RURAL COMMUNICATIONS TECHNOLOGY COMPARISON REPORT

The County of Hawaii and the State of Hawaii Department of Commerce and Consumer Affairs – Cable Television Division

Hawaii Island

Document Date

January 29, 2015

Version: Final

Table of Contents

Contents

1. EXECUTIVE SUMMARY

This report results from the partnership between the County of Hawaii and the Cable Television Division of the State of Hawaii, Department of Commerce and Consumer Affairs (DCCA), to examine the potential use of several identified wireless technologies to extend broadband service to unserved areas on Hawaii Island. The three identified technologies are TV Whitespace, unlicensed 900MHz and 3.65 GHz.

Specifically, this report compares the coverage predictions and the hardware and software features for each technology. This document is intended to serve as a resource report that may be used for planning purposes to extend broadband service, using wireless technologies, to unserved areas across the State where wireline internet connectivity is not available.

Section 3 of this report contains coverage predictions for each of the three technologies from eight identified base station locations across Hawaii Island. These locations selected by DCCA are unserved and present various terrain challenges and tree densities.

Section 4 of this report provides a technology overview for each of the three technologies. This includes a product review and a summary of key features and limitations of each technology.

Appendix A of this report, "Engineering Test Report for Wireless System Tests Conducted on January 15-16, 2015", provides the results of engineering tests performed with TV Whitespace and unlicensed 900MHz equipment for various link distances, link types (e.g., Full Line of Sight, Near-Line of Sight, and Non-Line of Sight), and equipment settings, on Hawaii Island. Tests were performed to measure speed, signal strength, signal quality, and end user broadband experience. The testing was performed on January 15 and 26, 2015, at the West Hawaii Civic Center.

2. WIRELESS TECHNOLOGIES

Scientel Wireless, at the request of the County of Hawaii and the State of Hawaii Department of Commerce and Consumer Affairs, Cable Television Division, has prepared coverage maps for eight locations, for each of three types of wireless technologies (TV Whitespace, 900 MHz and 3.65 GHz), and has performed engineering testing for two types of wireless technologies (TV Whitespace and 900 MHz). Refer to Appendix A, "Engineering Test Report for Wireless System Tests Conducted on January 15-16, 2015."

Carlson Wireless's Rural Connect solution was used in the coverage predictions, product and technology overview, and testing of TV Whitespace technology.

Ubiquiti Networks Rocket M900 solution was used in the coverage predictions, product and technology overview, and testing of 900 MHz technology.

Cambium Networks PMP450 3.65 GHz solution was used in the coverage predictions and product and technology overview of 3.65 GHz technology (this solution was not part of the engineering testing scope).

Each technology consists of a central Base Station and one or more remote CPEs (Customer Premise Equipment). The Base Station connects to the provider's internet backbone and CPEs connect to Customer's Laptop or PC via an Ethernet cable.

3. COVERAGE PREDICTIONS

Scientel Wireless has run multiple coverage predictions for the proposed eight Base Station locations on Hawaii Island: Kea'au Police Station, Volcano Village, Hamakua Health Center, Kaloko, Ohia Mill/Milolii, Paauilo, Pahoa, and Wood Valley/Pahala. Most of the coverage predictions are done for a Base Station with Directional antenna towards the area of interest. All of the predictions are done using EDX Wireless's radio coverage prediction software, Signal Pro. Here are a few of the pertinent parameters used in coverage predictions:

- 1 arc second terrain data from United States Geological Survey (USGS)
- 30m resolution Clutter data from USGS
- 4/3 k factor
- Remote CPE height of 9m

3.1 Legend

Receive Signal Levels - The following colours represent different predicted receive signal levels at the remote station. Note that for receive signal levels, a lower negative number is stronger (better) than a higher negative number.

- Green = areas with receive signal levels of -70dBm and stronger
- Yellow = areas with receive signal levels of -80dBm and stronger
- Red = areas with receive signal levels of -90dBm and stronger
- Blue = areas with receive signal levels below -90dBm

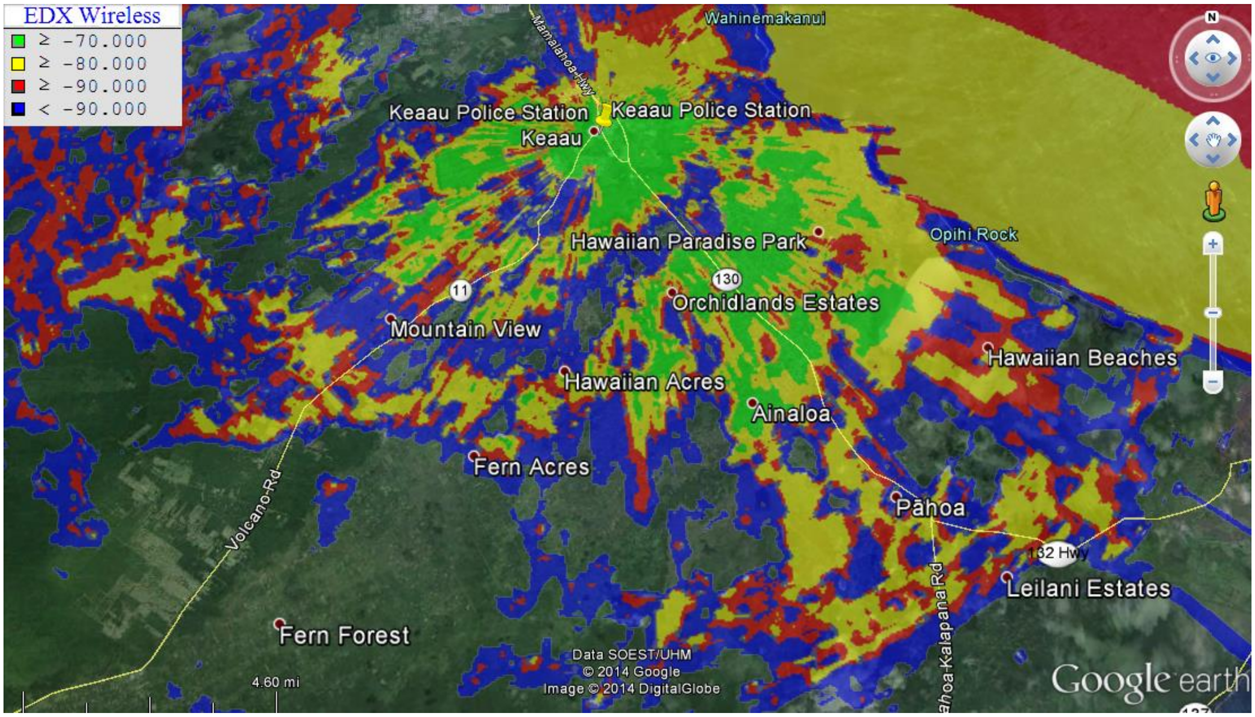
Scaling - provided on each map.
Coordinates – are in decimal degrees.

3.2 Kea'au Police Station

For this location the coverage predictions are based on a base station height of 90 ft. located at the Kea'au Police station tower at the GPS co-ordinates Latitude:19.620969, Longitude: -155.039797. Here are each of the coverage predictions for this location.

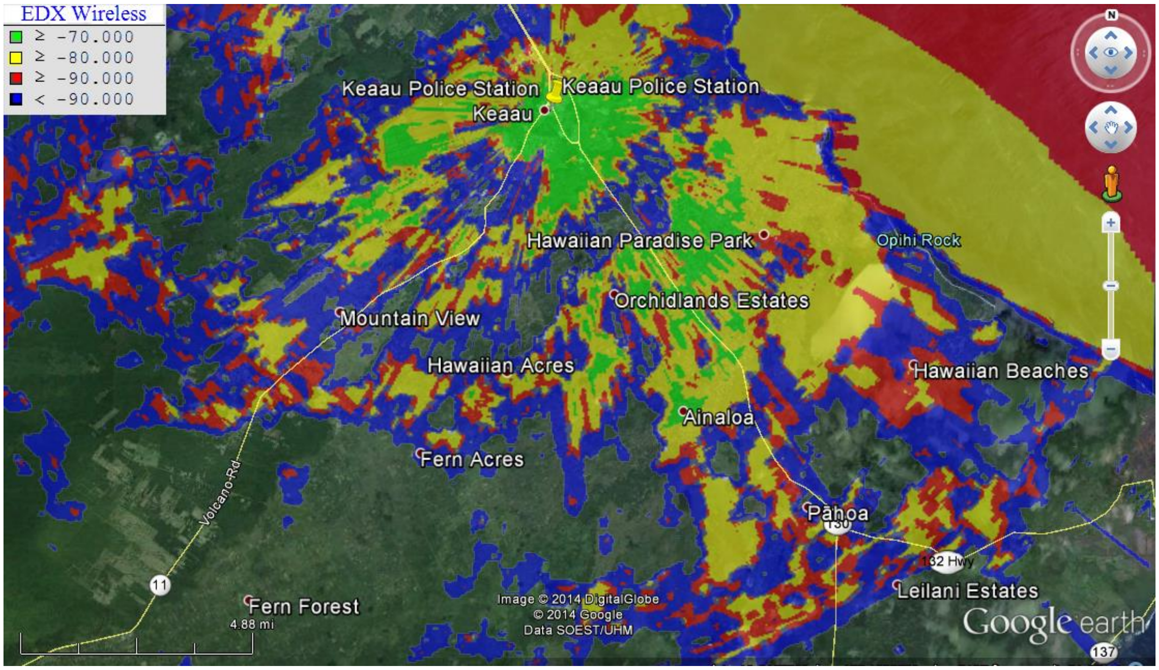
3.2.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 176 degrees towards Orchidland and Eden Roc Estates



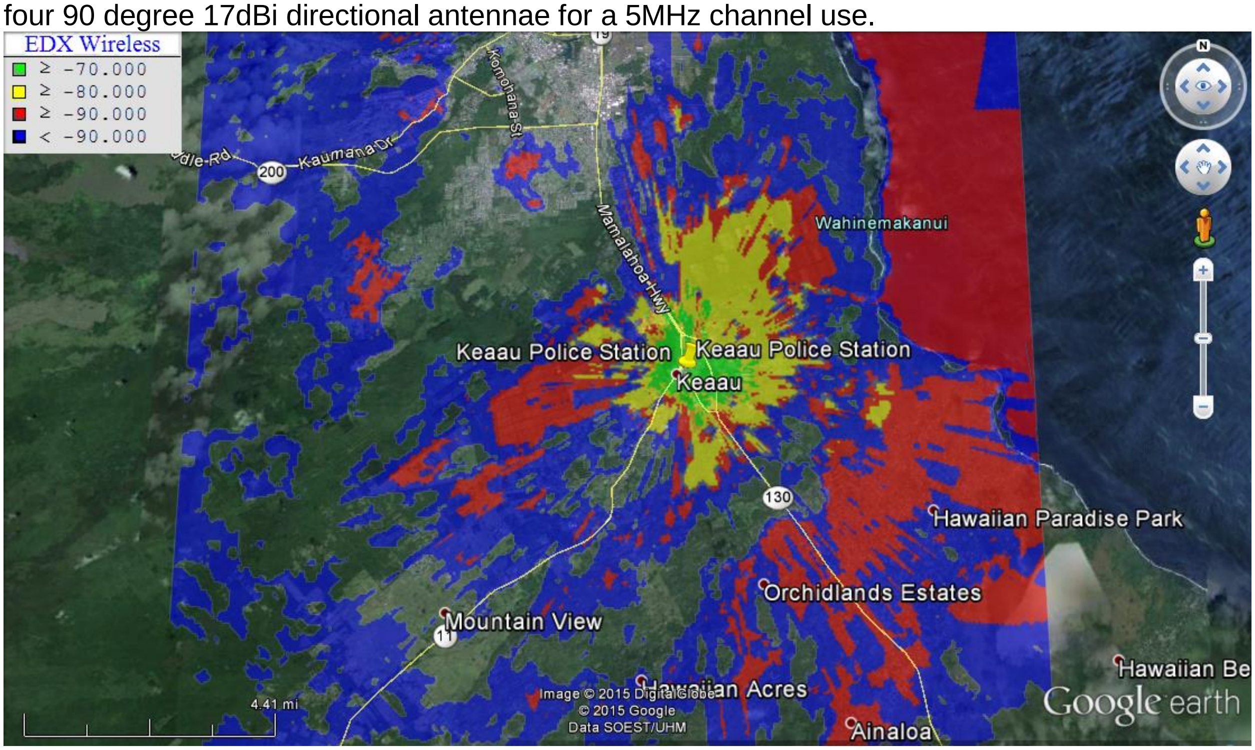
3.2.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 176 degrees towards Orchidland and Eden Roc Estates.



3.2.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

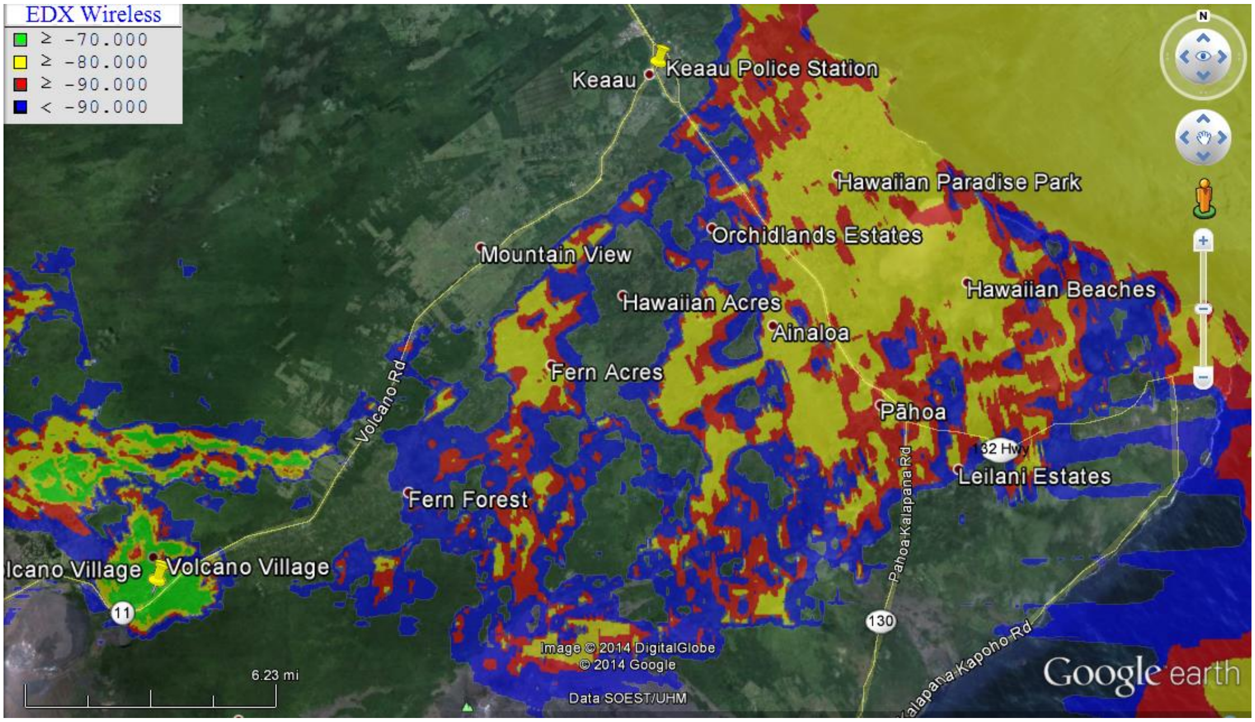


3.3 Volcano Village

For this location the coverage predictions are based on a base station height of 75 ft. located at the GPS co-ordinates Latitude: 19.429282, Longitude: -155.232875. Here are each of the coverage predictions for this location.

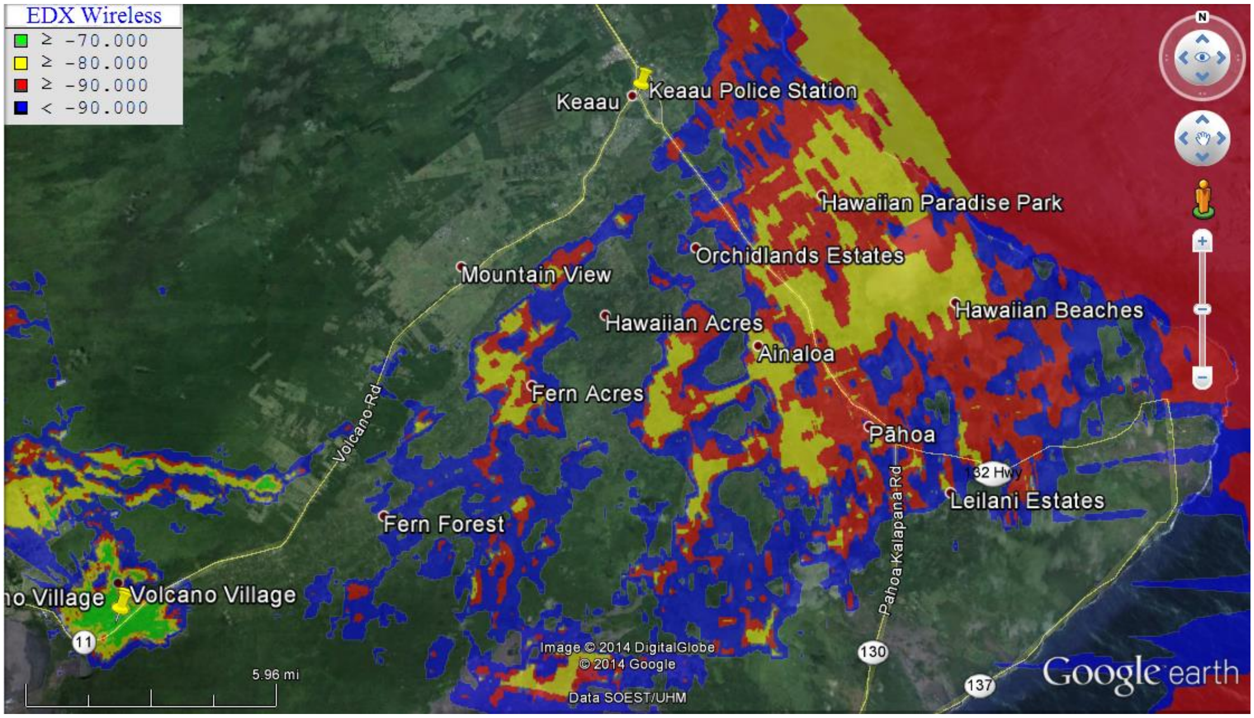
3.3.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 50 degrees towards Orchidland and Eden Roc Estates



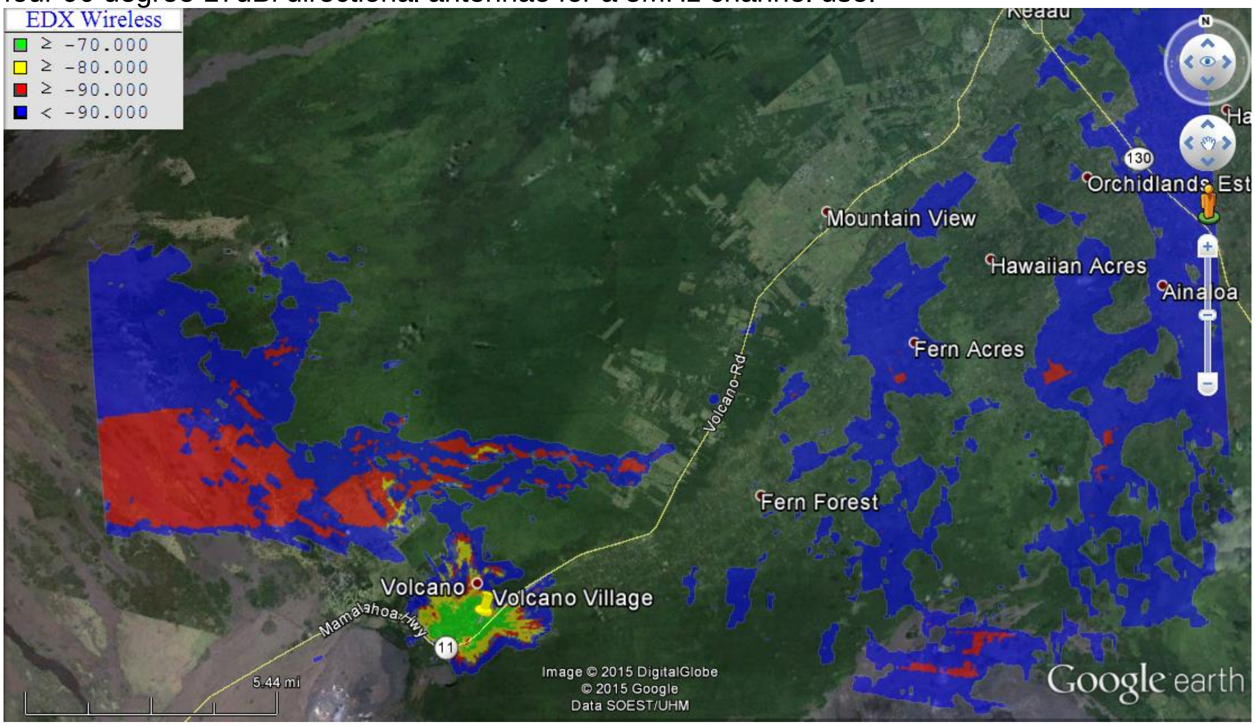
3.3.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 50 degrees towards Orchidland and Eden Roc Estates.



3.3.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

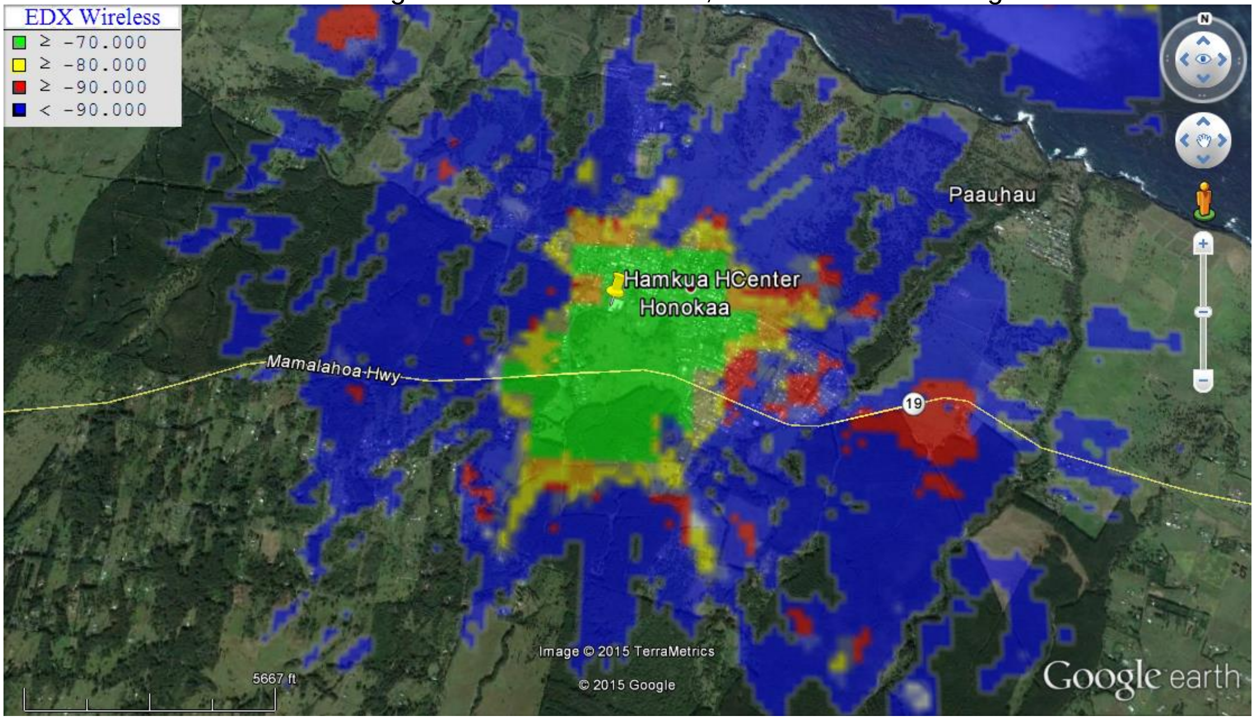


3.4 Hamakua Health Center

For this location the coverage predictions are based on a base station height of 25 ft. located at the GPS co-ordinates Latitude: 20.076106, Longitude: -155.470039. Here are each of the coverage predictions.

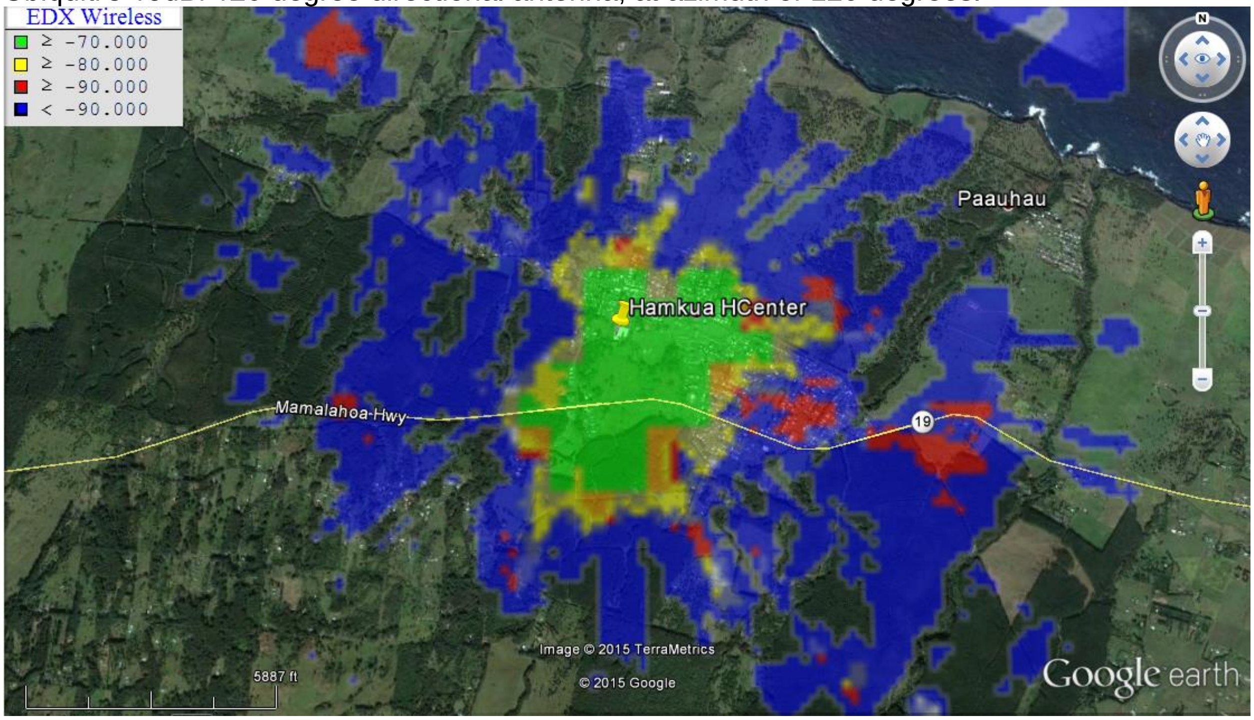
3.4.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 120 degrees.



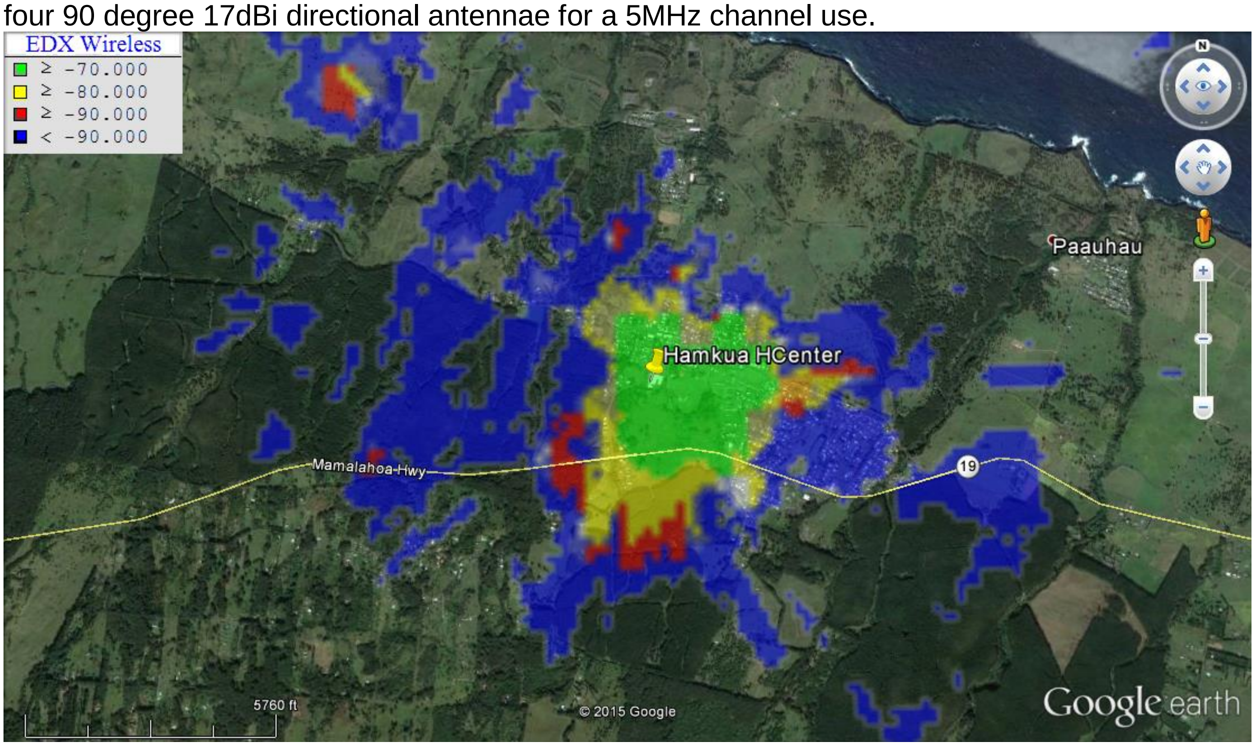
3.4.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 120 degrees.



3.4.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

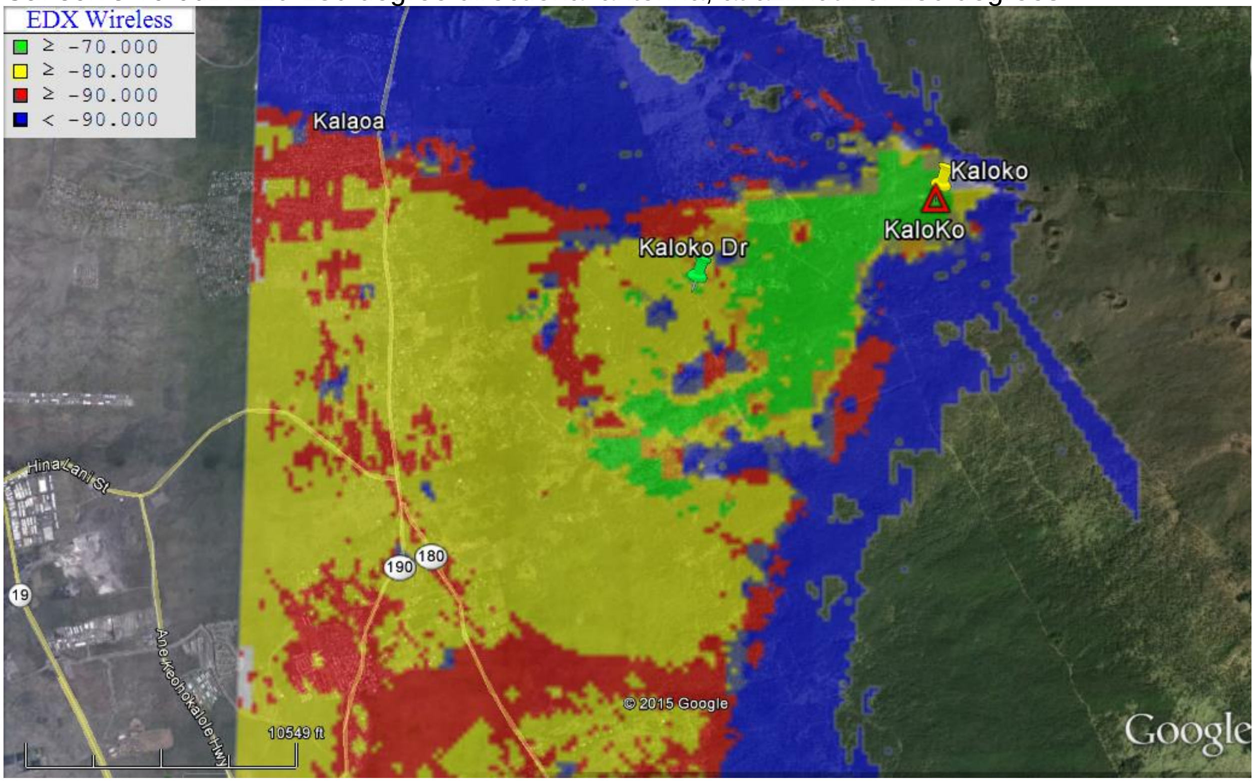


3.5 Kaloko

For this location the coverage predictions are based on a base station height of 65.6 ft. located at the GPS co-ordinates Latitude: 19.717677, Longitude: -155.917519. Here are each of the coverage predictions.

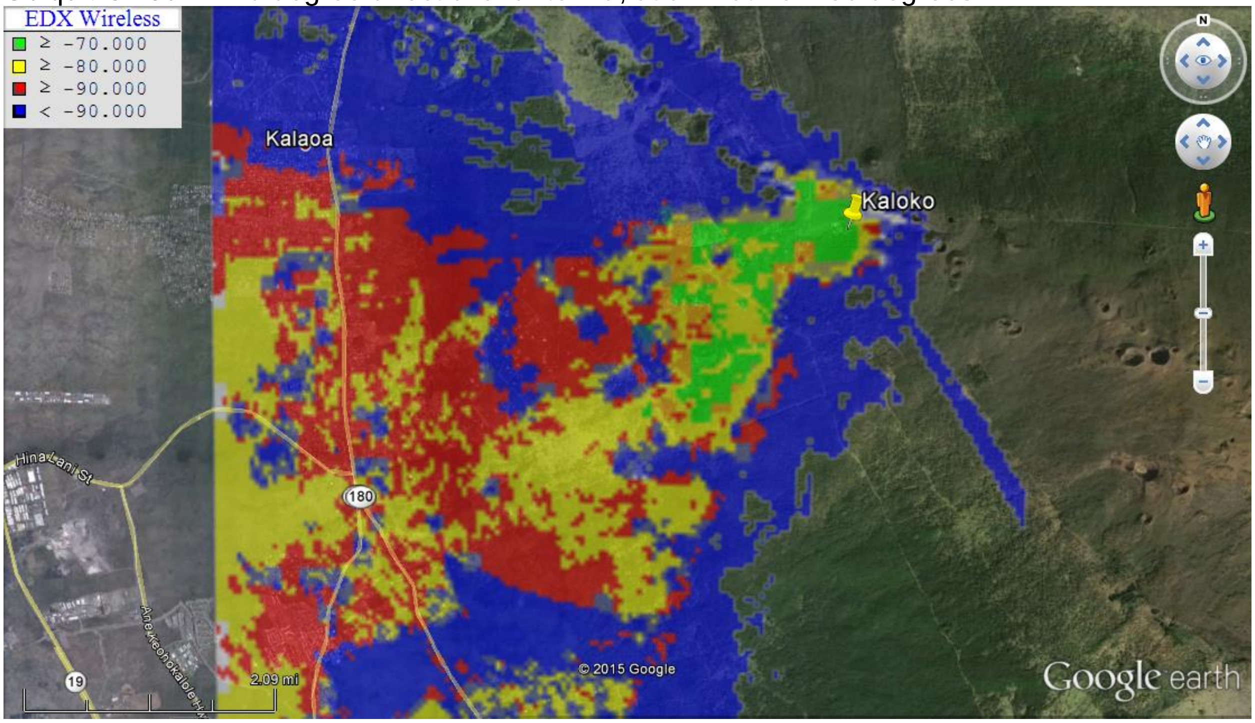
3.5.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 250 degrees.



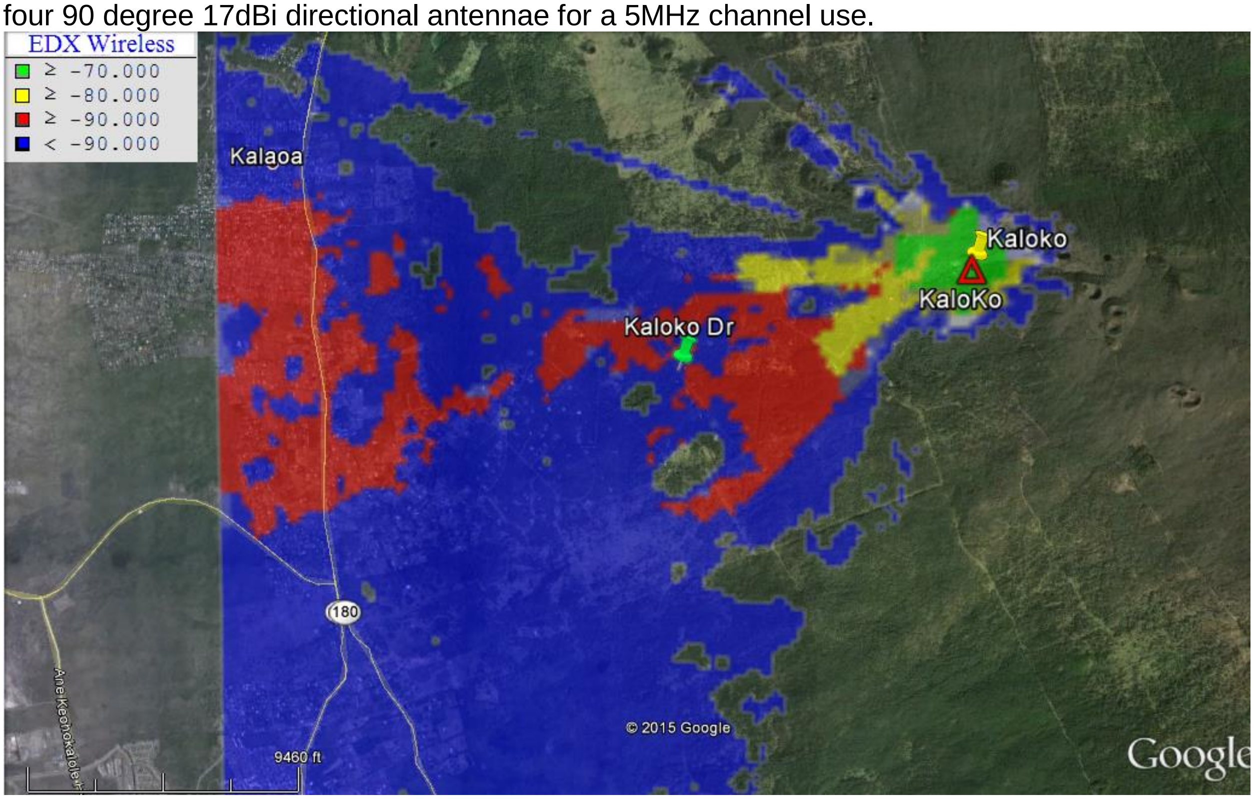
3.5.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 250 degrees.



3.5.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

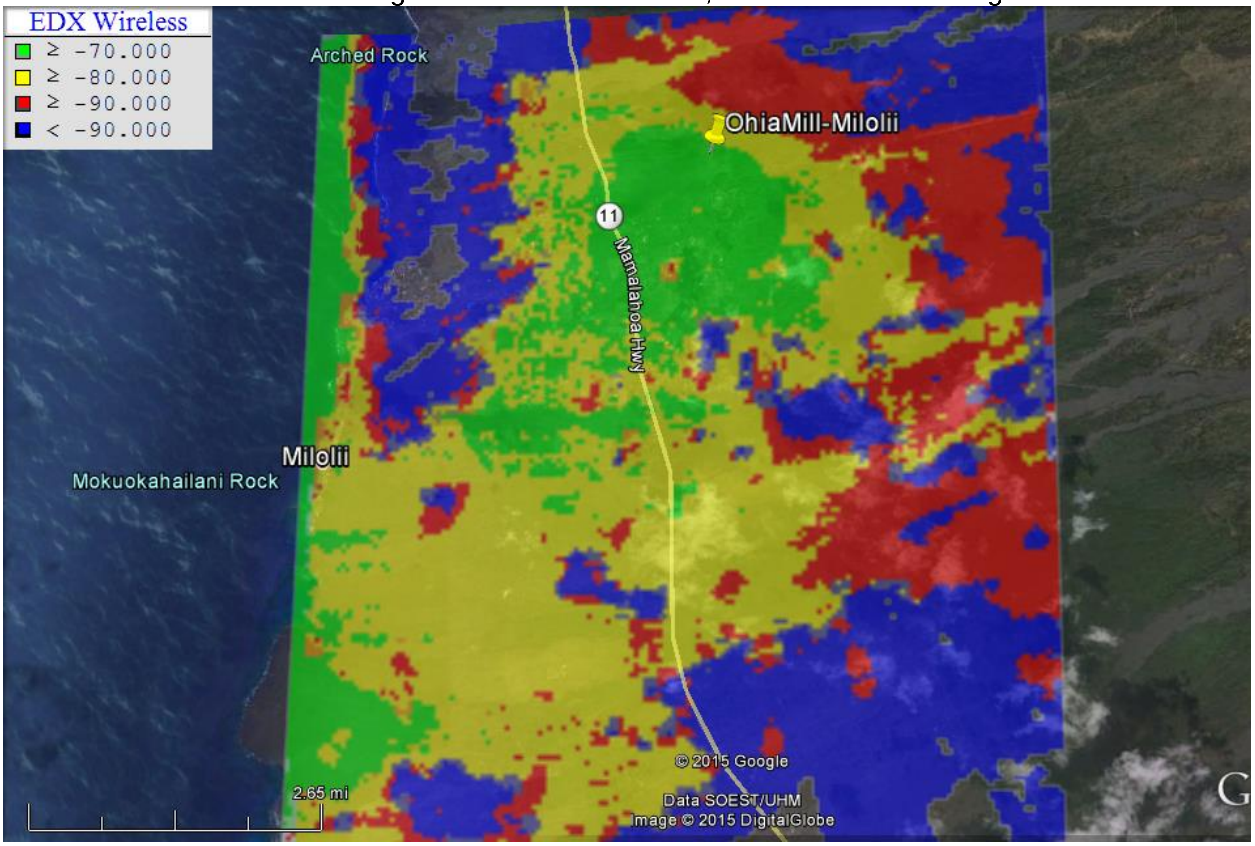


3.6 Ohia Mill/Milolii

For this location the coverage predictions are based on a base station height of 65.6 ft. located at the GPS co-ordinates Latitude: 19.221931, Longitude: -155.858887. Here are each of the coverage predictions.

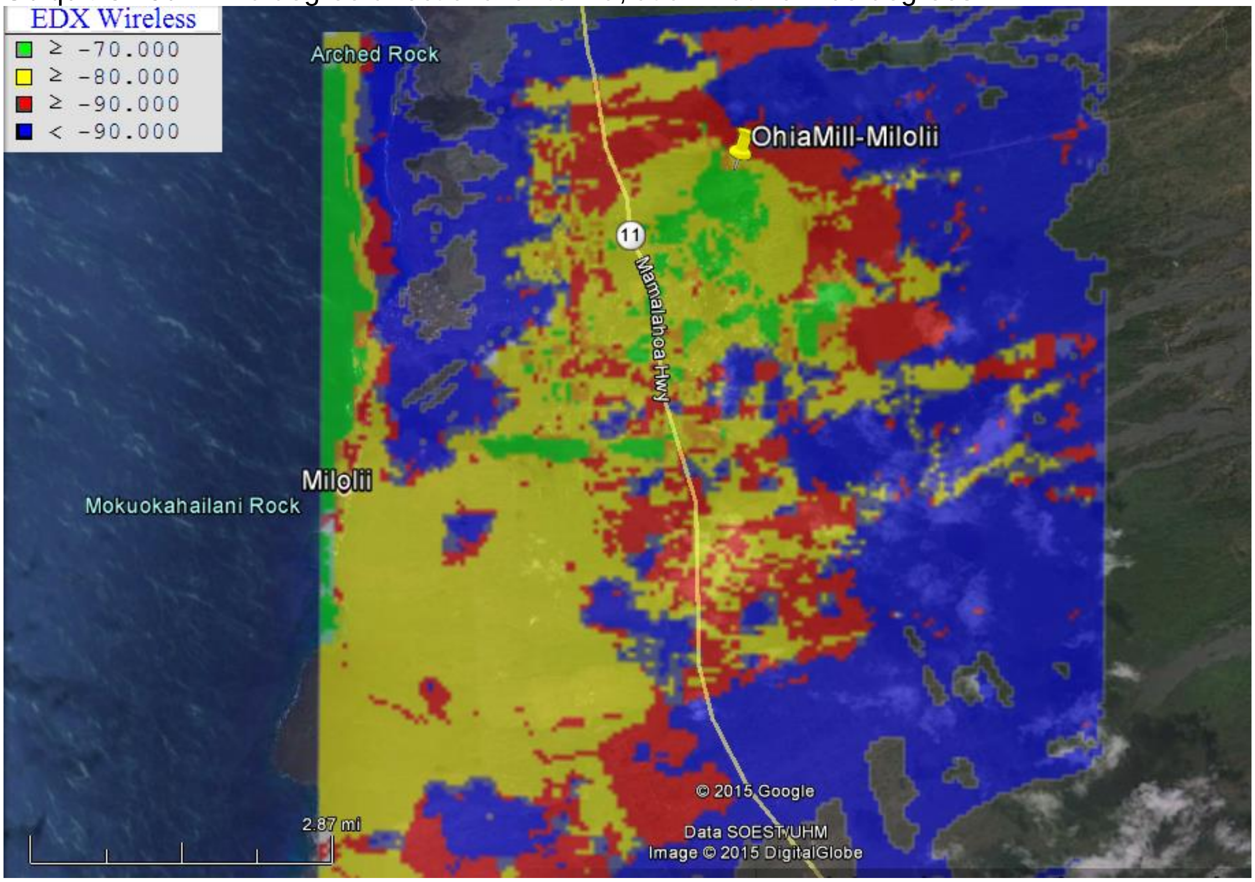
3.6.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 205 degrees.



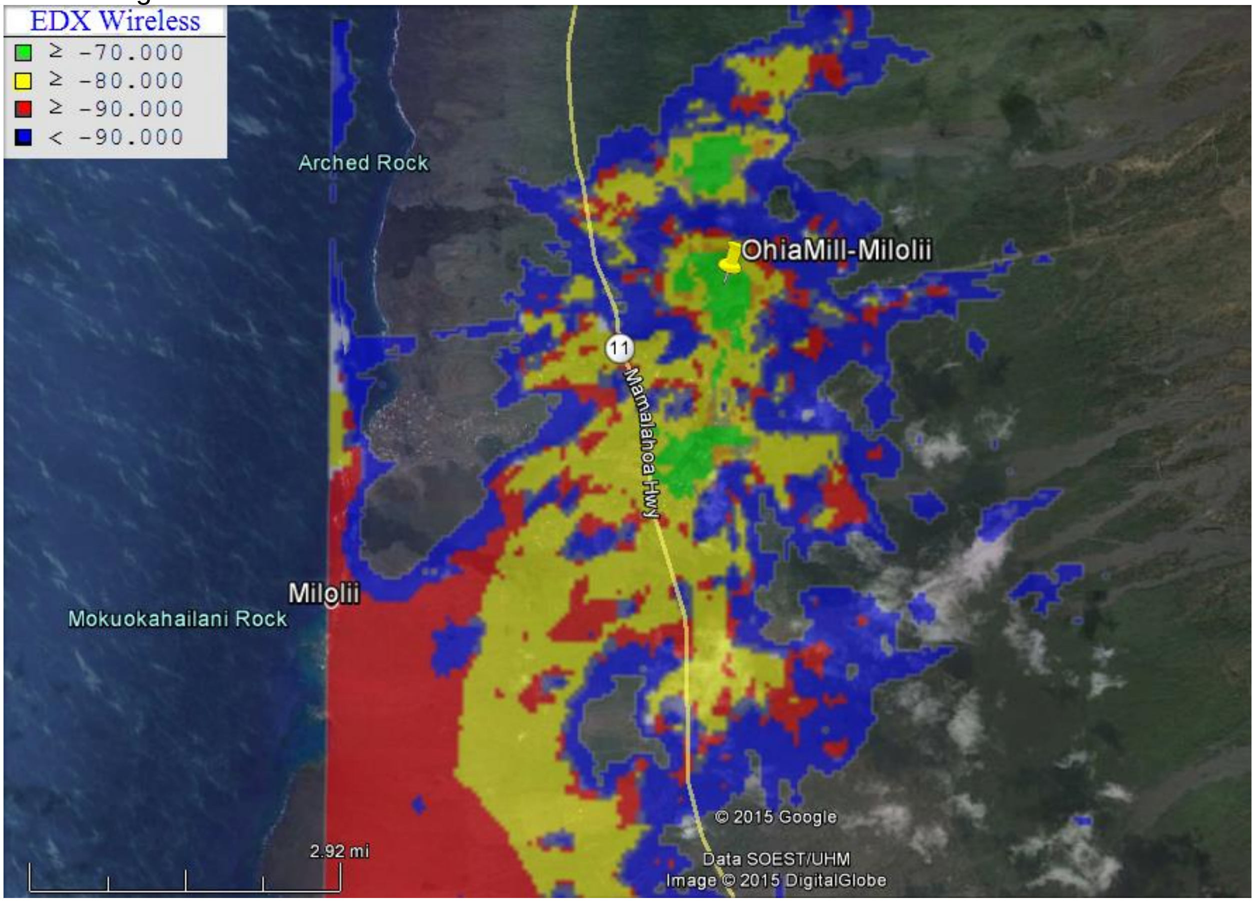
3.6.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 205 degrees.



3.6.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

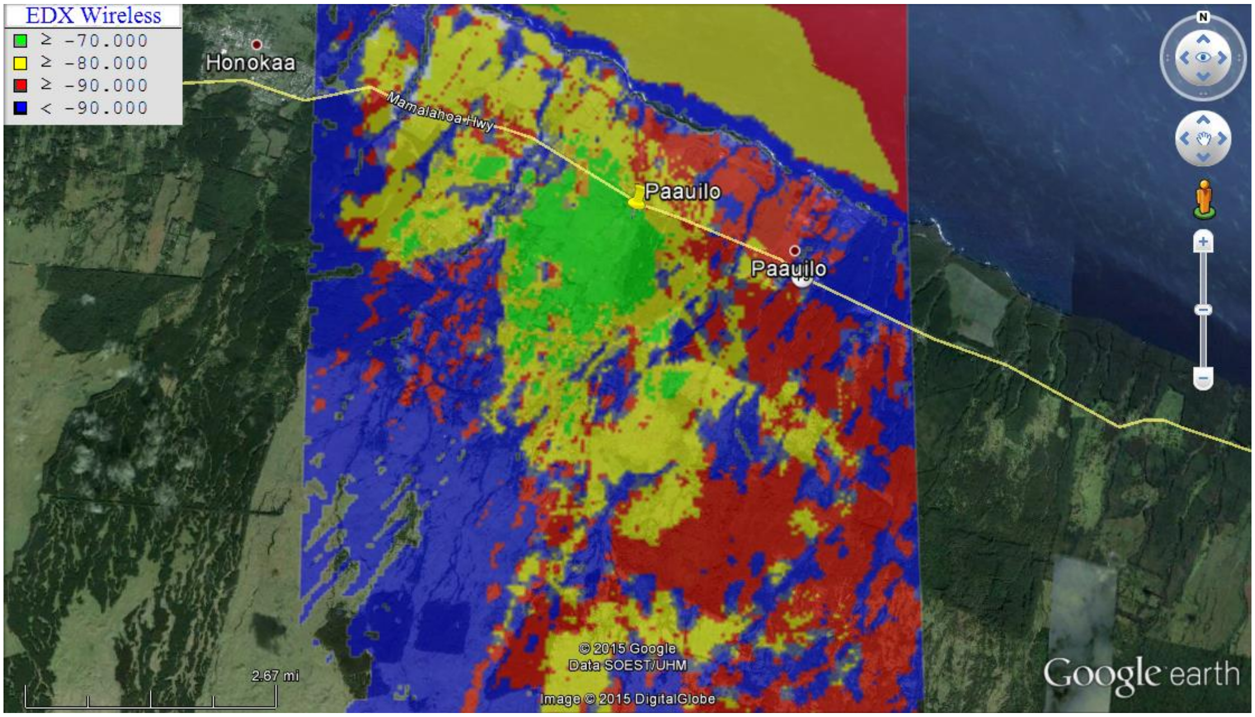


3.7 Paauilo

For this location the coverage predictions are based on a base station height of 98.4 ft. located at the GPS co-ordinates Latitude: 20.049225, Longitude: -155.398781. Here are each of the coverage predictions.

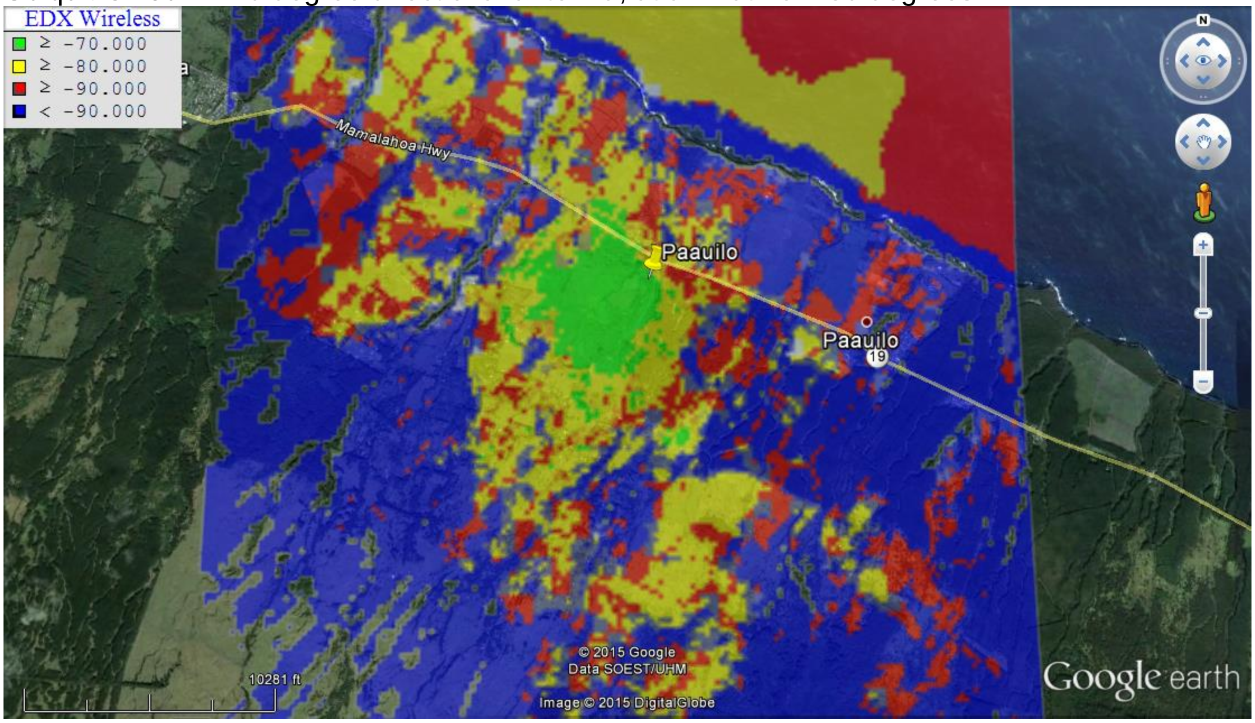
3.7.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 230 degrees.



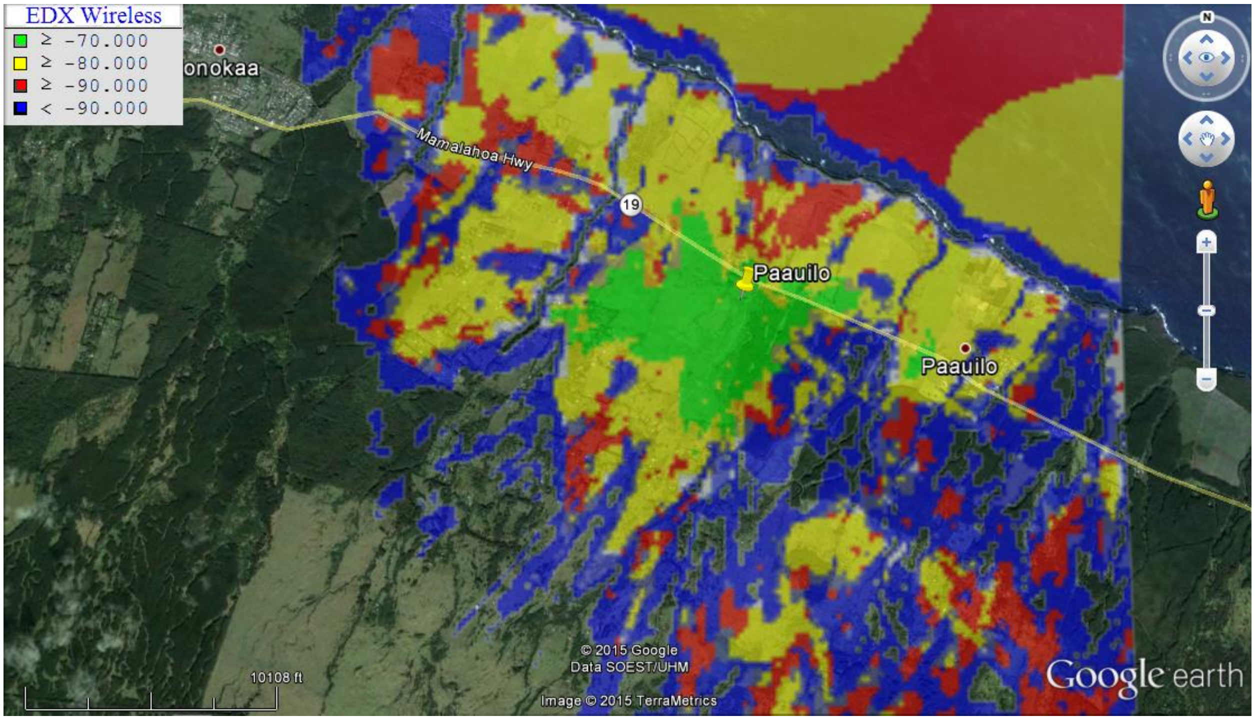
3.7.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 230 degrees.



3.7.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

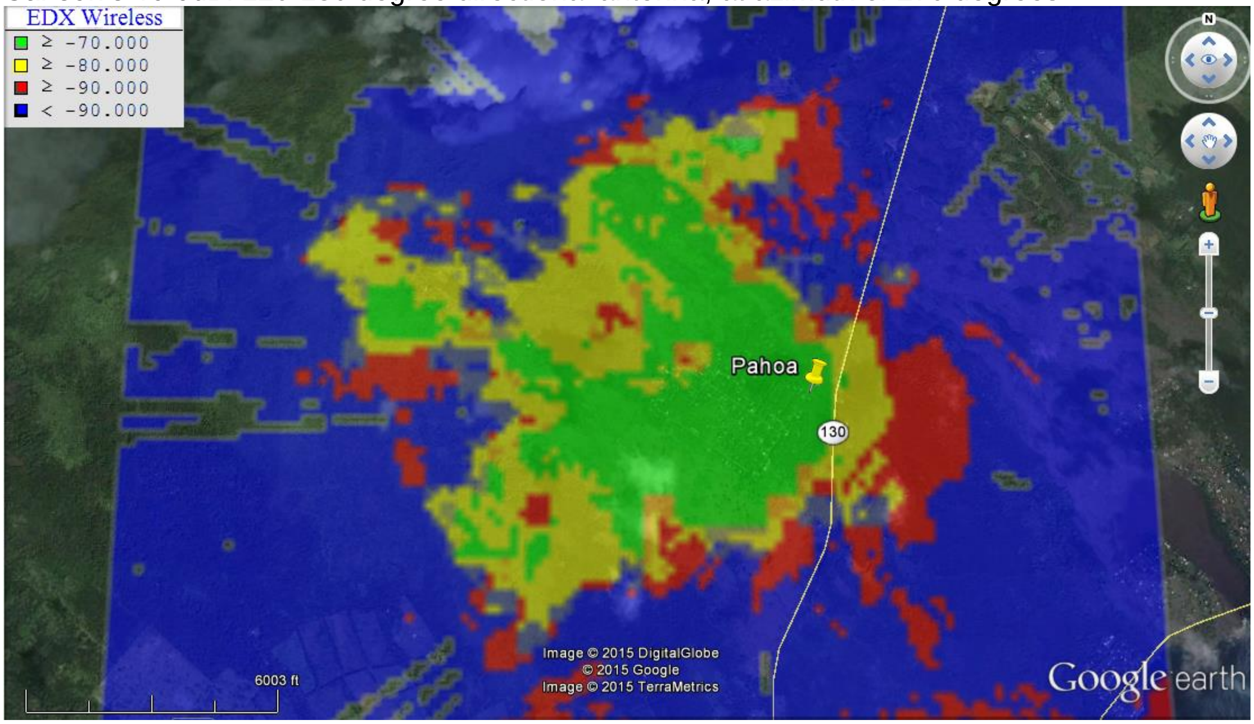


3.8 Pahoa

For this location the coverage predictions are based on a base station height of 28 ft. located at the GPS co-ordinates Latitude: 19.412822, Longitude: -154.954738. Here are each of the coverage predictions.

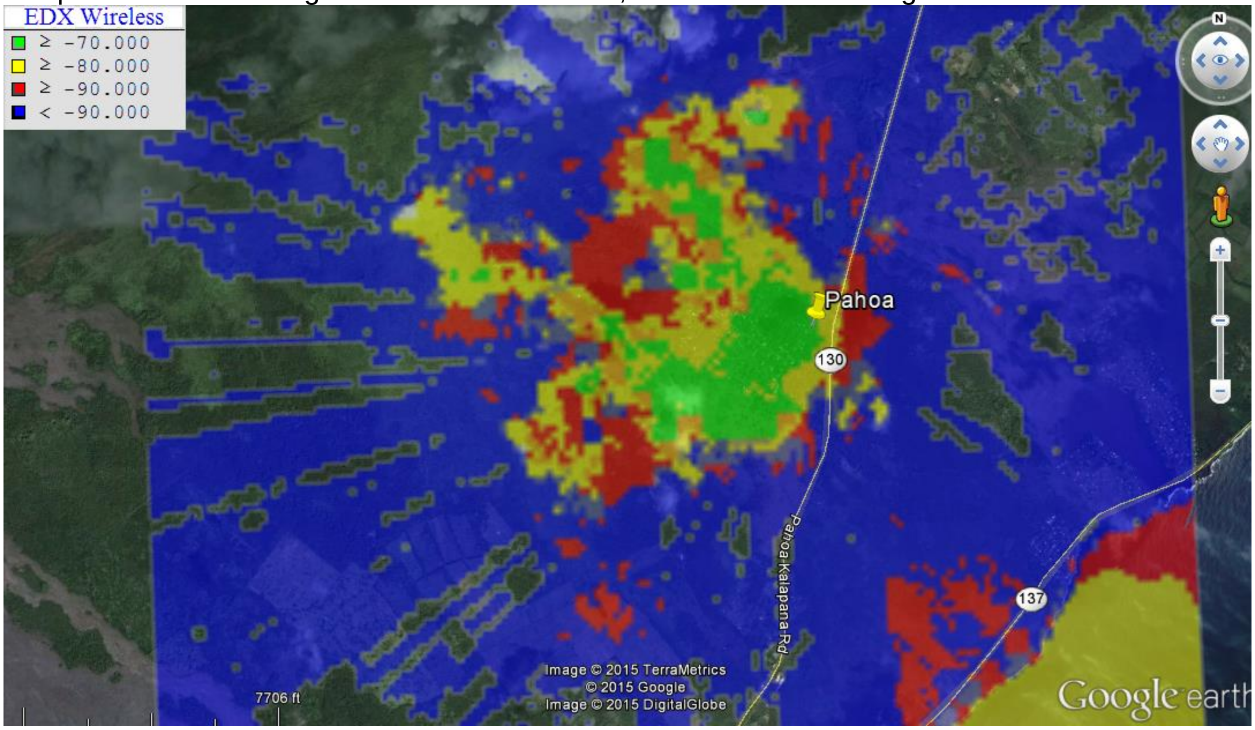
3.8.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 270 degrees.



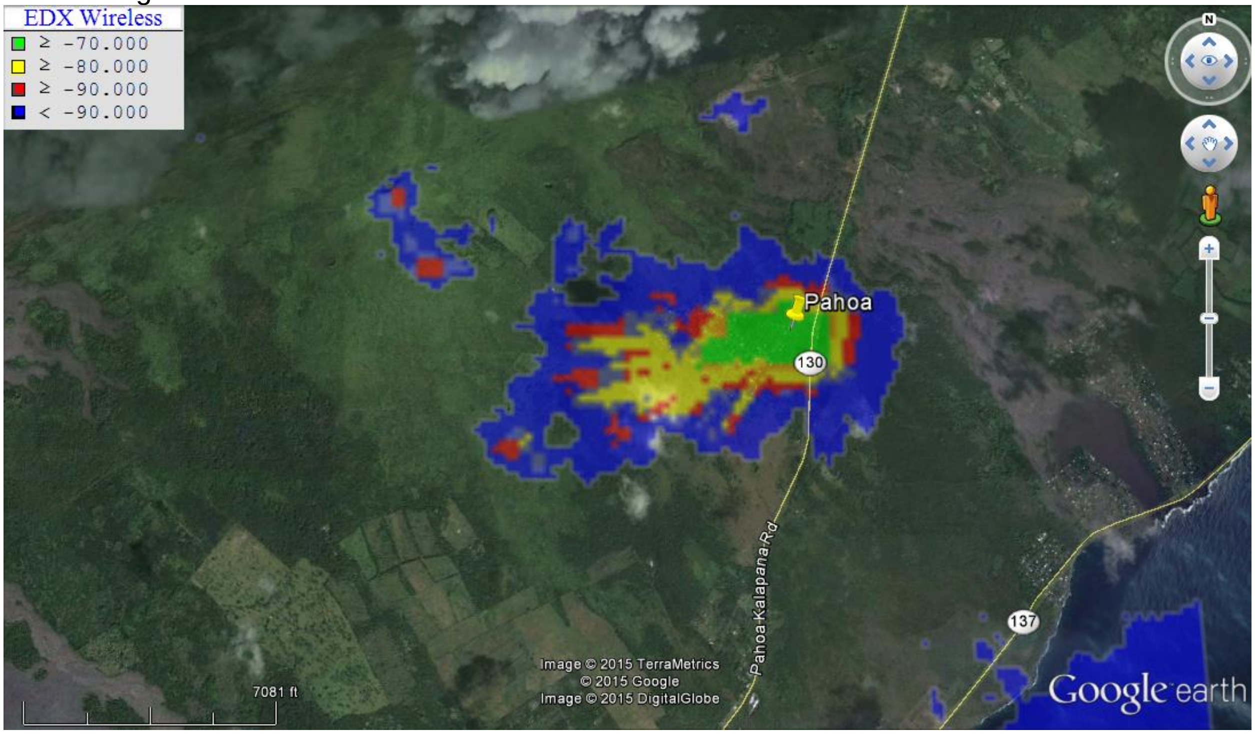
3.8.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 270 degrees.



3.8.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.

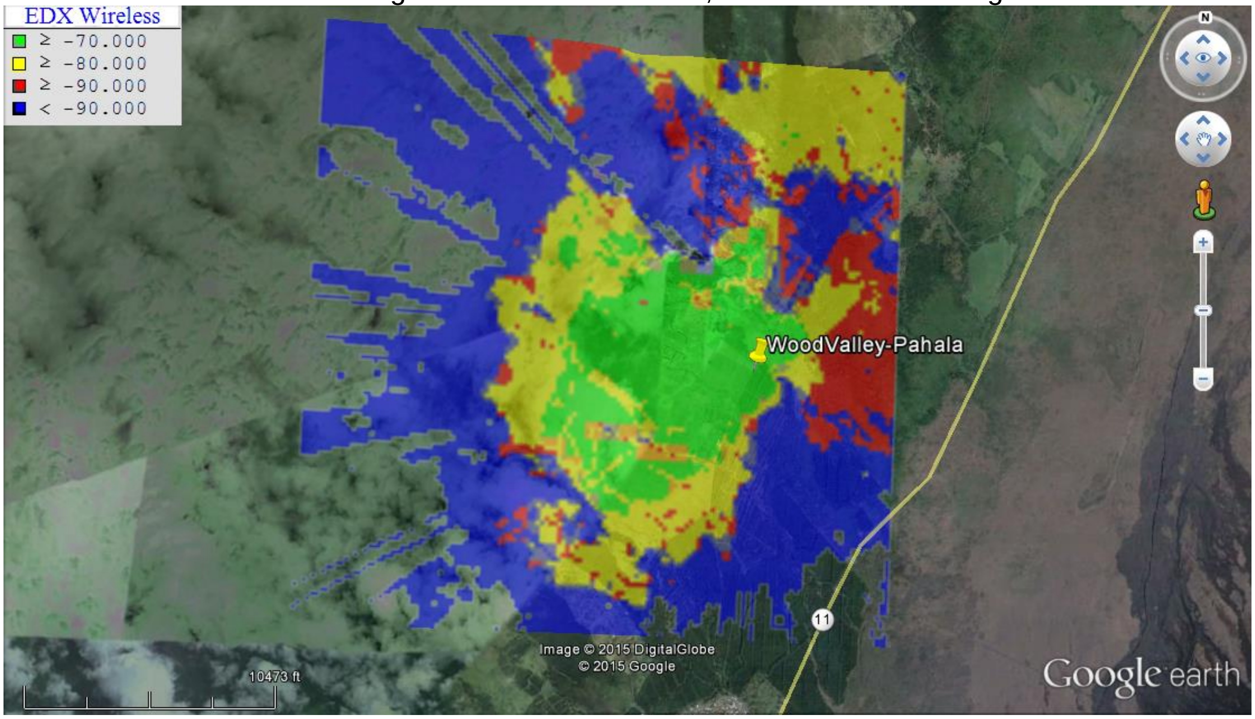


3.9 Wood Valley/Pahala

For this location the coverage predictions are based on a base station height of 28 ft. located at the GPS co-ordinates Latitude: 19.247122, Longitude: -155.474547. Here is each of the coverage predictions.

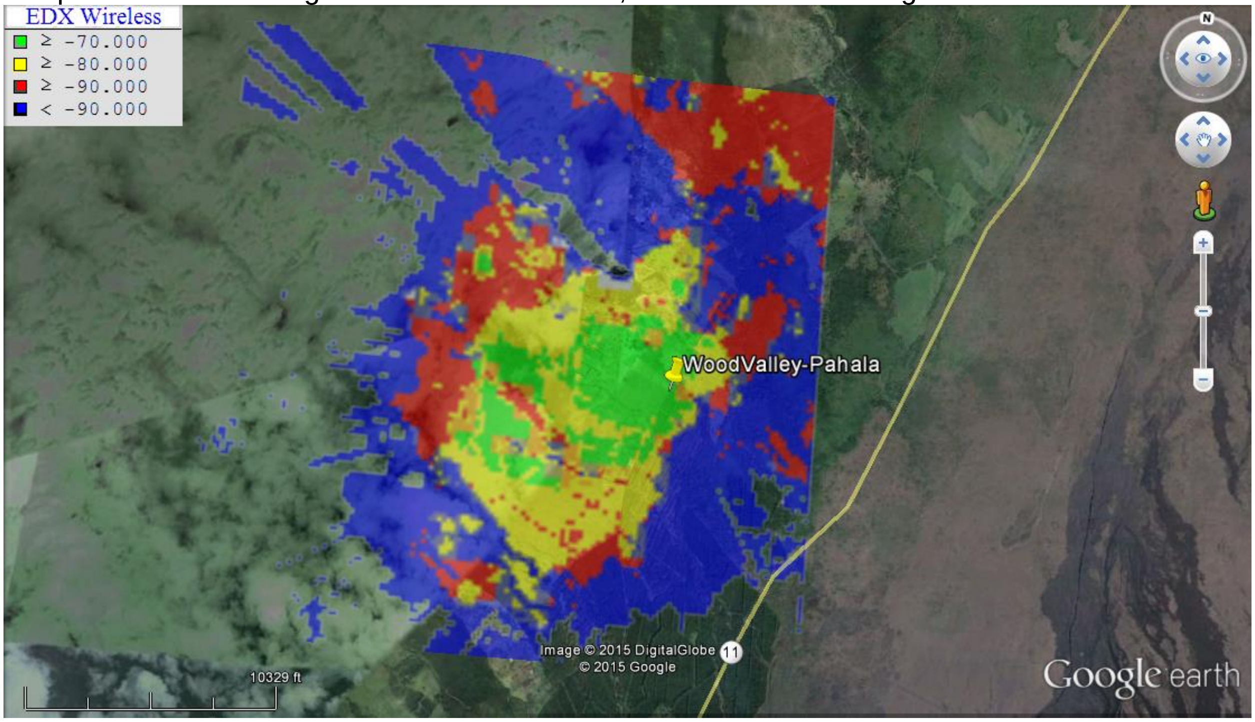
3.9.1 TV Whitespace Coverage Map

The map below shows the coverage prediction for Carlson Wireless Rural Connect using Carlson's 10.6dBi 120-180 degree directional antenna, at azimuth of 300 degrees.



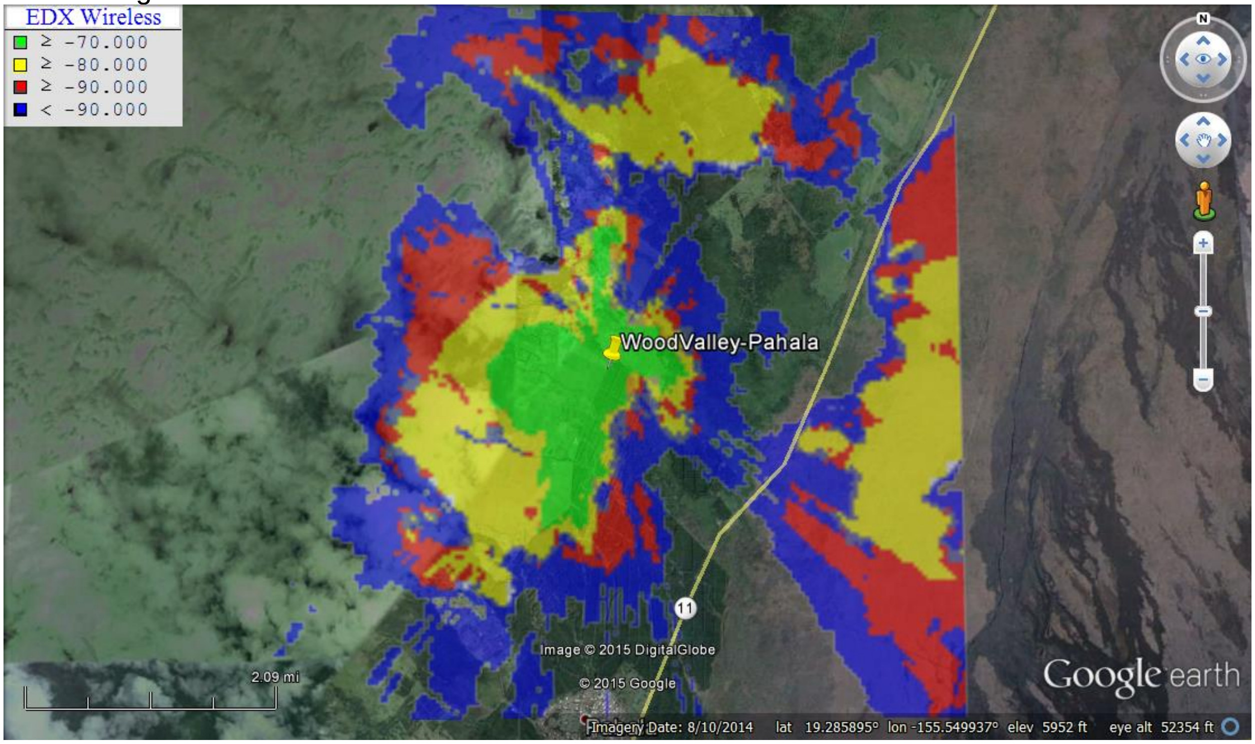
3.9.2 900MHz Coverage Map

The map below shows the coverage prediction for Ubiquiti Networks Rocket M900 using Ubiquiti's 13dBi 120 degree directional antenna, at azimuth of 300 degrees.



3.9.3 3.65 GHz Coverage Map

The map below shows the coverage prediction for Cambium Networks PMP450 Cluster with four 90 degree 17dBi directional antennae for a 5MHz channel use.



4. WIRELESS TECHNOLOGY OVERVIEW

4.1 Ubiquiti 900 MHz

4.1.1 Product Overview

Rocket M900 is part of the Ubiquiti's AirMax portfolio. It can be used both as a point to point and point to multipoint solution. It utilizes Time Division Multiple Access (TDMA) to provide each Customer Premise Equipment (CPE) its dedicated time slot, and it uses unlicensed 900MHz frequency. The TDMA AirMAX protocol enables unprecedented scalability, high throughput and low latency in unlicensed networks. The Base Station mounts on a built-in mount in the antenna for ease of installation. Picture 1 shows a Rocket M900 Base Station.

Picture 1

The CPE used for this project is a NanoStation M900 Loco. The CPE has an integrated 8dBi patch antenna, which eliminates the possibility of any cable loss. It also comes with an LED RSSI bar in the back of the unit to help with antenna alignment. Picture 2 shows front, side and back view of a NanoStation CPE.

Picture 2

Once powered up, the CPE actively scans the available channels and displays a list of all of available Base Stations along with their respective Received Signal Strength Indicator (RSSI) levels. The System User can select the Base Station with best RSSI and connect to it. CPE connects to customer's laptop or PC via Ethernet cable and Ubiquiti's Power over Ethernet (PoE) injector.

4.1.2 Advantages

- User has flexibility of using a 3MHz or 5MHz or 8MHz or 10MHz or 20MHz wide channel of operation
- Supports 2X2 Multiple Input and Multiple Output (MIMO). MIMO increases the Radio Frequency (RF) link robustness in harsh environments and increases overall throughput.
- Supports modulations up to 64 QAM (Quadrature Amplitude Modulation)
- Supports Adaptive Modulation, where if the User sets to "Auto" mode, each CPE will dynamically select the optimal modulation scheme based on the RF link quality.
- Separate Graphical User Interface (GUI) for both AP and CPE
- Flexibility to program the radio output power and IP address for both the Base Station and CPE from GUI. User has the option of selecting either Static or DHCP IP address scheme. If User selects Static, User has to provide an IP address for the device. If User selects DHCP, then device will look for DHCP server to assign a dynamic IP address
- Base Station and CPE GUI has Inbuilt Spectrum Analyzer, which can be used to identify cleaner frequency channels
- GUI has statistical reporting capabilities on various performance metrics such as uptime, signal levels, data rates, packet errors, etc.
- Supports 10/100BaseT Ethernet Interface
- CPE has integrated antenna, hence eliminating any coaxial cable losses
- Supports basic Wi-Fi Multimedia (WMM) Quality of Service (QoS) to prioritize voice and video traffic over other traffic

4.1.3 Key Technology (T) or Product (P) Limitations

- (T) Utilizes unlicensed 900MHz, which could increase susceptibility to external interference.
- (T) Increased free space path loss at 900MHz as compared to TVWS systems which operate at lower frequencies.
- (T) Only 26MHz of total spectrum available
- (P) There is no provision for Global Positioning System synchronization between collocated base stations
- Refer to Appendix A for engineering test results using this product and technology.

4.2 Carlson RuralConnect TV Whitespace

4.2.1 Product Overview

Carlson's RuralConnect system operates in TV Whitespace frequencies (470MHz to 698MHz in US). TV White Spaces (TVWS) frequencies are made available for unlicensed use at locations where the spectrum is not being used by licensed services, such as television broadcasting. In order to utilize this unlicensed spectrum band, TV Band Devices (TVBD) must communicate via the Internet with a Spectrum Management Database (SMDB) to obtain a list of allowable channels and ensure incumbent users are protected. Carlson's system checks the connection to SMDB every hour and pulls a new list of allowable channels on daily basis. A SMDB, in this case Spectrum Bridge, provides the radio with a list of available channels based on Base Station's location information entered during initial product configuration and registration. The available channels may vary, depending on TVBD device type and location.

The Carlson base station consists of a base station controller, a base station radio, and an antenna. The Carlson base station requires constant connectivity to the internet as part of FCC requirements for unlicensed operation. Picture 3 shows the Carlson Base Station.

Picture 3

The CPE consists of a radio connected to an antenna. The CPE connects to the Customer's laptop or PC via Ethernet cable and Carlson's Power over Ethernet injector. The CPE connects to its antenna via a RG-6 coaxial cable. It is recommended that the distances between the Base Station/CPE Radio and their respective antennas should be kept at a minimum, in order to achieve minimal loss of RF energy over the coaxial cable. Picture 4 shows a Carlson RuralConnect CPE.

Picture 4

4.2.2 Advantages

- RuralConnect operates in a clean channel designated by a Spectrum Management Database in an otherwise licensed spectrum, so there is very little likelihood of external interference
- Free space path loss for TVWS frequencies is lowest, because it operates in the lowest frequency band as compared to 900MHz and 3.65MHz frequencies. This also results in a better propagation in the same terrain as compared to 900MHz and 3.65GHz systems.
- Wider Spectrum (220MHz) available as compared to 26MHz in 900 MHz and 50MHz in 3.65GHz
- Base Station GUI reports signal level and Signal to Noise Ratio (SNR) for different registered CPEs
- Supports 10/100BaseT Ethernet Interface

4.2.3 Key Technology (T) or Product (P) Limitations

- (T) Does not provide flexibility of user-selectable channel size. Channel bandwidth is fixed at 6MHz wide
- (P) No MIMO capabilities
- (P) Supports modulations only up to 16QAM and no “Auto” mode. User must select one scheme for each CPE at time of installation
- (P) Adaptive modulation feature doesn’t work in the current firmware so the User must select a static modulation for CPE’s based on the signal level and Signal to Noise Ratio (SNR)
- (P) There is no GUI for CPEs, everything has to be done via Base Station GUI
- (P) User cannot adjust the transmit power in the field via the Base Station GUI
- (P) A Dynamic Host Configuration Protocol (DHCP) server is required for the Base Station to pull a dynamic IP address. The only way to assign a static IP address is by contacting Carlson Technical Support
- (P) CPE does not have an integrated antenna, so there is possibility of losses from the coaxial cable connecting CPE to antenna
- (P) Does not support any kind of QoS
- (P) All troubleshooting must be done remotely by Carlson Technicians directly connected to the radios
- (P) All logs are encoded with proprietary software and need to be decoded by a Carlson Wireless Technician.
- Refer to Appendix A for engineering test results using this product and technology.

4.3 Cambium 3.65 GHz

4.3.1 Product Overview

The Cambium 3.65 GHz PMP450 operates in the licensed spectrum and supports an Effective Isotropic Radiated Power (EIRP) of 36dBm in US for 5MHz channel size. A typical Cambium Point to Multipoint (PMP) solution comprises of 1 to 6 Access Points equipped with 60/90degree antennas, a cluster management module (CMM) to provide GPS synchronization, and a Subscriber Module (SM) at the remote end. The Cambium PMP450 can support up to 125Mbps per Access Point (AP). The AP takes power over Ethernet from Cambium's power injector and has a 10/100/1000baseT Ethernet interface. Picture 5 shows a Cambium PMP450 Access Point.

Picture 5

An Access Point can work in a standalone mode or synchronized mode if there are other APs collocated. In standalone mode there is no requirement for a CMM, as the AP provides a synchronization pulse to all of the associated SMs. In synchronized mode there are multiple APs collocated and a CMM provides a GPS sync pulse to each of the APs. Having a CMM at every cluster (usually 4 to 6 APs) to cover 360 degrees helps mitigate any self-interference and also makes it possible to re-use the same channel for collocated APs pointing in opposite directions, hence using fewer channels.

Picture 6

Every AP is assigned a frequency channel and a color code which is used as a unique identifier. An AP and SM use TDD (Time Division Duplex) to communicate on the same frequency channel. Each SM is allotted its own time slot to communicate with the AP. Cambium PMP450 SM (Picture 6) has an 8dbi integrated patch antenna and requires Power over Ethernet (PoE) using Cambium's PoE Injector. The antenna on the SM is integrated, hence there is no cable loss. Once the SM is powered it scans through the pre-selected frequencies for the band of operation and registers to the AP with a matching color code. After a SM is registered with an Access Point it transmits and receives during its allocated transmit and receive slots. A Cambium Subscriber Module is connected to customer PC/Laptop via Ethernet cable and Cambium's PoE injector.

4.3.2 Advantages

- User has flexibility of selecting a 5MHz or 10MHz or 20MHz wide channel size.
- Supports 2X2 MIMO. MIMO increases the Radio Frequency (RF) link robustness in harsh environments and increases overall throughput.
- Supports modulations up to 256QAM
- Supports Adaptive Modulation where AP and SM automatically adjust modulation being used for communication based on the RF link quality
- Separate GUI for both AP and SM
- Flexibility to program the radio output power for APs and IP address (for both AP and SM) from GUI. User has the option of selecting either Static or DHCP IP address scheme. If User selects Static, User has to provide an IP address for the device. If User selects DHCP, then device will look for DHCP server to assign a dynamic IP address
- GUI for AP and GUI for SM have an Inbuilt Spectrum Analyzer, which can be used to identify cleaner frequency channels
- GUI has statistical reporting capabilities on various performance metrics such as uptime, signal levels, SNR, Channel Bandwidth, Channel Frequency, etc.
- Supports 10/100/1000 BaseT Ethernet Interface
- Utilizes GPS Synchronization to avoid self-interference and enable efficient use of frequency spectrum via frequency reuse
- SM has integrated antenna, hence eliminating any coaxial cable losses
- Supports Diffserv Quality of Service (QOS). It is a standard for prioritizing the traffic on the network; for example, voice and video traffic should have higher priority as compared to regular data traffic

4.3.3 Key Technology (T) or Product (P) Limitations

- (T) 3.65GHz has highest free space path loss as compared to 900MHz and TVWS which operate at lower frequencies.
- (T) Only 50MHz of total spectrum available

5. APPENDIX A: ENGINEERING TEST REPORT FOR WIRELESS SYSTEM TESTS CONDUCTED ON JANUARY 15-16, 2015.

5.1 Test Report Executive Summary

This Engineering Test Report contains data collected by Scientel Wireless during the Engineering Tests conducted on Hawaii Island on January 15 (Day 1) and January 16 (Day 2), 2015. The tests were conducted at the County of Hawaii's West Hawaii Civic Center.

5.2 Purpose of the Rural Communications Engineering Test Report

The purpose of this Engineering Test Report is to test and document the performance of the two technologies (whitespace and 900MHz) chosen for this pilot system in the engineering test environment located on Hawaii Island.

5.3 Wireless Technology Link Overview

5.3.1 900 MHz Links

Description:
The following Ubiquiti 900MHz 2x2 AirMax MIMO BaseStation were tested as part of the DCCA's Rural and Under Served (RUS) system.

Basestation Site	Test Location	Frequency (MHz)
Southwest corner of Building A	19 40' 23.21"N, 156 0' 13.61" W	Channel 4/7 Freq: 907MHz/917MHz

5.3.2 TV Whitespace Links

Description:
The following Carlson Wireless Time Division Duplex (TDD) Whitespace Rural Connect Base Station will be tested as part of the DCCA's RUS system.

Base Station Site	Test Location	Frequency (MHz)
Southwest corner of Building A	19 40' 23.21"N, 156 0' 13.61" W	503 MHz

5.4 Measurement Equipment

5.4.1 Measurement Equipment Record

The following table has the record of measurement equipment used to conduct the tests in this report.

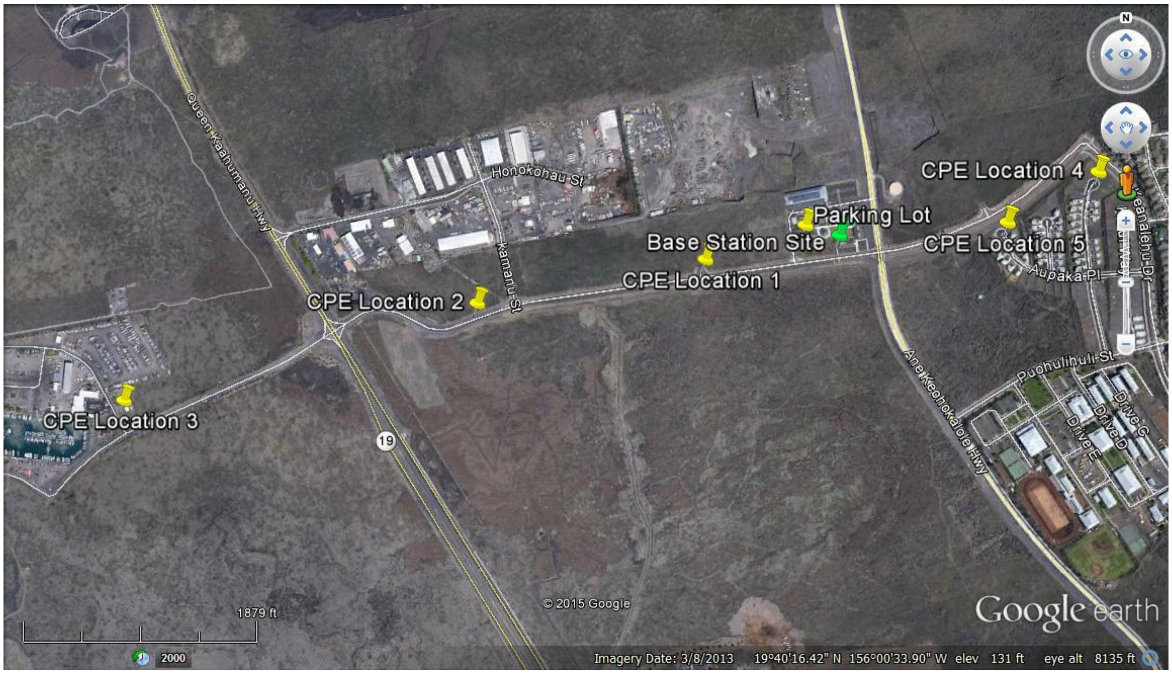
Throughput Tester	JDSU HST3000	**Bit Error Rate Tester**	JDSU HST3000
Internet Test Site	speedtest.charter.com		

5.5 Wireless Technology Link ATP Tests

5.5.1 Test Methodology

Tests will be completed by attaching a piece of test equipment to the base station, and then connecting a second piece of test equipment to the CPE. This will allow for an accurate and isolated test of the technology link.

5.5.2 Test Locations



CPE Test Locations Selected			
Location	**Latitude**	**Longitude**	**Approximate Distance from BaseStation**
Parking Lot	19°40'23.99"N	156° 0'16.37"W	.06mi
CPE Location 1	19°40’21.38”N	156° 0’24.49”W	.20mi
CPE Location 2	19°40’18.04”N	156° 0’43.38”W	.55mi
CPE Location 3	19°40’10.37”N	156° 1’13.14”W	1.12mi
CPE Location 4	19°40’ 27.83”N	155° 59’ 53.22”W	.38mi
CPE Location 5	19°40’ 24.09”N	156° 0’ 0.24”W	.24mi

5.5.3 900 MHz Technology Tests

5.5.3.1 List of Equipment Tested

All equipment for the test is listed below. Unit model numbers, serial numbers, and firmware version are documented in the respective tables. These tables detail the information regarding the major assemblies delivered.

900 MHz Radio Base Station Information		
Model Number	**Serial Number**	**Firmware Version**
NanoStation Rocket M900	6872510E60C0	XM v5.5.8

900 MHz Radio CPE Information			
Location	**Model Number**	**Serial Number**	**Firmware Version**
Parking Lot	NanoStation Loco M900	6872510EFFF8	XM v5.5.8
CPE Location 1	NanoStation Loco M900	6872510EFFF8	XM v5.5.8
CPE Location 2	NanoStation Loco M900	6872510EFFF8	XM v5.5.8
CPE Location 3	NanoStation Loco M900	6872510EFFF8	XM v5.5.8
CPE Location 4	NanoStation Loco M900	6872510EFFF8	XM v5.5.8
CPE Location 5	NanoStation Loco M900	6872510EFFF8	XM v5.5.8

5.5.3.2 RF Signal Level

The purpose of these tests is to verify the 900 MHz link’s RF characteristics. The Receive Signal Level (RSL) value and Signal Quality were recorded from the 900MHz GUI and supplemental data was taken by the Customer with a Spectrum Analyzer (SA), Anritsu MS2711D Portable Unit.

CPE Location	RSSI Value Off GUI	Supplemental RSSI Measured by Customer SA	LOS Type
Parking Lot[(1)]	-28db, -37db, -45db, -41db	-30db, -37db, -45db, -41db	Full
CPE Location 1	-45db	-45db	Near
CPE Location 2	-69db	NA[(2)]	Non
CPE Location 3	-52db	-45db	Full
CPE Location 4	-77db	NA[(2)]	Non
CPE Location 5	-34db	NA[(2)]	Full

[(1)] RSSI value updated per test scenario with power changes/modulation changes
[(2)] Did not do testing at these locations the 2nd day

5.5.3.3 RFC 2544 Test Results

Step 1: Connect the test equipment to the base station, and to the CPE.
Step 2: Run RFC 2544 test between the two pieces of test equipment.

CPE Location	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Avg. Jitter	Peak Latency
Parking Lot	2.98 Mbps	2.98 Mbps	5.54 ms	69.93 ms
CPE Location 1	2.04 Mbps	2.04 Mbps	6.36 ms	835.14 ms
CPE Location 2	1.01 Mbps	1.01 Mbps	15.01 ms	83.87 ms
CPE Location 3	3.02 Mbps	3.02 Mbps	4.6 ms	141.55 ms
CPE Location 4	NA(1)	NA(1)	NA(1)	NA(1)
CPE Location 5	4.84 Mbps	4.84 Mbps	4.46 ms	1320.39 ms

Note: All test results were recorded using a 1518byte packet size
(1) Unable to maintain a stable enough connection at this location to complete test

5.5.4 Whitespace Technology Tests

5.5.4.1 List of Equipment Tested

All equipment for the test is listed below. Unit model numbers, serial numbers, and firmware version are documented in the respective tables. These tables detail the information regarding the major assemblies delivered.

Whitespace Base Station Information		
Model Number	**Serial Number**	**Firmware Version**
OPA-RC2-B5	58877513-f1ad-4186-b790-2fc514c1b6a4	Built on 15 Nov 2014 at 01:17

Whitespace CPE Information			
Location	**Model Number**	**Serial Number**	**Firmware Version**
Parking Lot	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17
CPE Location 1	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17
CPE Location 2	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17
CPE Location 3	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17
CPE Location 4	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17
CPE Location 5	OPA-RC2-CPE	f45d7c65-2c4f-4cc7-98e5-badf157a677f	Built on 15 Nov 2014 at 01:17

5.5.4.2 RF Signal Level

The purpose of these tests is to verify the TV Whitespace link's RF characteristics. The RSL value and Signal Quality were recorded from the TV Whitespace GUI.

CPE Location	RSSI Value Off GUI	Line of Sight (LOS) Type
Parking Lot	NA(1)	Full
CPE Location 1	NA(1)	Near
CPE Location 2	NA(1)	Non
CPE Location 3	NA(1)	Full
CPE Location 4	NA(1)	Non
CPE Location 5	NA(1)	Full

(1)Unable to log into the CPEs to view the Receive Signal Strength Indicator (RSSI) value during testing.

5.5.4.3 RFC 2544 Test Results

Step 1: Connect the test equipment to the base station, and to the CPE.
Step 2: Run RFC 2544 test between the two pieces of test equipment.

CPE Location	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Jitter	Latency
CPE Location 1	NA[1]	NA[1]	NA[1]	NA[1]
CPE Location 2	NA[1]	NA[1]	NA[1]	NA[1]
CPE Location 3	NA[1]	NA[1]	NA[1]	NA[1]
CPE Location 4	NA[1]	NA[1]	NA[1]	NA[1]
CPE Location 5	NA[1]	NA[1]	NA[1]	NA[1]

[1] Unable to perform RFC 2544 tests since the multicast messaging required by the JDSU test sets was unable to pass through the RF link on the Carlson Wireless equipment.

5.6 End User Experience Testing

All tests were performed using speedtest.charter.com.

Note that for all tests, only one location, with only one CPE, is communicating to the base station at a time.

Iperf is a test application that measures downlink throughput of the link between a laptop connected to the Access Point Radio and a laptop connected to the CPE (CPE).

For the TVWS equipment, bandwidth is fixed at 6MHz and the modulation scheme for each CPE must be selected by the user.

For the 900 MHz equipment, bandwidth options ranged from 5 MHz to 20 MHz and the modulation scheme for each CPE can be selected by the user or set to “Auto”.

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
PC direct to Customer’s Internet feed at the Base Station Location	NA Day 1	1	6.55 Mbps	0.76 Mbps	90 ms	11 ms
		2	6.55 Mbps	0.79 Mbps	92 ms	11 ms
		3	6.55 Mbps	0.79 Mbps	90 ms	10 ms

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location -- Parking Lot (Full LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 2	1	4.47 Mbps	.77 Mbps	96 ms	16 ms
		2	4.53 Mbps	.80 Mbps	92 ms	29 ms
		Avg.	**4.50**	**0.79**	**94**	**23**
		Iperf	12.5 Mbps Downlink Throughput			
	900 MHz (Auto @ 20MHz bandwidth) Day 2	1	4.23 Mbps	0.79 Mbps	93 ms	4 ms
		2	4.86 Mbps	0.79 Mbps	91 ms	8 ms
		3	4.67 Mbps	0.77 Mbps	92 ms	5 ms
		Avg.	**4.59**	**0.78**	**92**	**6**
		Iperf	10 Mbps Downlink Throughput			
	900 MHz (16QAM @ 8MHz bandwidth) Day 2	1	5.93 Mbps	0.77 Mbps	98 ms	5 ms
		2	4.7 Mbps	0.82 Mbps	91 ms	5 ms
		3	6.19 Mbps	0.79 Mbps	92 ms	14 ms
		Avg.	**5.61**	**0.79**	**94**	**8**
		Iperf	6.8 Mbps Downlink Throughput			
	TVWS (16QAM @ 6MHz bandwidth) Day 2	1	5.12 Mbps	0.74 Mbps	200 ms	9 ms
		2	5.15 Mbps	0.75 Mbps	199 ms	17 ms
		3	4.16 Mbps	0.76 Mbps	199 ms	20 ms
		Avg.	**4.81**	**0.75**	**199**	**15**

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location 1 (Near-LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 1	1	4.04 Mbps	0.77 Mbps	107 ms	18 ms
		2	4.2 Mbps	0.78 Mbps	102 ms	32 ms
		3	4.32 Mbps	0.78 Mbps	102 ms	39 ms
		Avg.	**4.19**	**0.78**	**104**	**30**
	900 MHz (Auto @ 8MHz bandwidth) Day 2	1	4.29 Mbps	.78 Mbps	92 ms	9 ms
		2	5.61 Mbps	.70 Mbps	92 ms	7ms
		3	4.36 Mbps	.78 Mbps	95 ms	8ms
		Avg.	**4.75**	**.75**	**93**	**8**
	900 MHz (16QAM @ 8MHz bandwidth) Day 2	1	3.48 Mbps	.79 Mbps	93 ms	14 ms
		2	4.03 Mbps	.79 Mbps	96 ms	7 ms
		3	4.37 Mbps	.77 Mbps	93 ms	9 ms
		Avg.	**3.96**	**.78**	**94**	**10**
	TVWS (16QAM @ 6MHz bandwidth) Day 1	1	5.17 Mbps	0.77 Mbps	199 ms	7 ms
		2	3.86 Mbps	0.73 Mbps	199 ms	14 ms
		3	6.24 Mbps	0.75 Mbps	199 ms	14 ms
		Avg.	**5.09**	**0.75**	**199**	**12**
	TVWS (16QAM @ 6MHz bandwidth) Day 2	1	5.94 Mbps	0.77 Mbps	198 ms	6 ms
		2	6.23 Mbps	0.75 Mbps	198 ms	9 ms
		3	5.51 Mbps	0.77 Mbps	199 ms	7 ms
		Avg.	**5.89**	**0.76**	**198**	**7**

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location 2 (Non-LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 1	1	2.34 Mbps	0.78 Mbps	116 ms	14 ms
		2	2.59 Mbps	0.76 Mbps	102 ms	29 ms
		3	2.18 Mbps	0.79 Mbps	117 Ms	18 ms
		Avg.	**2.37**	**0.78**	**112**	**20**
	TVWS (16QAM1/2, 16QAM, QPSK @ 6MHz bandwidth) Days 1,2	1	NA*	NA*	NA*	NA*
		2	NA*	NA*	NA*	NA*
		3	NA*	NA*	NA*	NA*
		Avg.	**NA***	**NA***	**NA***	**NA***
	TVWS (BPSK1/2 @ 6MHz bandwidth) Day 1	1	0.78 Mbps	0.73 Mbps	200 ms	29 ms
		2	0.84 Mbps	0.68 Mbps	200 ms	18 ms
		3	0.8 Mbps	0.7 Mbps	223 ms	23 ms
		Avg.	**0.81**	**0.70**	**208**	**23**
	TVWS (BPSK @ 6MHz bandwidth) Day 2	1	1.59 Mbps	0.72 Mbps	200 ms	19 ms
		2	1.41 Mbps	0.74 Mbps	197 ms	20 ms
		3	1.62 Mbps	0.74 Mbps	198 ms	41 ms
		Avg.	**1.54**	**0.73**	**198**	**27**
	TVWS (QPSK1/2@ 6MHz bandwidth) Day 2	1	2.20 Mbps	0.75 Mbps	196 ms	9 ms
		2	2.19 Mbps	0.77 Mbps	198 ms	6 ms
		3	2.29 Mbps	0.76 Mbps	198 ms	6 ms
		Avg.	**2.23**	**0.76**	**197**	**7**

(*) – For these modulation settings, the TVWS CPE could not connect to the Internet via the Base Station.

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location 3 (Full LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 1	1	4.79 Mbps	0.77 Mbps	102 ms	32 ms
		2	4.52 Mbps	0.77 Mbps	96 ms	27 ms
		3	4.22 Mbps	0.77 Mbps	96 ms	20 ms
		Avg.	**4.51**	**0.77**	**98**	**26**
	900 MHz Auto @ 8MHz bandwidth) Day 2	1	5.37 Mbps	0.78 Mbps	95 ms	12 ms
		2	5.88 Mbps	0.76 Mbps	94 ms	16 ms
		3	4.57 Mbps	0.80 Mbps	92 ms	10 ms
		Avg.	**5.27**	**0.78**	**94**	**13**
		Iperf	4.0 Mbps Downlink Throughput			
	900 MHz (16QAM @ 8MHz bandwidth) Day 2	1	4.71 Mbps	0.79 Mbps	94 ms	16 ms
		2	5.29 Mbps	0.77 Mbps	101 ms	16 ms
		3	5.27 Mbps	0.76 Mbps	98 ms	11 ms
		Avg.	**5.09**	**0.77**	**98**	**14**
		Iperf	1.7 Mbps Downlink Throughput			
	TVWS (16QAM @ 6MHz bandwidth) Day 1	1	3.78 Mbps	0.74 Mbps	199 ms	24 ms
		2	2.91 Mbps	0.77 Mbps	199 ms	6 ms
		3	2.21 Mbps	0.73 Mbps	198 ms	did not measure
		Avg.	**2.97**	**0.75**	**198**	**15**
	TVWS (16QAM @ 6MHz bandwidth) Day 2	1	4.83 Mbps	0.77 Mbps	199 ms	4 ms
		2	5.07 Mbps	0.78 Mbps	200 ms	8 ms
		3	5.18 Mbps	0.76 Mbps	199 ms	17 ms
		Avg.	**5.03**	**0.77**	**199**	**9**

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location 4 (Non-LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 1	1	0.71 Mbps	0.69 Mbps	107 ms	did not measure
		2	0.82 Mbps	0.73 Mbps	112 ms	38 ms
		3	0.81 Mbps	0.73 Mbps	106 ms	26 ms
		Avg.	**0.78**	**0.72**	**108**	**32**
	TVWS (16QAM @ 6MHz bandwidth) Day 1	1	NA*	NA*	NA*	NA*
		2	NA*	NA*	NA*	NA*
		3	NA*	NA*	NA*	NA*
		Avg.	**NA***	**NA***	**NA***	**NA***
	TVWS (BPSK1/2 @ 6MHz bandwidth) Day 1	1	0.83 Mbps	0.73 Mbps	196 ms	24 ms
		2	0.82 Mbps	0.72 Mbps	199 ms	31 ms
		3	0.85 Mbps	0.73 Mbps	200 ms	19 ms
		Avg.	**0.83**	**0.73**	**198**	**25**
	TVWS (16QAM1/2 @ 6MHz bandwidth) Day 2	1	4.64 Mbps	0.76 Mbps	198 ms	1 ms
		2	4.62 Mbps	0.75 Mbps	198 ms	4 ms
		3	4.67 Mbps	0.71 Mbps	200 ms	22 ms
		Avg.	**4.64**	**0.74**	**199**	**9**
	TVWS (16QAM3/4 @ 6MHz bandwidth) Day 2	1	3.20 Mbps	0.72 Mbps	198 ms	17 ms
		2	1.83 Mbps	0.76 Mbps	198 ms	40 ms
		3	.63 Mbps	0.44 Mbps	199 ms	73 ms
		Avg.	**1.89**	**0.64**	**198**	**43**
	TVWS (QPSK @ 6MHz bandwidth) Day 2	1	4.63 Mbps	0.73 Mbps	199 ms	1 ms
		2	3.89 Mbps	0.74 Mbps	200 ms	17 ms
		3	3.87 Mbps	0.75 Mbps	199 ms	6 ms
		4	4.24 Mbps	0.76 Mbps	199 ms	1 ms
		Avg.	**4.16**	**0.75**	**199**	**6**

(*) – For these modulation settings, the TVWS CPE could not connect to the Internet via the Base Station.

CPE Location	Technology	Test #	Downlink Throughput (Mbps)	Uplink Throughput (Mbps)	Latency	Jitter
CPE Location 5 (Full LOS)	900 MHz (Auto @ 8MHz bandwidth) Day 1	1	5.84 Mbps	0.78 Mbps	94 ms	21 ms
		2	5.52 Mbps	0.71 Mbps	106 ms	13 ms
		3	5.49 Mbps	0.76 Mbps	101 ms	5 ms
		Avg.	**5.62**	**0.75**	**100**	**13**
	TVWS (16QAM @ 6MHz bandwidth) Day 1	1	3.4 Mbps	0.74 Mbps	198 ms	11 ms
		2	2.17 Mbps	0.76 Mbps	200 ms	1 ms
		3	1.74 Mbps	0.77 Mbps	198 ms	6 ms
		4	3.86 Mbps	0.76 Mbps	196 ms	15 ms
		5	3.33 Mbps	0.77 Mbps	200 ms	17 ms
		6	2.84 Mbps	0.77 Mbps	197 ms	6 ms
		7	4.47 Mbps	0.74 Mbps	200 ms	12 ms
		Avg.	**3.12**	**0.76**	**198**	**10**
	TVWS (16QAM @ 6MHz bandwidth) Day 2	1	6.43 Mbps	0.74 Mbps	199 ms	7 ms
		2	5.40 Mbps	0.75 Mbps	198 ms	1 ms
		3	6.07 Mbps	0.76 Mbps	200 ms	1 ms
		Avg.	**5.97**	**0.75**	**199**	**3**
	TVWS (16QAM1/2 @ 6MHz bandwidth) Day 2	1	4.67 Mbps	0.77 Mbps	198 ms	10 ms
		2	4.51 Mbps	0.78 Mbps	199 ms	12 ms
		3	4.67 Mbps	0.76 Mbps	199 ms	6 ms
		Avg.	**4.62**	**0.77**	**199**	**9**