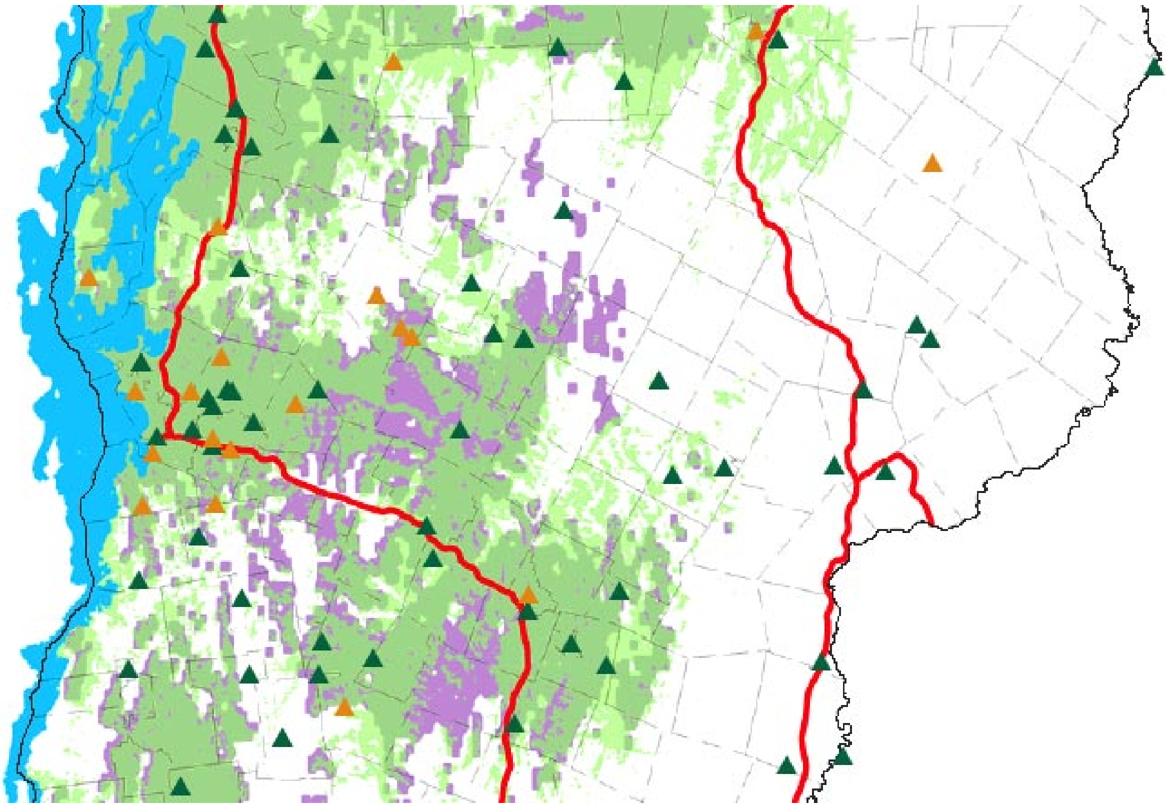
Vermont Wireless Broadband Mapping
Final Report



November 30, 2010
(supersedes all previous versions)

Prepared by:

Pericle Communications Company
1910 Vindicator Drive, Suite 100
Colorado Springs, CO 80919
www.pericle.com

For:

Vermont Center for Geographic Information
58 South Main Street, Suite 2
Waterbury, VT 05676

David F. Brotzman, Executive Director

Table of Contents

Vermont Wireless Broadband Mapping Final Report

1.0 Executive Summary

The Vermont Center for Geographic Information (VCGI) is the State of Vermont's designated agency to administer an ARRA grant from the National Telecommunications and Information Administration (NTIA) under the Broadband Technology Opportunities Program (BTOP). The purpose of this NTIA program, called the State Broadband Data & Development (SBDD) Grant Program, is to map broadband Internet access in the State of Vermont, where *broadband* is defined as at least 768 kbps on the downlink and at least 200 kbps on the uplink.

Broadband access technologies fall into two categories, wireline and wireless. This report is concerned solely with *wireless* broadband access. To assist in the mapping of wireless broadband services, VCGI hired Pericle Communications Company, a consulting engineering firm specializing in wireless communications. At the time the project started in January, 2010, it was common for wireless broadband mapping efforts to rely solely on coverage maps provided by wireless service providers, but VCGI wanted an independent assessment of wireless broadband coverage. The agency asked Pericle to provide this independent assessment through a combination of antenna site data collection, computer modeling of wireless coverage, and a drive test survey to measure actual wireless signal strength and data throughput. Drive test measurements were collected over nearly 4,000 miles of Federal Aid Highways in Vermont and were compared to computer-generated maps to improve the accuracy of these maps and to determine actual throughput rates. The end result is an assessment of broadband coverage that best matches the user experience.

In addition to the broadband data mapping, a parallel set of activities was conducted to assess coverage of wireless voice services.

1.1 Purpose of this Report. Most deliverables under this contract, including the wireless transceiver database, computer-generated coverage maps, and drive test survey data, are delivered separately from this report. The purpose of this report is to describe the wireless mapping process and results with particular focus on a comparison between computer-generated maps and drive test measurements. A key finding of this study is the stark difference between those areas that provide *some* wireless data service and the much smaller areas that provide *broadband* wireless data service (at least 768 kbps on the downlink and 200 kbps on the uplink).

1.2 Services Modeled and Measured. Wireless subscription services are provided by a variety of carriers in Vermont. For the purposes of this project, carriers are categorized as fixed wireless or mobile wireless.

Fixed wireless carriers or Wireless Internet Service Providers (WISPs) offer service via point-to-point radio links, usually with a directional antenna mounted at a elevated point on the subscriber's dwelling. In Vermont, virtually all fixed wireless carriers are companies operating in the license-free frequency bands, 902-928 MHz, 2.4 GHz and 5 GHz. These companies tend to cover small geographical areas. A total of nine companies provided antenna site information: Cloud Alliance, Finowen, GlobalNet, North Branch Networks, LLC, North Country Communications, NCIC, SVBC, WaveComm, LLC, and WirelessVT. Great Auk Wireless and Kingdom Connection declined to participate. Because of the very small geographical area covered and the need for elevated antennas to reliably intercept signals, VCGI decided to limit fixed wireless effort to coverage modeling of those nine companies that provided antenna site information. A total of 135 antenna sectors were modeled.

For our purposes, mobile wireless service is provided by cellular phone service providers, also known as *wireless carriers*. The principal mobile wireless carriers in Vermont are AT&T Mobility, Nextel, Sprint, T-Mobile, U.S. Cellular and Verizon Wireless. [1] All of these companies provide wireless voice services, but as of June 30, 2010 (per the NTIA SBDD grant requirements), only four provided broadband Internet access (> 768 kbps).

1.3 Approach. With assistance from Pericle, VCGI made formal requests to the four carriers for specific cell site information so this data could be entered into a database and used for computer coverage modeling. All four carriers declined to provide this information but after executing non-disclosure agreements, the carriers did provide electronic versions of their coverage maps (as Esri Shapefiles). No cell site information was provided by the carriers, but the State of Vermont's Act 250 database and other information sources were used to determine the location and technical parameters of the carriers' cell sites. An extraordinary effort was made to collect the information that was finally used but without cooperation from the carriers, the information was still incomplete.

It was possible to generate coverage maps from the data that was collected, but the lack of complete data made a drive test survey all the more important. The drive test survey was conducted in June, 2010 over more than 4,000 miles of Federal Aid Highways in Vermont. A software-controlled handset was used with registered service on each of the six wireless carriers' networks. Each handset was instrumented to collect GPS coordinates, time of day, serving cell site (if available), airlink technology, roaming status, and other relevant information. In addition to collecting this telemetry data, each handset was also controlled automatically to place and receive both data and voice calls. The success or failure of each data and voice call was recorded and 2-3 blocks of information were transmitted on each data call so that throughput could be measured. The throughput statistics were used to determine if the user could expect true broadband rates (768/200 kbps) or something less.

1.4 Broadband Wireless Data Service Results. Tables 1 and 2 summarize the broadband wireless data results measured from the drive test survey. The second column in each table

[1] Sprint acquired Nextel Corporation in 2004, but the Nextel network employs an entirely different airlink technology called iDEN and the two networks operate independently. We will consider each network separately.

shows the total number of call attempts made on each carrier's network. The next two columns indicate the percentage of calls that were successful at any rate and at broadband rates, regardless of whether the carrier claims to have coverage at that location or not. The last two columns indicate the percentage of successful calls that occurred inside a polygon from the carrier-furnished coverage map. In other words, these right most two columns consider only those calls placed in those areas where the carrier claims to have wireless coverage. We should point out that some carriers did not distinguish on their maps where broadband coverage (e.g., EV-DO) was available and where only low data rate coverage (e.g., 1XRTT) was available.

Table 1 - Broadband Wireless Data Drive Test Results - Downlink

Carrier	Call Attempts	All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	10969	77%	32%	89%	58%
Sprint	12575	45%	3%	93%	7%
U.S. Cellular	12761	32%	7%	86%	23%
Verizon Wireless	10205	76%	21%	94%	29%

Table 2 - Broadband Wireless Data Drive Test Results - Uplink

Carrier	Call Attempts	All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 200 kbps)	Successful (Any Rate)	Successful (> 200 kbps)
AT&T Mobility	10969	71%	34%	85%	62%
Sprint	12575	42%	16%	91%	40%
U.S. Cellular	12761	29%	2%	84%	6%
Verizon Wireless	10205	73%	32%	93%	44%

The reader will note the significant difference between the number of successful data calls completed at any rate and the number of data calls completed at broadband rates. There are several reasons why these differences might occur:

- The serving cell site was not configured for broadband service. For example, a Sprint, U.S. Cellular or Verizon cell site might be configured for older 1XRTT technology rather than EV-DO. Or, an AT&T or T-Mobile cell site might be configured for older GSM/EDGE technology rather than UMTS/HSPA.

- The signal was too weak or more generally, the carrier-to-interference plus noise ratio ($C/I+N$) was too small to reliably operate at broadband rates even if broadband service was available at the site.

- The site was congested with too many subscribers.

- The backhaul TCP/IP network was congested. This condition varies throughout the day and is independent of the condition of the radio link.

Performance differences between carriers for all call attempts (regardless of throughput) can be attributed to the size of the network. AT&T Mobility and Verizon Wireless have larger networks in Vermont than Sprint or U.S. Cellular. **The Sprint or U.S. Cellular user experience can be much better than indicated, however, because both Sprint and U.S. Cellular users are allowed to roam onto the Verizon Wireless network**. This roaming is often seamless and occurs unbeknownst to the subscriber.

1.5 Wireless Voice Service Results. The wireless voice drive test results are shown in Table 3. The values in the right most column indicate coverage within the Pericle computer-modeled coverage polygon.[2] In other words, these calls were placed in areas where one would expect service to be available. **Note that poor overall coverage for Sprint, T-Mobile and U.S. Cellular (third column from the left) is not necessarily representative of the user experience because subscribers on these systems can roam onto Verizon and AT&T Mobility networks**.

Table 3 - Wireless Voice Drive Test Results
(Percent of calls that were successful)

Carrier	Call Attempts	All Attempts	Within Coverage Polygon
AT&T Mobility	10969	86%	96%
Nextel	32654	51%	86%
Sprint	12575	49%	93%
T-Mobile	10404	24%	98%
U.S. Cellular	12764	34%	86%
Verizon Wireless	10209	80%	96%

Computer-generated and drive test survey coverage maps are found in Appendix C to this report.

The remainder of this report is organized as follows: Section 2.0 describes the scope of work and provides other project background information. Section 3.0 is a tutorial on wireless airlink technologies and standards. This information is important because it helps one understand the challenges with providing 768 kbps rates on a mobile wireless channel and the complexities of measuring coverage on operational networks. In Section 4.0, we explain the coverage modeling process and the software tools used to generate coverage maps. Section 5.0 describes the methods, software and hardware used to conduct the statewide drive test survey. Section 6.0 deals with data analysis and data post-processing. Section 7.0 concludes the report

[2]Pericle-generated coverage maps were the only maps provided for voice coverage because the carriers did not provide voice cover age Shapefiles, only data coverage.

with a summary of the results. Cited references and a list of acronyms are found in Sections 8.0 and 9.0, respectively.

2.0 Project Background

2.1 Project Description. The broadband wireless mapping effort is part of a larger State of Vermont broadband mapping project funded under the NTIA State Broadband Data & Development Grant Program. The purpose of this program is to map broadband Internet access in all 50 states so this information can be used by the public and by policy makers to increase broadband access. An initial assessment of broadband access as of December 31, 2009 was to be provided to the NTIA on March 31, 2010. A more complete and updated assessment of broadband access as of June 30, 2010 was to be provided to the NTIA on September 30, 2010.

Before the current project, it was common for broadband mapping efforts to rely solely on carrier-provided coverage maps to assess broadband access. This approach was widely criticized, especially when no assumptions were provided with the maps. For example, rarely did the carrier indicate what data rates could be expected within the coverage boundary nor did the carrier indicate whether the coverage boundary represented the mean threshold of service or some higher probability of service such as 95%. In the carrier's defense, its coverage maps are generated for the benefit of its subscribers and not for the NTIA.

VCGI wanted an independent assessment of wireless broadband data coverage and toward that end, the agency contracted with Pericle Communications Company ("Pericle") to collect transceiver data, model coverage and collect drive test measurements. The principal objectives were an independent assessment of the carrier-provided coverage maps and actual measurement of wireless data throughput under real-world conditions. [3] Pericle was chosen because the firm has over 17 years experience in both modeling and drive testing for government and commercial radio users.

The Vermont Telephone Authority (VTA) partnered with VCGI to characterize wireless voice coverage in the State of Vermont. Voice coverage was outside the scope of the NTIA-sponsored program, but all wireless carriers provide both data and voice services, so there were economies of scale if the projects were done jointly.

2.2 Scope of Work. The seven wireless mapping activities are summarized below. The complete scope of work for the Pericle subcontract is found in Appendix A to this report.

> Activity 1 – Description (Wireless Data Transceivers): The Contractor shall provide the location (Latitude/Longitude coordinate) and characteristics of terrestrial wireless broadband [4] transceivers for

[3] Originally, the contract with Pericle required only received signal strength from drive testing. Pericle suggested and subsequently provided data throughput and voice call success measurements in addition to received signal strength.

[4] In the NTIA State Broadband Data and Development Grant Program, Broadband is defined as "data transmission technology that

both commercial federally licensed wireless and commercial unlicensed wireless service. Each transceiver shall be identified as a transceiver providing mobile or fixed broadband service, and the spectrum used, including whether it is licensed or unlicensed.

Activity 2 – Description (Wireless Data Coverage Maps): The Contractor shall use the wireless transceiver information collected under Activity #1 to generate high-quality radio frequency (RF) propagation coverage maps accurately depicting the strength and geographic extent of wireless data services (fixed and mobile) emanating from each transceiver.

Activity 3 – Description (Wireless Voice Transceivers): The location (Latitude/Longitude coordinate) and characteristics of every transceiver providing terrestrial wireless voice services within the State of Vermont must be mapped under this activity.

Activity 4 – Description (Wireless Voice Coverage Maps): The contractor shall use the wireless transceiver information collected under Activity #3 to generate high-quality radio frequency (RF) propagation coverage maps accurately depicting the strength and geographic extent of wireless voice services emanating from each transceiver.

Activity 5 – Description (Wireless Drive Testing): The contractor shall collect real-time mobile and fixed wireless information in the field using appropriate drive-testing data collection and mapping methods.

Activity 6 – Description (Wireless Map Validation and Calibration): The contractor shall use the drive-test data collected under Activity #5 to determine the accuracy of the wireless propagation coverage datasets generated in Activity #2 and #4. The contractor shall also create a separate set of "calibrated" RF propagation maps (rasters) using the results of the drive-testing effort.

Activity 7 – (Deliverables Update): The Contractor shall provide updated data for all deliverables identified in Activities 2, 4 and 6 based upon updated transceiver location and characteristic information provided by VCGI. The existing requirements for each of those Activities will still apply, with the exception of the data collection accuracy date. All data collected and delivered for this activity shall be updated with information accurate as of 6/30/2010 or later.

The period of performance for this subcontract was January 4, 2010 through September 30, 2010.

3.0 Wireless Technologies and Airlink Standards

3.1 Mobile Wireless Airlink Standards. To date, cellular phones have seen three generations of technology and a fourth generation is on the verge of deployment.

In 1983, AT&T launched the first cellular phone network in Chicago, Illinois. This network was based on the Advanced Mobile Phone System (AMPS) developed and perfected by Bell Labs in the late 1970s. AMPS used frequency modulation and Frequency Division Multiple Access (FDMA). To enable this new service, the FCC allocated 666 channels, each 30 kHz wide, in two bands: 825-835 MHz for subscriber to base station and 870-890 MHz for base

provides two-way transmission to and from the Internet with advertised speeds of at least 768 kilobits per second (kbps) downstream and at least 200 kbps upstream to end users, or providing sufficient capacity in a middle mile project to support the provision of broadband service to end users within the project area". Broadband Service is defined as " the provision of broadband on either a commercial or non-commercial basis".

station to subscriber. To promote competition, the FCC further split the cellular spectrum into two parts and offered licenses to two carriers in each metropolitan or rural subscriber area. Each carrier was licensed for 333 channels, 21 of which were used for control channels. AMPS employed a 7-cell frequency reuse pattern which created spectrum efficiencies much greater than any previous land mobile radio system. After just a few years of service, cellular radio proved to be economically viable and in 1986 the FCC released an additional 10 MHz of spectrum which had been kept in reserve. This first generation network was almost exclusively a voice service.

By the early 1990s cellular radio had outgrown its spectrum allocation and no additional spectrum was immediately available. The wireless carriers badly needed improved spectrum efficiency and they chose new digital modulation techniques to solve the problem. Initially, all U.S. carriers agreed upon a Time Division Multiple Access (TDMA) solution which offered six time slots per 20 ms frame. Vocoders of the time period required two time slots per frame, so the spectrum efficiency was improved by a factor of three over AMPS. Before TDMA networks were fully deployed, a San Diego company called Qualcomm proposed a Code Division Multiple Access (CDMA) solution that promised capacity improvements of 20 times AMPS. Unlike Europe where all carriers agreed on single TDMA standard called GSM, the United States carriers split between the U.S. version of TDMA and Qualcomm's CDMA. At the time, subscriber growth was 40% per year and technology improvements alone could not keep up. Recognizing this problem, the FCC auctioned off the first PCS spectrum (1850-1990 MHz) in 1995 and opened the door to several more wireless carriers in each service area. For the most part, PCS licensees built networks based on GSM and CDMA. These second generation networks were still almost exclusively voice services.

In 1998, after prompting from the Japanese, the international standards bodies committed to develop third generation (3G) wireless standards with the primary goal of offering multimedia wireless services (voice, data and video). The Internet was just catching on and for the first time, wireless data was the primary motivation behind a new wireless standard. Interestingly, both technology camps chose CDMA as the basic 3rd generation technology, but with two incompatible flavors: UMTS for GSM carriers and cdma2000 for CDMA carriers. Today's third generation wireless networks offer between 384 kbps and 14 Mbps, depending on proximity to the cell site and user mobility.

At the same time these expensive 3G cellular phone technologies were being deployed, a cheap alternative called WiFi was quietly sweeping the nation using license-free spectrum in the 2.4 and 5 GHz bands. WiFi lacked a seamless nationwide network, but it offered much higher bit rates and often the service was free if one could find a "hot spot." WiFi radios are based on the IEEE 802.11 series of standards which employ Orthogonal Frequency Division Multiplexing (OFDM) and Carrier Sense Multiple Access with collision detection (CSMA-CD). WiFi networks typically operate between 6 Mbps and 54 Mbps, depending on proximity to the base station, called the Access Point (AP). A new WiFi standard, 802.11n, can theoretically operate at rates up to 600 Mbps (with a 40 MHz channel), but conditions must be highly favorable to achieve this high rate.

From a user perspective, the choice in 2010 is free high speed data with poor mobility and spotty coverage (WiFi), or relatively expensive medium speed data with seamless nationwide coverage (3G). Smart phones do both and it's not clear who is winning the wireless data war, but it is clear that wireless carriers are under extreme pressure to offer cheap high speed wireless data at comparable data rates to WiFi. The carriers' response to this challenge is the fourth generation (4G) standards process, begun in 2004.

The first 4G standard to be published and adopted by a nationwide carrier is called Long Term Evolution (LTE). LTE is fast, with peak data rates of 100 Mbps downlink and 50 Mbps uplink (assuming a 2 x 20 MHz channel). Downlink and uplink are decoupled for the first time in a cellular network. Third generation and older systems use Frequency Division Duplexing (FDD) which means that one band of frequencies is used for the downlink (base station to mobile user) and another band of frequencies is used for the uplink (mobile user to base station). Such a system uses spectrum inefficiently when the traffic is unbalanced, i.e., when there is more traffic on the downlink than the uplink. LTE offers both FDD and Time Division Duplexing (TDD), which means the uplink and downlink speeds need not be identical, so carriers can better optimize their networks to use more uplink channels. LTE is also IP-based, so all traffic, including voice, is packetized. Advantages of LTE over earlier technologies include higher throughput, lower latency, and a simple architecture resulting in low operating costs. LTE also supports seamless connection to existing 2G and 3G networks, including GSM, CDMA, UMTS, and cdma2000.

AT&T Mobility and Verizon Wireless announced plans to adopt LTE for their 4G networks with the first markets rolling out in late 2010. Sprint took a different approach and adopted WiMAX for deployment on channels in the 2.5 GHz EBS and BRS bands. Sprint's affiliate, Clearwire, is constructing this 4G network and the first markets were launched in 2010. Like LTE, WiMAX employs OFDM, but the link parameters differ and LTE and WiMAX are strictly speaking not compatible airlink standards. Table 4 lists the main U.S. mobile wireless bands and the carriers that operate in each band.

Table 4 - U.S. Personal Wireless Spectrum

Name	Frequency Band	Leading carriers
700 MHz	746-806 MHz	AT&T, Verizon
800 MHz SMR/ESMR	816-824/861-869 MHz	Sprint-Nextel
800 MHz Cellular	824-849/869-894 MHz	AT&T, Verizon, U.S. Cellular
PCS	1850-1990 MHz	AT&T, Verizon, T-Mobile, Sprint-Nextel, U.S. Cellular, Cricket
AWS	1710-1755/2110-2155 MHz	AT&T, Verizon, T-Mobile, Cricket
EBS/BRS	2496-2690 MHz	Clearwire

Table 5 lists the frequency bands used and the corresponding carriers in the State of Vermont as of June 30, 2010.

At the time this study commenced in January, 2010, the NTIA requirement was to identify and model coverage from the carriers providing broadband data service (768/200 kbps) in Vermont as of December 31, 2009. At that time, only Sprint and Verizon met this requirement. By June 30, 2010, AT&T, Sprint, U.S. Cellular and Verizon met the requirement.

Table 5 - Vermont Personal Wireless Operators
(As of June 30, 2010)

Carrier	Airlink Standards	Frequency Bands
AT&T Mobility	GSM/EDGE, UMTS/HSPA	800 MHz Cellular, PCS
Nextel	iDEN	800 MHz SMR/ESMR
Sprint	CDMA 1XRTT, EV-DO	PCS
T-Mobile	GSM/EDGE	PCS
U.S. Cellular	CDMA 1XRTT, EV-DO	800 MHz Cellular, PCS
Verizon Wireless	CDMA 1XRTT, EV-DO	800 MHz Cellular, PCS

3.2 Fixed Wireless Airlink Standards. While some fixed wireless services exist in the 2.5 GHz EBS/BRS bands using WiMAX technology, today most of these services operate in the 900 MHz, 2.4 GHz and 5 GHz license-free bands. In the license-free bands, services employ either proprietary standards (e.g., Motorola Canopy) or the IEEE 802.11 family of airlink standards. In Vermont, both proprietary and 802.11 fixed wireless systems are deployed. There were no known 2.5 GHz WiMAX systems deployed as of June 30, 2010.

Wireless Internet access using IEEE 802.11 standard devices is one of the great technology success stories of the 21st century. By leveraging free spectrum and a standards-based solution, the computer industry created untethered Internet access for the masses. Better known by its industry name, **WiFi**, 802.11 has given the cell phone industry a run for its money and most smart phones incorporate both WiFi and cellular data services in one device.

Like many successful technologies, WiFi was born from a pioneer group of hobbyists and true believers. Before there was wireless Internet access, there was a barren wasteland of spectrum called the Industrial, Scientific, and Medical (ISM) bands. ISM equipment is not used for radio communications, but radio frequency emissions are a consequence of ISM equipment operation. Examples of ISM equipment are industrial heaters, radio frequency welders, diathermy machines, and microwave ovens. Until the 1980s, the ISM bands were considered unacceptable for radio communication because of harmful interference created by ISM equipment. But several companies and small industry groups petitioned the FCC to open these bands for communications and these advocates showed that by using *spread spectrum modulation*, low-power radios could coexist with ISM radiators. In 1985, the FCC issued new rules for radio communication in the ISM bands in Part 15. These new rules authorized radios to operate license-free in the ISM bands at power levels up to 1 Watt provided the radios use spread spectrum techniques. In addition to ISM and Part 15 radio users, the ISM bands were and are used by vehicle tracking services, amateur radio operators, licensed point-to-point microwave, and U.S. Navy fire-control radars. Part 15 radios use the bands on a secondary basis to these other users.

One of the first communications uses of the ISM bands was wireless data networking, but these early networks predated widespread use of the Internet and solutions were proprietary. Then, in 1997, the Institute of Electrical and Electronics Engineers (IEEE) published its first wireless Ethernet standard, IEEE 802.11. This first standard was crude, even by 1997 technology standards, and much less sophisticated that cellular phones of the era. But the telecommunications industry lives and dies by interoperability standards and this first standard was key to widespread adoption of WiFi technology. Of course, it didn't hurt that the Internet was taking off at the same time and laptop computers were starting to achieve decent market penetration. The genius of 802.11 is that because it is wireless Ethernet, its operation is largely transparent to the user and software applications that work on the wireline network work the same on 802.11 networks. Figure 1 shows a typical Vermont WISP antenna site.

Figure 1 - Typical Vermont WISP Antenna Site

Because of FCC rules in place at the time, the first 802.11 standard was required to use spread spectrum modulation which limited bit rates to 2 Mb/s in a 20 MHz-wide radio channel. Over time, the FCC first relaxed the definition of spread spectrum and finally abandoned the spread spectrum requirement altogether, although a maximum power density (in Watts per Hertz) is still enforced for certain frequency bands.

Major revisions to the 802.11 standard were published in 1999 and 2003 when Orthogonal Frequency Division Multiplexing (OFDM) was introduced in the 5 GHz and 2.4 GHz bands, respectively. The peak data rate in each band was 54 Mb/s and this rate remained the state-of-the-art until September of 2009 when the 802.11n amendment was published. IEEE 802.11n employs a number of sophisticated techniques to boost the peak bit rate to 600 Mb/s. [5] These same techniques are used with slight variations in WiMAX and cellular 4G networks. Thus, WiFi radios are now every bit as sophisticated as the most up-to-date smart phones.

Table 6 summarizes the most important 802.11 revisions published to date. IEEE 802.11 amendments that have been ratified for at least six months can be downloaded for free from *http://standards.ieee.org/getieee802/.*

Table 6 - Partial List of IEEE 802.11 Amendments

Standard	Description
802.11-1997	Original Standard, Frequency Hopping & Direct Sequence Spread Spectrum (DSSS)
802.11a-1999	OFDM up to 54 Mb/s in 5 GHz Band, 20 MHz Channel
802.11b-1999	DSSS up to 11 Mb/s in 2.4 GHz Band, 20 MHz Channel
802.11g-2003	OFDM up to 54 Mb/s in 2.4 GHz Band, 20 MHz Channel
802.11i-2004	Security, Including Encryption and Key Management
802.11j-2004	OFDM up to 54 Mb/s in 4.9 GHz Band, 10 and 20 MHz Channels (Japan)
802.11s-2008	Mesh Networking (Still in Committee)
802.11n-2009	Improved coding, MIMO, reduced overhead, up to 600 Mb/s

4.0 Coverage Modeling

In this section, we describe the mathematical models and physical assumptions used in coverage modeling, the particular software tools used in this study, and the physical parameters applied in the software.

4.1 Mathematical Models. Before we jump into a discussion of propagation models, let's make it clear that we are interested only in models for land mobile radio propagation at frequencies greater than 30 MHz. This means that models for point-to-point microwave, tropospheric scatter, satellite, AM groundwave, and HF skywave are outside the scope of this discussion.

[5] We should emphasize that the 600 Mb/s rate is the peak rate and is only available over short ranges when the multipath environment is favorable and 40 MHz of spectrum is available.

The land mobile radio channel is rarely line-of-sight and the received signal is the sum of many reflected and diffracted signals. The term *multipath fading* is used to describe the time-varying amplitude and phase that characterize the composite signal at the receiver. Because mobile radio receivers are designed to operate in multipath fading with a minimum mean amplitude, we are more interested in modeling the mean signal, not the rapid fluctuations caused by fading.

The mean signal amplitude is a function of many factors, including free space loss, terrain loss, and clutter loss. At the frequencies used for land mobile radio, we can usually ignore losses due to precipitation and atmospheric absorption.

Most propagation models assume that the minimum loss is free space loss, given by $22 + 20\log_{10}(d/\lambda)$ dB where d is the path distance and λ is the wavelength of the radio carrier. Other losses are added to the free space loss to estimate the total path loss. This assumption is normally a good one, but one exception is the so-called waveguide effect in urban areas where tall buildings on either side of the street act as a waveguide, resulting in a path loss that is actually less than free space loss.

Free space loss is easy to compute, so the real problem is to predict the losses due to terrain and clutter. Let's first address each of these losses and then examine some popular computer models used to predict these losses.

4.1.1 <u>Terrain Loss and Digital Terrain Databases</u>. Terrain loss is primarily diffraction loss and most models use principles of ray optics to estimate diffraction loss. Much of the work in this area was done by engineers working at the National Bureau of Standards in the late 1950s and early 1960s. The definitive reference for this topic is NBS Tech Note 101, published in 1967. The Tech Note 101 model includes the geometry of diffraction as well as the roundness of the obstacle. More advanced models also use the conductivity of the soil, if it is known. NBS Tech Note 101 does a good job of predicting diffraction loss over isolated obstacles, but oftentimes obstacles appear back-to-back and summing the loss from all obstacles results in an overly conservative prediction. A popular method for sorting out the best way to treat multiple obstacles is the Epstein-Peterson method [5].

A computerized diffraction model is of little use without a digital terrain database. There are several to choose from, some coarse and others fine. In the United States, the earliest digital terrain databases were the National Geophysical Data Center (NGDC) 30 arc second and 3 arc second databases. One pitfall of these databases is that both are taken from the same coarse maps. In other words, the 3 second database is simply a more finely sampled version of the 30 second database. In mountainous terrain, large elevation errors from these databases are likely to occur.

In the early days of personal computers, better quality terrain data was not available and even if it was, a sampling finer than 3 arc seconds resulted in unwieldy databases and painfully slow computing. In the last ten years much more accurate terrain data has became available in the form of the 30 meter terrain database which is extracted from the 1:24,000 scale 7.5 minute "quad" maps popular with hikers. Modern propagation studies should be done with the 30 meter database or its equivalent, if at all possible. The 30 meter database is also referred to as the 1 second database because a distance of 30 meters is approximately equal to one second of latitude.

4.1.2 Clutter Loss and Clutter Databases. Clutter loss falls into two categories: foliage and man-made. Foliage loss is computed from a database of loss factors that are a function of both radio frequency and the type of foliage or it is included in a man-made clutter database. Man-made clutter includes buildings, vehicles, bridges, etc. Man-made clutter loss is usually calculated from a clutter database which applies a clutter category to individual tiles (cells) in the geographical area under study. Typical clutter categories include dense urban, urban, suburban, industrial, agricultural, and rural. A common approach is to apply a single clutter loss factor corresponding to the tile of interest, regardless of the antenna height of the base station/repeater site. This relatively crude model can result in inaccuracies because it is not a function of antenna look angle. The steeper the look angle, the smaller the clutter loss and the shallower the look angle, the greater the clutter loss. In the U.S., two land cover datasets are used to specify clutter type: The National Land Cover Dataset of 1992 (NLCD-92) and the National Land Cover Dataset of 2001 (NLCD-01). NLCD-92 is available as grid data in which one of 21 land cover types is assigned to each 30 meter square cell. NLCD-01 is similar, but uses a different categorization scheme. Because NLCD-01 contains more up-to-date information, it is the preferred dataset.

4.1.3 Propagation Model Used in This Study. For the Vermont study, Pericle used the Anderson 2-D model which is specified in an industry standard, TIA-TSB-88.2-C [5]. The Anderson 2-D model predicts mean signal level using a combination of free space loss, terrain diffraction loss, and clutter loss. Terrain diffraction loss is computed using the Epstein-Peterson method. The NLCD-01 database is used for clutter losses with Table 17 in TIA-TSB-88.2-C mapping clutter category to clutter loss in dB for each of several frequency bands. When employed by a particular software program, several parameters must be selected by the user to implement the Anderson 2-D model. These parameters are identified in Section 4.3 of this report.

4.2 Software Tools. There are many software tools available to perform coverage studies and there is no single tool used by all wireless carriers. For this study, Pericle employed the EDX Signal™ software program. This program employs sophisticated algorithms and it allows the user to choose from several different propagation models with several user-selectable parameters associated with each model. The model used for this study was Anderson 2-D with clutter loss.

4.3 Parameter Selection. The **EDX Signal™** program allows the user to specify terrain databases, clutter databases and several physical and modeling parameters for each study performed. For mobile wireless, the following databases and parameters were used:

Terrain database = USGS 30 meter (1 second)
Clutter database = NLCD-01
Clutter loss factors = TSB-88
Transmit EIRP = varies depending on site, see ACT-250 database or other sources
Transmit antenna pattern = depends on site, see ACT-250 database or other sources
Transmit antenna height = depends on site, see ACT-250 database or other sources
Receive antenna pattern = omnidirectional
Receive antenna gain = -3 dBi (includes 6 dB portable body loss)
Receive antenna height = 1.8 meters (6 feet)
Receiver sensitivity = depends on airlink standard, see Table 7

Note that only the downlink path (base station to subscriber) is modeled explicitly. The carrier designs his network for downlink/uplink balance, so uplink performance is assumed to be roughly the same as downlink performance.[6]

An important model parameter is the receiver sensitivity. Receiver sensitivity is the minimum signal level (in the absence of interference) required by the subscriber receiver to achieve some performance criterion.

$$\text{Service Threshold (dBm)} = -174 + 10\log_{10}(ENBW_{Hz}) + NF + (C/N)_{req} \qquad (1)$$

Where -174 dBm/Hz is the noise power density at room temperature, $ENBW$ is the equivalent noise bandwidth in Hertz, NF is the receiver noise figure in dB, and $(C/N)_{req}$ is the required carrier-to-noise ratio to achieve a channel performance criterion (e.g., BER < 1%). The receiver noise figure varies by manufacturer and model, but a typical handset noise figure is 8 dB. The $(C/N)_{req}$ depends on the airlink standard and the manufacturer's implementation. Newer data standards perform very close to the theoretical Shannon limit or about 2 dB carrier-to-noise for the lowest data rate. Channel bandwidths vary with airlink standard. 1XRTT and EV-DO channel bandwidths are 1.25 MHz, GSM and EDGE are 200 kHz, and UMTS/HSPA is 5 MHz. Using 1XRTT as an example, we see from Equation (1) that a handset with a noise figure of 8 dB and a $(C/N)_{req}$ of 5 dB has a receiver threshold of -100 dBm.

For voice, the performance criterion is typically a bit-error rate in the 1-5% range or a maximum frame error rate where a frame is usually equal to 20 ms of voice. Voice packets are not retransmitted if errors are detected and a higher bit error rate is tolerated than for data packets. Data packets must eventually be received error-free and lower bit-error rates are

[6] The carrier may consider the downlink and uplink to be balanced even if the uplink bit rate is lower because data service is downlink-dominated. In cellular radio networks, lower handset power and antenna gain are compensated in part by antenna diversity and low noise amplifiers at the base station.

usually required to minimize the number of retransmissions. A mitigating factor is that data services employ long error correcting codes (at the expense of time delay) and these better performing codes can achieve better error performance at the same signal threshold as voice services. It is in the carrier's interest for voice and data services to have identical coverage as it matches the subscriber's expectation.

Pericle collected receiver performance information from handset manufacturers, standards bodies and carriers to estimate the signal threshold for each type of service and for each airlink standard. Table 7 lists the receiver signal thresholds used in computer modeling. Only some carriers provided the service threshold used in their data maps (no carrier voice maps were provided), so the values of Table 7 may not match the carrier's value in all cases.

Table 7 - Receiver Threshold for Modeling

Carrier	Service Type	Airlink Standards	RX Threshold
AT&T Mobility	Data	EDGE, UMTS/HSPA	-101.5 dBm
	Voice	GSM, UMTS	-105.0 dBm
Nextel	Data	iDEN	-101.5 dBm
	Voice	iDEN	-101.5 dBm
Sprint	Data	1XRTT, EV-DO	-100.0 dBm
	Voice	1XRTT	-105.5 dBm
T-Mobile	Data	GSM/EDGE	-102.0 dBm
	Voice	GSM	-102.0 dBm
U.S. Cellular	Data	1XRTT, EV-DO	-100.0 dBm
	Voice	1XRTT	-105.5 dBm
Verizon Wireless	Data	1XRTT, EV-DO	-100.0 dBm
	Voice	1XRTT	-105.5 dBm

In Table 7, the threshold for 3G data service is calculated for broadband data rates, not necessarily the lowest or highest rate offered.

Cellular radio networks are frequency-reuse networks and co-channel interference is present at both the base station and the subscriber handset. Thus, signal amplitude alone is not the sole determinant of acceptable signal quality. That said, interference mitigation techniques and power control are present in the handset and at the base station and it is customary in the industry to use signal level and receiver thermal noise assumptions when modeling coverage.

Coverage maps were generated with **EDX Signal™** and exported as Shapefiles for use in **Esri Arcview**. For the four broadband data carriers who provided maps, both the carrier's map and the Pericle map are plotted along with the location of known cell sites. See Appendix C for the complete set of mobile wireless coverage maps and a full description of all assumptions used. See Appendix D for fixed wireless coverage maps (WISP coverage). A sample coverage map is shown in Figure 2 (AT&T Mobility).

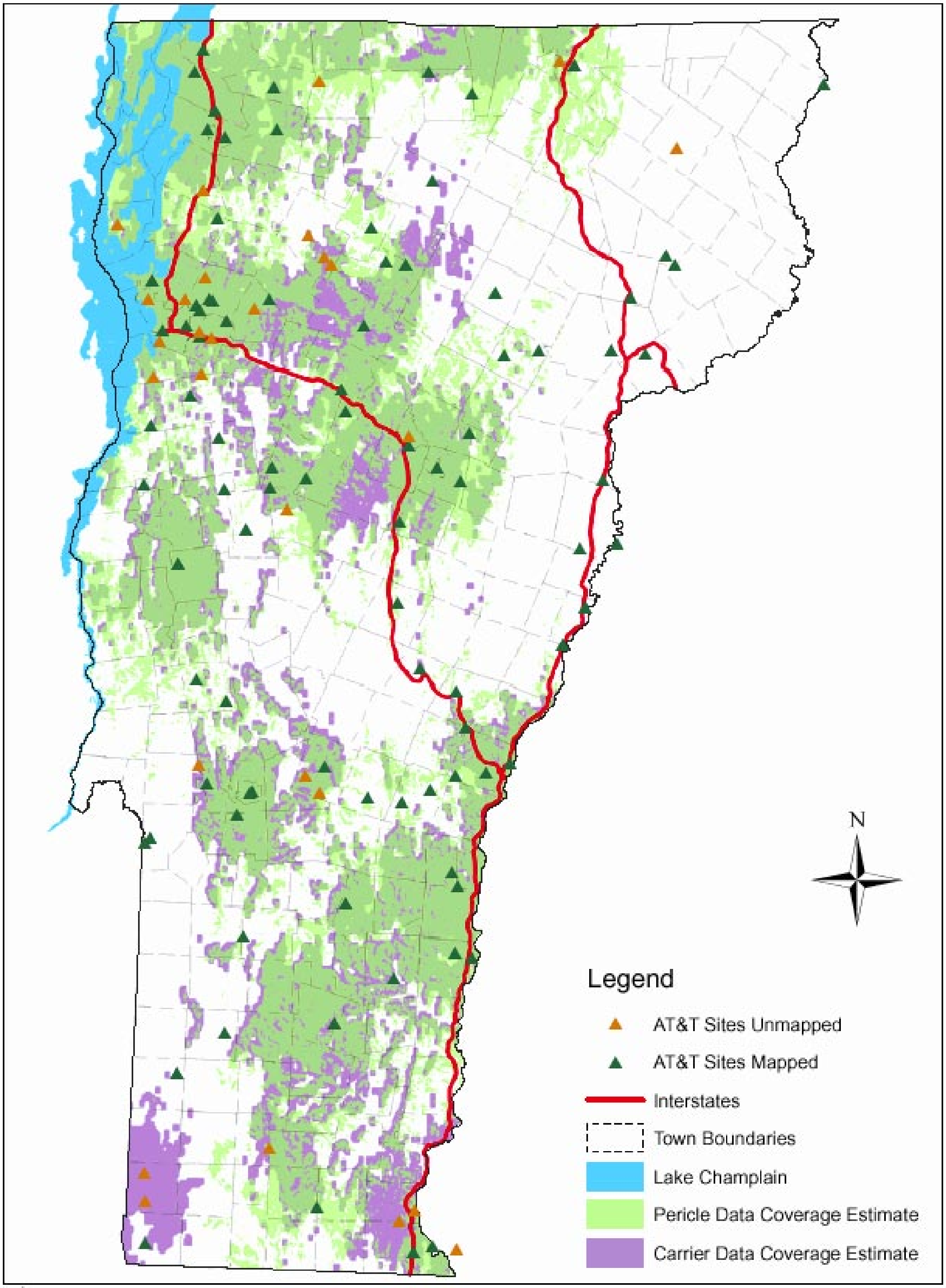


Figure 2 - AT&T Mobility Broadband Wireless Data Coverage Map

5.0 Drive Test Survey

The purpose of the drive test survey was to measure the performance of each of the six mobile wireless carrier networks by placing actual data and voice calls, collecting call data and measuring throughput on data calls. [7] The drive test survey was conducted over a two week period in June, 2010 and over 4,000 miles were driven on Federal Aid Highways and roads throughout the state of Vermont. The drive route is shown on the coverage maps in Appendix C. Two Pericle engineers conducted the survey: Bryan Petch and Mike McGinley

Prior to conducting the drive test survey, five HTC smart phones and one Motorola smart phone (for Nextel) were purchased with unlimited data and voice service plans. HTC phones were chosen because they employ an operating system that enabled us to develop and run custom software routines to execute the tests.

During the drive testing, each of the six test cell phones was programmed to continually execute a test loop and store data to the local SD memory card in each phone (Nextel data was saved to the control laptop used to monitor the drive route and status of the phones). Each data record was time-stamped with latitude and longitude using the GPS receiver in each phone (Nextel data was time stamped using a GPS receiver connected to the control laptop). The test sequences for all phones were independent of each other and the time for each test loop varied based on availability of coverage and data transfer speeds. A block diagram of the drive test setup along with a description of the test loop is shown Figure 3.

Information about the phone and network parameters were collected at various points in the test loop using a combination of HTC phone queries, Radio Interface Layer (RIL) calls and AT commands. Receive signal strength measurements were recorded multiple times in each loop. These commands and the data available from both phone and network varied for each phone and network tested. Collected data included signal amplitude, signal quality, serving site ID (when available), base station sector ID (when available), airlink technology, latitude, longitude, time-of-day, and roaming status.

Voice coverage was tested by actually placing a call from the handset and verifying that the call was connected.

Downlink data speed was measured by placing a data call and transferring a small 50 kB block of data followed by a 1 MB block of data from a remote test server (configured by Pericle) to the phone. The first small block is burdened with the bulk of the Internet Protocol (IP) overhead to establish the connection and the throughput speed was calculated over the 1 MB block, or portion thereof that could be transferred in the 15-20 seconds allowed for this portion of the test loop. Uplink data speed was measured by placing a data call and transferring a small 20 kB block of data followed by a 50 kB block and a 200 kB block of data

[7] A drive test of WISP fixed wireless coverage was not practical due to the point-to-point links used, the use of proprietary technology (in many cases) and the failure of the WISPs to provide SSIDs and MAC addresses.

from the phone to a test server. Like the downlink speed test, the first small block is burdened with the bulk of the IP overhead and the throughput was calculated over one or both of the 50 kB and 200 kB blocks (depending if one or both completed within the 15-20 seconds allowed for this portion of the test loop). If two or more blocks were successfully transmitted, the block resulting in the fastest throughput was used in the latency and throughput calculations.

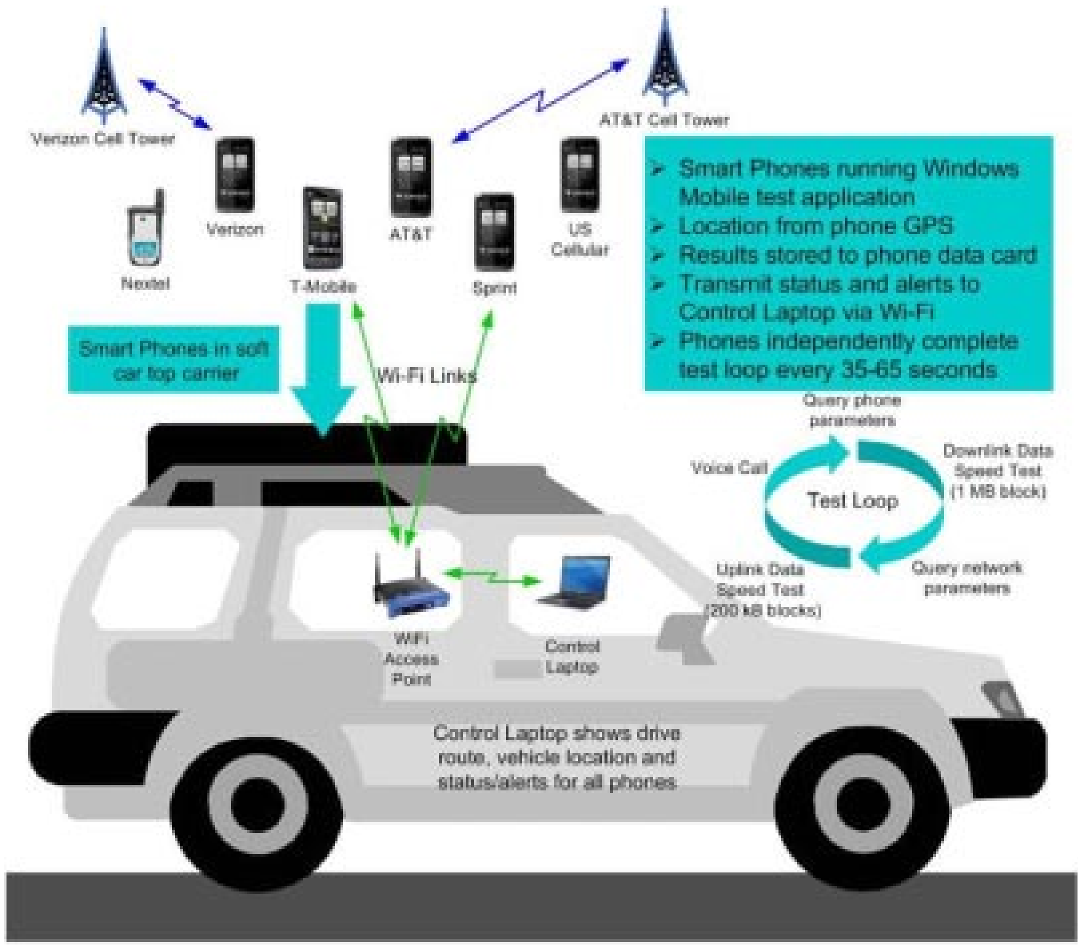


Figure 3 - Drive Test Survey Collection System

The duration of each test loop varied from 35 to 70 seconds depending on network coverage and data speeds supported. Over 10,000 data calls and over 10,000 voice calls were placed from each phone during the drive test survey.

Due to the low speed data capability of the Nextel iDEN technology, the Nextel phone was programmed to place just voice calls and record signal strength measurements approximately every 30-35 seconds.

6.0 Analysis

This document serves as the final project report for the entire scope of work performed by Pericle Communications Company for VCGI. A narrower scope for a written report is specified in the subcontract and the specific language is shown below:

> 6.1 The Contractor shall use the drive-test data to determine the accuracy of the original RF propagation dataset generated under Activity #2 and #4. The Contractor shall deliver the raw results, summary statistics, and a report describing the accuracy of the original RF propagation dataset.
>
> 6.2 The Contractor shall use the drive-test data to calibrate and refine the RF propagation data generated under Activity #2 and #4. The Contractor shall deliver a separate set of "calibrated" RF propagation maps (separate raster for each transceiver as stipulated under Activity #2 and #4). The Contractor shall use "calibration" methods consistent with industry standard "best practices". The methods must be fully documented in a report describing how the maps were calibrated and refined.

The following analysis addresses these two specific tasks in some detail along with an overall analysis of the drive test and computer modeling efforts.

6.1 <u>Summary Results</u>. The processed drive test data is found in the spreadsheets of Appendix B. Summary data is found in Tables 8, 9 and 10 below. Tables 8 and 9 show the broadband wireless summary data results for the downlink and uplink, respectively. The second column in each table shows the total number of call attempts made on each carrier's network. The next two columns indicate the percentage of calls that were successful at any rate and at broadband rates, regardless of whether the carrier claims to have coverage at that location or not. The last two columns indicate the percentage of successful calls that occurred inside a polygon from the carrier-furnished coverage map. In other words, these right most two columns consider only those calls placed in those areas where the carrier claims to have wireless coverage.[8]

Table 8 - Broadband Wireless Data Drive Test Results - Downlink

Carrier	Call Attempts	All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	10969	77%	32%	89%	58%
Sprint	12575	45%	3%	93%	7%
U.S. Cellular	12761	32%	7%	86%	23%
Verizon Wireless	10205	76%	21%	94%	29%

[8] When measuring throughput of computer networks, there is often a difference of opinion over which rate is correct. For example, an EV-DO network may provide a gross data rate of 3.1 Mbps, but there is overhead in the airlink protocol and the user's maximum realizable rate will always be less than the gross rate. Also, if the test employs TCP/IP protocols, there is an additional overhead of roughly 20% that further reduces the user's throughput. The throughput values listed in the tables in this section of the report represent the user's experience and include losses from airlink overhead and TCP/IP overhead (where applicable). For more information on this subject, see [10].

We should point out that some carriers did not distinguish on their maps where broadband coverage (e.g., EV-DO) was available and where only low data rate coverage (e.g., 1XRTT) was available.

Table 9 - Broadband Wireless Data Drive Test Results - Uplink					
Carrier	Call Attempts	All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 200 kbps)	Successful (Any Rate)	Successful (> 200 kbps)
AT&T Mobility	10969	71%	34%	85%	62%
Sprint	12575	42%	16%	91%	40%
U.S. Cellular	12761	29%	2%	84%	6%
Verizon Wireless	10205	73%	32%	93%	44%

The reader will note the significant difference between the number of successful data calls completed at any rate and the number of data calls completed at broadband rates. There are several reasons why these differences might occur:

- The serving cell site was not configured for broadband service. For example, a Sprint, U.S. Cellular or Verizon cell site might be configured for older 1XRTT technology rather than EV-DO. Or, an AT&T or T-Mobile cell site might be configured for older GSM/EDGE technology rather than UMTS/HSPA.

- The signal was too weak or more generally, the carrier-to-interference plus noise ratio ($C/I+N$) was too small to reliably operate at broadband rates even if broadband service was available at the site.

- The site was congested with too many subscribers.

- The backhaul TCP/IP network was congested. This condition varies throughout the day and is independent of the condition of the radio link.

Performance differences between carriers for all call attempts (regardless of throughput) can be attributed to the size of the network. AT&T Mobility and Verizon Wireless have larger networks in Vermont than Sprint or U.S. Cellular. The Sprint or U.S. Cellular user experience can be much better than indicated, however, because both Sprint and U.S. Cellular users are allowed to roam onto the Verizon Wireless network. This roaming is often seamless with no interruption to the subscriber's call.

The wireless voice drive test results are shown in Table 10. The values in the right most column indicate coverage within the Pericle computer-modeled coverage polygon. In other words, these calls were placed in areas where one would expect service to be available. Note that poor overall coverage for Sprint, T-Mobile and U.S. Cellular (third column from the left) is not necessarily representative of the user experience because subscribers on these systems can roam onto Verizon and AT&T Mobility.

Table 10 - Wireless Voice Drive Test Results (Percent of calls that were successful)			
Carrier	**Call Attempts**	**All Attempts**	**Within Coverage Polygon**
AT&T Mobility	10969	86%	96%
Nextel	32654	51%	86%
Sprint	12575	49%	93%
T-Mobile	10404	24%	98%
U.S. Cellular	12764	34%	86%
Verizon Wireless	10209	80%	96%

Computer-generated and drive test survey coverage maps are found in Appendix C to this report.

6.2 <u>Coverage Map "Calibration" and Improvements Using Drive Test Data.</u> Two issues became apparent during and after the drive test survey which limit the ability to adjust or calibrate the propagation map generated for each carrier using drive test data.

- For a given carrier, the density of sites in a given region in the propagation map differs from real world operation of the network in that area. This is due to the refusal of the cellular carriers to provide any site information (locations or transceiver characteristics). Other techniques to locate the sites (Vermont ACT 250 database, network reported site locations from the drive test, drive test observations and site visits, and comparison of suspected sites with other tower databases) resulted in a number of sites with known locations, but without enough site parameters to allow them to be included in the propagation map. In addition, there are some sites for each network which were not located through these techniques. Therefore, the propagation map is a good approximation of the *outline* of a carrier's coverage, but is not as accurate to predict the aggregate signal strength from multiple sites at a given location.

- Network infrastructure which is capable of broadband data speeds and a receive signal level at the cell phone above a threshold are required at a minimum to enable broadband data speeds. Above this threshold, data rate correlates very loosely with improvements in signal strength. The actual data rate is affected by a number of different factors including network capacity, number of simultaneous data users, interference levels from environment and other cell phones, limitations placed by the carrier on allowed data rates, complex network algorithms which direct bandwidth between users, backhaul capacity/congestion, Internet capacity/congestion and test server capacity/congestion. These various factors are very difficult to model. Therefore, the best estimate of throughput is not a computer-generated coverage map, but instead is the actual throughput measured during the drive test survey.

These two issues make it infeasible to adjust/calibrate the drive results and propagation maps by comparing predicted and measured received signal levels. Instead of using the drive test received signal strength to adjust the propagation maps, the transceiver database and propagation maps were improved through the following process:

1. All ACT-250 applications were reviewed for references to other carrier sites (sometimes identified/described in propagation predictions) which were not described in their own ACT-250 application. These potential sites (often just a general location) were identified prior to the drive test. During the drive test, these sites were validated visually, by use of spectrum analyzer readings during the drive or by comparing relative signal strength levels from the drive test data with the general site location.

2. Previously unknown site locations were identified visually during drive testing and recorded.

3. CDMA networks (Sprint, U.S. Cellular and Verizon) actually reported the serving cell location in the network parameters retrieved from the phone. This information confirmed a number of known site locations and identified a number of previously unknown site locations for both Sprint and U.S. Cellular. A significant number of these new sites were outside of Vermont. Unfortunately, this information was only partially loaded in the Verizon network and was deemed not reliable to identify actual sites.

4. Sites identified in Steps 1-3 were compared to several tower databases, including Federal Communication Commission (FCC), SBA, TowerCo, American Tower, AT&T Towers, Sprint Towers and Global Tower Partners. These sites were also compared with known sites from the other carriers. Site locations and characteristics were added to the transceiver database and if enough characteristic information was available, the sites were included in updated data and voice propagation maps.

Many cellular carriers are licensed in more than one frequency band. To provide coverage in both bands at a single site, a transceiver for each band is installed at the site with either separate or multi-band antennas. From the site information sources available, it is not always possible to tell if more than one band is supported. Multiple transceivers have been entered at a common site where there was some evidence that multiple bands were in use by the same carrier. This is most common in the cellular and PCS bands. The transceivers entered generally correlate with the frequency bands/channels observed to be in use from the drive test data. Some carriers have licenses for frequency bands which are not yet in use (for example: T-Mobile in the AWS band and Verizon in the 700 MHz band). Some of these transceiver locations were included in the transceiver database with a PMAP_STAT field of “I” for “Incomplete” when there was evidence they were deployed, but are not yet operational.

The final cellular site transceiver statistics are shown in Table 11.

Table 11 - Final Transceiver Database Statistics

Carrier	Included In Propagation Map (PMAP_STAT = F)	Location Known but Not Enough Information to Map (PMAP_STAT = I)	Total
WISP (all carriers)	135	5	140
AT&T Mobility	108	29	137
Nextel	67	5	72
Sprint	71	74	145
T-Mobile	56	14	70
U.S. Cellular	25	30	55
Verizon	194	17	211
		Grand Total	**830**

6.3 Roaming Issues During Drive Test Survey. Roaming allows a phone to operate on other carrier's infrastructure when the performance of the home network falls below a given threshold. To prevent the phone from bouncing back and forth between networks, the handoff algorithm includes some hysteresis in the selection of the network. Once a phone roams onto another network, the network performance of the home network must improve and the performance on the roaming network must degrade in order for the phone to switch back. The result is that a phone may stay on the roaming network, even though service is available on the home network.

Prior to conducting the drive testing, the team decided to disable roaming for each of the cell phones to get the best possible estimate of each cellular carrier's actual coverage in Vermont. Roaming was disabled for the Sprint, Verizon, U.S. Cellular and Nextel phones. Unfortunately, the AT&T phone did not allow roaming to be disabled. The T-Mobile phone allowed manual selection of a preferred network (set to prefer T-Mobile), but this setting was automatically overridden as soon as the T-Mobile network was not available – effectively re-enabling roaming.

The AT&T phone generally used the AT&T network with some roaming onto Unicel along the Vermont/New Hampshire border and some international roaming to Canadian carriers along the Canadian border. This behavior results in a slightly smaller footprint for AT&T's infrastructure when these roaming results are removed from the data.

Like AT&T, the T-Mobile phone also roamed onto Unicel along the Vermont/New Hampshire border and onto Canadian carriers along the Vermont/Canada border. However, the T-Mobile phone roamed onto the AT&T network in much of Vermont and this behavior resulted in a significantly smaller footprint for T-Mobile's infrastructure within Vermont than was predicted by the T-Mobile propagation map.

6.4 General Observations that Apply to More than One Carrier. The following general observations were made after analyzing the coverage maps and drive test data.

- In general, Pericle coverage predictions are more generous than the carrier's. This is likely due to Pericle using receive signal thresholds per the relevant communication standards, while the carriers appear to scale these back to a more conservative number. This scaling is believed to account for other factors in the carrier's network deployment including reduced output power to prevent interference between sites and allowance for in-vehicle operation. Also, the Pericle coverage predicts outdoor, head height operation with appropriate body loss for a person holding the phone. Carrier coverage maps often predict in-vehicle use of the phone which results in a smaller coverage area due to penetration losses associated with the vehicle.

- In general, Pericle-generated coverage maps closely approximate the overall shape of the coverage maps provided by the carriers. These carrier maps also closely match the drive test results with a high percentage of successful data call attempts within the carrier data coverage polygon. Thus, the carrier-provided coverage polygons can be considered to be independently verified by Pericle. However, both carrier and Pericle coverage maps imply that broadband data speeds can be achieved anywhere within these data coverage polygons. Drive test data shows these polygons to be an accurate indication of data service availability in general, but a rather poor prediction of locations where broadband data speeds (per the NTIA definition) can be achieved.

- Of the cellular carriers, AT&T, Sprint, U.S. Cellular and Verizon all have broadband data-capable infrastructure deployed in at least portions of Vermont and provide low and high speed data services to subscribers within the State. While T-Mobile has network equipment that is capable of broadband data speeds, this equipment is not deployed and/or turned on in Vermont. T-Mobile does provide low speed data services to subscribers within the state. Lastly, the iDEN technology used by Nextel (now owned by Sprint, but largely operated as a separate network) provides only low speed data services. As such, data testing was not performed on the Nextel network.

6.5 Observations Specific to Each Carrier.

6.5.1 AT&T Mobility.

- Of the carriers capable of broadband data speeds, AT&T has the distinction that not all of its sites are deployed with the UMTS/HSPA infrastructure equipment required to achieve these speeds. So, the Pericle broadband propagation map is based on a subset of the total AT&T sites. This differs from the CDMA technologies (Sprint, U.S. Cellular and Verizon) where all sites are capable of broadband data speeds.

- AT&T has the least complete site information of the cellular carriers in Vermont. This information is almost exclusively from ACT-250 and from observations during the drive test. The number of ACT-250 applications for southern Vermont is significantly fewer than for the rest of the state. A number of key sites have incomplete information and so are not mapped. For example, Bennington and Brattleboro show limited or no coverage in the propagation map despite both having good actual AT&T coverage.

- Very few AT&T sites outside of Vermont have been identified.

- The AT&T phone used for drive testing would not allow roaming to be disabled. The phone roamed onto other networks along the Vermont/New Hampshire and Vermont/Canada borders. Data attempts on non-AT&T infrastructure have been removed from the maps and statistics.

- Despite owning licenses for both cellular and PCS band frequencies, most of the AT&T service was provided in the 800 MHz cellular band throughout the state (per the drive test data). A number of PCS transceivers have been included in the data base and these are typically enabled where additional capacity is required and the network in Vermont is likely not capacity constrained. This data may be misleading as the network may prefer that the phone use the cellular band and there may be more PCS band coverage available that was not observed during the drive test.

- AT&T provides good coverage through large portions of Vermont. 77% of the data call attempts during the drive test were successful but only 39% of these attempts were completed on infrastructure capable of broadband data speeds (UMTS/HSPA network infrastructure). Of all the data calls attempted, 34% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 35% achieved uplink speeds exceeding the NTIA threshold of 200 kbps. For data calls attempted within the AT&T-provided data coverage area, 89% of these attempts were successful and 62% of downlink and 64% of uplink tests exceeded the relevant NTIA broadband data threshold. By contrast, for data calls attempted within the Pericle estimated data coverage area, 91% were successful and 59% of downlink and 60% of uplink tests exceeded the relevant NTIA broadband data threshold. Note that both the AT&T and Pericle data coverage estimates identify those areas where broadband data service is supported and does not cover all of the areas where lower speed AT&T data service is available.

- For voice coverage, AT&T has good coverage over the majority of Vermont. 86% of the non-roaming AT&T voice call attempts during the drive test were successful. When compared versus predicted coverage, 70% of the voice calls were attempted within the Pericle estimated voice coverage area and 96% of these calls were successful. The rather large discrepancy in these results is due to the several key sites within Vermont which did not have enough information to be mapped (Bennington, Brattleboro, Cambridge and Island Pond are good examples). The lack of identified sites outside of

Vermont also contributes to this discrepancy. Finally, there are likely several unidentified sites within Vermont. West/North Pawlett, Rochester and Townshend are areas where unmapped sites probably exist.

6.5.2 Nextel.

- Due to fundamental technology and service differences, the Nextel network is treated separately from the Sprint network despite the fact that Sprint owns both networks. The iDEN technology used by Nextel does not support data rates greater than 64 kbps and voice call tests were performed during the Vermont drive test rather than interleaved data and voice calls as was the case on all the other networks. As a result, the Nextel results have approximately three times the call attempts as the other phones.

- Information about Nextel sites is fairly complete with complete ACT-250 data sufficient to generate propagation maps for most sites. Nextel sites are typically deployed with four antennas per sector and three sectors per site, so they tend to be deployed on towers and sometimes large silos.

- Due to limitations with the Nextel phone technology, the Nextel network required a unique test software application and its test results were stored on the test control laptop and were time-stamped using the test laptop GPS connection rather than using these capabilities within the phone.

- Very few Nextel sites outside of Vermont were identified, but this does not significantly affect the shape of the Nextel coverage areas.

- Nextel provides good voice coverage through most of densely populated areas of Vermont with spotty coverage between these areas. Of all the Nextel voice calls placed during the drive test, 51% were successful. When compared versus predicted voice coverage, 49% of the voice calls were attempted within the Pericle estimated voice coverage area and 86% of these calls were successful. The drive test results do highlight several missing site locations in the West/North Pawlett area in southwest Vermont, along I-91 north of Brattleboro (the missing site(s) is likely in New Hampshire) and along the northern Vermont border near Richford and an stretch of highway north of Island Pond.

6.5.3 Sprint.

- Sprint sites tend to be small and unobtrusive and are the hardest to spot, most often with two and sometimes one antenna per sector. Sprint makes common use of silo antenna sites and often employs just two sectors pointing up and down a highway. The Sprint coverage is focused along major urban areas and highways and there is no coverage in northeastern Vermont. Of the wireless carriers, Sprint sites are most likely to be deployed at lower heights and they often occupy the lowest position in multi-carrier sites. Sprint is deployed entirely in the PCS B Block and therefore has simpler antenna requirements than its 800 MHz cellular competitors.

- The Sprint network reported serving cell locations and as a result the known site locations for Sprint are nearly complete. Many of these sites are out of state (New York, Massachusetts, New Hampshire) and fewer than half have enough information to include in the propagation map. A good approximation of the carrier's coverage is still obtained even with this smaller number of sites. Due to its relatively small and low deployment footprint, Sprint requires more sites in urban, higher capacity areas to provide service. The overall coverage footprint can be approximated from the sites mapped, but the signal strength prediction in a given location will be less accurate due to the reduced density of mapped sites. This can be seen in Figure 4 which shows mapped and unmapped Sprint sites in the Burlington area. This map illustrates the difficulty in calibrating coverage maps using the drive test data.

- Sprint provides good data coverage in selected urban and highway corridor areas in Vermont. 45% of the data call attempts during the drive test were successful and 36% of these attempts were completed on infrastructure capable of broadband data speeds (EV-DO network infrastructure). Of all the data calls attempted, only 7% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 28% achieved uplink speeds exceeding the NTIA threshold of 200 kbps. For data calls attempted within the Sprint-provided data coverage area, 93% of these attempts were successful and 19% of downlink and 71% of uplink tests exceeded the relevant NTIA broadband data threshold. By contrast, for data calls attempted within the Pericle estimated data coverage area, 87% were successful and 15% of downlink and 61% of uplink tests exceeded the relevant NTIA broadband data threshold. The differences in these statistics are due to Pericle's coverage estimate being optimistic versus that provided by Sprint (even though there are several sites between Burlington and Montpelier which were not complete enough to map). While Sprint provides high speed data services through much of their service area, they rarely exceed the NTIA broadband data threshold.

- Sprint provides good voice coverage in the same areas where it provides data coverage but the coverage is only average when compared across the state. For the entire state of Vermont, 49% of the Sprint voice call attempts during the drive test were successful. When compared versus predicted coverage, 42% of the voice calls were attempted within the Pericle estimated voice coverage area and 93% of these calls were successful. These results indicate that the Pericle estimated coverage is a reasonable approximation of the Sprint voice coverage.

Figure 4 - Sprint Sites in Burlington, VT

6.5.4 T-Mobile.

- T-Mobile has the distinction of having the least complete online ACT-250 site applications. While many appear to have been submitted with more complete applications, they are often only sparsely populated in the online database.

- While T-Mobile does offer broadband data speeds in many markets across the United States, this technology and the accompanying AWS band frequencies are not turned on in Vermont as of the early summer 2010 drive test. In Vermont, T-Mobile offers voice and low speed data on its GSM/EDGE infrastructure within its service area. When roaming, this same level of service is available (no broadband data). The coverage area for T-Mobile voice and low speed data is identical throughout Vermont

- T-Mobile provides a swath of coverage along the major interstate highways in Vermont including I-91 from the Massachusetts border to Hartford/White River Junction and then I-89 through Montpelier and Burlington all the way to the Canadian border.

- The T-Mobile phone used for drive testing would not allow roaming to be disabled. The phone consistently roamed onto the AT&T network throughout Vermont and roamed onto other networks along the Vermont/New Hampshire and Vermont/Canada borders. Voice and data call attempts on non-T-Mobile infrastructure have been removed from the maps and statistics.

- Throughout Vermont, 80% of voice calls placed with the T-Mobile phone were successful. However, only 24% of these successful calls used T-Mobile infrastructure. When compared with the T-Mobile provided voice coverage area, 23% of the voice call attempts were made within the T-Mobile estimated coverage area. 100% of these voice calls were successful. By contrast, 20% of the voice call attempts were placed within the Pericle estimated voice coverage area and 98% of these calls were successful. The T-Mobile provided and Pericle estimated voice coverage areas provide similar statistics. However, this is a limited portion of the T-Mobile coverage area due to the significant amount of time that the T-Mobile phone was roaming during the drive test.

6.5.5 U.S. Cellular.

- From the drive testing, it was learned that U.S. Cellular had significant broadband data coverage in southern Vermont, despite the carrier's online coverage maps not showing this coverage.

- U.S. Cellular coverage in southern and eastern Vermont is provided using its Cellular Band frequency license. This license has sufficient bandwidth to deploy broadband data technologies. U.S. Cellular has only pocket coverage in northern Vermont and this appears to be through purchase of the Devon Mobile Communications license and infrastructure. In these areas, U.S. Cellular has a PCS band license which does not offer enough bandwidth to operate broadband data technologies. U.S. Cellular frequency bands appear to be closely coordinated with Verizon in southern Vermont. Much of the broadband data coverage provided in eastern Vermont comes from U.S. Cellular sites in New Hampshire.

- The U.S. Cellular network reported serving cell locations and as a result the known site locations for U.S. Cellular are nearly complete. Many of these sites are out of state (New Hampshire) and less than half have enough information to include in the propagation map. A good approximation of the carrier's coverage map is still obtained even with this smaller number of sites.

- U.S. Cellular provides good data coverage in southern Vermont and along the eastern border, but does not provide broadband data in central to northern Vermont. As such, its data coverage is less than other cellular carriers when considered over the whole state. Only 32% of the data call attempts during the drive test were successful and only 15% of those attempts were completed on infrastructure capable of broadband data speeds (EV-DO network infrastructure). Of all the data calls attempted, 9% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 10% achieved uplink speeds exceeding the NTIA threshold of 200 kbps. For data calls attempted within the U.S. Cellular provided data coverage area, 86% of these attempts were successful and 29% of downlink and 30% of uplink tests exceeded the relevant NTIA broadband data threshold. By contrast, for data calls attempted within the Pericle estimated data coverage area, 81% were successful and 27% of downlink and 28 of uplink tests exceeded the relevant NTIA broadband data threshold. This discrepancy is due to the large number of sites in New Hampshire which provide coverage in eastern Vermont and which were not included in the Pericle coverage prediction due to incomplete site information.

- Similar to its data coverage, U.S. Cellular voice coverage is most prevalent in southern and eastern Vermont with isolated pockets of coverage in larger cities and towns in northern Vermont. Across the entire state of Vermont, 34% of the U.S. Cellular voice call attempts during the drive test were successful. When compared versus predicted coverage, 27% of the voice calls were attempted within the Pericle estimated voice coverage area and 86% of these calls were successful. The discrepancy in these results is due to a number of sites in New Hampshire providing coverage in eastern Vermont which were not included in the propagation map due to incomplete site characteristic information. A site in St. Johnsbury, VT provides a pocket of coverage, but is also not mapped due to incomplete information. Pericle coverage estimates are generally optimistic relative to drive test results (i.e., calls are not completed successfully within portions of the estimated coverage area). This is believed to be due to the reasons given in the general comments above. In southern Vermont, it may also be due to the relatively high sites used by U.S. Cellular in this area and more antenna downtilt may be deployed at these sites than was used in the model.

6.5.6 Verizon Wireless.

- Verizon has the most complete site information of the cellular carriers in Vermont. This information was obtained from ACT-250 (typically the most complete applications) and from observations during the drive test. Serving cell locations reported by the Verizon network were not believed to be reliable and were not included.

- Verizon sites tend to be large, most often three sector and with 4 and sometimes 5 antennas per sector. Verizon makes common use of tree towers (monopines) and these are often quite difficult to spot in Vermont. Verizon typically occupies the top spot in most multi-carrier sites.

- A number of Verizon sites in Massachusetts and New Hampshire have been identified and included in the coverage map. No Verizon sites in eastern New York were identified and this contributes to some of the gap between carrier and Pericle predicted coverage along the western Vermont border.

- Verizon makes good use of its licensed cellular and PCS band frequencies with more service provided in the cellular band in northern Vermont and the PCS band used more prominently in southern Vermont. This is believed to be due to coordination with U.S. Cellular in these areas.

- Verizon provides good data coverage through large portions of Vermont. 76% of the data call attempts during the drive test were successful and 62% of these attempts were completed on infrastructure capable of broadband data speeds (EV-DO network infrastructure). Of all the data calls attempted, 30% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 45% achieved uplink speeds exceeding the NTIA threshold of 200 kbps. For data calls attempted within the Verizon provided data coverage area, 94% of these attempts were successful and 42% of downlink and 63% of uplink tests exceeded the relevant NTIA broadband data threshold. By contrast, for data calls attempted within the Pericle estimated data coverage area, 92% were successful and 41% of downlink and 61% of uplink tests exceeded the relevant NTIA broadband data threshold. At a state-wide level, the Verizon-provided and Pericle estimated coverage areas provide similar statistics.

- Verizon has good voice coverage over the majority of Vermont. 80% of the Verizon voice call attempts during the drive test were successful. When compared versus predicted coverage, 70% of the voice calls were attempted within the Pericle estimated voice coverage area and 96% of these calls were successful. This discrepancy is due to several sites within Vermont which did not have enough information to be mapped. Three sites along the western Vermont border, north of Orwell are good examples. The site on Mount Robbins (southeast of Burlington) would help fill in the area between Burlington and Waterbury if it was mapped. In northeast Vermont, missing sites (likely in New Hampshire) account for the discrepancy in Pericle versus carrier coverage estimation in this area.

7.0 Conclusions

Through coverage modeling and a drive test survey, Pericle was able to independently verify the accuracy of wireless data coverage maps for AT&T Mobility, Sprint, U.S. Cellular and Verizon Wireless. An extensive drive test survey measured actual data throughput by placing over 10,000 data calls per carrier on over 4,000 miles of federally funded highways and roads in Vermont. The drive test survey revealed a stark difference between basic wireless data coverage and *broadband* data coverage per the NTIA definition (> 768 kbps downlink, 200 kbps uplink). The best performing carrier achieved broadband data rates in only 58% of its coverage area and on only 32% of the entire drive route which included locations outside the carrier's claimed coverage area.

For fixed wireless Internet access, Pericle modeled 135 transceivers from 11 different WISPs. These companies employed a combination of proprietary and 802.11x technologies. These transceivers were primarily used used for point-to-point links between the network transceiver and building-mounted subscriber equipment. This deployment model was verified for at least one WISP through transceiver site visits.

In addition to the broadband wireless data assessment, Pericle also modeled and measured wireless voice coverage in Vermont for the four previously mentioned carriers plus Nextel and T-Mobile. The best carrier had a voice call completion rate of 96% in its coverage area and 86% over the entire drive route.

8.0 Cited References & Bibliography

[1] W.C. Jakes, ed., Microwave Mobile Communications, IEEE Press Reissue, 1994.

[2] W. C. Y. Lee, Mobile Cellular Telecommunications Systems, McGraw-Hill, 1989.

[3] S. M. Ross, A First Course in Probability, New York: MacMillan, 1984.

[4] R. J. Larsen, M. L. Marx, An Introduction to Mathematical Statistics and its Applications, Prentice-Hall, 1986, pp. 281.

[5] TIA TSB-88.1-C, "Wireless Communications Systems Performance in Noise and Interference Limited Situations, Part 1: Recommended Methods for Technology Independent Performance Modeling and Part 3: Performance Verification, February, 2008.

[6] C. Hill and T. Kneisel, "Portable Radio Antenna Performance in the 150, 450, 800, and 900 MHz Bands "Outside" and In-Vehicle," *IEEE Transactions on Vehicular Technology*, November, 1991.

[7] A. Davidson and C. Hill, "Measurement of Building Penetration into Medium Buildings at 900 and 1500 MHz, *IEEE Transactions on Vehicular Technology*, February, 1997.

[8] D.R. Cox and W.L. Smith, Queues, London: Chapman and Hall, 1961.

[9] G.C. Hess, Land-Mobile Radio System Engineering, Artech House, 1993.

[10] Visualware, "Understanding Internet Speed Test Results," 2008.

9.0 Acronyms

1XRTT	CDMA packet radio service using 1.25 MHz channels, up to 153 kbps
AWGN	Additive White Gaussian Noise
AM	Amplitude Modulation
AMPS	Advanced Mobile Phone System
APCO	Association of Public Safety Communications Officers
ARQ	Automatic Repeat-Request
AWS	Advanced Wireless Service
BPSK	Binary Phase Shift Keying
BRS	Broadband Radio Service
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
DAQ	Delivered Audio Quality
dB	Decibels
dBi	Decibels relative to isotropic (for antenna gain)
dBd	Decibels relative to a half-wave dipole (for antenna gain)
dBm	Decibels relative to a milliwatt
DTR	Digital Trunked Radio
EBS	Educational Broadband Service
EDACS	Enhanced Digital Access Control System
EDGE	A high speed data service offered on GSM networks
EIRP	Effective Isotropic Radiated Power
EMS	Emergency Medical Services

ENBW	Equivalent Noise Bandwidth
ERP	Effective Radiated Power (relative to half-wave dipole)
ESMR	Enhanced Specialized Mobile Radio
Esri	A GIS software company and vendor of Arcview software
ETSA	Emergency Telephone Service Authority
EV-DO	3G CDMA wireless data standard, 2.4 Mbps (Rev. 0), 3.1 Mbps (Rev. A)
FCC	Federal Communications Commission
FM	Frequency Modulation
GHz	Gigahertz (10^9 cycles per second)
GIS	Geographic Information System
GPRS	Wireless data service on GSM networks; replaced by EDGE
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HSPA	High Speed Packet Access, a UMTS 3G standard, up to 14 Mbps
HSPA+	Evolved HSPA, improved UMTS standard, up to 56 Mbps
iDEN	Proprietary Motorola airlink standard used by Nextel
ITAC	Interoperability Tactical Channel
LTE	Long Term Evolution, a 4G wireless standard using OFDM
LTR	Logic Trunked Radio (a trunking protocol)
MHz	Megahertz (10^6 cycles per second)
NAMPS	Narrowband AMPS
NLEC	National Law Enforcement Channel
NPSPAC	National Public Safety Planning Advisory Committee
PCS	Personal Communications Services
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
SAR	Service Area Reliability
SBDD	State Broadband Data & Development
SMR	Specialized Mobile Radio
TDI	Time Delay Interference (in simulcast networks)
TDMA	Time Division Multiple Access
TIA/EIA	Telecommunications/Electronic Industries Association
3G	Third Generation Wireless
TTA	Tower-Top Amplifier
VHF	Very High Frequency (30 MHz to 300 MHz)
UHF	Ultra High Frequency (300 MHz to 3 GHz)
UMTS	Universal Mobile Telecommunications System, a 3G standard
WiFi	Trade name for systems that comply with IEEE 802.11 standards
WiMAX	A 4G airlink standard based on IEEE 802.16
WMS	Wireless Measurement System

Appendix A - Contractor Scope of Work

General Business Requirements

The Contractor shall be required to interact regularly with personnel from VCGI and the Department of Public Service to eliminate or resolve problems and inconsistencies that may occur in:

a. schedule and deliverable requirements,
b. data format and data transfer, and
c. achieving final acceptance of the contract deliverables.

The Contractor shall be required to notify VCGI of any changes in project personnel as well as the reason for the change for the duration of the project. Notification of personnel change should occur prior to the change implementation. The Contractor is responsible for replacing project personnel with personnel of equal or better skills and experience for the project if a change is implemented.

Project Technical Requirements

Activity 1 – Description (Wireless Data Transceivers): The Contractor shall provide the location (Latitude/Longitude coordinate) and characteristics of terrestrial wireless broadband[9] transceivers for both commercial federally licensed wireless and commercial unlicensed wireless service. Each transceiver shall be identified as a transceiver providing mobile or fixed broadband service, and the spectrum used, including whether it is licensed or unlicensed.

1.0 Activity 1 – Requirements (Wireless Data Transceivers):

1.1 The Contractor shall deliver a dataset that includes all transceivers providing wireless data services to end-users[10] in Vermont, including those transceivers that are located outside the state of Vermont, but provide wireless data service in the state.

1.2 The Contractor shall include a detailed set of attributes for every transceiver, including the full set of attributes required to support the creation of robust radio

[9] In the NTIA State Broadband Data and Development Grant Program Broadband is defined as being "data transmission technology that provides two-way transmission to and from the Internet with advertised speeds of at least 768 kilobits per second (kbps) downstream and at least 200 kbps upstream to end users, or providing sufficient capacity in a middle mile project to support the provision of broadband service to end users within the project area". Broadband Service is defined as being " the provision of broadband on either a commercial or non-commercial basis".

[10] NTIA NOFA definition "A residential or business party, institution or state or local government entity, including a Community Anchor Institution, that may use broadband service for its own purposes and that does not resell such service to other entities or incorporate such service into retail Internet-access services. Internet Service Providers (ISPs) are not "end users" for this purpose."

frequency propagation coverage maps outlined in Activity #2.[11] These attributes must be included with each point in the transceiver GIS shapefile. The source of each characteristic or attribute must also be identified in the shapefile at the transceiver level (example: source of height data, source of transmission power data, etc.). Each transceiver must also be identified by a unique transceiver identifier (TransID). The data must also identify the wireless carrier utilizing the transceiver to provide service. All transceivers registered*[12] with the FCC must include the FCC transceiver identifier (FCCID), owner FCC Federal Registration Number (FRN).

1.3 The Contractor shall deliver the wireless data transceiver location data in ESRI shapefile format. The shapefile must be in the WGS 1984 Geographic coordinate system.

1.4 The Contractor shall include detailed metadata documentation (in FGDC compliant metadata format) with the shapefile.

1.5 The Contractor shall map the location of all facilities to within +- 10 meters of their actual ground location.

1.6 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

Activity 2 – Description (Wireless Data Coverage Maps): The Contractor shall use the wireless transceiver information collected under Activity #1 to generate high-quality radio frequency (RF) propagation coverage maps accurately depicting the strength and geographic extent of wireless data services (fixed and mobile) emanating from each transceiver.

2.0 Activity 2 – Requirements (Wireless Data Coverage Maps):

2.1 The Contractor shall use sources and methods consistent with industry standard “best practices” for RF propagation analysis and mapping.

2.2 The Contractor shall utilize best-of-breed software to generate the RF propagation coverage maps.

2.3 The Contractor shall generate RF propagation maps for all transceivers identified in Activity #1, including fixed and mobile wireless.

[11] The attribution delivered should include all of the elements identified in the NTIA State Broadband Data and Development Grant Program Notice of Funding Availability, Technical Appendix, Section 1(b), Availability by Shapefile – Wireless Services Not Provided to a Specific Address, and Section 3(a), Last Mile Connection Points.

[12] The wireless transceiver dataset shall not be limited to those registered with the FCC. The dataset must include all wireless transceivers which meet the requirements of this RFP regardless of whether they are registered/unregistered, licensed/unlicensed.

2.4 The Contractor shall deliver the RF data files in one of the following raster formats: ERDAS IMAGINE, ESRI GRID, or ESRI ASCII raster. The data must be in the WGS 1984 Geographic coordinate system. The rasters must have 10 meter cell resolution.

2.5 The Contractor shall deliver a separate raster data file for each wireless data transceiver collected under Activity #1. Each cell in the raster dataset must identify signal strength as determined via the propagation analysis. The file naming convention must be as follows: WIREDATA_<TransID>. An example would be WIREDATA_21.

2.6 The Contractor shall propose and implement a methodology to identify the speed tier of the transceiver service at the raster cell level in accordance with the Technical Appendix of the NTIA Notice of Funds.[13]

2.7 The Contractor shall include detailed documentation (in FGDC compliant metadata format) with the data (a single metadata record for the entire set of raster files).

2.8 In the area covered by each fixed wireless transceiver coverage area, the wireless signal strength shown should be achievable to all locations within the raster cell boundary assuming typical customer premise receiving equipment. All assumptions regarding customer premise receiving equipment should be stated in the documentation.

2.9 In the area covered by each mobile wireless transceiver coverage area, subscribers must have service with the wireless link signal strength characteristics shown in the data record 95% of the time to within 50 feet of the raster cell boundary, assuming typical handheld subscriber equipment and walking-speed, outdoor use.

2.10 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

Activity 3 – Description (Wireless Voice Transceivers): The location (Latitude/Longitude coordinate) and characteristics of every transceiver providing terrestrial wireless voice services within the State of Vermont must be mapped under this activity.

3.0 Activity 3 – Requirements (Wireless Voice Transceivers):

3.1 The Contractor shall deliver a dataset that includes all transceivers providing wireless voice services to end-users in Vermont.

3.2 The Contractor shall include a detailed set of attributes for every transceiver,

[13] The speed tier identification should conform to the categories identified in the NTIA State Broadband Data and Development Gran t Program Notice of Funding Availability, Technical Appendix, Section 1(a) 7, Speed Tier Codes.

including the full set of attributes required to support the creation of robust radio frequency propagation coverage maps outlined in Activity #4. These attributes must be included with each point in the transceiver GIS shapefile. The source of each characteristic or attribute must also be identified in the shapefile at the transceiver level (example: source of height data, source of transmission power data, etc.). Each transceiver must also be identified by a unique transceiver identifier (TransID). The data must also identify the wireless carrier utilizing the transceiver to provide service. All transceivers registered[14] with the FCC must include the FCC transceiver identifier (FCCID), owner FCC Federal Registration Number (FRN).

3.3 The Contractor shall deliver the wireless voice transceiver location data in ESRI shapefile format. The shapefile must be in the WGS 1984 Geographic coordinate system.

3.4 The Contractor shall include detailed documentation (in FGDC compliant metadata format) with the shapefile.

3.5 The Contractor shall map the location of all facilities to within +- 10 meters of their actual ground location.

3.6 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

Activity 4 – Description (Wireless Voice Coverage Maps): The contractor shall use the wireless transceiver information collected under Activity #3 to generate high-quality radio frequency (RF) propagation coverage maps accurately depicting the strength and geographic extent of wireless voice services emanating from each transceiver.

4.0 Activity 4 – Requirements (Wireless Voice Coverage Maps):

4.1 The Contractor shall use sources and methods consistent with industry standard “best practices” for RF propagation analysis and mapping.

4.2 The Contractor shall utilize best-of-bread software to generate the RF propagation coverage maps.

4.3 The Contractor shall general RF propagation maps for all transceivers identified in Activity #3.

4.4 The Contractor shall deliver the RF data files in one of the following raster formats: ERDAS IMAGINE, ESRI GRID, or ESRI ASCII raster. The data must be in the WGS

[14] The wireless transceiver dataset shall not be limited to those registered with the FCC. The dataset must include all wireless transceivers which meet the requirements of this RFP regardless of whether they are registered/unregistered, licensed/unlicensed.

1984 Geographic coordinate system. The rasters must have 10-meter cell resolution.

4.5 The Contractor shall deliver a separate raster data file for each wireless voice transceiver collected under Activity #3. Each cell in the raster dataset must identify signal strength as determined via the propagation analysis. The file naming convention must be as follows: WIREVOICE_<TransID>. An example would be WIREVOICE_32.

4.6 The Contractor shall include detailed documentation (in FGDC compliant metadata format) with the data (a single metadata record for the entire set of raster files).

4.7 In the area covered by each wireless voice transceiver coverage area, subscribers must have service with the signal strength characteristics shown in the raster data 95% of the time to within 20 meters of the raster cell boundary.

4.8 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

Activity 5 – Description (Wireless Drive Testing): The contractor shall collect real-time mobile and fixed wireless information in the field using appropriate drive-testing data collection and mapping methods.

5.0 Activity 5 – Requirements (Wireless Drive Testing):

5.1 The Contractor shall use sources and methods consistent with industry standard “best practices” for wireless drive-test data collection and mapping.

5.2 The Contractor shall utilize best-of-breed software and hardware to collect and process the wireless drive-test data.

5.3 The Contractor shall collection drive-test data for wireless voice and data services (terrestrial mobile and fixed), including all of the carriers, spectrums, and technologies identified in Activity #1 and #3.

5.4 The Contractor shall include a sufficiently detailed set of attributes with every drive-test point to support 1) validation and 2) calibration of the RF propagation maps generated under Activity #2 and #4. The dataset must also include Latitude/Longitude coordinates (in WGS 1984 Geographic Coordinate System – Decimal Degrees) with every drive-test point utilizing an on-board GPS system capable of 1-meter horizontal accuracy.

5.5 The Contractor shall deliver the wireless drive-test data as a single table within an MS Access 2000 file (MDB).

5.6 The Contractor shall include detailed metadata documentation (in FGDC compliant metadata format) with the dataset.

5.7 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

Activity 6 – Description (Wireless Map Validation and Calibration): The contractor shall use the drive-test data collected under Activity #5 to determine the accuracy of the wireless propagation coverage datasets generated in Activity #2 and #4. The contractor shall also create a separate set of "calibrated" RF propagation maps (rasters) using the results of the drive-testing effort.

6.0 Activity 6 – Requirements (Wireless Map Validation and Calibration):

6.1 The Contractor shall use the drive-test data to determine the accuracy of the original RF propagation dataset generated under Activity #2 and #4. The Contractor shall deliver the raw results, summary statistics, and a report describing the accuracy of the original RF propagation dataset.

6.2 The Contractor shall use the drive-test data to calibrate and refine the RF propagation data generated under Activity #2 and #4. The Contractor shall deliver a separate set of "calibrated" RF propagation maps (separate raster for each transceiver as stipulated under Activity #2 and #4). The Contractor shall use "calibration" methods consistent with industry standard "best practices". The methods must be fully documented in a report describing how the maps were calibrated and refined.

6.3 All data collected and delivered for this activity shall be accurate as of 12/31/2009 or later.

7.0 Activity 7 – Deliverables Update:

7.1 The Contractor shall provide updated data for all deliverables identified in Activities 2, 4 and 6 based upon updated transceiver location and characteristic information provided by VCGI. The existing requirements for each of those Activities will still apply, with the exception of the data collection accuracy date. All data collected and delivered for this activity shall be updated with information accurate as of 6/30/2010 or later.

<u>Project Management Requirements</u>

The Contractor shall be responsible to VCGI, who has overall responsibility for the project schedule and adherence to contract provisions.

Because this contract is funded through American Recovery and Reinvestment Act (ARRA) monies there are ARRA specific requirements and provisions. The Contractor shall be responsible for compliance with all ARRA provisions as identified in Attachment E.

Upon award, the successful contractor shall be required to provide a completed response to the Tier 1 Contractor Self-Assessment document found in Attachment F.

The Contractor shall develop a project schedule consistent with the contract period specified in section 1.5 of the RFP, Schedule of Events. This project schedule must be maintained during the project and submitted along with a weekly Status Report during data collection periods of the contract.

- END OF SCOPE OF WORK -

Appendix B - Mobile Wireless Coverage Statistics

Appendix B.1 - Mobile Wireless Data Coverage Statistics

(AT&T Mobility, Sprint, U.S. Cellular, Verizon Wireless)

Broadband Wireless Data Summary Statistics

Table B.1 - Broadband Wireless Data Drive Test Results - Downlink					
		All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
Carrier	Attempts				
AT&T Mobility	10969	77%	32%	89%	58%
Sprint	12575	45%	3%	93%	7%
U.S. Cellular	12761	32%	7%	86%	23%
Verizon Wireless	10205	76%	21%	94%	29%

Notes:

1. Results within carrier polygon are not limited to those sites that are known to be UMTS/HSPA or EV-DO infrastructure.
2. Rates for downlink represent the user experience, not necessarily the gross or "raw" bit rate for the link.
3. Roaming calls removed.

Table B.2 - Broadband Wireless Data Drive Test Results - Uplink					
		All Attempts		Within Carrier Polygon Only	
		Successful (Any Rate)	Successful (> 200 kbps)	Successful (Any Rate)	Successful (> 200 kbps)
Carrier	Attempts				
AT&T Mobility	10969	71%	34%	85%	62%
Sprint	12575	42%	16%	91%	40%
U.S. Cellular	12761	29%	2%	84%	6%
Verizon Wireless	10205	73%	32%	93%	44%

Notes:

1. Rates for uplink are user experience (not scaled).
2. Roaming calls removed.

AT&T Data Statistics (Roaming Excluded)	# of Records (Based on Measured Speed)	% of Total	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	% of Total
Total Downlink Speed Test Attempts	**10969**	100%		
Total Downlink Successful (any rate)	8415	77%		
Total Downlink Successful on UMTS/HSPA Network	4315	39%		
Avg DL speed >= 768 kbps (user experience)	3483	32%	3718	34%
Max DL speed >= 768 kbps (raw data rate)	4042	37%	4075	37%
Total Uplink Speed Test Attempts	**10969**	100%		
Total Uplink Successful (any rate)	7741	71%		
Total Uplink Successful on UMTS/HSPA Network	4168	38%		
Avg UL speed >= 200 kbps (user experience)	3742	34%	3818	35%
Qualified with AT&T Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**5837**	**53%**		
Polygon Downlink Successful (any rate)	5199	89%		
Polygon Downlink Successful on UMTS/HSPA Network	4112	70%		
Polygon Avg DL speed >= 768 kbps (user experience)	3374	58%	3599	62%
Polygon Max DL speed >= 768 kbps (raw data rate)	3898	67%	3924	67%
Total Uplink Speed Test Attempts Within Polygon	**5837**	**53%**		
Polygon Uplink Successful (any rate)	4949	85%		
Polygon Uplink Successful on UMTS/HSPA Network	4014	69%		
Polygon Avg UL speed >= 200 kbps (user experience)	3642	62%	3714	64%
Qualified with Pericle Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**5162**	**47%**		
Polygon Downlink Successful (any rate)	4694	91%		
Polygon Downlink Successful on UMTS/HSPA Network	3454	67%		
Polygon Avg DL speed >= 768 kbps (user experience)	2853	55%	3023	59%
Polygon Max DL speed >= 768 kbps (raw data rate)	3278	64%	3300	64%
Total Uplink Speed Test Attempts Within Polygon	**5162**	**47%**		
Polygon Uplink Successful (any rate)	4466	87%		
Polygon Uplink Successful on UMTS/HSPA Network	3359	65%		
Polygon Avg UL speed >= 200 kbps (user experience)	3064	59%	3117	60%

Notes:

1. Because gross bit rates are those usually advertised, it is common in the industry to scale the measured throughput upward by 15-20% to account for protocol overhead and retries. The second column calculates number of records with a 20% scale factor.
2. AT&T polygon threshold was not provided by the carrier.
3. Pericle data polygon is defined by a mean predicted level of -101.5 dBm and includes only broaband data-capable sites (UMTS/HSPA).

Sprint Data Statistics	# of Records (Based on Measured Speed)	% of Total	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	% of Total
Total Downlink Speed Test Attempts	**12575**			
Total Downlink Successful (any rate)	5663	45%		
Total Downlink Successful on EVDO Network	4516	36%		
Avg DL speed >= 768 kbps (user experience)	323	3%	918	7%
Max DL speed >= 768 kbps (raw data rate)	3594	29%	3925	31%
Total Uplink Speed Test Attempts	**12575**			
Total Uplink Successful (any rate)	5290	42%		
Total Uplink Successful on EVDO Network	4512	36%		
Avg UL speed >= 200 kbps (user experience)	1970	16%	3554	28%
Qualified with Sprint Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**4463**	**35%**		
Polygon Downlink Successful (any rate)	4139	93%		
Polygon Downlink Successful on EVDO Network	3675	82%		
Polygon Avg DL speed >= 768 kbps (user experience)	307	7%	855	19%
Polygon Max DL speed >= 768 kbps (raw data rate)	3149	71%	3368	75%
Total Uplink Speed Test Attempts Within Polygon	**4463**	**35%**		
Polygon Uplink Successful (any rate)	4049	91%		
Polygon Uplink Successful on EVDO Network	3687	83%		
Polygon Avg UL speed >= 200 kbps (user experience)	1793	40%	3162	71%
Qualified with Pericle Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**4900**	**39%**		
Polygon Downlink Successful (any rate)	4246	87%		
Polygon Downlink Successful on EVDO Network	3587	73%		
Polygon Avg DL speed >= 768 kbps (user experience)	243	5%	739	15%
Polygon Max DL speed >= 768 kbps (raw data rate)	2972	61%	3203	65%
Total Uplink Speed Test Attempts Within Polygon	**4900**	**39%**		
Polygon Uplink Successful (any rate)	4115	84%		
Polygon Uplink Successful on EVDO Network	3627	74%		
Polygon Avg UL speed >= 200 kbps (user experience)	1667	34%	3012	61%

Notes:

1. Because gross bit rates are those usually advertised, it is common in the industry to scale the measured throughput upward by 15-20% to account for protocol overhead and retries. The second column calculates number of records with a 20% scale factor.
2. Sprint Polygon is -98 dBm mean 1XRTT coverage.
3. Pericle data polygon is -100 dBm mean coverage.

US Cellular Data Statistics	# of Records (Based on Measured Speed)	% of Total	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	% of Total
Total Downlink Speed Test Attempts	**12761**			
Total Downlink Successful (any rate)	4035	32%		
Total Downlink Successful on EVDO Network	1963	15%		
Avg DL speed >= 768 kbps (user experience)	885	7%	1153	9%
Max DL speed >= 768 kbps (raw data rate)	1608	13%	1703	13%
Total Uplink Speed Test Attempts	**12761**			
Total Uplink Successful (any rate)	3729	29%		
Total Uplink Successful on EVDO Network	1932	15%		
Avg UL speed >= 200 kbps (user experience)	252	2%	1213	10%
Qualified with US Cellular Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**3426**	**27%**		
Polygon Downlink Successful (any rate)	2942	86%		
Polygon Downlink Successful on EVDO Network	1151	34%		
Polygon Avg DL speed >= 768 kbps (user experience)	772	23%	1004	29%
Polygon Max DL speed >= 768 kbps (raw data rate)	1344	39%	1400	41%
Total Uplink Speed Test Attempts Within Polygon	**3426**	**27%**		
Polygon Uplink Successful (any rate)	2870	84%		
Polygon Uplink Successful on EVDO Network	1497	44%		
Polygon Avg UL speed >= 200 kbps (user experience)	218	6%	1037	30%
Qualified with Pericle Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**3195**	**25%**		
Polygon Downlink Successful (any rate)	2594	81%		
Polygon Downlink Successful on EVDO Network	1345	42%		
Polygon Avg DL speed >= 768 kbps (user experience)	673	21%	865	27%
Polygon Max DL speed >= 768 kbps (raw data rate)	1168	37%	1221	38%
Total Uplink Speed Test Attempts Within Polygon	**3195**	**25%**		
Polygon Uplink Successful (any rate)	2493	78%		
Polygon Uplink Successful on EVDO Network	1312	41%		
Polygon Avg UL speed >= 200 kbps (user experience)	175	5%	885	28%

Notes:

1. Because gross bit rates are those usually advertised, it is common in the industry to scale the measured throughput upward by 15-20% to account for protocol overhead and retries. The second column calculates number of records with a 20% scale factor.
2. US Cellular polygon threshold is not known.
3. Pericle data polygon is -100 dBm mean coverage.

Verizon Data Statistics	# of Records (Based on Measured Speed)	% of Total	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	% of Total
Total Downlink Speed Test Attempts	**10205**			
Total Downlink Successful (any rate)	7780	76%		
Total Downlink Successful on EVDO Network	6303	62%		
Avg DL speed >= 768 kbps (user experience)	2161	21%	3079	30%
Max DL speed >= 768 kbps (raw data rate)	4763	47%	5167	51%
Total Uplink Speed Test Attempts	**10205**			
Total Uplink Successful (any rate)	7487	73%		
Total Uplink Successful on EVDO Network	6197	61%		
Avg UL speed >= 200 kbps (user experience)	3273	32%	4640	45%
Qualified with Verizon Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**6712**	**66%**		
Polygon Downlink Successful (any rate)	6290	94%		
Polygon Downlink Successful on EVDO Network	5409	81%		
Polygon Avg DL speed >= 768 kbps (user experience)	1955	29%	2800	42%
Polygon Max DL speed >= 768 kbps (raw data rate)	4286	64%	4608	69%
Total Uplink Speed Test Attempts Within Polygon	**6712**	**66%**		
Polygon Uplink Successful (any rate)	6250	93%		
Polygon Uplink Successful on EVDO Network	5380	80%		
Polygon Avg UL speed >= 200 kbps (user experience)	2970	44%	4211	63%
Qualified with Pericle Data Coverage Polygon:				
Total downlink speed test attempts within Polygon	**6736**	**66%**		
Polygon Downlink Successful (any rate)	6174	92%		
Polygon Downlink Successful on EVDO Network	5278	78%		
Polygon Avg DL speed >= 768 kbps (user experience)	1943	29%	2768	41%
Polygon Max DL speed >= 768 kbps (raw data rate)	4207	62%	4520	67%
Total Uplink Speed Test Attempts Within Polygon	**6736**	**66%**		
Polygon Uplink Successful (any rate)	6108	91%		
Polygon Uplink Successful on EVDO Network	5222	78%		
Polygon Avg UL speed >= 200 kbps (user experience)	2881	43%	4094	61%

Notes:

1. Because gross bit rates are those usually advertised, it is common in the industry to scale the measured throughput upward by 15-20% to account for protocol overhead and retries. The second column calculates number of records with a 20% scale factor.
2. Verizon polygon threshold is not known.
3. Pericle data polygon is -100 dBm mean coverage.

Appendix B.2 - Mobile Wireless Voice Coverage Summary Statistics

(AT&T Mobility, Nextel, Sprint, T-Mobile, U.S. Cellular, Verizon Wireless)

Wireless Voice Summary Statistics

Table B.3 - Broadband Wireless Voice Drive Test Results			
Carrier	Attempts	Successful, All Attempts	Successful From Attempts Within Pericle Coverage Polygon
AT&T Mobility	10969	86%	96%
Nextel	32654	51%	86%
Sprint	12575	49%	93%
T-Mobile	10404	24%	98%
U.S. Cellular	12764	34%	86%
Verizon Wireless	10209	80%	96%

Notes:

1. Roaming calls removed.

Appendix C - Mobile Wireless Coverage Maps

This appendix contains coverage maps for each of the six mobile wireless carriers: AT&T Mobility, Nextel, Sprint, T-Mobile, U.S. Cellular and Verizon Wireless. These maps were generated by exporting the **EDX Signal™** map data or drive test map data to **Esri Arcview**. Soft copies have been provided to VCGI separately.

Only four carriers provided broadband data service as of June 30, 2010. These carriers are AT&T Mobility, Sprint, U.S. Cellular and Verizon Wireless. The other carriers, Nextel and T-Mobile, provided only low data rate services on that date. All carriers provided wireless voice services.

For the four broadband data carriers, six individual maps are provided:

- Computer modeled wireless data coverage from Pericle and the carrier
- Actual downlink wireless data coverage as measured during the drive test survey
- Actual uplink wireless data coverage as measured during the drive test survey
- Type of wireless data infrastructure provided (e.g., UMTS/HSPA vs. GSM/EDGE)
- Computer modeled voice coverage (Pericle) with cell site locations shown
- Actual voice call results as measured during the drive test survey

Note that the downlink is the radio path from the cell site to the subscriber device. The uplink is the radio path from the subscriber to the cell site.

For Nextel and T-Mobile, two maps are provided:

- Computer modeled voice coverage (Pericle) with cell site locations shown
- Actual voice call results as measured during the drive test survey

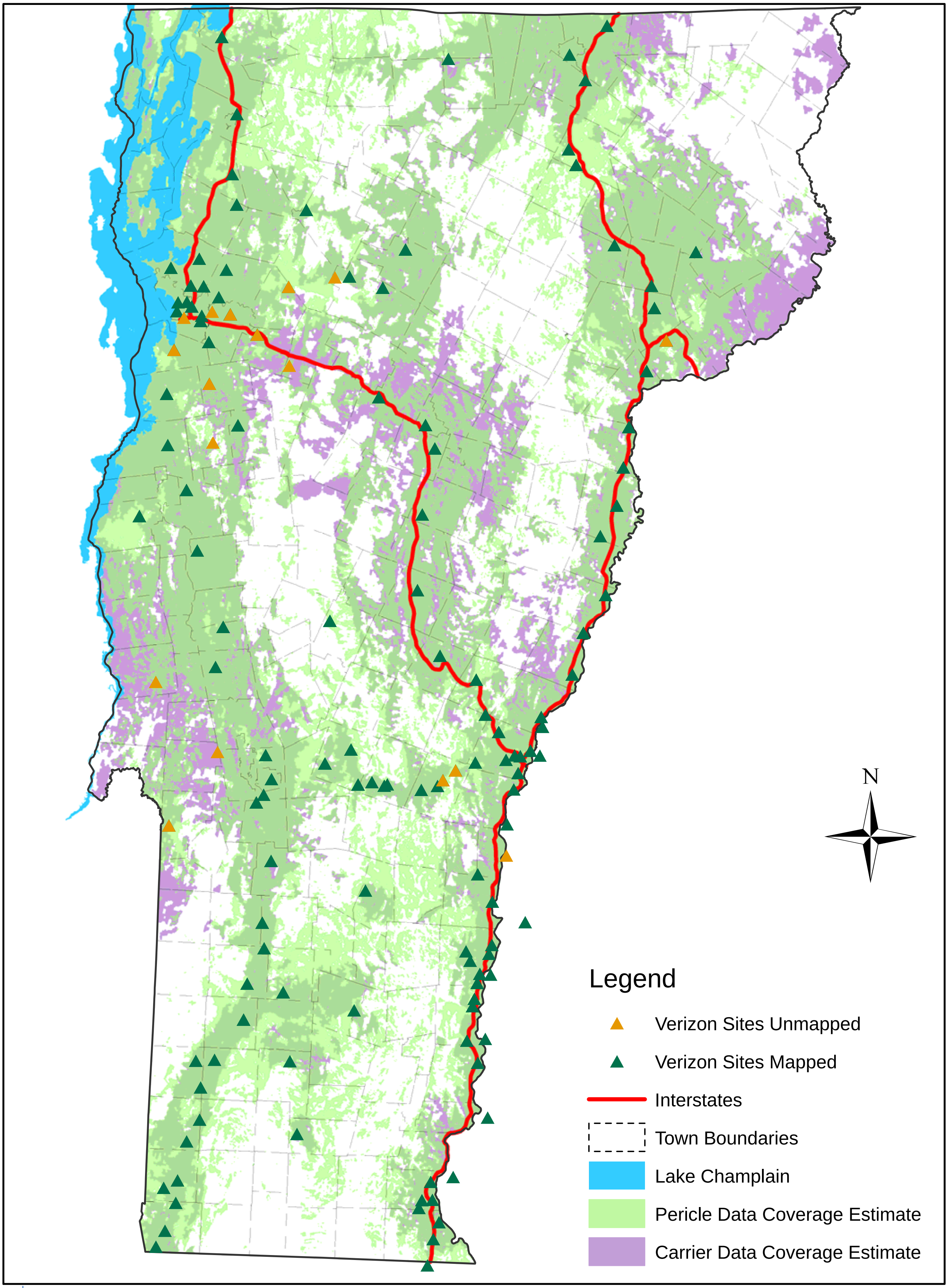
For these two carriers, one can assume that low speed data coverage is virtually identical to voice coverage as the two services are provided using the same infrastructure.

The layer showing Pericle computer-modeled coverage is above the layer containing carrier coverage.

The maps are presented in alphabetical order by carrier name.

[Note: This version of report is a sample and not all coverage maps are included.]

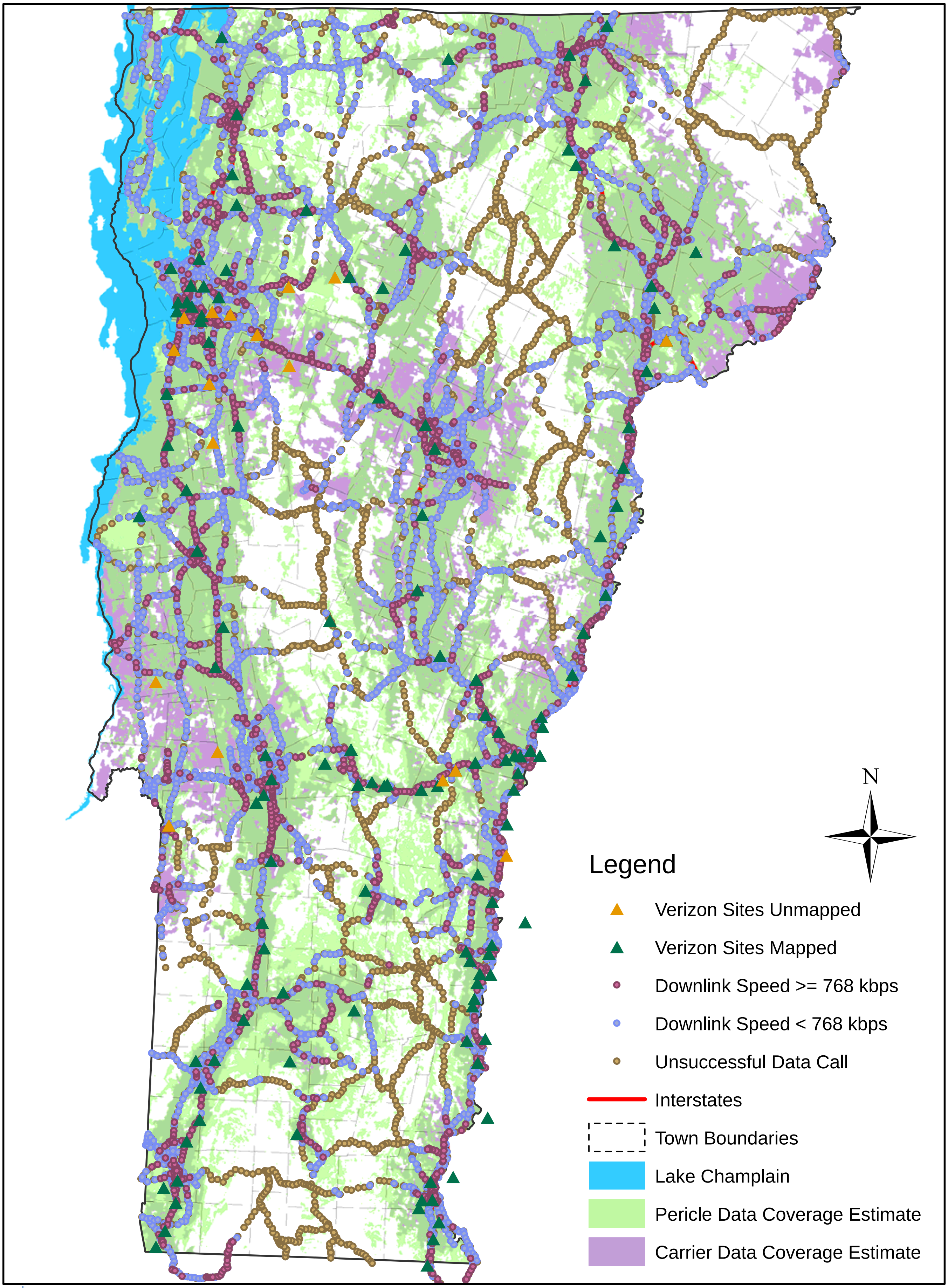
Verizon Data Coverage and Cell Sites



PERICLE

As of June 30, 2010

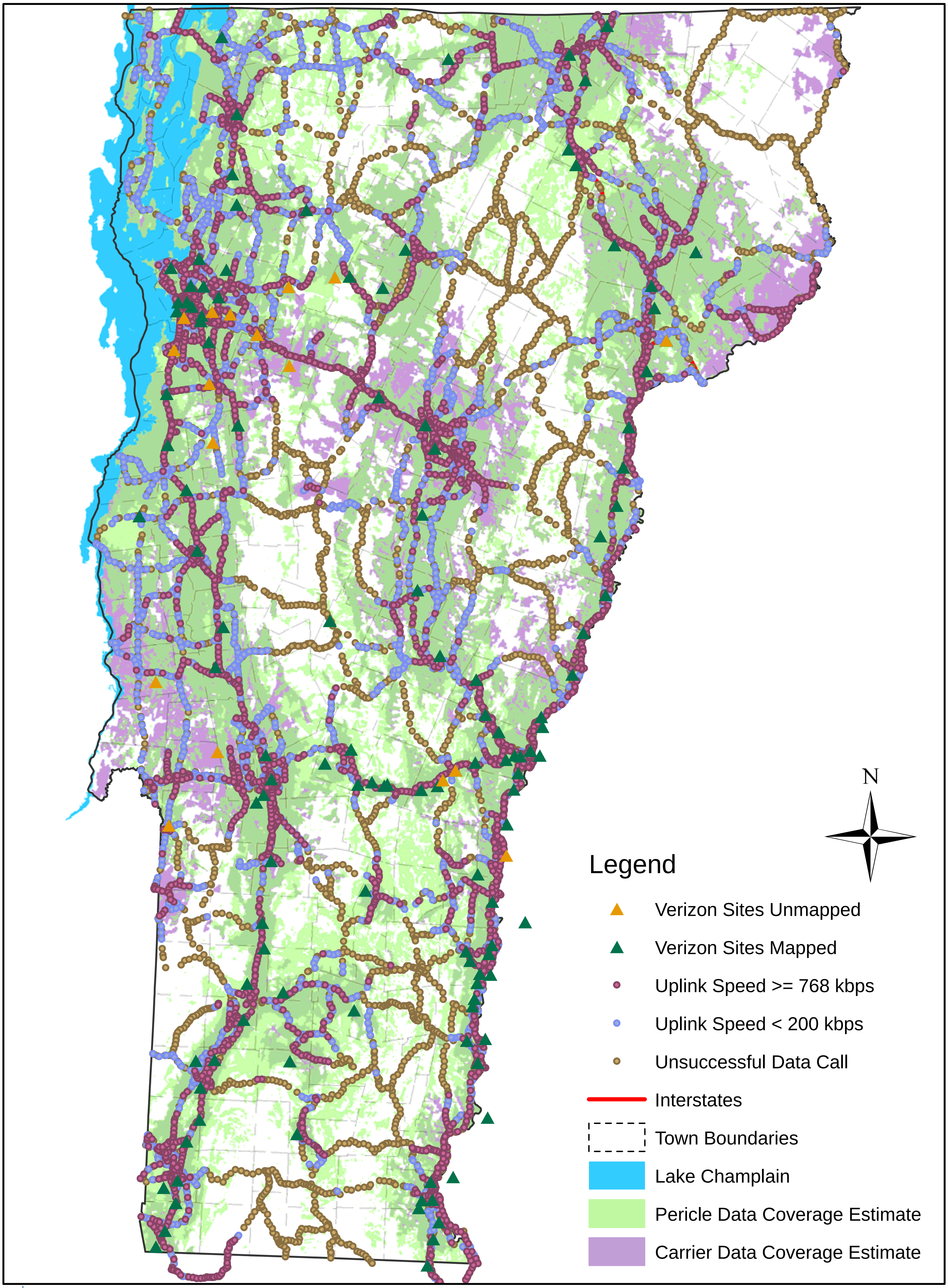
Verizon Downlink Data Test Results



PERICLE

As of June 30, 2010

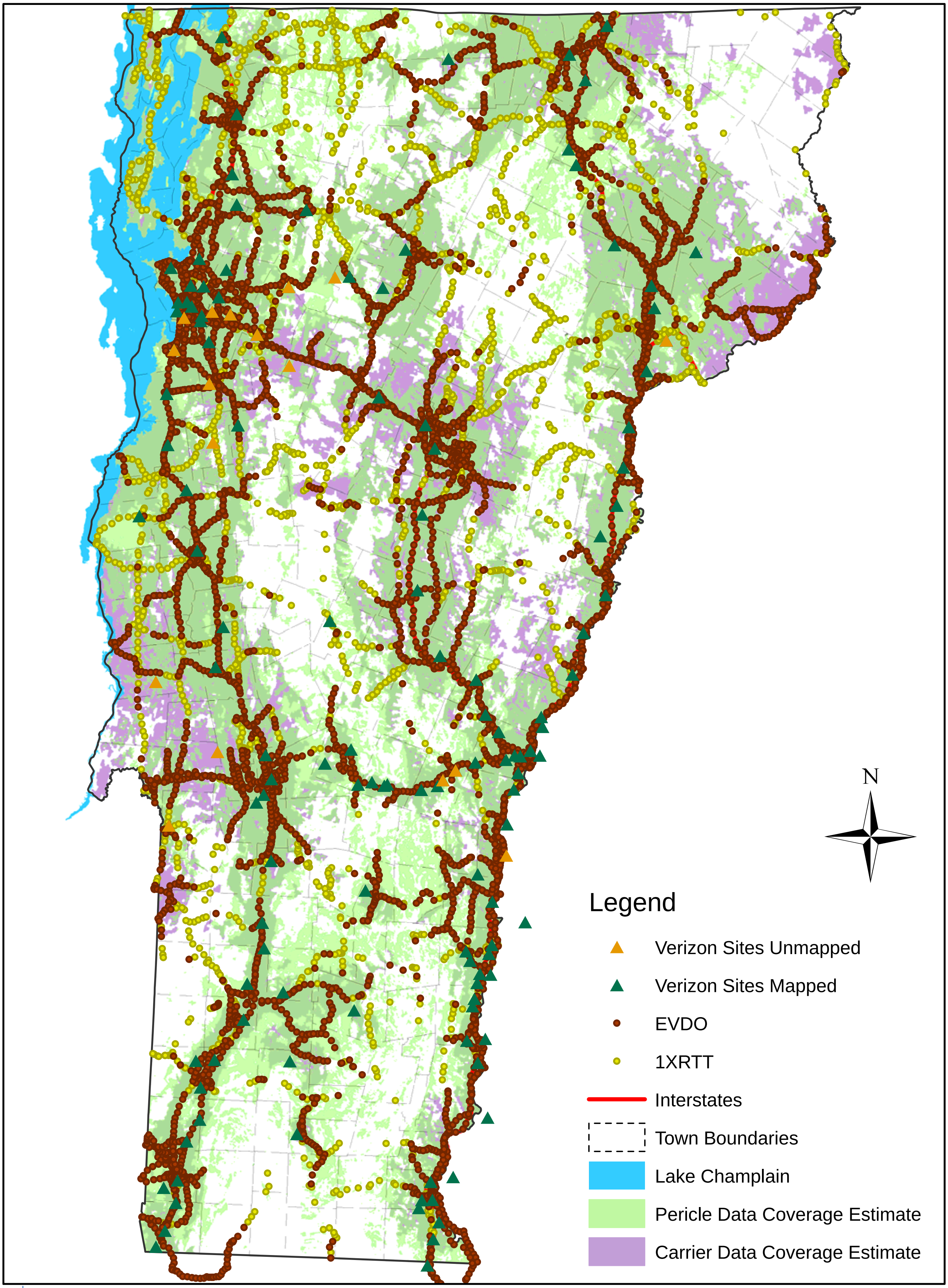
Verizon Uplink Data Test Results



PERICLE

As of June 30, 2010

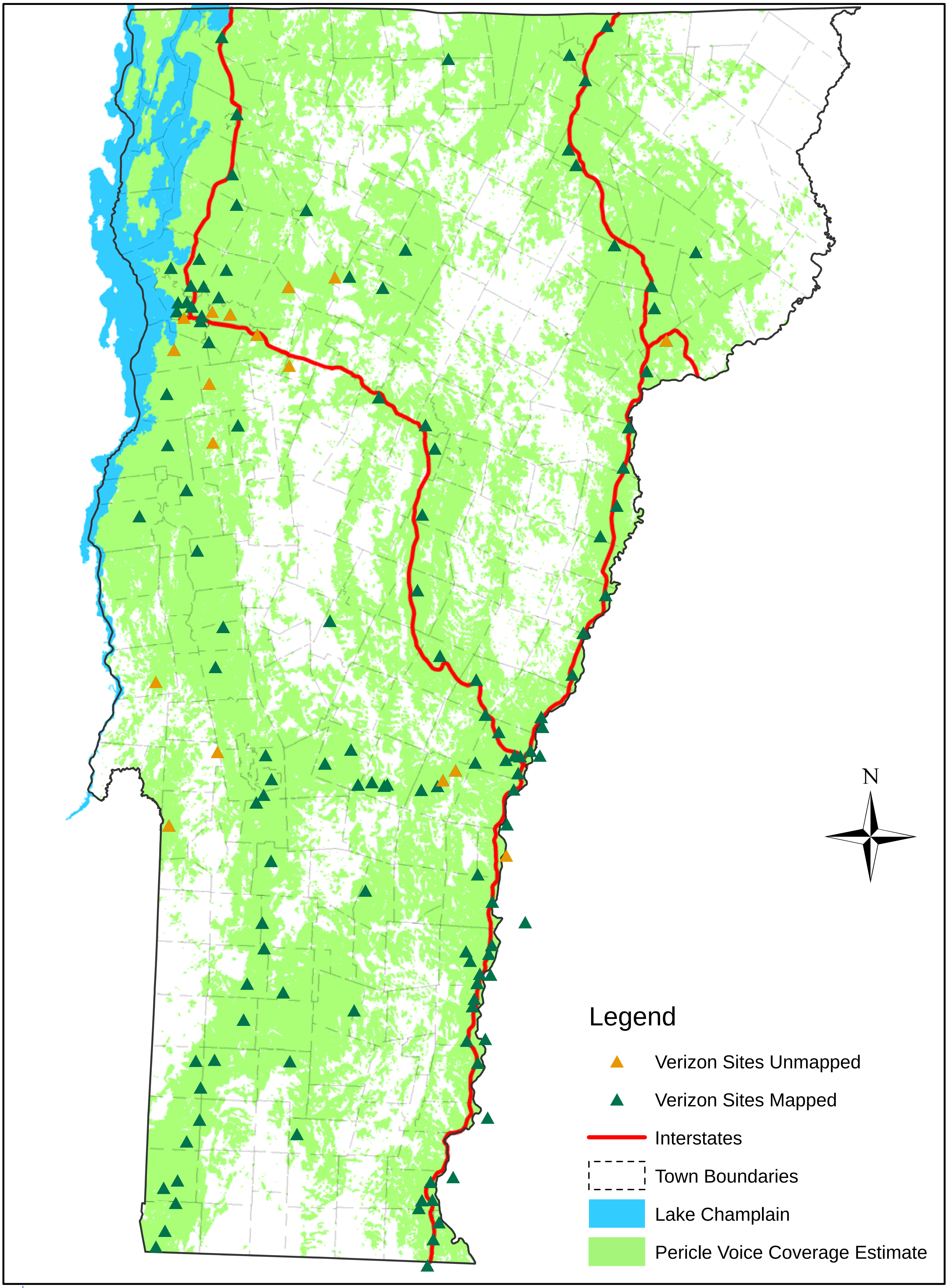
Verizon Data Call Infrastructure



PERICLE

As of June 30, 2010

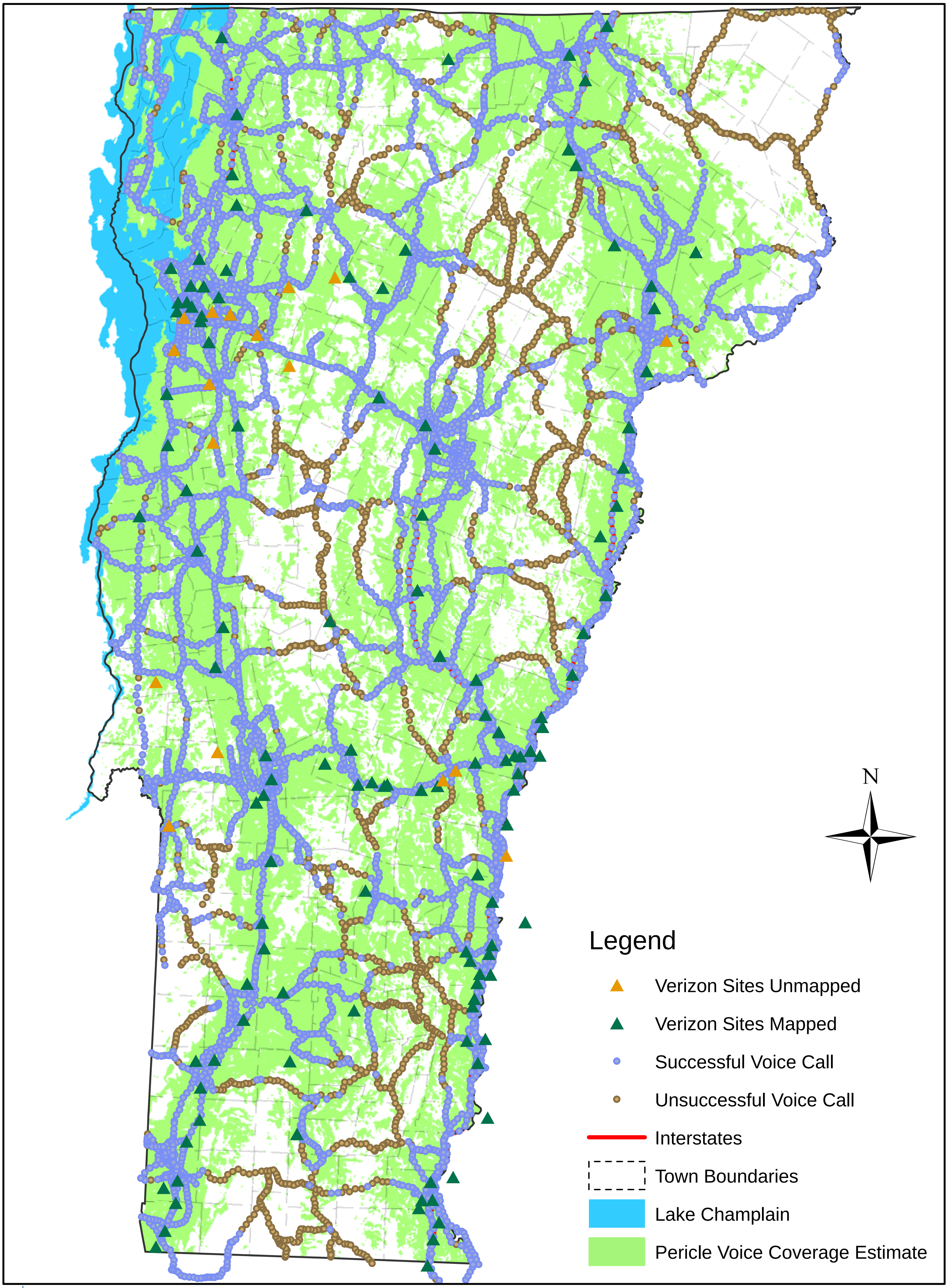
Verizon Voice Coverage and Cell Sites



PERICLE

As of June 30, 2010

Verizon Voice Call Results

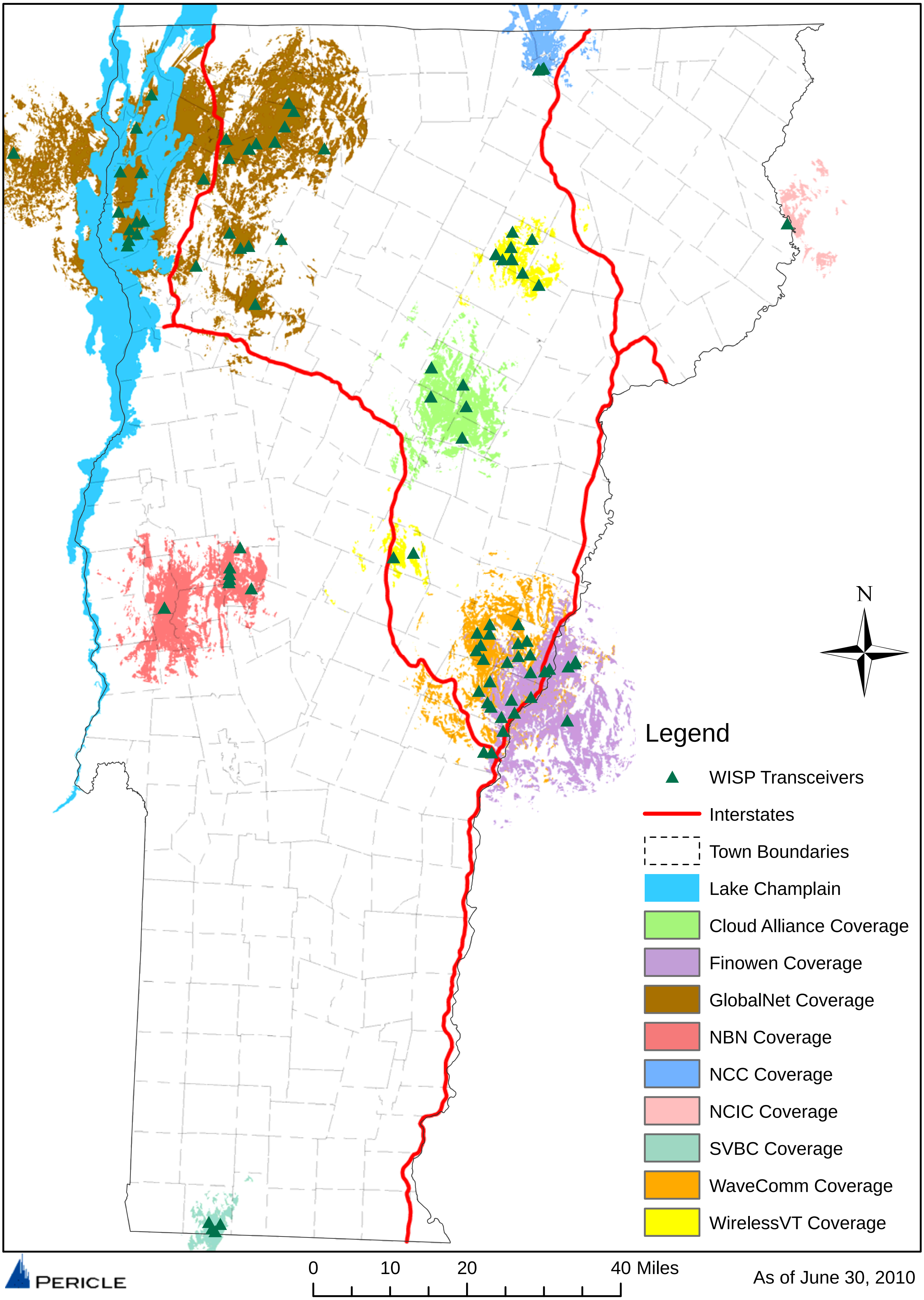


PERICLE

As of June 30, 2010

Appendix D - Fixed Wireless Coverage Maps

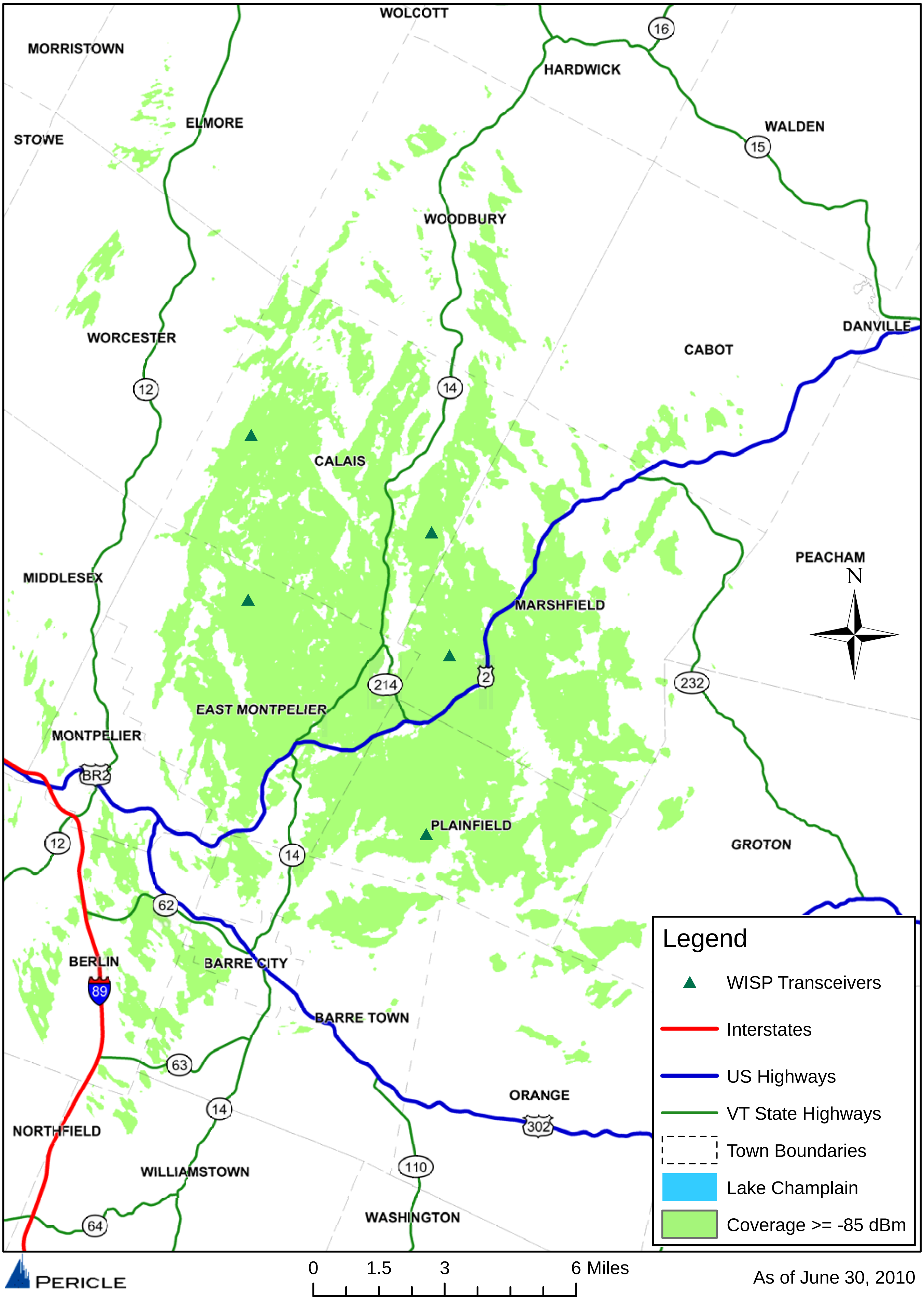
Vermont WISP Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

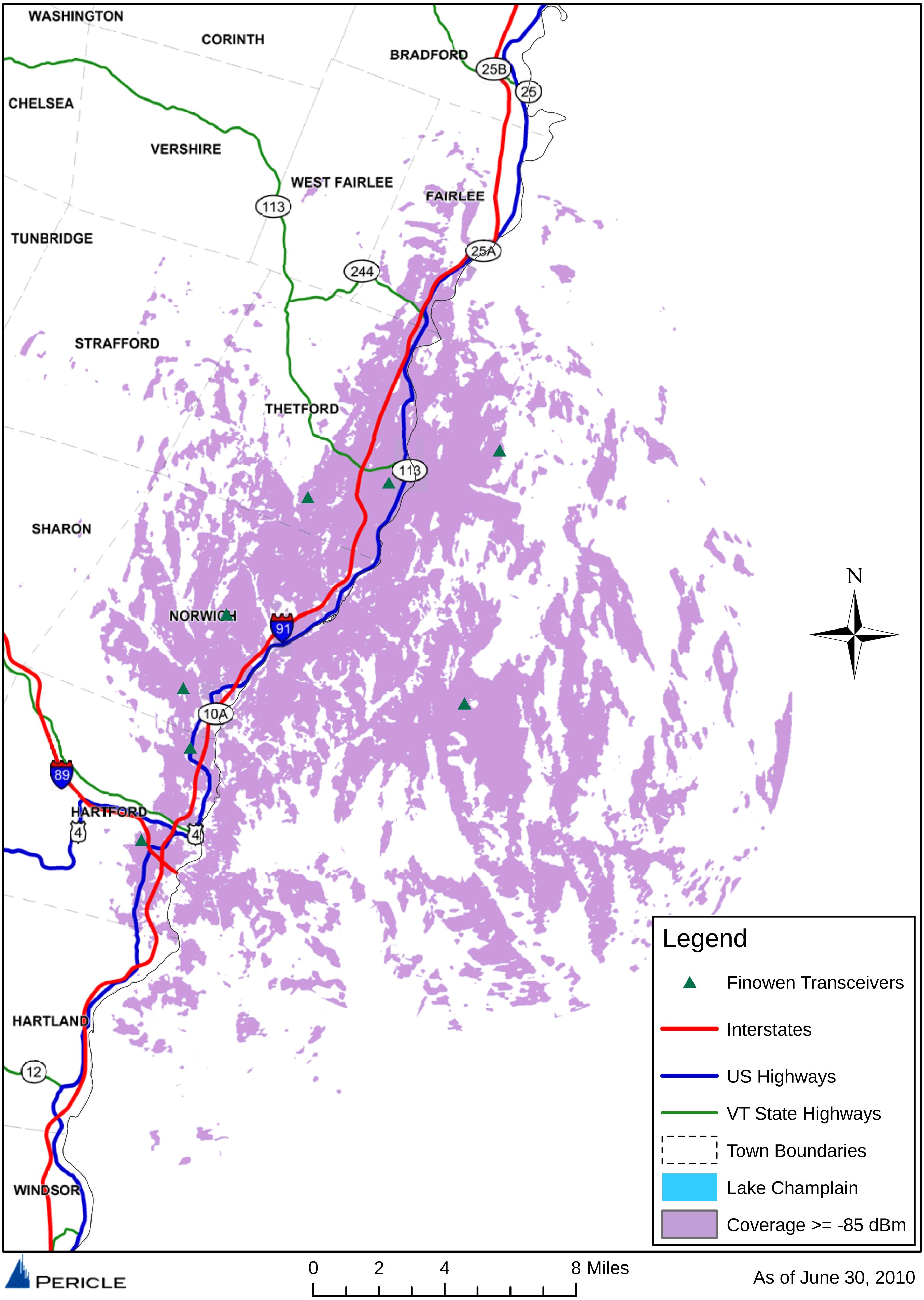
Cloud Alliance Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

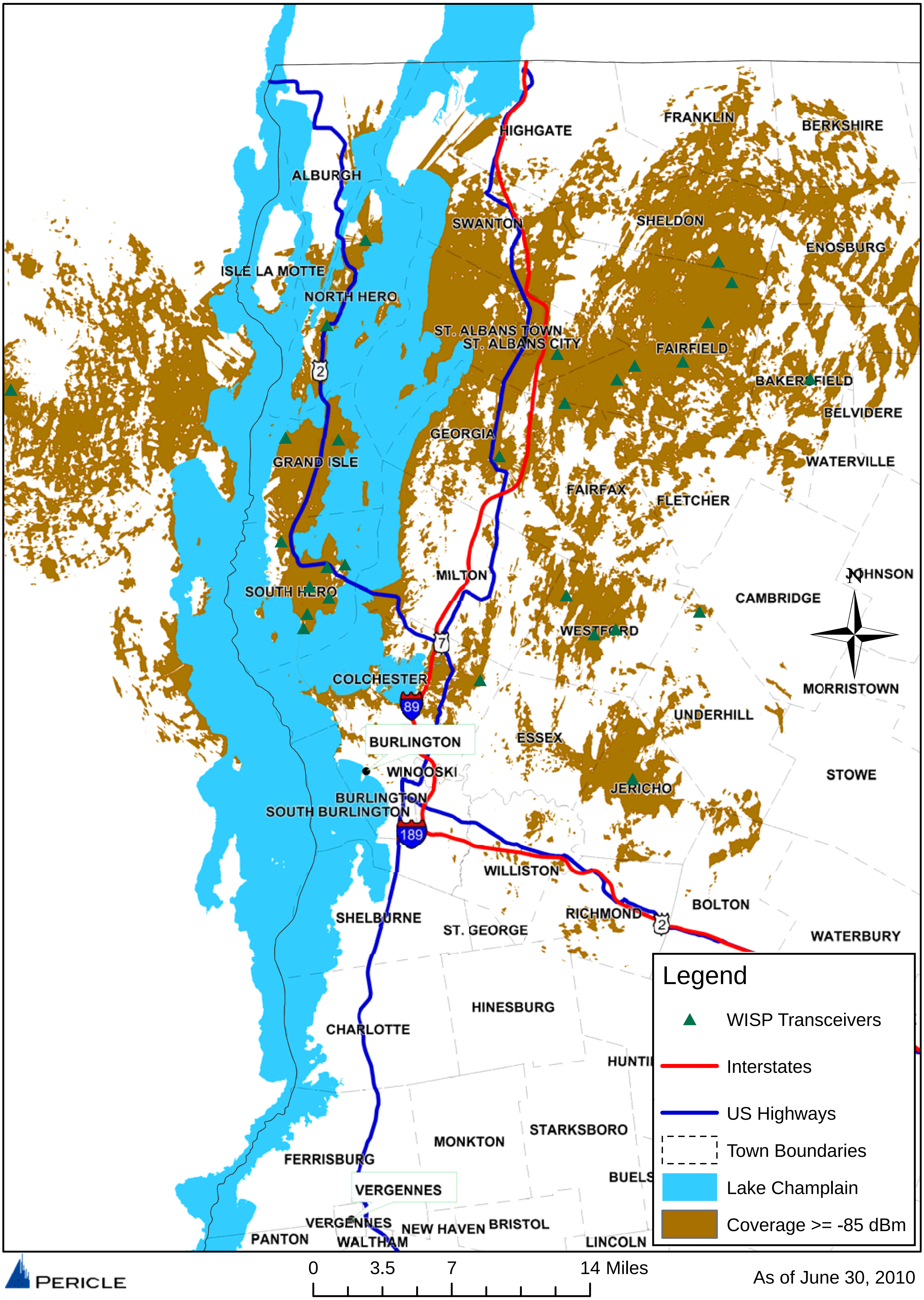
Finowen Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

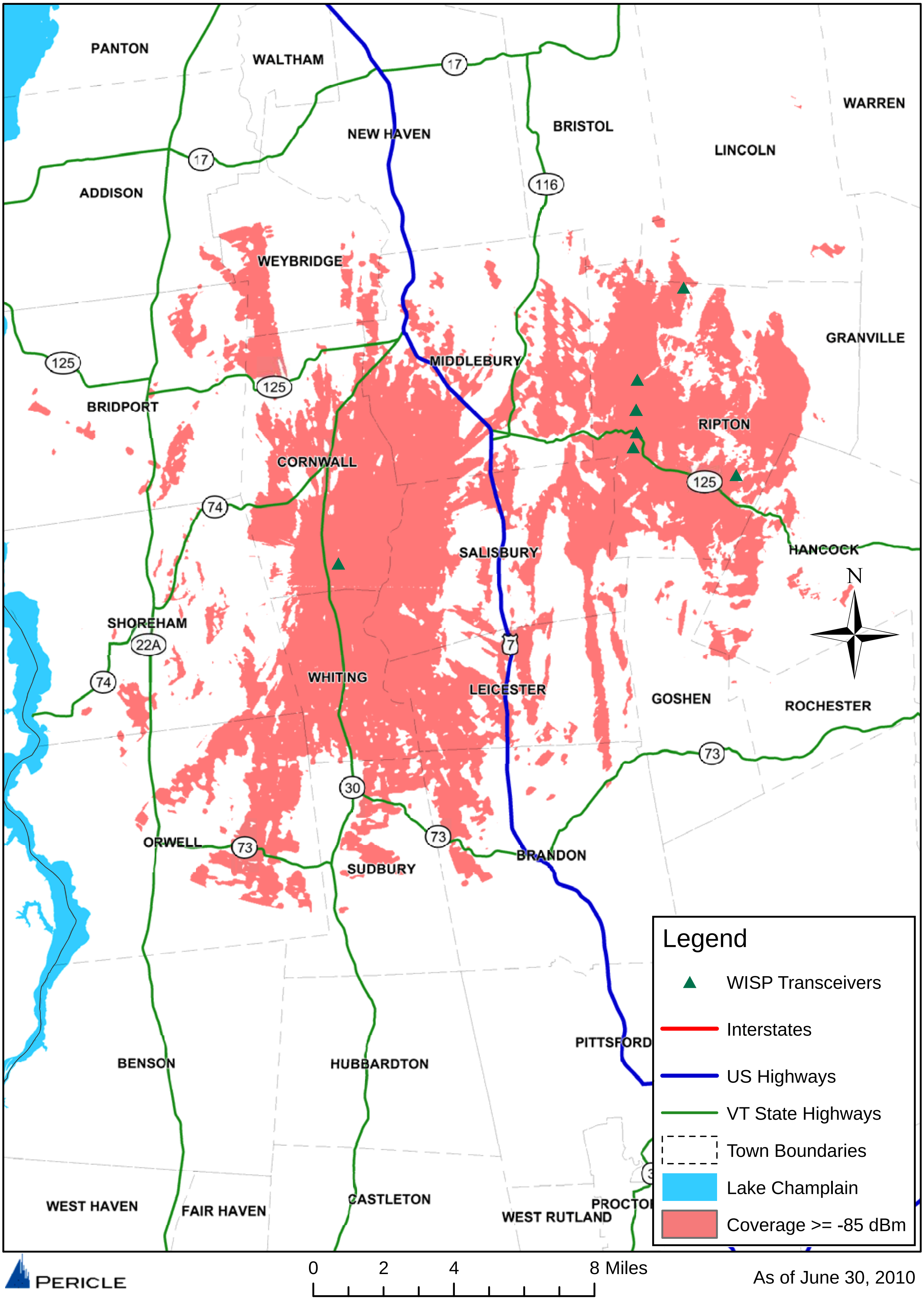
GlobalNet Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

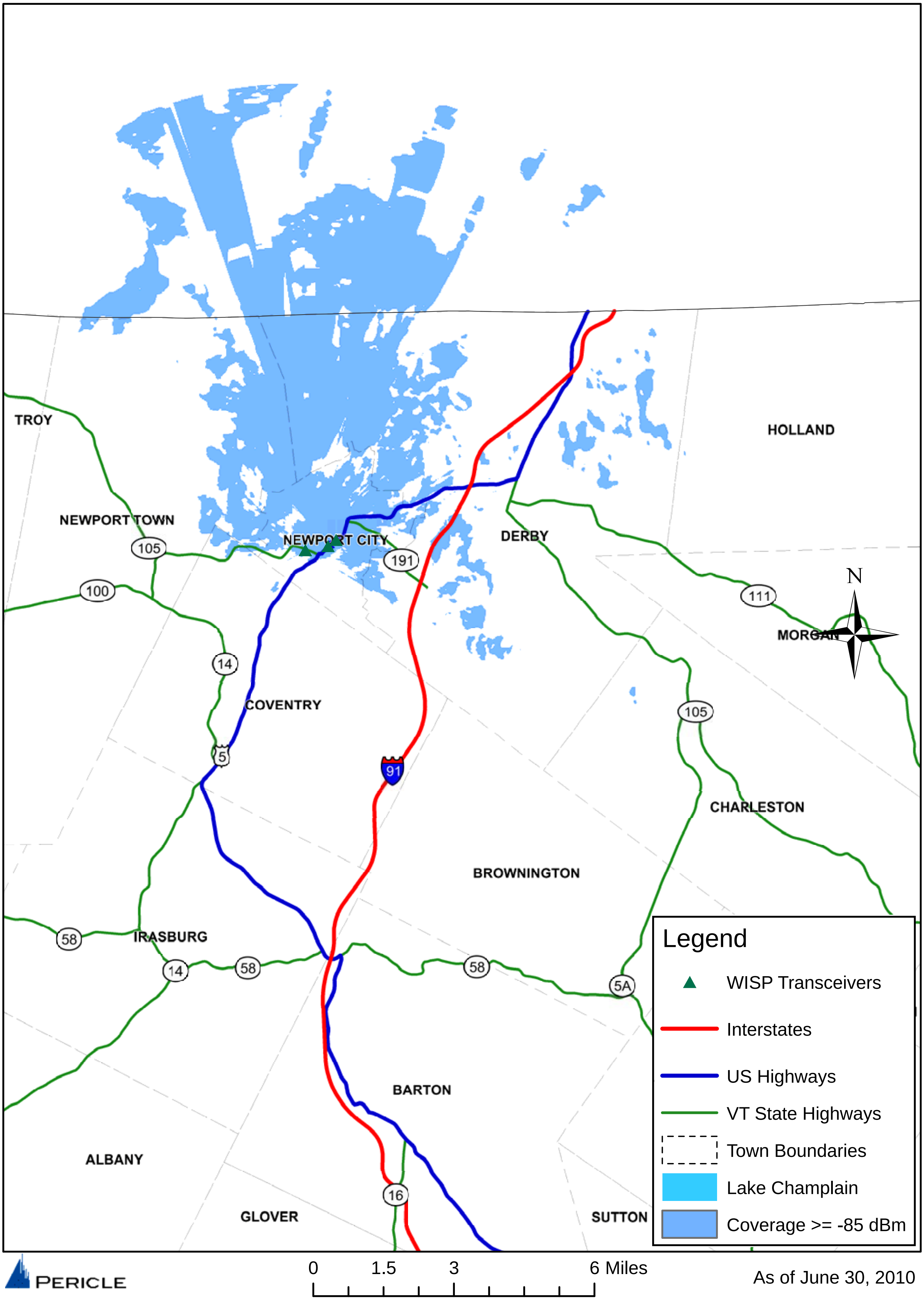
NBN Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

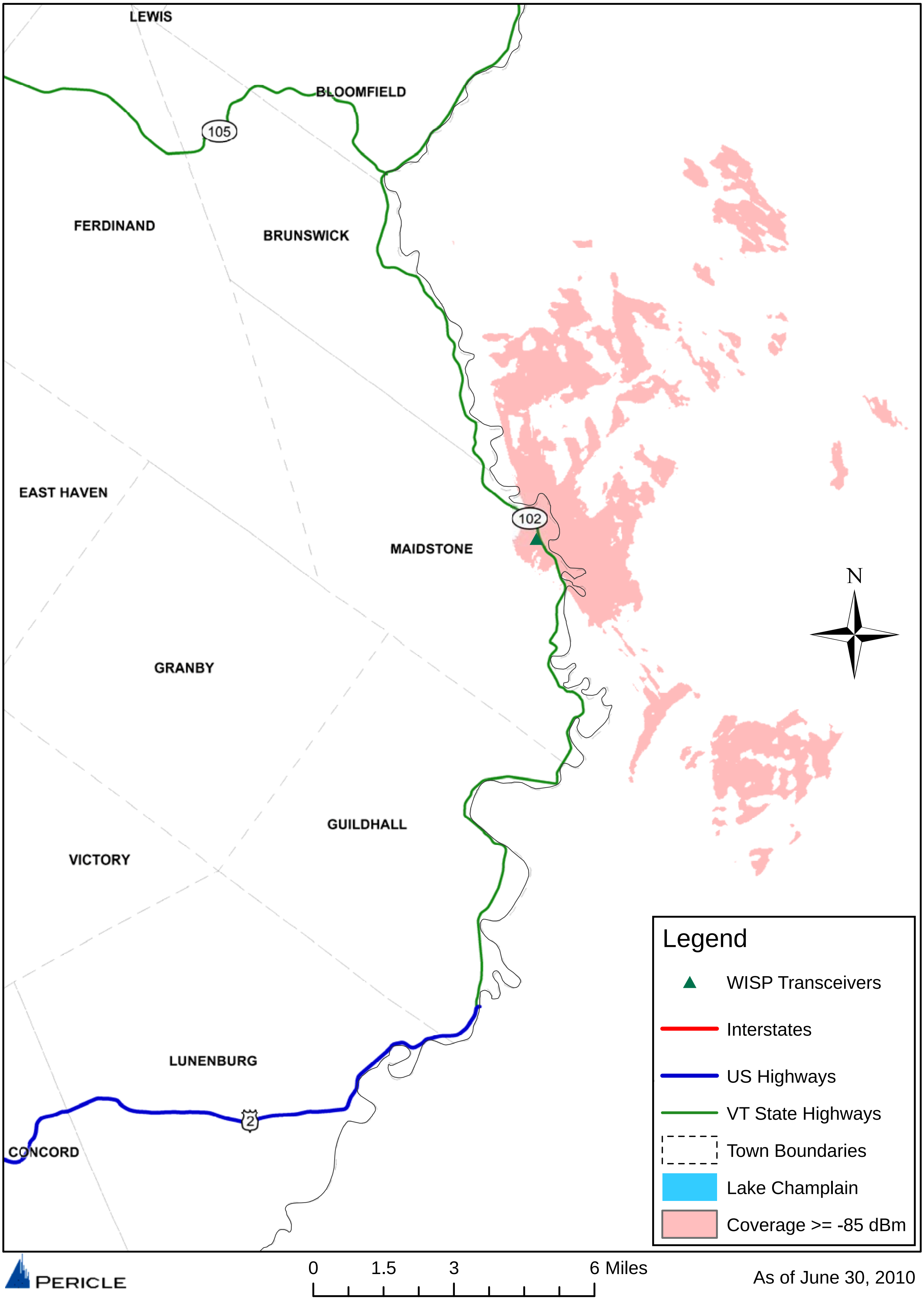
NCC Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

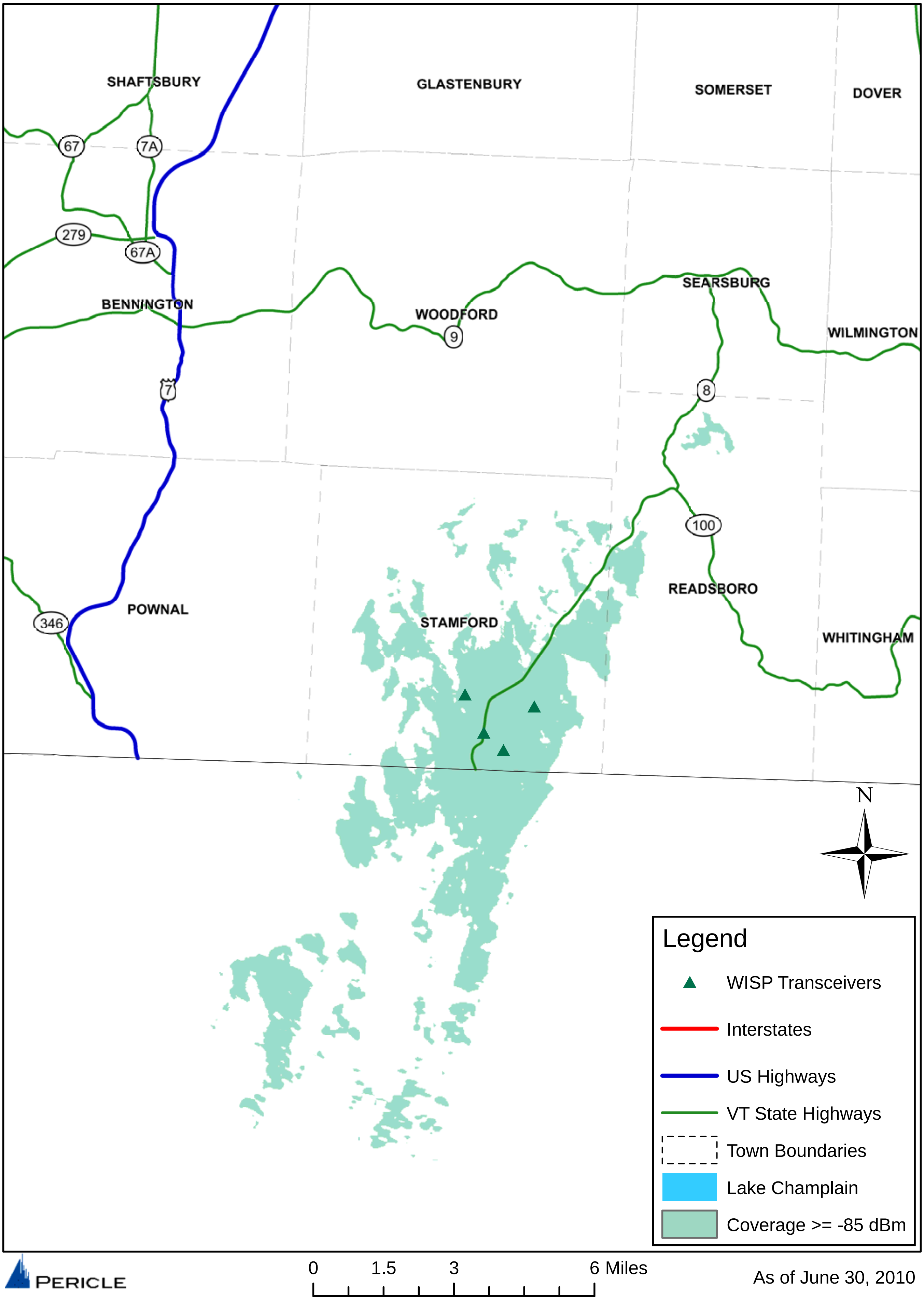
NCIC Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

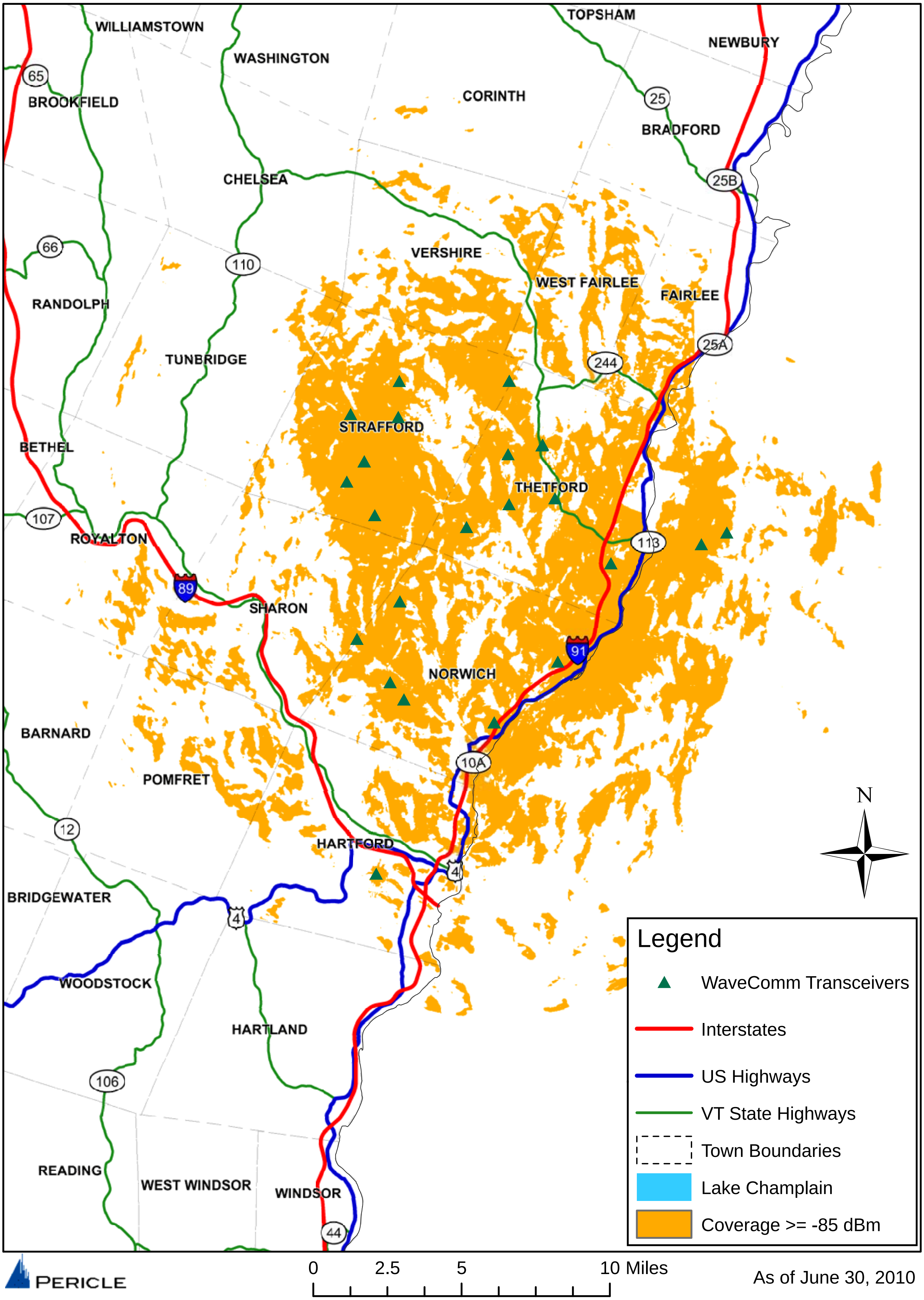
SVBC Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

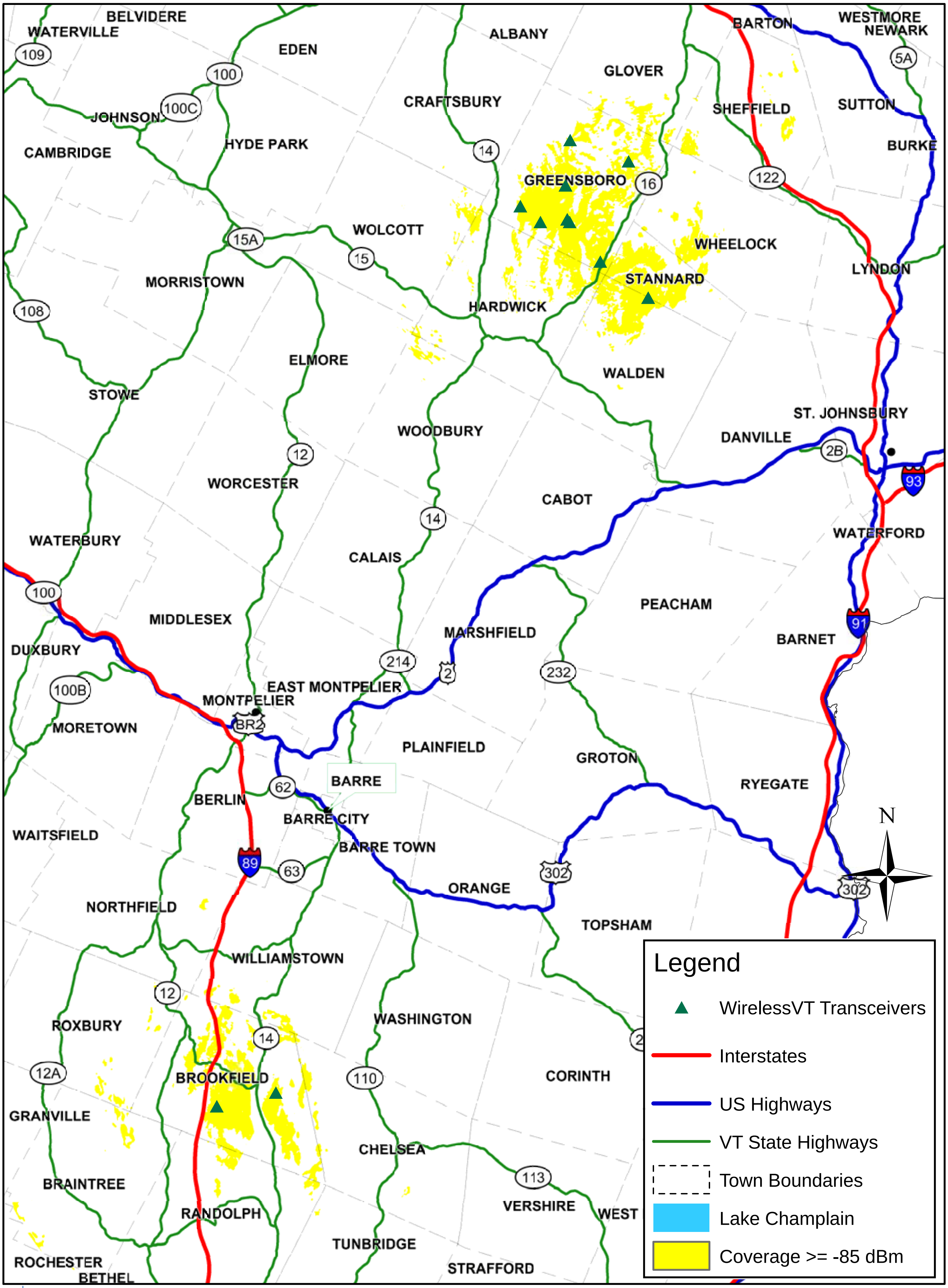
WaveComm Coverage and Transceiver Locations



PERICLE

As of June 30, 2010

WaveComm Coverage and Transceiver Locations



PERICLE

0 3.5 7 14 Miles

As of June 30, 2010