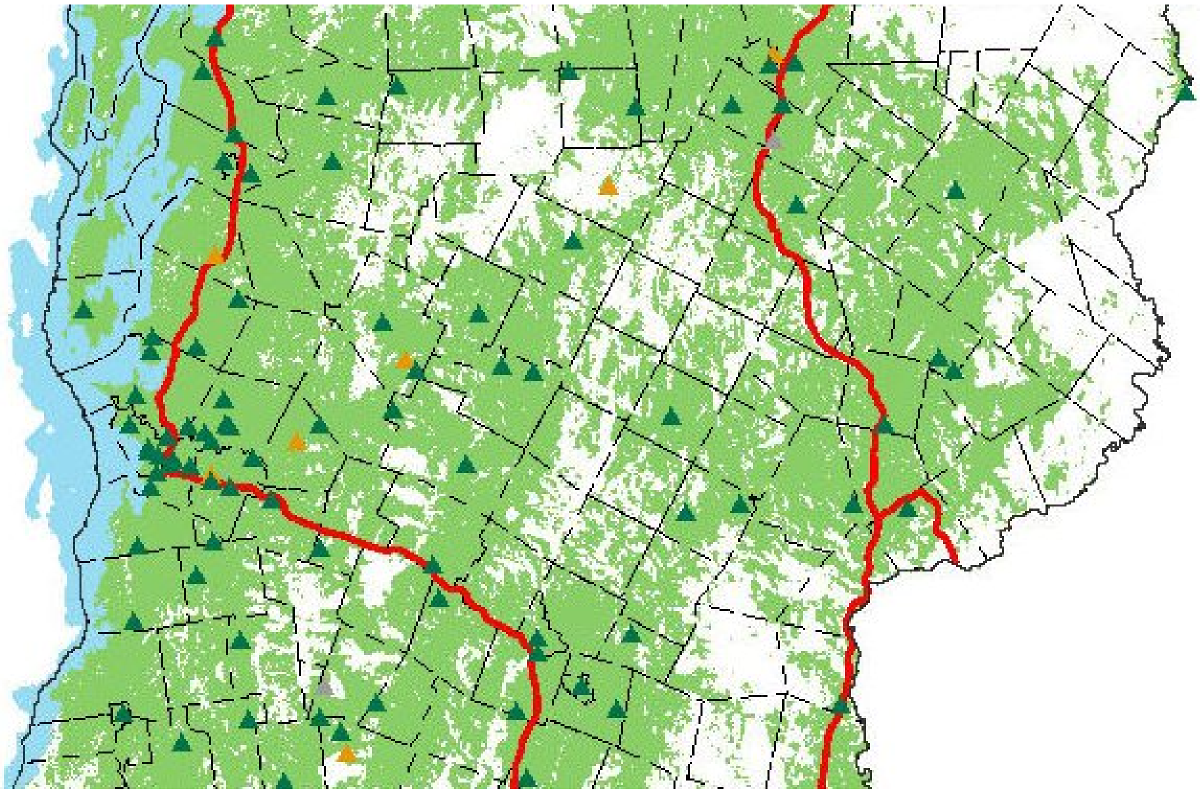
Vermont 2013 Wireless Broadband Mapping Final Report



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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. This report documents the second of two wireless mapping projects which Pericle has performed for VCGI and as such focuses on changes to the Vermont wireless broadband landscape since the first mapping project completed in 2010[1]. VCGI asked Pericle to update its previous independent wireless broadband Vermont coverage assessment through a combination of radio site transceiver and antenna configuration updates, 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 6,000 miles of Federal Aid Highways and other roadways of interest throughout Vermont to identify areas with broadband data coverage and to determine actual data throughput. These results were compared to updated computer-generated coverage maps to improve the accuracy of these maps. The end result is an assessment of broadband coverage that best matches the user experience for each wireless carrier's deployed infrastructure.

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

1.1 Purpose of this Report. Most deliverables under this contract, including an updated 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 2010 and 2013 computer-generated maps and drive test measurements. A key deliverable from this study quantifies those areas that provide *some* wireless data service versus the typically smaller areas that provide *broadband*

[1] For a detailed description of the first wireless mapping project, please see Pericle report "VCGI Final Report", dated November 30, 2010 [11].

wireless data service (at least 768 kbps on the downlink and 200 kbps on the uplink). While there has been only a modest increase in total coverage area since the 2010 analysis, wireless carriers in Vermont have made significant progress in the total area where broadband wireless data service is available in the state.

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 an 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. Several WISPs have more recently offered service in the licensed 3.65 GHz frequency band. These companies tend to cover small geographical areas. A total of ten companies provided antenna site information either for the original 2010 study or subsequent bi-annual updates: Cloud Alliance, Finowen (since acquired by Great Auk Wireless), GlobalNet, Great Auk Wireless, North Branch Networks, LLC, North Country Communications, NCIC, SVBC, WaveComm, LLC, and Wireless VT. Because of the very small geographical area covered and the need for elevated antennas to reliably intercept signals, fixed wireless coverage analysis has been limited to coverage modeling of those 10 companies that provided antenna site information. A total of 135 antenna sectors were originally modeled, and a total of 279 antenna sectors were modeled in the 2013 update described in this report. A large percentage of this increase was due to modeling Great Auk Wireless for which transceiver data was not available for the original analysis. Cloud Alliance and WaveComm, LLC have also grown in number of transceivers and coverage area since the 2010 analysis. A summary of WISP transceivers modeled is included in Appendix D.

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, Sprint, T-Mobile, U.S. Cellular and Verizon Wireless[2]. All of these companies provide wireless voice services, and as of September 2013 (per the NTIA SBDD grant requirements), only four provided broadband Internet access (downlink speed > 768 kbps). Additionally, Vermont Telephone (VTel) is currently deploying mobile wireless sites around Vermont. This deployment was not far enough along to include VTel sites in the drive test survey. Instead, wireless coverage maps have been generated based on provided site information to show expected VTel coverage once sites are constructed and on the air.

[2] Sprint acquired Nextel Corporation in 2004, but the Nextel network employs an entirely different airlink technology called iDEN and the two networks operate independently. Nextel, or more recently Sprint Push to Talk Service, was mapped in the original study but has recently been discontinued nationwide and was not included in the 2013 update.

During the drive test, the T-Mobile test phone served the dual purpose of monitoring and recording CoverageCo coverage in Vermont. CoverageCo is installing mobile wireless infrastructure in rural areas of Vermont which augments primary carrier coverage in these areas. The CoverageCo equipment is typically deployed on a utility pole with low antenna heights and provides small cell (~0.5 mile) coverage. While not an independent wireless carrier, the CoverageCo technology augments T-Mobile and Sprint service footprints and is currently limited to voice and low data speed service (not broadband data speeds).

1.3 Approach. Due to limited carrier input, Pericle and VCGI have made due with carrier site information gleaned from the State of Vermont's ACT 250 database and more recently from the Vermont 248a tower filing database. All new mobile wireless site and transceiver parameter information used in the current project was provided by VCGI or from a data mining activity undertaken by the Vermont Department of Public Service. This included significant new information for AT&T Mobility, Verizon Wireless and VTel Wireless. Very little new information was available for U.S. Cellular, Sprint or T-Mobile. Pericle reviewed all previously identified but incomplete sites to determine minimum information to include these sites in the overall coverage maps. Finally, additional site information/confirmation was obtained during the drive test, either reported by the test phone or determined through analysis of the drive test data logs.

It is possible to generate coverage maps from the data that has been collected, but the lack of complete data made a drive test survey all the more important. The second drive test survey described in this report was conducted in September, 2013 over more than 6,000 miles of Federal Aid Highways and other roadways in Vermont. A software-controlled cell phone was used with registered service on each of the five 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. A large data file was 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 2013 drive test survey. Additional tables comparing the 2013 drive data to the 2010 drive data are included in Section 6 and Appendix B.1 of this report. The third 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 is predicted 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

Pericle coverage prediction estimate. In other words, these right most two columns consider only those calls placed in those areas where the coverage prediction shows the carrier has wireless coverage. We should point out that it is difficult to predict where carrier broadband coverage (e.g., EV-DO) was available and where only low data rate coverage (e.g., 1XRTT) was available as radio site equipment and antenna upgrades are generally required to support higher speed data service.

Table 1 - Broadband Wireless Data Drive Test Results - Downlink						
Carrier	Date	Call Attempts	All Attempts		Within Coverage Polygon	
			Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	Sep 2013	12935	76%	62%	90%	78%
Sprint	Sep 2013	13463	38%	10%	91%	27%
U.S. Cellular	Sep 2013	14727	29%	16%	88%	57%
Verizon Wireless	Sep 2013	14790	83%	67%	98%	85%

Table 2 - Broadband Wireless Data Drive Test Results - Uplink						
Carrier	Date	Call Attempts	All Attempts		Within Coverage Polygon	
			Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	Sep 2013	12931	76%	62%	90%	79%
Sprint	Sep 2013	13451	37%	26%	91%	71%
U.S. Cellular	Sep 2013	14721	28%	20%	88%	71%
Verizon Wireless	Sep 2013	14785	82%	68%	97%	87%

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, although the percentage of successful broadband calls has increased dramatically since the 2010 test. 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 LTE. 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.

- A new condition was observed during this test where the network is not ready to allow a data transfer during the time allotted by the test phone. This causes in failed voice and more often failed data calls in areas of good service and signal strength. This condition is described in more detail in Section 6.

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, T-Mobile 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. Likewise, Verizon phones roam onto the U.S. Cellular infrastructure in southern Vermont. This roaming is often seamless and occurs unbeknownst to the subscriber. In order to measure each carrier's actual infrastructure, roaming was either disabled on the test phone or removed during post processing if roaming could not be disabled.

1.5 <u>Wireless Voice Service Results.</u> The wireless voice drive test results are shown in Table 3. An additional table comparing the 2013 voice results to the 2010 drive test results is included in Section 6 and Appendix B.2 of this report. The values in the right most column indicate coverage within the Pericle computer-modeled coverage polygon[3]. In other words, these calls were placed in areas where one would expect service to be available. This column shows that the coverage prediction is a reasonable, but not perfect, approximation of the carrier's actual coverage. Note that poor overall coverage for Sprint, T-Mobile and U.S. Cellular (fourth 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	Date	Call Attempts	All Attempts	Within Coverage Polygon
AT&T Mobility	Sep 2013	12923	83%	96%
Sprint	Sep 2013	13441	38%	88%
T-Mobile	Sep 2013	13145	25%	93%
U.S. Cellular	Sep 2013	14286	29%	86%
Verizon Wireless	Sep 2013	14676	83%	97%

[3] Pericle generated coverage maps are the only maps provided for data and voice coverage for this project. In the 2010 project, some carriers provided data coverage maps which were included in the analysis.

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 explain some of the wireless technologies, 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 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.

Before the first broadband wireless mapping 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[4]. Pericle was chosen for this wireless update project due to its pervious mapping experience in Vermont and because the firm has over 20 years

[4] 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.

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.

The current project described in this report is an update to the original effort completed in 2010 and is intended to show coverage and throughput improvements between June 2010 and September 2013.

2.2 Scope of Work. This project includes updates to the previously generated wireless transceiver database and new mobile wireless and fixed coverage maps showing areas with both broadband data and voice coverage. The mobile wireless coverage maps will be improved through comparison to actual wireless network and call data collected during a second drive test of the State of Vermont.

The complete scope of work for the current Pericle subcontract is found in Appendix A to this report.

The period of performance for this subcontract is July, 2013 through November, 2013.

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 currently in widespread 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 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 and LTE is now widely deployed by Verizon in Vermont while AT&T has yet to upgrade their Vermont markets to this technology. 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 Bands	Deployed (Planned) Carriers
700 MHz	746-806 MHz	AT&T, Sprint, U.S. Cellular, Verizon
800 MHz SMR/ESMR	816-824/861-869 MHz	None (Previously Nextel)
800 MHz Cellular	824-849/869-894 MHz	AT&T, U. S. Cellular, Verizon
PCS	1850-1990 MHz	AT&T, Cricket, Sprint, T-Mobile, U. S. Cellular, Verizon
AWS	1710-1755/2100-2155 MHz	AT&T, Cricket, T-Mobile, Verizon
EBS/BRS	2496-2690 MHz	Clearwire

Table 5 lists the frequency bands used and the corresponding carriers in the State of Vermont as of September 30, 2013.

At the time the original 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. As of September 30, 2013, those same four carriers still meet the requirement with no broadband data service offered in Vermont by T-Mobile.

Table 5 – Vermont Persona Wireless Operators (As of September 30, 2013)

Carrier	Airlink Standards	Frequency Bands
AT&T Mobility	GSM/EDGE, UMTS/HSPA	800 MHz Cellular, PCS
Sprint	1xRTT, EV-DO, EHPRD	PCS
T-Mobile	GSM/EDGE	PCS
U.S. Cellular	CDMA 1xRTT, EV-DO, EHRPD, LTE	800 MHz Cellular, PCS, 700 MHz
Verizon Wireless	CDMA 1xRTT, EV-DO, EHRPD, LTE	800 MHz Cellular, PCS, 700 MHz

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 September 30, 2013.

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 than 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,

[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.

satellite, AM groundwave, and HF skywave are outside the scope of this discussion.

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 Terrain Loss and Digital Terrain Databases. 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. For the current study the land cover dataset used to specify clutter type was updated from the National Land Cover Dataset of 2001 (NLCD-01) to the National Land Cover Dataset of 2006 (NLCD-06). Because NLCD-06 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.

EDX Signal version 11.0.0 and ArcMap version 10.0 were used for this project.

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-06
Clutter loss factors = TSB-88
Transmit EIRP = varies depending on site, from ACT-250 database or other sources
Transmit antenna pattern = depends on site, from ACT-250 database or other sources
Transmit antenna height = depends on site, from 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.

[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.

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 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 (dBm)
AT&T Mobility	Data	EDGE, UMTS/HSPA	-101.5
AT&T Mobility	Voice	GSM/UMTS	-105.0
Sprint	Data	1XRTT , EV-DO, EHRPD	-100.0
Sprint	Voice	1XRTT, EHRPDPCS	-105.5
T-Mobile	Data	GSM/EDGE	-102.0
T-Mobile	Voice	GSM	-102.0
U.S. Cellular	Data	1XRTT , EV-DO, EHRPD, LTE	-100.0
U.S. Cellular	Voice	1XRTT, EHRPD, LTE	-105.5
Verizon Wireless	Data	1XRTT , EV-DO, EHRPD, LTE	-100.0
Verizon Wireless	Voice	1XRTT, EHRPD, LTE	-105.5
VTel Wireless	Data	LTE	-100.0
VTel Wireless	Voice	LTE	-105.5

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 ArcMap**. For the four broadband data carriers the Pericle coverage prediction is plotted along with the location of known cell sites. See Appendix C for the complete set of mobile wireless coverage maps. See Appendix D for fixed wireless coverage maps (WISP coverage).

5.0 Drive Test Survey

The purpose of the drive test survey was to measure the performance of each of the five mobile wireless carrier networks and the coverage from the CoverageCo infrastructure 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 from September 5 2013 through September 19, 2013 and over 6,000 miles were driven on Federal Aid Highways and other roads of interest throughout the state of Vermont. The drive route is shown in Figure 2 below and on the coverage maps in Appendix C. In Figure 2, the road segments in red are Federal Aid Highway roads while those in blue are other roads of interest requested by the Vermont Transit Authority (VTA). Two Pericle employees conducted the survey: Mike Ray and Jo Wilson. The drive test was conducted in a generally clockwise direction starting and ending in Burlington, VT so that the northern portions of the state were driven first to measure performance with as much foliage as possible.

[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.

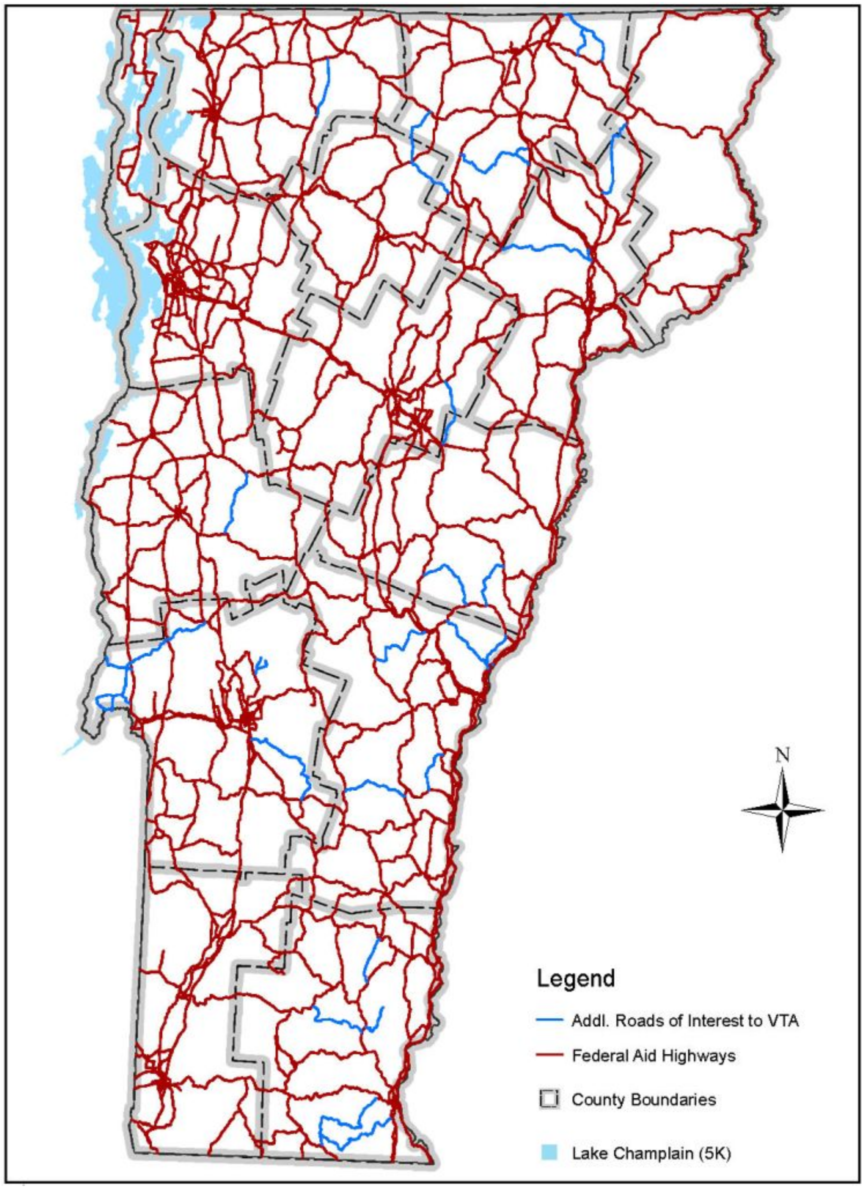

Figure 2 – 2013 Drive Test Survey Roadways Driven

Prior to conducting the drive test survey, five HTC or Samsung Android smart phones were procured and provisioned with unlimited data and voice service plans by the Vermont Telecommunications Authority (VTA). HTC phones were preferred because they provide the best utilities for monitoring phone and network parameters of the phones we tested. This enabled us to collect the most complete information from the custom test application developed to execute the tests. The cell phone configurations used in the test are summarized in Table 8.

Table 8 – Cell Phones Configurations Used for Drive Test					
Carrier	**Make/Model**	**Max Data Supported**	**IMEI**	**Android OS Version**	**Pericle Test App. Version**
AT&T Mobility	HTC One	4G LTE	354439056339197	4.1.2	VtDriveTest-1.12
Sprint	HTC EVO	4G LTE	99000066184406	4.1.1	VtDriveTest-1.12
T-Mobile	HTC One	4G LTE	355972053088671	4.1.2	VtDriveTest-1.12
U.S. Cellular	Samsung Galaxy S4	4G LTE	99000336089349	4.2.2	VtDriveTest-1.12
Verizon Wireless	HTC Droid	4G LTE	990000643996335	4.0.4	VtDriveTest-1.12

During the drive testing, each of the five test cell phones was programmed to continually execute a test loop and store data to the local SD memory card or internal memory in each phone. Each data record was time-stamped with latitude and longitude using the GPS receiver in each phone. 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.

Several changes were made to improve the test application for this second drive test. First, the test application was ported to the Android operating system in order to use latest high speed data capable Smart Phones (many more phone choices available with Android versus the previous Windows Mobile operating system). As before, the test loop has four main functions which occur in the following order 1) download a 2.5MB file from a Pericle internet server, 2) upload a 1.5MB file to the server, 3) place a voice call and 4) communicate status to the control laptop in the test vehicle via WiFi. A complete set of phone parameter data was logged at the beginning and end of each data and voice call, so six times per test loop. Larger data transfers of 2.5 MB in the downlink and 1.5 MB were used in this test to more accurately measure the higher average and maximum data speeds of the wireless networks, while maintaining a balance with overall data usage/wireless data costs and time between tests for each phone.

Approximately 77.5 GB of data was transferred during the test with the following breakdown by carrier:

Carrier	Total:	Roaming Total:
AT&T Mobility	26.6GB	28.1MB
Sprint	7.3GB	0MB
T-Mobile	0.8GB	41.8MB
U.S. Cellular	6.7GB	0MB
Verizon Wireless	36.1GB	162.4MB
	77.5GB	

Information about the phone and network parameters including position, network service flags, roaming status and receive signal strength were logged every second during the test in order to later extrapolate between service test points if needed.

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 2.5MB block of data from a remote test server (configured by Pericle) to the phone. The throughput speed was calculated for the portion of the data that could be transferred in the 15 seconds allowed for this portion of the test loop. Uplink data speed was measured in a similar fashion for a 1.5MB block of data transferred from phone to server over another 15 second test period.

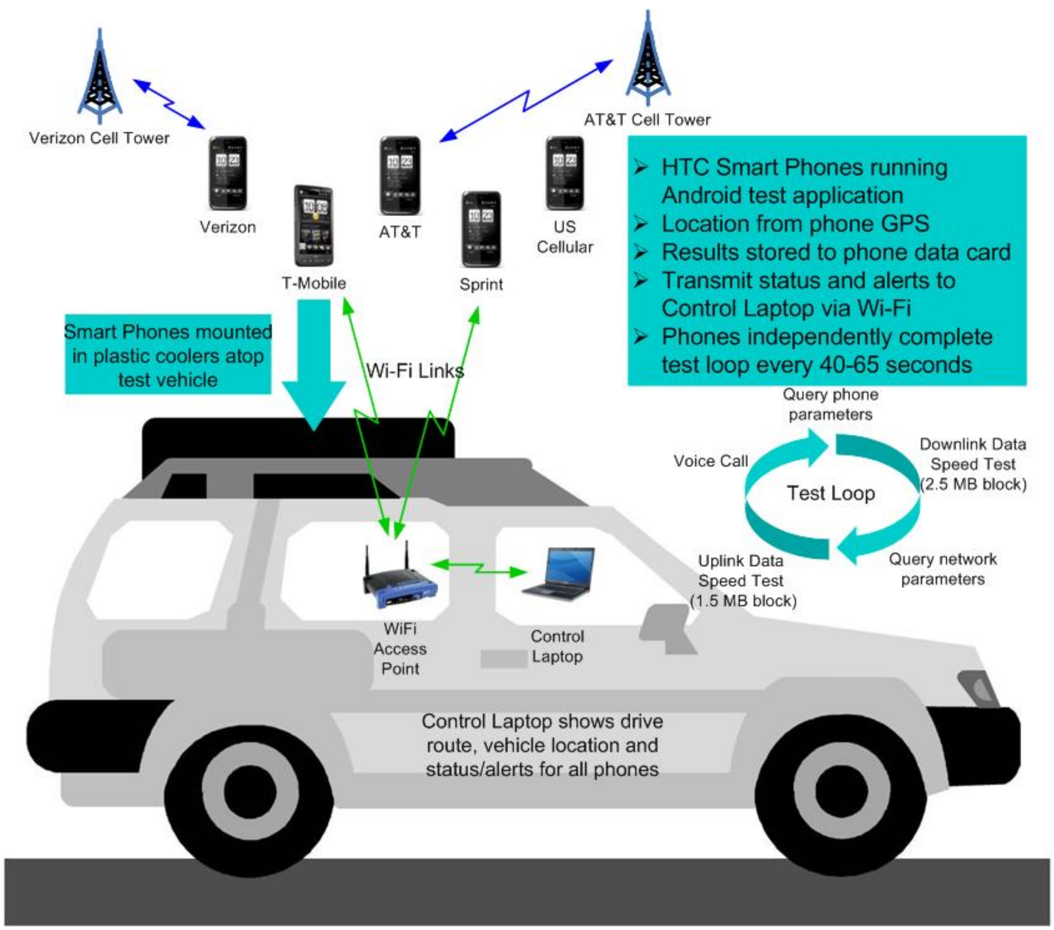

Figure 3 - Drive Test Survey Collection System

The duration of each test loop varied from 40 to 65 seconds depending on network coverage and data speeds supported. Over 12,900 data calls and over 12,900 voice calls were placed from each phone during the drive test survey. More calls were placed on networks with faster data speed or with limited coverage area as both conditions push test loop cycle times towards the minimum.

6.0 Analysis

This document serves as the final project report for the entire scope of work performed by Pericle Communications Company for VCGI. This includes the following key tasks as defined in the scope of work.

> 12.1 Pericle shall use the drive-test data to determine the accuracy of the original RF propagation dataset generated under Activity #10. Pericle shall deliver the raw results, summary statistics, and a report describing the accuracy of the original RF propagation dataset.
>
> 12.2 Pericle shall use the drive-test data to calibrate and refine the RF propagation data generated under Activity #10. Pericle shall deliver a separate set of "calibrated" RF propagation maps (an aggregated raster for each provider as stipulated under Activity #10). Pericle 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 Summary Results and General Observations. The processed drive test data is found in the spreadsheets of Appendix B and visually displayed in the maps in Appendix C. Summary drive test data is found in Tables 9, 10 and 12 below. Tables 9 and 10 show the broadband wireless summary data results for the downlink and uplink, respectively. The third 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 is predicted 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 Pericle generated coverage map. In other words, these right most two columns consider only those calls placed in those areas where the carrier is predicted to have wireless coverage.[8] Tables 9 and 10 also show previous data from 2010 for comparison.

[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].

Table 9 - Broadband Wireless Data Drive Test Results - Downlink June 2010 vs. September 2013						
Carrier	Date	Call Attempts	All Attempts		Within Coverage Polygon	
			Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	Jun 2010	10969	77%	32%	91%	55%
AT&T Mobility	Sep 2013	12935	76%	62%	90%	78%
Sprint	Jun 2010	12575	45%	3%	87%	5%
Sprint	Sep 2013	13463	38%	10%	91%	27%
U.S. Cellular	Jun 2010	12761	32%	7%	81%	21%
U.S. Cellular	Sep 2013	14727	29%	16%	88%	57%
Verizon Wireless	Jun 2010	10205	76%	21%	92%	29%
Verizon Wireless	Sep 2013	14790	83%	67%	98%	85%

Table 10 - Broadband Wireless Data Drive Test Results - Uplink June 2010 vs. September 2013						
Carrier	Date	Call Attempts	All Attempts		Within Coverage Polygon	
			Successful (Any Rate)	Successful (> 768 kbps)	Successful (Any Rate)	Successful (> 768 kbps)
AT&T Mobility	Jun 2010	10969	71%	34%	87%	59%
AT&T Mobility	Sep 2013	12931	76%	62%	90%	79%
Sprint	Jun 2010	12575	42%	16%	84%	34%
Sprint	Sep 2013	13451	37%	26%	91%	71%
U.S. Cellular	Jun 2010	12761	29%	2%	78%	5%
U.S. Cellular	Sep 2013	14721	28%	20%	88%	71%
Verizon Wireless	Jun 2010	10205	73%	32%	91%	43%
Verizon Wireless	Sep 2013	14785	82%	68%	97%	87%

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.

- A new "network not ready" condition was observed during this test where the network is not ready to place allow a data transfer during the time allotted by the test phone. This results in failed voice and data calls in areas of good service and signal strength. This condition is described in more detail below.

This "network not ready" condition was observed in the data for the phones which use the CDMA family of technologies (Sprint, US Cellular, Verizon) and the result is that not all voice and data calls connect in areas of adequate signal strength. This is due to the network not being available for the data call. The phone returns an error code and our test software moves on to the next action in its test sequence. This is a real condition which occurs primarily when the highest rate LTE technology is not available. We did not encounter this in the previous drive test and believe it is due to upgrades in the carrier technology and call control/handover algorithms to optimize network resources, prioritize use of new LTE infrastructure and allow call handover to older EVDO and 1XRTT technologies. All three networks have a new technology upgrade deployed (and reported by the phone) called Evolved High Rate Packet Data (EHRPD). EHRPD is essentially 3G EVDO technology with a software upgrade to support seamless interaction with LTE when deployed. This new software routes calls through a 4G LTE core network rather than the legacy core network which handles only EVDO and 1XRTT traffic. When LTE is deployed, the network interaction is more efficient than with the older technologies and explains why, we believe, the issue does not occur frequently in areas with good LTE coverage. However, it is likely that a data call at a different time, in the same location might complete successfully. Actual users placing data calls that might not be moving as quickly and/or might wait longer for the connection might have a different experience than was observed during the drive test. We have tried to quantify and correct these locations using an algorithm to review the drive data for failed calls where the network is clearly valid (in service, on valid network infrastructure and adequate signal strength before and after the call attempt). We have included these manually corrected call attempts in the statistics above and discussion later in this Section. The more detailed statistics in Appendix B.1 show the data statistics as measured and after correction for comparison.

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. Likewise, Verizon phones roam onto the U.S. Cellular infrastructure in southern Vermont. This roaming is often seamless and occurs unbeknownst to the subscriber. In order to measure each carrier's actual infrastructure, roaming was either disabled on the test phone or removed during post processing if roaming could not be disabled.

From Tables 9 and 10, the following observations are notable:

- More calls were attempted in the 2013 test than in 2010 due to additional roads and more days of driving (see blue roadways in Figure 2) and to relatively faster data rates and test cycle times.

- When comparing 2013 vs. 2010 success rates, the additional roads driven have minimal impact on the carriers with larger coverage areas (AT&T and Verizon), but tend to penalize carriers like Sprint and U.S. Cellular with smaller footprints as most of the new roads were in rural areas where they don't have coverage. So for these carriers, total calls goes up while successful calls does not.

- All carriers which previously provided broadband data made improvements in the percentage of their infrastructure and coverage area which supports broadband data speeds. For the downlink in Table 9, AT&T nearly doubled from 32% to 62% of all calls while Verizon more than tripled from 21% to 67%. Due to their smaller footprints, Sprint and U.S. Cellular show much more modest downlink gains, despite having deployed broadband capable infrastructure at most of their sites. T-Mobile does not have broadband capable infrastructure turned on in Vermont. The Data Call Infrastructure maps in Appendix C show those areas where broadband capable infrastructure is deployed for each carrier.

- When limited to just those areas predicted to have coverage for each carrier, the results are even better with 78% of downlink calls achieving broadband speeds for AT&T and 85% for Verizon. In this case, U.S. Cellular provides broadband speed in over half (57%) of its predicted coverage area while Sprint lags at 27% of their coverage area.

- The percentage of successful data calls at any rate within the predicted coverage polygon (2nd column from right), provide an indication of the accuracy of the carrier coverage predictions and vary from 88% for U.S. Cellular to 98% for Verizon. For the downlink, this metric was flat for AT&T and improved for the other carriers during this project from efforts to 1) identify and map new and previously known but incomplete sites and 2) verify/identify other site locations from drive test signal strength measurements.

All of the above trends are even more pronounced in the uplink direction (see Table 10) as newer wireless technologies are more balanced in downlink and uplink throughput, and due to the relatively lower broadband threshold 200 kbps in the uplink direction vs. 768 kbps for the downlink.

Table 11 below shows the two main families of wireless technologies employed by T-Mobile/AT&T and Sprint/U.S. Cellular/Verizon and simplifies the deployed technologies into three main speed tiers. The percent and mean speed of data calls made on each infrastructure are shown for downlink and uplink directions for each carrier. The leftmost technology tier (1XRTT or GPRS/EDGE) is generally considered 2nd generation (2G) and is not capable of broadband speeds. The rightmost technology tier (LTE) is latest 4th generation technology which most uniformly provides broadband data speeds. The middle tier is the most complex and includes a number of technology variations which are lumped into the UMTS/HSPA and EVDO titles. These are 3G/4G technologies which are capable of broadband speeds, but as can be seen from Table 11, provide some variation in the mean speeds supported. T-Mobile is 100% in the left tier while 75% of Verizon's infrastructure is in the rightmost tier. AT&T Mobility, Sprint and U.S. Cellular are primarily in the middle tier and of these carriers; U.S. Cellular has the 2nd most LTE coverage (mainly southeast from sites in New Hampshire) after Verizon. It is interesting to note the different mean throughput speeds between the carriers in the middle technology tier. AT&T Mobility has the highest mean throughput in this tier.

Table 11 - Average Date Throughput by Carrier and Airlink Standard

Carrier	Direction	GPRS/EDGE		UMTS/HSPA (and Variants)		LTE	
		% Data Calls	Mean Throughput (kbps)	% Data Calls	Mean Throughput (kbps)	% Data Calls	Mean Throughput (kbps)
AT&T Mobility	Downlink	3%	26.8	97%	1886.7	0.1%	4277.2
AT&T Mobility	Uplink	3%	26.7	97%	719.6	0.1%	2904.4
T-Mobile	Downlink	100%	77.5				
T-Mobile	Uplink	100%	65.2				
Carrier	**Direction**	**1XRTT**		**EVDO (and Variants)**		**LTE**	
		% Data Calls	**Mean Throughput (kbps)**	**% Data Calls**	**Mean Throughput (kbps)**	**% Data Calls**	**Mean Throughput (kbps)**
Sprint	Downlink	16%	51.9	84%	560.8	0.2%	2554.0
Sprint	Uplink	17%	55.5	82%	535.0	0.2%	1657.6
U.S. Cellular	Downlink	32%	59.9	77%	703.3	13%	2601.1
U.S. Cellular	Uplink	28%	49.2	77%	485.3	13%	2202.7
Verizon Wireless	Downlink	6%	52.1	19%	872.6	75%	3139.1
Verizon Wireless	Uplink	5%	46.8	18%	460.5	75%	2355.4

The wireless voice drive test summary results are shown in Table 12. 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 (fourth 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 12 also shows previous voice results from 2010 for comparison.

Table 12 - Wireless Voice Drive Test Results (Percent of calls that were successful) June 2010 vs. September 2013				
Carrier	**Date**	**Call Attempts**	**All Attempts**	**Within Coverage Polygon**
AT&T Mobility	Jun 2010	10969	86%	96%
AT&T Mobility	Sep 2013	12923	83%	96%
Sprint	Jun 2010	12575	49%	93%
Sprint	Sep 2013	13441	38%	88%
T-Mobile	Jun 2010	10404	24%	98%
T-Mobile	Sep 2013	13145	25%	93%
U.S. Cellular	Jun 2010	12764	34%	86%
U.S. Cellular	Sep 2013	14286	29%	86%
Verizon Wireless	Jun 2010	10209	80%	96%
Verizon Wireless	Sep 2013	14676	83%	97%

From Table 12, the number of successful voice calls is relatively flat between the 2010 and 2013 drive tests with some carriers declining. This is due in part to the additional rural roads driven in this test, especially for Sprint/U.S. Cellular but even taking this into account, the number of total calls connected for these two carriers declined between the two tests. This may be an indication of reduced coverage, for Sprint we noted several sites from the drive test results which don't appear to be active, while U.S. Cellular sites remain about the same. This may also be due to performance differences between the phones used in this test - slightly poorer receive sensitivity or less resistant to interference in one or modes. Protocol signaling and churn between the various network technologies for these carriers may also be a factor. Overall, across all five carriers, the voice call results support the observation that carrier's overall coverage footprints have not changed substantially between 2010 and 2013.

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

6.2 Coverage Map Calibration Using Drive Test Data. The underlying site and radio parameter information which generates the coverage maps is contained in a large transceiver database. This transceiver database and the resulting coverage map updates were improved during the project in the following ways.

1. Through the efforts of the Vermont Department of Public Service a number of new and modified sites were identified in the 248a tower filing database. Several other applications were also provided by VCGI from recent Act 250 applications. This new site and transceiver data was carefully reviewed by Pericle versus the baseline transceiver database to determine which sites were actually new and update existing sites with any new parameter information such as latitude/longitude, address, band used, structure and or antenna height, antenna azimuth and types/gain of antennas used.

2. Previously identified, but incomplete sites and new site locations reported by phones during the drive test (mainly U.S. Cellular) were reviewed vs. Google Earth coordinates and street level photos and compared to the Antenna Site Registration (ASR) database and/or compared with other carrier information on the same structure to estimate the minimum information to allow the site to be mapped. Typical parameters for each carrier were used where not available. Due to this process, these sites have a lower confidence rating in the transceiver database than sites where more complete information was available.

3. Following the drive test, the received signal strengths before and after downlink, uplink and voice calls for each phone were plotted vs. mapped and unmapped sites for each carrier and also the set of all site locations for all carriers. This data was carefully reviewed to ensure that previously mapped and incomplete sites were still active and that new sites were actually on the air. Areas where signal strengths indicated a site might be missing were reviewed and new sites added if enough information existed to estimate minimum parameters to map the site (latitude/longitude, structure/antenna height and signal strength indication that it was active). Through this process the coverage map confidence has increased although there are still areas where a few sites are still missing. Unidentified sites may also exist within the coverage polygon which increase signal strength but don't change the polygon outline significantly.

The final cellular site transceiver statistics for this coverage map update are shown in Table 13. Through the efforts described above, 206 additional sites were included in the 2013 coverage maps vs. the baseline in 2010. These include both new sites and previously identified sites for which transceiver parameter data was too incomplete to map. Also, in this update, some sites previously thought to be active or identified as new from the 248a filing data, were observed to be inactive (either disabled or not yet turned on) following a review of measured drive test signal strength vs. each carrier's site locations.

Table 13 Final Cellular Transceiver Database Statistics					
Carrier	Included in Propagation Map (PMAP_STAT = F)	Inactive Site per 2013 Drive Test (PMAP_STAT = IA)	Location Known but Not Enough Information to Map (PMAP_STAT = I)	Total	Addl. Sites Mapped Since 2010 (new or prev. incomplete)
AT&T Mobility	181	10	9	200	73
Sprint	108	7	29	144	37
T-Mobile	69	1	4	74	13
U.S. Cellular	54	2	11	67	29
Verizon Wireless	248	8	4	260	54
VTel Wireless	75	0	2	77	NA
			Grand Total	**822**	**206**

The following general observations were made after analyzing the coverage maps and drive test data.

- In general, Pericle coverage predictions are slightly more generous than the drive test data indicates. This is likely due to Pericle using consistent transmit power and receive signal thresholds per the relevant communication standards, while the carriers may 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. For some phones, this may also be due to the effect of roaming which is discussed in the next section.

- In general, Pericle-generated coverage maps closely approximate the overall shape of the call results observed during the drive test with a high percentage of successful data and voice call attempts within the carrier data coverage polygon.

The following issues prevent more accurate calibration between coverage maps and drive test results.

- For a given carrier, the density of sites in a given region in the propagation map may differ from real world operation of the network in that area. Due to cellular carrier's refusal to provide site information, the sites have been identified and mapped through mining of incomplete and often dated information. 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.

- Many cellular carriers are licensed in more than one frequency band. To provide coverage in multiple 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 and the drive test data, 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 AT&T Mobility in the 700 MHz band). New frequencies enabled at a site may add to or replace previous transceivers in other bands. It is likely that many sites support transceivers in more bands than shown in the transceiver database. This does not have a large effect on the propagation map as transmit power and antenna gain are specified to generally provide similar coverage in the different bands..

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 above a threshold 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 causing the edge of service to be is less clear.

As with the previous drive test, we tried 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 remained disabled for the Sprint and U.S. Cellular phones. As was observed in the last test, the T-Mobile phone, and in this test both the AT&T and Verizon phones, allowed manual selection of a preferred network, but this setting was automatically overridden as soon as the preferred network was not available – effectively re-enabling roaming. Roaming was manually enabled for the T-Mobile phone in the first couple of CoverageCo areas encountered (see Figure 5), until the team realized that it was roaming most of the time anyway, after which it was allowed to roam for the remainder of the drive test.

The AT&T phone generally used the AT&T network with some minimal 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 and to the CoverageCo network in a few areas. The T-Mobile phone roamed onto the AT&T network in much of Vermont and this behavior resulted in a measurably smaller footprint for T-Mobile's infrastructure within Vermont than was predicted by the Pericle T-Mobile propagation map.

Finally, roaming for the Verizon phone was new during this drive test and sporadic operation on Canadian carriers was observed along with more significant roaming to U.S. Cellular infrastructure in southern Vermont, again slightly reducing the footprint for Verizon's infrastructure in these areas.

Roaming data and voice call attempts were removed from the data during post processing and roaming was included as appropriate to calculate statistics that would fairly compare to the 2010 collected data (T-Mobile and AT&T roamed, Verizon did not).

6.4 Observations Specific to Each Carrier.

6.4.1 AT&T Mobility.

Of the carriers capable of broadband data speeds, AT&T had the distinction that not all of its sites were deployed with the UMTS/HSPA infrastructure equipment required to achieve broadband speeds. As such, the 2010 Pericle broadband propagation map was based on a subset of the total AT&T sites. This is no longer the case as UMTS/HSPA deployment was found to be available at nearly all sites.

AT&T previously had the least complete site information of the cellular carriers in Vermont resulting in fewer sites and a number of key sites that had incomplete information and were not mapped. This has been largely corrected as the mining of the 248a applications dramatically increased the number and confidence of the AT&T mapped sites.

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.

Of all the non-roaming data calls attempted, 62% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 62% achieved uplink speeds exceeding the NTIA threshold of 200 kbps, approximately double the 2010 results. For data calls attempted within the Pericle estimate data coverage area, 90% of these attempts were successful and 78% of downlink and 79% of uplink tests exceeded the relevant NTIA broadband data threshold.

For voice coverage, AT&T has good coverage over the majority of Vermont. 83% of the non-roaming AT&T voice call attempts during the drive test were successful. When compared versus predicted coverage, 77% of the voice calls were attempted within the Pericle estimated voice coverage area and 96% of these calls were successful.

There are likely several unidentified AT&T sites within Vermont. Route 118 south of Montgomery Center, West/North Pawlett and other areas along the border with New York may be missing a site or receiving coverage from New York sites. Some coverage along the border near Lancaster NH is provided by an unidentified site in New Hampshire.

The only AT&T LTE coverage in Vermont was observed on small stretches of Highway 7 and Route 100 from an unidentified site in Massachusetts.

6.4.2 CoverageCo.

During the drive test, the T-Mobile test phone served the dual purpose of monitoring and recording CoverageCo coverage in Vermont. CoverageCo is installing mobile wireless infrastructure in rural areas of Vermont which augments primary carrier coverage in these areas. The CoverageCo equipment is typically deployed on a utility pole with low antenna heights and provides small cell (~0.5 mile) coverage in these areas. A typical CoverageCo site is shown in Figure 4. The CoverageCo technology augments T-Mobile and Sprint service footprints and is currently limited to voice and low data speed service (not broadband) using GMS/EDGE and 1XRTT wireless technologies for the two carriers.

Figure 4 – Typical CoverageCo Site

For the drive test, CoverageCo identified 15 areas around Vermont where CoverageCo installations were planned. It was decided that CoverageCo would be measured with only a T-Mobile phone for the drive test (Sprint use of CoverageCo infrastructure was not tested). Just prior to the test, the list of coverage areas was reduced to four areas marked with red circles in Figure 5.

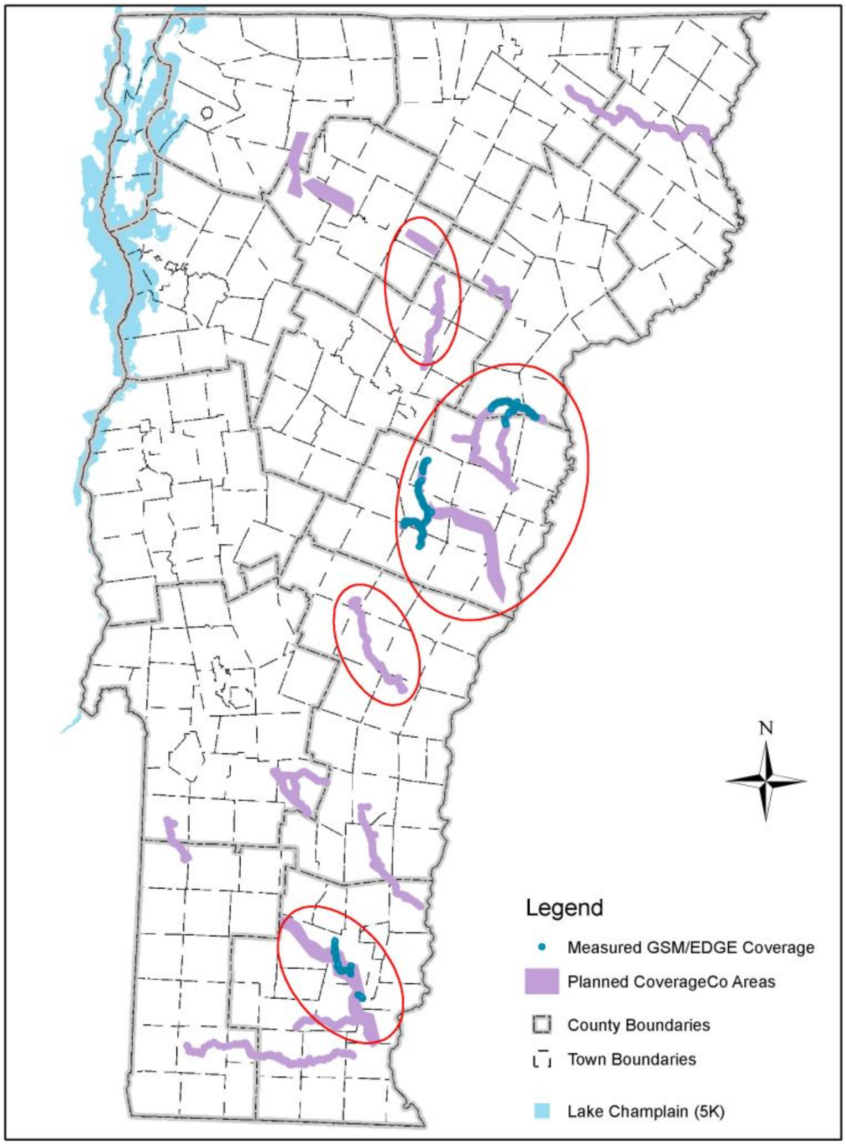

Figure 5 – Planned CoverageCo Areas with Active Marked (Red Circles)

The drive test results showed active CoverageCo service in just two of these four areas as shown in Figure 5. A number of sites were observed along Route 110 both north and south of Chelsea in Orange County VT. Another group of sites was observed along Highway 302 between West Groton and South Ryegate and along Powder Spring Road just south of 302 in Caledonia County, VT. Finally, several more sites were observed along Highway 30 around Townshend and West Townshend in Windham County VT. During the drive test, other partially built-out CoverageCo infrastructure was observed, so clearly this deployment is in progress.

The T-Mobile phone was allowed to roam in order to connect to CoverageCo infrastructure when available and these connections were sorted from the drive test logs by the unique MCC/MNC network code 312060. Due to the small cell sites, received signal strength indications while on this network provide the best mapping of coverage because they are recorded every second. Maps of these coverage areas are included in Appendix C.

6.4.3 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.

Many of the Sprint sites are out of state (New York, Massachusetts, New Hampshire) and a concerted effort was made to map the first tier of these (those closest to Vermont). Use of the others farther from the border is very limited with only a few data points and very few successful calls using these sites. Due to its relatively small and low deployment footprint, Sprint requires more sites in urban, higher capacity areas to provide service.

Sprint provides data coverage in selected urban and highway corridor areas in Vermont but does not provide much rural coverage and is fairly limited in areas supporting broadband data speeds. Approximately 38% of all data calls were successful. Of the data calls attempted, only 10% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 26% achieved uplink speeds exceeding the NTIA threshold of 200 kbps. For data calls attempted within the Pericle data coverage area, 34% of these attempts were successful and 27% of downlink and 71% of uplink tests exceeded the relevant NTIA broadband data threshold.

Sprint provides 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, 38% of the Sprint voice call attempts during the drive test were successful. When compared versus predicted coverage, 38% of the voice calls were attempted within the Pericle estimated voice coverage area and 88% of these calls were successful. All of these are lower than the results achieved in 2010 (see the technical discussion in 6.1 and 6.2). Drive test results indicated several inactive Sprint sites in southwest Vermont around Manchester Center and another along I-89 south of Sharon and yet another near Plymouth VT. The drive results show relatively poorer performance around Randolph and spotty coverage along I-89 from northwest of Sharon to just west of White River Junction.

A few Sprint calls connected to LTE infrastructure during the drive test, but these were in northern Massachusetts near Bernardston MA.

6.4.4 T-Mobile.

T-Mobile had the distinction of having the least complete online ACT-250 site applications. No T-Mobile site information was provided from the recent 248a application mining.

While T-Mobile does offer broadband data speeds in many markets across the United States, this technology is still not turned on in Vermont. 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.

Throughout Vermont, only 25% of all calls were successful using T-Mobile infrastructure. When compared with the Pericle voice coverage estimate, 22% of the voice call attempts were made within the T-Mobile estimated coverage area. 93% of these voice calls were successful. These results are very similar to 2010 and there has been little observable statewide improvement in T-Mobile coverage or data rates since that time.

6.4.5 U.S. Cellular.

U.S. Cellular coverage in southern and eastern Vermont is provided using its Cellular Band frequency license and in this testing, LTE coverage was observed in the Brattleboro are and along I-91, south of Windsor VT, often from sites in New Hampshire. U.S. Cellular appears to have the same pocket coverage in northern Vermont but has deployed EVDO technology in all these areas (Burlington, Montpelier, Stowe, St. Johnsbury, and Rutland) since the 2010 drive test.

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 as with Sprint, a concerted effort was made to map the first tier of these (those closest to Vermont). Use of the other sites farther from the border is very limited with only a few data points and almost no successful calls using these sites.

U.S. Cellular provides good data coverage in southern Vermont and along the eastern border with coverage in high density areas in central to northern Vermont. Of all the data calls attempted, 16% 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 Pericle data coverage estimate, 88% of these attempts were successful and 57% of downlink and 71% of uplink tests exceeded the relevant NTIA broadband data threshold. While the overall coverage footprint is relatively unchanged, the availability of broadband speeds within the coverage area increased substantially.

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, 29% of the U.S. Cellular voice call attempts during the drive test were successful. When compared versus predicted coverage, 28% of the voice calls were attempted within the Pericle estimated voice coverage area and 86% of these calls were successful.

Pericle coverage estimates are generally optimistic relative to U.S. Cellular 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 where antenna heights have sometimes been estimated and more antenna downtilt may be deployed at these sites than was used in the model.

6.4.6 Verizon Wireless.

Verizon has the most complete site information of the cellular carriers in Vermont. Good information from ACT-250 (typically the most complete applications) was augmented with additional site and transceiver information from the 248a filing review.

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.

Verizon continues to have good data coverage through large portions of Vermont and has deployed LTE technology through most of its network leading to a dramatic increase in broadband data availability. 83% of the data call attempts during the drive test were successful and of all the data calls attempted, 67% achieved downlink speeds exceeding the NTIA threshold of 768 kbps and 68% achieved uplink speeds exceeding the threshold of 200 kbps. For data calls attempted within the Pericle data coverage area, approximately 98% of these attempts were successful and 85% of downlink and 87% of uplink tests exceeded the relevant NTIA broadband data threshold.

Verizon has good voice coverage over the majority of Vermont. 83% of the Verizon voice call attempts during the drive test were successful. When compared versus predicted coverage, 72% of the voice calls were attempted within the Pericle estimated voice coverage area and 97% of these calls were successful.

Several areas were observed in north central Vermont where drive test call success and strong signal strength do not match a known site. Coverage in NE Vermont is likely provided by sites in Colebrook NH and Lancaster NH. However, there was not enough certainty about site locations and transceiver parameters in these areas to map these missing sites.

6.4.7 VTel Wireless.

VTel, through its subsidiary VTel Wireless, is deploying a mobile wireless network throughout Vermont utilizing its statewide licenses in the 700 MHz and AWS frequency bands. This network is planned to deploy latest generation Long Term Evolution (LTE) radio technology capable of providing very high speed broadband data for Internet access service.

VTel site and transceiver parameter data was provided by the Vermont Department of Public Service following a data mining activity of submitted 248a filings. This site data was reviewed and used to locate and map 75 unique cell site locations for VTel with 2 more sites identified but lacking complete data to include in the coverage map. These sites were modeled assuming operation in the 700 MHz band. As shown in the coverage maps in Appendix C, these sites will provide substantial coverage around Vermont once constructed and on the air.

From publicly available VTel information, VTel plans to support under-served and un-served subscribers in Vermont and nearly 200 cell site locations have been identified for build out of the VTel network. From the VTel coverage maps in Appendix C, we note that some of the identified sites are common with other wireless carriers and provide coverage to higher population areas and highway corridors similar to other commercial wireless carriers. These maps differ somewhat from the coverage predictions available on the VTel web site, which show more rural coverage and less higher population area coverage than our prediction. It seems obvious that a number of VTel site locations are planned for which we do not have any input to map.

7.0 Conclusions

This project has provided an updated picture of the mobile wireless broadband data and voice coverage in Vermont. Through new site and transceiver data mining and review of incomplete sites, over 200 more sites were mapped in this coverage modeling update. Through these efforts, coverage model confidence has increased and the generated coverage compares well with drive test measurements of locations where data and voice calls. Percentages of successful data and voice calls within these coverage areas continue to be high with data calls varying from 88% for U.S. Cellular to 98% for Verizon Wireless. Voice calls vary from 86% to 97% for these same carriers. Predicted coverage areas also closely match expected coverage publicly available on wireless carrier websites.

Overall, the addition of these sites to the coverage model and the results from the drive test survey data does not show a significant increase in mobile wireless coverage area in Vermont. The smaller carrier networks, T-Mobile, U.S. Cellular and Sprint, show very little coverage area change and in the case of Sprint may have declined slightly over the last three years. The big two continue to have strong statewide coverage, covering all the main population areas and major highway corridors and appears to have improved somewhat. 76% of all data calls were successful on the AT&T Mobility network compared to 82% for Verizon Wireless. Voice call success rates were even at 83% for the two carriers. It is unlikely this will change significantly any time soon as there is not a strong commercial incentive for the large carriers to expand further. By the same token, the smaller carriers roam onto these larger networks and also don't have strong incentive to improve their footprints due to limited numbers of new subscribers. Sprint, and other carriers, has a potential for improvement by taking over older Nextel sites and tower positions. Nextel previously had a large Vermont coverage footprint but service was disabled nationwide in 2013. There is not strong evidence in the drive test results that this has occurred yet.

The big success story highlighted by the drive test survey is the large increase in broadband data speeds within the areas covered by each carrier. This can be best seen in the Data Call Infrastructure maps in Appendix C. AT&T Mobility, Sprint, U.S. Cellular and Verizon Wireless all made significant advances in this area with broadband capable infrastructure deployed over much of the coverage area. Within each carrier's expected coverage area the following 2010 to 2013 broadband data increases were measured:

- AT&T Mobility from 55% to 78%
- Sprint increased from 5% to 27%
- U. S. Cellular from 21% to 57%
- Verizon Wireless from 29% to 85%

Of these, Verizon Wireless is the clear leader as 75% of the successful calls on this network were completed using their latest 4G LTE technology. AT&T Mobility, Sprint, T-Mobile and U.S. Cellular are all deploying higher rate LTE technologies across the nation, but these have not yet been enabled in Vermont as of the September 2013 drive test. For all but T-Mobile, this improved network infrastructure was observed just outside Vermont – AT&T Mobility and Sprint in northern Massachusetts and U.S. Cellular in southwest New Hampshire and a couple of sites in the

Brattleboro in southeast Vermont.

For fixed wireless Internet access, Pericle previously modeled over 135 transceivers from 10 different WISPs. These companies employed a combination of proprietary and 802.11x technologies. These transceivers were primarily used for point-to-point links between the network transceiver and building-mounted subscriber equipment. For this project, a total of 279 WISP antenna sectors were modeled. A large percentage of this increase was due to modeling Great Auk Wireless for which transceiver data was not available for the original analysis. Great Auk Wireless further expanded by acquiring and operating the previously modeled Finowen network. Cloud Alliance and WaveComm, LLC have also grown in number of transceivers and coverage area since the 2010 analysis. Several WISPs including Cloud Alliance, Great Auk Wireless and WaveComm are now offering service in the licensed 3.65 GHz frequency band in addition to the traditional unlicensed bands. Operation in this additional band also increased the number of modeled transceivers. A summary of WISP transceivers modeled is included in Appendix D.

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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
DSSS	Direct Sequence Spread Spectrum
DTR	Digital Trunked Radio
EBS	Educational Broadband Service
EDACS	Enhanced Digital Access Control System
EDGE	A high speed data service offered on GSM networks
EHRPD	Enhanced High Rate Packet Data
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

FDMA	Frequency Division Multiple Access
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
NTIA	National Telecommunications and Information Administration
OFDM	Orthogonal Frequency Division Multiplexing
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
WISP	Wireless Internet Service Provider
WiMAX	A 4G airlink standard based on IEEE 802.16
WMS	Wireless Measurement System

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Appendix A – Contractor Scope of Work

Activity 9 – 2013 Wireless Data and Voice Transceivers.

Pericle will update the previously delivered wireless transceiver database with wireless industry advances since the last project to the extent they are deployed in Vermont. This will include technology updates, for example, Long Term Evolution (LTE) technology and resulting frequency band, bandwidth and data rate updates.

VCGI will provide an updated database with the locations and transceiver parameters of all of the state's known transceiver sites including the most recent Wireless Internet Service Providers (WISP). Where complete information is not available, Pericle will use transceiver parameters typical of each carrier in Vermont.

Pericle will review transceiver site locations and parameter data based upon the content in the new drive test data and update as needed. The transceiver database will continue to identify those transceivers capable of voice and/or data transmissions.

Pericle shall provide the location (Latitude/Longitude coordinate) and characteristics of voice or terrestrial wireless broadband[1] transceivers for both commercial federally licensed wireless and commercial unlicensed wireless service. Each transceiver shall be identified as a transceiver providing voice service and/or mobile/fixed broadband service, the spectrum used, and whether it is licensed or unlicensed.

<u>Wireless Data Transceivers</u>

9.1 Pericle shall deliver a dataset that includes all transceivers providing wireless data services to end-users[2] in Vermont, including those transceivers that are located outside the state of Vermont, but provide wireless data service in the state.

9.2 Pericle shall include a detailed set of attributes for every transceiver, including the full set of attributes required to support the creation of robust radio frequency propagation coverage maps outlined in Activity #10.[3] 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

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[1] 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".

[2] 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."

[3] 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.

also be identified by a unique transceiver identifier (TransID). The data must also identify the wireless carrier utilizing the transceiver to provide service. Where possible all transceivers registered*[4] with the FCC shall include the FCC transceiver identifier (FCCID), owner FCC Federal Registration Number (FRN).

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

9.4 Pericle shall include detailed metadata documentation (in FGDC compliant metadata format) with the shapefile. Metadata shall conform to the format and content agreed for previous deliverables.

9.5 Pericle shall map the location of all facilities to within +- 10 meters of their actual ground location.

9.6 All data collected and delivered for this activity shall be accurate as of 6/30/2013 or later.

Voice Transceivers

9.7 Pericle shall deliver a dataset that includes all transceivers providing wireless voice services to end-users in Vermont.

9.8 Pericle shall include a detailed set of attributes for every transceiver, including the full set of attributes required to support the creation of robust radio frequency propagation coverage maps outlined in Activity #10. These attributes, at minimum, should be the same attribute types as delivered for the first drive test. Additional attribute types are allowed if supported by the data. The 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. Where possible, all transceivers registered[5] with the FCC shall include the FCC transceiver identifier (FCCID), owner FCC Federal Registration Number (FRN).

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

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[4] 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.

[5] 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.

9.10 Pericle shall include detailed documentation (in FGDC compliant metadata format) with the shapefile. Metadata shall conform to the format and content agreed for previous deliverables.

9.11 Pericle shall map the location of all facilities to within +- 10 meters of their actual ground location.

9.12 All data collected and delivered for this activity shall be accurate as of 06/30/2013 or later.

Activity 10 – 2013 Wireless Data and Voice Coverage Maps.

Pericle shall use the wireless and voice transceiver information collected under Activity #9 to generate high-quality radio frequency (RF) propagation coverage maps accurately depicting the strength and geographic extent of both voice and wireless data services (fixed and mobile) emanating from each transceiver.

Pericle will utilize the latest National Land Cover Dataset database to model terrain characteristics and recent modeling and mapping tool versions: EDX Signal version 11.0.0 and ESRI ArcView/ArcMap V10.0. Terrain and land cover database resolution will be 30 meters and coverage prediction resolution for statewide maps will be 90 meters.

<u>Wireless Data Transceivers</u>

10.1 Pericle shall use sources and methods consistent with industry standard “best practices” for RF propagation analysis and mapping.

10.2 Pericle shall utilize best-of-breed software to generate the RF propagation coverage maps.

10.3 Pericle shall generate RF propagation maps for all transceivers identified in Activity #9, including fixed and mobile wireless.

10.4 Pericle shall deliver the RF data files in the following formats: ERDAS IMAGINE and Adobe PDF, combined with post processed drive test data. The data must be in the WGS 1984 Geographic coordinate system. The rasters must have 30 meter cell resolution.

10.5 Pericle shall deliver aggregated statewide coverage for each carrier rather than a separate raster data file for each wireless data transceiver as collected under Activity #9. Each cell in the raster dataset must identify signal strength as determined via the propagation analysis.

10.6 Pericle shall 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.[6]

10.7 Pericle shall include detailed documentation (in FGDC compliant metadata format) with the data (a single metadata record for the entire set of raster files). Metadata shall conform to the format and content agreed for previous deliverables.

10.8 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.

10.9 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.

10.10 All data collected and delivered for this activity shall be accurate as of 06/30/2013 or later.

<u>Voice Transceivers</u>

10.11 Pericle shall use sources and methods consistent with industry standard “best practices” for RF propagation analysis and mapping.

10.12 Pericle shall utilize best-of-breed software to generate the RF propagation coverage maps.

10.13 Pericle shall general RF propagation maps for all transceivers identified in Activity #9.

10.14 Pericle shall deliver the RF data files in the following formats: ERDAS IMAGINE and Adobe PDF, combined with post processed drive test data. The data must be in the WGS 1984 Geographic coordinate system. The rasters must have 30-meter cell resolution.

10.15 Pericle shall deliver aggregated statewide coverage for each carrier rather than a separate raster data file for each wireless data transceiver collected under Activity #9. Each cell in the raster dataset must identify signal strength as determined via the propagation analysis.

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

10.16 Pericle shall include detailed documentation (in FGDC compliant metadata format) with the data (a single metadata record for the entire set of raster files). Metadata shall conform to the format and content agreed for previous deliverables.

10.17 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.

10.18 All data collected and delivered for this activity shall be accurate as of 06/30/2013 or later.

Activity 11 – 2013 Wireless Drive Testing.

Pericle shall collect real-time mobile and fixed wireless information in the field using appropriate drive-testing data collection and mapping methods.

Pericle will complete a new drive test of the Federal Aid Highways in Vermont plus an approximate 10% increase in road mileage to include some other routes to be identified by VTA. The northern portion of the state will be driven first to ensure as much foliage on the trees as possible. Areas of the interstate where Pericle is to reduce speed (while maintaining a safe driving speed) will be provided by VTA.

Voice and data wireless coverage for six (6) cellular carriers will be monitored during the drive test to include AT&T, Sprint, T-Mobile, U.S. Cellular, Verizon and CoverageCo. In the areas of CoverageCo availability a T-Mobile phone will be used and Pericle will be required to extract the CoverageCo data from the T-Mobile phone by using the network codes. CoverageCo availability will then be used to create all of the same Activity 10 and 11 products and deliverables as required for the other providers. A map of CoverageCo availability area will be provided to Pericle prior to drive testing to facilitate CoverageCo testing. CoverageCo transceivers and coverage prediction are not required in Activities 9 and 10.

New phones and service plans adequate to support drive testing within the state for the period required will be provided by the VT Telecommunications Authority. Pericle will return all of the phones to VTA after the completion of the work. VTA will ensure roaming is turned off for all supplied phones.

Pericle will employ a similar test application as was used during the previous drive test. Data throughput is expected to be higher on several networks which will decrease the duration of each test cycle and increase the overall data usage, but will also yield more data points. Pericle will quantify the expected cycle time and throughput for the phones prior to the drive test. Collected data will be stored locally in each phone and archived periodically throughout the drive test. VTel technology and deployment will not be included in the drive test.

11.1 Pericle shall utilize best-of-breed software and hardware to collect and process the wireless drive-test data.

11.2 Pericle shall collect drive-test data for wireless voice and data services (terrestrial mobile and fixed), including all of the carriers, spectrums, and technologies identified in Activity #9 and #10.

11.3 Pericle 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 #9 and #10. 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.

11.4 Pericle shall deliver the wireless drive-test data as one or more tables within an MS Access 2000 file (MDB).

11.5 Pericle shall include detailed metadata documentation (in FGDC compliant metadata format) with the dataset. Metadata shall conform to the format and content agreed for previous deliverables.

11.6 All data collected and delivered for this activity shall be accurate as of 06/30/2013 or later.

Activity 12 – Wireless Map Validation and Calibration.

Pericle shall use the drive-test data collected under Activity #11 to determine the accuracy of the wireless propagation coverage datasets generated in Activities 9# and #10. Pericle shall also create a set of “calibrated” RF propagation maps (rasters) using the results of the drive-testing effort.

Following completion of the drive test, the collected data will be post processed to extract useful phone/network parameters and voice and data call success rates and data speeds will be calculated.

The data for all six tested providers will be plotted and reviewed for consistency vs. expected coverage and site information and discrepancies resolved. Transceiver locations and parameters will be updated as required to best reflect the drive test data. Project deliverables will include a final report with PDF coverage and drive test maps and will focus on changes since the coverage study and drive test. Table 1 includes a list of the project deliverables.

Pericle will create a Vermont Wireless Broadband Mapping Final Report 2013 similar in scope to the 2010 version of the same report. The 2013 report should include Mobile

Wireless Data Coverage Statistics for all six of the tested providers. Fixed and Mobile Wireless Coverage Maps for all of the wireless service providers shall be provided in the report. The specifications for updating the WISP propagation maps and transceiver characteristics should be consistent with those defined previously in Activity 8 (Tasks 8.2 to 8.8) of this contract.

The primary focus of the 2013 report will be the representation of the state of broadband availability in Vermont at the time of the drive test including recognition of changes that have occurred in coverage and technology since the 2010 report.

12.1 Pericle shall use the drive-test data to determine the accuracy of the original RF propagation dataset generated under Activity #10. Pericle shall deliver the raw results, summary statistics, and a report describing the accuracy of the original RF propagation dataset.

12.2 Pericle shall use the drive-test data to calibrate and refine the RF propagation data generated under Activity #10. Pericle shall deliver a separate set of “calibrated” RF propagation maps (an aggregated raster for each provider as stipulated under Activity #10). Pericle 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.

12.3 All data collected and delivered for this activity shall be accurate as of 06/30/2013 or later.

Table 1 - Deliverables

Deliverable Activity Format	**Activity**	**Format**
Update to Transceiver Database Field Descriptions	9	Word
Metadata Update	9, 10	Word
Transceiver Database Update	9, 12	Shapefile
Cellular and WISP Coverage Prediction Graphic (separate data and voice)	10, 12	Imagine
Update to Drive Test Field Descriptions	11	Word
Metadata Update	11	Word
Post Processed Drive Test Data Tables	11, 12	MS Access File
Final Report, Drive Test Statistics and Maps (similar to results summaries and maps in the last project final report)	12	PDF

Table 2 - Schedule		
Date	**Milestone**	**Responsible**
8/1/13		
8/9/13	Test Application Complete	Pericle
8/9/13	Phones Sent to Pericle; roaming turned off	VTA
8/15/13	Final Roads to be Driven Shapefile to Pericle	VTA/VCGI
8/16/13	Transceiver Location Information to Pericle	VCGI
9/4/13	Drive Test Start	Pericle
9/18/13	Drive Test Complete	Pericle
10/31/13	All Project Deliverables Completed	Pericle

Appendix B – Mobile Wireless Coverage Statistics

Appendix B.1 – Mobile Wireless Data Coverage Statistics

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

AT&T Data Statistics: (Roaming Excluded)	2010 # of Records (Based on Measured Speed)	2010 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2010 % of Tot	2013 # of Records (Based on Measured Speed)	2013 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2013 % of Tot
Total Downlink Speed Test Attempts	**10969**				**12935**			
Total Downlink Successful (any rate)	8415	77%			9820	76%		
Avg DL speed >= 768 kbps (user experience)	3483	32%	3718	34%	8036	62%	8286	64%
Max DL speed >= 768 kbps (raw data rate)	4042	37%	4075	37%	8942	69%	9040	70%
Total Uplink Speed Test Attempts	**10969**				**12931**			
Total Uplink Successful (any rate)	7741	71%			9816	76%		
Avg UL speed >= 200 kbps (user experience)	3742	34%	3818	35%	8069	62%	8201	63%
Qualified with Pericle Data Coverage Polygon:								
Total Downlink Speed Test Attempts Within Polygon	**5162**	**47%**			**9634**	**74%**		
Polygon Downlink Successful (any rate)	4694	91%			8656	90%		
Polygon Avg DL speed >= 768 kbps (user experience)	2853	55%	3023	59%	7508	78%	7700	80%
Polygon Max DL speed >= 768 kbps (raw data rate)	3278	64%	3300	64%	8215	85%	8286	86%
Total Uplink Speed Test Attempts Within Polygon	**5162**	**47%**			**9610**	**74%**		
Polygon Uplink Successful (any rate)	4466	87%			8638	90%		
Polygon Avg UL speed >= 200 kbps (user experience)	3064	59%	3117	60%	7616	79%	7721	80%

Notes:

1. It is common in the industry to scale the throughput by 15-20% to account for protocol overhead and retries.
   The second column calculates # of records with a 20% scale factor.

2. Pericle Data Polygon is -101.5 dBm mean coverage.

Sprint Data Statistics:	2010 # of Records (Based on Measured Speed)	2010 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2010 % of Tot	2013 # of Records (Based on Measured Speed)	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2013 % of Tot
Total Downlink Speed Test Attempts	**12575**				**13463**		**13463**			
Total Downlink Successful (any rate)	5663	45%			4841	36%	5063	38%		
Avg DL speed >= 768 kbps (user experience)	323	3%	918	7%	1174	9%	1310	10%	1734	13%
Max DL speed >= 768 kbps (raw data rate)	3594	29%	3925	31%	2725	20%	2861	21%	3235	24%
Total Uplink Speed Test Attempts	**12575**				**13451**		**13451**			
Total Uplink Successful (any rate)	5290	42%			4720	35%	5011	37%		
Avg UL speed >= 200 kbps (user experience)	1970	16%	3554	28%	3294	24%	3494	26%	3551	26%
Qualified with Pericle Data Coverage Polygon:										
Total Downlink Speed Test Attempts Within Polygon	**4900**	**39%**			**4541**	**34%**	**4541**	**34%**		
Polygon Downlink Successful (any rate)	4246	87%			3968	87%	4134	91%		
Polygon Avg DL speed >= 768 kbps (user experience)	243	5%	739	15%	1100	24%	1220	27%	1614	36%
Polygon Max DL speed >= 768 kbps (raw data rate)	2972	61%	3203	65%	2480	55%	2600	57%	2898	64%
Total Uplink Speed Test Attempts Within Polygon	**4900**	**39%**			**4525**	**34%**	**4525**	**34%**		
Polygon Uplink Successful (any rate)	4115	84%			3879	86%	4105	91%		
Polygon Avg UL speed >= 200 kbps (user experience)	1667	34%	3012	61%	3054	67%	3231	71%	3275	72%

Notes:

1. It is common in the industry to scale the throughput by 15-20% to account for protocol overhead and retries.
   The second column calculates # of records with a 20% scale factor.

2. Pericle Data Polygon is -100 dBm mean coverage.

T-Mobile Data Statistics: (Roaming Excluded)	2013 # of Records (Based on Measured Speed)	2013 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2013 % of Tot
Total Downlink Speed Test Attempts	**13160**			
Total Downlink Successful (any rate)	3010	23%		
Avg DL speed >= 768 kbps (user experience)	0	0%	0	0%
Max DL speed >= 768 kbps (raw data rate)	0	0%	0	0%
Total Uplink Speed Test Attempts	**13155**			
Total Uplink Successful (any rate)	3000	23%		
Avg UL speed >= 200 kbps (user experience)	0	0%	0	0%
Qualified with Pericle Data Coverage Polygon:				
Total Downlink Speed Test Attempts Within Polygon	**2930**	**22%**		
Polygon Downlink Successful (any rate)	2467	84%		
Polygon Avg DL speed >= 768 kbps (user experience)	0	0%	0	0%
Polygon Max DL speed >= 768 kbps (raw data rate)	0	0%	0	0%
Total Uplink Speed Test Attempts Within Polygon	**2901**	**22%**		
Polygon Uplink Successful (any rate)	2438	84%		
Polygon Avg UL speed >= 200 kbps (user experience)	0	0%	0	0%

Notes:

1. It is common in the industry to scale the throughput by 15-20% to account for protocol overhead and retries.
   The second column calculates # of records with a 20% scale factor.
2. T-Mobile Data Stats Not Calculated in 2010.
3. Pericle Data Polygon is -102 dBm mean coverage.

US Cellular Data Statistics:	2010 # of Records (Based on Measured Speed)	2010 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2010 % of Tot	2013 # of Records (Based on Measured Speed)	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2013 % of Tot
Total Downlink Speed Test Attempts	**12761**				**14727**		**14727**			
Total Downlink Successful (any rate)	4035	32%			3332	23%	4218	29%		
Avg DL speed >= 768 kbps (user experience)	885	7%	1153	9%	1715	12%	2389	16%	2603	18%
Max DL speed >= 768 kbps (raw data rate)	1608	13%	1703	13%	2346	16%	3020	21%	3143	21%
Total Uplink Speed Test Attempts	**12761**				**14721**		**14721**			
Total Uplink Successful (any rate)	3729	29%			3286	22%	4179	28%		
Avg UL speed >= 200 kbps (user experience)	252	2%	1213	10%	2254	15%	2934	20%	2989	20%
Qualified with Pericle Data Coverage Polygon:										
Total Downlink Speed Test Attempts Within Polygon	**3195**	**25%**			**3809**	**26%**	**3809**	**26%**		
Polygon Downlink Successful (any rate)	2594	81%			2677	70%	3347	88%		
Polygon Avg DL speed >= 768 kbps (user experience)	673	21%	865	27%	1607	42%	2162	57%	2344	62%
Polygon Max DL speed >= 768 kbps (raw data rate)	1168	37%	1221	38%	2115	56%	2670	70%	2762	73%
Total Uplink Speed Test Attempts Within Polygon	**3195**	**25%**			**3777**	**26%**	**3777**	**26%**		
Polygon Uplink Successful (any rate)	2493	78%			2630	70%	3306	88%		
Polygon Avg UL speed >= 200 kbps (user experience)	175	5%	885	28%	2122	56%	2682	71%	2724	72%

Notes:

1. It is common in the industry to scale the throughput by 15-20% to account for protocol overhead and retries.
   The second column calculates # of records with a 20% scale factor.

2. Pericle Data Polygon is -100 dBm mean coverage.

Verizon Data Statistics:	2010 # of Records (Based on Measured Speed)	2010 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2010 % of Tot	2013 # of Records (Based on Measured Speed)	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot	# of Records (With 20% Speed Increase to Account for Protocol Overhead)	2013 % of Tot
Total Downlink Speed Test Attempts	**10205**				**14790**		**14790**			
Total Downlink Successful (any rate)	7780	76%			11486	78%	12249	83%		
Avg DL speed >= 768 kbps (user experience)	2161	21%	3079	30%	9678	65%	9918	67%	10078	68%
Max DL speed >= 768 kbps (raw data rate)	4763	47%	5167	51%	10222	69%	10462	71%	10552	71%
Total Uplink Speed Test Attempts	**10205**				**14785**		**14785**			
Total Uplink Successful (any rate)	7487	73%			11406	77%	12186	82%		
Avg UL speed >= 200 kbps (user experience)	3273	32%	4640	45%	9865	67%	10110	68%	10218	69%
Qualified with Pericle Data Coverage Polygon:										
Total downlink speed test attempts within Polygon	**6736**	**66%**			**10106**	**68%**	**10106**	**68%**		
Polygon Downlink Successful (any rate)	6174	92%			9439	93%	9871	98%		
Polygon Avg DL speed >= 768 kbps (user experience)	1943	29%	2768	41%	8423	83%	8620	85%	8737	86%
Polygon Max DL speed >= 768 kbps (raw data rate)	4207	62%	4520	67%	8812	87%	9009	89%	9063	90%
Total Uplink Speed Test Attempts Within Polygon	**6736**	**66%**			**10083**	**68%**	**10083**	**68%**		
Polygon Uplink Successful (any rate)	6108	91%			9389	93%	9828	97%		
Polygon Avg UL speed >= 200 kbps (user experience)	2881	43%	4094	61%	8596	85%	8797	87%	8876	88%

Notes:

1. It is common in the industry to scale the throughput by 15-20% to account for protocol overhead and retries.
   The second and far right columns calculate # of records with a 20% scale factor.
2. Pericle Data Polygon is -100 dBm mean coverage.

Appendix B.2 – Mobile Wireless Voice Coverage Summary Statistics
(AT&T Mobility, Sprint, T-Mobile, U.S. Cellular, Verizon Wireless)

AT&T Voice Statistics: (Roaming Excluded)	2010 # of Records	2010 % of Tot	2013 # of Records	2013 % of Tot
Total Voice Call Test Attempts	**10969**		**12923**	
Total Voice Calls Successful on AT&T Infrastructure	9416	86%	10709	83%
Qualified with Pericle Voice Coverage Polygon:				
Total Voice Call Test Attempts Within Polygon	**7711**	**70%**	**9931**	**77%**
Polygon Voice Calls Successful	7427	96%	9519	96%

Notes:

1. Pericle Voice Polygon is -105 dBm mean coverage.

Sprint Voice Statistics	2010 # of Records	2010 % of Tot	2013 # of Records	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot
Total Voice Call Test Attempts	**12575**		**13441**		**13441**	
Total Voice Calls Successful	6217	49%	4897	36%	5139	38%
Qualified with Pericle Voice Coverage Polygon:						
Total Voice Call Test Attempts within Polygon	**5228**	**42%**	**5063**	**38%**	**5063**	38%
Polygon Voice Calls Successful	4850	93%	4256	84%	4432	88%

Notes:

1. Pericle Voice Polygon is -105.5 dBm mean coverage.

T-Mobile Voice Statistics: (Roaming Excluded)	2010 # of Records	2010 % of Tot	2013 # of Records	2013 % of Tot
Total Voice Call Test Attempts	**10404**		**13145**	
Total Voice Calls Successful on T-Mobile Infrastructure	2510	24%	3295	25%
Qualified with Pericle Voice Coverage Polygon:				
Total Voice Call Test Attempts Within Polygon	**2075**	**20%**	**2936**	**22%**
Polygon Voice Calls Successful	2035	98%	2733	93%

Notes:

1. Pericle Voice Polygon is -102 dBm mean coverage.

US Cellular Voice Statistics:	2010 # of Records	2010 % of Tot	2013 # of Records	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot
Total Voice Call Test Attempts	**12764**		**14286**		**14286**	
Total Voice Calls Successful	4324	34%	3847	27%	4130	29%
Qualified with Pericle Voice Coverage Polygon:						
Total Voice Call Test Attempts within Polygon	**3427**	**27%**	**4045**	**28%**	**4045**	28%
Polygon Voice Calls Successful	2958	86%	3334	82%	3461	86%

Notes:

1. Pericle Voice Polygon is -105.5 dBm mean coverage.

Verizon Voice Statistics:	2010 # of Records	2010 % of Tot	2013 # of Records	2013 % of Tot	2013 # of Records (Final Corrected Totals)	2013 % of Tot
Total Voice Call Test Attempts	**10209**		**14676**		**14676**	
Total Voice Calls Successful	8206	80%	11808	80%	12198	83%
Qualified with Pericle Voice Coverage Polygon:						
Total Voice Call Test Attempts within Polygon	**7106**	**70%**	**10568**	**72%**	**10568**	72%
Polygon Voice Calls Successful	6813	96%	10012	95%	10256	97%

Notes:

1. Pericle Voice Polygon is -105.5 dBm mean coverage.

Appendix C – Mobile Wireless Coverage Maps

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

Only four carriers provided broadband data service in Vermont as of September 2013. These carriers are AT&T Mobility, Sprint, U.S. Cellular and Verizon Wireless. Consistent with 2010 results, T-Mobile still provided only low data rate services as of the completion of the drive test survey. These five carriers provided wireless voice services. VTel Wireless is currently deploying its infrastructure and did not have a significant number of sites on the air at the time of the drive test. The maps for VTel Wireless show expected coverage once the known and modeled sites are deployed and operational.

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

- Computer modeled wireless data coverage from Pericle with cell locations shown
- Actual downlink wireless data results as measured during the drive test survey.
- Actual uplink wireless data results as measured during the drive test survey.
- Type of wireless data infrastructure provided (e.g. UMTS/HSPA vs. GSM/EDGE).
- Computer modeled voice coverage from Pericle with cell 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 T-Mobile, voice and low speed data coverage are virtually identical as the two services are provided using the same infrastructure. Five maps are provided for T-Mobile:

- Computer modeled voice/data coverage from Pericle with cell locations shown.
- Actual downlink wireless data results as measured during the drive test survey.
- Actual uplink wireless data results as measured during the drive test survey.
- Type of wireless data infrastructure provided.
- Actual voice call results as measured during the drive test survey.

For VTel Wireless, two maps are provided:

- Computer modeled wireless data coverage from Pericle with cell locations shown
- Computer modeled voice coverage from Pericle with cell locations shown.

The maps are presented in alphabetical order by carrier name.

Appendix D – Fixed Wireless Coverage Maps

This appendix contains coverage maps for each of nine Wireless Internet Service Providers (WISPs) in Vermont. Table 14 below provides summary information for each WISP including date of most recent WISP transceiver input, frequency bands used and number of transceivers modeled. Due to their relatively smaller coverage areas, these WISP coverage predictions and resulting maps have a 30 meter resolution whereas the mobile wireless coverage maps are modeled with 90 meter resolution. These maps were generated by exporting the EDX Signal™ coverage prediction data Esri Arcview. Soft copies have been provided to VCGI separately.

Table 14 - WISP Transceiver Summary

WISP	Latest Transceiver Input	900 MHz Band Transceivers (Unlicensed)	2400 MHz Band Transceivers (Unlicensed)	3650 MHz Band Transceivers (Licensed)	5800 MHz Band Transceivers (Unlicensed)	Total Transceivers Modeled
Cloud Alliance	Q4 2013	8	3	14	N/A	25
GlobalNet	Q2 2010	31	11	N/A	N/A	42
Great Auk Wireless (GAW) North	Q4 2013	24	18	N/A	7	49
GAW South	Q4 2013	5	1	2	N/A	8
GAW Finowen	Q4 2013	11	N/A	N/A	4	15
NBN	Q4 2013	11	5	N/A	N/A	16
NCC	Q2 2010	1	3	N/A	N/A	4
NCIC	Q4 2013	12	N/A	N/A	N/A	12
SVBC	Q4 2013	5	N/A	N/A	N/A	5
WaveComm	Q3 2012	27	51	4	N/A	82
Wireless VT	Q2 2010	N/A	21	N/A	N/A	21
	Totals:	135	113	20	11	279

Note that these maps are dependent on WISP's providing input for their system deployments including transceiver locations and parameters. Data for several of the WISPs (GlobalNet, NCC and WirelessVT) is quite dated and has not been updated since the 2010 predictions. All WISP transceivers were re-modeled in this project, whether or not new transceiver information was provided, in order to provide consistent coverage maps using the newer NLCD 2006 clutter database and 30 meter resolution. For each WISP, a separate coverage prediction and raster data set for each frequency band was generated and the combined coverage area of all bands for each WISP is shown in this Appendix. Coverage area for each WISP is therefore presented in a single coverage map with the exception of Great Auk Wireless (GAW). In order to maintain 30 meter resolution, the GAW coverage prediction was generated separately for three geographic areas: GAW North (includes Morrisville, Craftsbury and NEK networks), GAW South and GAW Finowen which shows coverage from those transceiver assets acquired from Finowen.

All of the technologies reported by the WISPS and modeled in these coverage maps are capable of broadband uplink (min. 200 kbps) and downlink (min. 768 kbps) data speeds.