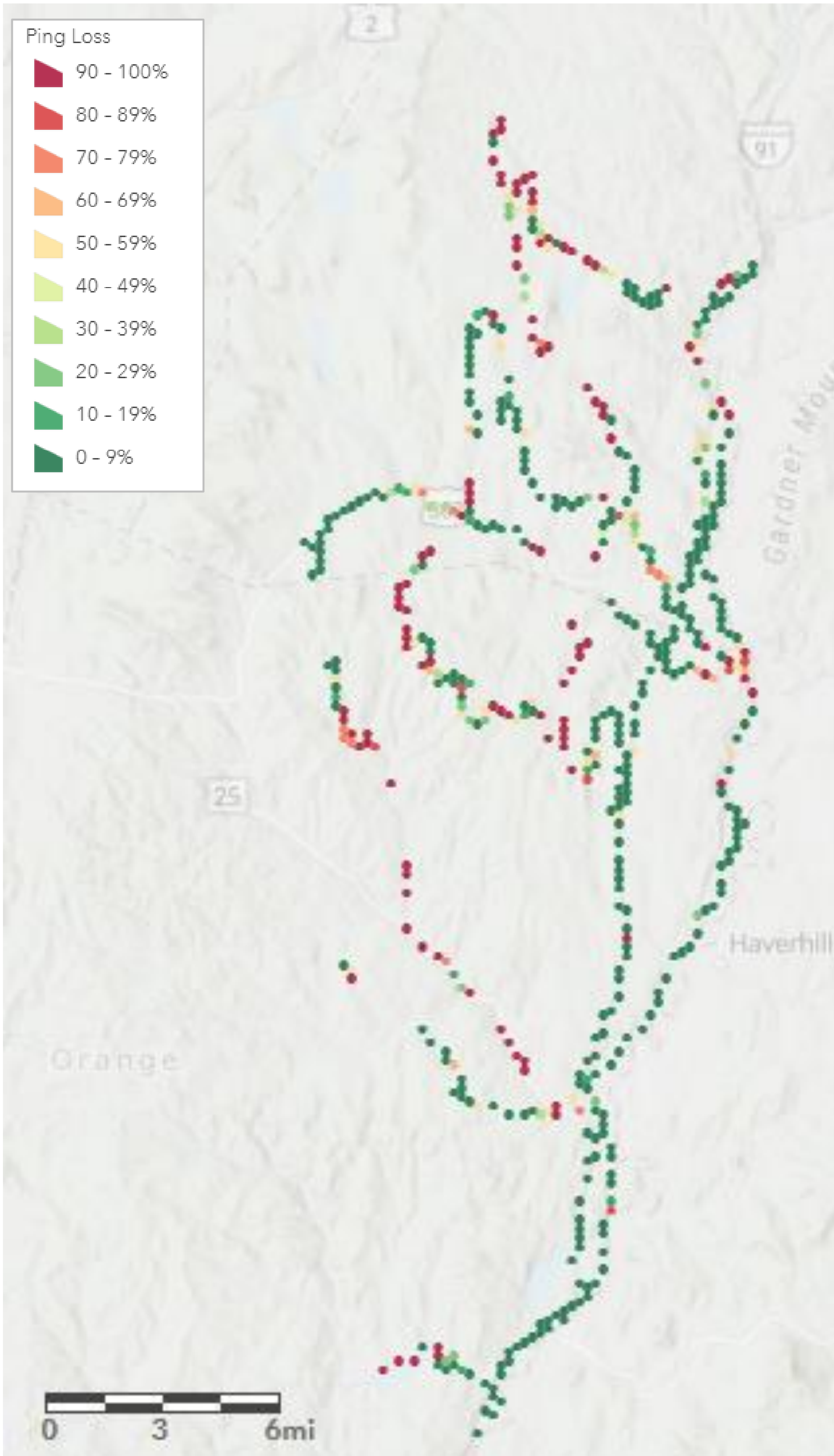


Figure 28: Route 2 Ping Loss Map

Route 3

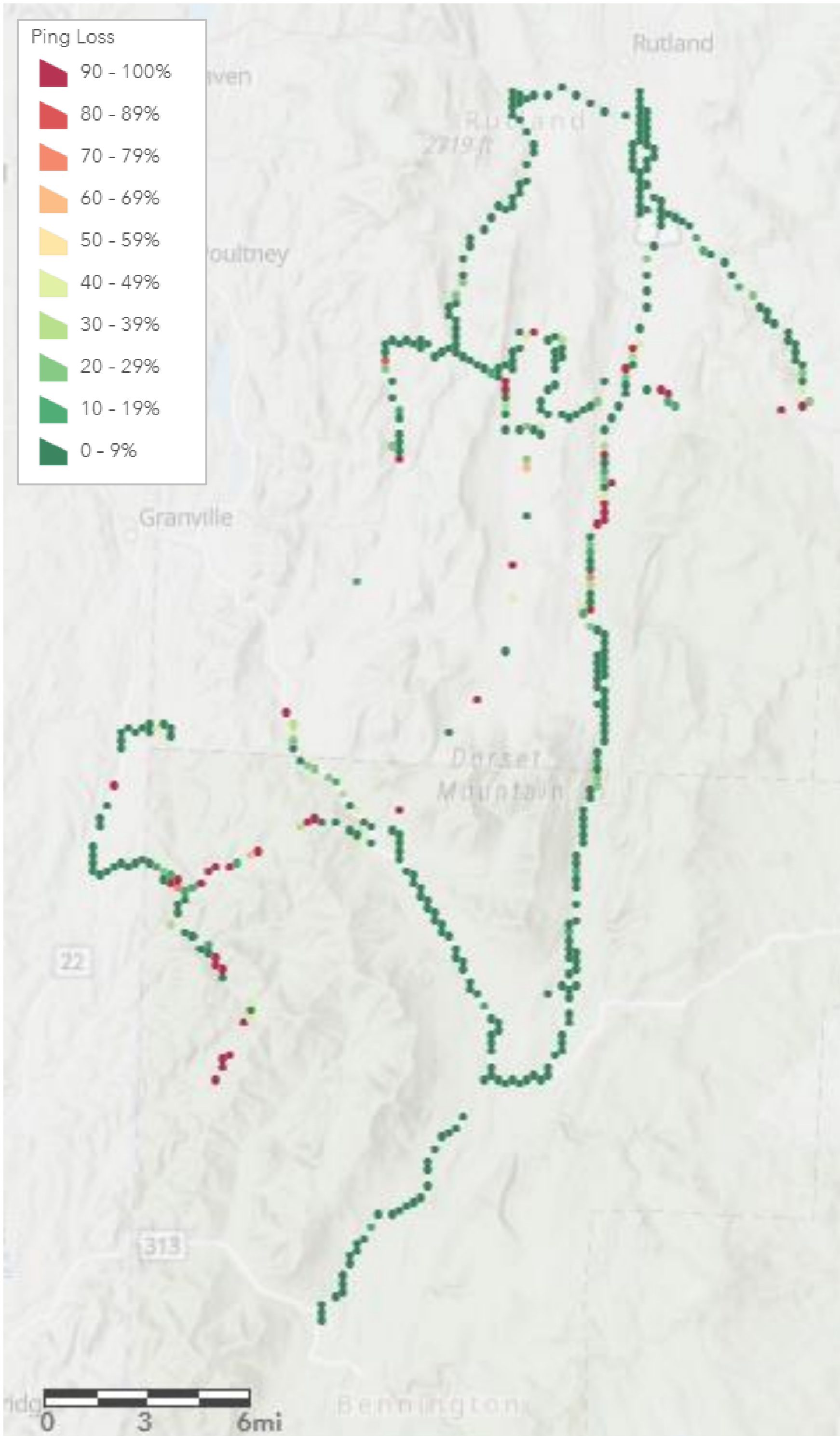


Figure 29: Route 3 Ping Loss Map

Route 4

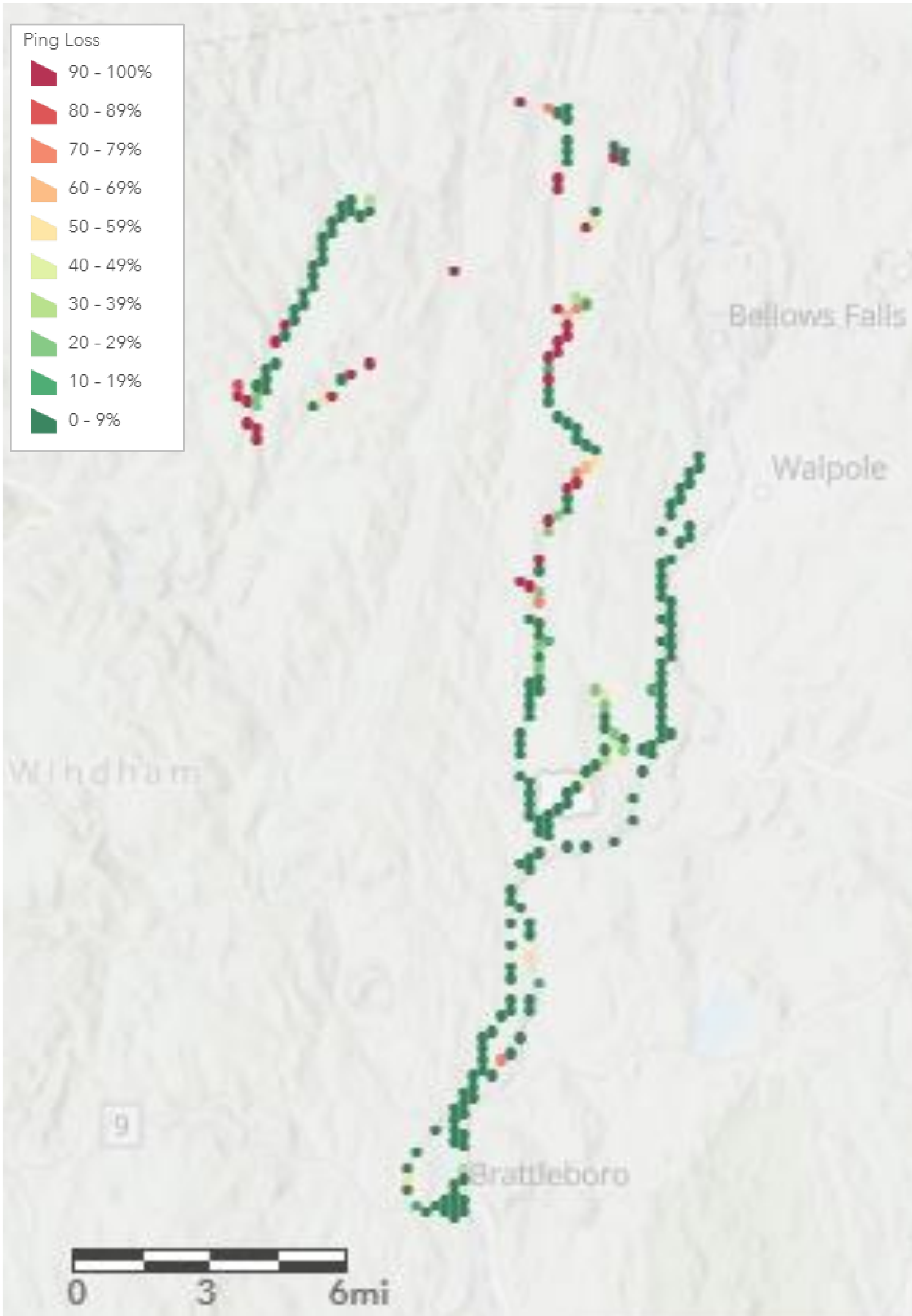
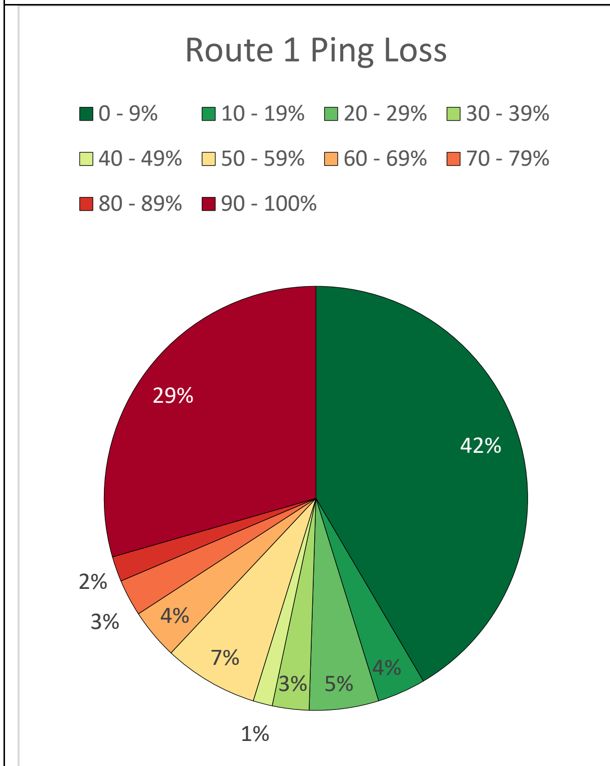
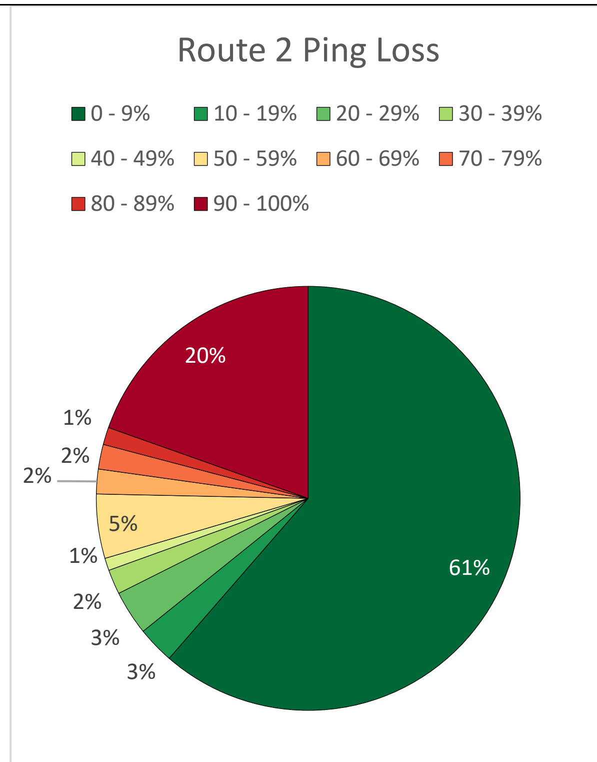


Figure 30: Route 4 Ping Loss Map

Note on Ping Loss: • *Pie charts only represent the percentage of the time the phone was both in service <u>and</u> experienced varying degrees of ping loss. Periods of no service or signal reception are not represented in the charts below.*	
	

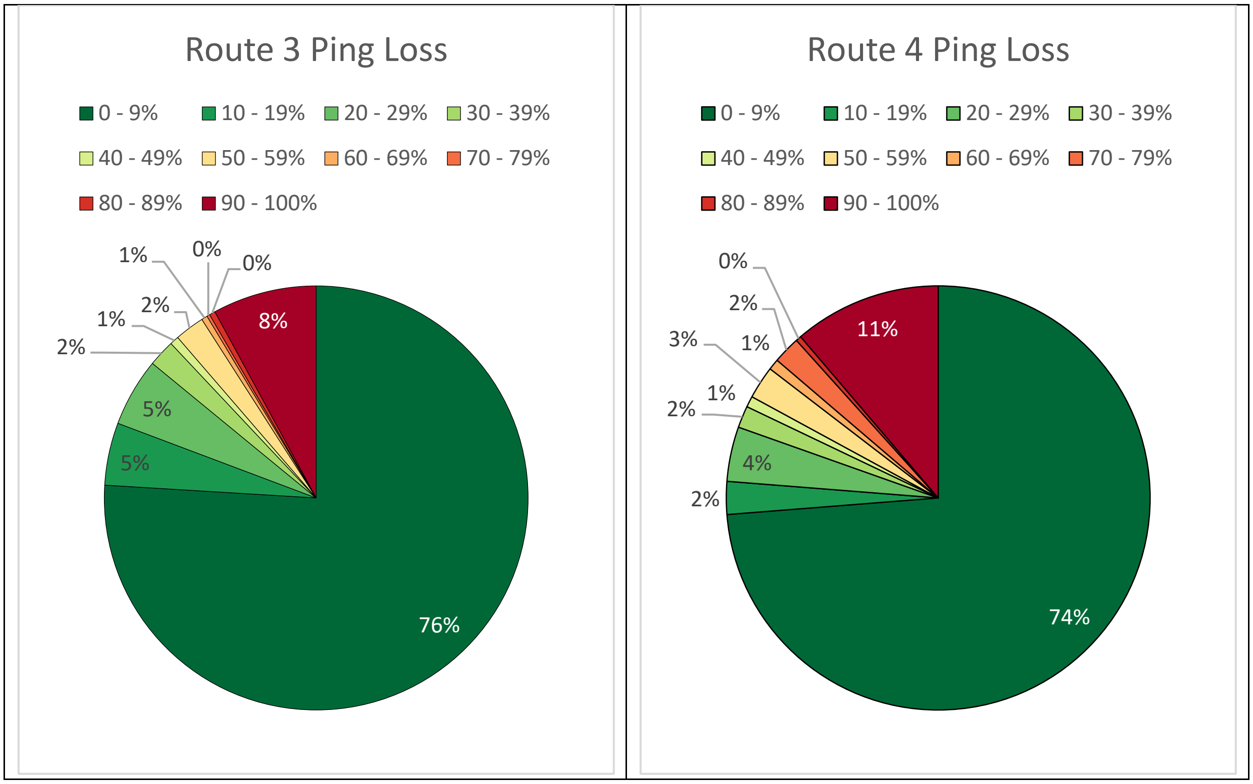


Figure 31: Ping Loss Percentage Per Drive Test Area

The previous charts represent the ping test results where FirstNet service was available. The ping data generally mirrored the data throughput results presented above. In similar terms, Route #3 had the best performance with very low ping loss (less than 10%) 76% of the time, followed by Route #4 at a rate of 74%, Route #2 at a rate of 61% and Route #1 at a rate of 42%. Routes 1 and 2 had very large areas (between 20% and 30% of the ping tests that were conducted) where the ping losses were very high (more than 90%), suggesting that a large amount of the area where there was service, was not sufficiently reliable to fully communicate with a server on the Internet.

Service Level

The service level represents the number of RF signal power level bars provided in the top tray of a smartphone device. The service level varies from zero to four. Because there is no standard with regards to the signal levels or quality the phone manufacturer uses, it is not the indication to compare two services, but is familiar to most users. Service levels range from a value of 0 to 4 bars and may be a meaningful way to compute service reliability for some subscribers.

Note on Service Level:

- *A Service Level of 0 indicates service is low and may be unusable. However, it does not mean the phone is entirely out of service. Map areas with no coloration indicate out of service.*

Route 1

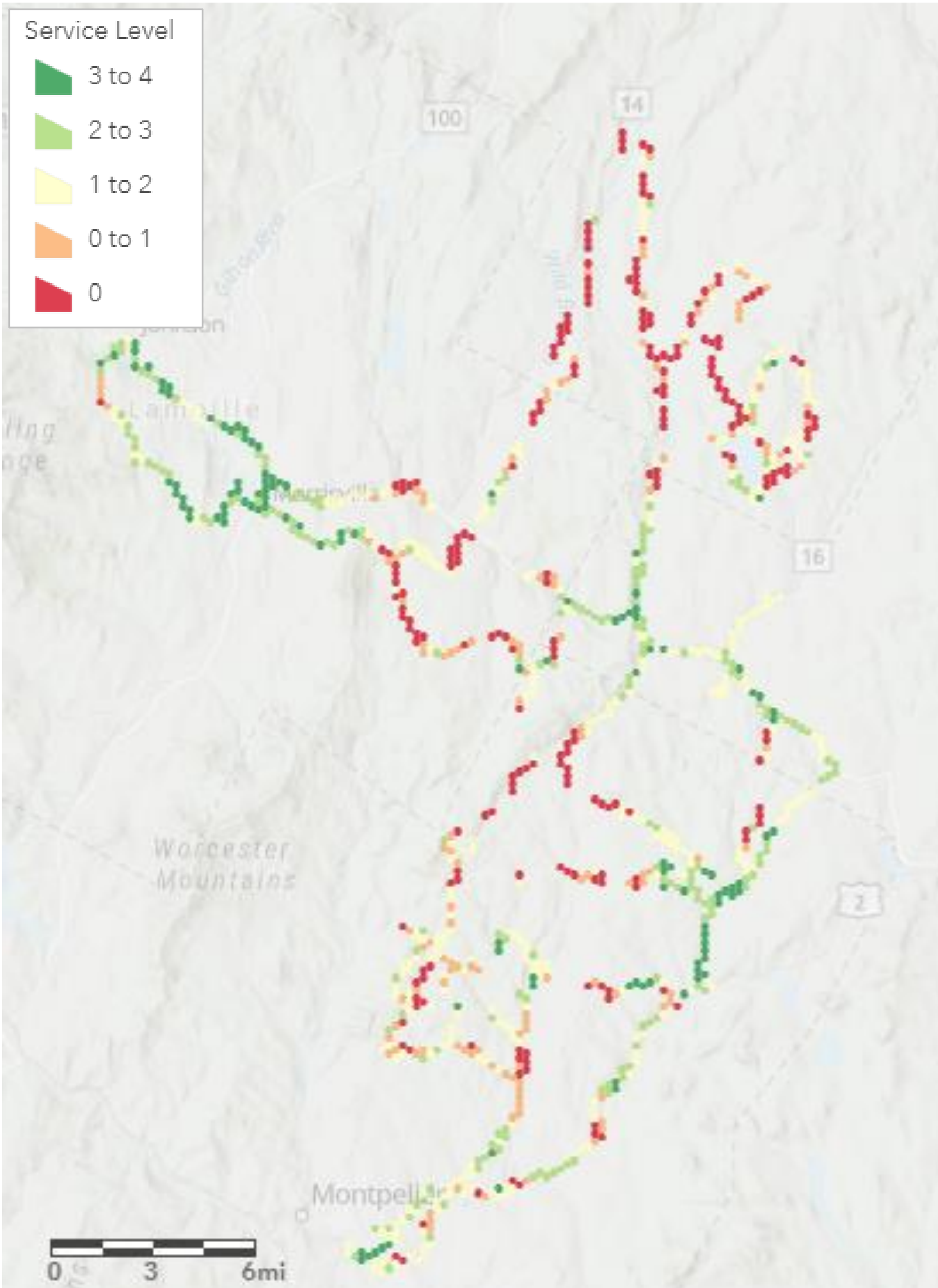


Figure 32: Route 1 Service Level Map

Route 2

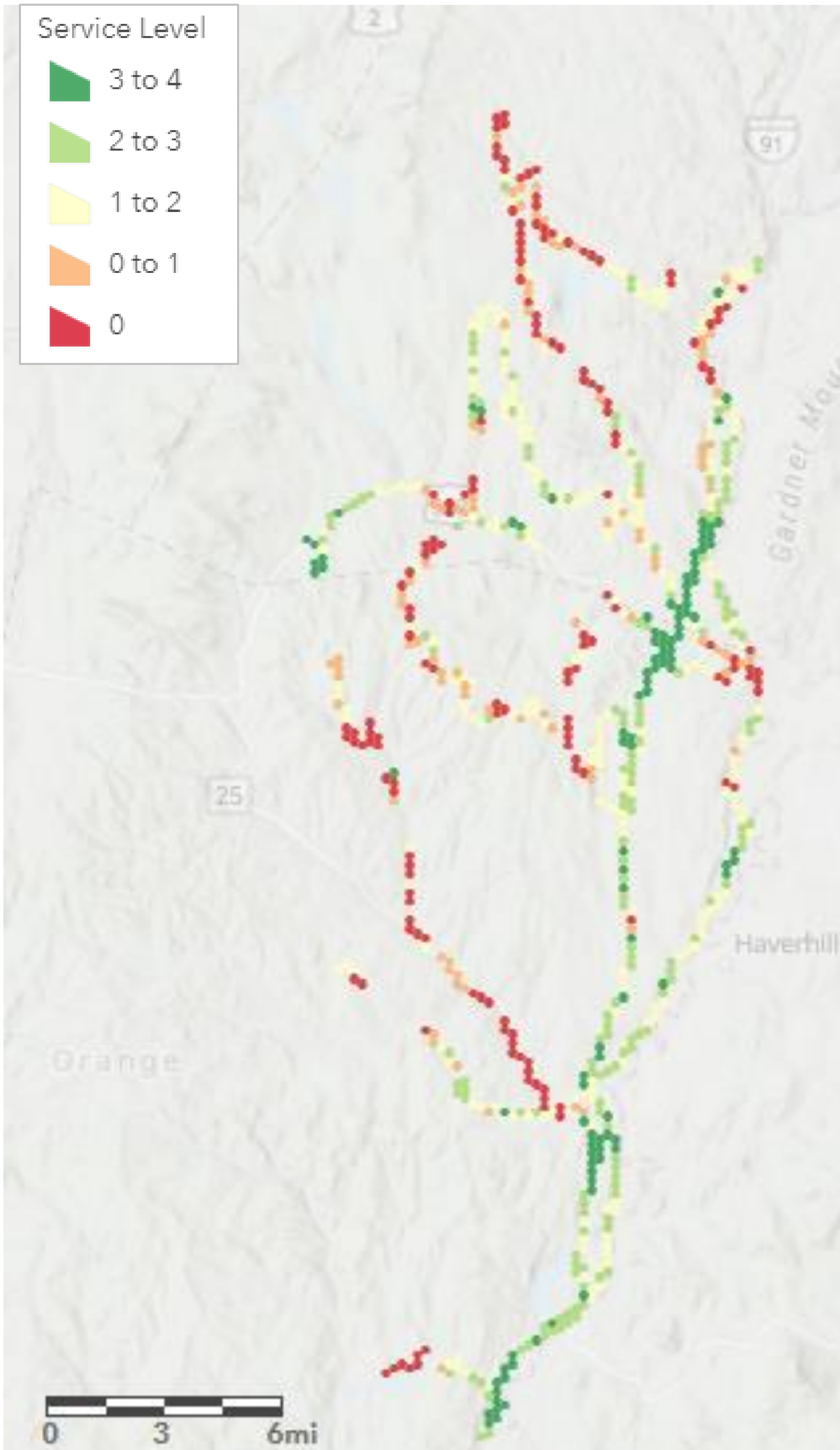


Figure 33: Route 2 Service Level Map

Route 3

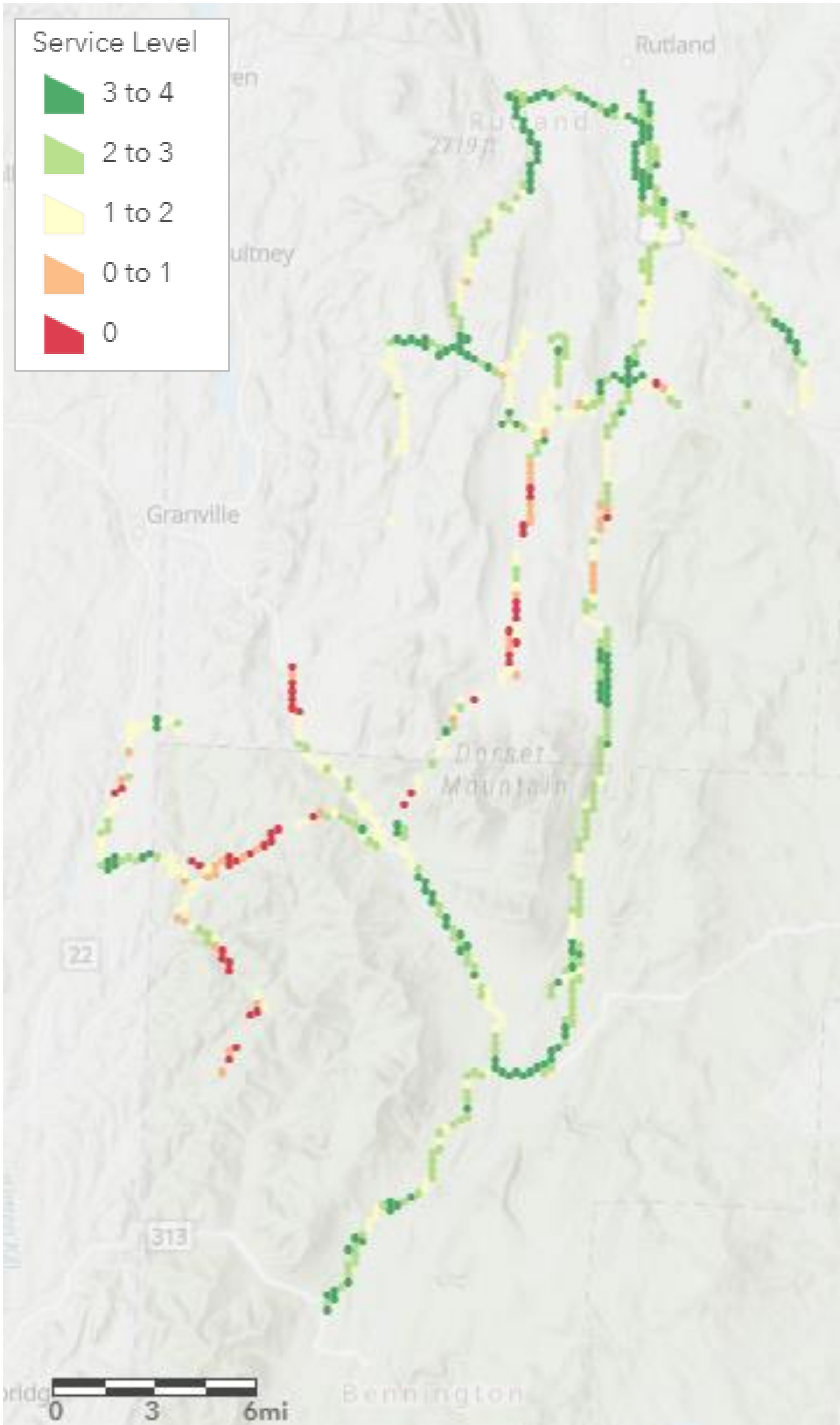


Figure 34: Route 3 Service Level Map

Route 4

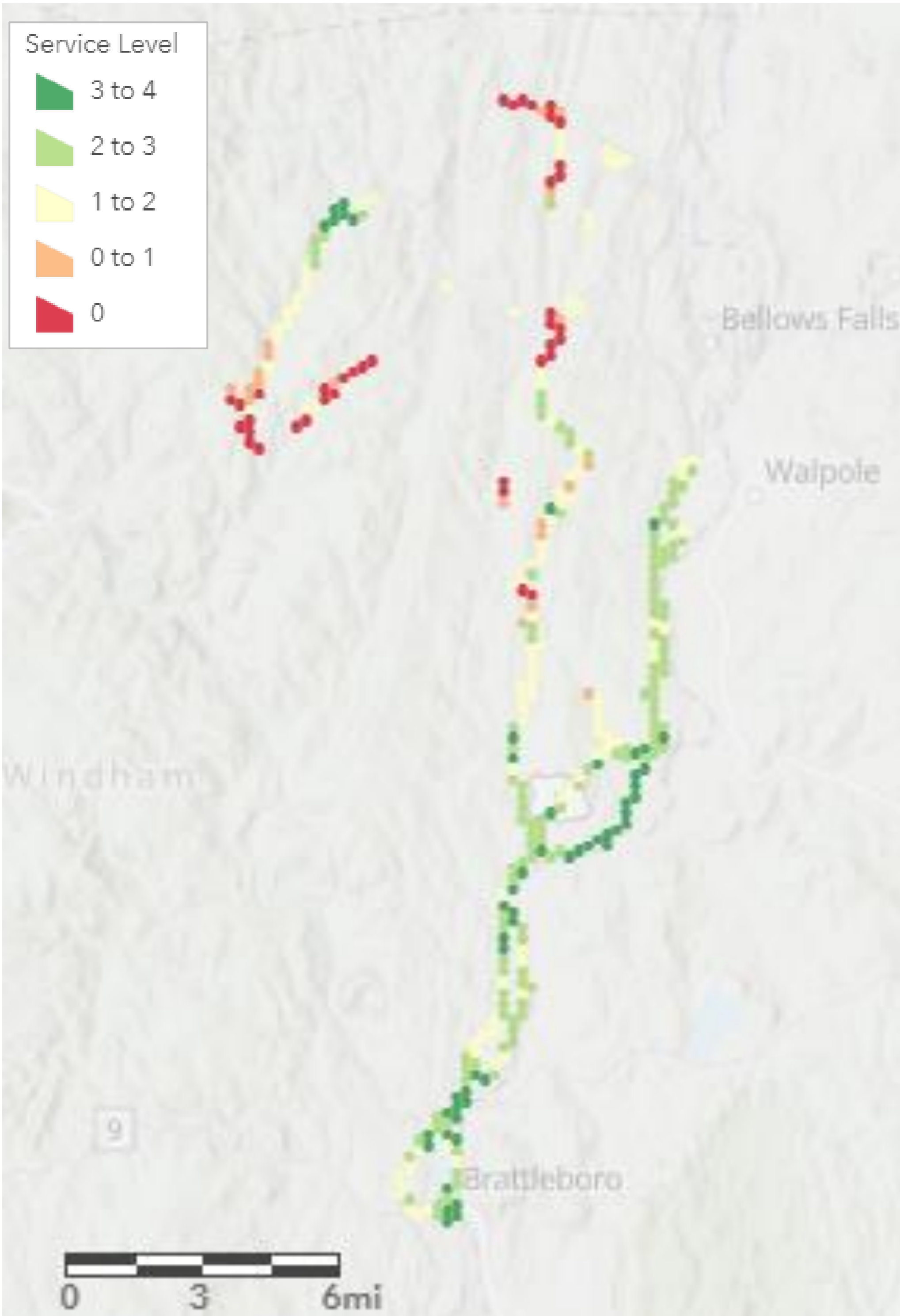


Figure 35: Route 4 Service Level Map

Note on Service Level:

- *Pie charts show the percentage of the time the phone was both in service <u>and</u> reported each service level. Periods of no service or signal reception are not represented in the charts below.*

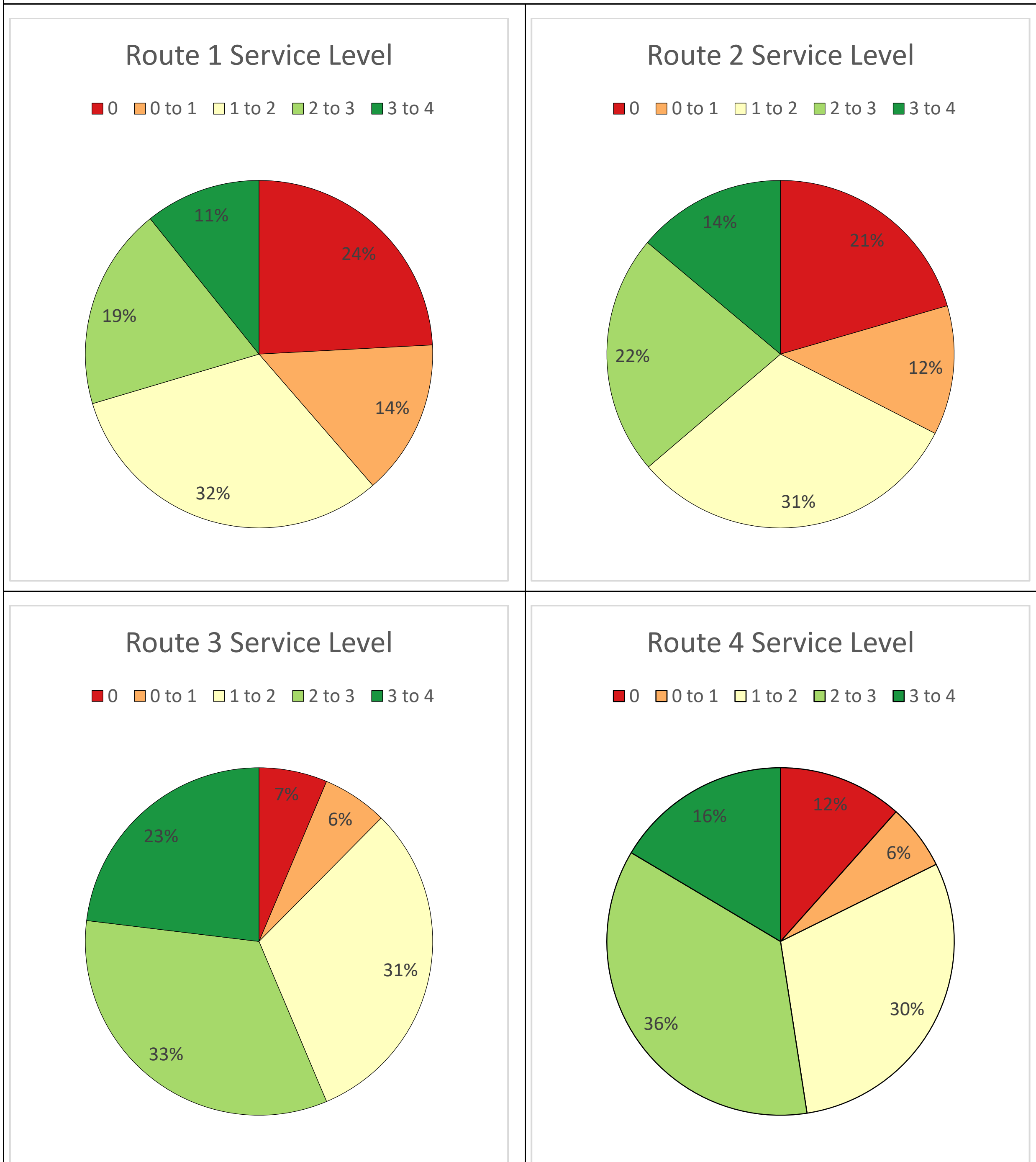


Figure 36: Service Levels Per Drive Test Area

The general expectation from a user's perspective, is that two bars is sufficient for a minimal level of service. Taking this perspective into account Route #3 had the best level of service as indicated with 56% of the time the device had 2 bars or more displayed on the device. Route #4 experienced this level of service 52% of the time followed by Route #2 at 36% and Route #1 at 30%.

Test Result Summary

Over the course of the 1,200 miles driven along the noted test routes, an equivalent of 326 square miles of area was tested. The following table summarizes the results for each route and the key performance indicators of the FirstNet service.

Table 2: Summary of FirstNet Drive Test Coverage Statistics

	Route 1	Route 2	Route 3	Route 4
Equivalent Area (square miles)[17]	120	88	77	41
Good Service Availability (% total area)[18]	44	52	58	56
Spotty Service (% total area)[19]	28	20	25	18
No/Limited Service (% total area)[20]	28	28	17	26
LTE Technology Available (% total area)	51	65	85	83
Good Ping Performance (% area served)[21]	42	61	76	74
Target Download Performance (% area served)[22]	44	62	83	90
Target Upload Performance (% area served)[23]	32	59	75	86

The data suggest that very limited portions of the routes have reliable in-vehicle, broadband service. For example, on Route 1, the device had reliable service in only 44% of the grids, yet, only 32% of the area with any service had good upload performance. The best performing route, Route 3, achieved reliable service in 58% of the grids, and 75% of the grids with any service achieved target data speeds, or a net of 55% of the route had reliable "broadband" service. Roughly a quarter of the routes had little to no coverage.

While Routes 3 and 4 performed fairly well with nearly three quarters of their service areas achieving good performance for ping, upload, and download, the performance for Routes 1 and 2 were

[17] The sum total of the area of all grids traversed on the route.
[18] Percentage of all grids per route that have service availability of 90% or higher
[19] Percentage of all grids per route that have service availability between 10% and 90%
[20] Percentage of all grids per route that have service availability of 10% or less
[21] Percentage of all grids that achieve an average ping loss of less than 10%
[22] Percentage of all grids that achieve average download speed of 768 kbps or higher. Note some users might expect download speeds of 5,000 kbps (5 megabits per second) for broadband service.
[23] Percentage of all grids that achieve average upload speed of 256 kbps or higher. Note some users might expect upload speeds of 2,000 kbps (2 megabits per second) for broadband service.

particularly poor. The data seems to suggest that the data connection from the device to the cell sites (the "uplink") lacked sufficient quality to achieve good ping and upload performance.

Route 1 Summary

Service Availability[24]: Starting from the north, there is a lack of service from Albany to Craftsbury Common. Starting in Craftsbury, there is a large area with no service extending south to Route 15 and Wolcott. East Craftsbury has sparse and inconsistent coverage. Between the village of Greensboro and along Taylor Road there is a large area with a lack of service that extends south along Route 16 to East Hardwick. In the southwest, there is no service along Route 12 between Elmore and Worcester. The entire central area spanning from Woodbury to Calais has poor to no service available. Forty-two percent (42%) of the area tested has excellent service availability (100%). At least 52% of the area has relatively "good" service availability between 70% and 100%, leaving 48% of the area tested with marginal or no service available.

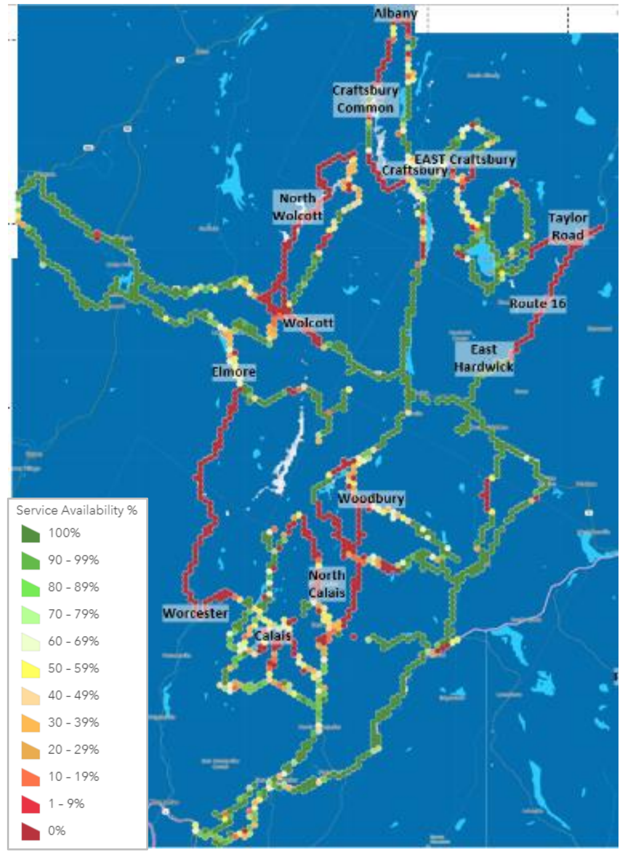


Figure 37: Route 1 Network Availability Map

Signal Level: The signal level maps show a very small area of indoor service (less than 5% of the service area[25]). Based on the measurement data, a total of 34% of the area would have sufficient in-vehicle coverage. Ninety-eight (98%) of the area would have sufficient outdoor service. A total of 2% of the service area was found to have signal levels that would be deemed unreliable even for outdoor service.

Technology: Based on the drive test results, only 51% of the service area had access to 4G-LTE service.

Throughput: Roughly 44% of the service area had sufficient to excellent downlink throughput of 768 kbps or greater. On the uplink, only 32% of the service area had sufficient to excellent uplink

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[24] Overlays of Pinpoint service availability on FirstNet coverage prediction maps are provided in Appendix D.

[25] It is important to note that where the area is the "service area", this represents those aggregate of data where there was any service available. In this case, of the areas where service was available, five percent of that area had signal levels that were sufficient for "indoor" coverage.

throughput of 256 kbps or greater. Examples of typical services that can be supported by different throughput data rates are given by the FCC.[26]

Ping Loss: A ping test is a reflection of reliable service but can be affected by network congestion. The results show that 42% of the service area had a ping loss of 9% or less. A total of 51% of the service area had a marginal reliability with a ping loss of 29% or less.

Frequencies/Band Use: This test evaluated the frequency bands in use by the FirstNet service. For Route 1, only 2% of the service area was served by Band 14. Ninety-eight percent (98%) of the service area was served by AT&T's commercial cellular spectrum holdings.

Route 2 Summary

Service Availability: Starting from the north, Route 2 from Peacham to Barnet has very little to no service. There is a small area of no service north of McIndoe Falls on both Route 5 and Interstate 91. South Ryegate and the area around it suffer from a lack of service. Groton has reasonably good service; however, roads north and south have areas of no service. The area north of Topsham toward the Norwich Reservoir is an area without service. Nearly the entire area from Post Milles to West Fairlee to Vershire along Route 113 is without service. And the area of Corinth and the roads south also lack service. Overall, 50% of the area had excellent service availability (100%). At least 58% of the tested area has relatively "good" service availability between 70% - 100%; leaving 42% of the area tested with marginal or no service available.

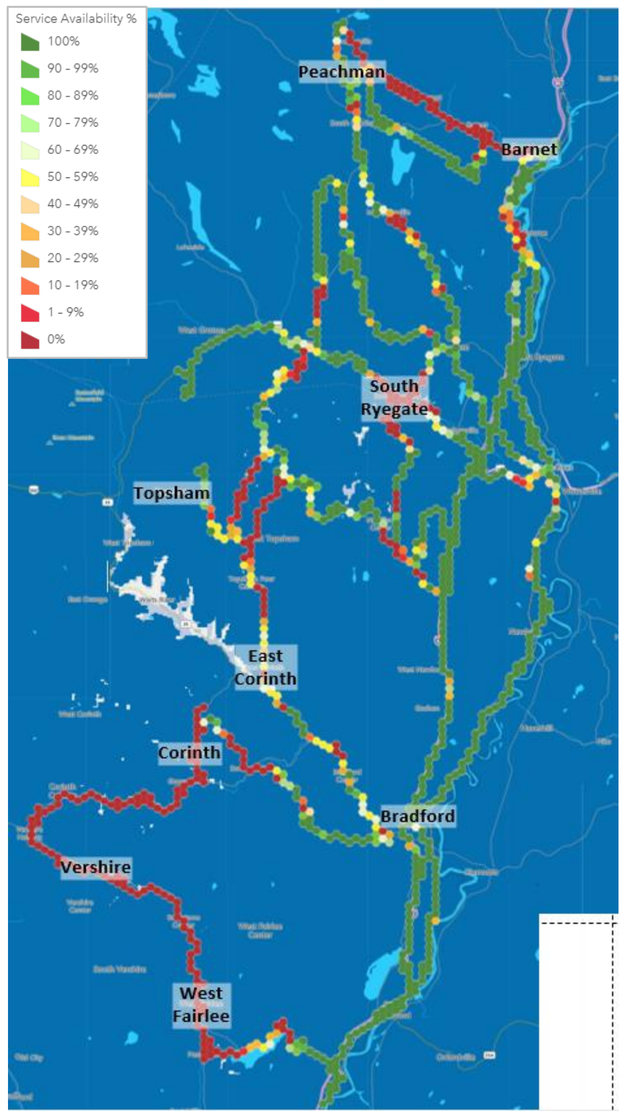

Figure 38: Route 2 Network Availability Map

Signal Level: The signal level maps show a very small area of indoor service (approximately 6% of the service area). Based on the measurement data, a total of 42% of the service area would have sufficient in-vehicle coverage. Ninety-seven percent

[26] See FCC's Household Broadband Guide: https://www.fcc.gov/research-reports/guides/household-broadband-guide and Broadband Speed Guide: https://www.fcc.gov/reports-research/guides/broadband-speed-guide.

(97%) of the service area would have sufficient outdoor service. A total of 3% of the area was found to have signal levels that would not produce reliable, broadband, outdoor service.

Technology: Based on the drive test results, over 65% of the service area had access to 4G-LTE service.

Throughput: Up to 62% of the service area had sufficient to excellent downlink throughput of 768 kbps or greater. On the uplink, 59% of the service area had sufficient to excellent uplink throughput of 256 kbps or greater. Examples of typical services that can be supported by different throughput data rates are given by the FCC.[27]

Ping Loss: A ping test is a reflection of reliable service but can be affected by network congestion. The results show that 61% of the service area had a ping loss of 9% or less. A total of 68% of the service area had a marginal reliability with a ping loss of 29% or less.

Frequencies/Band Use: This test evaluated the frequency bands in use by the FirstNet service. For Route 2, less than 1% of the service area was served by Band 14. Well over 99% of the service area was served by AT&T's commercial cellular spectrum holdings.

Route 3 Summary

Service Availability: Starting from the north, Route 3 had a large area of no service between Middletown Springs and Pawlet on Route 133. The area south of Danby has sporadic coverage. Route 140 from Wallingford to East Wallingford is a large area of no service. Route 313 from West Arlington to Arlington lacks service. Lastly, the roads north from West Arlington to Sandgate and areas further north lack service. Overall, 56% of the area had excellent service availability (100%). At least 68% of the tested area has relatively "good" service availability between 70% and 100%, leaving 32% of the area tested with marginal or no service available.

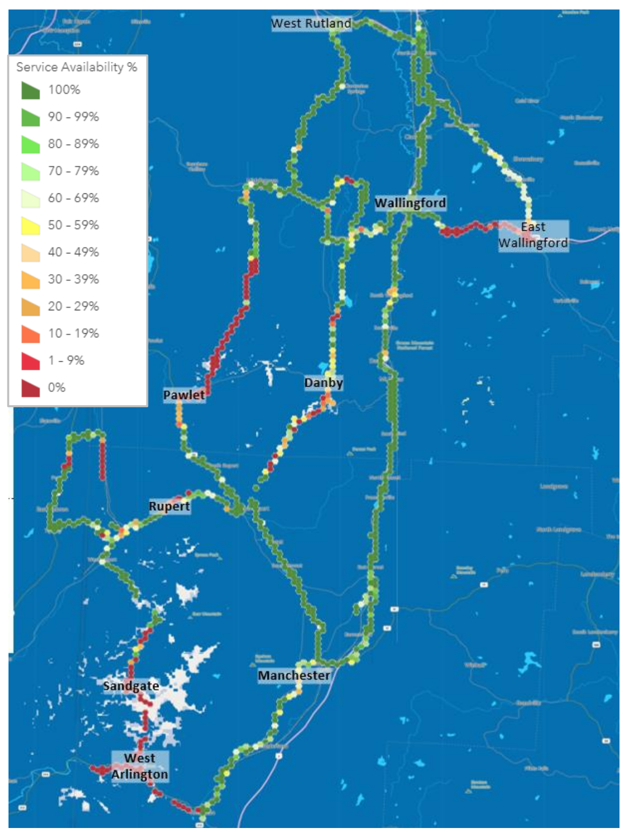

Figure 39: Route 3 Service Availability Map

Signal Level: Route 3 had the largest area with strongest average signal strength. The signal level maps show a very small area of indoor service (less than 10% of the service area). Based on the

[27] See FCC's Household Broadband Guide: https://www.fcc.gov/research-reports/guides/household-broadband-guide and Broadband Speed Guide: https://www.fcc.gov/reports-research/guides/broadband-speed-guide.

measurement data, a total of 62% of the service area would have sufficient in-vehicle coverage. Approximately 98% of the service area would have sufficient outdoor (or greater) service. A total of 2% of the service area was found to have signal levels that would not be sufficient for outdoor reliable broadband service.

Technology: Route 3 had the largest area served by 4G-LTE service. Based on the drive test results, 85% of the service area had access to LTE service. Examples of typical services that can be supported by different throughput data rates are given by the FCC.[28]

Throughput: Around 83% of the service area had sufficient to excellent downlink throughput of 768 kbps or greater. On the uplink, and 75% of the service area had sufficient to excellent uplink throughput of 256 kbps or greater.

Ping Loss: A ping test is a reflection of reliable service but can be affected by network congestion. The results show that 76% of the service area had a ping loss of 9% or less. A total of 86% of the service area had a marginal reliability with a ping loss of 29% or less.

Frequencies/Band Use: This test evaluated the frequency bands in use by the FirstNet service. Of greatest interest is use of Band 14. For Route 3, only 1% of the service area was served by Band14. An estimated 99% of the service area was served by AT&T's commercial cellular spectrum holdings.

Route 4 Summary

Service Availability: There is a large area without service stretching from Grafton to Cambridgeport, south to Athens then west to Saxton River and north to the Town of Rockingham. The road from Saxon River to Westminster West also lacks service. The area north of Simpsonville also lacks service. Overall, 55% of the area tested had excellent service availability (100%). At least 63% of the area has relatively "good" service availability between 70% - 100%, leaving 37% of the area tested with marginal or no service available.

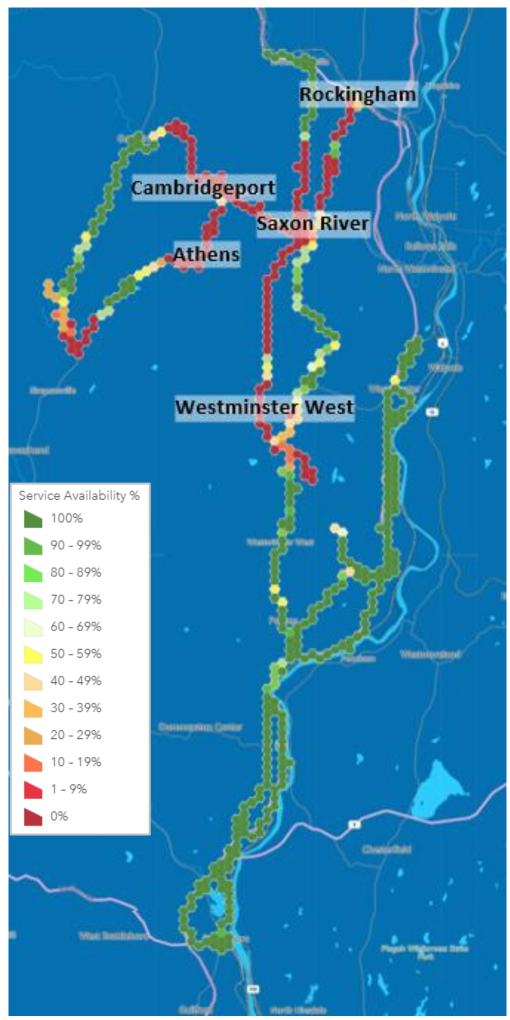

Figure 40: Route 4 Service Availability Map

Signal Level: The signal level maps show a very small area of indoor service (approximately 6% of the service area).

[28] See FCC's Household Broadband Guide: https://www.fcc.gov/research-reports/guides/household-broadband-guide and Broadband Speed Guide: https://www.fcc.gov/reports-research/guides/broadband-speed-guide.

Based on the measurement data, a total of 60% of the service area would have sufficient in-vehicle signal levels. Upwards of 97% of the service area has signals with sufficient levels for outdoor, broadband, service, or better. A total of 3% of the service area had signal levels that were insufficient for reliable, broadband, service.

Technology: Based on the drive test results, 83% of the service area had access to 4G-LTE service. Examples of typical services that can be supported by different throughput data rates are given by the FCC.[29]

Throughput: Route 4 had the largest area with excellent throughput; approximately 90% of the service area had sufficient to excellent downlink throughput of 768 kbps or greater. On the uplink, 86% of the service area had sufficient to excellent uplink throughput of 256 kbps or greater.

Ping Loss: A ping test is a reflection of reliable service but can be affected by network congestion. The results show that 74% of the service area had a ping loss of 9% or less. A total of 80% of the service area had a marginal reliability with a ping loss of 29% or less.

Frequencies/Band Use: This test evaluated the frequency bands in use by the FirstNet service. Route 4 had the largest area covered by Band 14 at 6% of the service area. An estimated 94% of the service area was served by AT&T's commercial cellular spectrum holdings.

[29] See FCC's Household Broadband Guide: https://www.fcc.gov/research-reports/guides/household-broadband-guide and Broadband Speed Guide: https://www.fcc.gov/reports-research/guides/broadband-speed-guide.

Appendix A: Signal Level Discussions

Radio frequency (RF) signal levels received by the subscriber device play a substantial role in the performance of a device. The stronger the signal level, the more likely service will be available and reliable, the more likely broadband data speeds can be achieved, and the more likely signals will be able to penetrate buildings, walls, and vegetation.

Normalizing Signal Levels

The Pinpoint software first normalizes signal levels so that they can be viewed independently of the technologies represented in any map product. This has to do with the channel size of each individual technology and the amount of energy contained in what is measured by the device. Pinpoint normalizes the signal levels of all 3G and 4G wireless technologies to those of 4G-LTE. As a result, other technologies, such as WCDMA employed by AT&T and T-Mobile and EDGE and GPRS employed by AT&T are adjusted to match the levels associated with 4G-LTE.

Imputed Coverage

When the precise configuration associated with all collected data is known, coverage levels can be imputed (computed based on known reference signals). Because we know the general difference in signal losses for various structures, those differences can implicitly approximate coverage in other scenarios. Rather than providing the raw signal level, Televate has performed extensive research on the relationship between signal levels, reliable communications, and various usage scenarios to determine imputed coverage levels.

The ability of a subscriber device to successfully transmit and receive data requires enough signal strength to ensure that the transmission can overcome the effects of noise, i.e., RF interference from common 4G-LTE signals. In addition, devices require even more signal to reliably achieve broadband data speeds. Users are likely to have experienced circumstances where the device shows signal level strength bars that should support service yet cannot transmit any data. This is precisely why Televate uses a more conservative approach to what signal level constitutes "coverage." This signal level baseline establishes the starting point for all other imputed signal levels. As a result of this more conservative approach, less area will be shown to achieve "reliable" communication than the area that receives "any" communication. In other words, the imputed coverage levels for in-vehicle service will represent less area than the service availability of the device operating in the vehicle. This is because additional signal level margins are needed to achieve reliable and beneficial broadband service above and beyond the point where the device shows "out of range" or the equivalent.

From this baseline level, Televate's imputed coverage levels depict general loss factors to impute the coverage in other environment scenarios. The following table represents the associated signal loss factors and the resulting signal levels required to achieve reliable coverage. They assume, as is the case here, that the device was operating in a vehicle and using 4G-LTE based signal levels (the baseline scenario).

Table 3: Signal Loss Factors

	Loss (Gain) Factor (dB)	Minimum Value (dBm)	Notes
In-Vehicle Smartphone Broadband (Baseline)	0	-114	From Televate's research regarding reliable broadband service in Appendix B. Establishes the baseline signal level to achieve "broadband" speeds.
Outdoor Mobile Service	- 11	-125	Based on the calibration for Vermont in Appendix B below, the difference between in vehicle smartphone and mobile rooftop using the baseline reference is 11 dB.
Residential Inbuilding	+10	-104	Using the baseline signal level of -114 dBm for the in-vehicle smartphone, there is a gain of 6 dB from the vehicle-based losses, less 16 dB of residential building loss, netting 10 dB from the baseline.
Commercial Inbuilding	+20	-94	Using the baseline signal level of -114 dBm for the in-vehicle smartphone, there is a gain of 6 dB from the vehicle-based losses, less 26 dB of commercial building loss, netting 20 dB from the baseline.

It is important to note that the receiver sensitivity of various manufacturer smartphones and other 4G-LTE end user devices differ and while one device may support communications at the absolute minimum signal levels noted above, other devices may not maintain communications at the noted minimum signal levels. Communicating over weak 4G-LTE signals may or may not be reliable depending on a variety of factors including the actual end user device, the presence of inter-LTE signal interference, the type of data transmission and the data throughout requirements, and others.

Appendix B: Calibration

Televate calibrated the Pinpoint application against "commercially available signal testing and data processing solutions commonly used by the commercial cellular community." To do so, Televate employed the Infovista TEMS[30] cellular signal measurement system combined with the PCTel's MxFlex scanning receiver[31] to collect signals received for a roof-mounted high-gain antenna. This test configuration was also considered to best mimic the AT&T's outdoor coverage maps that are thought to convey the area that delivers 768 kilobits per second downloads and 256 kilobits per second uploads.[32]

The first step in this calibration process revolves around the signal level at which the Pinpoint application achieves these data speeds for 70% of the time at the "edge" of service (equivalent to a 95% area reliability).[33] Due to the excessively low signal levels received in the areas tested by Televate, the cell area itself was biased to lower signal levels and did not result in an even distribution over the entire cell area of each AT&T cell site. The goal of the calibration is to determine the difference between this roof-mounted, higher-gain antenna produced signal levels and the in-vehicle signal levels received by a standard, off-the-shelf, Samsung phone, and to establish a baseline in-vehicle signal level that achieves 256/768 kbps at the 70th percentile at the cell edge. As previously noted, the in-vehicle smartphone was installed on the vehicle dashboard to provide more optimal in-vehicle service.

Because signal levels can change dramatically over the course of a single download or upload transmission (Pinpoint's downloads and uploads will occur over two to three seconds), there is no one signal level value for each transmission of data. Televate opted to use the localized and averaged signal levels that occurred in each hexagonal grid (approximately one-quarter miles in width) and each grid's associated average upload and download speeds to determine the signal level at which the 50th percentile occurs for the AT&T data speeds. Televate then used signal level groupings in 3-dB increments to pool the samples.[34] The 95th area reliability level would then be the signal level at which the "cell edge" level dropped below the 70th percentile for achieving at least 768 kbps down and 256 kbps up[35].

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[30] https://www.infovista.com/resources/tems/the-evolution-of-the-tems-network-testing-portfolio

[31] https://www.pctel.com/wp-content/uploads/2017/09/SeeGull-MXflex-Brochure.pdf

[32] These throughput levels are referenced as the FCC defined "broadband speeds" for public safety and were the thresholds defined by FirstNet in its RFP for the NPSBN.

[33] See TSB-88.1-E, Section 5.3.2 Service Area Reliability regarding the relationship between area reliability and edge reliability. Because signals are stronger nearer the site, they are inherently more reliable. The edge or "fringe" of the cell site's coverage area is the least reliable and given specific parameters for general radio propagation, the point at which a cell's service area is 95% reliable, the very edge of the cell has 70% reliability.

[34] This increment was chosen to ensure there were a statistical significance number of points in each individual grid.

[35] It should be noted that this approach of equating system performance at these determined percentiles is a common mathematical computation method employed in the wireless industry.

The following figure depicts the percentage of samples achieving the target throughput objective for each 3-dB increment (the high-end signal level is depicted in the *x* axis).

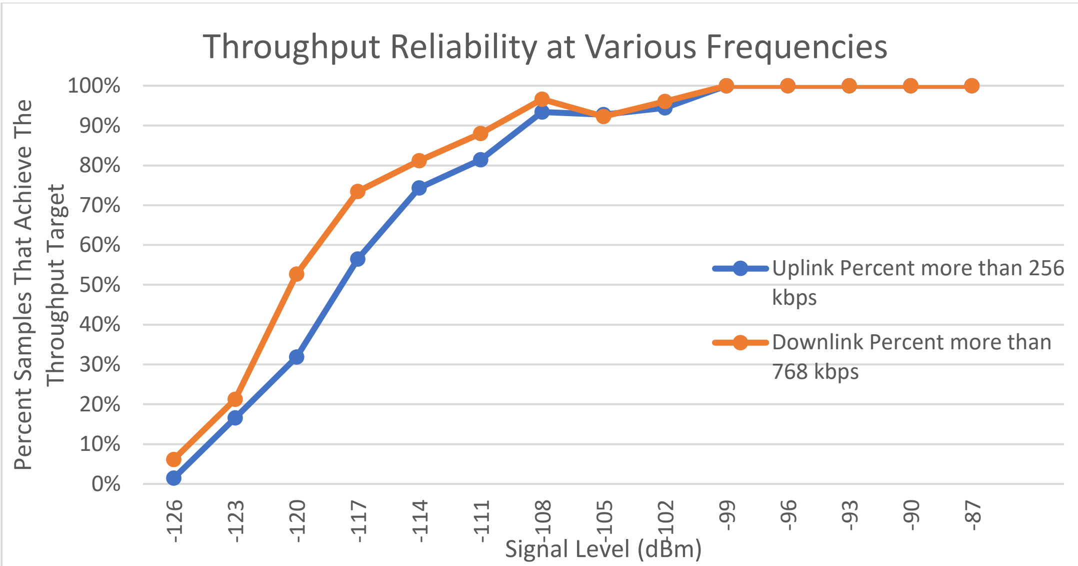

Figure 41: Throughput Reliability at Various Frequencies

The figure above illustrates that 70% of the downlink throughput measurements from the in-vehicle device drop below 768 kbps when the signal level drops below -117 dBm (73% at signal levels between -117 dBm and -114 dBm versus 53% between -117 dBm and -120 dBm). The uplink performed slightly poorer and requires a minimum of -114 dBm in order to achieve 256 kbps (74% of samples for signal levels between -114 and -111 dBm versus 56% of the samples between -114 and -117 dBm). **As a result, the signal level needed to reliably achieve the target 768 kbps down and 256 kbps up for the in-vehicle Samsung smartphone device is -114 dBm because once the signal drops below -114 dBm, the device does not achieve both throughput targets 70% of the time or more.**

It is also interesting to note that the signal level received by the device did not achieve the target throughput reliably until the signal levels were -99 dBm or better. Furthermore, at signal levels between -123 and -120 dBm, the device was only 15 to 20% likely to achieve the desired throughput levels.

In order to then calibrate the in-vehicle versus outdoor device scenario, Televate aligned the measurements between the TEMS/PCTEL "mobile" data against the Pinpoint "smartphone data to determine the signal levels that were captured at the same location. Because the scanner and Pinpoint collects signal level samples at different time intervals, this alignment process ensures that the signal levels occurred in the same location. The process identified the nearest PCTEL signal level value to the Pinpoint coordinates for a frequency operating in the cellular band (comparison of values for different bands is not feasible as the propagation between bands would cause artificial differences). Televate further filtered out points where the GPS accuracy was greater than 20 meters as those points are not deemed to be sufficiently accurate to identify a "co-located" measurement.

Televate then calculated the difference in the “mobile” and “smartphone” signal levels for these filtered points. The average of the difference is 11.25 dB and the median difference is 10.84 dB for this frequency for “co-located” measurement points. This means then that the combination of using a higher gain antenna, which is not subjected to in-vehicle losses, results in a net “gain” of roughly 11 dB.

As a result of this calibration, the signal level for the smartphone inside the vehicle needed to achieve “reliable” broadband speeds is -114 dBm, and, by virtue of the difference in signal levels, a mobile, rooftop based device would be able to achieve this performance for an equivalent in-vehicle level of -125 dBm (-114 dBm – 11 dB difference). This does not mean that the reliability of a rooftop mobile based device scenario is -125 dBm; instead, it means that a signal received by a smartphone inside a vehicle at -125 dBm would have produced a “reliable” broadband connection for a rooftop “high-gain” mobile antenna.