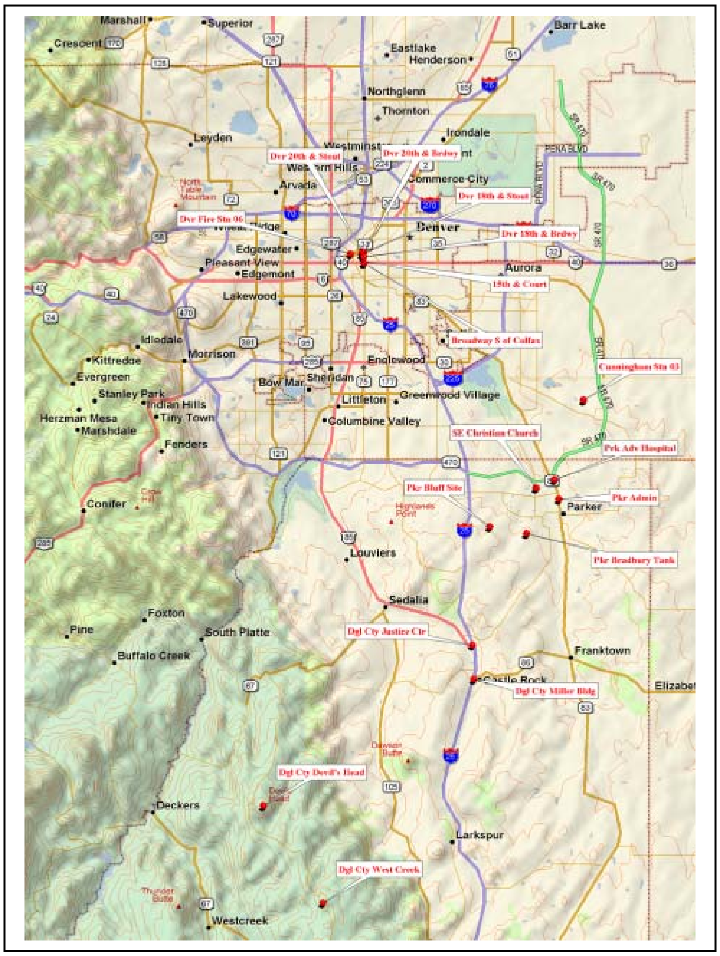
The Colorado 4.9 GHz Project

Studying the Deployment of 4.9 GHz Mobile Broadband

The 4.9 GHz Colorado Project



Date of Grant: October 1, 2004 through April 30, 2006

Funded by: National Telecommunications and Information Administration (NTIA)
Under a Technology Opportunities Program (TOP) Grant

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Abstract

The Colorado 4.9 GHz project is a federal grant which was funded by a TOP (Technology Opportunities Program) under NTIA (National Telecommunications and Information Administration. The grant period was October 1, 2004 through April 30, 2006.

The purpose of the grant was to study whether the 50 MHz of spectrum in the 4.9 GHz band which was allocated by FCC Docket 00-32[1] could be effectively used for mobile broadband applications by fire, police, and other emergency responders. The spectrum is licensed by jurisdiction, and is under the oversight of Regional Public Safety Planning Committees[2] .

The study evaluated the 4.9 GHz spectrum in mobile applications. Drive tests were done by KNS Communications in urban and suburban areas and in mountains, foothills, and plains. Proprietary drive test software[3] was used to collect data arriving at the mobile AP in the MIB[4] files. These measurements include a GPS time stamp and coordinates. Measurements were made at intervals varying from every 20 milliseconds to every second.

Bench level testing was done to confirm a number of parameters which were being used during the drive tests, including actual power out from the Access Points in dBm, measured antenna gains in dB, measured losses in dB, bandwidth versus throughput and relationships between "RSSI" which was collected from the MIB files and actual field strength in dBm. These bench tests were overseen by Pericle Communication's professional engineering staff. Algorithms to relate the "RSSI[5]" and dBm were developed and used in the post processing

The drive test data was analyzed to show actual coverage under various scenarios. This data is supported by photographs, satellite maps, coverage maps, scatter graphs of distance versus field strength and throughput, scatter graphs of distance versus path loss.

Application testing was done at the end of the study. The purpose of this testing was to

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[1] Federal Communications Commission. *Memorandum Opinion and Order and Third Report and Order*. (April 23, 2003). FCC 03-99, WT Docket 00-32. Washington DC.

[2] U.S. Government Printing Office. *Code of Federal Regulations (CFR). (2005). Title 47, Part 90, Private Land Mobile Radio Services*, §90.122.

[3] AP Survey Software, Owned by Pericle Communications.

[4] **M**anagement **I**nformation **B**ase, see chapter 1 page 1 footnote 6.

[5] "RSSI" readings in the MIB files did not equate to the standard definition for RSSI (receive signal strength indication).

determine if the equipment was capable of handling real-life applications such as video, large file transfers, internet access, fire-manager application access, etc. Measurements were also made to determine the effectiveness of meshing (ad hoc) between AP's, the costs in throughput and distance for each additional hop, and effects of antenna elevation on distances.

Additional studies by KNS were performed to evaluate the ability to predict coverage of a proposed system prior to installation. In order to make these predications, both the Longley Rice Engineering Model and the Bullington Engineering model[6] were evaluated. In addition, the effect of obstructions on propagation were evaluated. The NED dataset was used in all predictive modeling.

> "The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous US and 1:63,360-scale DEM data for Alaska. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NAVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10m) data covers the US, then this will also be a seamless dataset." [7]

These methods were refined to match actual drive tests as closely as possible, to provide end-users with resources to aid in system design.

The final goal of this study was to present emergency-responders with tools to help them evaluate their own individual situations, equipment capabilities, and vendor proposals so that they could determine what is needed to deploy a viable 4.9 GHZ system that meets their requirements. The study also presented recommendations for review by NTIA, the FCC, and regional planning groups for deployment of 4.9 GHz spectrum.

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6 TAP (Terrain Analysis Program) by SoftWright, LLC., Aurora Colorado

7 Retrieved July 3, 2006 from USGS web site, http://ned.usgs.gov/

Acknowledgements

Funded by: National Telecommunications and Information Administration (NTIA)
Under a Technology Opportunities Program (TOP) Grant
and by the Partners Listed below
Date of Grant: October 1, 2005 through April 30, 2006

Governmental partners:
Denver, City and County of – (In-kind, facilities for testing)
Douglas County Sheriff - (In-kind, facilities for testing)
Cunningham Fire Protection District - (In-kind, facilities for testing)
Parker Fire Protection District – Lead Agency - (Monetary, in-kind, facilities for testing)

Commercial partners:
Communications Systems, Inc. – (Services, in-kind)
KNS Communications Ltd. – (Testing, Report Preparation Services, in-kind)
Pericle Communications – (Professional Engineering Services, Independent Project Evaluation, Test Equipment, in-kind)
Proxim – (Equipment for testing, Engineering Services, Services)

Federal Support
Technology Opportunity Program – - (matching funds)
National Institute of Telecommunications Sciences (NITA) – technical and scientific support

The project was funded by a 50-50 match with the partners providing 50% of the funding and TOP providing the matching 50% of the funding. **Commercial Partners** included **Proxim Corporation, KNS Communications, Ltd., Pericle Communications, and Communications Systems, Inc.**

Proxim Corporation donated all the Access Points used in the study and who also provided significant engineering support.

KNS Communications Ltd. provided in kind donations of labor and also paid for some of the software development to help process the data. In addition, KNS designed each installation, performed all of the drive testing and data collection, post-processed the collected data, did gain and loss calculations for all of the tests, prepared maps showing radio coverage, and prepared the spreadsheets and graphs showing received signal versus distance and path loss versus distance. KNS also worked under Pericle's direction to complete the bench tests and field tests which measured both AP and antenna performance. L. Sue Scott-Thomas, President, authored this report.

Pericle Communications provided in-kind donation of labor, loan of test equipment, and developed the AP survey software and post-processing software. Pericle Communications wrote various tests which were necessary to determine and characterize the actual performance of the equipment used during testing. This included an analysis of the actual power out of the AP's, a confirmation of the gains of each antenna used, throughput tests of at various bandwidths, throughput tests during drive testing, and a detailed analysis of the "RSSI" measurement, and the subsequent development of algorithms to convert the RSSI to field strength readings (in dBm) both with and without BDA.s. Jay Jacobsmeyer, President of Pericle Communications Company, authored the independent engineering evaluation of the project.

Communications Systems, Inc. provided in-kind donations of hours and miscellaneous parts to the project. In addition, Communications Systems did all of the fixed antenna deployment, vehicle deployments, programming of the Access Points, software configuration for deployment testing, as well has handling any repairs or maintenance issues which arose during the testing.

Each public safety partner provided in-kind donations of time, oversight, and equipment to the project. **Parker Fire**, the lead agency provided monetary donations, in-kind donation of time, computer equipment, an IP camera, and IT support, and facilities for use during the testing. **Cunningham Fire** provided two laptop computers, an in-kind donation of time, and use of their facilities for use during testing. **The City and County of Denver** provided in-kind donation of time, and the use of their mobile command post for testing in downtown Denver, as well as other facilities for testing. **Douglas County** in-kind donation of time, laptops, and facilities for testing.

Additional equipment was donated to the project, or was provided for use by the project by several vendors. **Til-Tek** donated the sector antennas for use in testing. **Mobile-Mark** donated mobile antennas for use in testing. **mWave, LLC** provided a 4.9 MHz Microwave dish for use during testing. **RF Linx** provided mobile bidirectional amplifiers for use during testing. **Cerragon** provided a 4.9 MHz point to point pair of radios for use during testing

Additional fixed facilities for testing made available by **Parker Water and Sanitation District, Southeast Christian Church**, **Parker Adventist Hospital**.

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Terminology

This section is designed to introduce some of the terms, which will be used in this report.

Access Points - a wireless access point (WAP or AP) is a device that connects wireless communication devices together to form a wireless network.[1]

Ad-hoc (mesh) is a network where the client devices manage themselves - without the need for any access points. On wireless computer networks, ad-hoc mode is a method for wireless devices to directly communicate with each other. Operating in ad-hoc mode allows all wireless devices within range of each other to discover and communicate in peer-to-peer fashion without involving central access points (including those built in to broadband wireless routers)[2].

Performance suffers as the number of devices grows, and a large ad-hoc network quickly becomes difficult to manage. . Ad-hoc networks cannot bridge to wired LANs or to the Internet without installing a special-purpose gateway.

BDA (Bidirectional Amplifier) is a unit that goes in line between the Access Point and the Antenna and provides gain in both directions.

Binary Phase Shift Keying (BPSK) is the simplest modulation that uses the shift or change in phase for the modulation.

Bullington Engineering Model - The method of computing terrain attenuation is described in "Radio Propagation for Vehicular Communications", by Kenneth Bullington (IEEE Transactions on Vehicular Technology, vol. VT-26, no. 4, November 1977… (This method is used by the National Bureau of Standards for computing field strengths in the protected Table Mountain quiet zone near Boulder, Colorado. Extensive field strength measurements demonstrate the accuracy of the Bullington method.).[3]

dB The decibel (dB) is a measure of the ratio between two quantities

dBm is a power level expressed in dB above one milliwatt. For instance, 20 dBm = .1 watt, 30 dBm equals 1 watt, 33 dBm equals 2 watts, 36 dBm equals 4 watts, 39 dBm = 8 watts, 42 dBm = 16 watts, etc.

desense - Desense is a reduction in receiver sensitivity, which is caused by noise or RF that overloads the receiver front end. In other words, a signal other than the one we wish to receive is so strong that it overloads the receiver and makes the receiver relatively insensitive to the signal we wish to receive. The

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[1] http://en.wikipedia.org/wiki/Wireless_access_point. [Electronic Version] Retrieved August 14, 2006

[2] http://compnetworking.about.com/cs/wirelessfaqs/f/adhocwireless.htm. [Electronic Version] Retrieved August 14, 2006

[3] Softwright., LLC., http://www.softwright.com/faq/engineering/prop_bullington.html. [Electronic Version] Retrieved August 14, 2006.

result may be that we hear nothing; or, we may hear the desired signal at a reduced volume level; or, we could even hear an undesired signal[4]

downlink is the transmission of data from the portal or fixed unit to the mobile or subscriber unit.

Effective Radiated Isotropic Power (EIRP) In radio communication systems, Effective isotropically-radiated power (EIRP) or, actually, Equivalent isotropic radiated power is the amount of power that would have to be emitted by an isotropic antenna (that evenly distributes power in all directions and is a theoretical construct) to produce the peak power density observed in the direction of maximum antenna gain.

EIRP can take into account the losses in transmission line and connectors and includes the gain of the antenna. The EIRP is often stated in terms of decibels over a reference power level, that would be the power emitted by an isotropic radiator with an equivalent signal strength. The EIRP allows making comparisons between different emitters regardless of type, size or form.[5]

Fire Manager Application – data storage application for fire department

Field Strength - While field strength at any location is independent of antenna gain, received voltage at the receiver is not. . . There is also a great deal of confusion in the vocabulary for field strength (also called field intensity). Values are commonly expressed in dBu, dBµV, and dBm.
The widespread confusion about how they relate to one another causes both frustration and misunderstandings about system design and actual performance.[6]

dBu is E (electric field intensity) is always in decibels above one microvolt/meter (dBµV/m)

dBµV (using the Greek letter µ ["mu"] instead of u) is voltage expressed in dB above one microvolt into specific load impedance; in land mobile and broadcast, this is commonly 50 ohms.

dBm is a power level expressed in dB above one milliwatt

Free Space Path Loss [7] **–** Although **t**he atmosphere and terrain over which a radio beam travels have a modifying effect on the loss in a radio path, there is, for a given frequency and distance, a characteristic loss. This loss increases with both distance and frequency as is known as the free space loss…

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[4] ARRL Handbook, Published by the American Radio Relay League; http://users3.ev1.net/~medcalf/ztx/desense.html Electronic Version' Retrieved August 14, 2006

[5] Wikipedia. http://en.wikipedia.org/wiki/Eirp. [Electronic Version]. Retrieved August 14, 2006.
[6] Softwright, LLC. http://www.softwright.com/faq/engineering/FIELD%20INTENSITY%20UNITS.html .{Electronic Version] Retrieved August 14, 2006

[7] GTE Lenkurt, Incorporated. (1970) *Engineering Considerations for Microwave Communications Systems.* .. p. 34-35.

Gain - Gain may be expressed either as a power multiplier or in dB. Antenna gain stated in dB is referenced to either isotropic or a half-wave dipole. The microwave industry has universally established the convention of reporting antenna gain in dBi (referenced to isotropic).[8]

Longley Rice Engineering Model - The Longley-Rice model predicts long-term median transmission loss over irregular terrain relative to free-space transmission loss. The model was designed for frequencies between 20 MHz and 40 GHz and for path lengths between 1 km and 2000 km[9]

Mesh Mode[10] is unlike basic point-to-multipoint mode in that there is no separate downlink and uplink sub frames in the mesh mode. Each station (BS or SS) is able to create direct communications links to a number of other stations in the network instead of communicating only with the BS.

NPSTC – National Public Safety Telecommunications Council, www.npstc.org.

Quadrature Phase Shift Keying (QPSK) has four possible states or phases – 45°, 135°, 225°, and 315° Because there are four possible phases; QPSK is able to encode 2 bits per symbol[11]

Quadrature Amplitude Modulation (QAM) uses many different phases known as states: 16, 32, 64, and 256. Each state is defined by a specific amplitude and phase. This means the generation and detection of symbols is more complex than a simple phase or amplitude device. Each time the number of states per symbol is increased the total data and bandwidth increases. The modulation schemes shown occupy the same bandwidth (after filtering), but have varying efficiencies (in theory at least)".[12]

uplink – transmission of data from the mobile subscriber AP to the portal AP

MIB [1] MIB files are plain text files that map numbers (such as 1.3.6.1.4.1.11) used by SNMP queries into semi-readable names. Short for *Management Information Base,* this database of objects can be monitored by a network management system such as SNMP. The standardized MIB formats allowed the AP Survey software to monitor the Proxim AP's

NED dataset was used in all predictive modeling. "The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous [13]

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[8] Softwright, LLc. http://www.softwright.com/faq/engineering/FIELD%20INTENSITY%20UNITS.html. [Electronic Version, Retrieved August 14, 2006.

[9] Softwright, LLC, http://www.softwright.com/faq/engineering/prop_longley_rice.html, -[Electronic Version] Retrieved August 14, 2006.

[10] (http://www.ieee802.org/16/tg4/contrib/802164c-01_39.pdf. -[Electronic Version] Retrieved August 14, 2006.

[11] http://www.tech-faq.com [electronic version], retrieved August 10, 2006.

[12] http://www.blondertongue.com/QAM-Transmodulator/QAM_defined.php [Electronic Copy]. Retrieved August 10, 2006.

[13] Retrieved July 3, 2006 from USGS web site, http://ned.usgs.gov/

Multipath[14] wireless telecommunications, **multipath** is the propagation phenomenon that results in radio signals' reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings.

The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading, named after Lord Rayleigh. The standard statistical model of this gives a distribution known as the Rayleigh distribution.

NTIA (National Telecommunications and Information Administration

SNR - Signal-to-noise ratio[15] (often-abbreviated **SNR or S/N**) Signal-to-noise ratio is an engineering term for the power ratio between a signal (meaningful information) and the background noise.

Receiver Sensitivity - The sensitivity of a receiver is the minimum magnitude of input signal required for the access point to receive and decode incoming data. As the sensitivity increases, the ability to receive weaker signals also increases.

Rayleigh fading In electromagnetic wave propagation, phase-interference fading caused by multipath, and which may be approximated by the Rayleigh distribution.[16]

RSSI (Received Signal Strength Indication*)* is a measurement of the received radio signal strength (energy integral, not the quality).

Spanning-Tree Protocol[17] is a link management protocol that provides path redundancy while preventing undesirable loops in the network. For an Ethernet network to function properly, only one active path can exist between two stations. Multiple active paths between stations cause loops in the network

WDS, short for **Wireless Distribution System**, is a wireless LAN Bridge that refers to two or more 802.11 access points that send traffic between them (from access point to access point). The distinction between WDS and mesh routing is that WDS pre-configures each packet-forwarding path and the paths are static.

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[14] Wikipedia.http://en.wikipedia.org/wiki/Multipath [Electronic Version] Retrieved August 14, 2006

[15] Wikipedia. http://en.wikipedia.org/wiki/Signal-to-noise_ratio. [Electronic Version]. Retrieved August 14, 2006.

[16] http://www.its.bldrdoc.gov/fs-1037/dir-030/_4436.htm. [Electronic Version]. Retrieved August 14, 2006

[17] Cisco http://www.cisco.com/univercd/cc/td/doc/product/rtrmgmt/sw_ntman/cwsimain/cwsi2/cwsiug2/vlan2/stpapp.htm. [Electronic Version]. Retrieved August 14, 2006.

Chapter 1

Project Summary, Methods, and Report Interpretation

The first questions most people ask when they first hear about the 4.9 GHz broadband mobile frequencies is "How far will it propagate?", "Does mobile broadband really work?", "How many sites will it take?", or "Can large files be opened on transferred in route to an incident?".

The purpose of The 4.9 GHz Colorado Project was to answer some of these questions, and to provide the emergency-responder with the tools needed to evaluate system requirements and to make informed decisions about various equipment options and configurations needed for their departments and jurisdictions.

Summary and Overview of Project

The study looked at deployment of 4.9 GHz mobile broadband in a variety of environments and topographies, including mountainous sites {Chapter 3), Suburban Foothills (Chapter 4), Inner City Urban (Chapter 5), Dense inner City Urban (Chapter 6), Plains and Suburban (Chapter 7), and Plains and Foothills (Chapter 8). Detailed project summary information and guidelines for successfully system deployment is discussed in Chapter 9.

Deployment in the mountains was found to be suitable for hot-spot type deployment or ad-hoc deployment. Because of the height above the average terrain, the Devil's Head site was able to support hot spot deployments at distances over 2.5 miles. The West Creek Site, which had a lower elevation, and where the antennas were purposely deployed below tree level, had high throughput hot-spot coverage close to the site, but no coverage beyond .6 miles. One important observation was that the actual path loss was considerably less when the site was deployed so it looked down into the tree canopy rather than out into the tree canopy.

Deployment in the suburban foothills showed that a large footprint could be sustained when the AP's were deployed at advantageous locations on the top of buildings. Coverage was limited by obstructions such as trees and buildings.

Both **10 and 20 MHz Bandwidths** were compared in the suburban foothill deployment. While the 20 MHz bandwidth can sustain higher throughputs, which are almost double that of a 10 MHz bandwidth, the wider bandwidth caused a significant reduction in the coverage footprint. The 20 MHz bandwidth should be limited to local hot-spot coverage. For most deployments, the 10 MHz bandwidth should be chosen.

Deployment in the urban setting in downtown Denver was limited by the location of buildings and obstructions. Streets, which run toward the AP, tend to have good coverage. Locations, which are obstructed by buildings, have very limited coverage. Surprisingly, adjacent blocks near the deployment site also had coverage in spite of the obstructions.

Deployment in the dense urban setting in the central part of downtown Denver showed coverage, which was, at times, better than the calculated theoretical coverage. All Dense Urban deployments were made at lamppost height of 28 or 32 feet AGL (above ground level). It was thought that deployments in the center of the block would have less coverage than deployments at or near the intersections. However, this was not the case and some of the center-of-the-block deployments actually out-performed the other deployments near the intersections.

The dense urban setting is unique because it has buildings which are very close together and which often have flat reflective sides. The footprints were much larger than expected, and adjacent blocks coverage close to the site was 2 blocks, 3 blocks, or even more.

Successful deployments in this environment will require drive testing using software, which is capable of averaging thousands of readings per hour, so effects from multipath, Rayleigh fading, reflections, etc. are averaged out to give a reasonable prediction of the deployed coverage.

Deployment in the plains and suburban setting was in a typical middle class suburban neighborhood in a relatively flat area. The controlling factor is this type of deployment was the surrounding neighborhood, and the obstructions from housing and vegetation in the neighborhood. The maximum distance was slightly over ½ mile, and the coverage footprint closely followed the main streets that converged on the Fire Station where the fixed AP's were deployed. Throughout the course of the project testing it because apparent that ubiquitous deployments in neighborhoods would be very difficult and would require a high density of AP's.

Coverage in neighborhoods could be increased through ad-hoc deployments by raising an antenna on one of the vehicles so it could access to the nearest fixed AP, or through multiple vehicles to get to the fixed AP. Testing did indicate that at least one of the two antennas in a hop must be above 10 feet AGL, or the distance of the hop will be limited to distances of between .1 and .3 of a mile.

Deployment in the plains and foothills setting had much larger footprints than the coverage, which was seen in the plains and suburban setting. The foothills gave high vantage points for deployment of fixed AP's, and the topography was such that the AP's were positioned around the lower areas, and the four deployed AP's complimented each other and provided a large footprint of coverage which was 6.92 square miles with a mobile BDA and 3 square miles without a mobile BDA.

Deployments with BDA's (Bidirectional Amplifiers) were evaluated in several of the tests. The Denver Dense Urban testing had 6 side-by-side tests that were run concurrently from the same vehicle. One set of AP's has had BDA's on each end, the other set of AP's has had no BDA's at all. By using different antennas (an omni in the deployment with the BDA's, and sector antennas in the deployment without the BDA's), the EIRP (Effective Radiated Isotropic Power) for the two tests were kept within ½ dB of each other. This meant that the tests compared the effect of the BDA on the receiver sensitivity of the mobile, and excluded from consideration, the effects of increased power from the amplification of the BDA.

Bench testing had confirmed that the receiver sensitivity in the AP's was increased by 2 dB when a BDA was installed in the system. The approximate size of the footprints in the Dense Urban tests were compared, and the use of the BDA increased the coverage 200% to 400%.

The effect of the BDA was also checked in the Parker deployment – but in this deployment, the BDA was only in the mobile, and the same fixed equipment was used for both tests. Since the study was measuring down-link performance only, the up-link effects of the mobile BDA were not be measured. The test with the mobile BDA had a coverage footprint of 6.82 square miles, while the test without the mobile BDA had a coverage footprint of 3.00 square miles. The tests conclusively show that the effect of the BDA on the mobile receiver substantially increased coverage.

It is important to note that the tests measured the effects of the BDA on receiver sensitivity, not the effects of increasing the EIRP. The use of a BDA in the receiver increased the receiver sensitivity, which caused a dramatic increase in the size of the coverage footprint.

A decrease in EIRP dramatically reduced the coverage footprint. The footprint with a BDA area was 470 acres, while the footprint at 26 dBm was only 281 acres. Since the 26 dBm is the maximum allowable EIRP under the current regulations, it is hoped that the FCC will revisit the EIRP limitations for the loose-mask radio. The high cost proprietary tight-mask radio will greatly increase deployment costs. Studies by NPSTC, referred to earlier in this document conclusively showed that the small amount of adjacent channel interference created by 802.11 devices created a negligible loss in performance for public safety applications.

The application testing showed that the mobile AP's were able to transfer large files, view streaming video, and manage the Fire Manager Database. The 4.9 GHz mobile deployments were able to transfer large amounts of data in a seamless fashion.

The Ad-hoc (mesh) testing had some unexpected results. When in the ad-hoc or mesh mode, the AP's were able to transfer signals from one AP to the next in a serial fashion. Each hop resulted in an approximate 50% reduction in throughput, and the equipment limited the maximum number of hops to four. When there was clear line of sight between two AP's, the maximum hop distance was controlled by the height of the antennas above the ground. If one of the antennas was more than 10 feet above ground level, then the hop lengths from 2 to 4.7 miles were achieved. When both antennas were mounted on vehicle roofs, the hop lengths dropped from .1 to .3 miles!

The access points were able to determine link-cost, and would associate with the AP that provided the best link-cost. This association would change as the different mobile AP's moved and changed directions.

Networking issues during deployment must also be considered. Layer 3 routers were needed at the different fixed access points. During one of the tests there were several fixed AP's which were connected into the test network by the District's existing backhaul. The mobile AP's were able to associate with multiple fixed AP's, and because there were no layer 3 routers in place, the same signal from one AP entered the network from multiple locations, causing a spanning-tree issue which shut the entire system down.

It will be necessary to have the IT department to design the network topology carefully to avoid this type of problem.

Two Propagation Models, (Bullington and Longley-Rice), were used during the course of the testing. Unless the obstructions were entered into the system, the results were overly optimistic. The time required to enter obstruction files was excessive, and it was difficult to enter building sizes accurately, since the obstructions are represented by a radius around a point. Once the obstructions had been entered, the results were poor, because of the difficulty in accurately representing multiple obstructions.

Both propagation models were very useful in predicting coverage issues which result from topography (hills, valleys, etc)., and should be used to help define a maximum initial footprint. After the initial maximum footprint has been defined, on-site testing is critical to final system deployment. Because the units are mobile, static point-to-point testing does not give a realistic evaluation of system performance. It is essential that all testing be done with software capable of collecting a significant number of samples so that Rayleigh Fading, multipath, and Doppler Effect are averaged.

Methods used during Drive Testing

Extensive drive tests were performed in a number of different environments. In order to collect as much drive test data as possible, the mobile AP was configured as a portal. The amount of data contained in the MIB[1] files arriving at the portal was considerably more than the MIB files arriving at the subscriber unit, so most of the drive tests were done with the Portal AP in the mobile unit.

After the initial drive tests, the units were set in WDS[2] mode for testing purposes only. In mesh mode, the AP's have a built in hysteresis of about 6 dB to keep the access points from alternating "in and out" of coverage. During the testing, the hysteresis was approximately 6 dB. [Hysteresis means that, once the system connection is lost, it takes a signal, which is approximately 6 dB stronger than the weakest signal the AP can receive and decode, before the AP will reconnect to the system.] In the WDS mode, there is no hysteresis, so it was possible to measure the actual receive signal without the effects of the hysteresis. During an actual deployment, the mesh mode should be used. The WDS mode is designed for point-to-point use.

Samples were automatically logged by the AP Survey logging software[3]. The logging software takes thousands of samples during each drive test. The sampling rate was set in milliseconds, and ranged from 20 to 1000 milliseconds. This resulted in thousands of samples in a drive test of several hours. The RSSI value contained in the MIB file was constantly fluctuating because of factors, which affect mobile receivers; including delay spread, multipath, and Doppler Effect. Multiple samples were taken and averaged, to compensate for these natural fluctuations.

Format and Interpretation of Logged Data Files

The data files were logged by the AP Survey software into a log file in a comma-delimited format (.CSV). The header of each file, as shown in Figure 1 below, gives basic information collected from the AP's MIB files during the drive testing.

The "#@" which precede each line serve as a "remark" note to the post-processing software. This information tells us the name of the program and its version. The log file name was chosen to describe the date of the test, the test number, and a short description of the test.

---

[1] MIB files are plain text files that map the incomprehensible numbers (such as `1.3.6.1.4.1.11`) used by SNMP queries into semi-readable names. Short for ***M**anagement **I**nformation **B**ase,* this database of objects can be monitored by a network management system such as SNMP. The standardized MIB formats allowed the AP Survey software to monitor the Proxim AP's.

[2] WDS, short for **W**ireless **D**istribution **S**ystem, is a wireless LAN Bridge that refers to two or more 802.11 access points that send traffic between them (from access point to access point). The distinction between WDS and mesh routing is that WDS pre-configures each packet-forwarding path and the paths are static.

[3] AP Survey Software – proprietary logging software written for the project by Pericle Communications.

The access point is identified by model, version, build, and serial number. The test mode is identified (mode=station or mode=mesh), and the RSSI to DBM conversion table is identified. The final line gives the actual date and time the test began.

RSSI_DBM Table. The RSSI_DBM table is the conversion that the software used during the drive test to display estimated field strength in dBm.

Until the final drive tests, information had not been provided from the Atheros, the chipset manufacturer, to give an accurate determination of what their "RSSI" reading actually meant in relationship to field strength (given in dBm).

Extensive bench testing had to be performed in order to characterize what the "**RSSI**" actually was, and how it related to field strength. A detailed discussion of how these algorithms were obtained is contained in the independent engineering report submitted to NTIA on April 30, 2006.[4]

The raw RSSI values were retained in the original log files. After this algorithm was finally determined, all drive test logs were modified during the post-processing of the data to reflect the actual field strength in dBm.

```
#@PROGRAM=AP-4000 Survey
#@PROGRAM_VERSION=0.99
#@LOGFILE=C:\Documents and Settings\Administrator\My Documents\ShopTest\
                    Test\2006-02-03 - Test0105 - CmdPOmni.log
#@ACCESS_POINT=AP-4900M v3.1.0(1069)  SN-05UT48600238 v3.1.0
#@MODE=STATION
#@RSSI_DBM_TABLE=0,-95.6 10,-85.3 20,-75.1 30,-64.8 40,-54.5 50,-44.3 60,-34.0
                    70,-23.7 80,-13.5 90,-3.2 100,7.1
#@TIME=Feb 3, 2006 9:48:49 AM
```

After the header, the rows of data are collected. Figure 1.2 shows what each line of data looks like.

GPS. Every second a new GPS header is put in front of the collected data. The GPS data included is:

Fix Type	– 0, no fix; 1 fix
Latitude	– decimal degrees

[4] Jacobsmeyer, J. (2006). *Colorado 4.9 GHz Project.* p.20.

Longitude	– decimal degrees
Altitude	– meters
Number of Satellites	
HDOP	– Horizontal Dilution of Precision[5]
GPS Time	– given in seconds since midnight

The date is included in the header of the file and is taken from the computer date. Unfortunately, the "Data Rate" parameter always defaulted to 0, and has no valid data in the MIB files. There are additional parameters in the software that will be filled in when these values become available in the AP's MIB files. Throughout the course of the testing, additional MIB file information was added in subsequent software builds.

```
#@GPS=1,39.528983,-104.769300,1785.4,10,1.0,200218
39.528983,-104.769300,1785.4,0,00:20:a6:5d:9e:66,-91.5,-100.0,0, ,"00:20:a6:5d:9e:66",4,0,A,mesh,102,
3123,56,1528,0,48,724,221287,56502,480,61,584,0,0,10
```

For legibility – the line above is shown below with the appropriate headers:

#Latitude,	Longitude,	Altitude,	Channel,	MAC Address,	Signal(dBm),	Noise(dBm),	DataRate
39.528983,	-104.769300,	1785.	4,0,	00:20:a6:5d:9e:66,	-91.5,	-100.0,	0.0,

AP_Name,	Signal(RSSI),	Noise(RSSI),	Protocol,	StationType,	Age,
00:20:a6:5d:9e:66",	4,	0,	A,	mesh,	0

Figure 1.2 – AP Survey Software - Comma Delimited Readout with Explanation

RSSI. RSSI is generally defined as "a circuit to measure the strength of an incoming signal. The basic circuit is designed to pick RF signals and generate an output equivalent to the signal strength"[6]. The RSSI readings included in the AP's MIB file is not actually a receive signal value as it is generally understood, nor as just defined.

Early during the testing process, it was realized that the RSSI had characteristics more like SNR (Signal to Noise Ratio) rather than RSSI. Signal to Noise Ratio is defined as a signal "which in

---

[5] Horizontal Dilution of Precision is a measure of GPS receiver/satellite geometry. A low HDOP indicates better relative geometry and higher corresponding accuracy.

[6] Iyler, S. (2006). RSSI- Receive Signal Strength Indicator. Bird's Eye.net. [Electronic version] Retrieved May 20, 2006, from http://www.birds-eye.net/definition/r/rssi-receive_signal_strength_indicator.shtml

analog and digital communications . . . is a measure of signal strength relative to background noise. The ratio is usually measured in decibels (dB)”[7].

Jay Jacobsmeyer, P.E. explains the characterization of RSSI in the independent engineering evaluation for The Colorado Project., and shows that RSSI is, in fact signal plus noise-to-noise ratio.

$$\frac{(S+N_1)}{N_2},$$

> N_1 is the noise power measured during the sampling period when the signal is active
> N_2 is the noise power measured during a quiet period.[8]

During post-processing, these corrections were made to all of the data based upon the raw RSSI readings, which were obtained during the original drive test.

Figure 3 shows the output of the drive test software. As the driving was done the screen could be observed showing which AP's which were visible to the mobile unit, their MAC address, the protocol (A=802.11A), the approximate field strength in dBm, the RSSI, the mode (either mesh or station), and the age reading.

Age Reading. The AGE readings refer to the time since the last known good signal. Because the MIB files report the last known good signal, it was necessary during post processing to flag readings where the "age" was greater than 0. These readings were automatically defaulted to -115 dBm so that areas, which were driven but had no coverage would show up in the final coverage maps.

The "age" field proved to be invaluable in analyzing the data because it detected and recorded the time when a connection was lost. Figure 1 shows that thousands of samples were taken during each drive test.

AP Software Screen. The screen gives detailed information during the drive test. This enables the driver to understand what is happening during the testing, and increases understanding of the performance of the systems under test as the testing is being done. The size of the screen is purposely very large so the driver can easily see the screen during the drive testing.

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[7] Whatis.com. Networking Definitions [Electronic Version], retrieved May 20, 2006 from http://searchnetworking.techtarget.com/sDefinition/0,290660,sid7_gci213018,00.html

[8] Jacobsmeyer, J. (2006). *Colorado 4.9 GHz Project.* p.20

Access Point	- MAC addresses of AP is which the mobile AP is receiving
Protocol	- "A" under Protocol represents 802.11 A.
dBm	- Approximate field strength as determined from internal calibration table[9]
RSSI	- The raw data from the AP MIB file.
Type	- Mesh, station or WDS mode
Age	- Time since last known good signal from the AP on this line
STOP/START	- Used to start and stop software
Status	- RUNNING or OFF
Number of Samples	- The number of samples since the start button was pushed. This number resets each time the system is stopped.
Build	- AP Software Build is on the bottom of the screen.
Display Averaging	- Set in
Log File	- Name of the log file. Buttons allow setting the log file name, or viewing it.
GPS	- Coordinates are given. There is a green block if GPS is locked on.
AP Information	- Model, software version and build, serial number, AP version

[9] The calibration table was created by testing the original AP's which were received during testing. This value is modified during post processing to conform with algorithms developed during subsequent bench testing which re accurately characterize the RSSI to dBm conversion for the AP's under test.

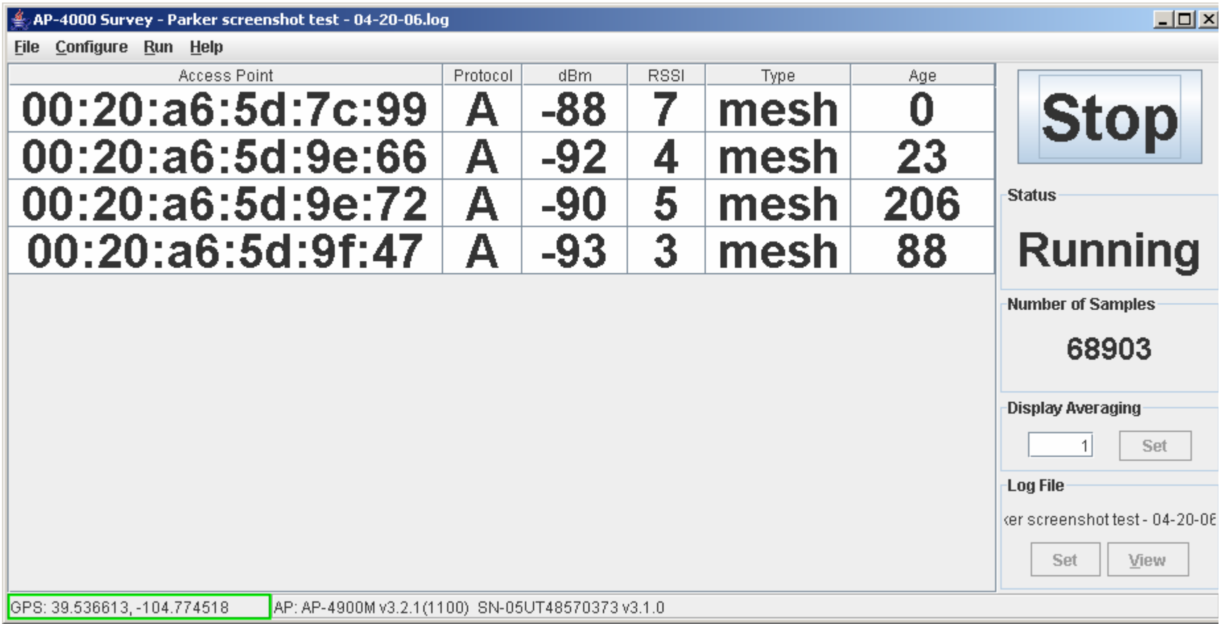

Figure 1.3 – AP Survey Software Screen

During post processing the samples were averaged every 30 meters (approximately 1° or approximately every 98 to 100 feet) so the results could be posted to a map. Detailed deployment information was maintained in field books, which were used to record all of the parameters for each test performed. This information was transferred to comma-delimited files. During the post-processing, all of this data was automatically added to the post-processed files and then transferred into gain/loss calculations for later analysis.

The distance from the transmitting AP must be accurate for the test results to have any validity. This distance was calculated in two different ways in order to provide a check for the accuracy of the data. The spherical earth algorithm[10] was built into the spreadsheet, which calculated the distance from the AP transmitter to each GPS reading. As a means of verification, the post processing software took the distance from the master AP and used Vincenty's algorithm for geometric distance and azimuth calculations[11]. This formula is slightly more accurate and takes into account the elliptical nature of the earth.

During post processing the two numbers were compared to make sure they were close in value. The post processing software calculated both vertical and horizontal distance from the AP.

[10] Pearson software Consulting, LLC., Latitude and Longitude in Excel. {Electronic Version} retrieved November 23, 2005 from http://www.cpearson.com/excel/latlong.htm.

[11] Martin, L. (2006, Feb. 2) Post Processing of AP Survey Data.

Surface Distance (ft)	Vertical Distance (ft)	Total Distance (ft)	Azimuth (deg from true north	GPS Time	Computer Time	Total Distance, Miles-Calculated by Software	RBD_DIST (Miles)	Master Latitude	Master Longitude
6087	-23	6087	0	192048	2/2/2006 15:59	1.15284091	0.00693191	39.75012780	-104.98882220
6087	-34	6088	0	192036	2/2/2006 15:59	1.15303030	0.00693191		

Figure 1.4 – Processed Data showing Distance Calculations

Compare the two distance columns and notice that the distances, as calculated are within .003 miles of each other. This was a cross check to make sure the distances which are used in the study were accurate and was well within an acceptable margin of error.

Calculations

Receiver Sensitivity Calculation

IEEE P 802.20™ PD-09 Version 1.0 discusses the theoretical receiver sensitivity. While the sensitivity is expected to vary from one technology to another, for the sake of comparison the sensitivity is compared for a raw data bit error rate (BER) of 0.1%. The receiver sensitivity (in dBm) shall be calculated using the following formula: [12]

Sensitivity = (-174.5 dBm) + NF (in dB) + 10 log (channel-BW in Hz) + C/N_{min} for 0.1%

In this study, calculations were done as follows: The noise figure [NF] or equivalent noise bandwidth was calculated by taking 10 Log_{10} the bandwidth in Hertz **plus** the measured composite noise figure for the Proxim AP'S [10 dB with a BDA, 8 Db without a BDA] **plus** the required S/N for the lowest bit rate. Table 1.1 shows the receiver sensitivity for the Proxim AP's under the different conditions used during the project testing.

Receiver Sensitivity in dBm		
Channel Bandwidth in MHz	**Without BDA**	**With BDA**
10	-92	-90
20	-89	-87

Table 1.1 Sensitivity and Bandwidth

[12] IEEE Working Group 802.20™. (2005). *IEEE P 802.20™. PD-09 Version 1.0* [Electronic Version], p. 40.

Maximum Path Loss Calculation

The maximum path loss is calculated by taking the EIRP, subtracting the free space path loss, adding the antenna gain of the receiver, and subtracting any losses in the receiver feed line. This gives the receive signal level. The receiver's sensitivity is then subtracted from this number, and the resulting number is the maximum path loss.

Excess Path Loss Margin or Fade Margin Calculation

The excess path loss margin (fade margin) can be determined in one of two ways. First, subtract the free space path loss from the maximum path loss to get excess path loss margin. Or, take the EIRP of the transmitter subtract the free space path loss, the antenna gain of the receiver, subtracted any losses in the antenna feedline, and subtract the receiver sensitivity to get excessive path loss margin or fade margin.

Maximum in Range Calculation

The maximum range in miles is calculated using the following formula, where MPL equals maximum path loss, and F equals frequency in MHz. The 300 represents the speed of light. [300,000 kilometers per second is divided by the frequency in kilohertz. Reducing this fraction to 300 over MHz results in the same result.] The fraction 5280/.3048 is a conversion from meters to feet.

Maximum Range in miles = 10^((MPL-21.98+20*LOG10(300/F))/20)/(5280/0.3048)

Free Space Path Loss Calculation

The free space path loss (FSPL) can be calculated buy one of two methods, the traditional GTE Lenkurt formula:

$$FSPL = 36.6 + 20\log_{10}F + 20\log_{10}D,$$

F in MHz
D in miles

It can also be calculated using the following formula, which is designed as a metric calculation, and has been converted to feet. Again, 300 represent the speed of light.

$$FSPL = 21.98 + 20*\mathrm{Log}_{10}(D*5280*0.3048/(300/F))$$

Table 1.2 illustrates how the calculations were done for each separate test installation. Formulas used in the spreadsheet were discussed above.

Power Levels and Performance

Various power levels were evaluated to determine how power levels affect propagation and throughput. Various bandwidths were also tested during the course of the drive testing. The 10 MHz bandwidth had an increased range over the 20 MHz bandwidth. The 20 MHz bandwidth has approximately twice the throughput of the 10 MHz bandwidth. The effects of a BDA (Bidirectional Amplifier) on receiver sensitivity were also studied

Test Radios – Proxim AP 4900

All testing was done with the Proxim AP4900 radios. Initial tests were done using beta test units, and final testing was done with production model units. The early beta units had a transmit power as low as 10.0 dBm. Production model units had a transmit power of 16.5 dBm. This power out was confirmed by bench testing done under the supervision of Pericle Communications.

Understanding the Link-Budget Calculations

Table 1.2 shows how the link budgets were calculated for each deployment. The EIRP is determined by adding the transmitter power out (in dBm) to the antenna gain, and then subtracting all the losses from the feedline, connectors, and lightning arrestors. If there is a BDA, the gain from that BDA is also added.

The receiver calculations show the theoretical path losses which were used in all of the graphs in the study.

.

Transmitter						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	1	10.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	1	(0.10)		dB
Coax - dB loss/100 ft	LMR-600 6	-0.066	6	(0.40)		dB
Antenna	Til-Tek 90 Sector TA-4904-14-90	NA	NA	14.90		dBi
			EIRP	**40.70**		**dBm**
Receiver						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**138.00**		**dB**
	Maximum Range Assuming Line of Sight			**23.83**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**18.00**		**dB**

Table 1.2 - Transmitter, Receiver, and Path Loss and Loss Margin Calculations

Regulatory Issues

The current FCC limitations for loose-mask products substantially limit coverage, and these FCC power limitations unnecessarily hamper performance. Studies by NPSTC show conclusively that the small amount of adjacent channel interference created by 802.11 devices creates a negligible loss in performance for public safety applications. **This study shows that the range of low power devices is severely limited. The public interest would best be served if the FCC relaxed its rules and allows 802.11 radios, with 'loose' emission mask, to operate at the higher power levels allowed today only for proprietary 'tight mask' radios.**[13]

If economies of scale are to be used to benefit the public safety agencies using these radios, it is imperative that the loose-mask radios be allowed higher power ranges. Failure to do this greatly increases the costs of these systems, and will prevent many agencies from deployment because of the costs. **The FCC is strongly encouraged to evaluate the data presented in this report and in the NPSTC study, and to relax current power restrictions and allow the use of high power in the loose mask radios**!

[13] Jacobsmeyer, J. (2006). *Colorado 4.9 GHz Project.* p. 2.

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Chapter 2
Coverage and Propagation

How to Interpret the Graphs in this Report:

In each of the drive tests, scatter graphs were plotted to show the results of the test. There were four (4) graphs printed with each drive test.

1) Graph 1 – Measured Receive Signal Level versus Distance
2) Graph 2 – Measured Receive Signal Level versus Distance, in a Log-Log format
3) Graph 3 – Measured Path Loss versus Distance
4) Graph 4 – Measured Path Loss versus Distance - in a Log-Log format

Each graph has a **red line** representing the theoretical calculated result using the free space path loss formula. The historic microwave engineering text by GTE Lenkurt gives an excellent description of free space loss and the associated calculations:

> "Although the atmosphere and terrain over which a radio beam travels have a modifying effect on the loss in a radio path, there is, for a given frequency and distance, a characteristic loss. This loss increases with both distance and frequency as is known as the free space loss…
>
> ….Free space loss is defined as the loss that would (be) obtained between two isotropic antennas in free space, where there are no ground influences or obstructions; in other words, where blocking, refraction, diffraction and absorption do not exist. An isotropic antenna is defined as one, which radiates or receives energy uniformly in all directions. Although such an antenna is physically unrealizable, it provides a convenient reference point for calculations…
>
> ….This relationship represents the loss between a point source and an antenna whose 'gain' in terms of A is equal to $\frac{4\pi A.}{\lambda^2}$ where λ is wavelength.
>
> ….By appropriate substitutions and converting d to miles and frequency in GHz as an inverse function of wavelength, the loss between the two isotropic antennas becomes:
>
> $$A = 96.6 + 20 \log_{10}F + 20 \log_{10}D$$
>
> where A = free space attenuation between isotropics, in dB
> F = Frequency in GHz
> D = path distance, in miles

…For very short distances . . . a distance equal to one wavelength the loss is 22 dB, and each time the distance is doubled, another 6 dB is added… This progression builds up rapidly and can be used in connection with near-end crosstalk calculations where the antennas are separated on the tower. The two loss formulas can be shown to produce identical results at a given distance."[1]

Graph 2.1 and Graph 2.2 are comparing Receive Signal Level at the input port to the mobile AP versus the distance in miles from fixed AP. The theoretical calculation was programmed into an Excel spreadsheet, and was calculated as follows:

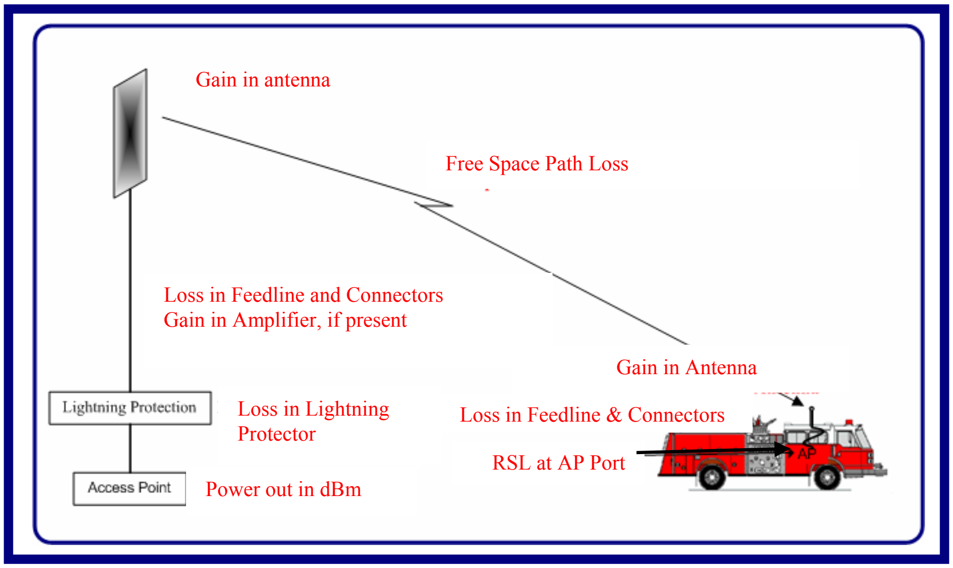


Figure 2.1 - Calculation of Theoretical Receive Signal Level In Mobile

\+ Transmitter Power out
\- Lightning Protection Loss
\- Connector and Feedline Loss
\- Amplifier Gain
\+ Antenna Gain

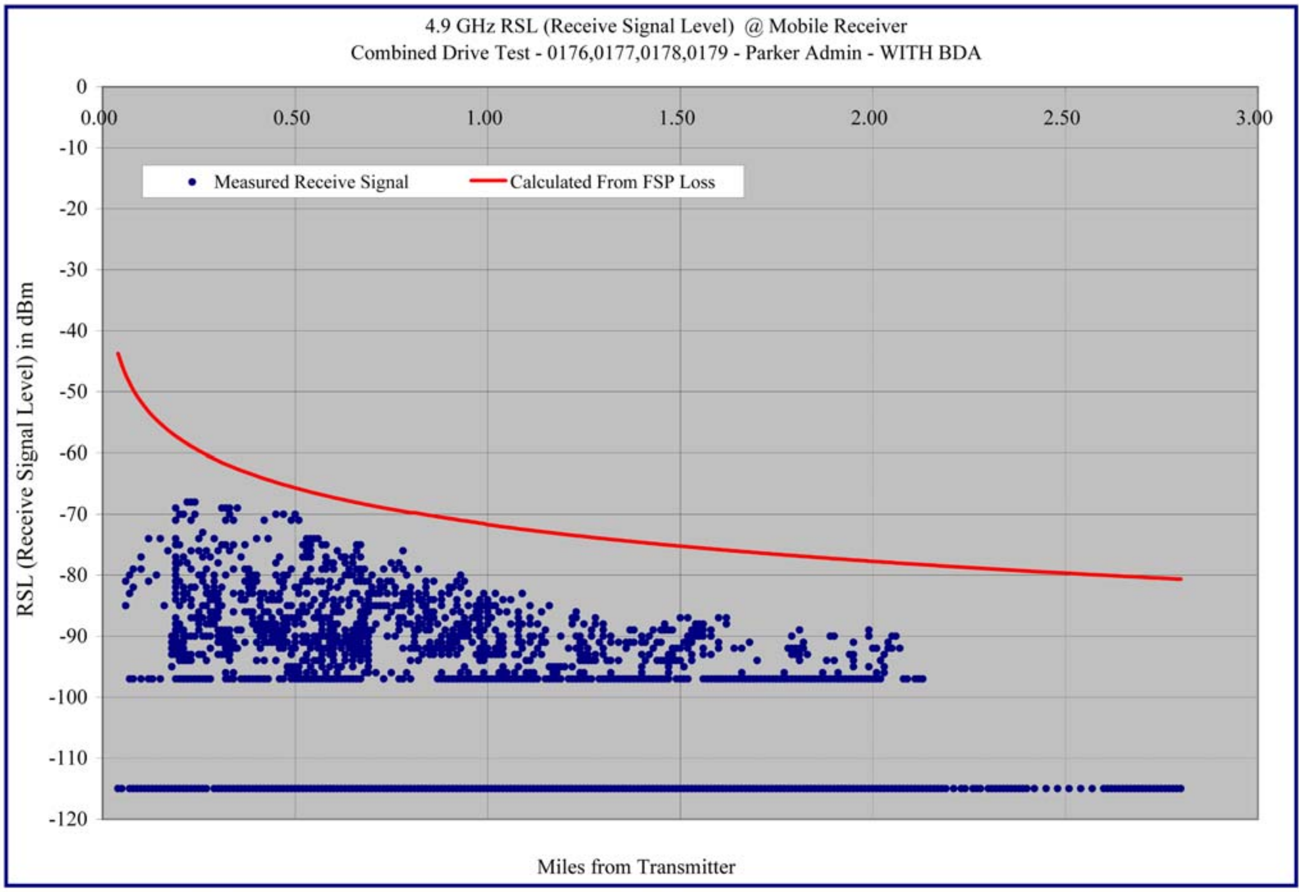
= EIRP – Effective Isotropic Radiated Power
\- Free Space Path Loss (Use formula for Isotropic Antennas)

= Receive Signal at Mobile Antenna
\+ Receiver Antenna Gain
\+ Amplifier RX Gain
\- Connector Loss
\- Feedline Loss
\- Lightning Protection Loss

=RSL – Receive Signal Level at the input to the AP

[1] GTE Lenkurt, Incorporated. (1970) *Engineering Considerations for Microwave Communications Systems.* .. p. 34-35.

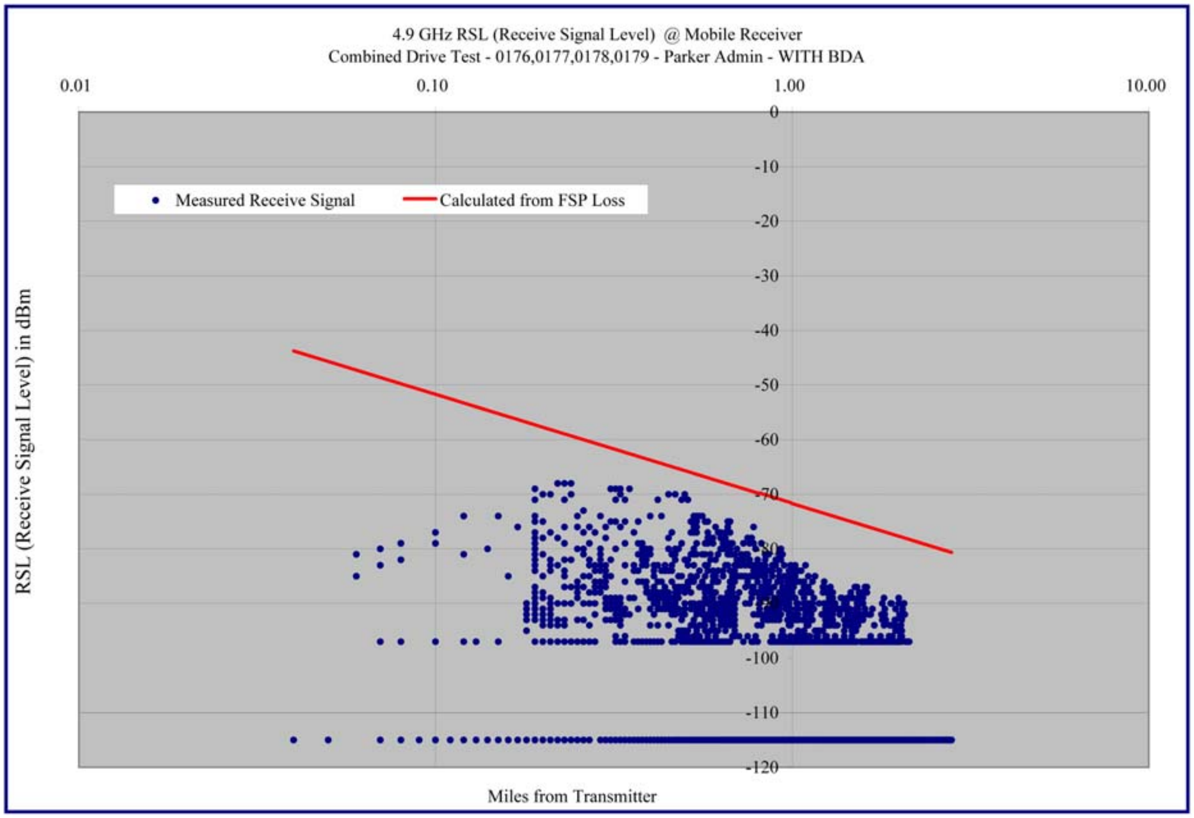
Even with obstructions and various path losses, results of the final drive test in Parker (Graph 2.1) show a pattern, which closely follows the theoretical prediction. The points at -115 dBm represent locations, which were driven and had no signal. The -115 dBm is a "default" that was plotted for "No Signal". There is also a line of points at -97 dBm. These points were connecting to the AP, but were not able to support usable throughput.



Graph 2.1 – Measured Receive Signal Level versus Distance

This same data is also presented in Graph 2.2 in a log-log format. The RSL is already in a log format, but the distances are not. The log-log format converts the distance to a log format, which will result in the red line appearing as a straight line.

The marked distances are all one "decade" apart. This means that each distance is 10 times that of the previous distance. For instance, .01 mile, .1 mile, 10 miles, etc. This presentation is a common format, which makes it easier to evaluate the data.

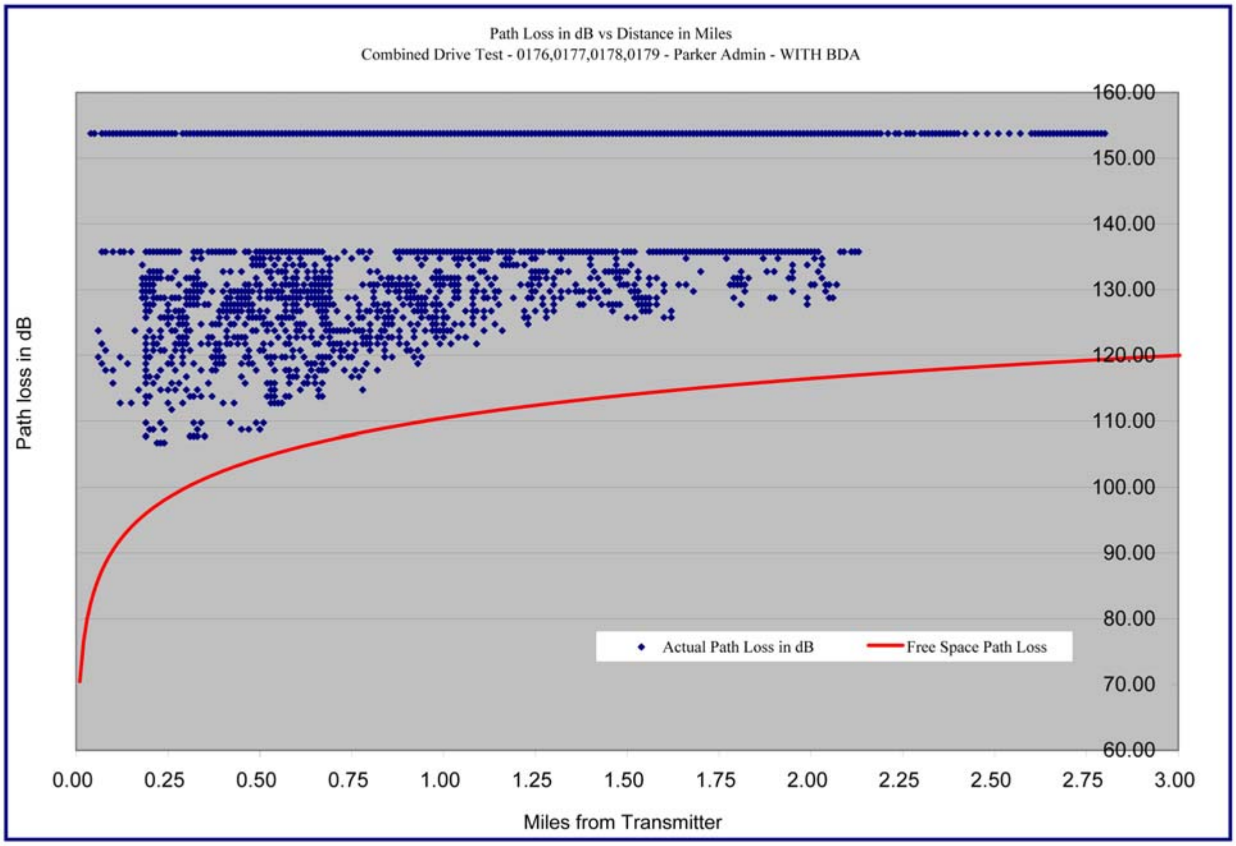


Graph 2.2 - Measured Receive Signal Level versus Distance – Log-Log Format

The last two graphs show the free space path loss versus distance. These graphs are equipment independent – meaning they reflect only the measured free space path loss. Power from the transmitter, antenna gains, and various loses from feedline, connectors, lightning arrestors, etc. are all ignored. These empirical results can be used to evaluate similar installations, and to help determine probable results for systems, which are being planned.

While it is still very <u>important to test and evaluate any proposed system before final installation</u> – these graphs, along with associated maps, will provide useful planning tools, and will assist the reader in estimating required AP densities, probably coverage, and preliminary costs for installations similar to the ones that were tested.

These graphs are also presented in two formats, the second format being a log-log format.

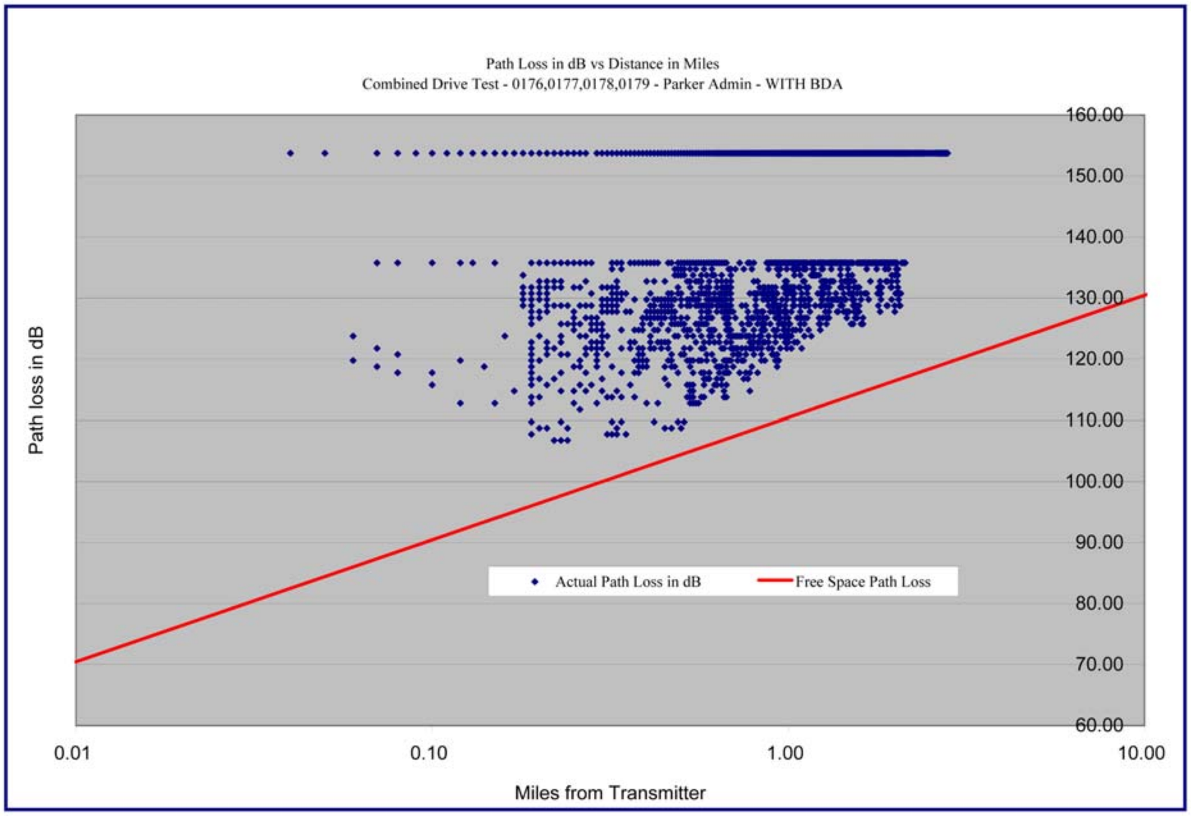


Graph 2.3 - Measured Free Space Path Loss versus Distance

The maximum loss shown, 154 dB, represent points which were driven, but which had no signal. This number was an arbitrary default so there would be an indication of points at each distance which were driven, but where there was no signal.

There was also a line of points at 137 dB of loss. These points were connecting to the AP, but were not able to support usable throughput.

It was encouraging to see that the plots follow show a predictable relationship to the theoretical predicted free space loss.



Graph 2.4 - Measured Free Space Path Loss Versus Distance – Log-Log Format

As a reminder, the maximum loss shown, 154 dB, represent points which were driven, but which had no signal. This number was an arbitrary default so there would be an indication of points at each distance which were driven, but where there was no signal.

There was also a line of points at 137 dB of loss. These points were connecting to the AP, but were not able to support usable throughput.

How to Interpret Maps in this report

The standard 802.11j has a table that describes modulation type, SNR, and data rate in Mbps. This chart was used in some of the preliminary testing to estimate expected throughput. Bench testing done under Pericle Communications' oversight, equated S/N on from Table 2.1 to field strength measurements in dBm. There was a 2 dB difference between measurements made from mobile units, which had BDA's and mobile units, which did not have BDA's. These differences were accounted for in all post processing of the drive test data.

In order to show coverage, certain field strength ranges were chosen for the maps that show the output of the drive tests. These ranges were not arbitrary, but rather match the recommendations in 802.11j for SNR's relationship to modulation. Table 2.1 shows the relationship between modulation types and required signal to noise ratio.[2]

Table 2.1 - IEEE 802.11j Rate Dependent Parameters (Required S/N Assumes Static Conditions)

Modulation	Coding Rate	Required S/N, dB	10 MHZ Channel Data Rate (Mbps)	20 MHZ Channel Data Rate (Mbps)
BPSK	1/2	4	3	6
BPSK	3/4	5	4.5	9
QPSK	1/2	7	6	12
QPSK	3/4	9	9	18
16-QAM	1/2	12	12	24
16-QAM	3/4	16	18	36
64-QAM	2/3	20	24	48
64-QAM	3/4	21	27	54

Table 2.1 – Relationship of Modulation Type to SNR and Data Rate

The actual throughput that may be experienced in the field will probably be less than the throughput shown by Table 2.1. For the presentations used in this report, the SNR was equated to a comparable field strength reading.

Although the BDA is specified with a 9 dB receiver gain, the improvement in receiver sensitivity is only 2 dB. The BDA has a 10 dB gain for the transmitter.

[2] LAN/MAN Standards Committee. 2004. 802.11j, Part 11, Amendment 7. IEEE Computer Society. pg. 8.

The map legends, which were developed from the bench testing, are shown below in Table 2.2 and Table 2.3.

Table 2.2 - Map Legend 1 – With BDA

With BDA			
	Mbps	**S/N**	**dBm**
Dark Blue	NO signal		-115
Light Blue	unusable	see comment	<-97
Turquoise	marginal	0-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

Table 2.3 - Map Legend 2 – Without BDA

Without BDA			
	Mbps	**S/N**	**dBm**
Dark Blue	NO signal		-115
Light Blue	unusable	see comment	<-95
Turquoise	marginal	0-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

The dark blue represents areas, which were actually driven, but there was no signal at all. The light blue represents areas where the mobile AP is able to connect to the fixed AP by RF, but no usable throughput was seen at these levels. The turquoise represents areas below the 802.11j standards for modulation (SNR < 3) but which had marginal throughput.

There are four types of modulation schemes used in the 802.11j standard. Modulation is a change that can be interpreted by the computer as either a 1 or a 0, so the data stream can be sent. The **Binary Phase Shift Keying (BPSK)** is the simplest modulation that uses the shift or change in phase for the modulation.

Quadrature Phase Shift Keying (QPSK) has four possible states or phases – 45°, 135°, 225°, and 315° . Because there are four possible phases, QPSK is able to encode 2 bits per symbol[3]

[3] http://www.tech-faq.com [electronic version], retrieved August 10, 2006.

"Quadrature Amplitude Modulation (QAM) uses many different phases known as states: 16, 32, 64, and 256. Each state is defined by a specific amplitude and phase. This means the generation and detection of symbols is more complex than a simple phase or amplitude device. Each time the number of states per symbol is increased the total data and bandwidth increases. The modulation schemes shown occupy the same bandwidth (after filtering), but have varying efficiencies (in theory at least)".[4]

QAM — Constellation Diagrams

Constellation diagrams are used to graphically represent the quality and distortion of a digital signal. [5]

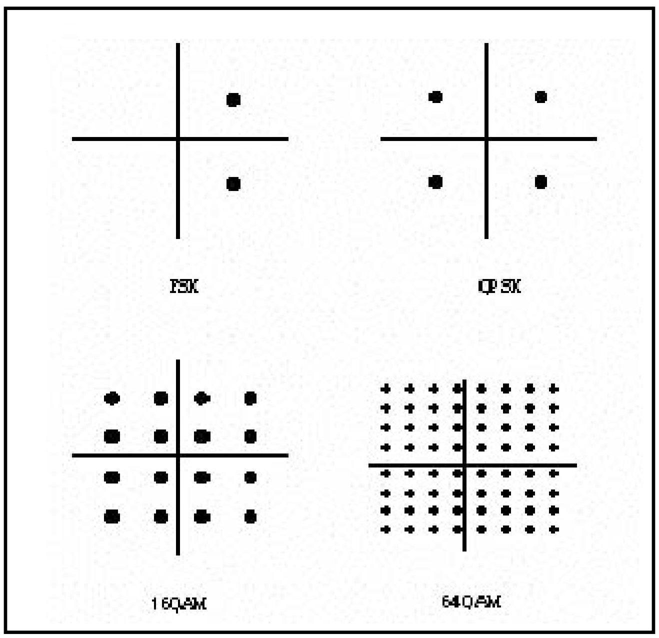


Figure 2.2– Schematic of Modulation Types

As the complexity of the modulation increases, the ability to transmit more data increases. The explanations in this report are overly simplified and are intended to give the reader an idea of how the modulation types differ.

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[4] http://www.blondertongue.com/QAM-Transmodulator/QAM_defined.php [Electronic Copy]. Retrieved August 10, 2006.
[5] http://www.blondertongue.com/QAM-Transmodulator/QAM_defined.php [Electronic Copy]. Retrieved August 10, 2006.

From the 802.11j standard (Table 1) and the Legends (Tables 2 and 3) the following colors represent the various modulations. The bench testing which was performed by this report associated different SNR values to the field strength values that were measured during the testing.

Red	BPSK	SNR 4 to 7
Orange	QPSK	SNR 7 to 12
Yellow	16-QAM	SNR 12-18
Green	64-QAM	SNR > 18

Table 2.4 - Modulation and SNR from 802.11j

Chapter 3
Coverage in the Mountains in Douglas County

The Colorado Rockies are very remote, densely forested, and rugged. They are mostly covered with evergreen conifers of various types in old growth areas and aspen tress in the new growth areas. Because most of the land being tested is United States Forest Service property, there are no populated areas in this study. Unlike the deciduous forests of the Midwestern and Eastern United States, the climate is very dry.

Hypotheses and Summary of Results

It was hoped that the dry climate might be conducive to propagation of 4.9 GHz signals to allow for "hot spot" coverage. No expectation was made for ubiquitous coverage under these conditions. The elevation of the study was 8000 to 9700 feet above sea level. It was felt that there would be better coverage from a higher vantage point where the AP looked down into the forest canopy, rather than from a lower vantage point where the AP looked out into the forest canopy.

While this hypothesis proved to be correct, the coverage looking down into the canopy was less than expected.

Summary of Tests Performed for Mountainous Coverage

Two studies were performed. Study 1 was from **Devil's Head Fire Lookout Tower,** the highest point for many miles around, and a point where the AP looked down into the canopy of the forest. Study 3 was from the **West Creek Communications Site**, a point where the AP looks out into the forest. The coverage from Devil's Head would provide various hotspots and locations up to three miles from the site at the minimum throughput. Coverage from West Creek, on the other hand, provided excellent high-throughput at the various hot spot, which were close to the site. Neither site was appropriate for point-to-multipoint operations. Limited ad hoc (mesh) coverage would also be possible through hot spots, which have coverage back to the fixed AP's at either the West Creek site or the Devil's Head site.

Study 1
Devil's Head Fire Lookout Tower
An evaluation looking down into the forest canopy

Tables 3.1 and 3.2 provide details of the Devils Head Fire Lookout Tower deployment. This site is characterized by its panoramic view of the surrounding mountains. It looks down into the forest canopy below.

Project Name	**The Colorado 4.9 GHz Project**					
Test Date	9/12/2005					
Study Area	**Devil's Head Lookout Tower**					
Test Description	Test 0012, 0013, 0014 0015					
MAC Address for Fixed AP	00:20:a6:49:85:b7					
Deployment Number	3					
Frequency	4950	MHz				
Sector Azimuth	multiple	Degrees				
Site 1						
Latitude	39° 15' 37.5 N					
Longitude	105° 06' 4.4" W					
Elevation	9748.0	Feet AMSL				
Elevation	5	Feet AGL				
Site 2	Mobile					

Table 3.1 – Devil's Head Site Parameters

The Devil's Head test was conducted with a Linx 4.9 GHz BDA in the mobile unit. Bench testing conducted under the supervision of Frank Pratte, P.E., of Pericle Communications, confirmed that it was an increase in the receiver sensitivitiy of the mobile by 2 dB. This increased the sensitivitiy of the mobile unit from -90 dBm to -92 dBm.

The increase in receiver sensitivity in the receive portion of the BDA results in an increase in the area of coverage for the entire system. The mobile BDA also has a 10 dB gain that increases the mobile EIRP from 22.8 dBm to 33.8 dBm. For a system to work well, the talk-out downlink must be balanced with the talkback uplink. When the EIRP on the uplink is close to the EIRP on the downlink, the system will have similar ranges in both directions, an extremely important design parameter! Table 3.2 shows a difference of only 1.67 dB.

Description	Fixed Transmitter Downlink	Mobile Receiver Uplink	Link EIRP Delta
Proxim AP4900 M	16.5	16.5	
Linx BDA	0	10	
Connector Loss	-0.2	0	
Coax - dB loss/100 ft	-0.07	-1.7	
Antenna	15.9	9	
EIRP	**32.13**	33.8	1.67

Table 3.2 – Uplink versus Downlink EIRP– Devil's Head

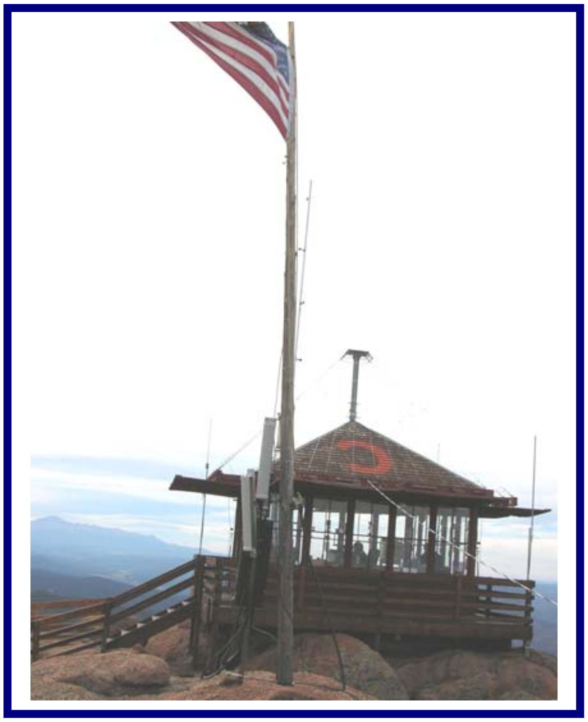
Transmitter Devil's Head	**No BDA** Description	Value in dB	Qty.	Gain/Loss	_	Units
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	0.00	1	0.00		dB
Connector Loss		-0.10	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.10	0	0.00		dB
Coax - dB loss/100 ft	LDF4-50A	-0.01	10	(0.07)		dB
Antenna	Proxim 60 ° Sector 5054-SA60-17	15.90	1	15.90		dBi
			EIRP	**32.13**		**dBm**
Mobile Receiver	**with BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0.00	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated [see C1, pg. 6]			(92.00)		dBm
	Maximum Path Loss			**131.43**		**dB**
	Maximum Range Assuming LOS			**11.17**		**miles**
Path Loss and Loss						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**11.42**		**dB**

Table 3.3 - Devil's Head Lookout Tower Deployment Details

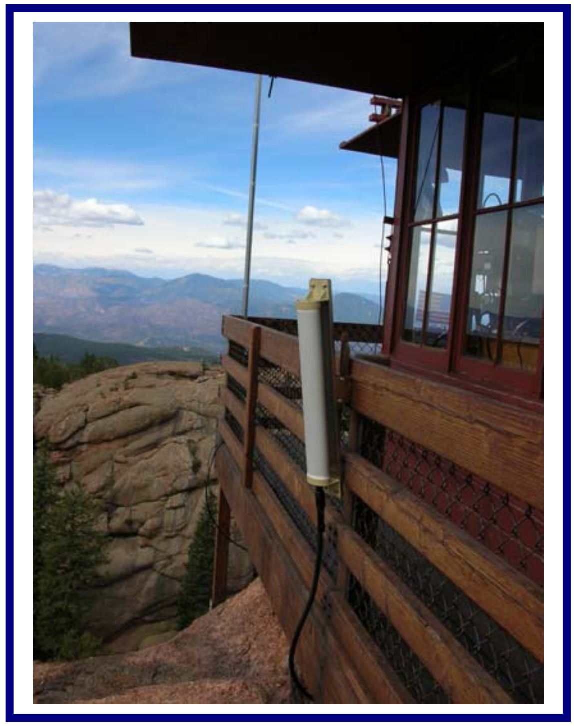
Fixed AP equipment was installed temporarily at Devil's Head Fire Lookout Tower, an elevation of 9748 MSL (above sea level), the highest point for many miles around overlooking the dense forest below.

Three AP's were installed with 60° Sector antennas which had a 3° downtilt to reach the road far below which varies in elevation from 8400 feet to 9000 feet. The vehicle had a mobile BDA. The EIRP was 32.13 dBm. "Hot spot" coverage was seen at points a far as 4.6 miles from the site, but most of the viable "hot spots" were within 2.5 miles.

As expected, looking "down" into the canopy had less loss than was seen in the second test at West Creek, where the AP's looked "out" into the forest. Path Losses from Devil's Head were 10 to 18 dB above the calculated theoretical losses, while losses from West Creek were 20 to 30 dB above the calculated theoretical losses.



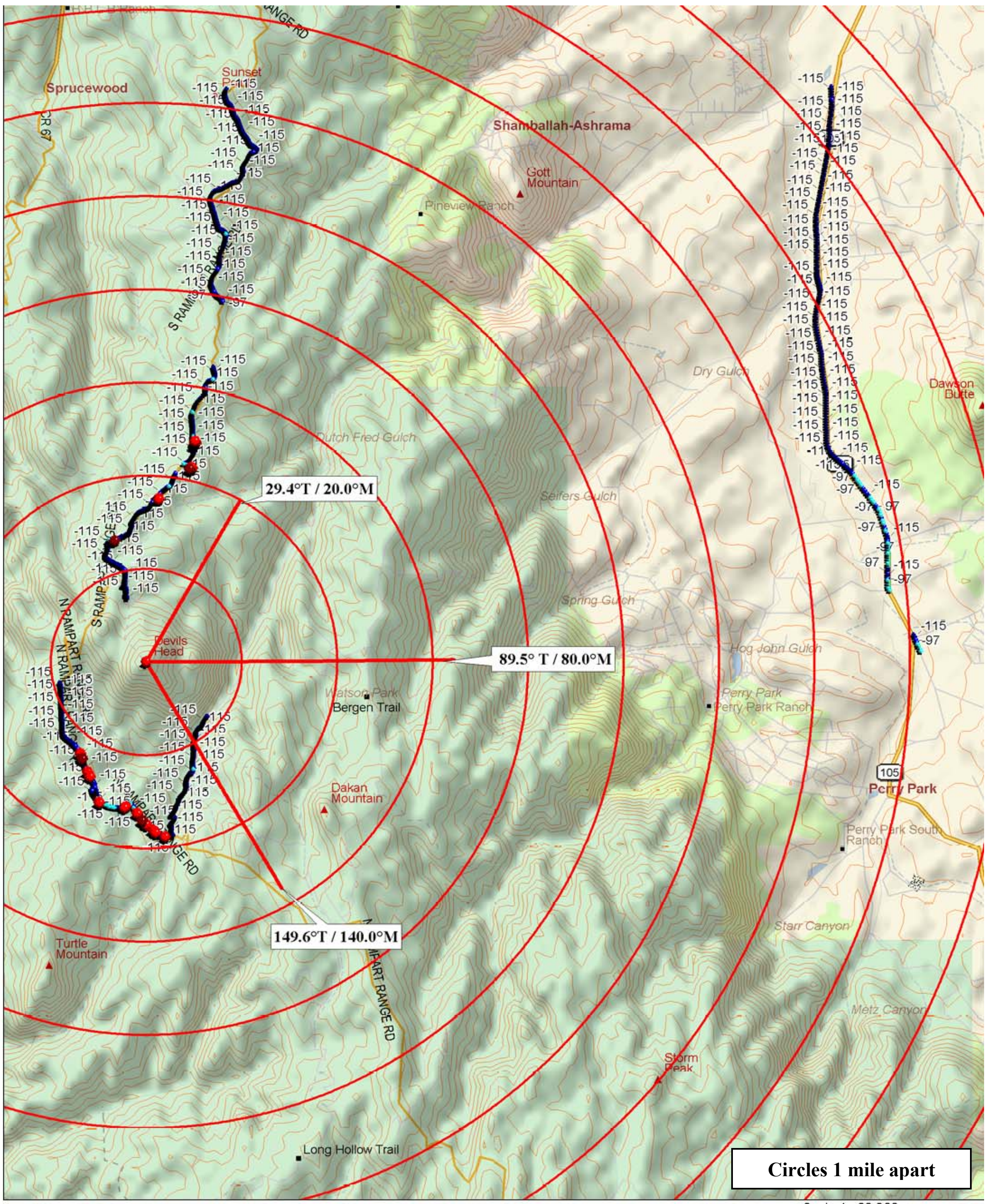
Picture 3.1 – Devil's Head Fire Lookout



Picture 3.2 – Devils Head Antenna Downtilt

Map 3.1 shows the areas that were driven, and areas where there was coverage. Table 3.3 shows the legend for the map.

- The dark blue dots show areas driven where there is no coverage.
- The light blue dots show areas where it is possible to connect to the fixed AP, but data could not be passed at all.
- The turquoise dots show areas where the SNR is less than 3, but minimal amounts of data could be passed. These areas are very marginal.
- The red dots show areas of BPSK modulation that have reliable data connections.
- The brown/orange dots show areas of QPSK modulation, and higher data throughput.
- There are no yellow or green dots on these maps.



Map 3.1 Devil's Head Coverage

Table 3.4 – Devil's Head Map Legend			
With BDA			
	Mbps	**S/N**	**dBm**
Dark Blue	NO signal		-115
Light Blue	unusable	see comment	<-97
Turquoise	marginal	0-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

The Mbps shown in the legend are nominal or optimal rates. Lower rates would be expected in actual deployments.

There was no coverage testing near the site because of the very rugged terrain and the "hike in" only access. All test equipment had to be hand carried to the site. .

Picture 3.3 – View from Devil's Head

Map 3.1 gives the overall test area from Devil's Head. Maps 3.2, 3.3, and 3.4, show more details of the same area.

The coverage studies from the Devil's Head Lookout Tower and West Creek Communications Site represent the most difficult of all the studied areas. It is obvious that dense forested areas will be challenging at the best, and suitable only for specific hotspot coverage.

Picture 3.3 clearly shows the dense forest which lies far below the lookout tower. It also shows areas where there are some clearings that can serve as hot spots.

If the EIRP of the Fixed AP (32.13 dBm) was dropped to 26 dBm, **in accordance with the current FCC loose mask guidelines, then the deployment would not work! The FCC limitations on the loose mask radio unnecessarily limit system deployments to very expensive proprietary radios.**

The stated purpose of this grant was to determine how to deploy 4.9 GHz effectively for emergency-responders. The effective deployment of these units is very much a cost issue. The area of this testing was within a few miles of the Hayman Fire which was the largest recorded fire in Colorado History. The fighting of this fire would have been much easier had broadband access been made available so emergency responders could have downloaded information (maps, video, etc.) which would have assisted in fighting the fire.

The study clearly demonstrated that the inexpensive loose-mask radio can accomplish this task by making hot-spot deployments feasible, but only if the FCC allows higher power in loose mask radios.

Evaluation of Coverage Maps

Detailed coverage maps follow. Testing was done at 32.23 dBm EIRP, 6 dB above the current FCC limitations of 26 dBm[1]. If the EIRP had been reduced to 26 dBm, then the system would not work in most places. The resulting decrease of 6 dB would result in average field strength readings of approximately -95 to -98 dBm, equivalent to an SNR (Signal to Noise Ratio), which is less than 4, the minimum required level in 802.11J for usable throughput.

Map 3.1 shows the entire test area. Map 3.3 shows the area to the north of the site. Each circle represents one mile from the transmitter site. There were several usable hot spots between one and three miles. All of these hot spots had line of sight to the transmitter. During the drive testing, it was noted that only line-of-site locations worked.

Backhaul: For this type of deployment, a point-to-point back-haul will be needed at the fixed AP location (Devil's Head) to the County's network in Castle Rock. Table 3.5 shows the link budget calculations using a low power radio and a high gain mWave microwave dishes with a BDA. The resulting EIRP is 52.23 dBm. The link budget demonstrates that the loose mask AP has the capability of providing a reliable link with more than adequate fade margin.

The problem is that the FCC's current regulations do not permit an EIRP above 26 dBm for the loose mask radio. If the EIRP were reduced to 26 dBm, this path would not work. The cost of deployment of a tight-mask AP link would be considerably higher than to deploy a loss-mask AP. The FCC is urged to reconsider the EIRP limitations, so this type of deployment can be affordable for emergency responders.

Figure 3.1 shows the path profile for the microwave backhaul from Devil's Head to Justice Center. This path is shown in Map 3.2. . The performance of line of sight microwave links is well documented, so even without testing the calculations show the link would perform well. The link has a fade margin of over 35 dB, the approximate minimum that most engineers require for a high-reliability microwave backhaul. This would be a viable path if sufficient EIRP were allowed by the FCC regulations.

[1] Jacobsmeyer, J. (2006). *Colorado 4.9 GHz Project.* P 9.

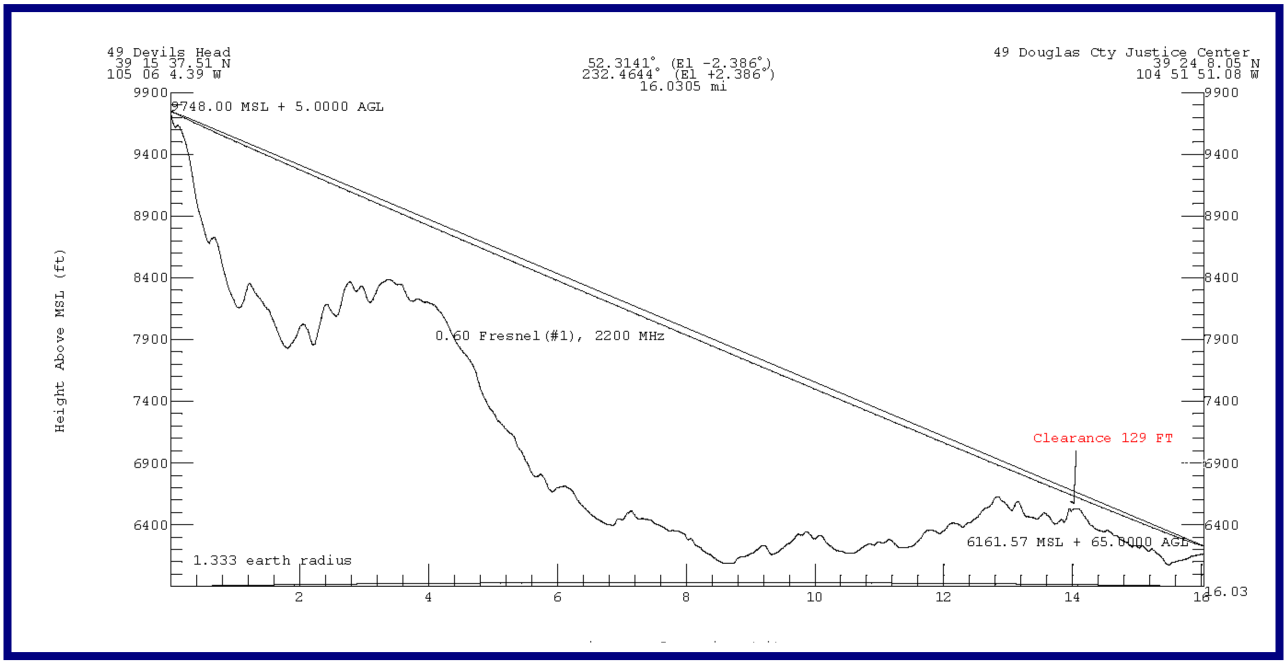
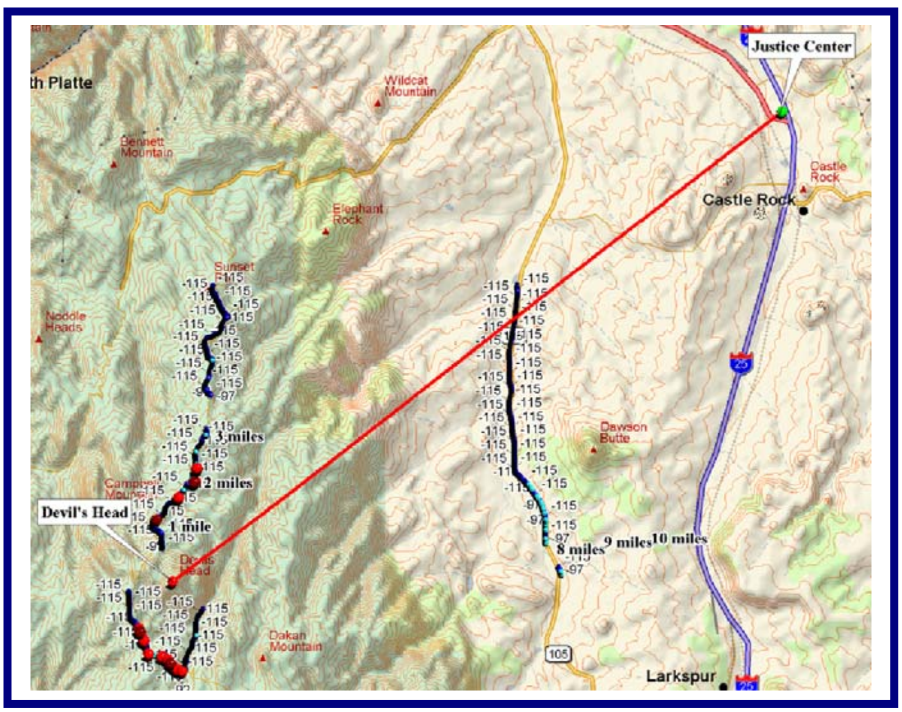


Figure 3.1 Microwave Path Profile from Devil's Head to Douglas County Justice Center



Map 3.2 – Proposed Point-to-Point 4.9 GHz Backhaul from Devil's Head to the Justice Center

Site 1	**Devil's Head Lookout Tower**					
Latitude	39° 15' 37.5 N					
Longitude	105° 06' 4.4" W					
Elevation	9748.0	Feet AMSL				
Elevation	5	Feet AGL				
Site 2	**Douglas County Justice Center**					
Latitude	39° 24' 8.05 N					
Longitude	105° 51' 51.08 W					
Elevation	6161.5	Feet AMSL				
Elevation	65'	Feet AGL				
Transmitter	**Description**	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10.00	1	10.00		dB
Connector Loss		-0.10	2	(0.20)		dB
Lightning Arrrestor	Polyphaser	-0.10	1	(0.10)		dB
Coax - dB loss/100 ft	LDF4-50A	-0.01	10	(0.07)		dB
Antenna	mWaveP2-54N	26.10	1	26.10		dBi
			EIRP	**52.23**		**dBm**
Receiver	**Description**	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna	mWaveP2-54N	26.10	1	26.10		dBi
Connector Loss		-0.10	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.10	1	(0.10)		dB
Coax - dB loss/100 ft	LDF4-50A	-0.01	50	(0.37)		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(92.00)		dBm
	Maximum Path Loss			**169.66**		**dB**
Path Loss and Loss Margin						
Path Length				16.02		miles
Free Space Path Loss	Calculated			134.56		dB
	Excess Path Loss Margin [Fade Margin]			**35.11**		**dB**

Table 3.5– Point to Point Backhaul from Devil's Head to Douglas County Justice Center

Ad-hoc and mesh deployment: Once the back-haul has been established, then the hot spot deployments can be implemented. Two possible ways of implementation are as follows:

(1) Install permanent point-to-point backhaul to Devil's Head, with a point-to-multipoint AP at the hot spot to talk to vehicles that are near the location.

- The advantage of this type of deployment is that the throughput is not reduced in the point-to-point backhaul hops.

(2) Use ad-hoc or mesh to connect from the hot spot to Devil's Head to one vehicle. That vehicle could be temporarily positioned at one of the hot spots, and other vehicles within sight of the vehicle could use meshing to talk back into the network.

- The advantage of this deployment is any of the hotspot locations could be used.

- The disadvantage of this deployment is that throughput is cut by 50% plus overhead for each mesh or ad-hoc hop.

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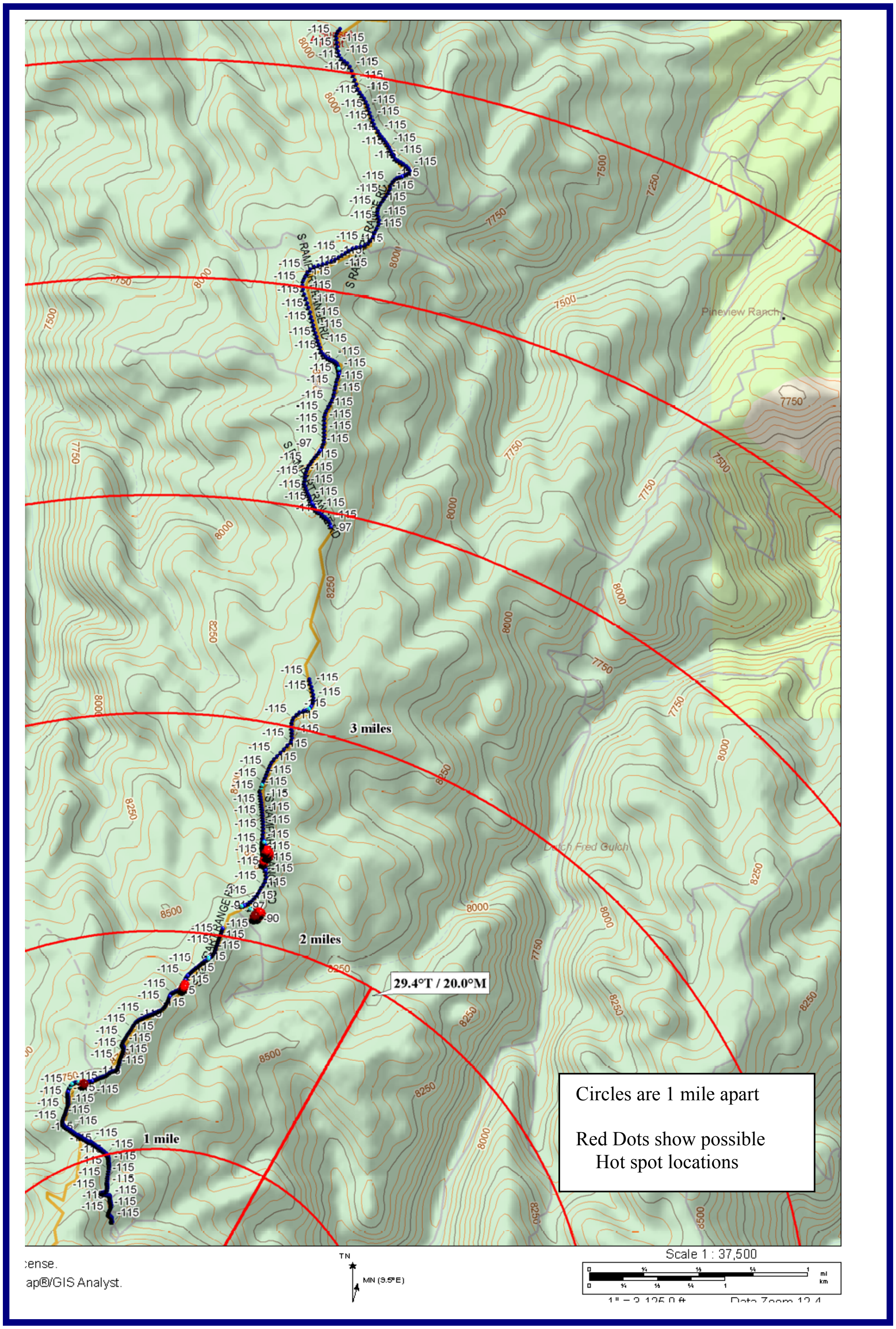
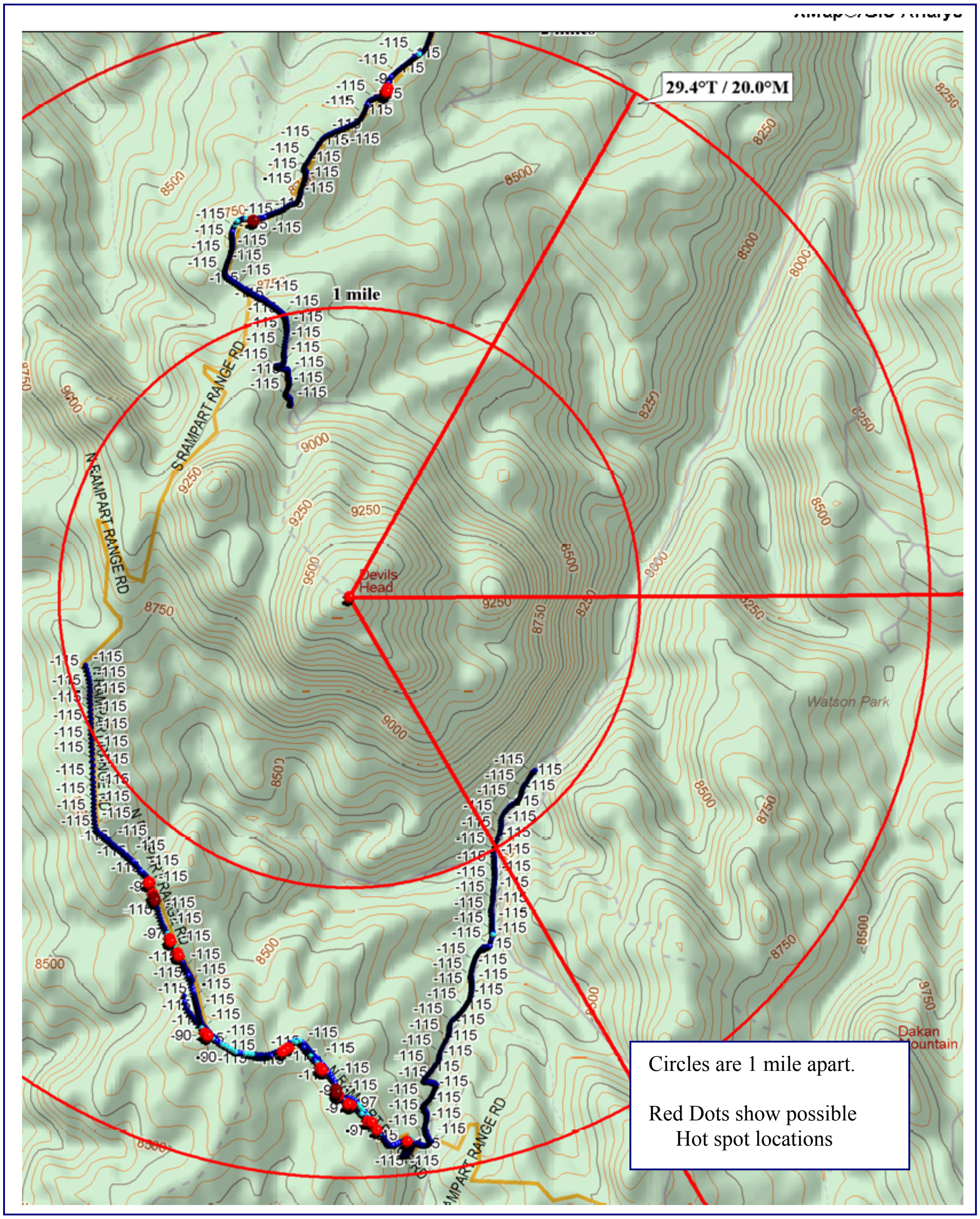
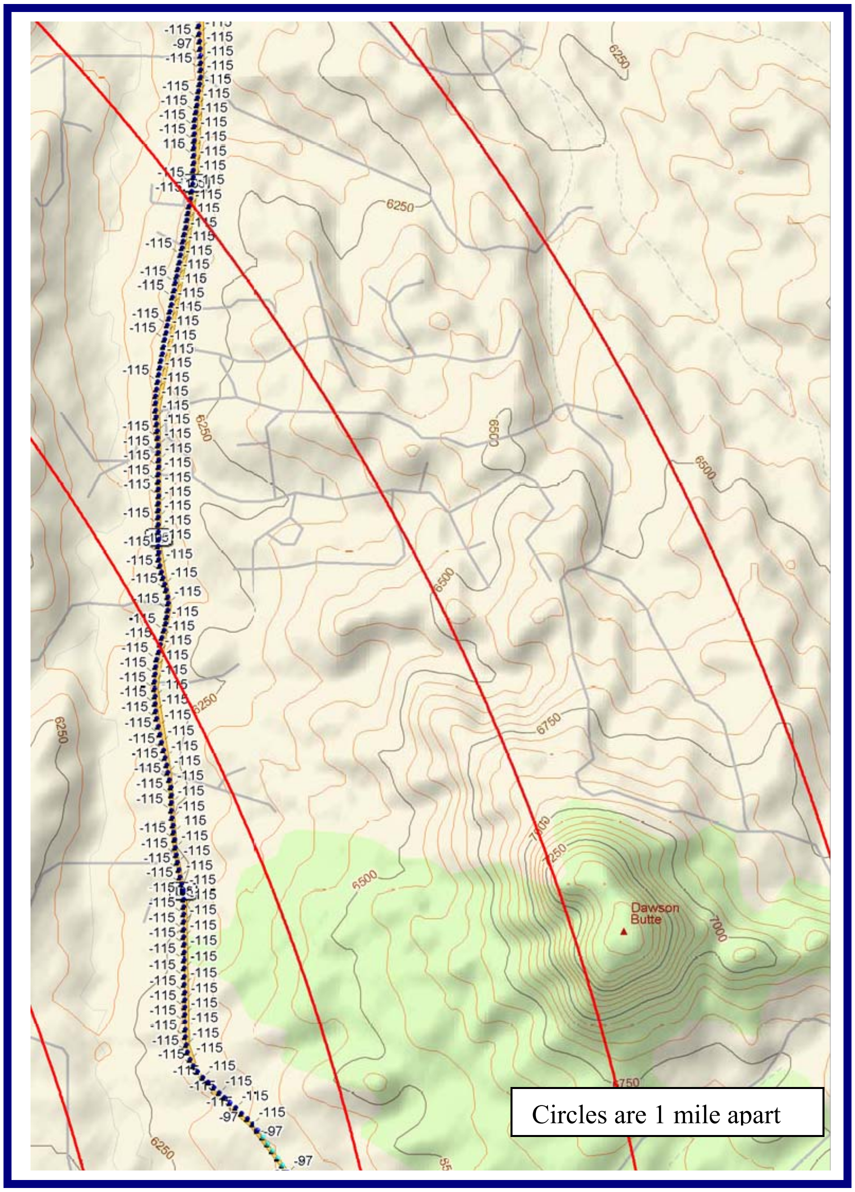


Map 3.3 – Coverage North from Devil's Head with Hot Spot Locations



Map 3.4 – Devil's Head – Hot Spot Locations near the Site

Map 3.4 shows that there are a number of available hot spots to the south of the site. The turquoise dots show areas of marginal coverage where the signal to noise ratio has less than that allowed for reliable throughput by 802.11j.

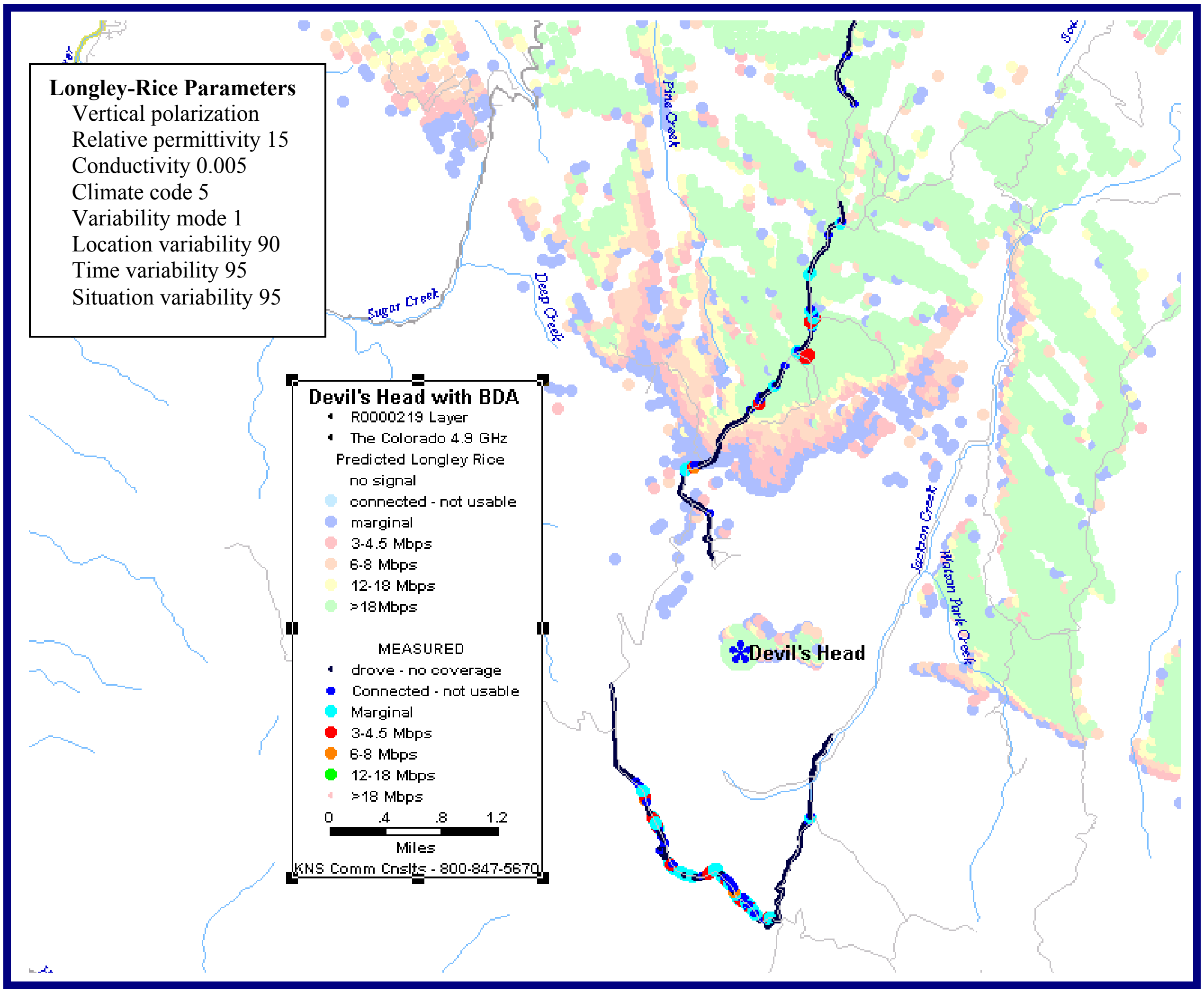


Map 3.5 - Coverage to the East of Devils Head

Map 3.5 shows areas seven to ten miles east of the site. There was no usable coverage at these locations. Although some of these areas are line of sight, the power is so low that the system was unable to associate at these distances.

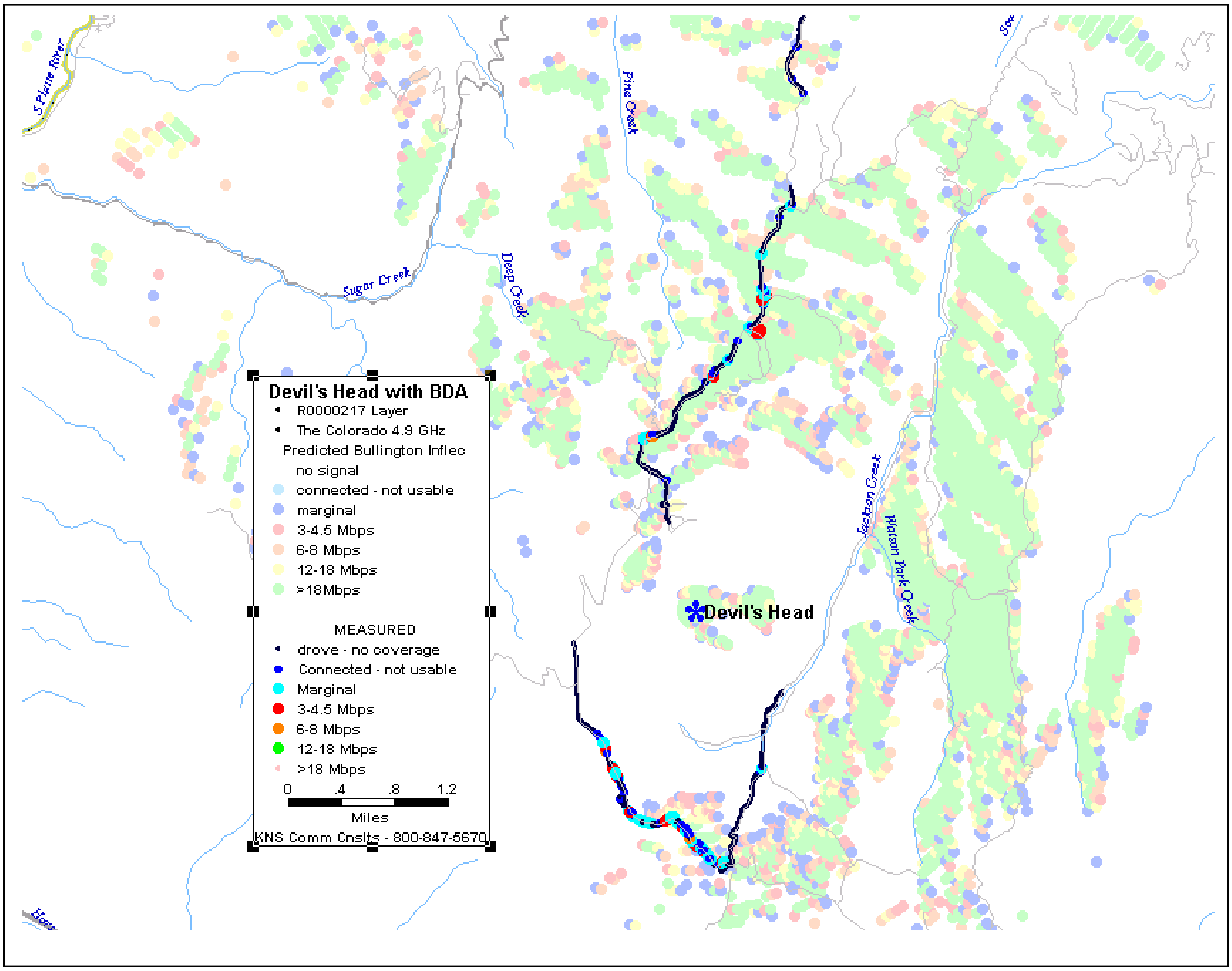
Predicted Coverage versus Actual Coverage

Throughout this study, an effort was made to determine whether any of the predictive modeling programs can be successfully used for 4.9 GHz deployments. The Longley-Rice and the Bullington models were used to evaluate this deployment. In both cases, 50-foot trees were used in the obstruction files and calculated into the evaluations.



Map 3.6 – Longley-Rice Predicted Area Coverage versus Actual Coverage

The Longley-Rice model is overly conservative in some areas and overly optimistic in other areas for this type of deployment.



Map 3.7 – Bullington Predicted Area Coverage versus Actual Coverage

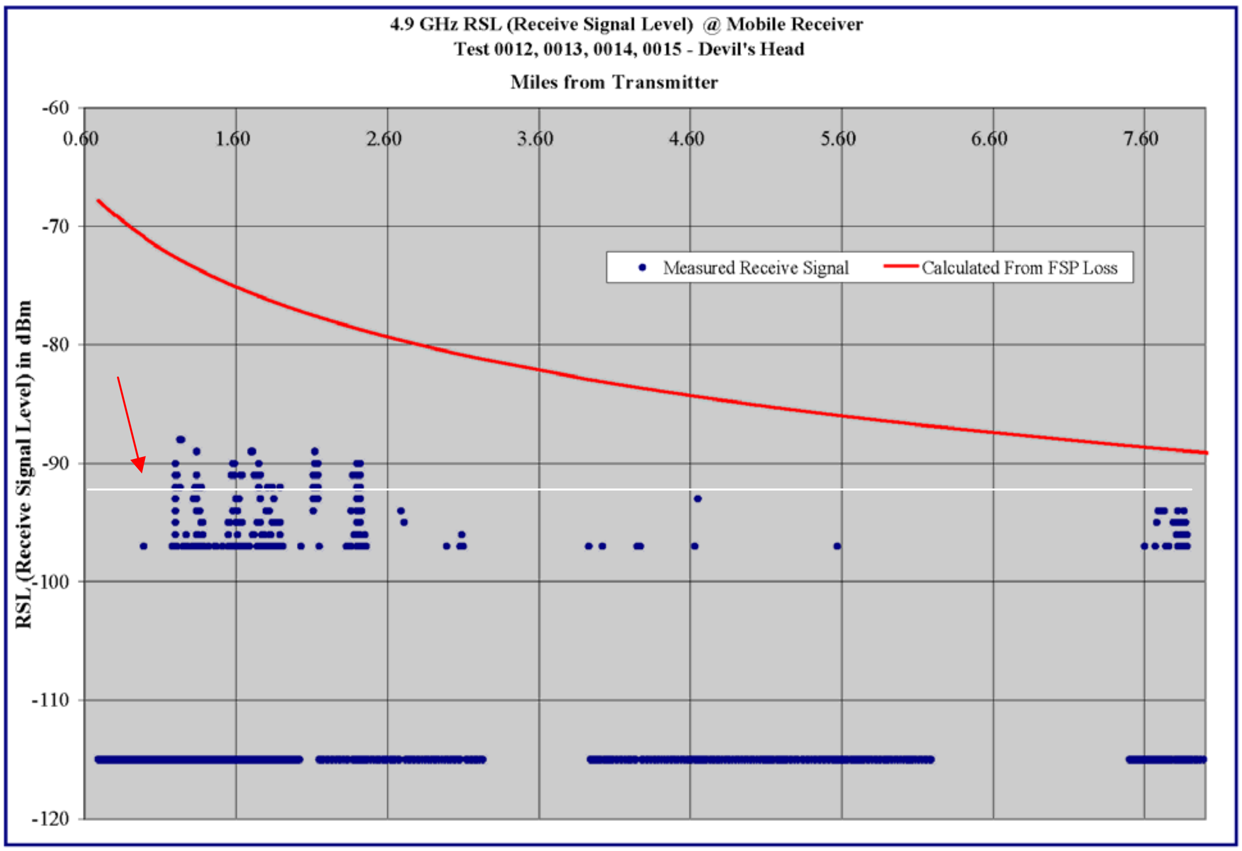
The Bullington Inflection model gives a better indication of potential coverage.

Neither of the two models was accurate in determining the final coverage – however, both models were useful in evaluating the effects of topography upon the maximum potential footprint for the site.

Evaluation of Graphs

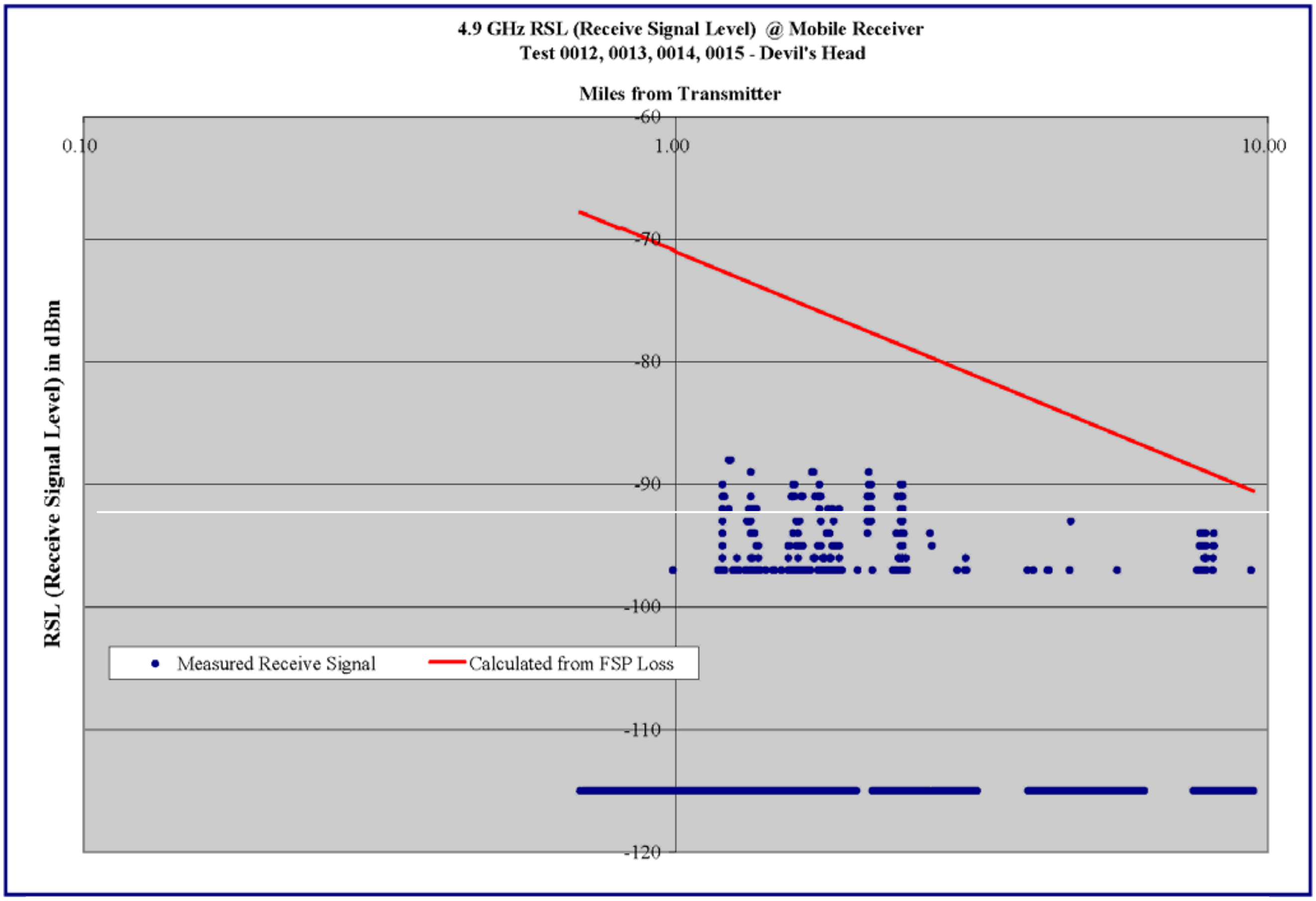
For each of the drive tests, two sets of graphs were prepared. The first set of graphs showed measured field strength versus distance. The second set of graphs showed measured path loss versus distance. In each set of graphs, the second graph showed the distance in a log format. The log-log format results in a straight line that was more easily evaluated.

Each of the four graphs also has a red line that showed the theoretical calculated result. In all cases this line was based upon the free space path loss formula that was discussed in detail in chapter one of this report.



Graphs 3.1 - Measured Receive Signal versus Distance – Devil's Head

Graphs 3.1 and 3.2 showed Measured Receive Signal Level versus Distance. For a mobile AP with a BDA, the nominal receiver sensitivity is -92 dBm. This means that for a reliable signal, there must be a level of at least -92 dBm [SNR= 4] where BPSK modulation begins to work according to 802.11j. This graph showed hot spots that are usable at -92 dBm or above. Signal strengths from -93 dBm to -96 dBm were passing some data, but this was below the 802.11j specifications for usable throughput. Usable throughput is where SNR>or equal to 4, which is a field strength of -93 dBm. The white line on the graph is -92 dBm, or where SNR equals 4.



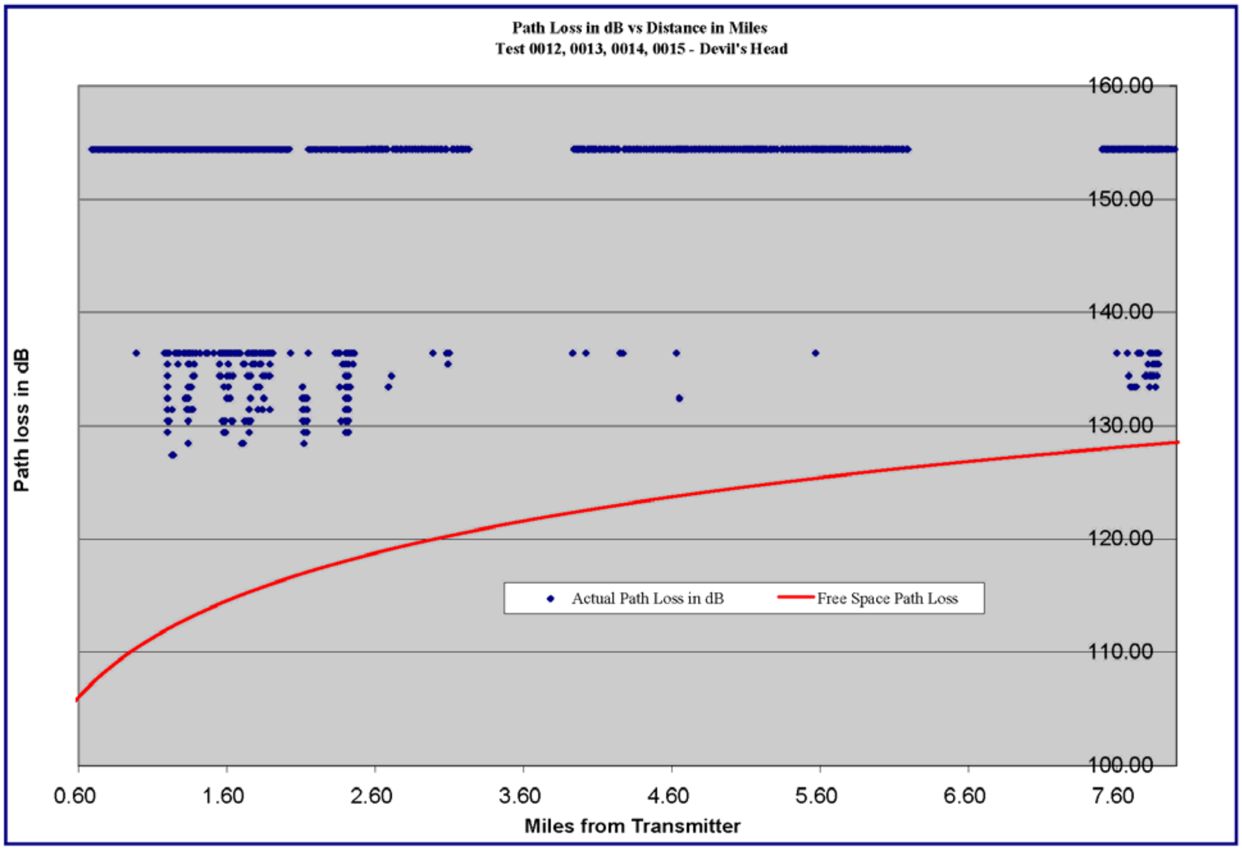
Graph 3.2 - Measured Receive Signal versus Distance – Log-Log Format – Devil's Head

Graph 3.2 shows the same information as Graph 3.1 but the distance is in a log format.

Figures 3.4 and 3.5 show the Graphs of Measured Path Loss versus Distance. These graphs are equipment independent, and can be used to calculate path loss for whatever equipment configuration is being used. For instance, in a similar installation, estimated path loss would be determined from the graph. Then the RSL, or receive signal level could be determined with a link budget calculation as follows:

RSL = EIRP - Path Loss + Receiver Antenna Gain – Feedline and Connector Losses

If the RSL, receive signal level is greater than or equal to -92 dBm, then the system will work. Every installation is different, but these graphs can be used to give an indication of probable performance of a similar installation for planning and budgetary purposes. Every proposed installation should be tested prior to deployment.



Graph 3.3 - Measured Path Loss versus Distance – Devil's Head

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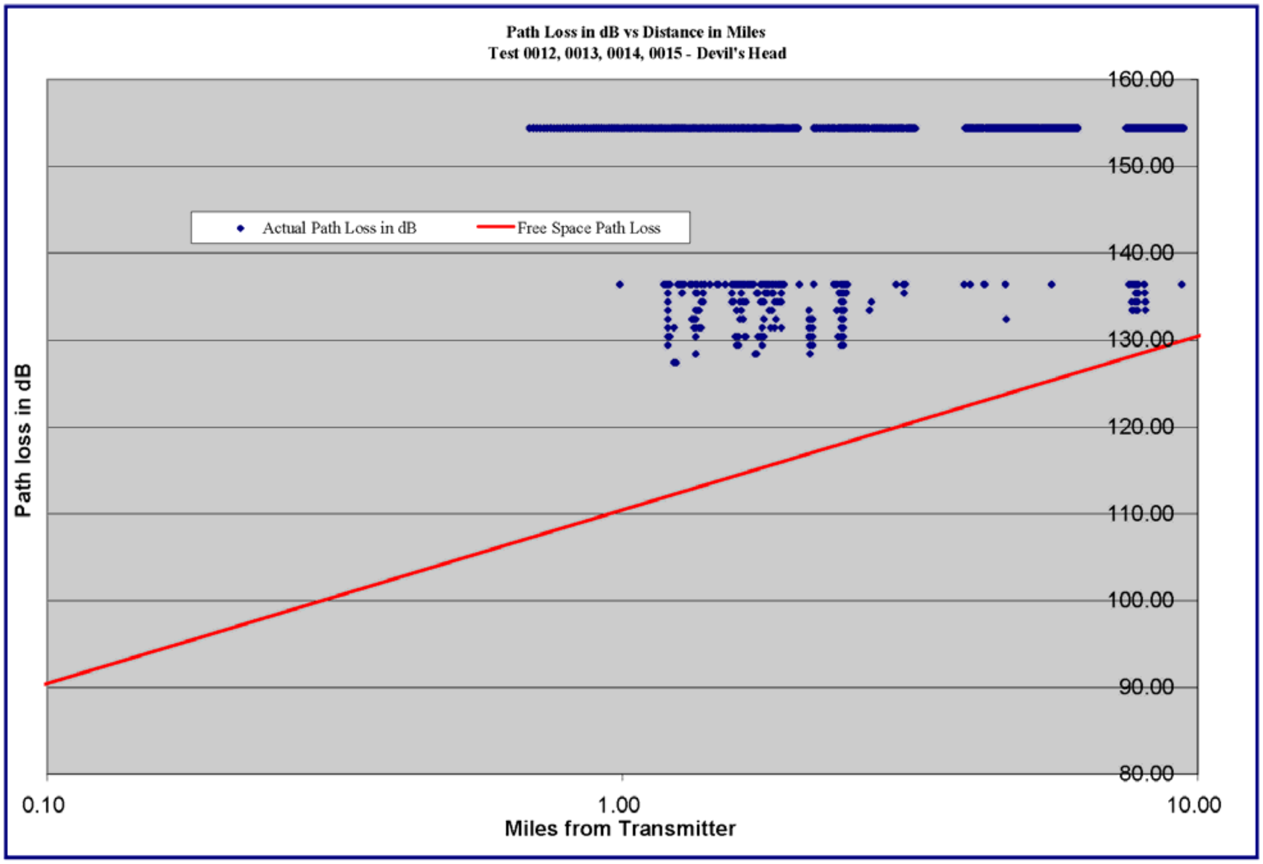


Graph 3.4 - Measured Path Loss versus Distance – Log-Log format – Devil's Head

Summary

Devil's head deployment was characterized by the fact that it looked down into the forest canopy from very high location. Because of the rugged nature of the terrain, it was only possible to test locations on existing roads. There are probably many more locations that would work around this location. Similar deployments would only be appropriate for hot spots. The usability of this type of deployment would depend upon adequate back-haul to the main site and an ad hoc or mesh deployment around the hot-spot locations.

The Devil's Head deployment, which looked down into the canopy, showed losses of 10 dB to 18 dB above the theoretical losses, while West Creek, which was a similar deployment that looked out into that canopy, experienced losses of 22 dB to 30 dB above the theoretical. The conclusion is that it is advantageous to deploy sites in similar environments at a high locations that look down into the canopy of the trees, rather than out into the canopy.

Picture 3.4 – Satellite View of Devil's Head Lookout Tower

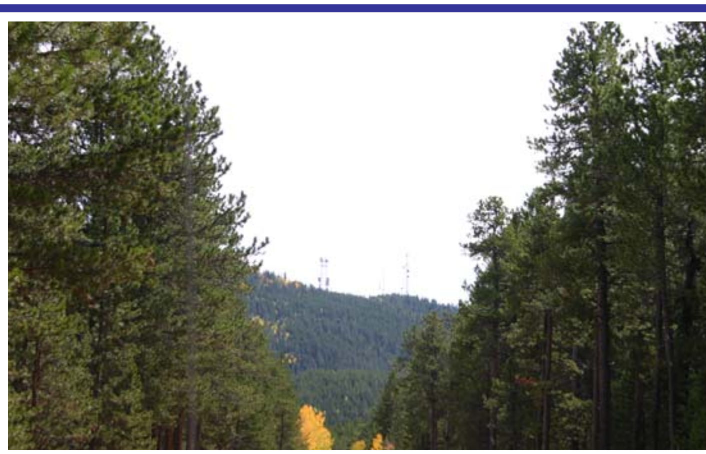
Study 2
West Creek Communications Site

Table 3.1 and Table 3.2 give the details of the West Creek Communications deployment. West Creek, an existing telecommunications site, has an elevation of 9195 feet MSL. . West Creek on the Rampart Range Road south of Devil's Head Lookout Site. The topography of the area is the same – except West Creek does not have as a high vantage point to look down into the forest canopy like Devil's Head.

. Picture 3.4 shows the West Creek towers from a distance.

Project Name	**The Colorado 4.9 GHz Project**					
Test Date	9/30/2005					
Study Area	**West Creek Communications Site**					
Test Description	Test 0017, 0018, 0019					
MAC Address for Fixed AP	00:20:a6:49:85:b7					
Deployment Number	4					
Frequency	4950	MHz				
Sector Azimuth	multiple	Degrees				
Site 1						
Latitude	39° 10 '28.0" N					
Longitude	105° 02' 2.30" W					
Elevation	9195.6	Feet AMSL				
Elevation	40	Feet AGL				
Site 2	Mobile					

Table 3.6 - West Creek Parameters



Picture 3.5 - West Creek Communications Site

Although the West Creek site has a high vantage point, the access points were mounted at the 40 ft. level. This simulated a site that would look out into the forest canopy rather than down upon it. Picture 3.4 gives an excellent idea of the area and the dense vegetation that lines the roads. The two towers located at West Creek can be seen in the picture.

Picture 3.7– View from West Creek

Picture 3.6 - Tower and AP Location

Picture 3.8 Antennas

Pictures 3.5 and 3.6 show the tower itself and the surrounding area. Picture 3.7 shows the antennas that are mounted on the side of the tower these antennas can also be seen on the left side of picture 3.5.

Losses from the West Creek Site were 12 to 20 dB above the theoretical calculations. The losses from the Devil's Head site were only 3 to 10 dB above the theoretical calculations. Looking into the forest canopy induces significantly more attenuation and path loss, as was expected.

Map 3.8 shows the coverage area, which was tested for the site.

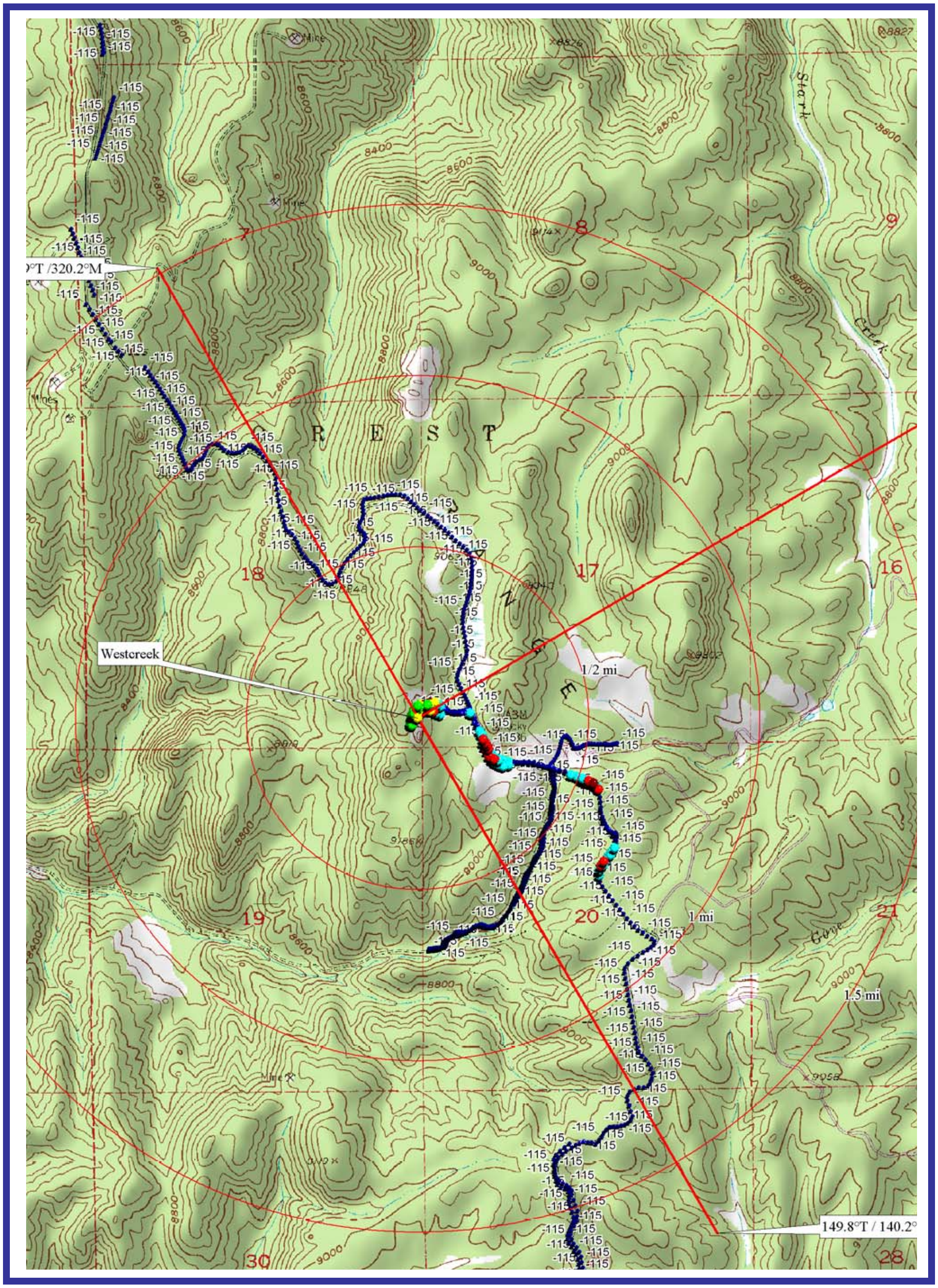
Transmitter						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	0.00	1	0.00		dB
Connector Loss		-0.10	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.10	0	0.00		dB
Coax - dB loss/100 ft	LDF4-50A	-0.01	10	(0.07)		dB
Antenna	Proxim 60 ° Sector 5054-SA60-17	15.90	1	15.90		dBi
			EIRP	**32.13**		**dBm**
Receiver						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0.00	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11j standard				4.00	dB
Receiver Sensitivity	Calculated			(92.00)		dBm
	Maximum Path Loss			**131.43**		**dB**
	Maximum Range Assuming LOS			**11.17**		**miles**
Path loss / Fade Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**11.42**		**dB**

Table 3.7 West Creek Deployment

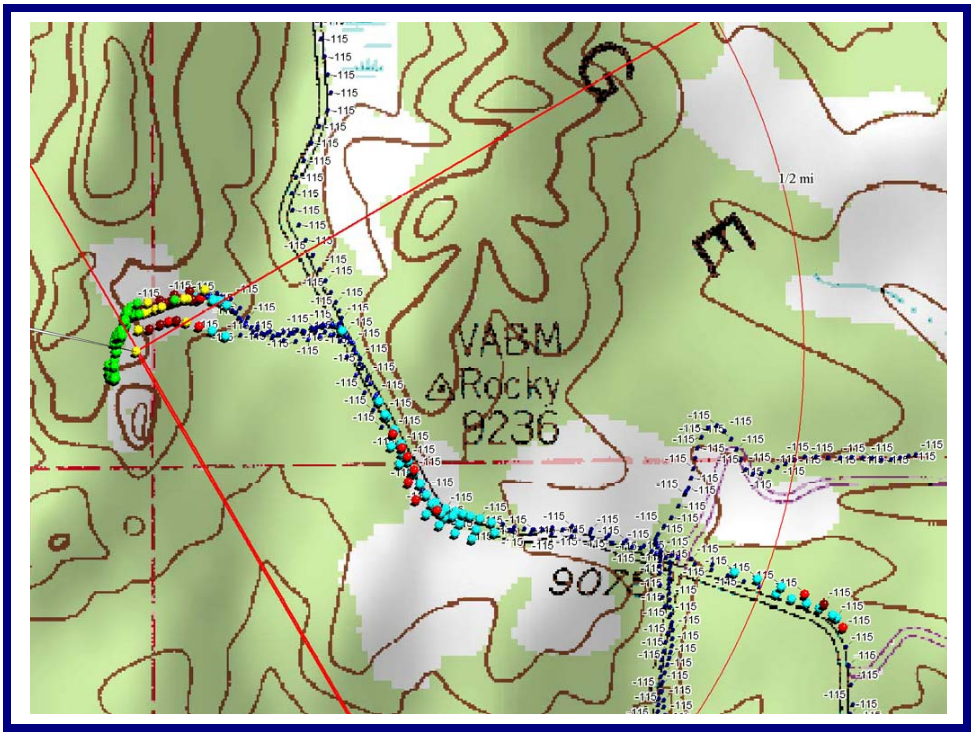
Table 3.8 – Map Legend with BDA			
	With BDA		
	Mbps	**S/N**	**dBm**
Dark Blue	NO signal		-115
Light Blue	unusable	see comment	<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

Evaluation of maps

Maps 3.8 and 3.9 show the tested coverage for the West Creek Site. . The testing was done from the tower belonging to Jefferson County, which has existing microwave backhaul.



Map 3.8 – West Creek Coverage Map



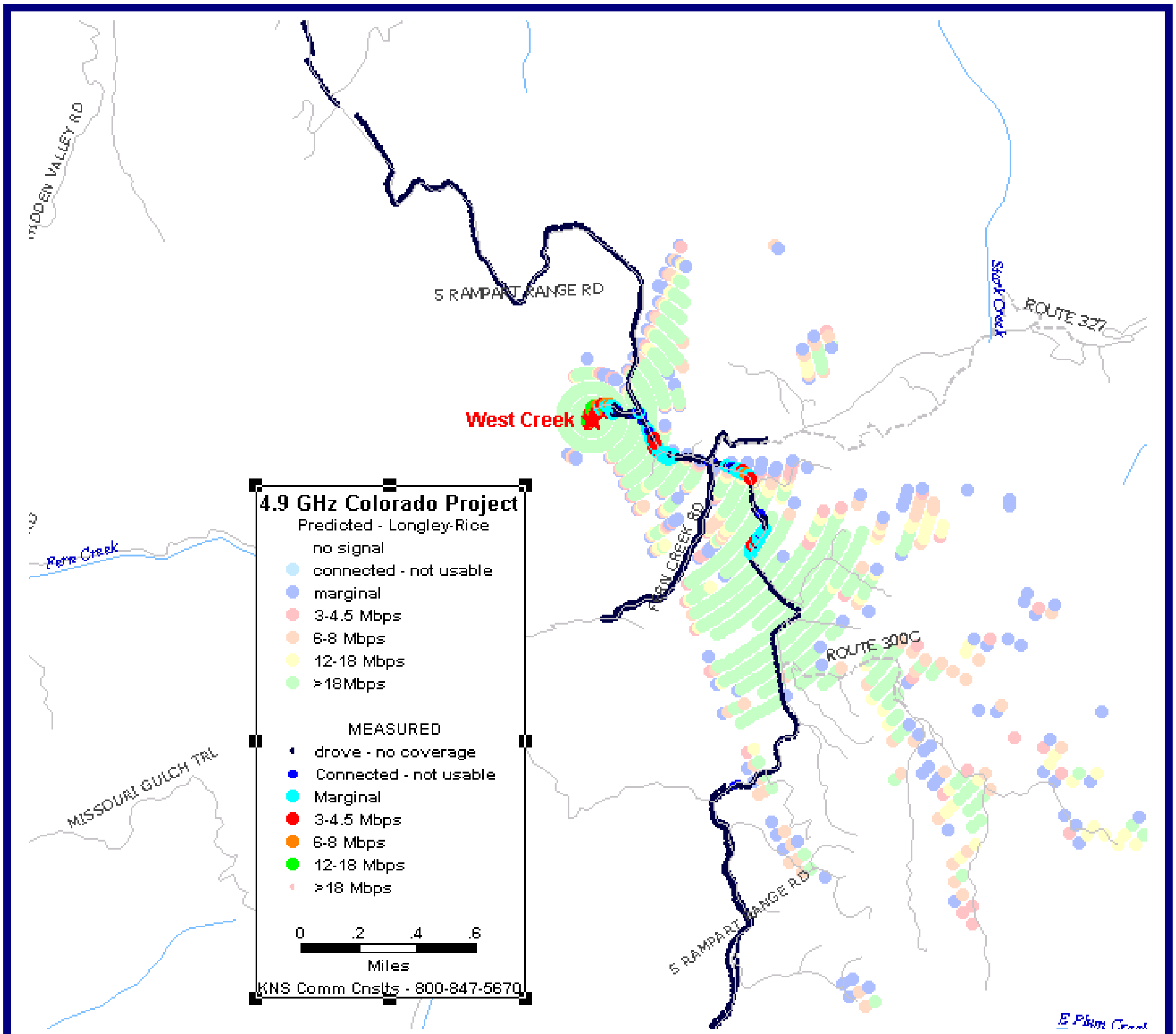
Map 3.9 – Enlarged Map of West Creek Coverage

The coverage from West Creek was considerably different than the coverage from Devils Head. There was no usable signal beyond 1 mile from the transmitter site, while Devil's Head has usable signals as far as 2½ miles from the transmitter site. There were a number of usable hotspot points immediately around the transmitter. Map 3.8 shows some points with high levels of throughput.

Predicted Coverage versus Actual Coverage

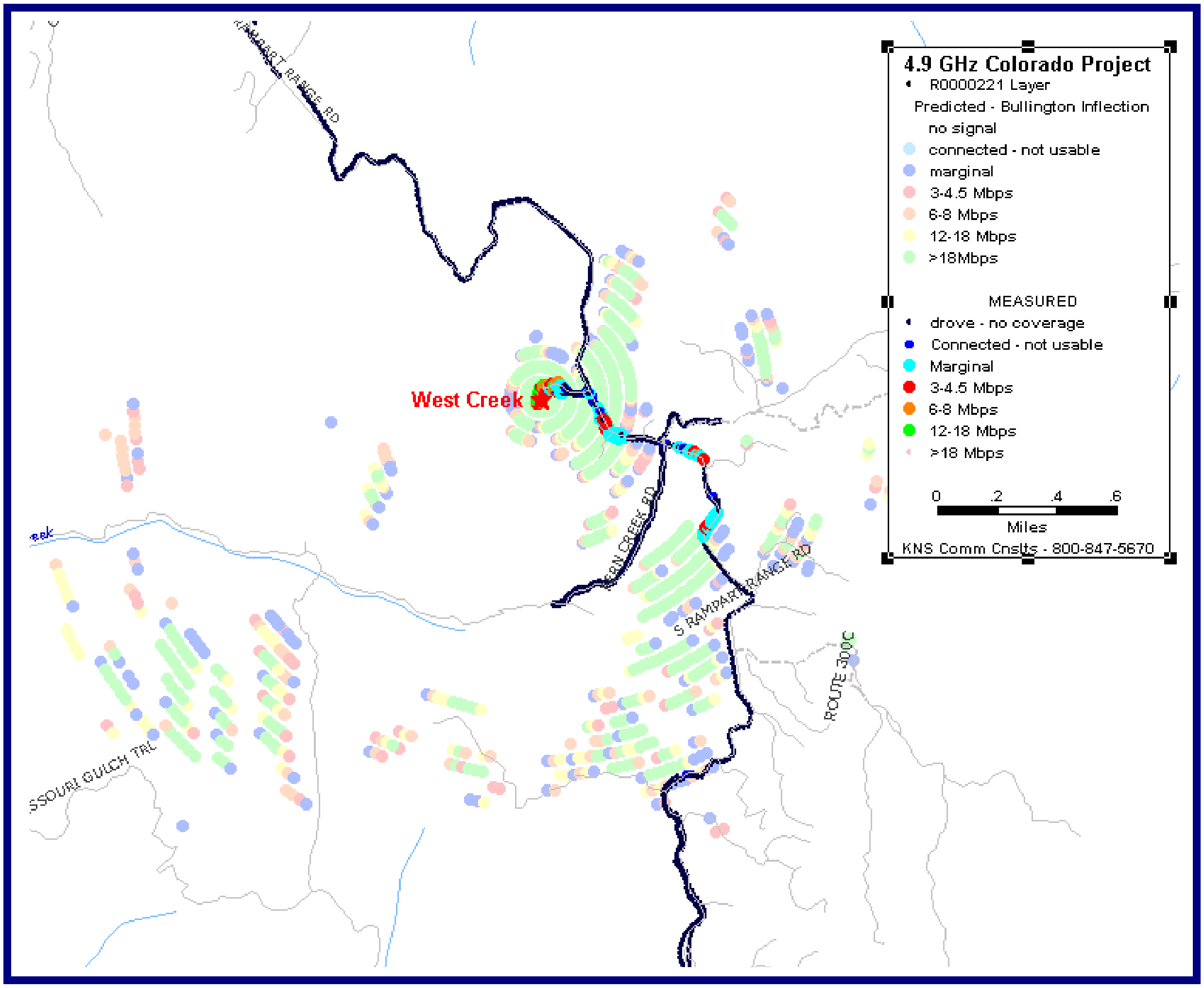
Two predictive models were used to study the coverage from West Creek. Obstruction files representing 50-foot trees were created for use by the modeling software. These files were incorporated into both studies.

The Longley-Rice model was the more accurate of the two. Although it showed areas of coverage where the testing showed no coverage, the actual coverage was within the boundaries, which predicted coverage. While the Longley-Rice model does not give a final coverage map, it is very useful in determining the maximum footprint where coverage would be expected. The Longley-Rice study is shown and a Map 3.10.



Map 3.10 – West Creek-Longley-Rice Model – Predicted Coverage versus Actual Coverage

The Bullington Obstruction Model with inflection was also used to study the coverage around the West Creek Communications Site. Map 3.11 showed the result of this study. The map was overly conservative in some areas while in other areas it showed coverage that did not exist. The Longley-Rice model was more useful for this deployment. It helped establish a maximum footprint for the coverage. It did not give an accurate portrayal of the areas within this footprint where there was coverage and where there was not coverage.

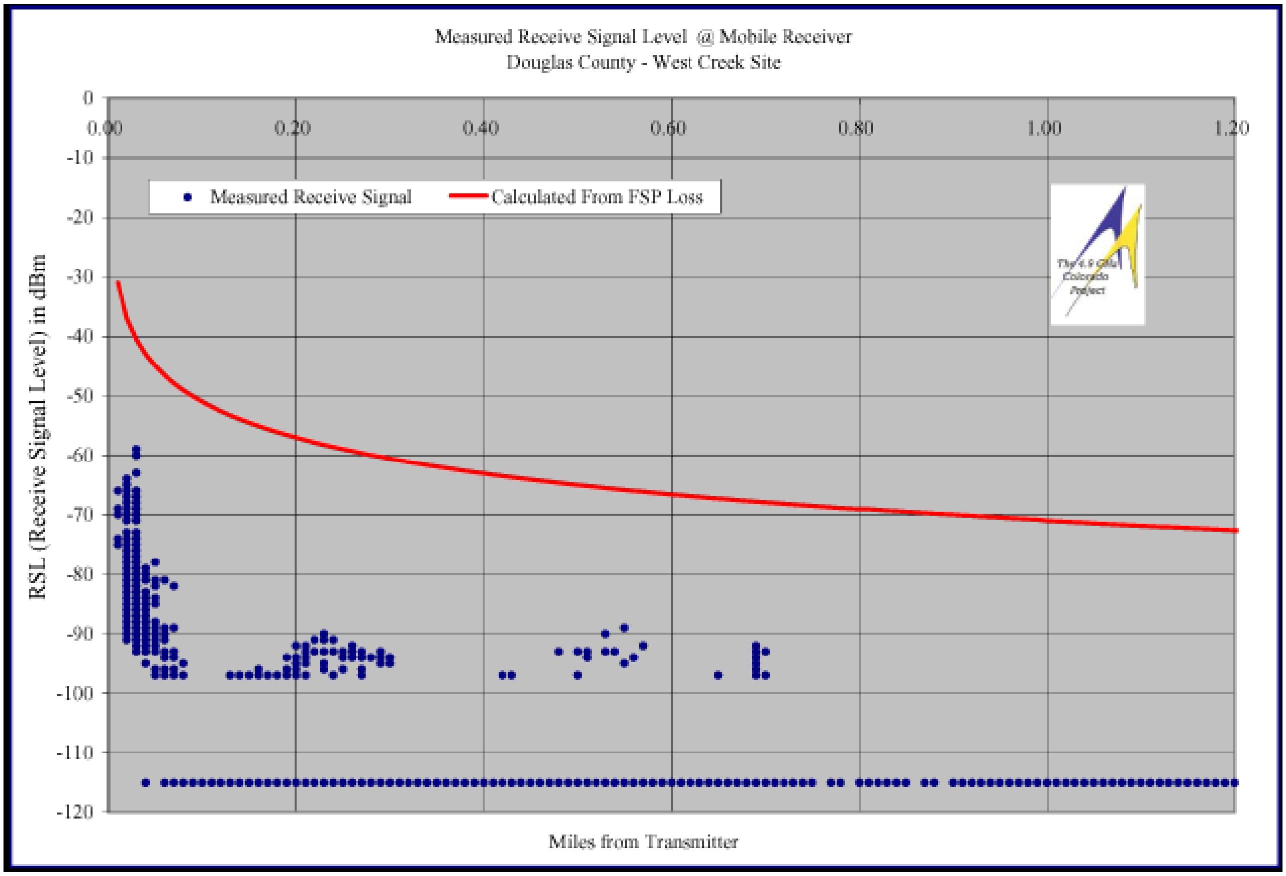


Map 3.11 – West Creek-Bullington Model – Predicted Coverage versus Actual Coverage

Evaluation of Graphs

For each of the drive tests two sets of graphs were prepared. The first set of graphs showed measured field strength versus distance, and the second set of graphs showed measured path loss versus distance. In each set of graphs, the second graph showed the distance in a log format, which returns a straight line representing the theoretical calculations.

In all of the graphs, the red line shows the theoretical calculated result. This line is based upon the free space path loss formula.

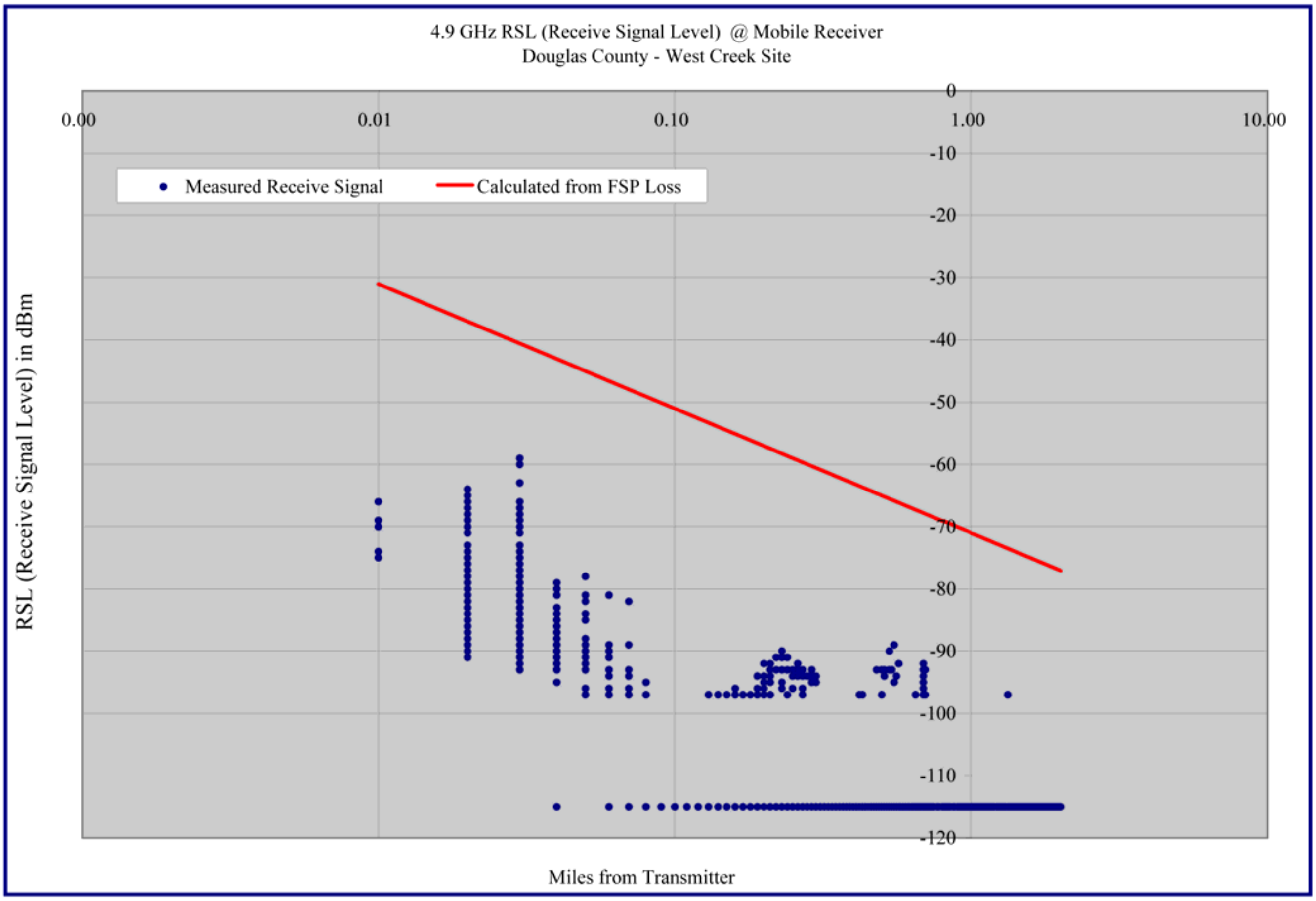


Graph 3.5 - West Creek - Predicted Receive Signal Level versus Distance

Graphs 3.5 and 3.6 show Measured Receive Signal Level versus Distance. For a mobile AP with a BDA, the nominal receiver sensitivity is -92 dBm. This means that for a reliable signal, there must be a level of at least -92 dBm [SNR = 4]. The modulation at SNR = 4 is BPSK, and this is the minimum signal for reliable communications according to 802.11j.

At -92 dBm or greater on the graph showed there are hot spots which will work. Signal strengths from -93 dBm to -96 dBm were passing some data, but this is below the 802.11j specifications for usable throughput [SNR>or equal to 4, which is a field strength of -92 dBm.

Unlike the Devil's Head deployment, which a useful signals up to 2½ miles from the site, the West Creek deployment shows no useful signals beyond .7 mile from the site, with the majority of the signals being within a first .3 mile. The West Creek deployment did have much higher throughput levels than the Devil's Head deployment. If the RSL, receive signal level is greater than or equal to -92 dBm, then the system will work. Every installation is different, and these graphs can be used to give an indication of probable performance for similar installations. Every proposed installation should be tested prior to deployment.

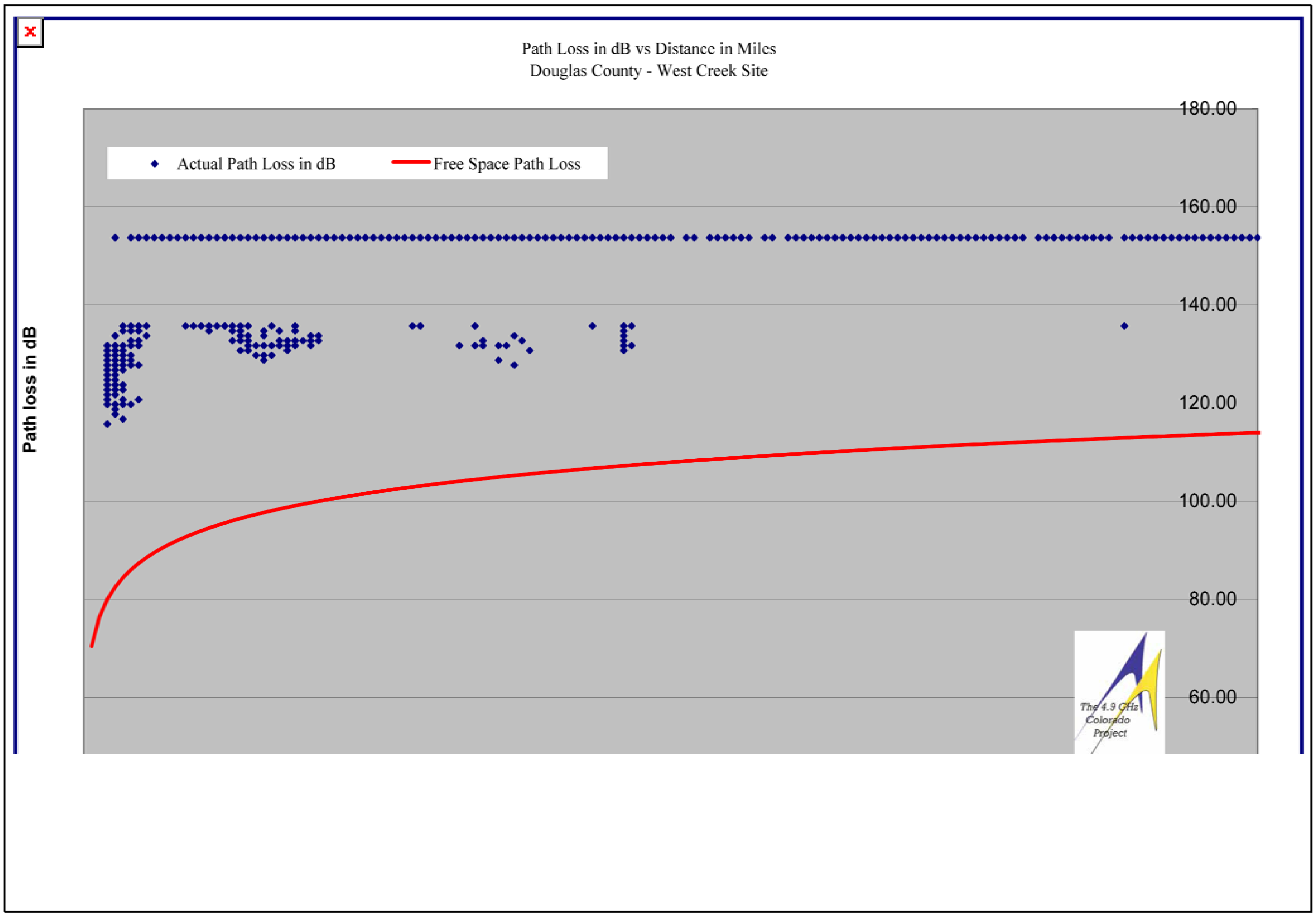


Graph 3.6 - West Creek –Predicted Receive Signal Level versus Distance – Log-Log Format

Graph 3.7 shows the Log-Log version of the predicted path loss formula.

West Creek was an excellent location for a hot spot deployment. It has existing microwave for back-haul, and the high throughput at hot spot locations close to the site.

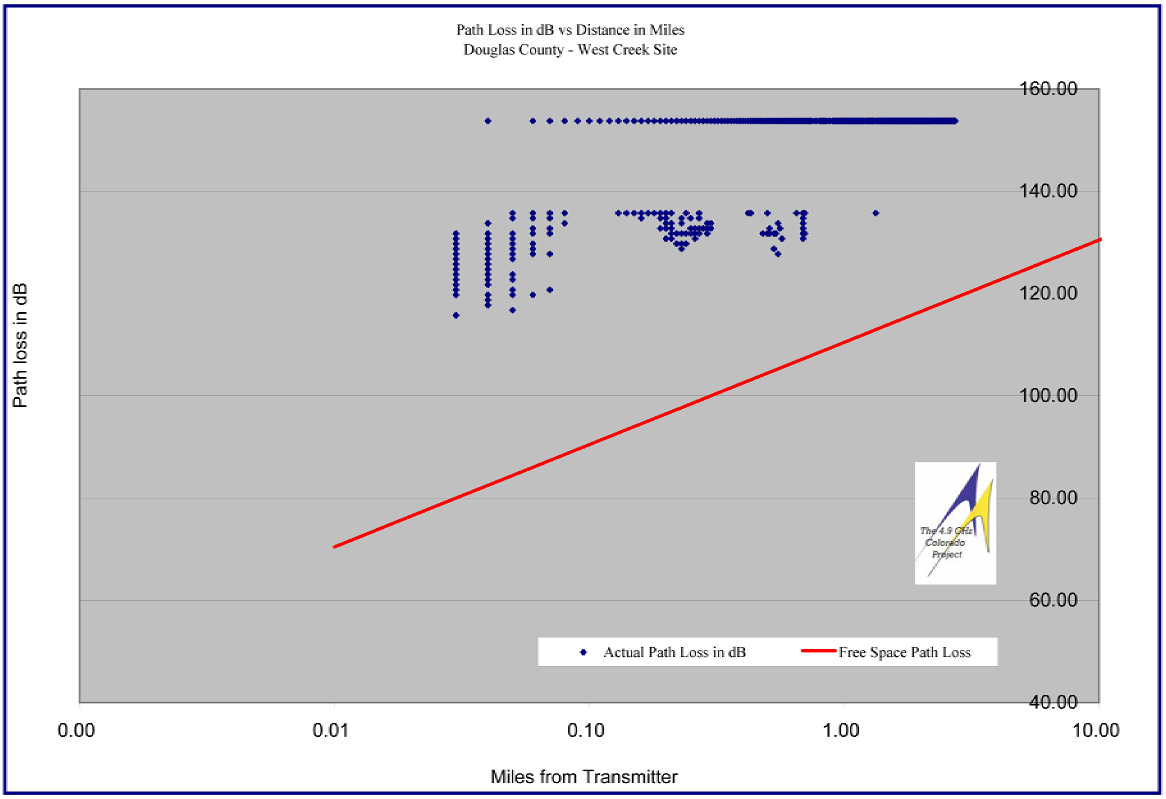
If the RSL, receive signal level is greater than or equal to -92 dBm, then the system will work. Every installation is different, and these graphs can be used to give an indication of probable performance of a similar installation for planning and budgetary purposes. Every proposed installation should be tested prior to deployment.



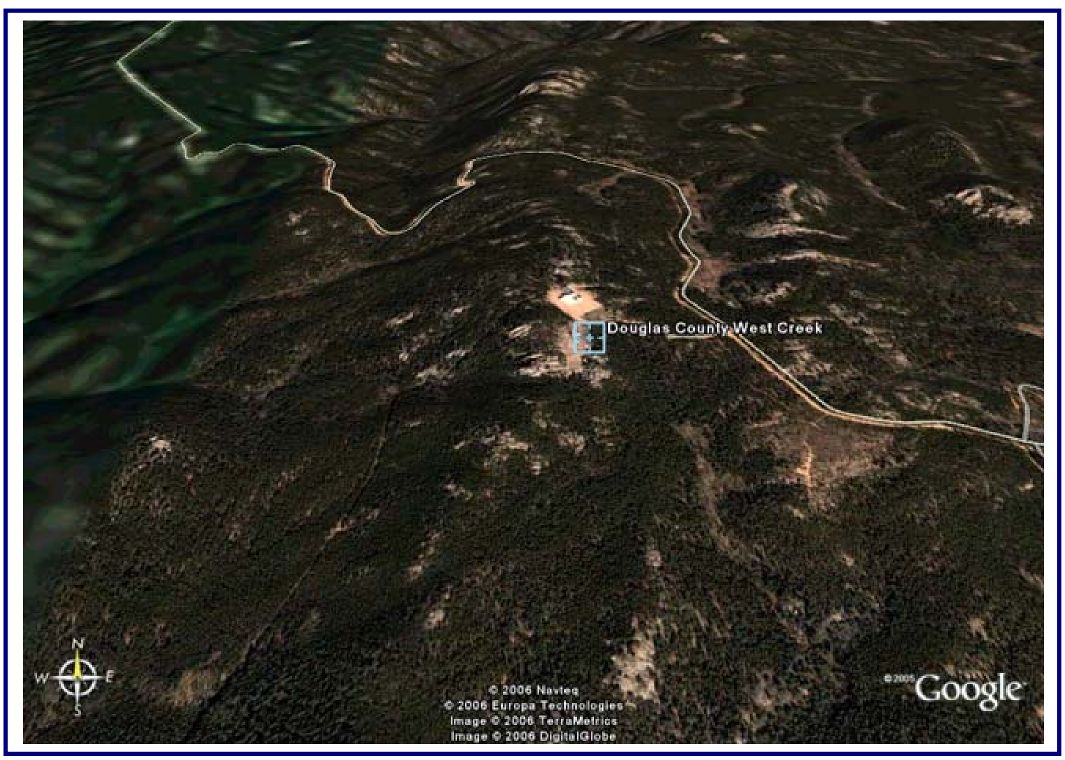
Graph 3.7 - West Creek - Predicted Path Loss versus Distance

Graph 3.8 shows the log-log version of the predicted path loss versus distance.

West Creek that make an excellent location for a hot spot deployment in the middle of the mountains. It already has microwave links to the site that could be used for back-haul, and the throughput at locations close to the site is at the maximum level.



Graphs 3.8 - West Creek - Predicted Path Loss versus Distance – Log-Log



Picture 3.9 – Satellite View of West Creek Communications Site

Summary – Coverage in the Mountains

Mountainous coverage presented the most difficult of all the types of coverage, which were studied. The Rocky Mountains have a high mountain arid climate. Because of the arid climate, this coverage would be better than would be expected in some of the humid climates found in the mountainous regions of the Central and Midwestern part of the United States.

Testing showed that mountainous deployments were suitable for hot spot and limited ad hoc or mesh deployment. Chapter 10 covers application testing and characterizes ad hoc and mesh deployments...

	Devil's Head	West Creek
Deployment Parameters		
EIRP	32.13 dBm	32.13 dBm
Antennas	downtilt 90°	no downtilt 90°
Topography	rugged mountainous	rugged mountainous
Vegetation	dense conifer forest	dense conifer forest
Climate	arid	arid
Vantage Point	down into the canopy	out into the canopy
Distance for Hot-spots		
Maximum	2.5 miles	0.6 miles
Minimum	1.4 months	0.05 miles
Throughput - Mbps		
Maximum	24 to 27	3 to 4.5
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in Db		
Minimum	10	22
Maximum	18	30
Backhaul		
feasibility	yes	microwave in place
Deployment Type		
Point to Multipoint	no	no
Hot-Spot	yes	yes
Ad Hoc or Mesh	limited	limited
Site Comparison		
Overall Coverage	limited	Very Limited
Comment	Devil's Head has better coverage, West Creek has better throughput	

Table 3.9 – Summary of Mountainous Coverage

Checklist for deployment in the mountains:

 Evaluate potential sites

- Choose a high site for multiple hot-spots
- Choose a lower site for a higher speed local hot-spots
- Make sure backhaul is available to the site

- Use predictive model such as Bullington or Longley Rice to the maximum footprint for the coverage. These models are tools that help evaluate topography. If there are obstruction files for the area (for buildings), this will increase the accuracy of the model. Note that these models do not present an accurate map of the final coverage, but are simply one of many tools that can be used to help in the final planning process.

Before final deployment set up a temporary deployment and drive test the area and record the results. The results are best recorded with software that takes many readings per seconds so that the multipath and effects of Raleigh fading can averaged into a reading that is more reflective of the actual results.

Proper and professional installation is critical to satisfactory performance.

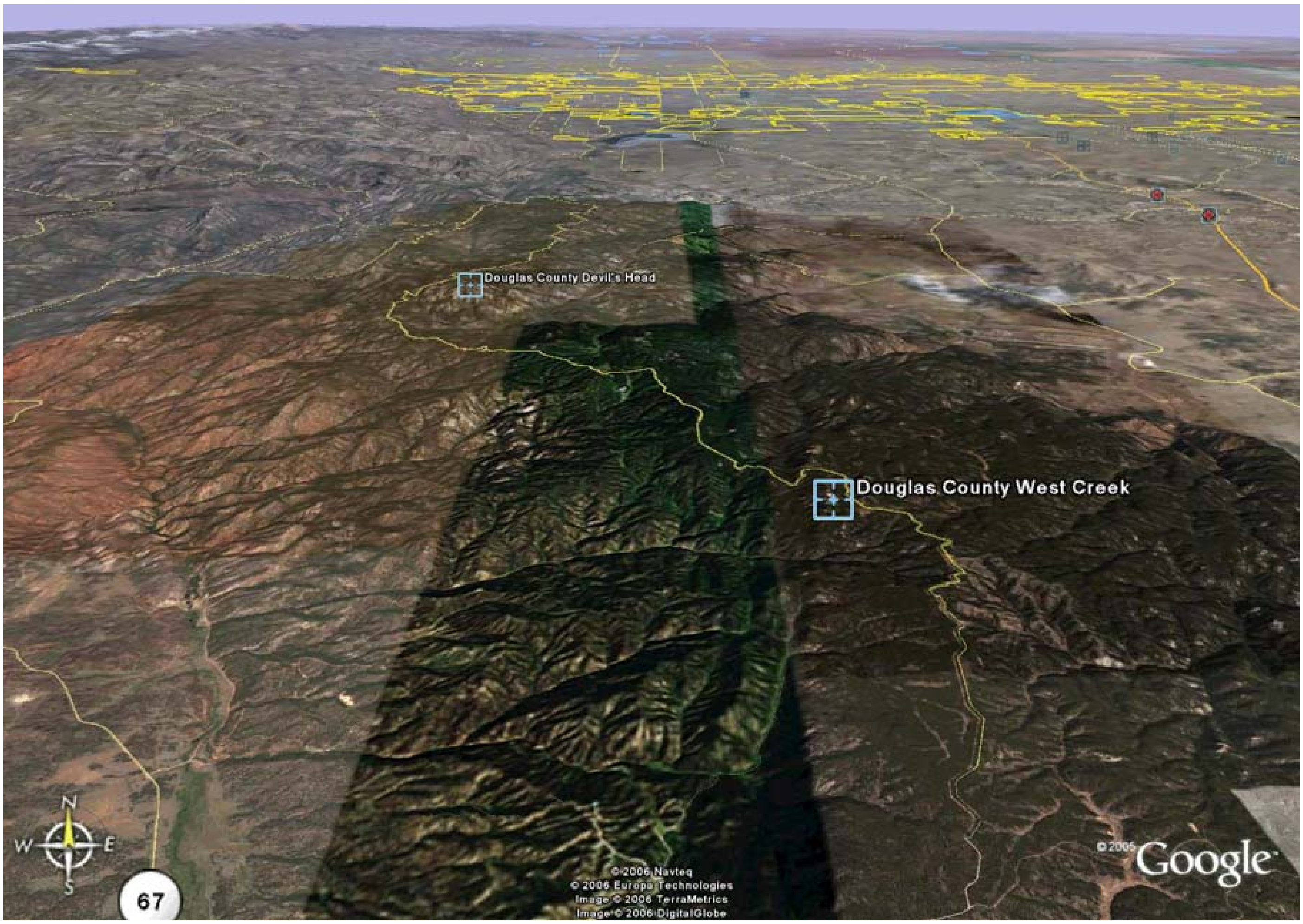
Networking of the system is CRITICAL. Multiple sites require a Layer 3 router to prevent spanning tree issues.

"Spanning-Tree Protocol is a link management protocol that provides path redundancy while preventing undesirable loops in the network. For an Ethernet network to function properly, only one active path can exist between two stations.

"Multiple active paths between stations cause loops in the network. If a loop exists in the network topology, the potential exists for duplication of messages. When loops occur, some switches see stations appear on both sides of the switch. This condition confuses the forwarding algorithm and allows duplicate frames to be forwarded.

"To provide path redundancy, Spanning-Tree Protocol defines a tree that spans all switches in an extended network. Spanning-Tree Protocol forces certain redundant data paths into a standby (blocked) state. If one network segment in the Spanning-Tree Protocol becomes unreachable, or if Spanning-Tree Protocol costs change, the spanning-tree algorithm reconfigures the spanning-tree topology and reestablishes the link by activating the standby path.

"Spanning-Tree Protocol operation is transparent to end stations, which are unaware whether they are connected to a single LAN segment or a switched LAN of multiple segments."[1]



Picture 3.10 – Satellite View of Mountainous Sites
(Denver can be seen in the background on the top of the map.)

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[1] Cisco. Spanning Tree Protocol. http://www.cisco.com/univercd/cc/td/doc/product/rtrmgmt/sw_ntman/cwsimain/cwsi2/cwsiug2/vlan2/stpapp.htm. [Electronic Version]. Retrieved August 11, 2006.

Chapter 4
Summary - Castle Rock – Suburban Foothills

The hypothesis was that as bandwidth was increased, the throughput would also increase, but at a cost[1] of distance or area of coverage. It was also believed that an increase in the equipment's maximum throughput would also decrease the distance or coverage area.

Summary

As expected, increasing the bandwidth increased the throughput and decreased the distance and size of the footprint. Increasing the maximum throughput also decreased the distance.

Effects of changing from 10 MHz to 20 MHz Bandwidth

Table 4.35 and 4.36 compared the results of increasing the Bandwidth. In both the Justice Center and the Miller Building, the throughput was better close to the AP's, but the maximum distance at which an AP would associate was decreased. In the following graphs the maximum distance for the hot spots decreased as the bandwidth increased. The maximum path loss above the theoretical predicted calculations also increased as the bandwidth increased.

Table 4.1 - Comparing 10 MHz and 20 MHz Bandwidths – Justice Center

Chapter 4 Study Number	Study 2	Study 3	Study 6	Study 7	Study 8	Study 9
Deployment Parameters						
Bandwidth MHz	10	20	10	20	10	20
Max Throughput Setting Mbps	6	6	18	18	24	24
EIRP	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm
Distance for Hot-spots						
Maximum, miles	2.2	1.6	2.1	1/3	1/3	1/4
Minimum, miles	0	0	0	0	0	0
Throughput - Mbps						
Maximum Mbps	24-27	24-27	24-27	24-27	24-27	24-27
Minimum Mbps	3-4.5	3-4.5	3.4-5	3.4-5	12-18	3.4-5
Path Loss Above Theoretical in dB						
Minimum dB	2	11	1	16	6	10
Maximum dB	13	15	8	24	12	18

[1] The network cost is a loss that occurs in the network. Cost can also be a measurement of these losses.

	Table 4.2 - Comparing 10 MHz and 20 MHZ Bandwidth - Miller Building					
Study No for this Chapter	**Study 2**	**Study 3**	**Study 6**	**Study 7**	**Study 8**	**Study 9**
Deployment Parameters						
Bandwidth	10 MHz	20	10	20	10	20
Max Throughput Setting	6 Mbps	6 Mbps	18 Mbps	18 Mbps	24 Mbps	24 Mbps
EIRP	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm
Distance for Hot-spots						
Maximum	4	1	1-1/3			1/4
Minimum	0	0	0			0
Throughput - Mbps						
Maximum	24-27	24-27	24-27			6-8
Minimum	3-4.5	3-4.5	3.4-5			3.4-5
Path Loss Above Theoretical in dB						
Minimum	7	12	16			34
Maximum	30	20	30			38

Effects of Changing Maximum Throughput Settings in the AP's

Tables 4.36, 4.37, 4.38 and 4.39 show the how increasing the maximum throughput affected the studies. In general, the distance to the hot spots decreased and path loss increased as the maximum throughput setting for the AP increased.

Table 4.3 - Maximum Throughput Affects @ 10 MHz- Justice Center				
Study No for this Chapter	**Study 1**	**Study 2**	**Study 6**	**Study 8**
Deployment Parameters				
Bandwidth MHz	10	10	10	10
Max Throughput Setting Mbps	3	6	18	24
EIRP	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm
Distance for Hot-spots				
Maximum, miles	2.5	2.2	2.1	1/3
Minimum, miles	0	0	0	0
Throughput - Mbps				
Maximum Mbps	24-27	24-27	24-27	24-27
Minimum Mbps	3-4.5	3-4.5	3.4-5	12-18
Path Loss Above Theoretical in dB				
Minimum dB	1	2	1	14
Maximum dB	4	13	8	16

Table 4.4 - Maximum Throughput Affects @ 10 MHz - Miller Building				
Study No for this Chapter	**Study 1**	**Study 2**	**Study 6**	**Study 8**
Deployment Parameters				
Bandwidth	10 MHz	10 MHz	10	10
Max Throughput Setting	3 Mbps	6 Mbps	18 Mbps	24 Mbps
EIRP	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm
Distance for Hot-spots				
Maximum	3.6 miles	4	1-1/3	
Minimum	0 miles	0	0	
Throughput - Mbps				
Maximum	24-27	24-27	24-27	
Minimum	3-4.5	3-4.5	3.4-5	
Path Loss Above Theoretical in dB				
Minimum	8	7	16	
Maximum	18	30	30	

Table 4.5 - Maximum Throughput Affects @ 20 MHz- Justice Center					
Study No for this Chapter	**Study 3**	**Study 4**	**Study 5**	**Study 7**	**Study 9**
Deployment Parameters					
Bandwidth MHz	20	20	20	20	20
Max Throughput Setting Mbps	6	9	12	18	24
EIRP	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm	30.32 dBm
Distance for Hot-spots					
Maximum, miles	1.6	2.5	2.1	1/3	1/4
Minimum, miles	0	0	0	0	0
Throughput - Mbps					
Maximum Mbps	24-27	24-27	24-27	24-27	24-27
Minimum Mbps	3-4.5	3.4-5	3.4-5	3.4-5	3.4-5
Path Loss Above Theoretical in dB					
Minimum dB	11	9	12	6	10
Maximum dB	15	13	19	12	18

Table 4.6 - Maximum Throughput Affects @ 10 MHz- Justice Center					
Study No for this Chapter	**Study 3**	**Study 4**	**Study 5**	**Study 7**	**Study 9**
Deployment Parameters					
Bandwidth	20	20	20	20	20
Max Throughput Setting	6 Mbps	9 Mbps	12 Mbps	18 Mbps	24 Mbps
EIRP	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm	31.32 dBm
Distance for Hot-spots					
Maximum	1	1	3/8		1/4
Minimum	0	0	0		0
Throughput - Mbps					
Maximum	18-Dec	12-18	12-18		6-8
Minimum	3-4.5	3.4-5	3.4-5		3.4-5
Path Loss Above Theoretical in dB					
Minimum	12	20	18		34
Maximum	20	34	38		38

The most reliable settings for the implementation were 10 MHz bandwidth with 6 Mbps or with auto fallback mode. This setting worked well and was a good compromise between bandwidth and distance.

Even though both implementations were similar, the Justice Center had a better overall coverage. It was slightly higher and was at a vantage point that overlooked the clutter rather than looked out into the clutter.

Checklist for deployment in the suburban setting:

Evaluate potential sites

- Choose a higher sight clear of clutter for a larger area of coverage
- Choose a lower sight for local hotspots and localized coverage
- Make sure backhaul is available to the site.
- Use predictive model such as Bullington or Longley Rice to determine preliminary coverage. These models are tools that help evaluate topography. Obstruction files for the area (showing buildings), will increase the accuracy of the model. These models do not present an accurate map of the final coverage, but are simply one of many tools, which can be used to help in the final planning process.

Before final deployment set up a temporary deployment and drive test the area and record the results. The results are best recorded with software that takes many readings per seconds so that the multipath and effects of Raleigh fading can averaged so the resulting reading is more reflective of the actual predicted performance.

Proper and professional installation is critical to satisfactory performance.

Networking of the system is CRITICAL. Routing must be done with a Level 3 router to prevent spanning tree issues.

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Coverage in the Suburban Foothills – Castle Rock

Castle Rock is located in Douglas County south of the Denver metropolitan area. It is a growing suburban community, with both old and new development. The study area is located along I-25. Two buildings were used for the study, the Douglas County Justice Center, which lies to the west of I-25, and the Miller Building which will lies several miles south of the Justice Center and to the east of I-25.

Summary

Fairly good coverage was expected in this area. Most of the buildings other than the Justice Center and the Miller Building, Are less than two stories tall. Although there are deciduous trees in the area, the vegetation fairly sparse. One of the goals of the Castle Rock deployment was to compare the effects of various bandwidths and the effects of various maximum throughput rates to determine what the optimum bandwidth and throughput setting were for the deployment.

It was expected that 10 MHZ bandwidth would provide the best overall performance, although 20 MHz bandwidth would allow higher throughput. As expected, distances decreased significantly with the 20 MHz bandwidth, and it was felt that throughput levels at 10 MHz bandwidth was adequate for most applications.

Table 4.7 - Castle Rock Tests

	Bandwidth	
Mbps	**10 MHz**	**20 MHz**
3	test 39, 43, 44	
6	test 41	test 56
9		test 57
12		test 58
18	test 42	test 59
24	test 54	tests 55, 60

An additional observation was that coverage decreased when the maximum throughput rate was increased.

Although no network backhaul was available, the second purpose of this study was to evaluate whether coverage was available through the I-25 corridor from one of the two sites. For this reason the coverage maps which will be shown will be overlapping maps, showing coverage from both of the sites.

The Justice Center is a large building and the antennas were approximately 65 ft. above ground, added on top of the roof. The Miller Building deployment was approximately 45 ft. above the ck.
ground, with the antennas mounted against the side of the building. For this reason each antenna would be heavily shielded to the back.

Picture 4.4 shows a satellite photo of the area[1]. Map 4.1 shows the USGS map of the same location.. The two arrows show the locations of the two buildings under study. The Justice Center lies to the north and that Miller Building to the south. The I- 25 corridor can be clearly seen. Pictures 4.1, 4.2, and 4.3 show the Justice Center and Miller Building deployments

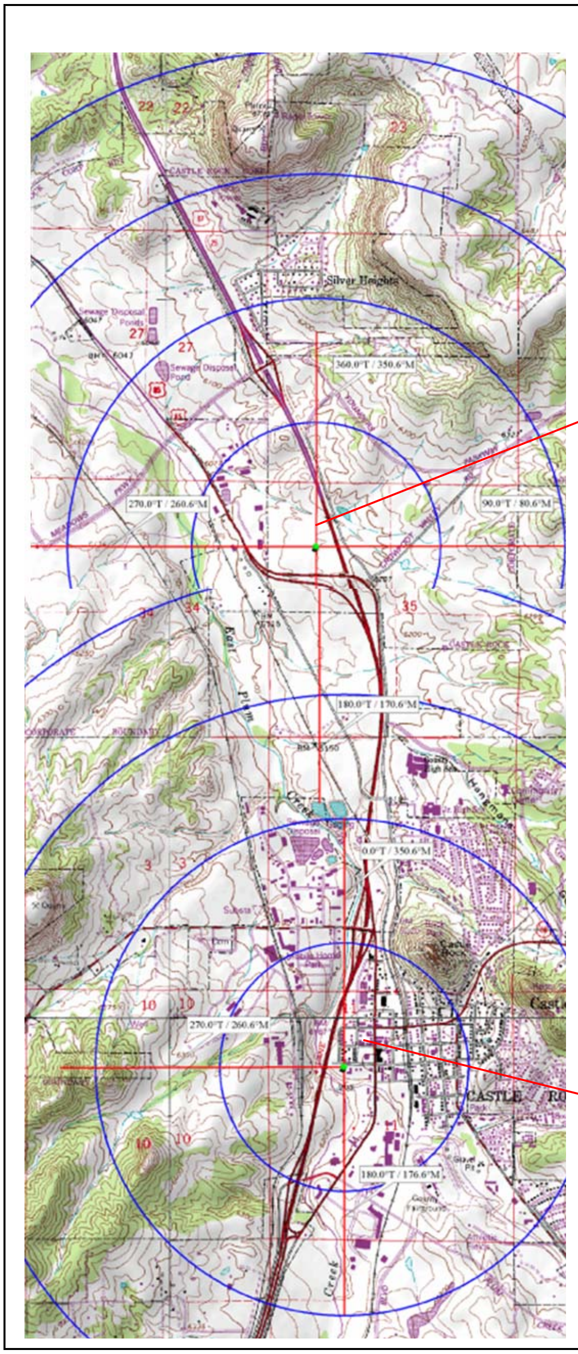
There were a number of tests run from these two buildings. Purpose of the multiple tests was to compare the effects of various parameters on coverage. The EIRP remained the same in all the tests. No BDA's were used in any of the tests. For this reason that parameters will only be shown in this preliminary overview.

Picture 4.2 – Miller Building

Picture 4.1 – Justice Center

Picture 4.3 – Miller Building

[1] Google Earth Pro, licensed to KNS Communications Consultants



Map 4.1– Castle Rock Deployment

Picture 4.4 – Satellite Photo

Project Name	The Colorado 4.9 GHz Project				
Test Date	November 2005				
Study Area	**Justice Center**				
Test Description	Test 0039-0060				
MAC Address for Fixed AP	00:20:A6:5D:9E:72				
Deployment Number	12				
Frequency	4950	MHz			
Sector Azimuth	multiple	Degrees			
Site 1	Justice Center				
Latitude	39° 24' 8.05" N				
Longitude	104° 51' 51.08" W				
Elevation	6161.57	Feet AMSL			
Elevation	65	Feet AGL			
Site 2	Mobile				
Transmitter	**No BDA**				
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	
Power Out	Proxim AP4900 M			16.50	
Amplifier Gain	Linx BDA	10	0	0.00	
Connector Loss		-0.1	2	(0.20)	
Lightning Arr	Polyphaser	-0.1	0	0.00	
Coax - dB loss/100 ft	LDF4-50A	-0.073	12	(0.88)	
Antenna	Til-Tek 90 Sector TA-4904-14-90	NA	NA	14.90	
			EIRP	**30.32**	

Table 4.8 - Justice Center EIRP Calculations

Picture 4.5 - Justice Center

Project Name	The Colorado 4.9 GHz Project					
Test Date						
Study Area	**Miller Bldg**					
Test Description	Test 0039- 3 Mbps Max - 10 MHz Bandwidth					
MAC Address for Fixed AP	00:20:A6:5D:9E:72					
Deployment Number	12					
Frequency	4950	MHz				
Sector Azimuth	multiple	Degrees				
Site 1	**Miller Bldg**					
Latitude	39° 22' 19.52" N					
Longitude	104° 51' 44.39" W					
Elevation	6194.72	Feet AMSL				
Elevation	45	Feet AGL				
Site 2	Mobile					
Transmitter	**No BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	0	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arr	Polyphaser	-0.1	0	0.00		dB
Coax - dB loss/100 ft	LDF4-50A	-0.073	12	(0.88)		dB
Antenna	Proxim 60 Sector 5054-SA60-17	15.9	1	15.90		dBi
			EIRP	**31.32**		**dBm**

Table 4.9 – Miller Building EIRP Calculations

Picture 4.6 – Miller Building

Receiver	**No BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**129.62**		**dB**
	Maximum Range Assuming LOS			**7.21**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**7.62**		**dB**

Receiver						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				20.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(86.99)		dBm
	Maximum Path Loss			**134.99**		**dB**
	Maximum Range Assuming LOS			**16.85**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**14.99**		**dB**

Table 4.10 - Receiver Parameters - 10 MHz and 20 MHz Bandwidths

Study 1

Test parameters: 10 MHz Bandwidth / Maximum Throughput 3 Mbps.

Summary

The hypothesis was that an increase in bandwidth will increase the throughput, but at a cost of distance. The coverage will decrease as the bandwidth is increased. The hypothesis is that increasing the Access Point's maximum throughput will also result in a decrease in distance or coverage area. The goal of the next 8 studies is to determine what the effect is when the bandwidth or maximum throughput is changed.

Since it is difficult to compare these results, a chart has been made which shows the following

Bandwidth
Maximum Throughput Setting
EIRP
Distance for Hot-spots – Maximum and Minimum
Throughput in Mbps – Maximum and Minimum
Path Loss above Theoretical in dB

The hot spot distances show the most distant location from the access point where there is usable throughput, and the closest distance where there is usable throughput. (The closest distance has more meaning in a rugged deployment where close access may not be possible).

The path loss above theoretical is a rough approximation of the distance from the scatter points to the theoretical line – showing the most distance from the cluster of points or the least distance from the cluster of points. This gives an approximate estimation to help compare coverage.

The same legend is still used for all the maps, though the receiver sensitivitiy is 2 dB less because there was no BDA and the receiver. The lowest reliable signal per 802.11j is -90 dBm.

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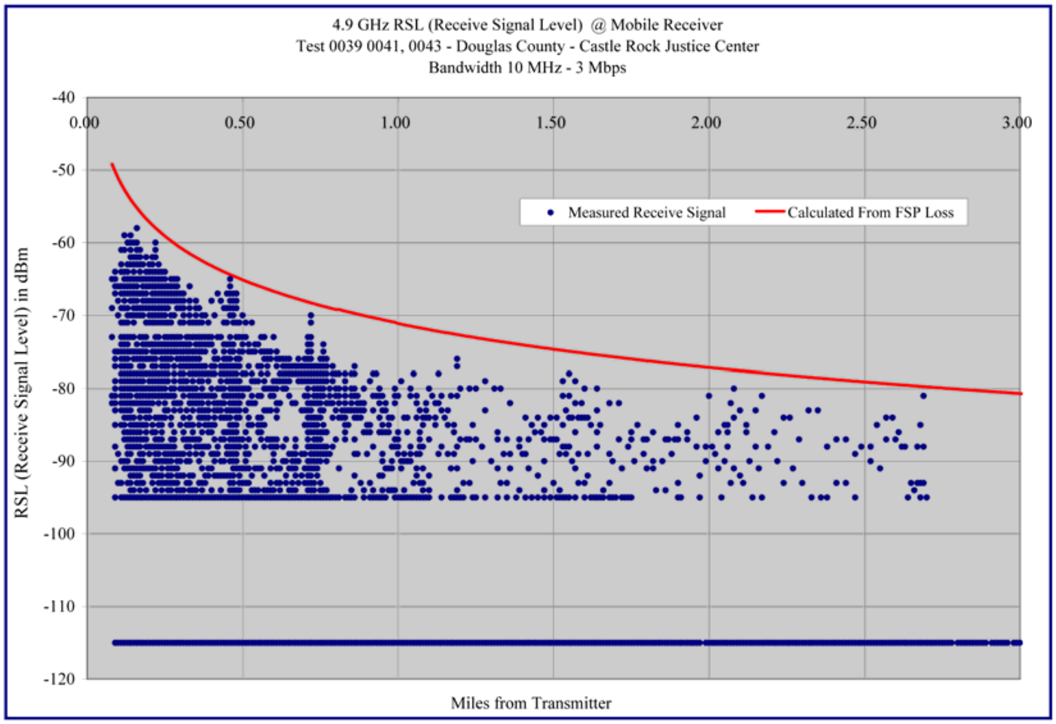
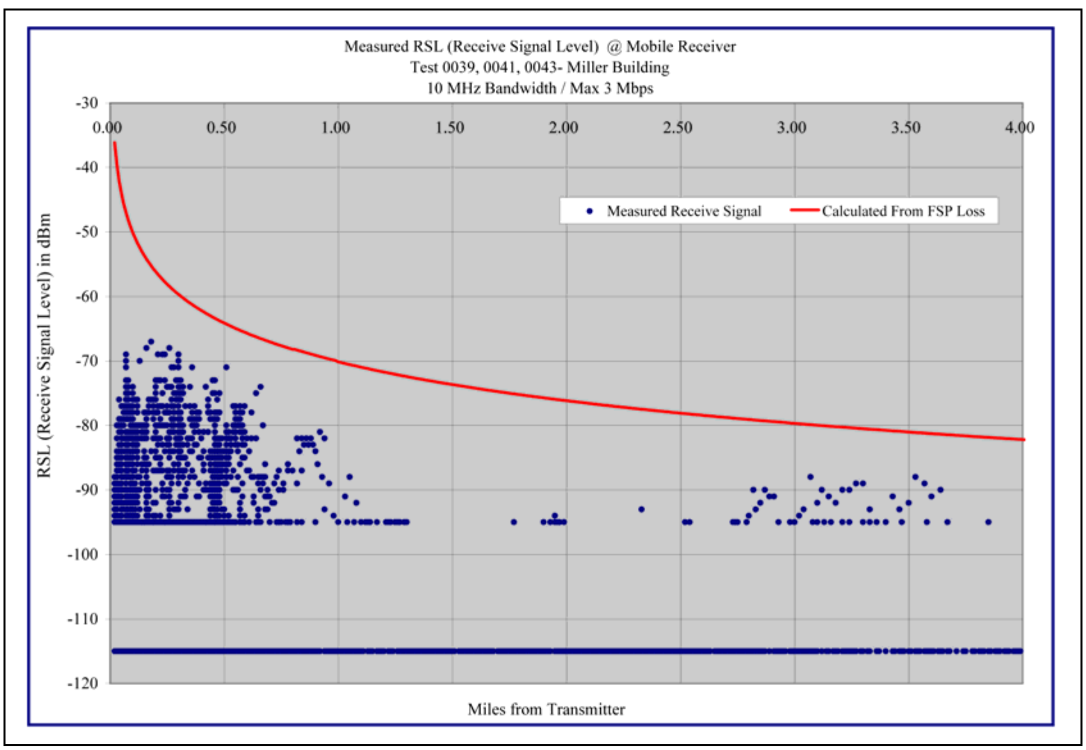
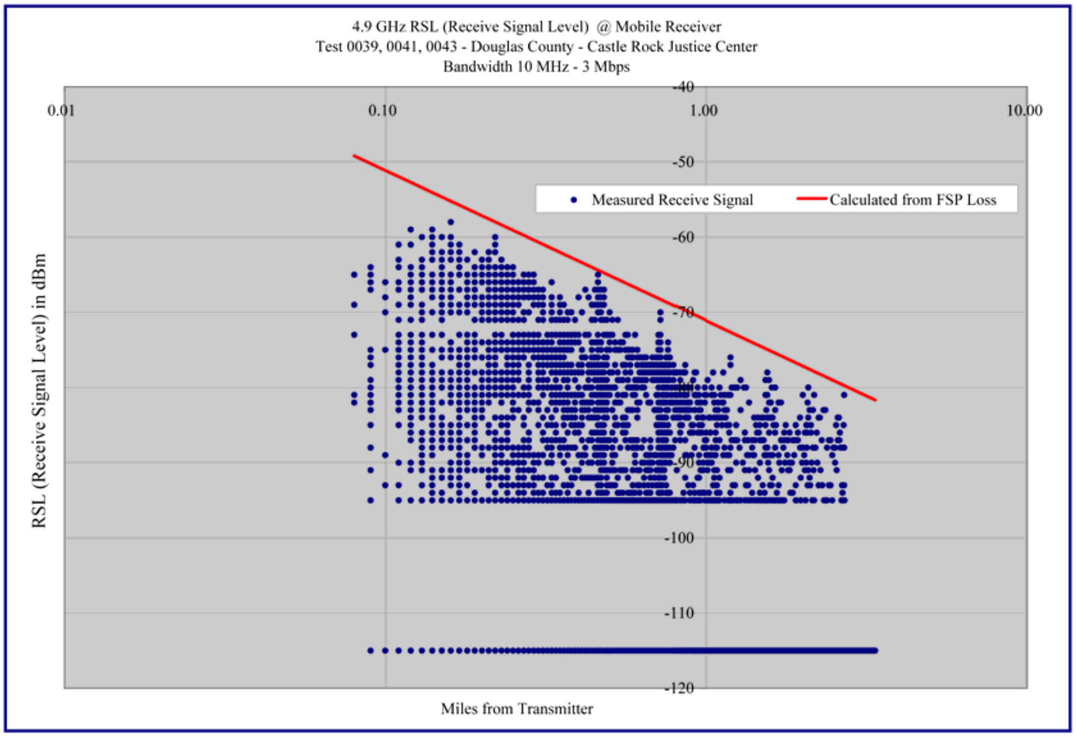
Table 4.11 – Map Legend			
Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76



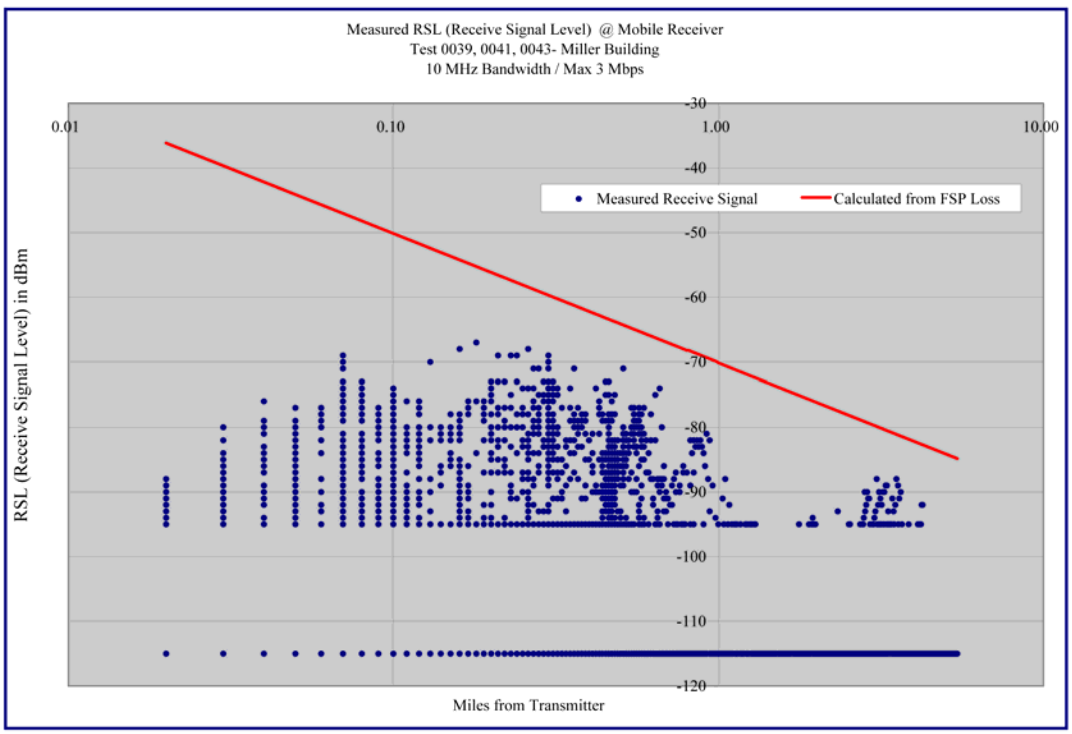
Graph 4.1 - Justice Center – 10 MHz / 3 Mbps -Receive Signal Level versus Distance



Graph 4.2 – Miller Building – 10 MHz / 3 Mbps - Receive Signal Level versus Distance



Graph 4.3 – Justice Center – 10 MHz / 3 Mbps - Receive Signal Level Versus Distance-Log-Log



Graph 4.4 – Miller Building – 10 MHz / 3 Mbps - Receive Signal Level Versus Distance-Log-Log

Graphs 4.1, 4.3, 4.5, and 4.7 show coverage from the Justice Center, and 4.2, 4.4, 4.4, and 4.8 from the Miller Building in Douglas County in Castle Rock, Colorado. The drive test was done simultaneously for both buildings.

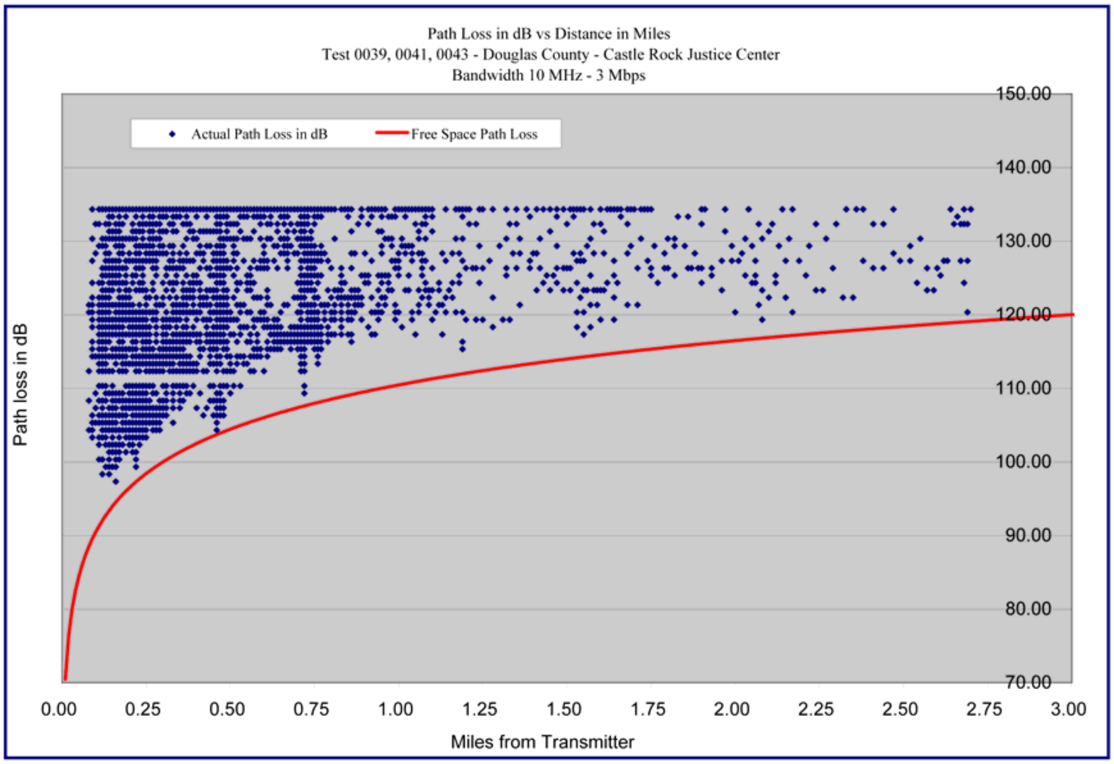
There were differences in the installations. The Justice Center installation was a rooftop installation with four to 90° sector antennas, at approximately 65 ft. above ground level. The justice center Is in a slightly more open area. The Miller Building installation was against the side of the penthouse, with three 60° sector antennas at approximately 45ft. above

Although the 60° Proxim antennas were rated for 5.2 GHz, testing showed only a one 1 dB degradation of performance for these antennas. The difference in coverage is more likely because of the surrounding obstructions.

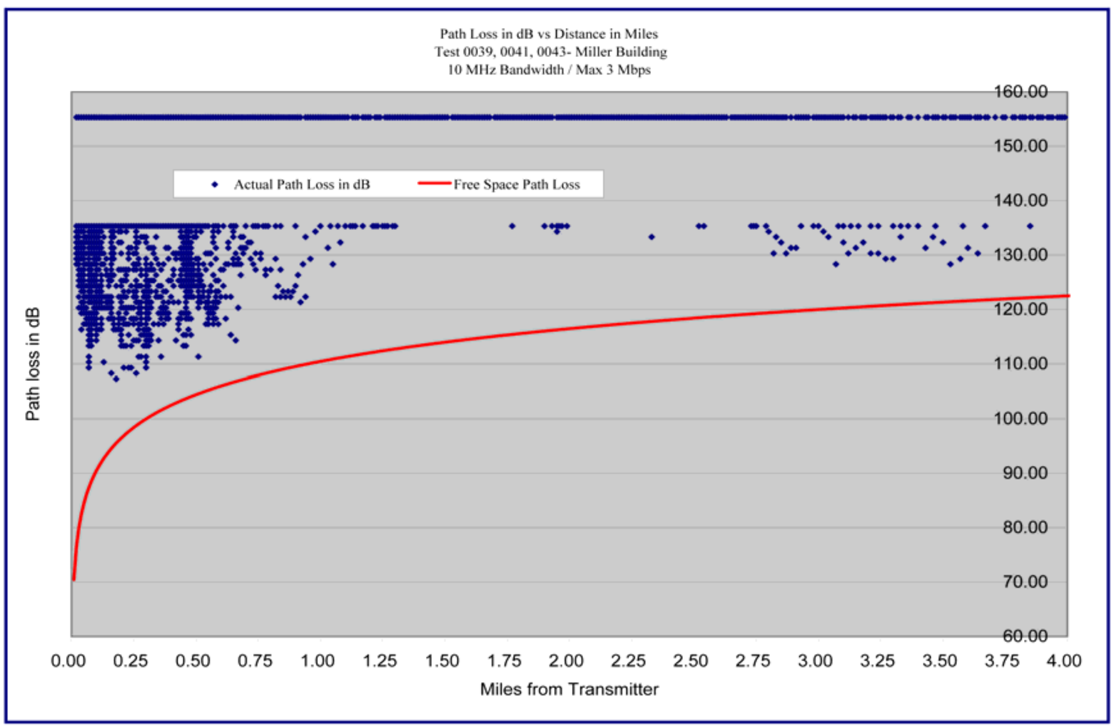
Both of these drive tests show substantially better performance in the test which were done in the mountains (Chapter 3). While both follow the theoretical closely, the Justice Center was within one dB of the theoretical while the Miller Building was within 7 dB of the theoretical. The higher above ground elevation improved the coverage, as is shown from the Justice Center. In new

Free space pathloss graphs.

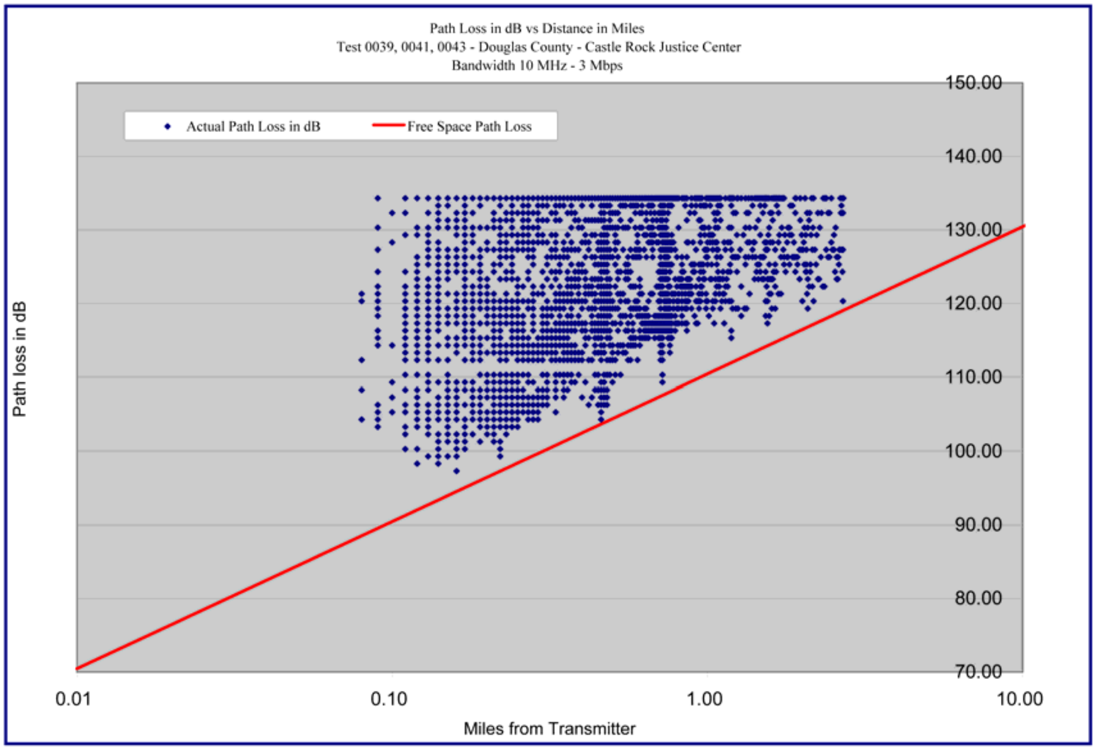
The next four graphs, 4.5, 4.6, 4.7, and 4.8 show the actual measured pathloss versus theoretical pathloss. These graphs can be useful in planning similar installations, because they are equipment-independent. Keep in mind that the minimum useful signal level without a receiver BDA is -92 dBm.



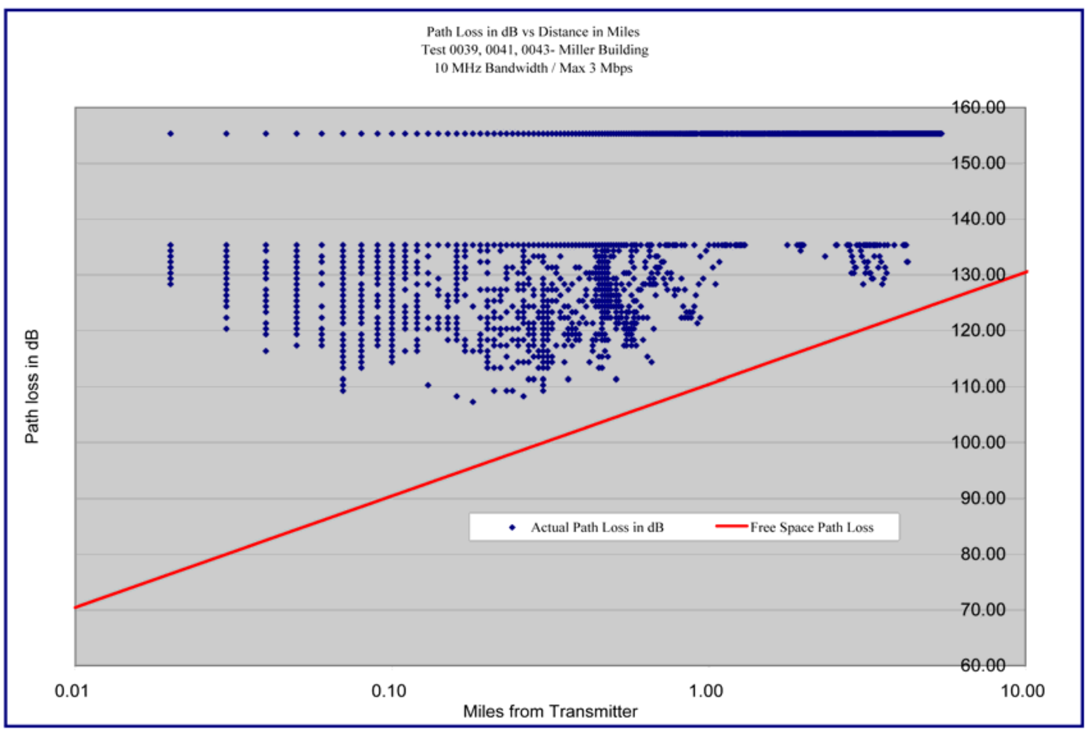
Graph 4.5 – Justice Center – 10 MHz / 3 Mbps – Path Loss versus Distance in Miles



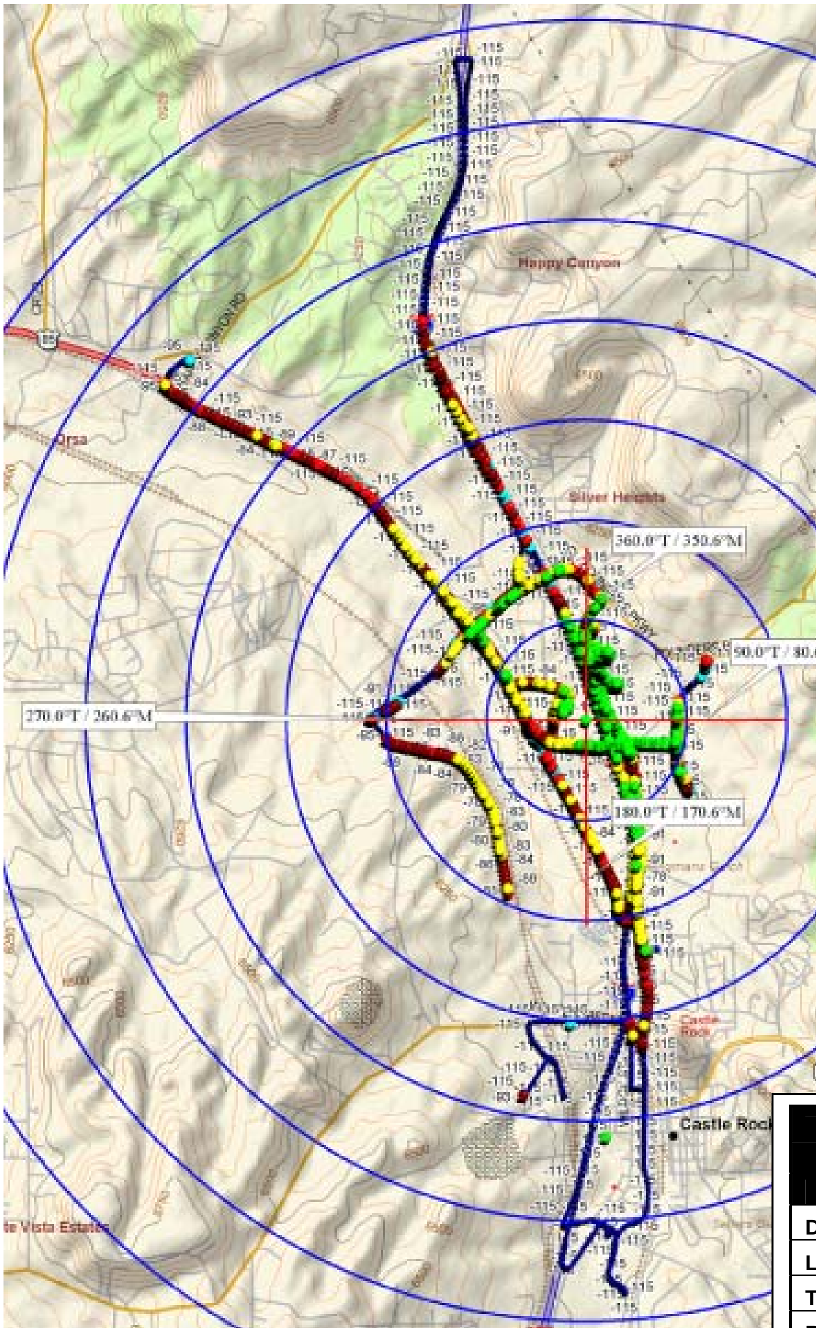
Graph 4.6 – Miller Building – 10 MHz / 3 Mbps – Path Loss versus Distance in Miles



Graph 4.7 – Justice Center – 10 MHz / 3 Mbps - Path Loss versus Distance in Miles – Log-Log Format



Graph 4.8 – Miller Building – 10 MHz / 3 Mbps – Path Loss versus Distance in Miles – Log-Log Format



Map 4.2—Justice Center Coverage

The circles are ½ mile apart to help you judge distances from the transmitter. You'll notice you have green dots up to ¾ of a mile from the transmitter. This nominal rate would be 24 to 27 Mbps. This would be the highest expected throughput.

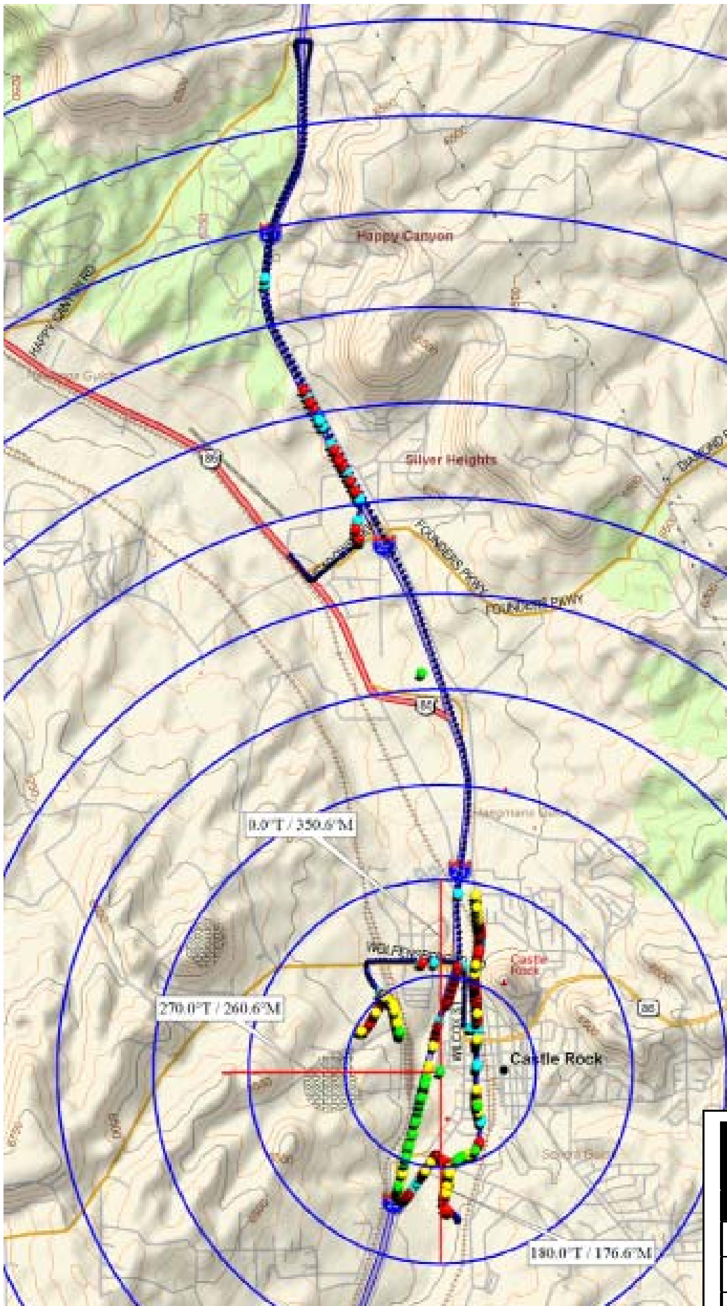
There are still a few locations in two miles from the transmitter that show a nominal rate of twelve 12-18 Mbps.

There are a number of locations up to two miles which show red dots, or a nominal rate of 3 to 4.5 Mbps.

The deployments similar to this shows quite good coverage would make an excellent hotspot or point to mobile multipoint deployment.

Table 4.12 – Map Legend Justice Center
Without BDA

	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76



Map 4.3 Miller Building Coverage

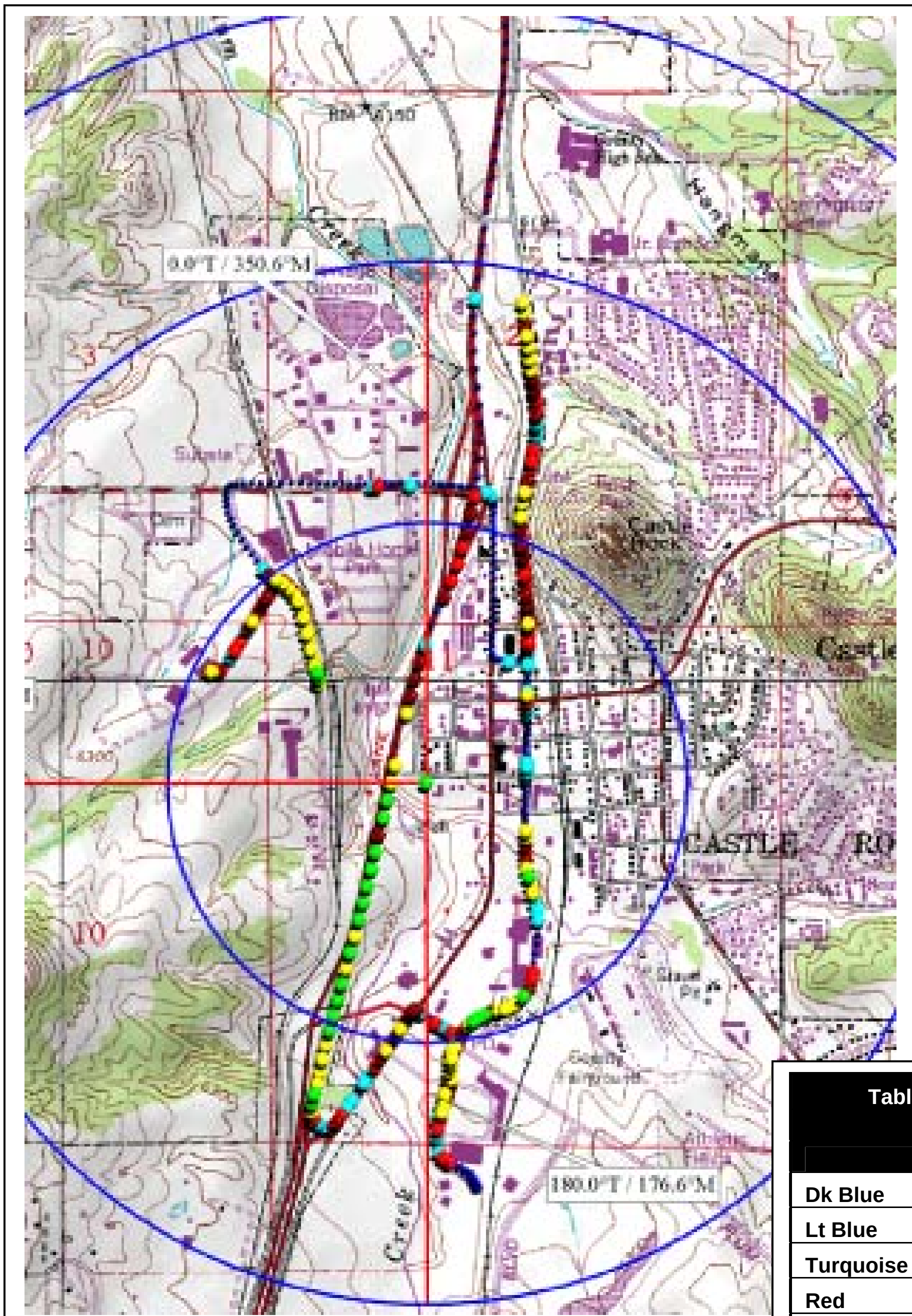
Maps 1.3 and 1.4 Show coverage from the Miller Building. Although the coverage is not as good as the coverage from the Justice Center, is relatively good coverage from the site.

Circles on the map: ½ mile apart and show red dots (low throughput) at 3 and 3½ miles from the site. This indicates a nominal coverage of at least 3 Mbps.

There is an area on I-25 for this no coverage due to the topography.

Table 4.13 – Map Legend – Miller Building Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 4.13 Miller Building Legend



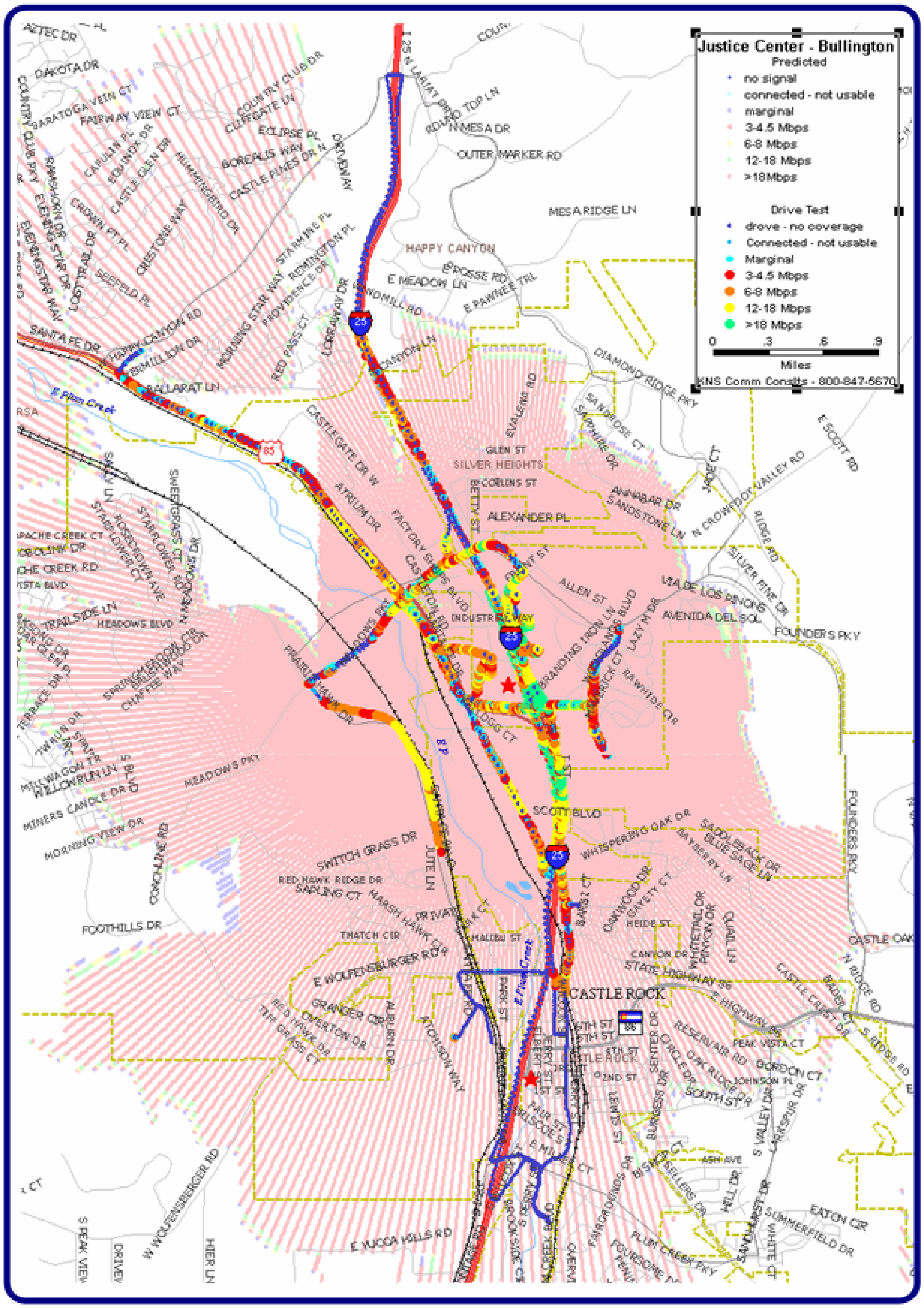
Map 4.4 - Miller Building Coverage

Maps 1.3 shows a more detailed coverage map. Many spots within a mile of the site show good coverage.

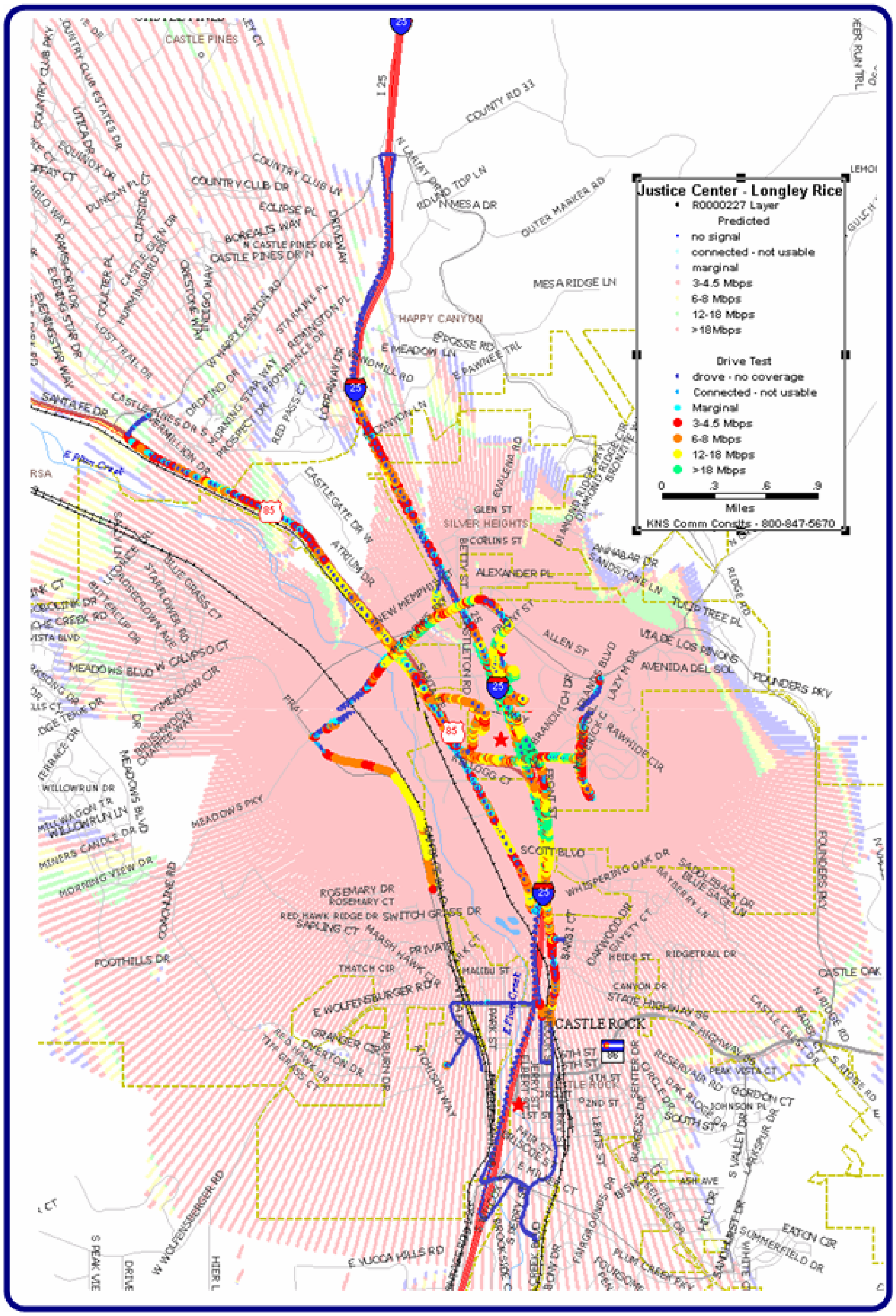
One of the purposes of testing both the Miller Building and the Justice Center at the same time was to determine whether seamless coverage would be possible if both buildings were included in a network infrastructure. The maPS indicate that this would indeed be possible.

Table 4.14 – Map Legend – Miller Building
Without BDA

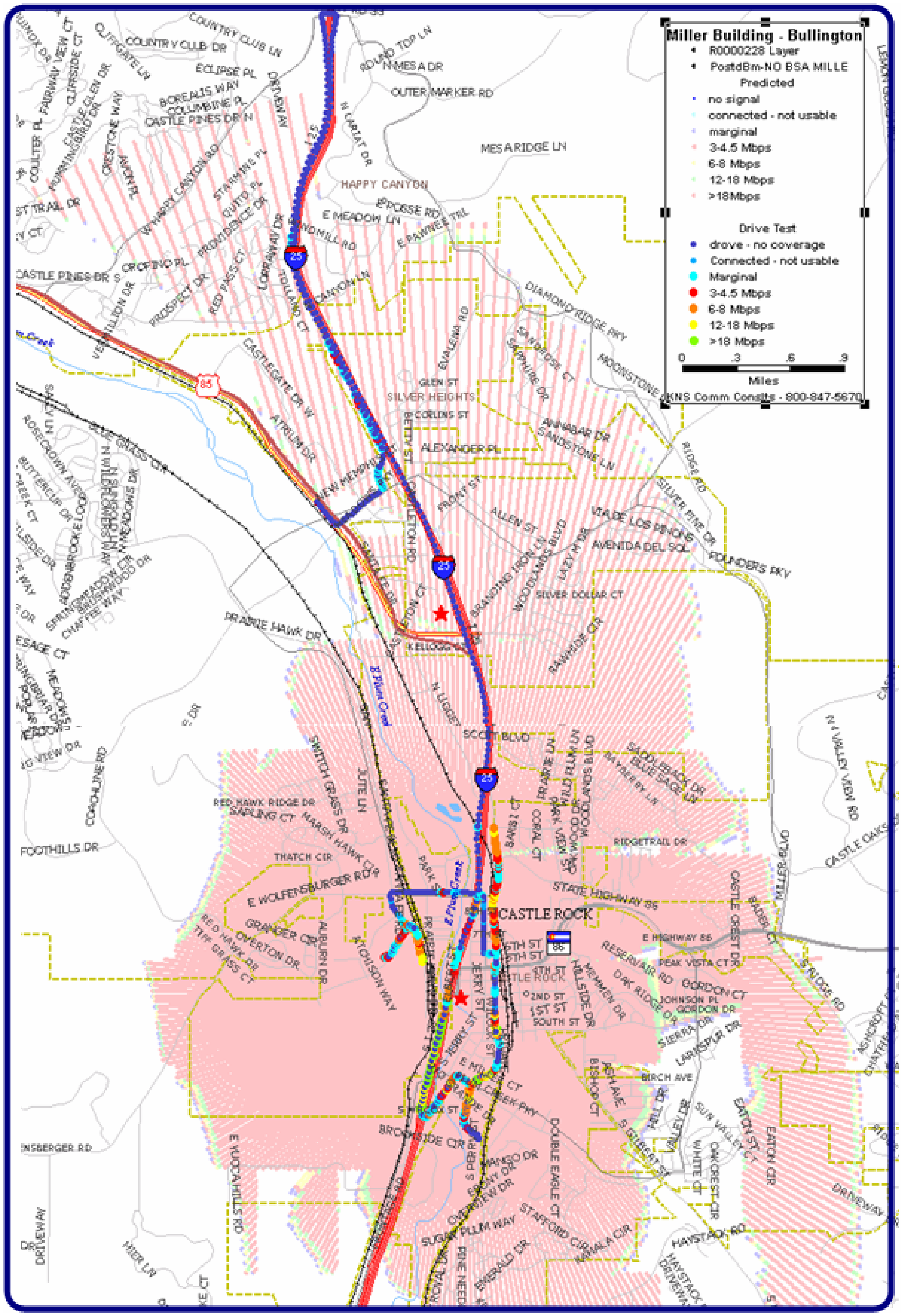
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76



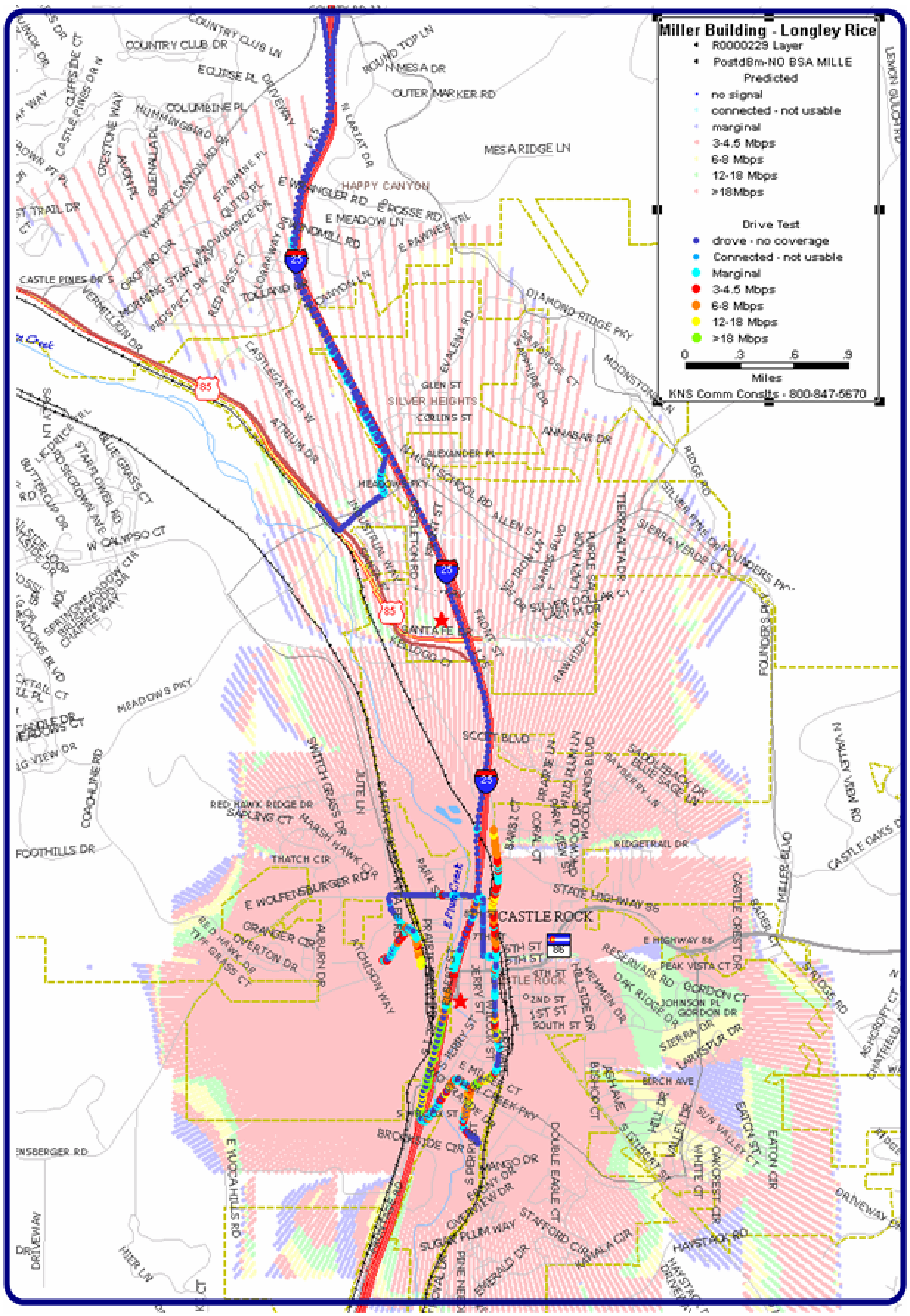
Map 4.5 – Justice Center – Bullington Coverage Prediction



Map 4.6 – Justice Center – Longley-Rice Coverage Prediction



Map 4.7 – Miller Building – Bullington Coverage Prediction



Map 4.8– Miller Building – Longley-Rice Coverage Prediction

Maps 4.5 and 4.6 show two predictive models which were used to determine possible coverage at the Justice Center.   Maps 4.7 and 4.8 showed two predictive models that are used to determine possible coverage of the Miller Building. Two models which were used were the Bullington inflection model, and the Longley-Rice model. When used with area obstruction files, the models were overly conservative.   The time to build a building by building obstruction model is too expensive to be realistic and usable.

Both models are useful in determining areas where coverage is probably not feasible.   The Longley-Rice model was slightly more accurate – but either model could be used for initial first pass to determine coverage. Under no conditions, for the models the use without accompanying drive tests.

For a drive test the accurate, it must have many samples taken every second in order to average the effects of Raleigh Fading or multipath conditions. Automatic logging software which is associated with logging of GPS coordinates must be used in order to accurately determine access point placement.

Summary Study 1 – 10 MHz Bandwidth, 3 Mbps Max Throughput

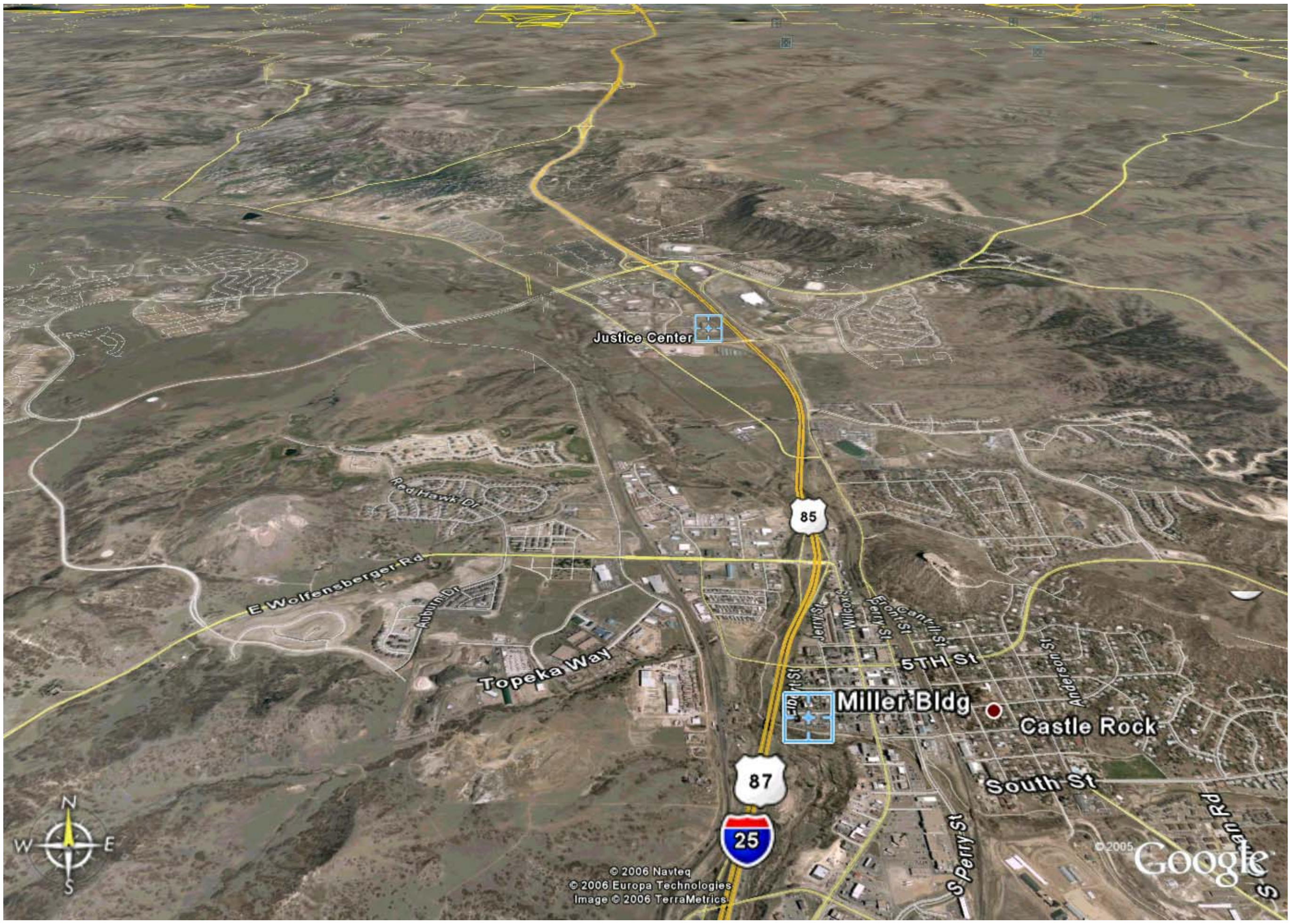
Both the justice center and Miller Building installations performed very well. While the Miller Building had some hotspot locations at further distances, the overall best performance was I-25 corridor as well as some of the ancillary side streets.

Table 4.8 shows a summary of the various performance parameters, side by side for easy comparison. Installations in similar settings should perform very well.

Even if the EIRP must be reduced to 26 dBm, the system would perform very well. The performance penalty is approximately 30% for the reduction in EIRP.

	Justice Center	Miller Building
Test Numers	0039, 0043, 0044	0039, 0043, 0044
Study No for this Chapter	1	1
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Thoroughput Setting	3 Mbps	3 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	surburban foothills	surburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	Semi-arid	Semi-arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	2.5 miles	3.6 miles
Minimum	0 miles	0 miles
Throughput - Mbps		
Maximum	24-27	24-27
Minimum	3-4.5	3-4.5
Path Loss Above Theoretical in dB		
Minimum	1	8
Maximum	4	18
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		
Overall Coverage	Very Good	Good
Comment	Justice Center has better overall coverage	

Table 4.15 – 10 MHz Bandwidth, Max 3 Mbps Throughput – Site Comparison



Picture 4.7 – Satellite View of Castle Rock Study Area

Study 2
Test Parameters: 10 MHz Bandwidth / Maximum Throughput 6 Mbps

Summary

The maximum throughput was limited to six Mbps for Study 2. The field strengths showed good coverage and high throughput. The lowest reliable signal per 802.11j is -90 dBm. It was expected that as the bandwidth increased, the throughput would also increase, but the cost is a decreased coverage footprint. As the maximum throughput increased, the coverage also decreased.

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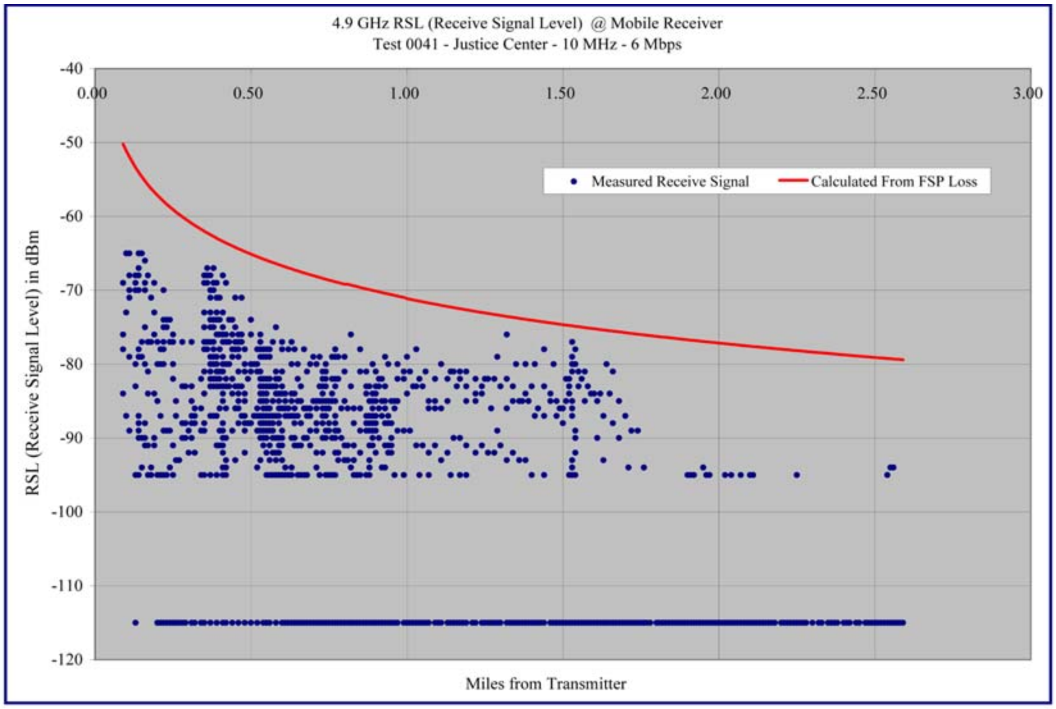
Table 4.16 - Map Legend			
Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Graphs 4.9, 4.11, 4.13 and 4.15 show scatter graphs from the Justice Center. Graphs 4.10, 4.12, 4.14, 4.16 show scatter graphs from the Miller Building. Graphs 4.9 and 4.10 compare field strength readings versus distance for Justice Center and the Miller Building. Graphs 4.11 and 4.12 show the same comparison, but in a log-log format.

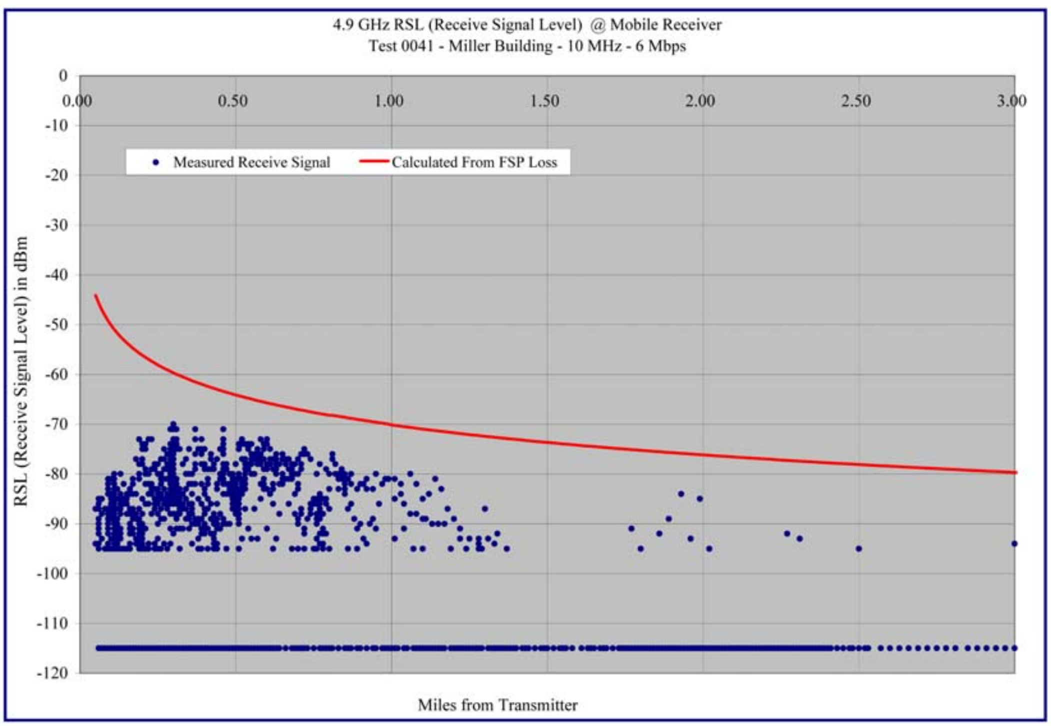
Graphs 4.13 and 4.14 show scatter graphs which compare path loss versus distance from Justice Center and the Miller building. Graphs 4.15 and 4.16 show the same comparison, but in a log-log format.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable.

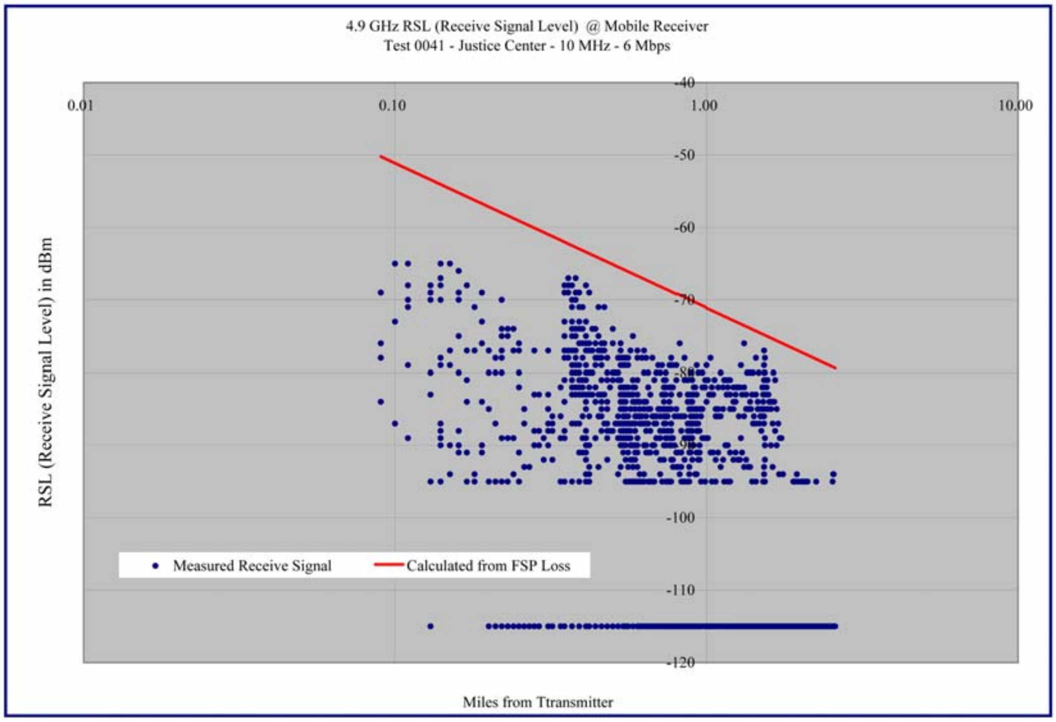
The path loss graphs are equipment independent and can be used to evaluate specific equipment for performance in similar installations.



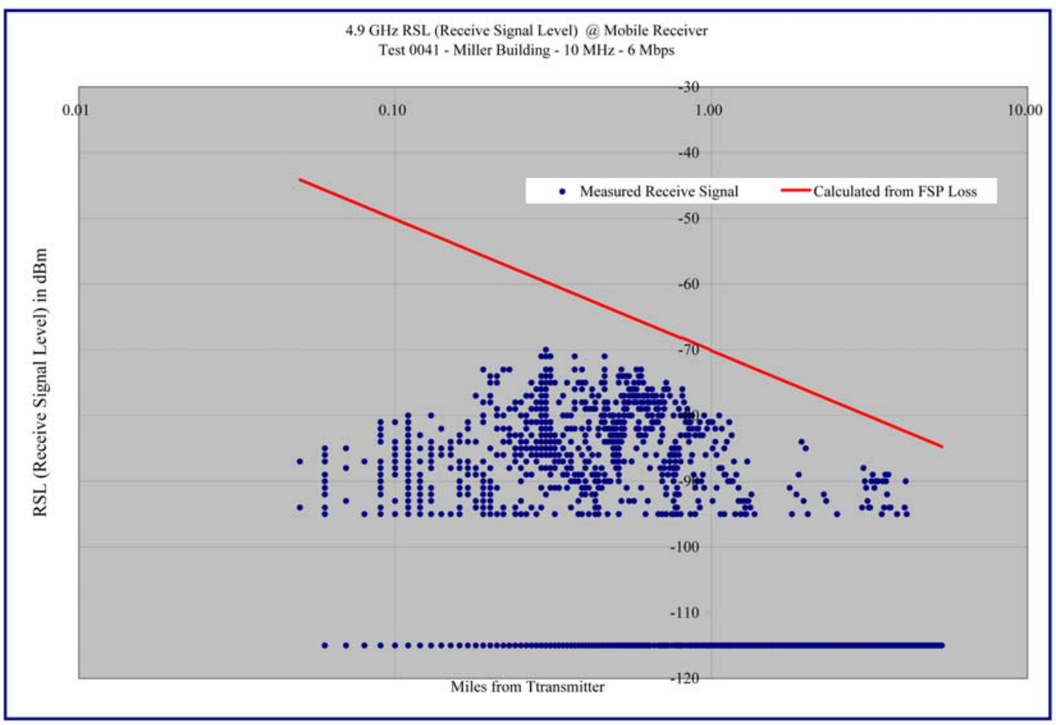
Graph 4.9 – Justice Center - 10 MHz/ 6 Mbps – Receive Signal versus Distance



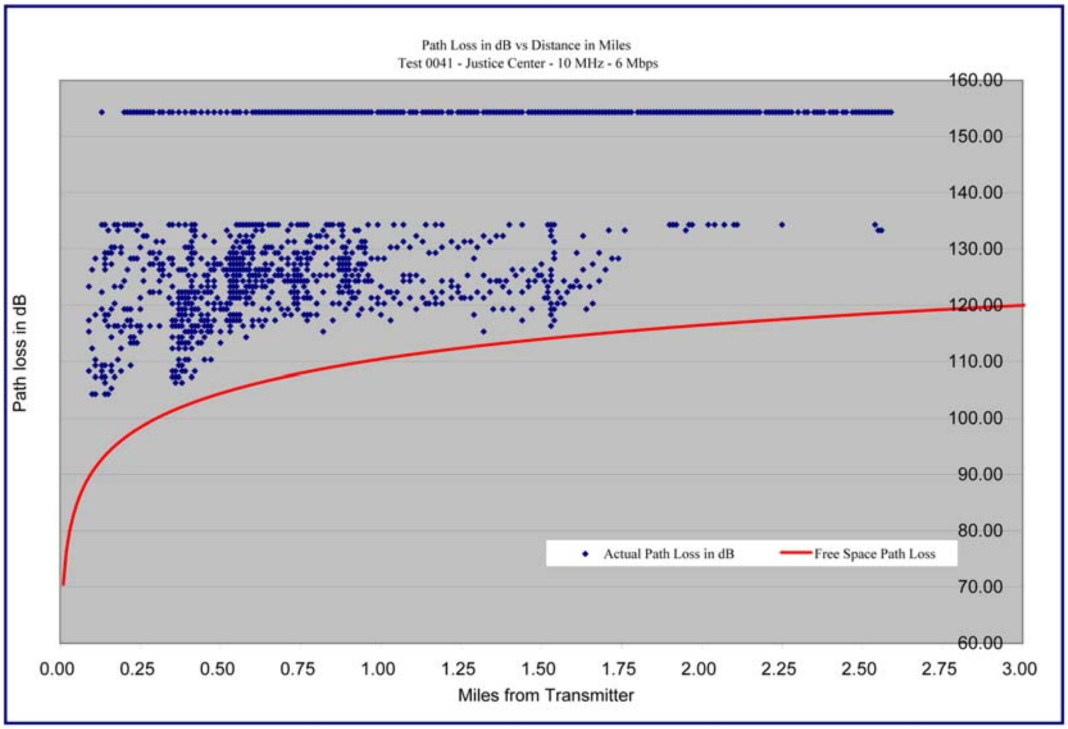
Graph 4.10 – Miller Building – 10 MHz/ 6 Mbps - Receive Signal versus Distance



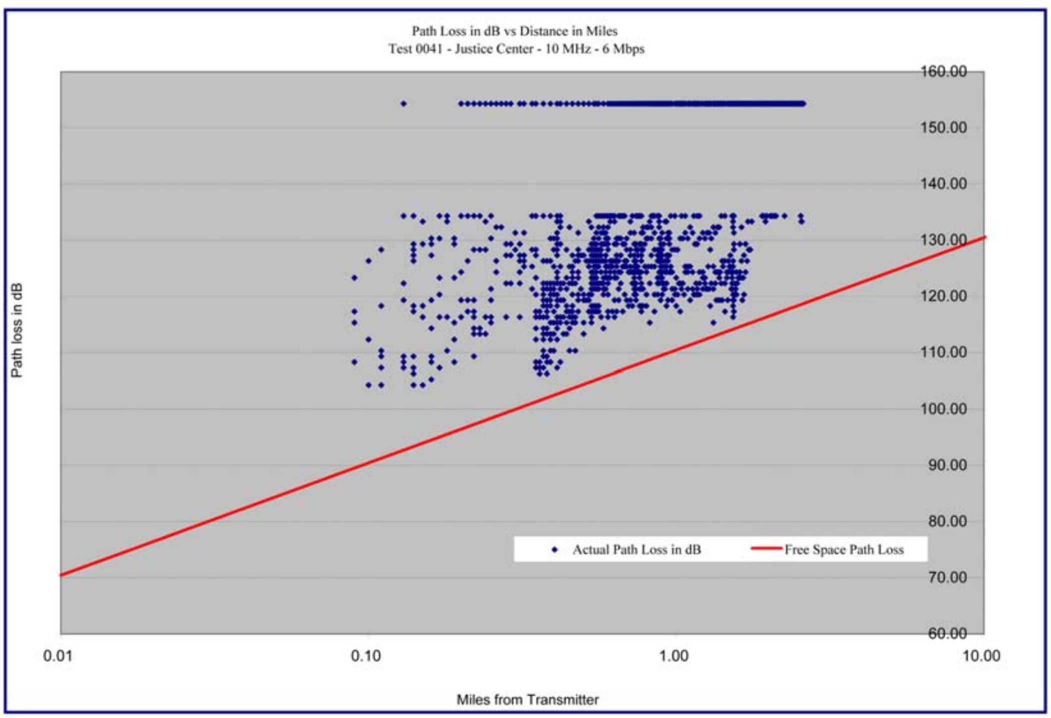
Graph 4.11 – Justice Center -10 MHz/ 6 Mbps - Receive Signal versus Distance- Log-Log Format



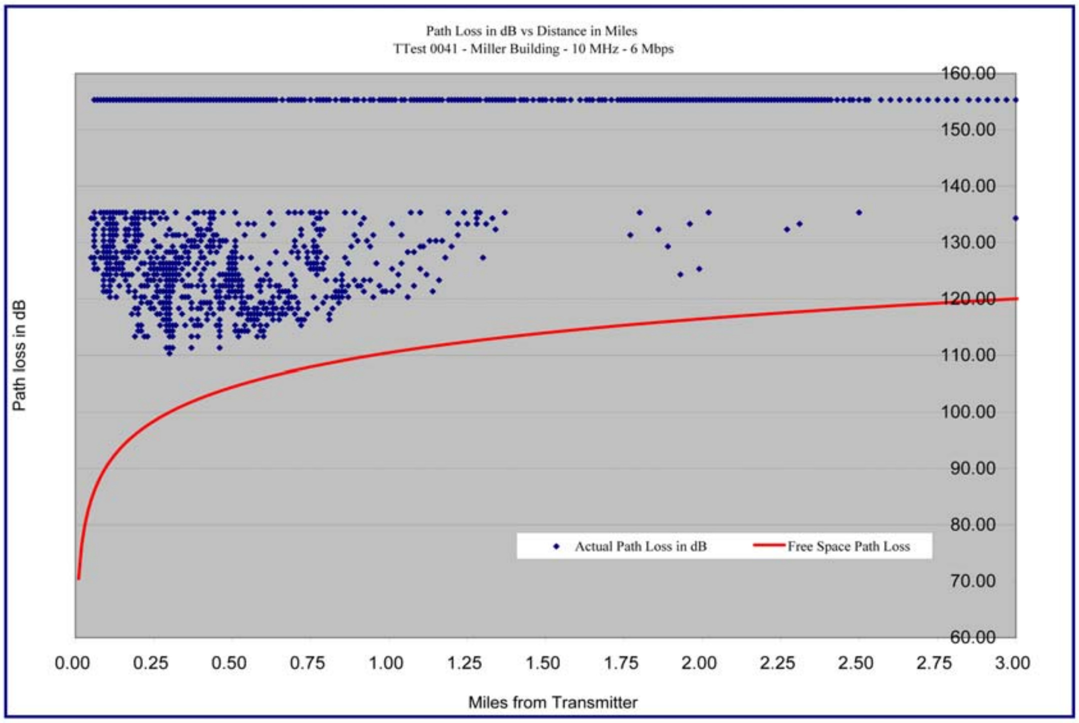
Graph 4.12 – Miller Building – 10 MHz / 6 Mbps - Receive Signal Level versus Distance — Log-Log Format



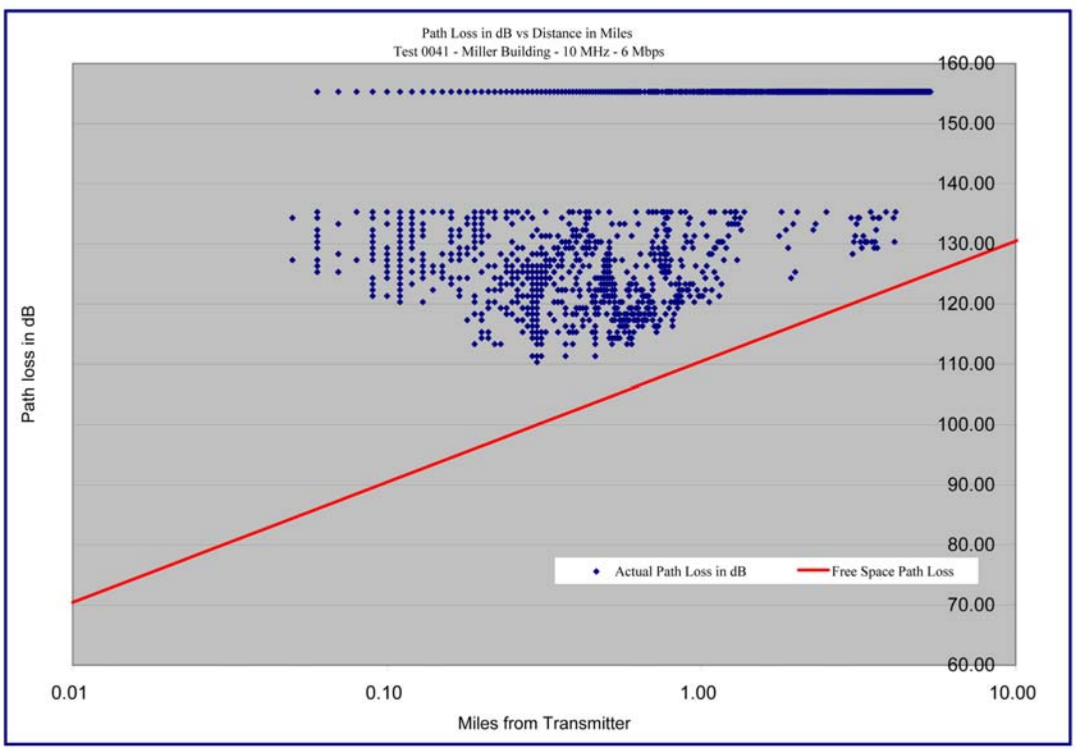
Graph 4.13– Justice Center – 10 MHz / 6 Mbps– Path Loss versus Distance



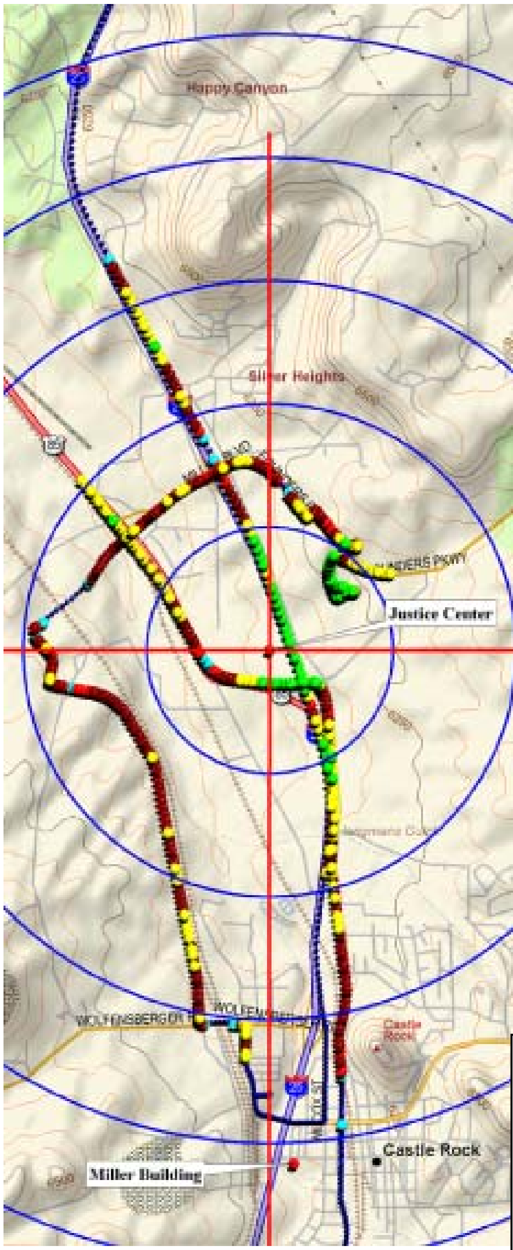
Graph 4.14– Justice Center –10 Mhz / 6 Mbps - Path Loss versus Distance – Log-Log Format



Graph 4.15– Miller Building –10 MHz / 6 Mbps - Path Loss versus Distance



Graph 4.16– Miller Building – 10 MHz / 6 Mbps - Path Loss versus Distance – Log-Log Format



Map 4.9 Justice Center Coverage

Justice Center – 10 MHz, Maximum 6 Mbps

The circles are ½ mile apart. This will help the reader to judge distances from the transmitter.

There were green dots representing the highest throughput up to almost 1½ mile from the transmitter. Most locations with higher throughput were within ½ mile of the transmitter.

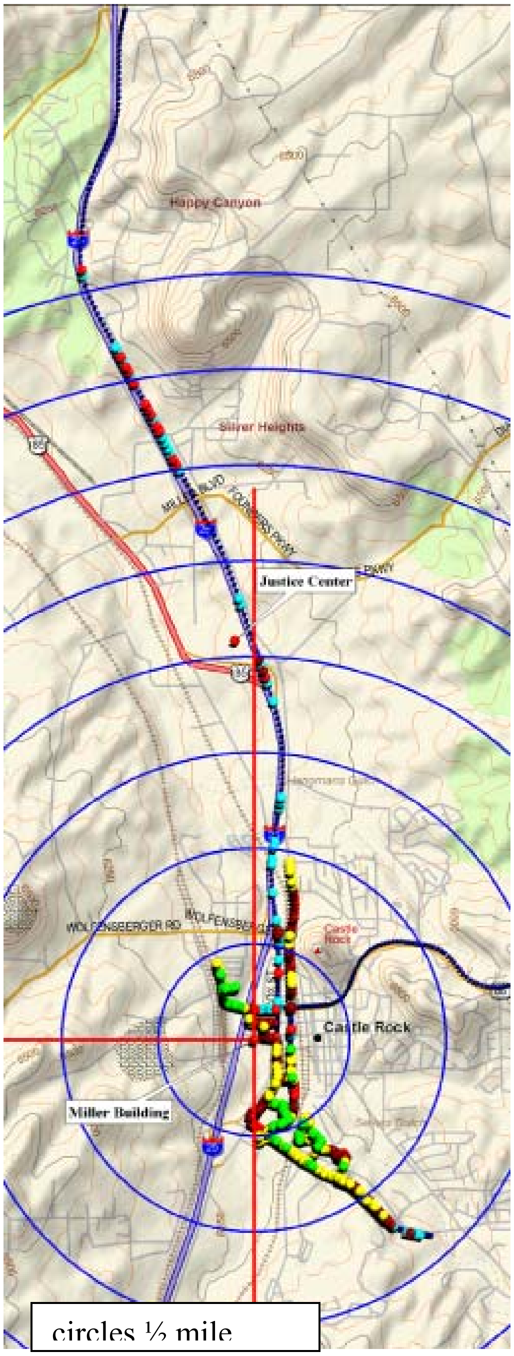
Coverage extended slightly beyond 1½ to 2 miles from the transmitter site.

In contrast, Study 1 which had 10 MHz bandwidth and a maximum throughput of 3 Mbps showed coverage from 2.5 from the Justice Center AP's. Increasing the allowable bandwidth in the AP's resulted in decreased coverage.

All of the rates shown are "nominal" rates has defined in 802.11j.

Table 4.17 – Legend – Justice Center Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Circles are ½ mile apart



Map 4.10 - Miller Building Coverage

The Miller Building – 10 MHz, Maximum 6 Mbps

The circles are ½ mile apart. There is coverage up to 3½ miles from the Miller Building. In contrast Study 2 (10 MHz bandwidth, Maximum 3 Mbps) had sites slightly over 3.5 miles.

The difference was not as noticeable between the two studies as it was with the Justice Center.

All high throughput areas (green dots) are within 1 mile of the building.

An increase the maximum allowable throughput decreased the coverage slightly.

Table 4.18 – Map Legend – Miller Building Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

	Justice Center	Miller Building
Test Numbers	**0041**	**0041**
Study No for this Chapter	**Study 2**	**Study 2**
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	6 Mbps	6 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	2.2	4
Minimum	0	0
Throughput - Mbps		
Maximum	24-27	24-27
Minimum	3-4.5	3-4.5
Path Loss Above Theoretical predictions in dB		
Minimum	2	7
Maximum	13	28
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		
Overall Coverage	Good	Good
Comment	Justice Center has better overall coverage	

Table 4.19 – 10 MHz Bandwidth / Max 6 Mbps Throughput – Site Comparison

Study 3
Test Parameters: 20 MHz Bandwidth /Maximum Throughput 6 Mbps

Summary

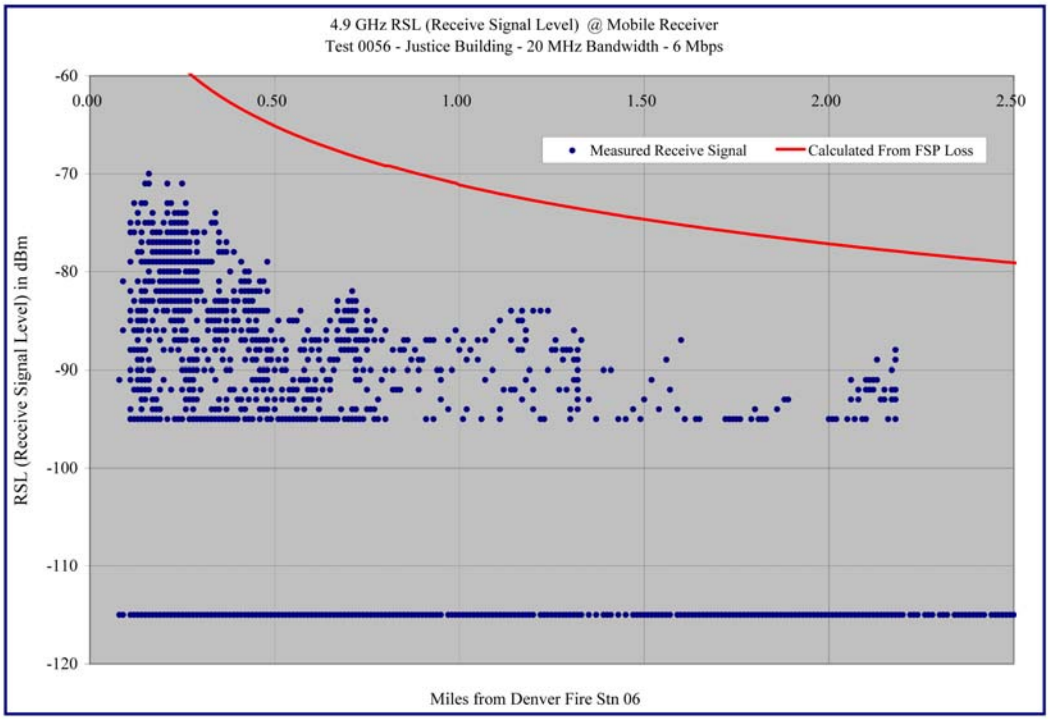
All studies done in Castle Rock (Chapter 4) used the same equipment, so the tests are comparable. As the bandwidth increased, the throughput also increased, but at a cost of a decreased coverage footprint. . When the AP increased the maximum allowable throughput setting, the coverage also decreased.

Table 4.20 – Map Legends			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

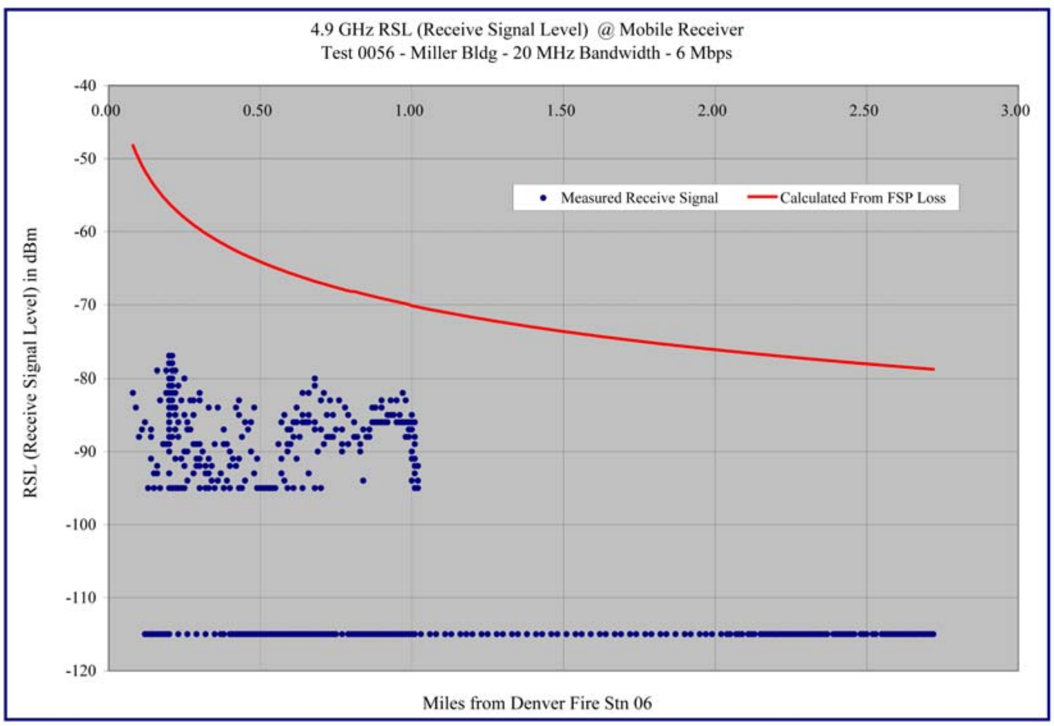
Graphs 4.17, 4.19, 4.21 and 4.23 show scatter graphs from the Justice Center. Graphs 4.16, 4.18, 4.20, 4.22 show scatter graphs from the Miller Building.

Graphs 4.17 and 4.18 compare field strength readings versus distance for Justice Center and the Miller Building. Graphs 4.19 and 4.20 show the same comparison, but in a log-log format. Graphs 4.21 and 4.22 show scatter graphs, which compare path loss versus distance from Justice Center and the Miller building. Graphs 4.23 and 4.24 show the same comparison, but in a log-log format.

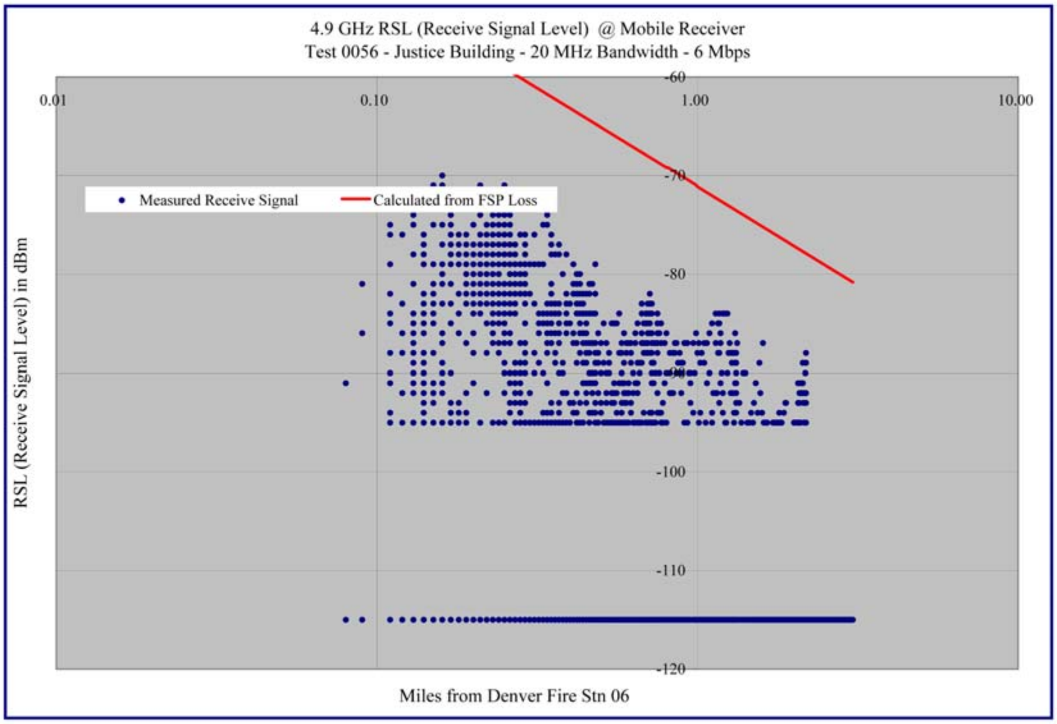
Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable. The path loss graphs are equipment independent and can be used to evaluate specific equipment for performance in similar installations.



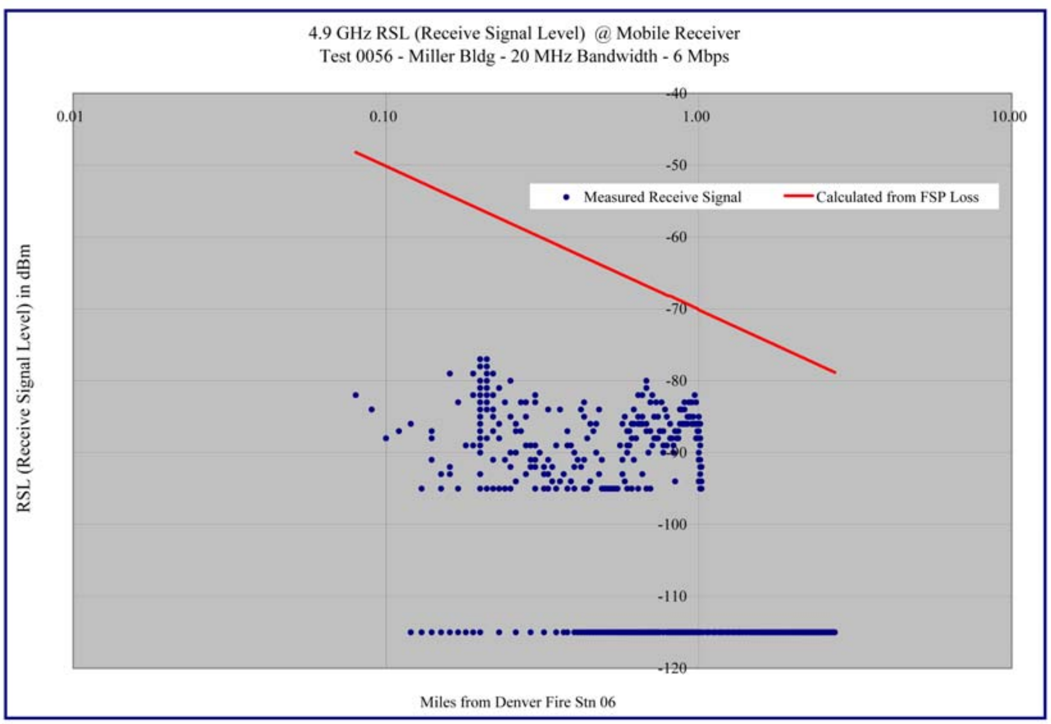
Graph 4.17 – Justice Center – 20 MHz / 6 Mbps - Receive Signal versus Distance



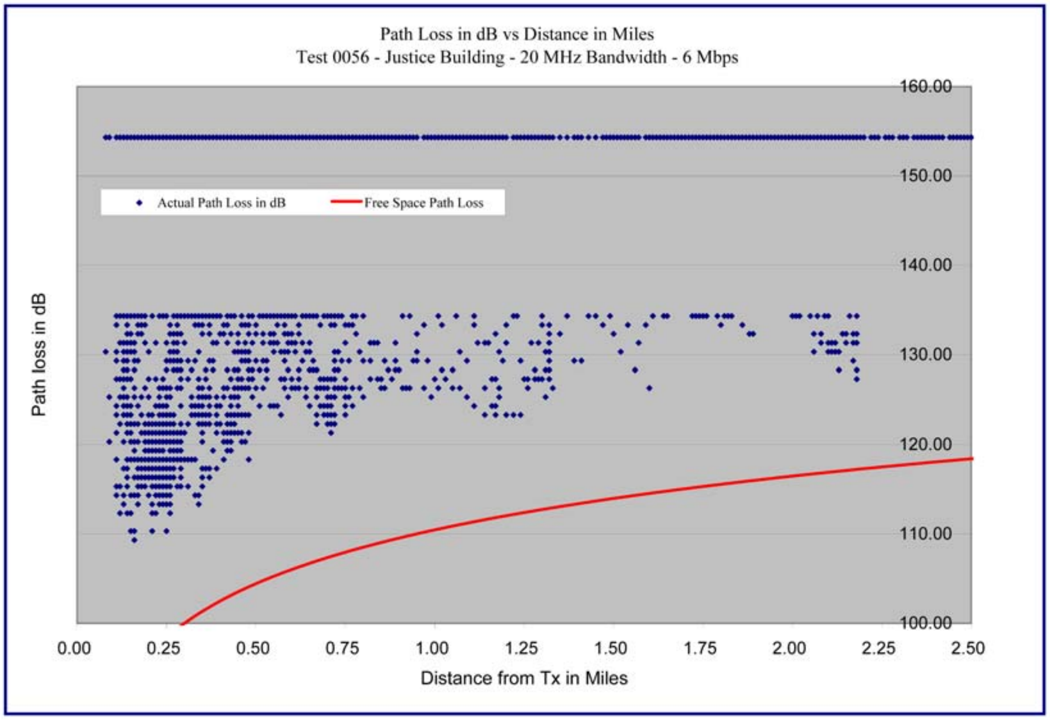
Graph 4.18 – Miller Building – 20 MHz / 6 Mbps - Receive Signal versus Distance



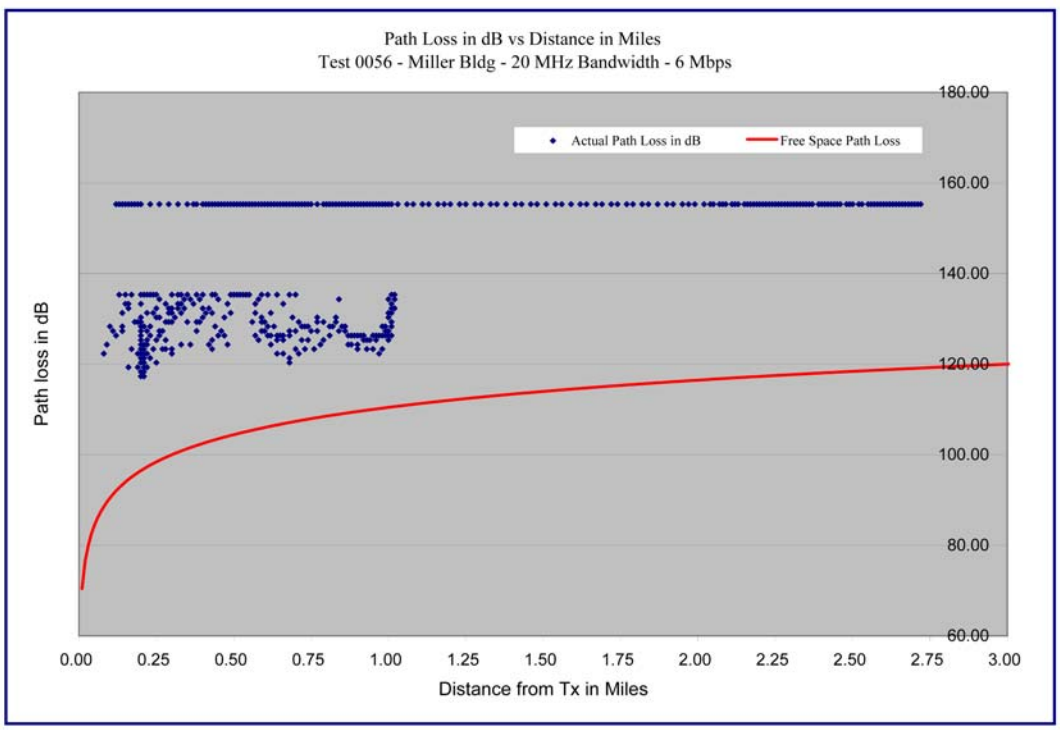
Graph 4.19 Justice Center – Receive Signal Level versus Distance – 20 MHz / 6 Mbps – Log-Log Format



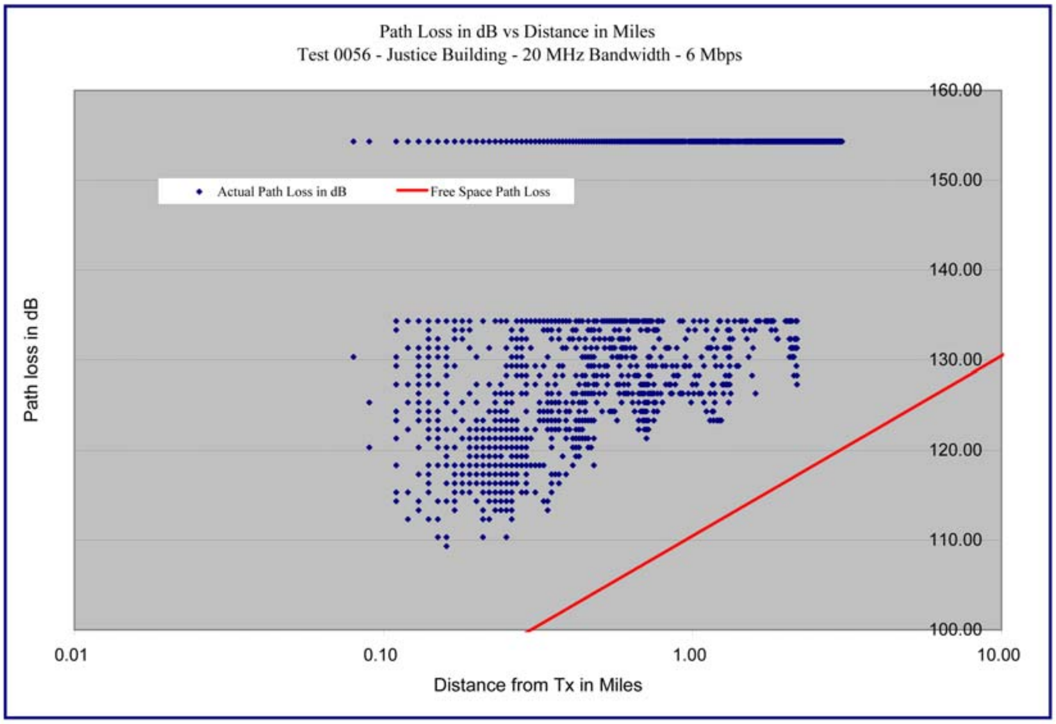
Graph 4.20 Miller Building – Receive Signal Level versus Distance – 20 MHz / 6 Mbps – Log-Log Format



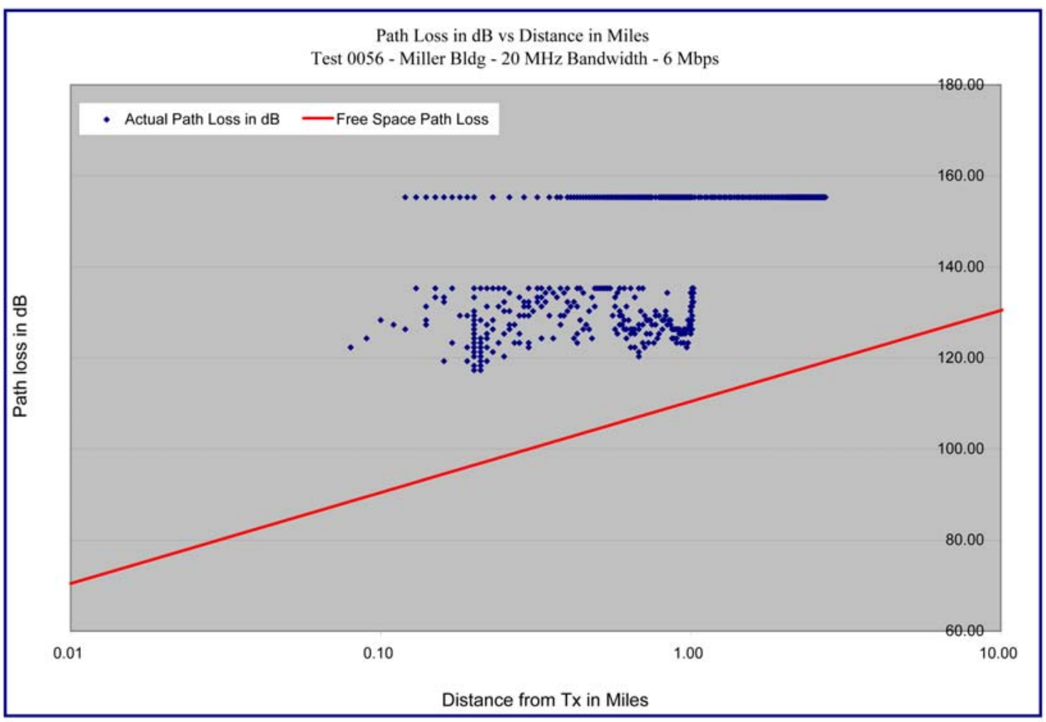
Graph 4.21 – Justice Center – 20 MHz / 6 Mbps – Path Loss versus Distance



Graph 4.22 – Miller Building- 20 MHz / 6 Mbps - Path Loss versus Distance



Graph 4.23 – Justice Center – Path Loss versus Distance – 20 MHz / 6 Mbps – Log-Log Format



Graph 4.24 – Miller Building – Path Loss versus Distance – 20 MHz / 6 Mbps – Log-Log Format

Justice Center – 20 MHz, Maximum 6 Mbps

Maximum throughput points (green dots), were all within ½ mile of the transmitter. The maximum distance for hot spot coverage (red dots) was slightly over 1½ miles.

In comparison, the coverage at 10 MHz bandwidth extended over 2 miles.

<u>When the bandwidth was increased, the coverage footprint decreased, but throughput increased.</u>

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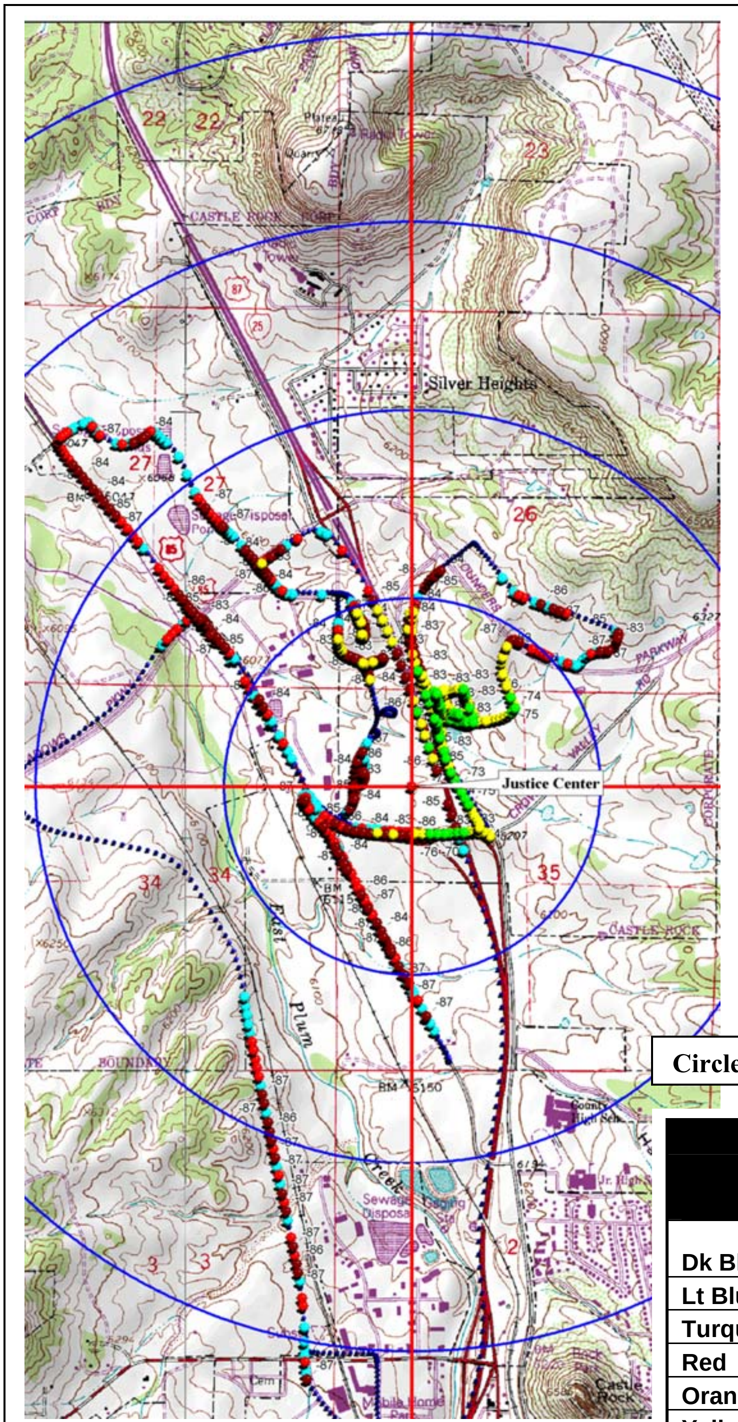
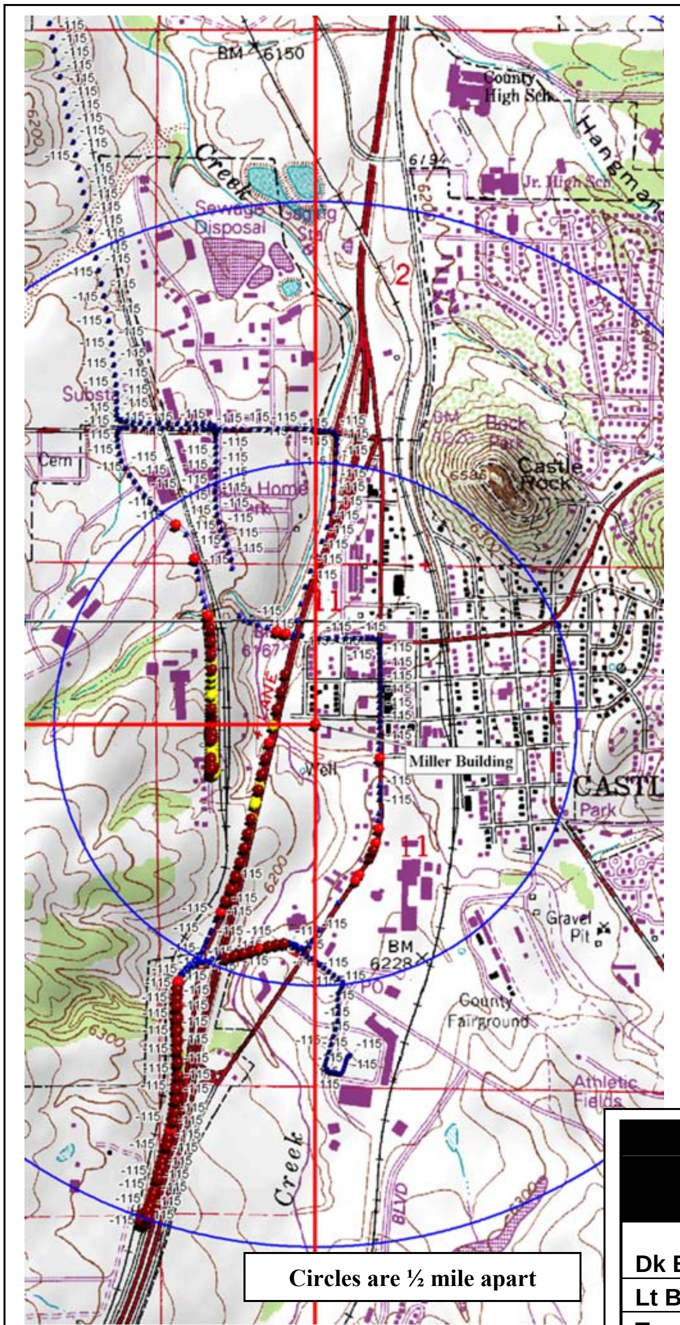


Map 4.11 – Justice Center Coverage

Table 4.21 Justice Center Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76



Map 4.12 Miller Building Coverage

Miller Building – 20 MHz, Maximum 6 Mbps

There was coverage up to 1 mile away from the building. There is no high throughput coverage (green dots) from this building for this test.

The increased bandwidth not only decreased the coverage distance, it also decreased the coverage close to the site. With 10 MHz bandwidth, there were sites with the maximum throughput – there were none observed for this study.

<u>Increasing bandwidth decreased the coverage footprint</u>.

Table 4.22 – Miller Building Map Legend			
	Without BDA		
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

	Justice Center	Miller Building
Test Numbers	0056	0056
Study No for this Chapter	Study 3	Study 3
Deployment Parameters		
Bandwidth	20 MHz	20 MHz
Max Throughput Setting	6 Mbps	6 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	1.6	1
Minimum	0	0
Throughput - Mbps		
Maximum	24-27	18-Dec
Minimum	3-4.5	3-4.5
Path Loss Above Theoretical in dB		
Minimum	11	12
Maximum	15	20
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes

Table 4.23 – Comparison of Sites

Study 4
Test Parameters: 20 MHz Bandwidth / Maximum Throughput 9 Mbps

Summary:

All Castle Rock studies used the same equipment, so the tests were comparable. As the bandwidth increased, the throughput increased, but the cost was a decreased coverage footprint. . When the AP's settings to limit the throughput to a certain rate was increased, the coverage decreased.

Table 4.24 – Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

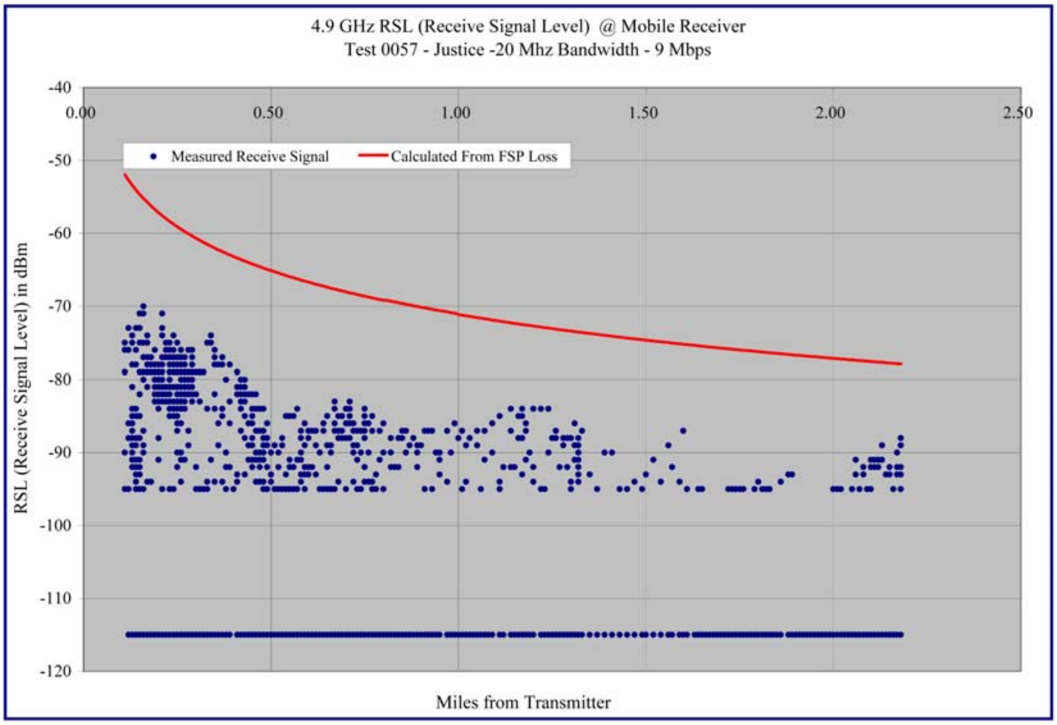
Graphs 4.25, 4.27, 4.29 and 4.31show scatter graphs from the Justice Center. Graphs 4.26, 4.28, 4.30, 4.32 show scatter graphs from the Miller Building.

Graphs 4.25 and 4.26 compare field strength readings versus distance for Justice Center and the Miller Building. Graphs 4.27 and 4.28 show the same comparison, but in a log-log format.

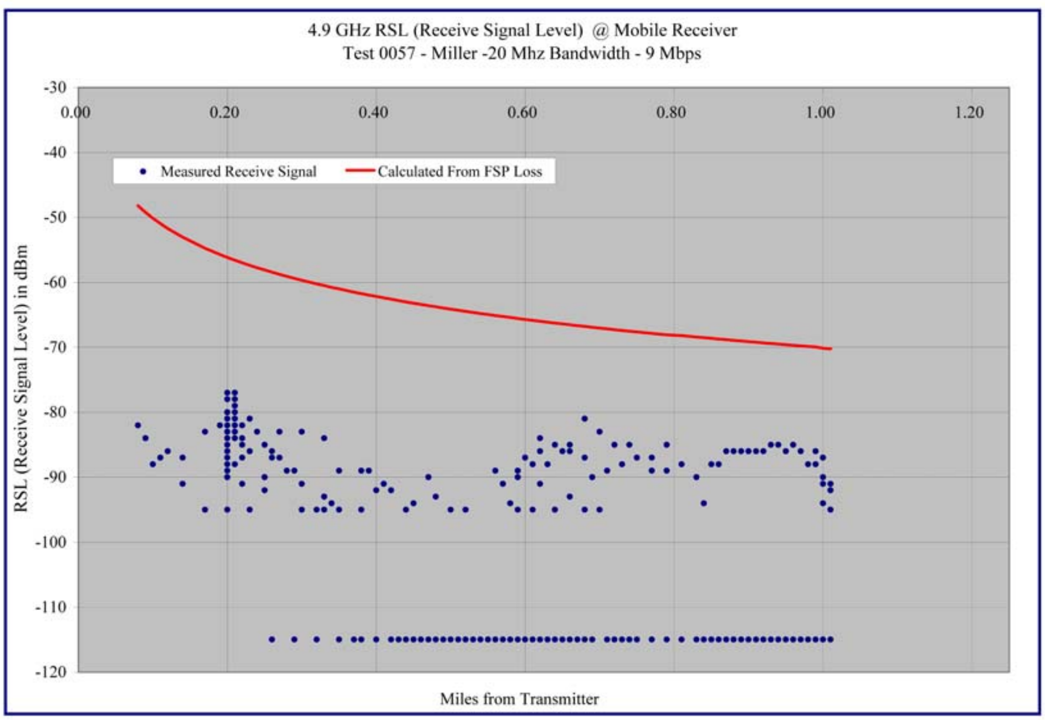
Graphs 4.29 and 4.30 show scatter graphs that compare path loss versus distance from Justice Center and the Miller building. Graphs 4.31 and 4.32 show the same comparison, but in a log-log format.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable.

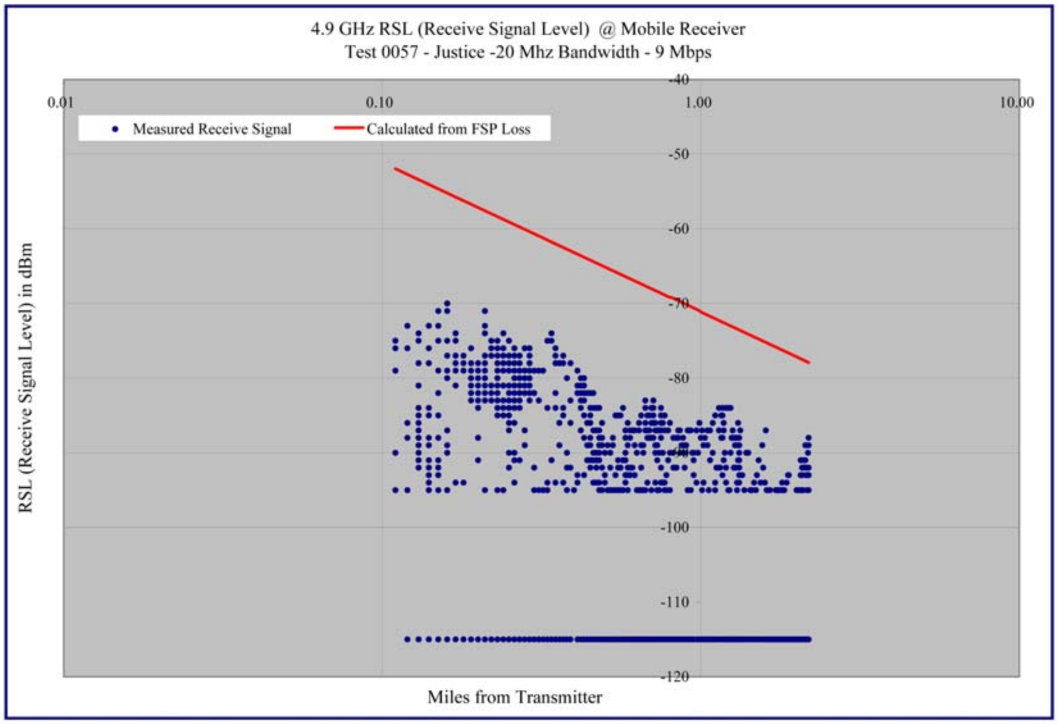
The path loss graphs are equipment independent and can be used to evaluate your specific equipment for performance in similar installations.



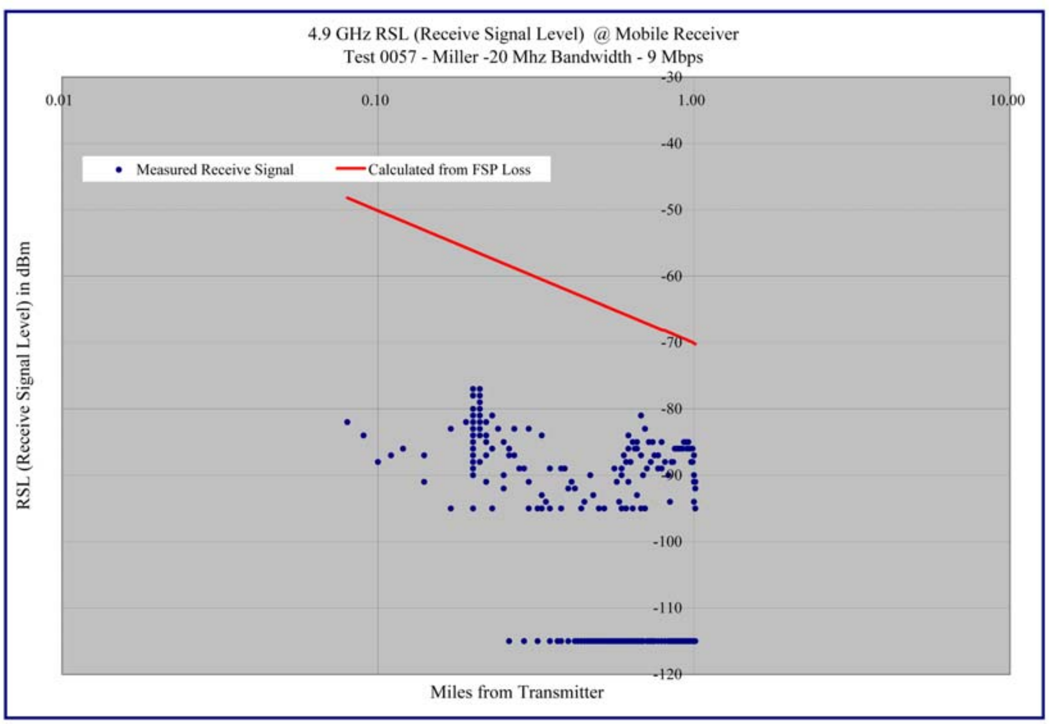
Graph 4.25 – Justice Center – 20 MHz / 9 Mbps - Receive Signal Strength versus Distance



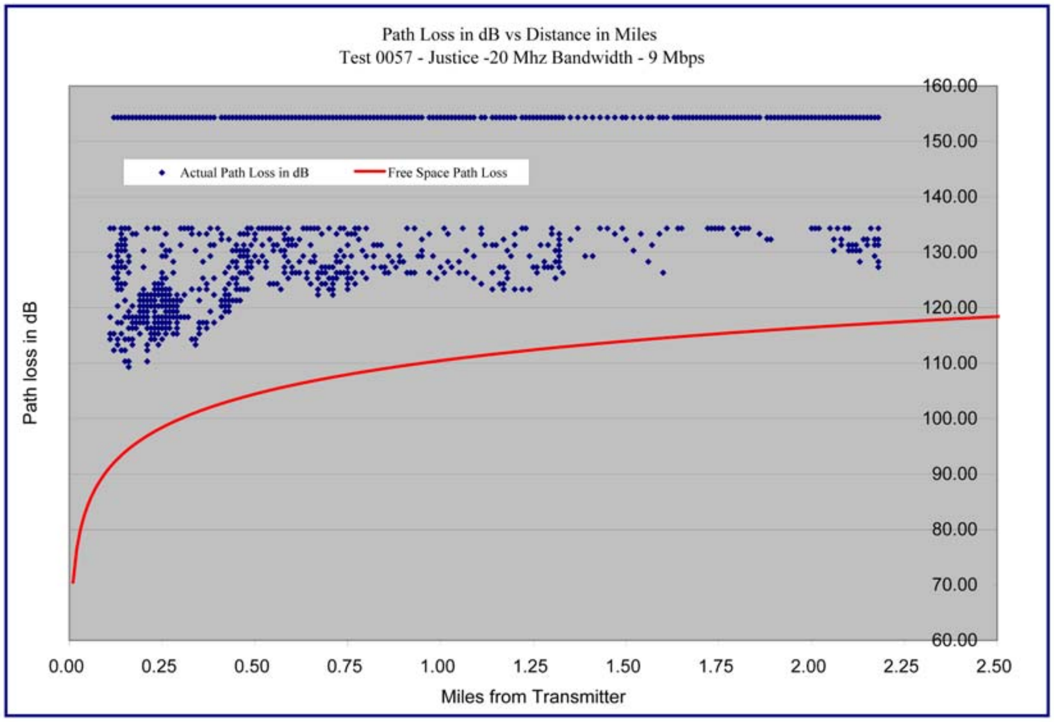
Graph 4.26 – Miller Building - 20 MHz / 9 Mbps – Receive Signal Strength versus Distance



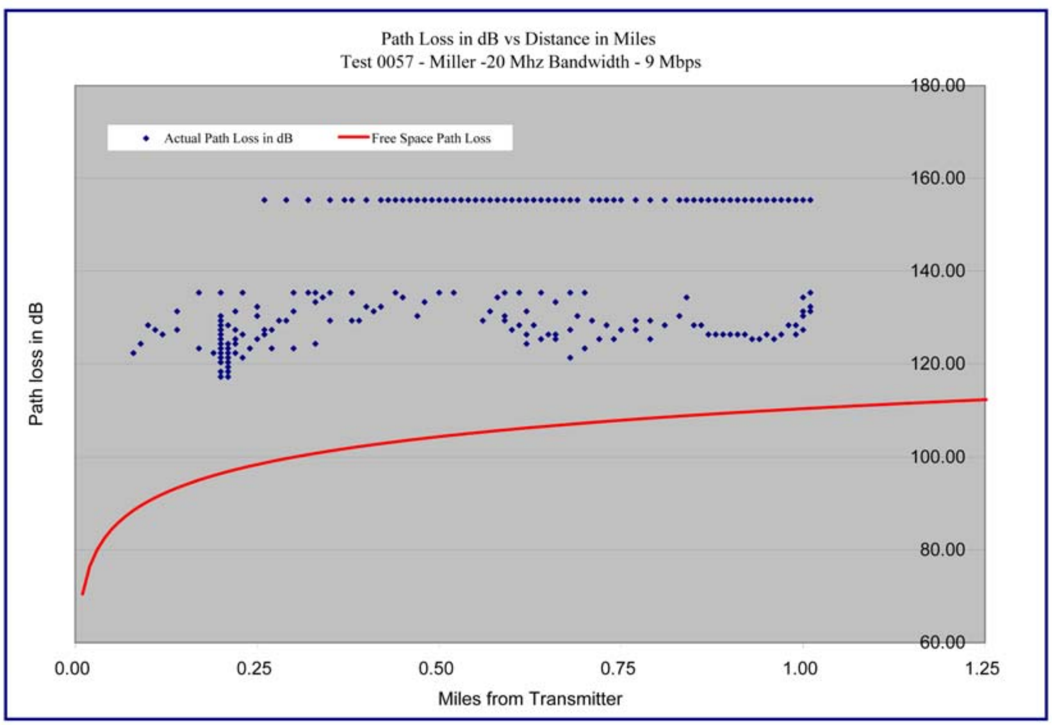
Graph 4.27 – Justice Center - 20 MHz / 9 Mbps – Receive Signal Strength versus Distance – Log-Log Format



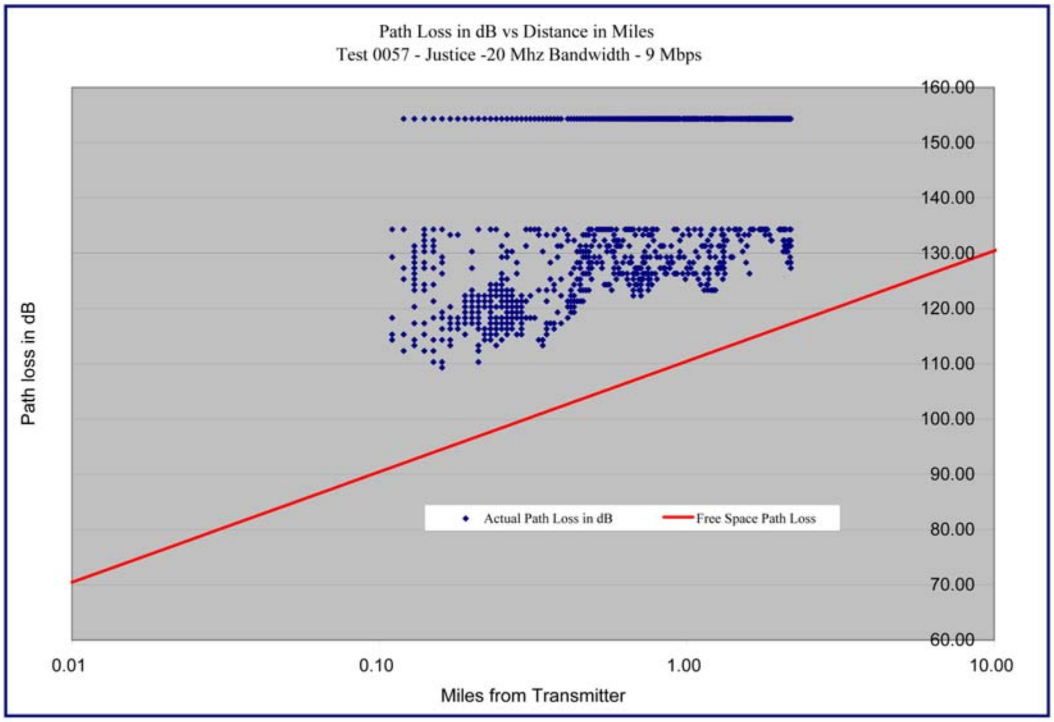
Graph 4.28 – Miller Building - 20 MHz / 9 Mbps – Receive Signal Strength versus Distance – Log-Log Format



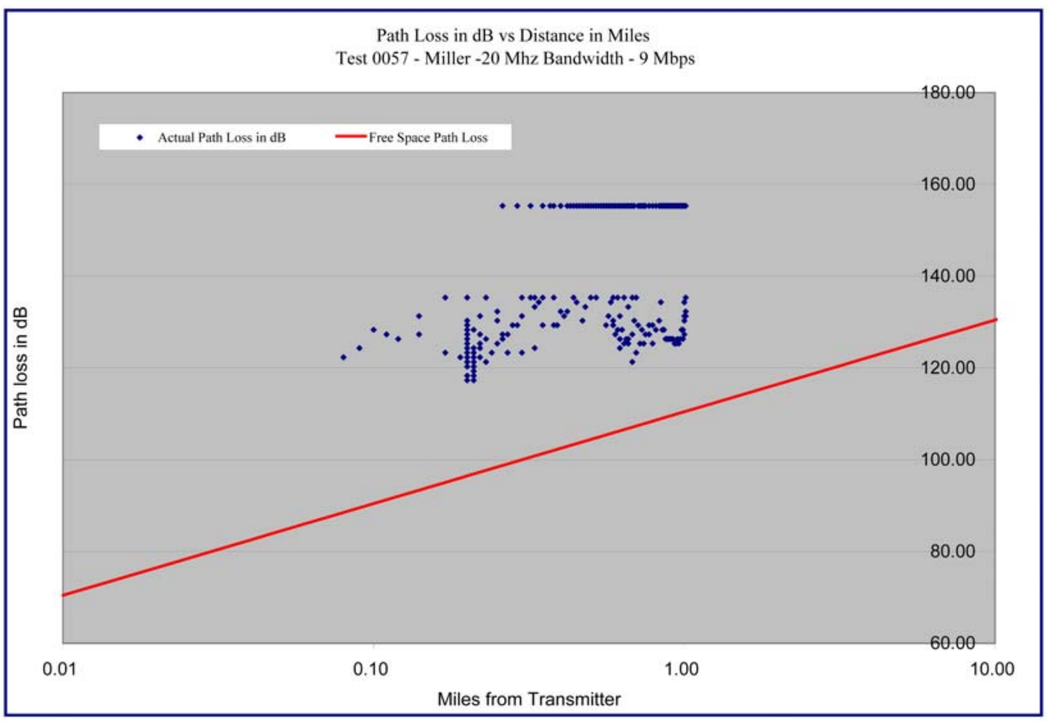
Graph 4.29 – Justice Center - 20 MHz / 9 Mbps – Path Loss versus Distance



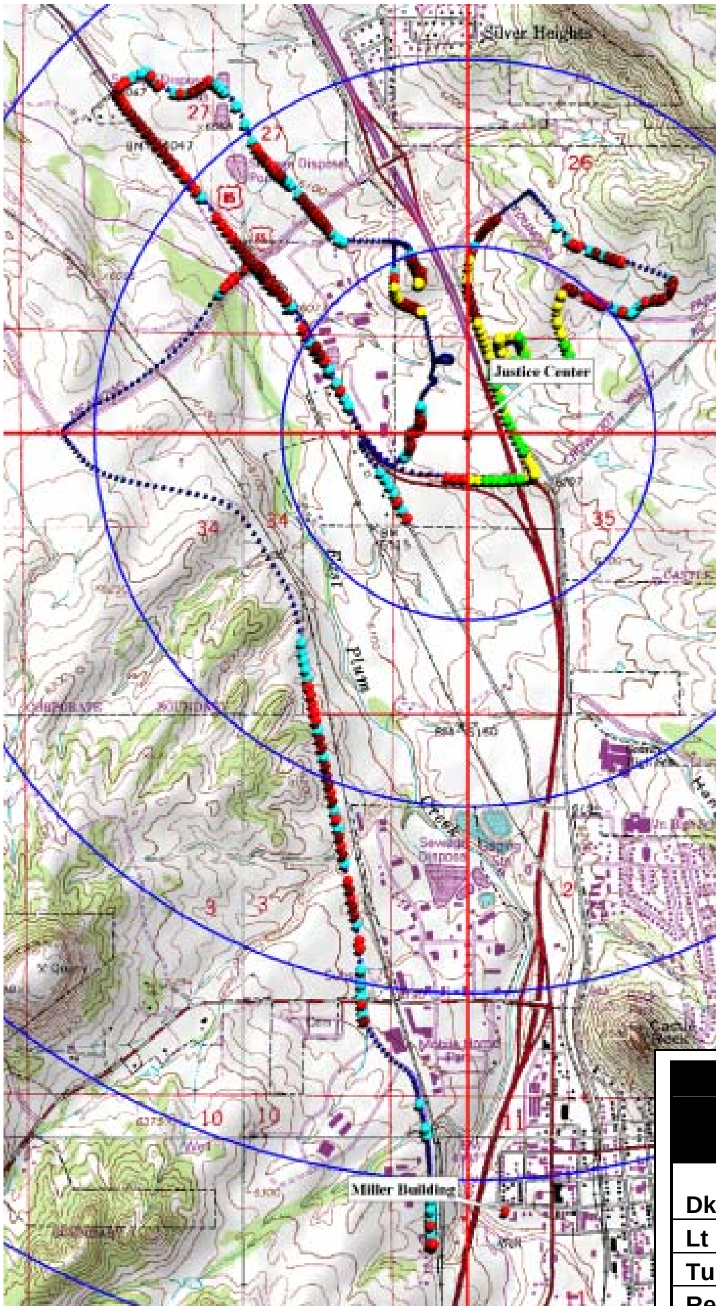
Graph 4.30 – Miller Building- 20 MHz / 9 Mbps – Path Loss versus Distance



Graph 4.31 – Justice Center - 20 MHz / 9 Mbps – Path Loss versus Distance – Log-Log Format



Graph 4.32 – Miller Building - 20 MHz / 9 Mbps – Path Loss versus Distance – Log-Log Format



Map 4.13 – Justice Center Coverage

Justice Center – 20 MHz, Maximum 9 Mbps

- The circles are ½ mile apart.
- There was coverage up to 2¼ miles away
- There was not a great deal of difference in this coverage and the coverage for 20 MHz and 6 Mbps.

Table 4.25 – Justice Center Map Legend

Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Map 4.14 – Coverage Miller Building

Miller Building – 20 MHz, Maximum 9 Mbps

- The circles are ½ mile apart.
- There was coverage up to 1 mile away from the building.
- There was coverage up to 2¼ miles away.
- There was not a great deal of difference in this coverage and the coverage for 20 MHz and 6 Mbps.
- There was no coverage with the maximum throughput (green dots).

Table 4.26 – Map Legend Miller Building			
	Without BDA		
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

	Justice Center	Miller Building
Test Numbers	**0057**	**0057**
Study No for this Chapter	**2**	**2**
Deployment Parameters	**Study 4**	**Study 4**
Bandwidth	20	20
Max Throughput Setting	9 Mbps	9 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	2.5	1
Minimum	0	0
Throughput - Mbps		
Maximum	24-27	12-18
Minimum	3.4-5	3.4-5
Path Loss Above Theoretical in dB		
Minimum	9	20
Maximum	13	34
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		

Table 4.27 – Comparison of Sites

Study 5
Test Parameters: 20 MHz Bandwidth / Maximum Throughput 12 Mbps

Summary:

All Castle Rock studies used the same equipment, so the tests were comparable. As the bandwidth increased, the throughput decreased, at a cost of a decreased coverage footprint. When the AP's setting for maximum throughput was increased, the also decreased.

Table 4.28 – Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 4.28 – Map Legends

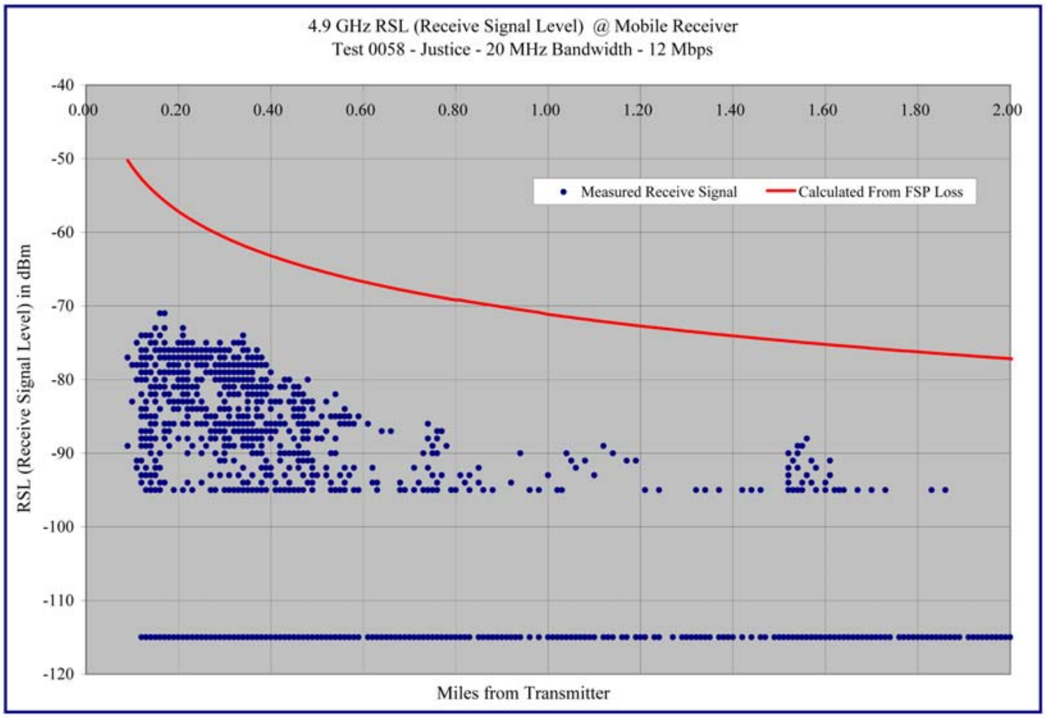
Graphs 4.33, 4.35 4.37 and 4.39 show scatter graphs from the Justice Center. Graphs 4.34, 4.36, 4.38, 4.40 show scatter graphs from the Miller Building.

Graphs 4.33 and 4.34 compare Field Strength Readings versus distance for Justice Center and the Miller Building. Graphs 4.38 and 4.36 show the same comparison, but in a log-log format.

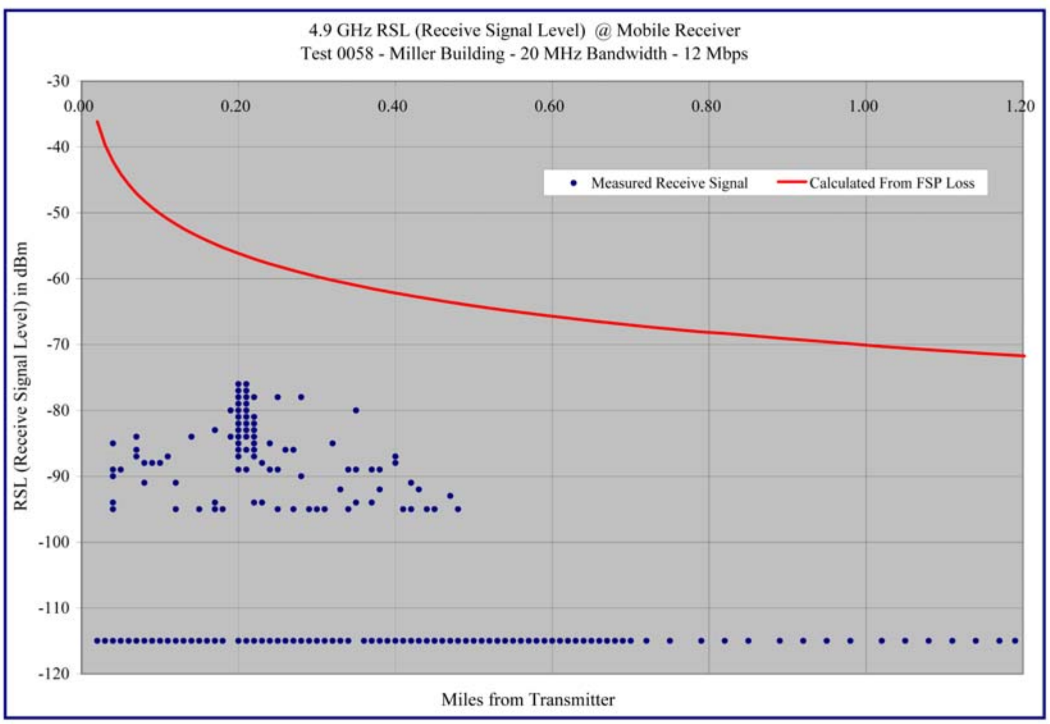
Graphs 4.37 and 4.38 show scatter graphs, which compare path loss versus distance from Justice Center and the Miller building. Graphs 4.39 and 4.40 show the same comparison, but in a log-log format.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable.

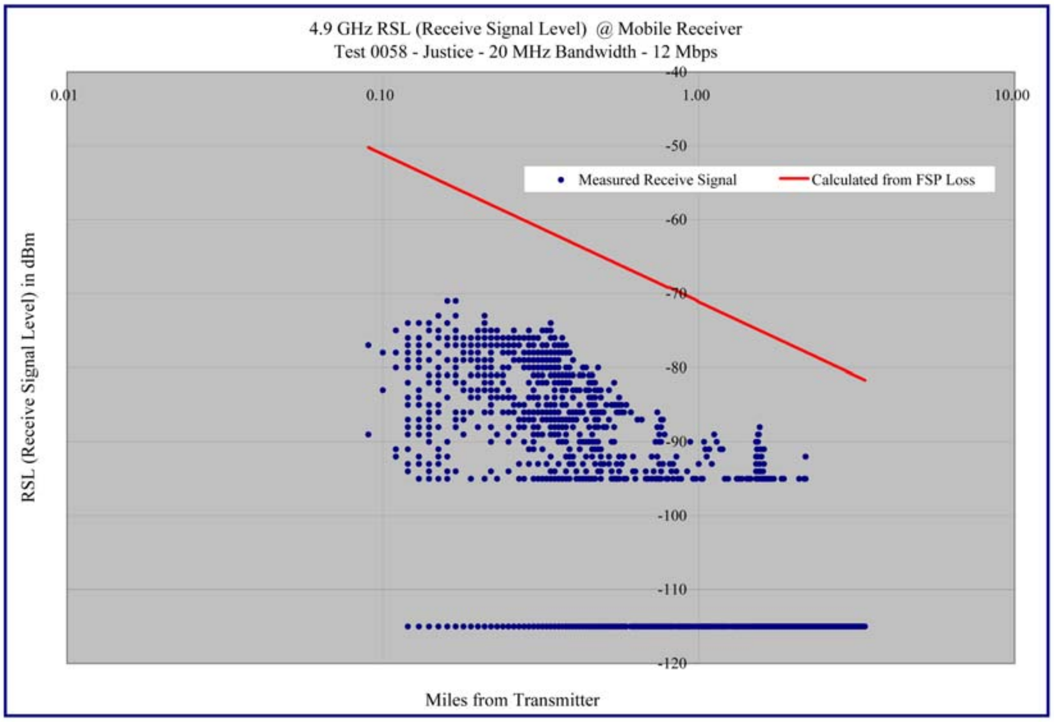
The path loss graphs are equipment independent and can be used to evaluate specific equipment for performance in similar installations.



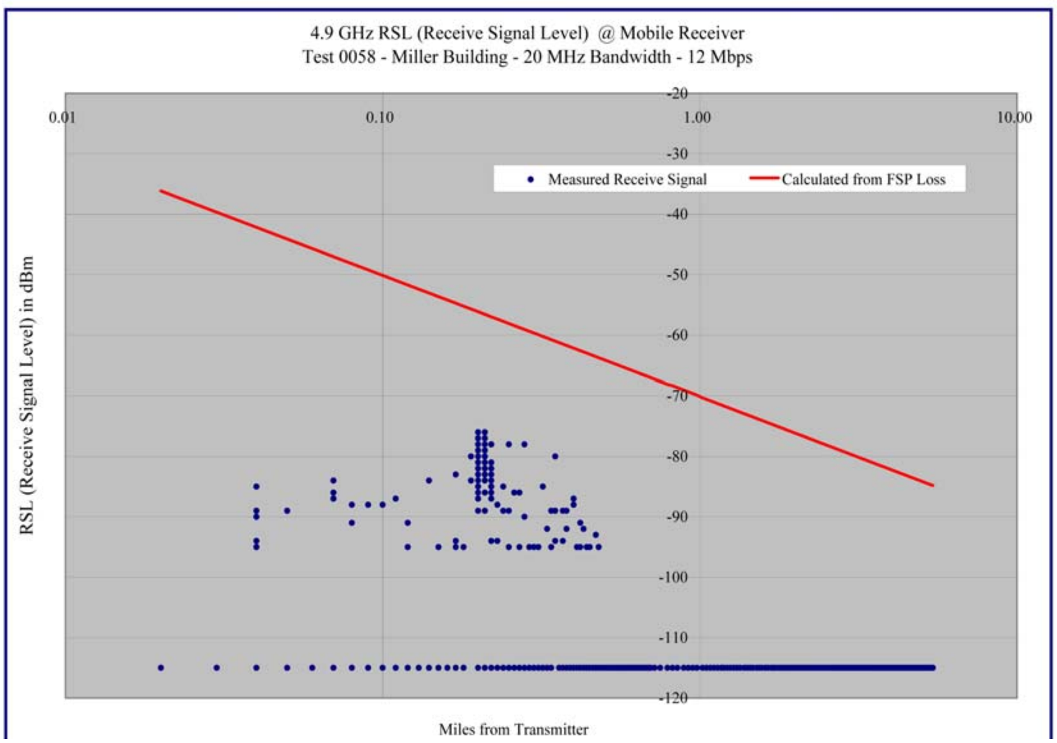
Graph 4.33 – Justice Center – 20 MHz / 12 Mbps - Receive Signal Strength versus Distance



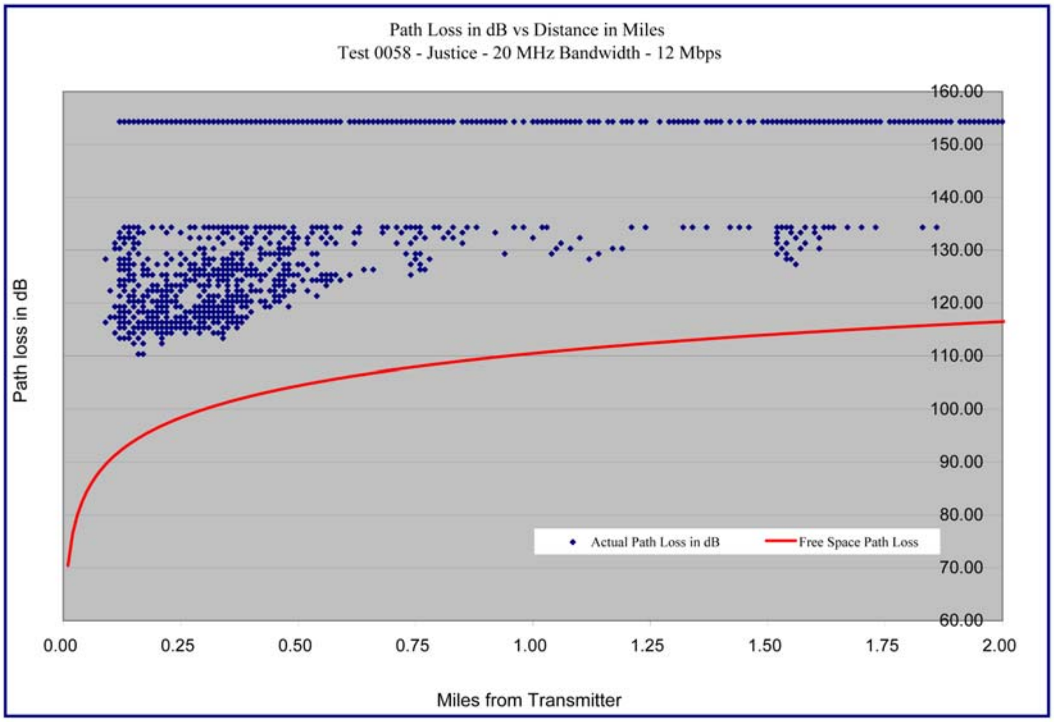
Graph 4.34 – Miller Building - – 20 MHz / 12 Mbps - Receive Signal Strength versus Distance



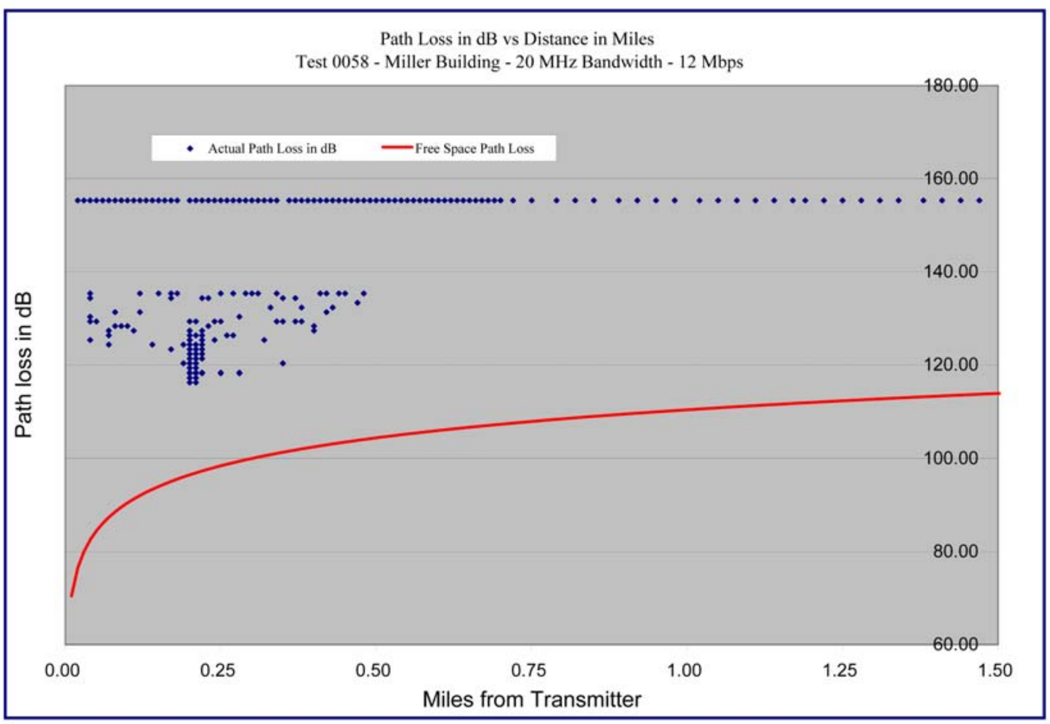
Graph 4.35 – Justice Center - 20 MHz / 12 Mbps - Receive Signal Strength versus Distance- Log-Log Format



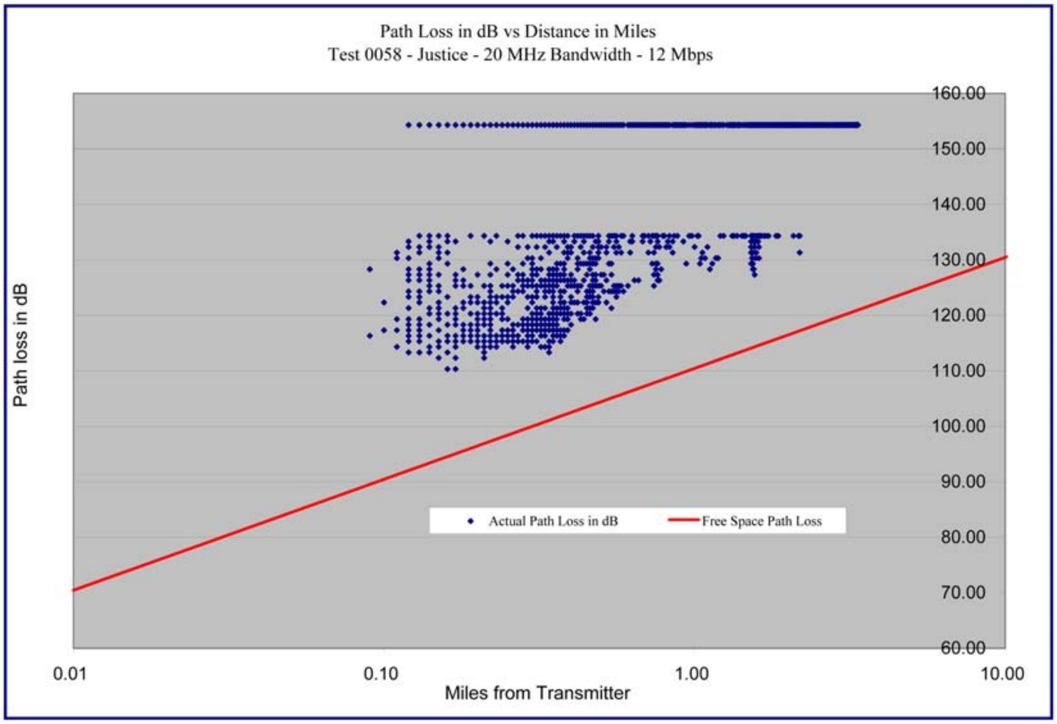
Graph 4.36 – Miller Building - 20 MHz / 12 Mbps - Receive Signal Strength versus Distance- Log-Log Format



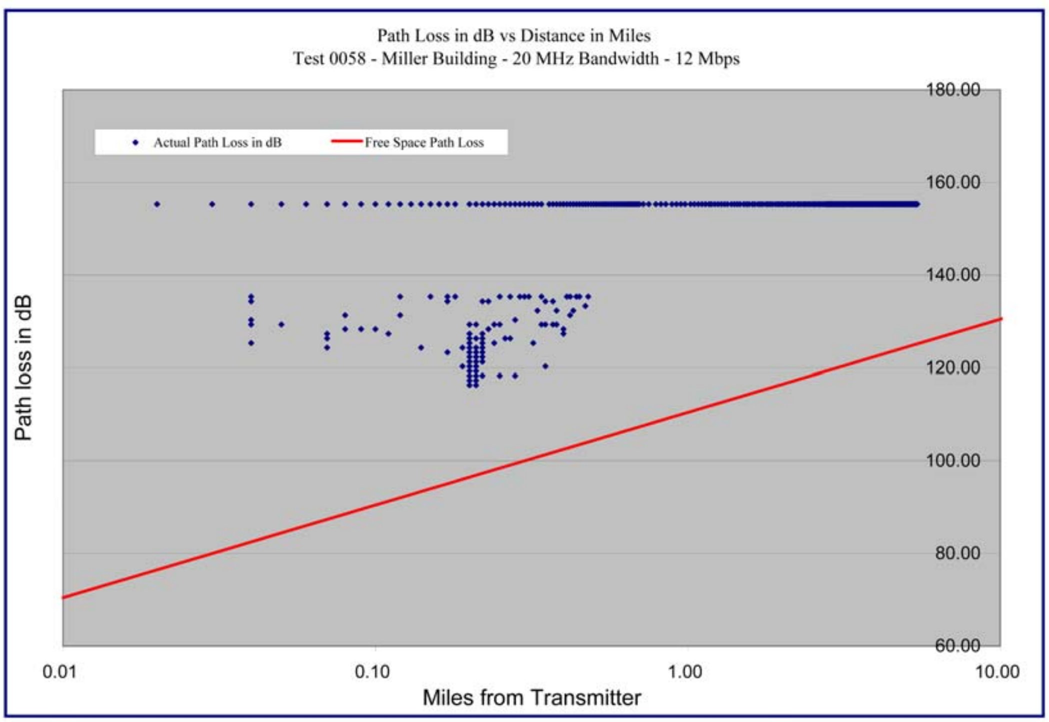
Graph 4.37 – Justice Center – 20 MHz / 12 Mbps - Path Loss versus Distance



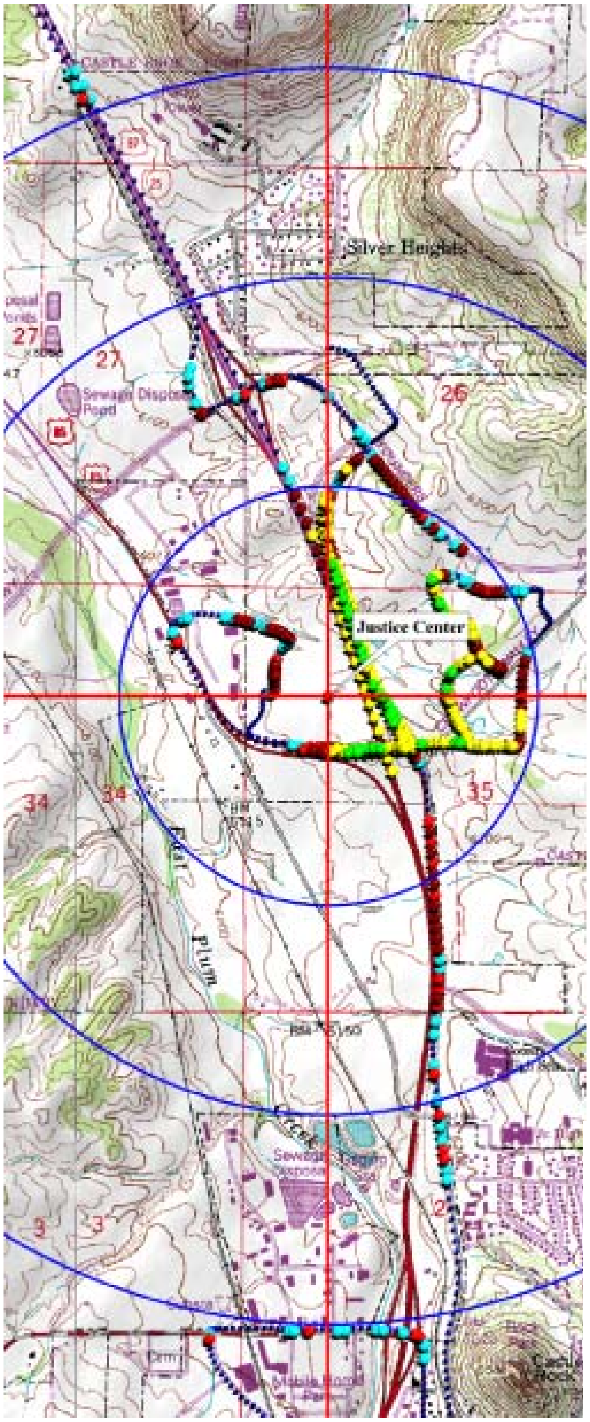
Graph 4.38 – Miller Building – 20 MHz / 12 Mbps - Path Loss versus Distance



Graph 4.39 – Justice Center – 20 MHz / 12 Mbps -Path Loss versus Distance – Log-Log Format



Graph 4.40 – Miller Building - 20 MHz / 12 Mbps - Path Loss versus Distance – Log-Log Format



Map 4.15 - Justice Center Coverage

Justice Center – 20 MHz, Maximum 12 Mbps

- The circles are ½ mile apart.
- There was virtually no coverage beyond 1 mile.
- There were several hot spots at 1½ miles away.
- Compare this to Study 4 where the bandwidth was 20 MHz and the maximum throughput for the mobile AP was 12 Mbps. In Study for the hotspot coverage extended to 2½ miles, and there was general coverage up to 1 ½ miles
- There was more high-speed coverage close to the building than at 9 Mbps at 20 MHz, but the distance was reduced.
- Compared with the Study 4 (20 MHz, Maximum of 9 Mbps) the coverage is substantially less.
- Increasing the maximum allowable throughput for the AP decrease the coverage footprint

Table 4.29 – Justice Center Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Map 4.16– Coverage Miller Building

Miller Building- 20 MHz, Maximum 12 Mbps

- The circles are ½ mile apart.
- There is coverage up to 3/8 mile from the building.
- Compare this to Study 4, where at 20 MHz and a maximum of 9 Mbps, there was coverage up to 1 mile from the building.
- Increasing the maximum allowable throughput in the AP from 9 to 12 Mbps drastically reduced the coverage footprint.
- Hot spots are available only very close to the building.

Table 4.30 – Miller Building Map Legend Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 4.30 Miller Building Legend

	Justice Center	Miller Building
Test Numbers	**0058**	**0058**
Study No for this Chapter	**Study 5**	**Study 5**
Deployment Parameters		
Bandwidth	20	20
Max Throughput Setting	12 Mbps	12 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	2.1	3/8
Minimum	0	0
Throughput - Mbps		
Maximum	24-27	12-18
Minimum	3.4-5	3.4-5
Path Loss Above Theoretical in dB		
Minimum	12	18
Maximum	19	38
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		
Overall Coverage	Good	Good
Comment	Justice has better overall coverage	

Table 4.31 – Comparison of Sites

Study 6
Test Parameters: 10 MHz Bandwidth / Maximum Throughput 18 Mbps

Summary:

All studies, which were done in Castle Rock, used the same equipment, so the tests were comparable. As the bandwidth increased, the throughput would increased, but at a cost of a decreased coverage footprint. When the maximum throughput on the AP was increased, the coverage decreased. In Study 6 the coverage costs which resulted from increasing the maximum throughput were mitigated by decreasing the bandwidth from 20 MHz to 10 MHz.

Table f.43 Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

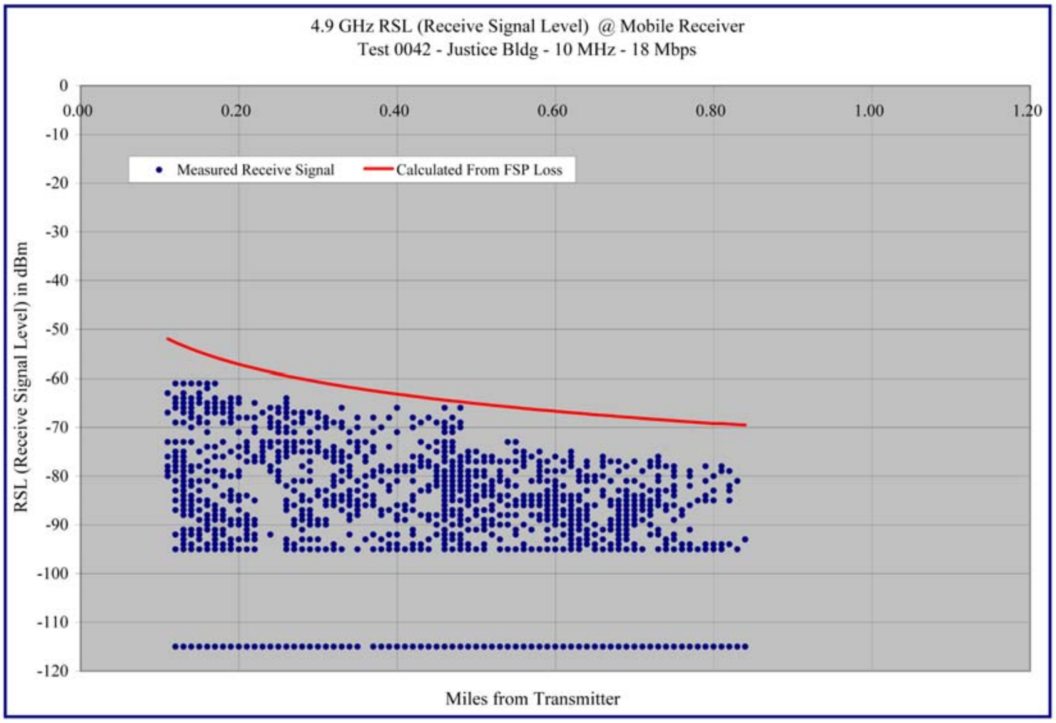
Graphs 4.41 4.43, 4.45, and 4.47 show scatter graphs from the Justice Center. Graphs 4.42, 4.44, 4.46, 4.48 show scatter graphs from the Miller Building.

Graphs 4.25 and 4.42 compare Field Strength Readings versus distance for Justice Center and the Miller Building. Graphs 4.43 and 4.44 show the same comparison, but in a log-log format.

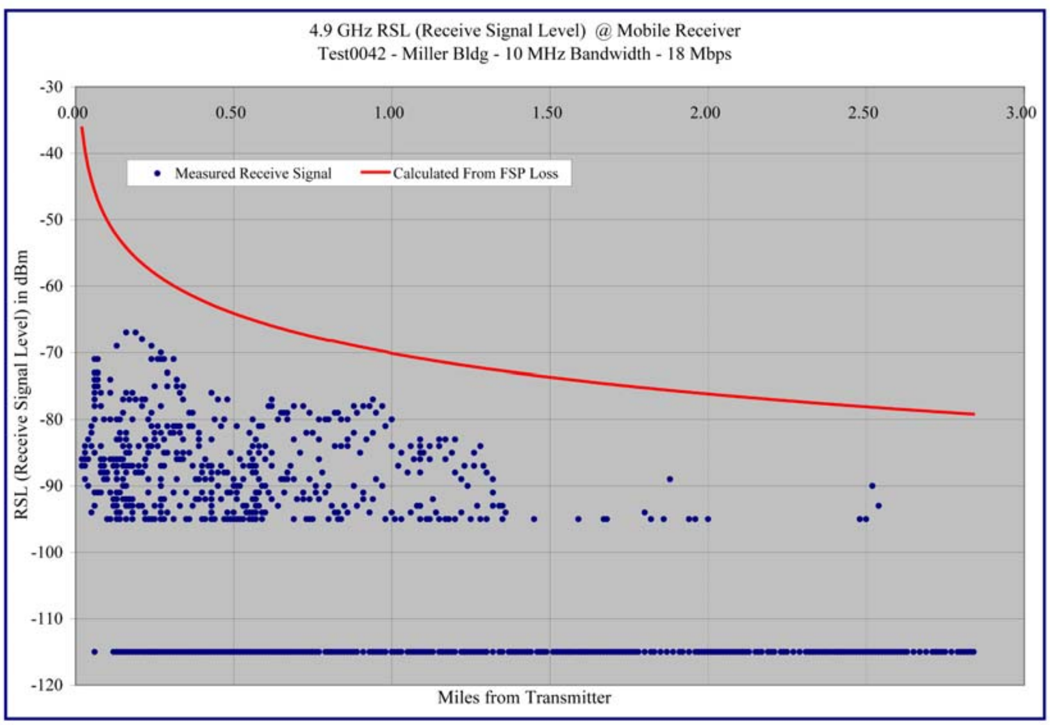
Graphs 4.45 and 4.46 show scatter graphs, which compare path loss versus distance from Justice Center and the Miller building. Graphs 4.47 and 4.48 show the same comparison, but in a log-log format.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable.

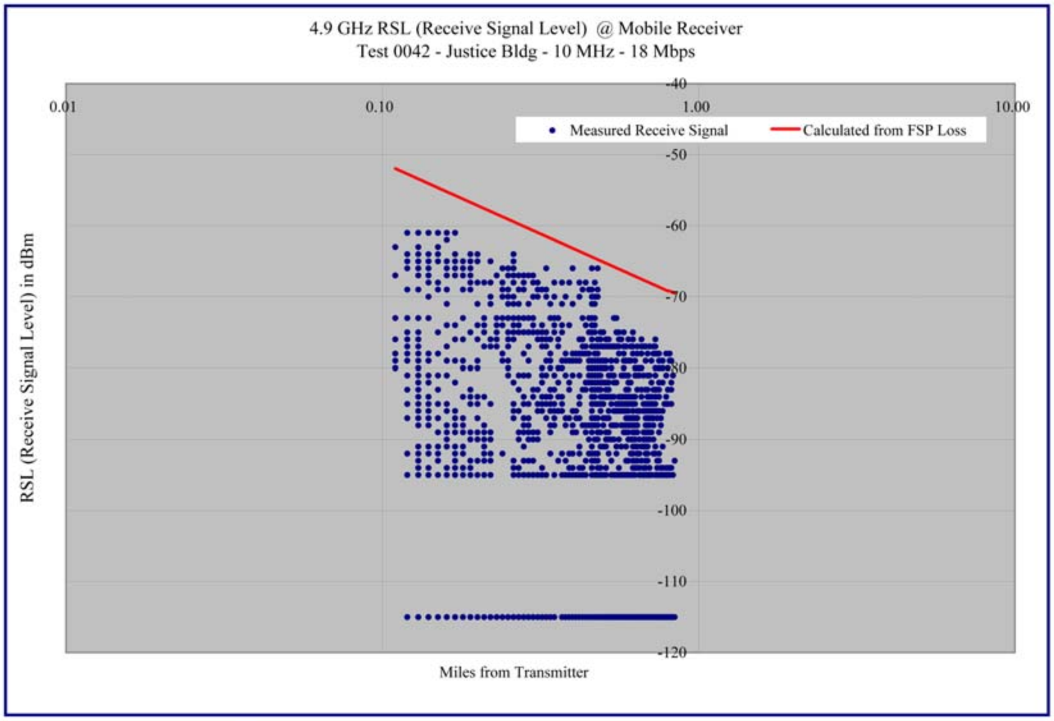
The path loss graphs are equipment independent and can be used to evaluate your specific equipment for performance in similar installations.



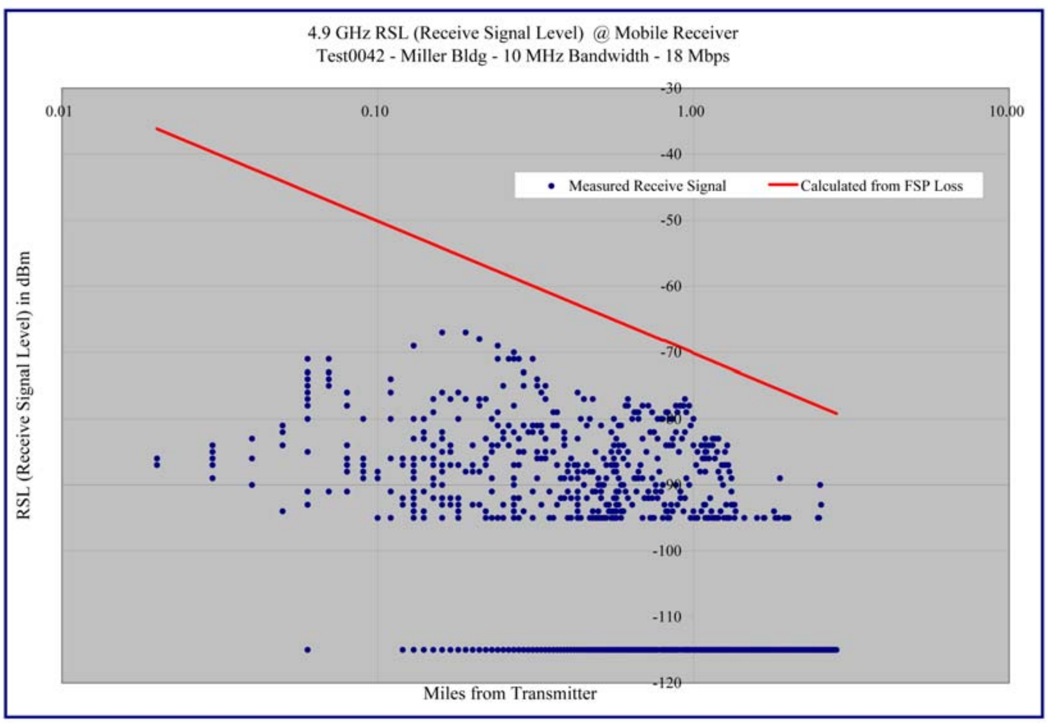
Graph 4.41 – Justice Center – 10 MHz / 18 Mbps - Receive Signal Strength versus Distance



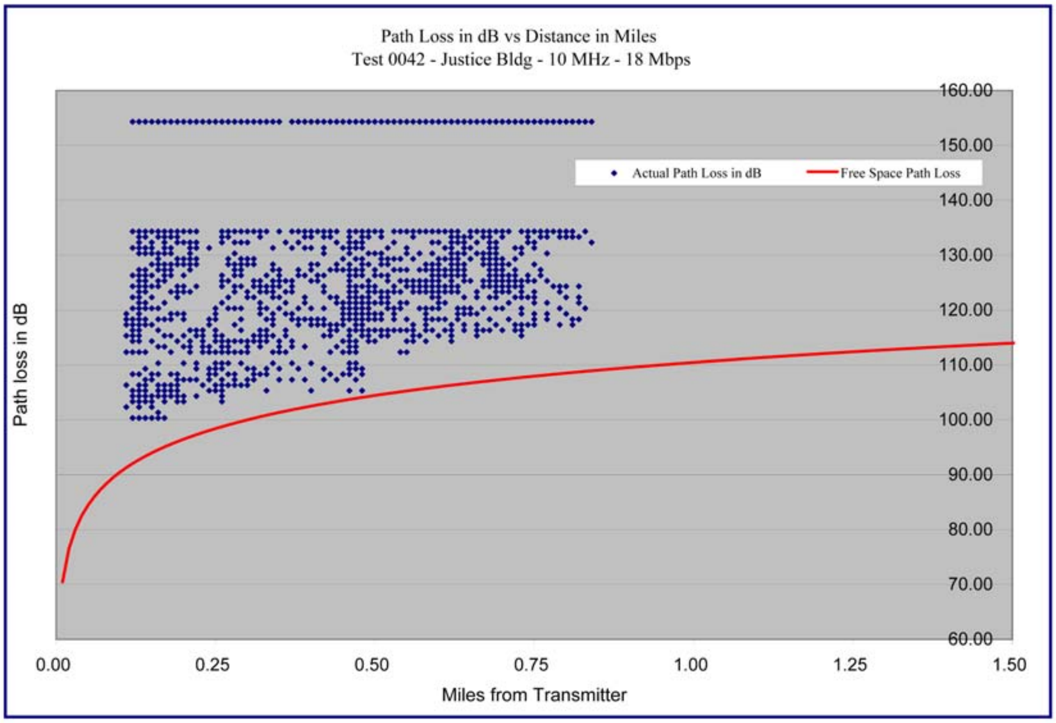
Graph 4.42 – Miller Building -10 MHz / 18 Mbps - Receive Signal Strength versus Distance



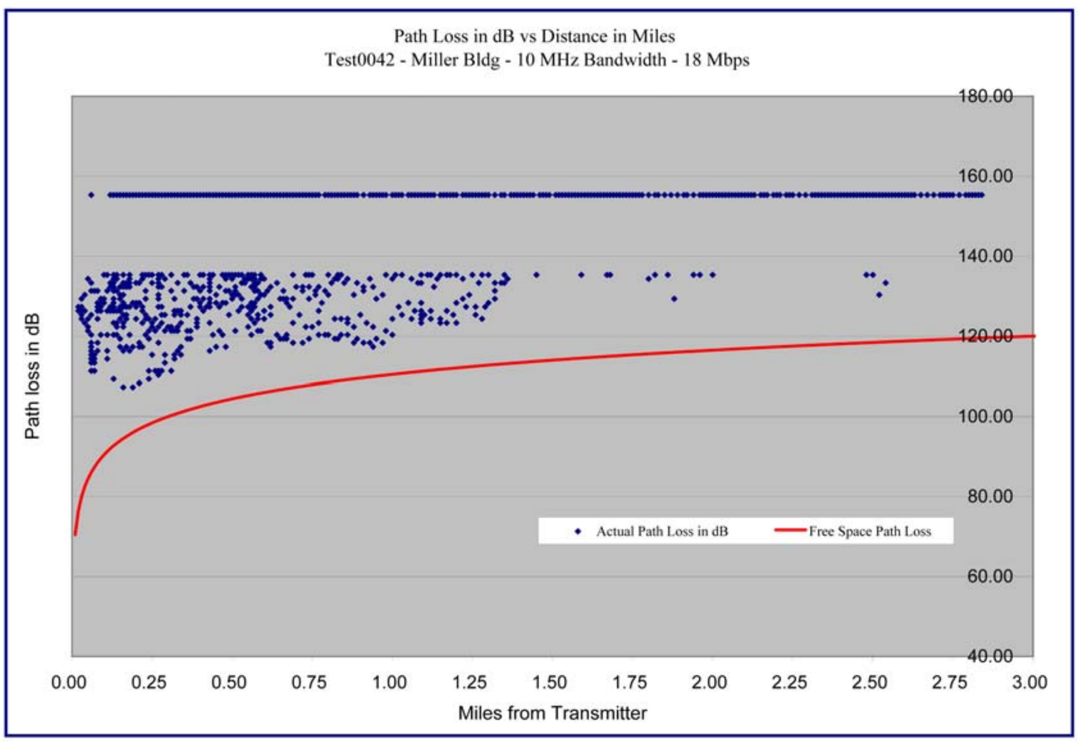
Graph 4.43 – Justice Center -10 MHz / 18 Mbps - Receive Signal Strength versus Distance- Log-Log Format



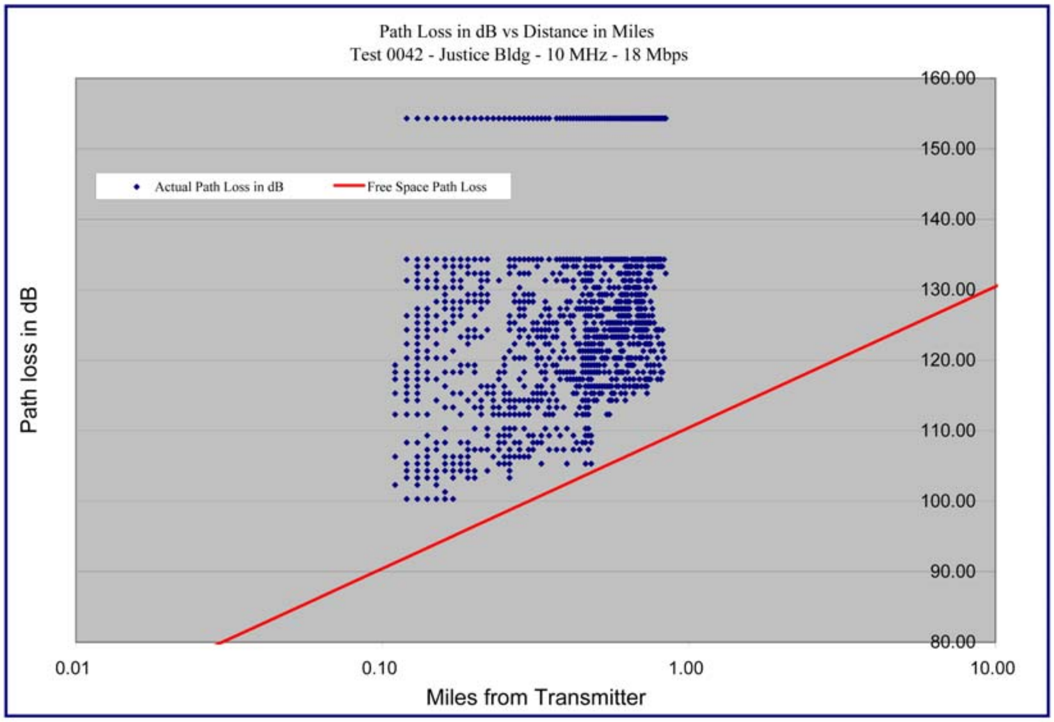
Graph 4.44 – Miller Building -10 MHz / 18 Mbps - Receive Signal Strength versus Distance- Log-Log Format



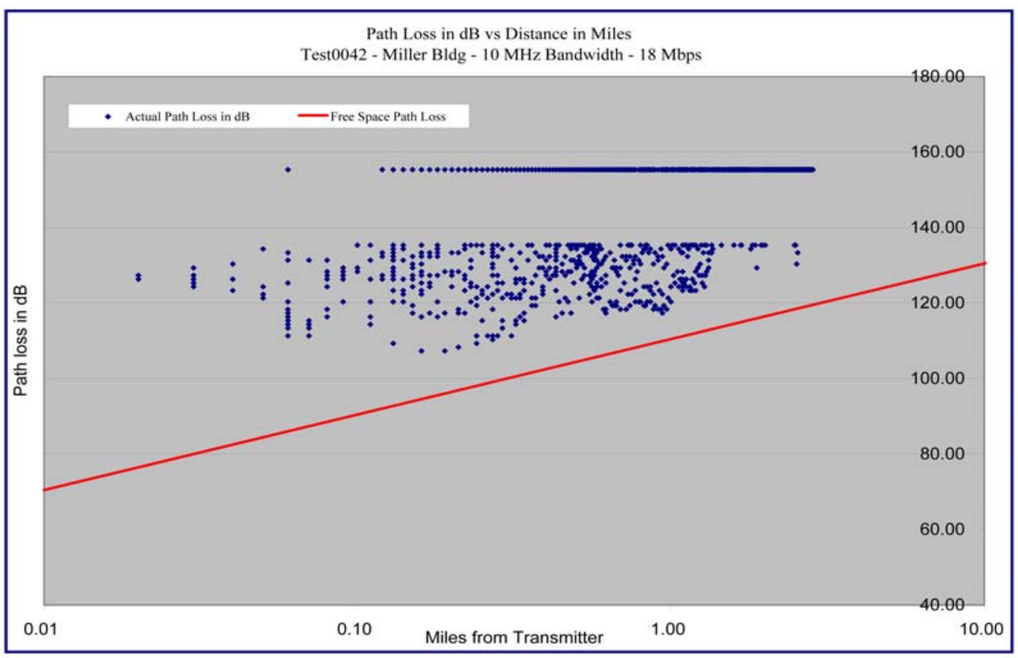
Graph 4.45 – Justice Center -10 MHz / 18 Mbps - Path Loss versus Distance



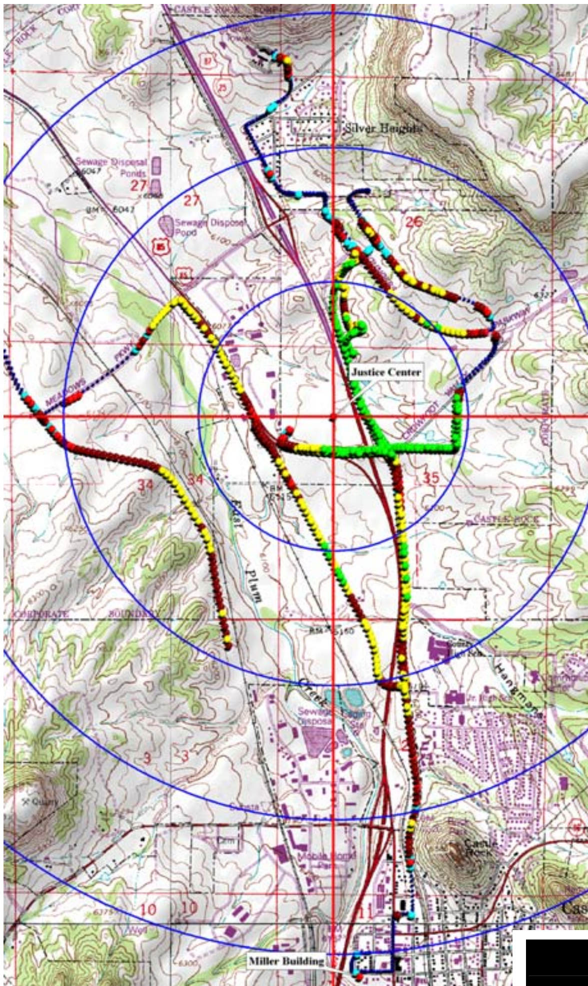
Graph 4.46 – Miller Building -10 MHz / 18 Mbps - Path Loss versus Distance



Graph 4.47 – Justice Center - 10 MHz / 18 Mbps - Path Loss versus Distance – Log-Log Format



Graph 4.48 – Miller Building - 10 MHz / 18 Mbps - Path Loss versus Distance – Log-Log Format



Map 4.17 – Justice Center Coverage

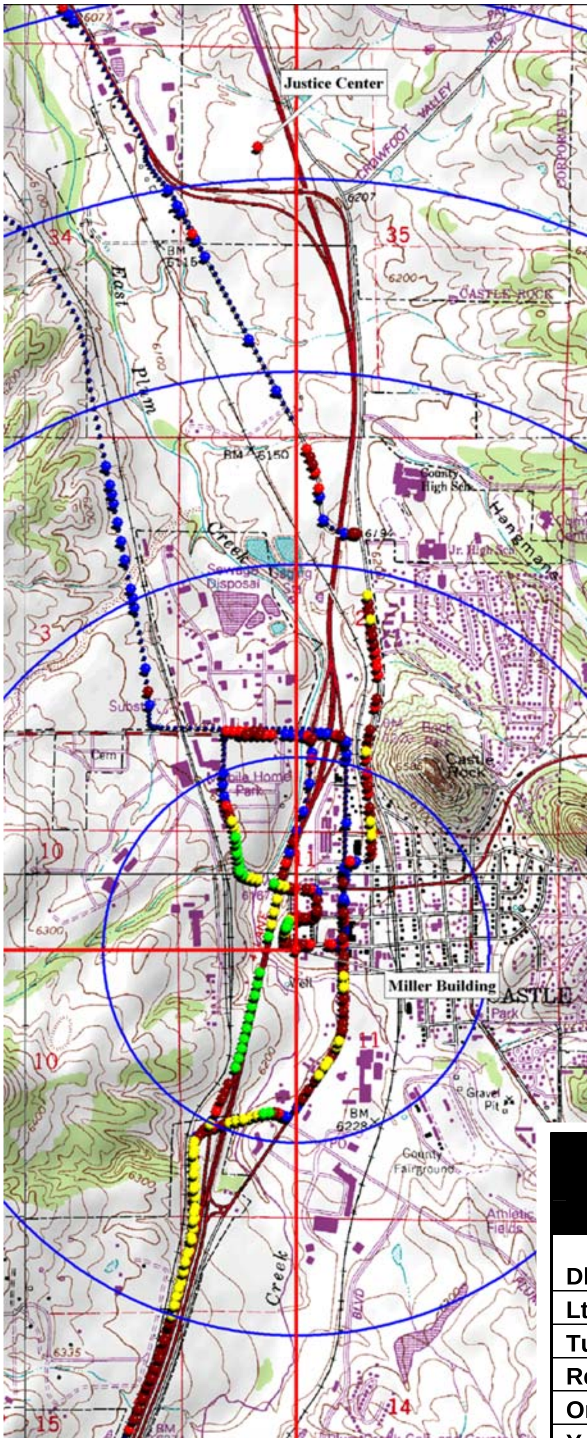
The Justice Center – 10 MHz, Maximum 18 Mbps

- Study 5 was 20 MHz at 12 Mbps The coverage was severely limited.
-
- For this study, the bandwidth was decreased from 20 MHz to 10 MHz. The maximum Mbps rate was increased to 18 Mbps.
- The maximum hotspot distance increased from 2.1 miles to over 2.5 miles.
- The coverage footprint also increased from ½ mile to 1 mile, and the throughput levels were higher in this study.
- <u>Some of the losses incurred by increasing the maximum allowable throughput setting in the AP can be offset by decreasing the bandwidth</u>.

Table 4.33 – Justice Center Legend			
Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Miller Building – 10 MHz, Maximum 18 Mbps

- The circles are ½ mile apart.
- There is hotspot coverage up to 2 miles.
- There is high throughput coverage available up to ½ mile, with lesser throughput coverage up to 1 mile.
- Study 5 (20 MHz, Max 12 Mbps) showed hotspot coverage up to 3/8 of a mile, this study showed hotspot coverage up to 2 miles.
- Study 5 (20 MHz, Max 12 Mbps) showed usable coverage up to ½ mile, this study showed usable coverage up to 1 mile.
- <u>Some of the losses incurred by increasing the maximum allowable throughput setting in the AP can be offset by decreasing the bandwidth</u>.



Map 4.18 Miller Building Coverage

Table 4.34 – Miller Building Legend Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

	Justice Center	Miller Building
Test Numbers	0058	0058
Study No for this Chapter	Study 6	Study 6
Deployment Parameters		
Bandwidth	10	10
Max Throughput Setting	18 Mbps	18 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	2.1	1-1/3
Minimum	0	0
Throughput - Mbps		
Maximum	24-27	24-27
Minimum	3.4-5	3.4-5
Path Loss Above Theoretical in dB		
Minimum	1	16
Maximum	8	30
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		
Overall Coverage	Good	Good
Comment	Justice has better overall coverage	

Table 4.35 – Comparison of Sites

Study 7
Test Parameters: 20 MHz Bandwidth / Maximum Throughput 18 Mbps

Summary

All studies that were done in Castle Rock used the same equipment, so the tests are comparable. As the bandwidth increased, the throughput also increased, but the cost was decreased coverage. As the AP's maximum allowable throughput was increased, the coverage also decreases. No coverage was recorded from the Miller Building at these settings. The combination of the higher bandwidth (20 MHz) and the increased allowable throughput in the AP resulted in a system that was non-functional from the Miller Building, and seriously degraded from the Justice Center.

Table 4.36 – Map Legend			
Without BDA			
	Mbps	S/N	dBm
Do Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Graphs 4.49, 4.51 show scatter graphs from the Justice Center.

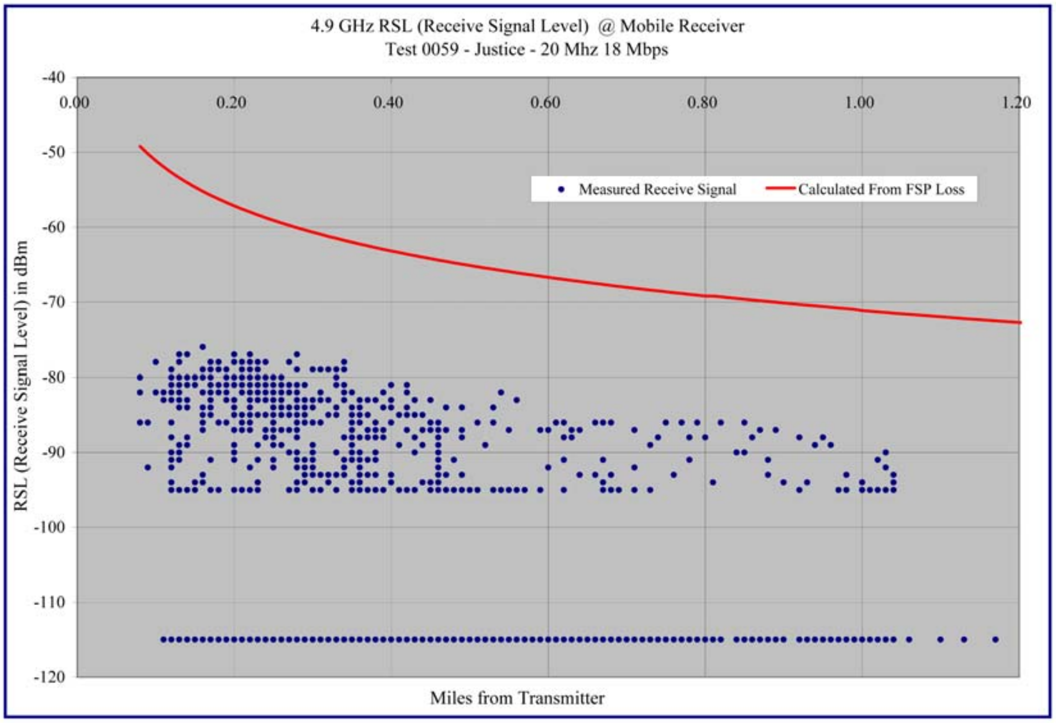
Graph 4.50 shows field strength readings versus distance for Justice Center. Graphs 4.51 showed the same information in a log-log format.

Graphs 4.52 shows a scatter graph of Path Loss versus distance from Justice Center. Graph 4.53 shows the same information in a log-log format.

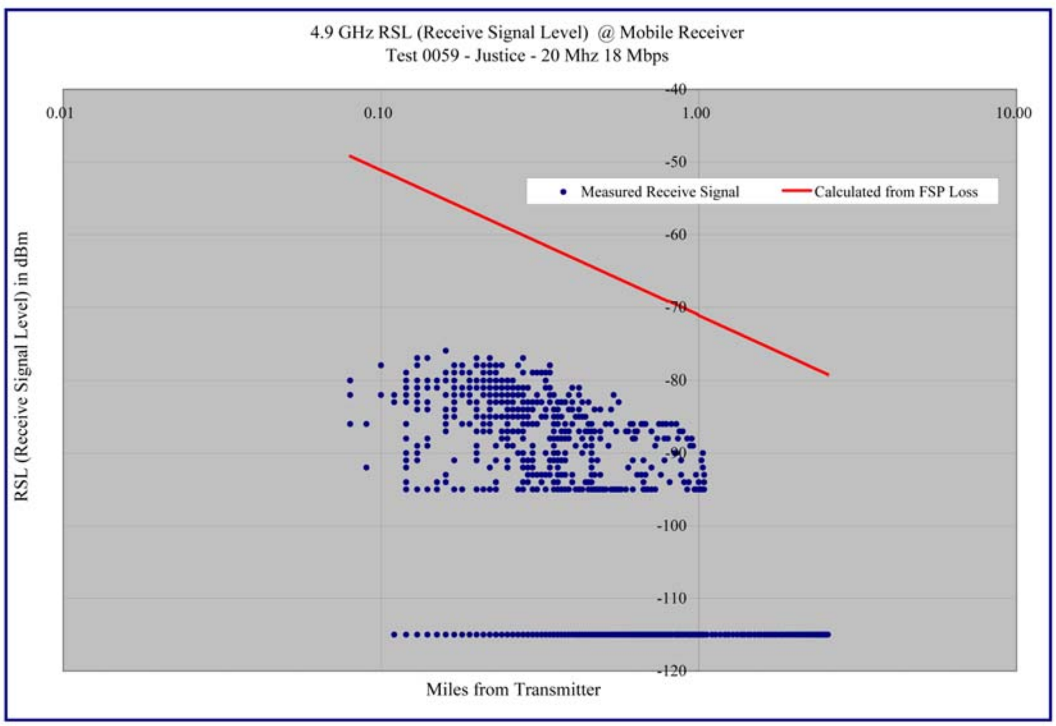
The Miller Building did not work with these parameters.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered dependable.

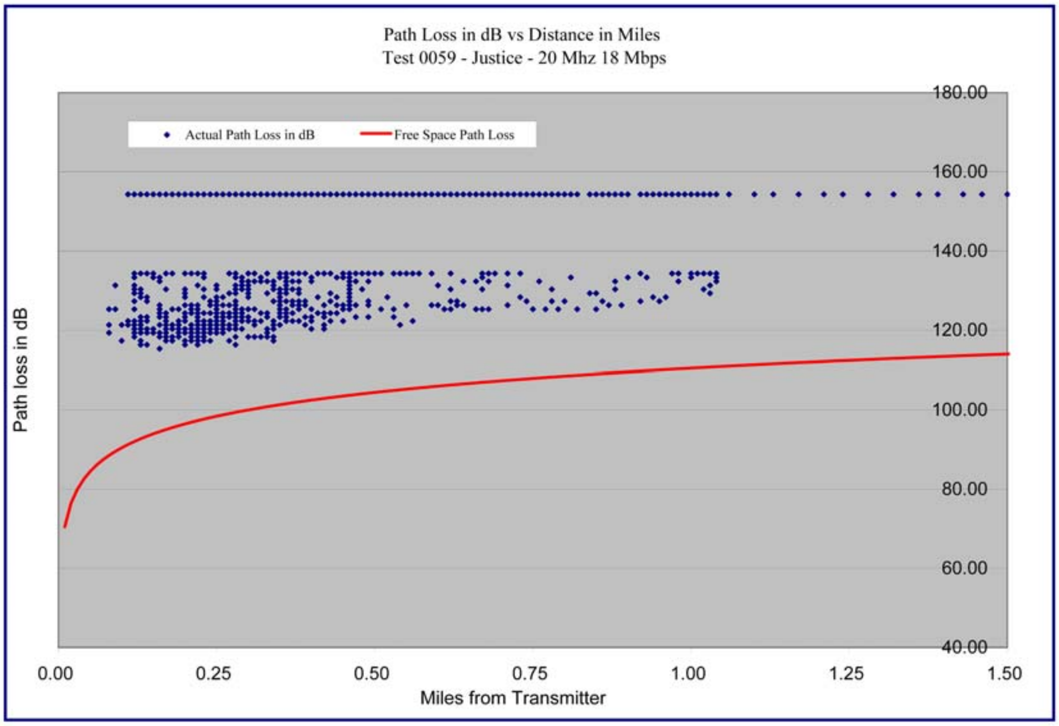
The path loss graphs are equipment independent and can be used to evaluate your specific equipment for performance in similar installations.



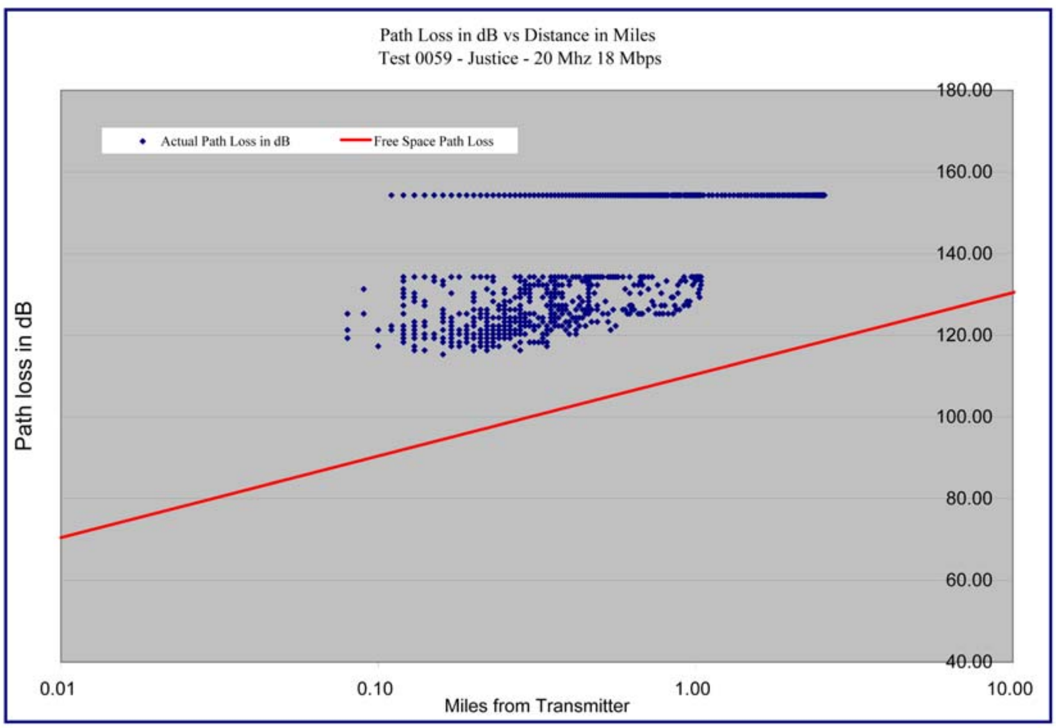
Graph 4.49 – Justice Center – 20 MHz / 18 Mbps - Receive Signal Strength versus Distance



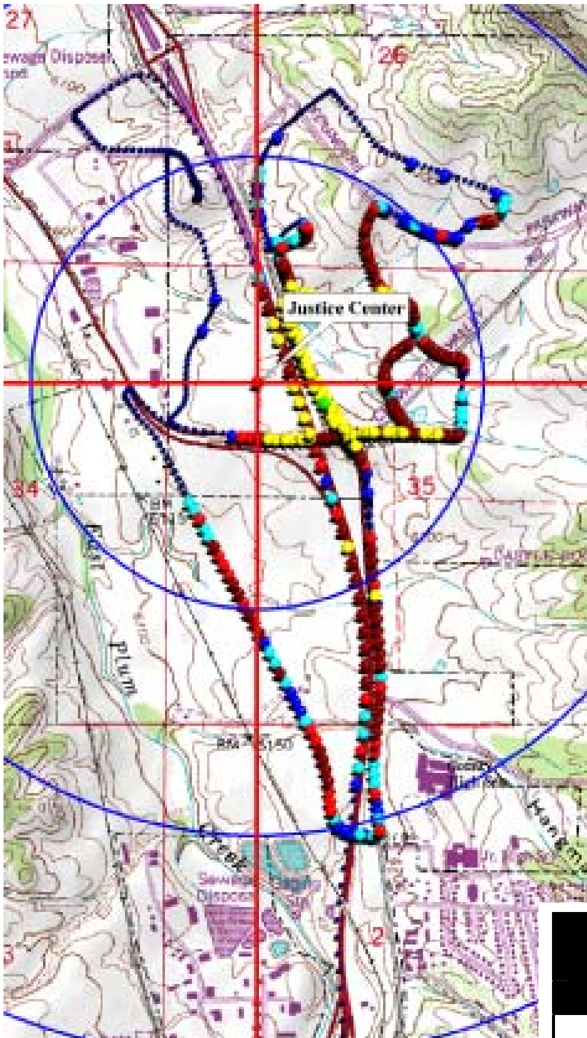
Graph 4.50 – Justice Center - – 20 MHz / 18 Mbps - Receive Signal Strength versus Distance – Log-Log Format



Graph 4.51 – Justice Center – 20 MHz / 18 Mbps - Path Loss versus Distance



Graph 4.52 – Justice Center – 20 MHz / 18 Mbps - Path Loss versus Distance – Log-Log Format



Map 4.19 – Justice Center Coverage

The Justice Center – 10 MHz, Maximum 18 Mbps

- Circles are ½ mile apart
- Maximum hot spot distance was 1 mile
- Coverage footprint was 1 mile with high (green) and medium (yellow) coverage throughout that area.
- Study 5 (20 MHz / 12 Mbps) showed hotspots up to 2.1 miles.
- Study 5 (20 MHz / 12 Mbps) also showed a coverage footprint of 1 mile, but the throughput was decreased, and there were virtually no high-throughput areas.
- <u>Increasing the maximum allowable Mbps in the AP's decreased the coverage footprint and the throughput.</u>

Table 4.37 – Justice Center Legend Without BDA			
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

The Miller Building was tested simultaneously, but no signals were received for this test.

	Justice Center	Miller Building
Test Numbers	**0042**	**0042**
Study No for this Chapter	**Study 7**	**Study 7**
Deployment Parameters		NO COVERAGE
Bandwidth	20	20
Max Throughput Setting	18 Mbps	18 Mbps
EIRP	30.32 dBm	31.32 dBm
Antennas	no downtilt 90°	no downtilt 60°
Topography	suburban foothills	suburban foothills
Vegetation	minimal - deciduous trees	minimal - deciduous trees
Climate	arid	arid
Vantage Point	65ft AGL Good View	45 ft - more limited view
Distance for Hot-spots		
Maximum	1/3	
Minimum	0	
Throughput - Mbps		
Maximum	24-27	
Minimum	3.4-5	
Path Loss Above Theoretical in dB		
Minimum	16	
Maximum	24	
Backhaul		
feasibility	microwave in place	
Deployment Type		
Point to Multipoint	yes	
Hot-Spot	yes	
Ad Hoc or Mesh	yes	
Site Comparison		
Overall Coverage	Good	did not work
Comment	Only Justice Center Worked	

Table 4.38 – Comparison of Sites

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Study 8
Test Parameters: 10 MHz Bandwidth / Maximum Throughput 24 Mbps

Summary

All studies done in Castle Rock used the same equipment, so the tests are comparable. As the bandwidth increased, the throughput increased, but at a cost of decreased coverage. As the AP's maximum allowable throughput was increased, the coverage decreased.

Table 4.39 Map Legend			
Without BDA			
	Mbps	S/N	dBm
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

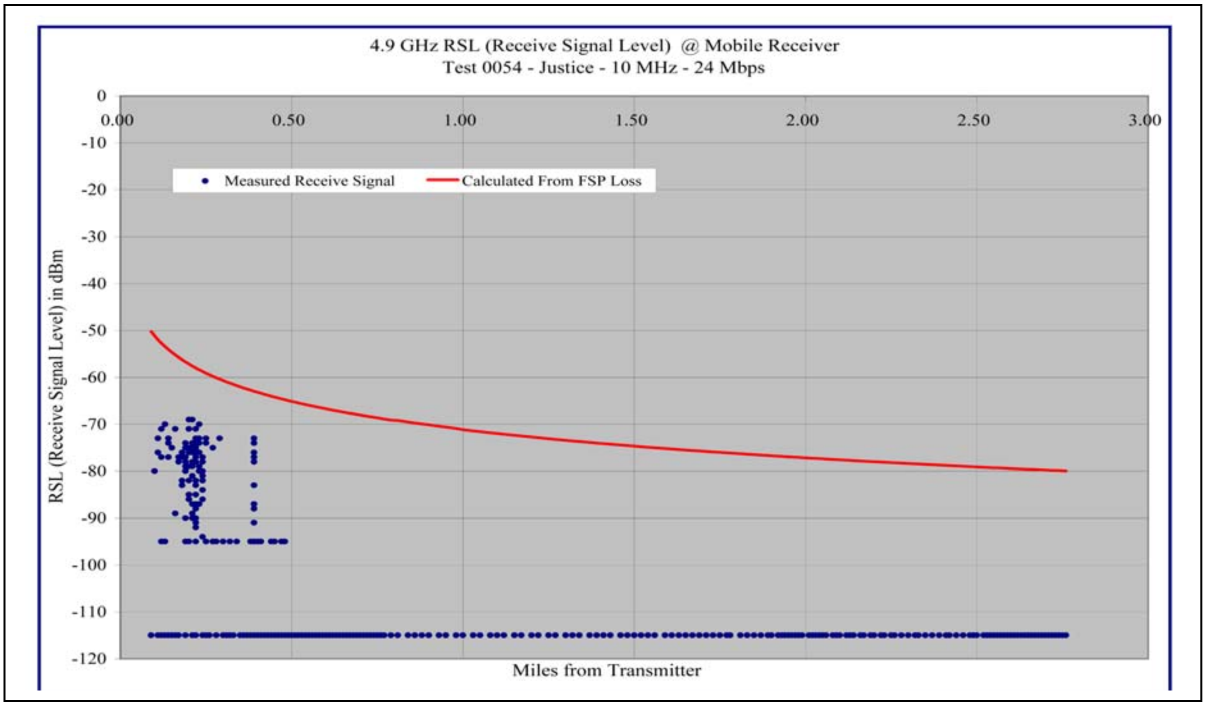
Graphs 3.53 and 3.54 show Justice Center and Miller Building Receive Signal Level versus Distance. Graph 3.55 and 3.56 are in the log-log format and show the same information.

Graphs 3.57 and 3.58 show Justice Center and Miller Building Path Loss versus Distance. Graphs 3.59 and 3.60 are in the log-log format and show the same information.

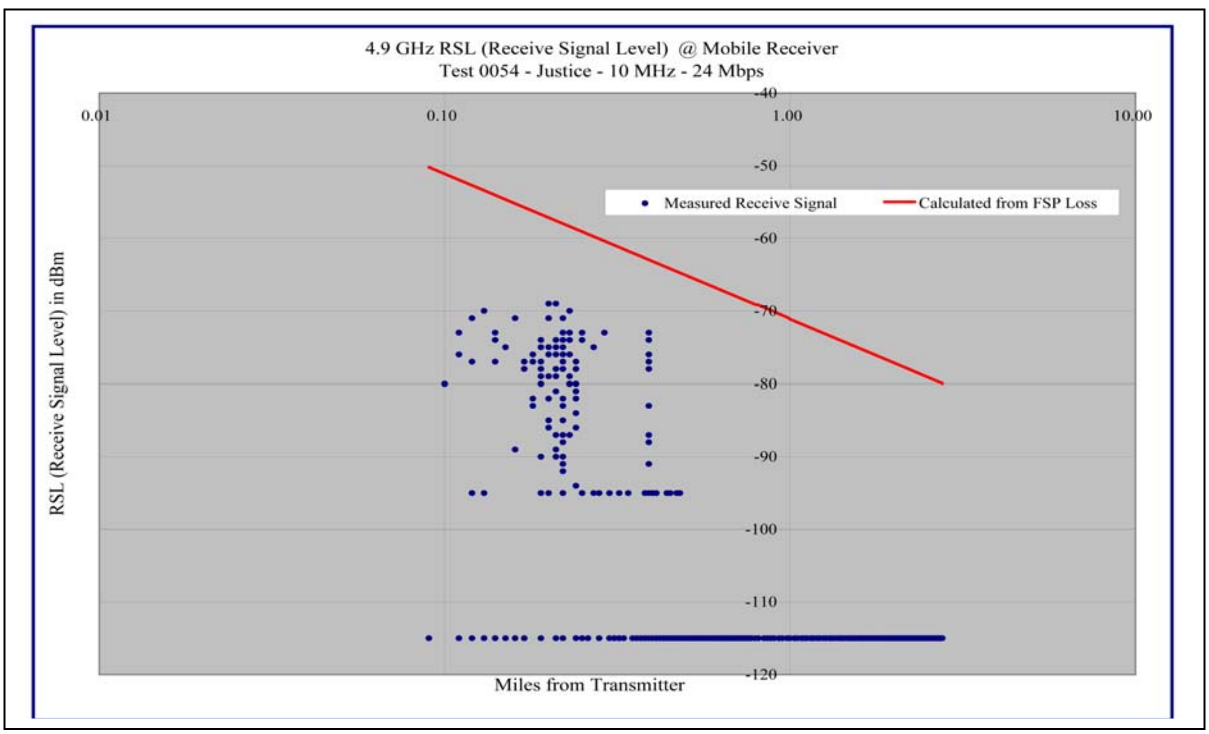
Miller Building was showing some coverage – but one additiona Proxim 60° sector antenna pointed 90° east was added for this study. It was 60° sector like the other antennas on the Miller Building.

Any field strength less than -90 dBm is below the minimum threshold recommended by 802.11j for reliable throughput. Throughput may occur at these levels – but cannot be considered to be dependable.

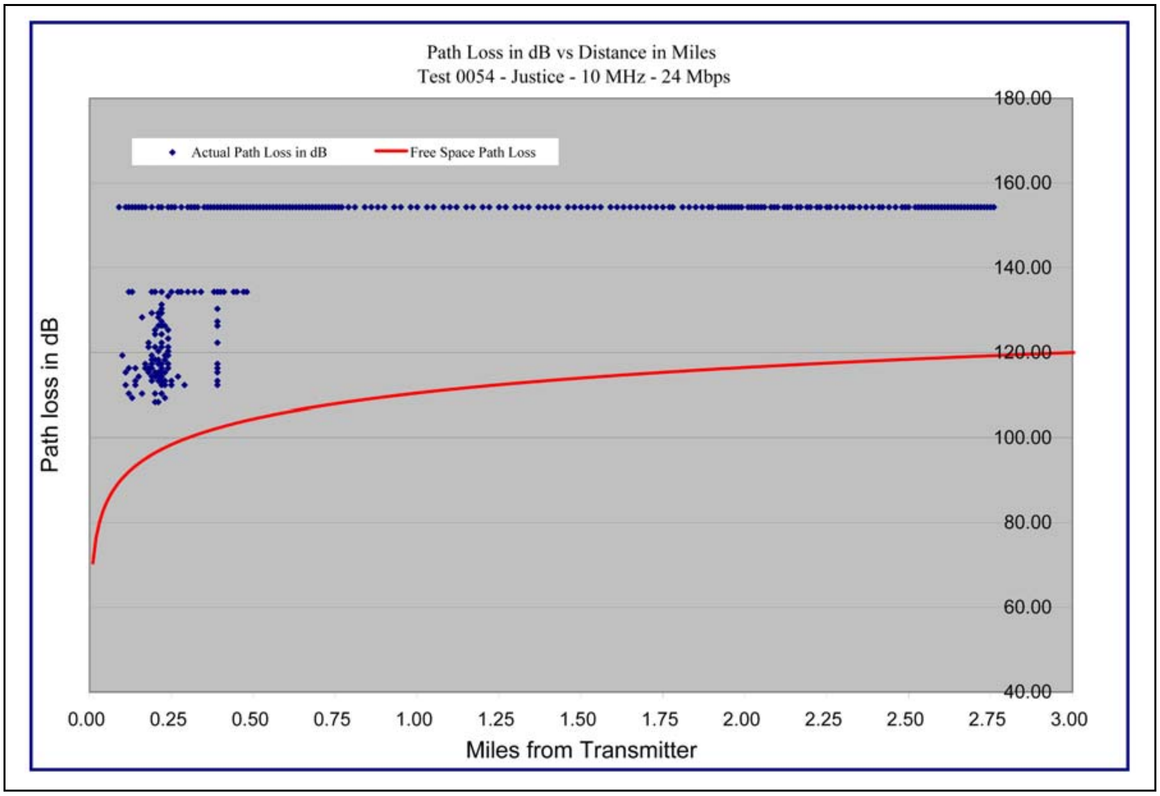
The path loss graphs are equipment independent and can be used to evaluate your specific equipment for performance in similar installations.



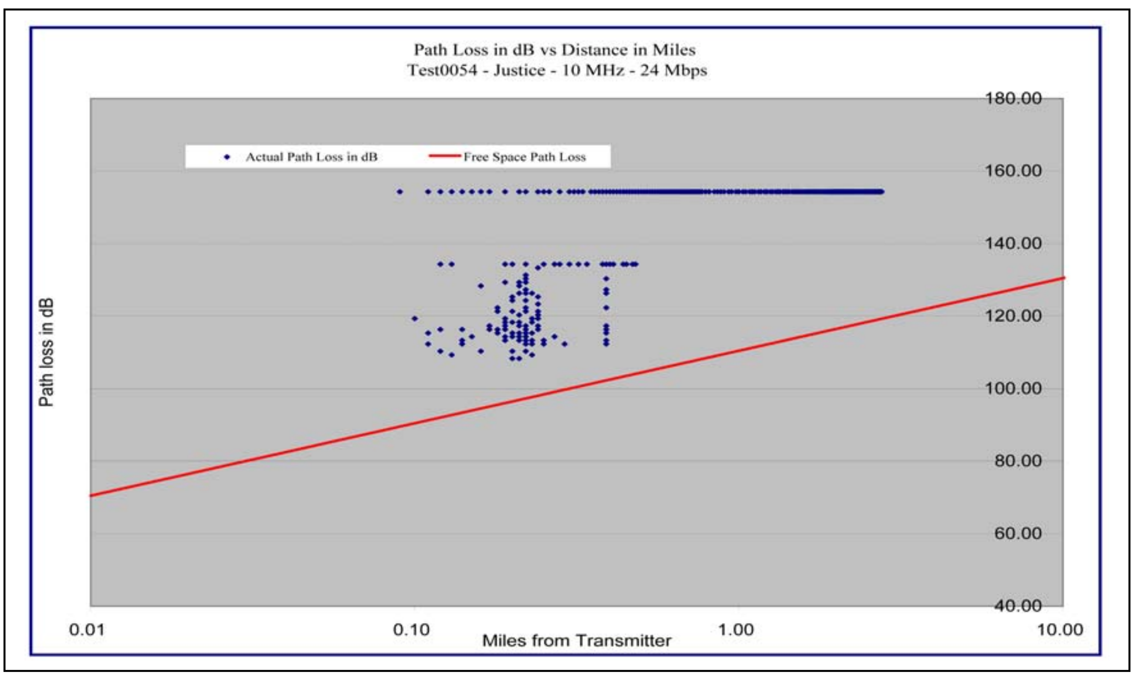
Graph 4.53 Justice Center – 10 MHz / 24 Mbps – Receive Signal Strength versus Distance



Graph 4.54 Justice Center –10 MHz / 24 Mbps – Receive Signal Strength versus Distance – Log-Log Format

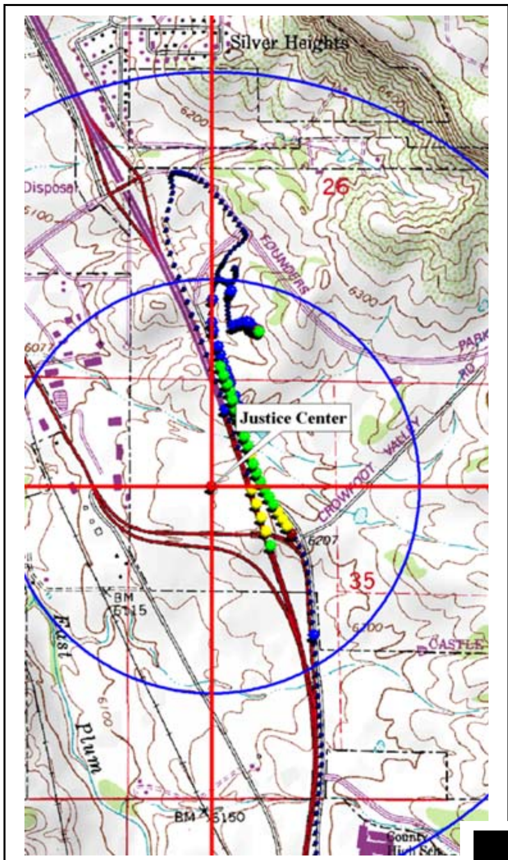


Graph 4.55 – Justice Center - 10 MHz / 24 Mbps – Path Loss versus Distance



Graph 4.56 – Justice Center – 10 MHz / 24 Mbps – Path Loss versus Distance – Log-Log Format

10 MHz Bandwidth, Maximum 24 Mbps



Map 4.26 – Justice Center

- Circles are ½ mile apart
- The Justice Center – 10 MHz, Maximum 24 Mbps
- This configuration had the smallest area of coverage of any of the Castle Rock Studies
- There were no hotspots beyond the general coverage at about 3/8 of a mile
- The overall footprint was less than 3/8 of a mile, although the throughput was very high in this area
- Study 4 (10 MHz Bandwidth, 18 Mbps) showed hotspots at 2.1 miles and had a general coverage footprint up to 1 mile
- This last test dramatically shows how increasing the AP's maximum allowable throughput affects coverage, even if the bandwidth is 10 MHz

Table 4.40 – Justice Center Map Legend

	Without BDA		
	Mbps	**S/N**	**dBm**
Dk Blue	NO signal		-115
Lt Blue	unusable	see comment	<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

	Justice Center	Miller Building
Test Numbers	**0055, 0060**	**0055, 0060**
Study No for this Chapter	**Study 8**	**Study 8**
Deployment Parameters		NO COVERAGE
Bandwidth	20	
Max Throughput Setting	24 Mbps	
EIRP	30.32 dBm	
Antennas	no downtilt 90°	
Topography	suburban foothills	
Vegetation	minimal - deciduous trees	
Climate	arid	
Vantage Point	65ft AGL Good View	
Distance for Hot-spots		
Maximum	1/3	
Minimum	0	
Throughput - Mbps		
Maximum	24-27	
Minimum	12-18	
Path Loss Above Theoretical in dB		
Minimum	6	
Maximum	12	
Backhaul		
feasibility	microwave in place	
Deployment Type		
Point to Multipoint	yes	
Hot-Spot	yes	
Ad Hoc or Mesh	yes	
Site Comparison		
Overall Coverage	Fair	
Comment	Limited Coverage – Justice Center only	

Table 4.41 – Site Comparison

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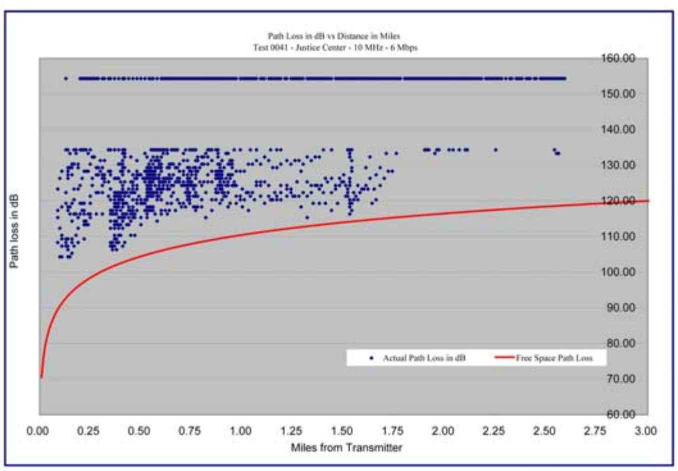
Summary
Castle Rock – Foothills / Suburban
Testing the Effects of Bandwidth and Maximum Allowable AP Settings

The studies done in Castle Rock tested propagation in this environment, but they also tested the affects of changing the bandwidth and the affects of changing the maximum allowable throughput in the AP's.

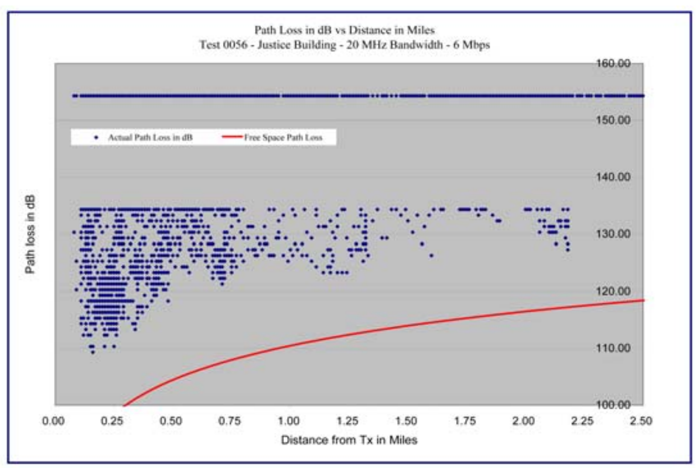
- Increasing the bandwidth resulted in a decrease in the coverage footprint.
- Increasing the bandwidth resulted in a higher throughput at all sites, which had coverage.
- Increasing the setting in the Proxim AP's that control the maximum allowable throughput decreased the coverage footprint.
- The effects of an increased bandwidth could be mitigated by decreasing the maximum allowable throughput.

In order to compare these effects, studies from the Justice Center will be compared:

Effects of Increasing Bandwidth from 10 MHz to 20 MHz
AP's Maximum Allowable Bandwidth 6 Mbps



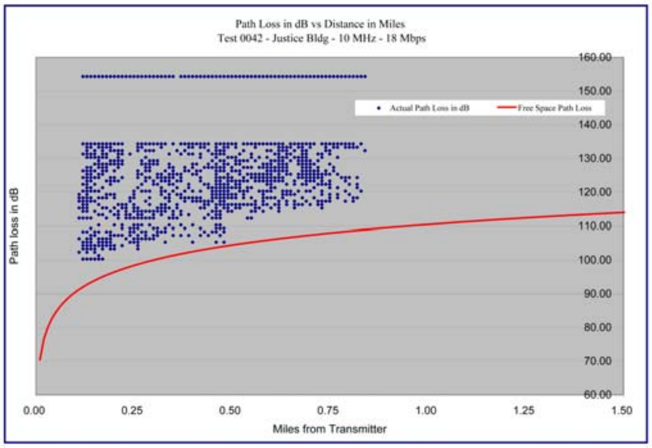
Graph 4.57 Path Loss from Justice Center – 10 MHz / 6 Mbps



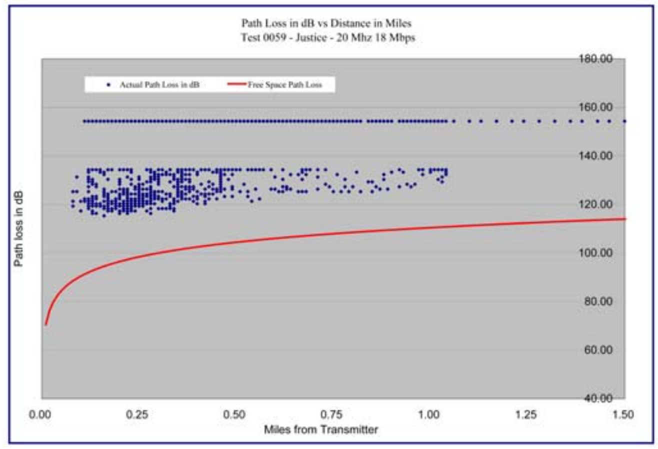
Graph 4.58 – Path Loss from Justice Center – 20 MHz / 6 Mbps

Path loss was considerably greater at 20 MHz bandwidth, resulting in decreased coverage.

Effects of Increasing Bandwidth from 10 MHz to 20 MHz
AP's Maximum Allowable Bandwidth 18 Mbps



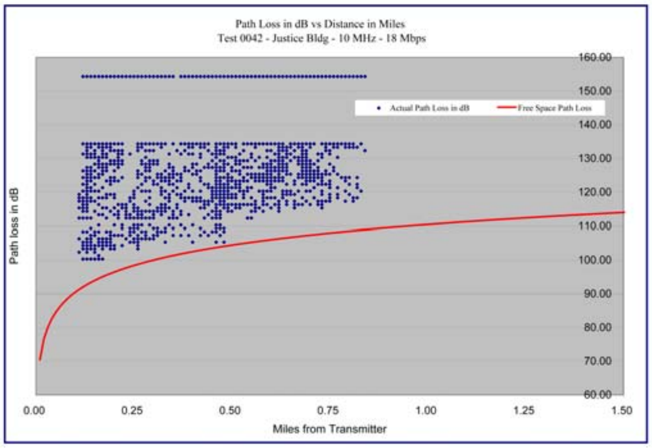
Graph 4.59 Path Loss from Justice Center – 10 MHz / 18 Mbps



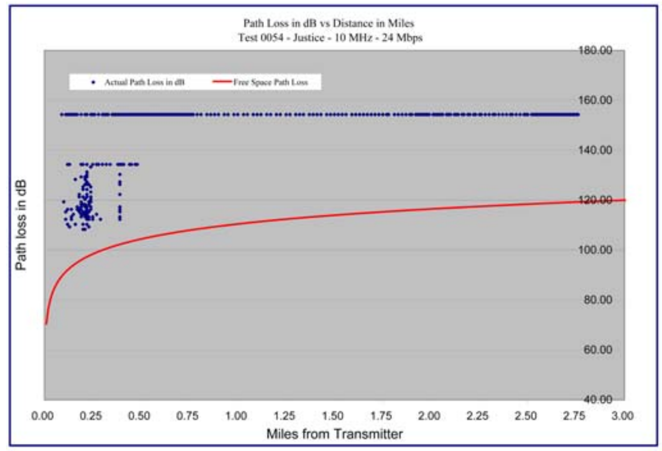
Graph 4.60 – Path Loss from Justice Center – 20 MHz / 18 Mbps

Path loss was considerably greater at 20 MHz bandwidth, resulting in decreased coverage in both sets of tests, which were run.

Effects of Increasing the AP's Maximum Allowable Throughput from 18 Mbps to 24 Mbps
10 MHz Bandwidth



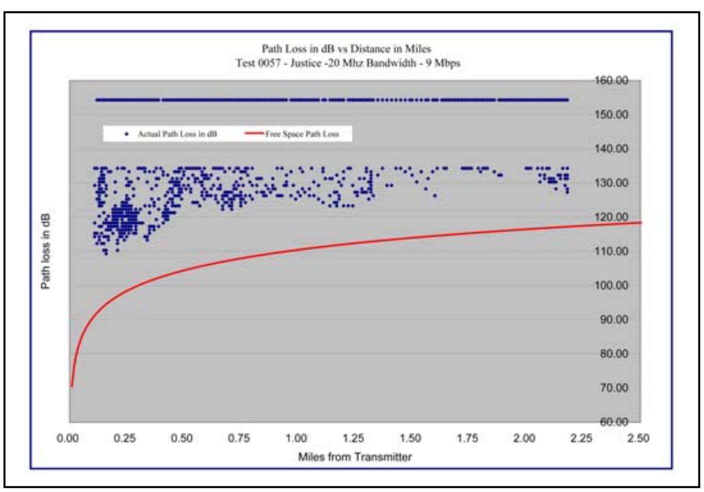
Graph 4.61 – Path Loss from Justice Center – 10 MHz / 18Mbps



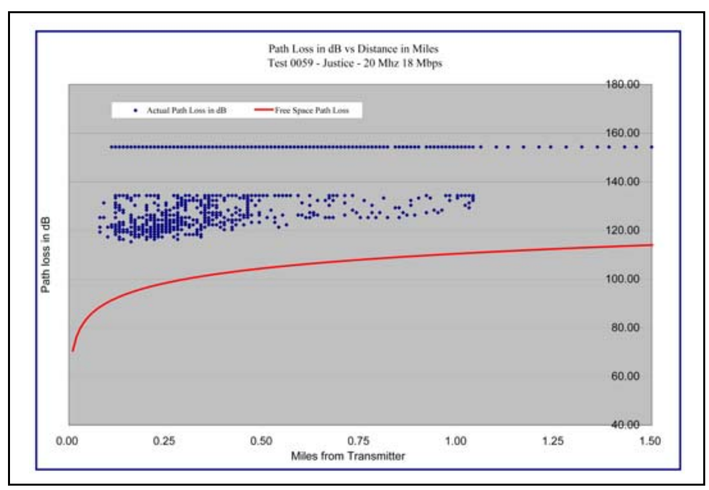
Graph 4.62 Path Loss from Justice Center – 10 MHz / 24 Mbps

The graphs dramatically show the effects of increasing the maximum allowable data throughput rate in the AP. The scales differ on the graphs. <u>The maximum coverage at 18 Mbps was less than 1 mile while the maximum coverage at 24 Mbps was less than ½ mile.</u> The losses are also greater at 24 Mbps

Effects of Increasing the AP's Maximum Allowable Throughput from 9 Mbps to 18 Mbps
20MHz Bandwidth



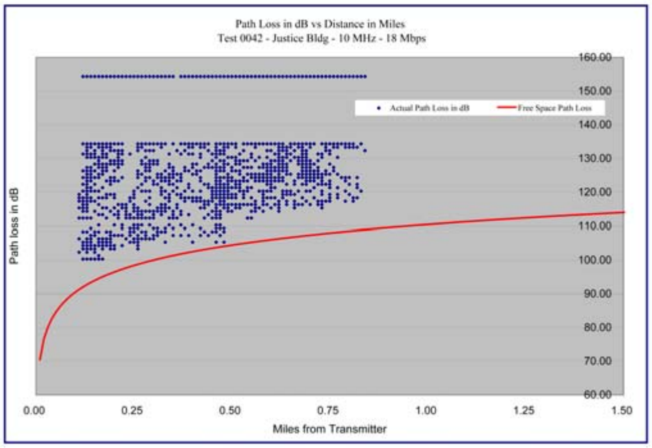
Graph 4.63 – Path Loss from Justice Center – 20 MHz / 9Mbps



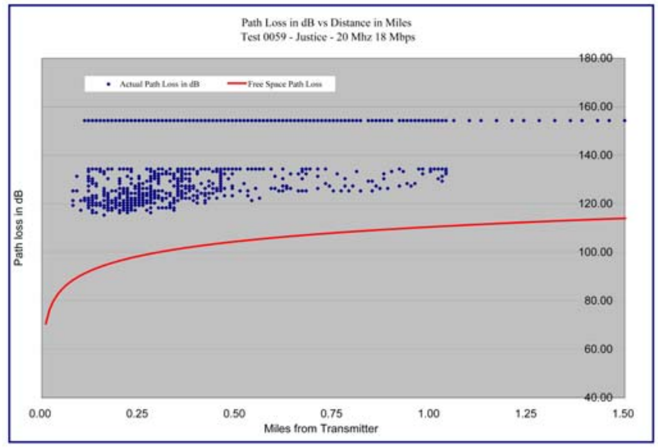
Graph 4.64 – Path Loss from Justice Center – 20 MHz / 18Mbps

The scales are different. The distance covered at 9 Mbps is 2.25 miles, while it is only 1 mile at 18 Mbps. There vertical scale is also different, and the losses are considerable more at 18 Mbps.

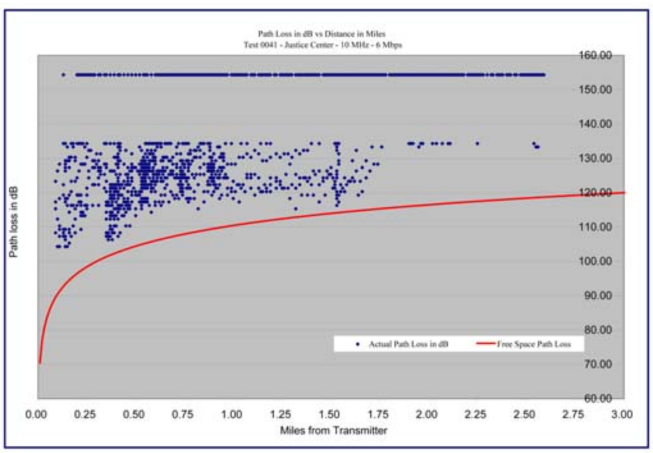
Effects of Increasing the Bandwidth while Decreasing the Throughput



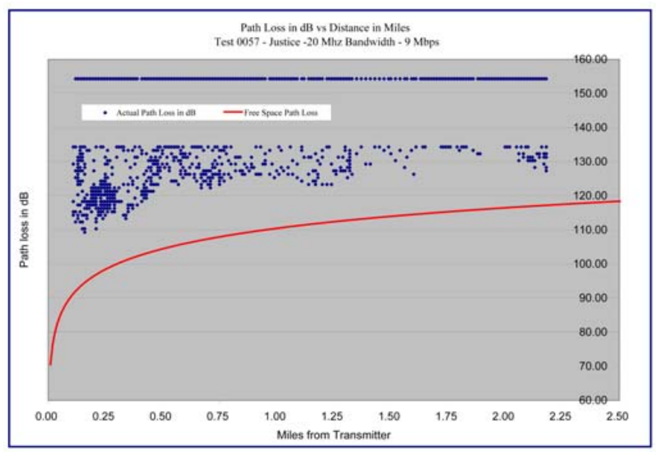
Graph 4.65 - Path Loss from Justice Center 10 MHz/ 6 Mbps



Graph 4.66 – Path Loss from Justice Center 20 MHz / 18 Mbps



Graph 4.67 – Path Loss from Justice Center 10 MHz/ 9 Mbps



Graph 4.68 – Path Loss from Justice Center 20 MHz / 9 Mbps

When Graphs 4.65 to 4.58 are compared, it is noted that the losses in distance caused by increasing the bandwidth can be mitigated by decreasing the AP's maximum allowable throughput. Be sure to note that both the horizontal and vertical scales differ between the graphs.

Checklist for deployment in the suburban foothills:

- Evaluate potential sites

  - Choose a tall building or hill for multiple hot-spots.
  - Choose a lower building site for a higher speed local hot-spots.
  - Make sure the AP's are above the clutter such as trees.
  - Make sure backhaul is available to the site.

- Use predictive model such as Bullington or Longley Rice to the maximum footprint for the coverage. These models are tools that help evaluate topography. If there are obstruction files for the area (for buildings), this will increase the accuracy of the model. Note that these models do not present an accurate map of the final coverage, but are simply one of many tools that can be used to help in the final planning process.

Before final deployment set up a temporary deployment and drive test the area and record the results. The results are best recorded with software that takes many readings per seconds so that the multipath and effects of Raleigh fading can averaged into a reading that is more reflective of the actual results.

Proper and professional installation is critical to satisfactory performance.

Networking of the system is CRITICAL. Multiple sites require a Layer 3 router to prevent spanning tree issues.

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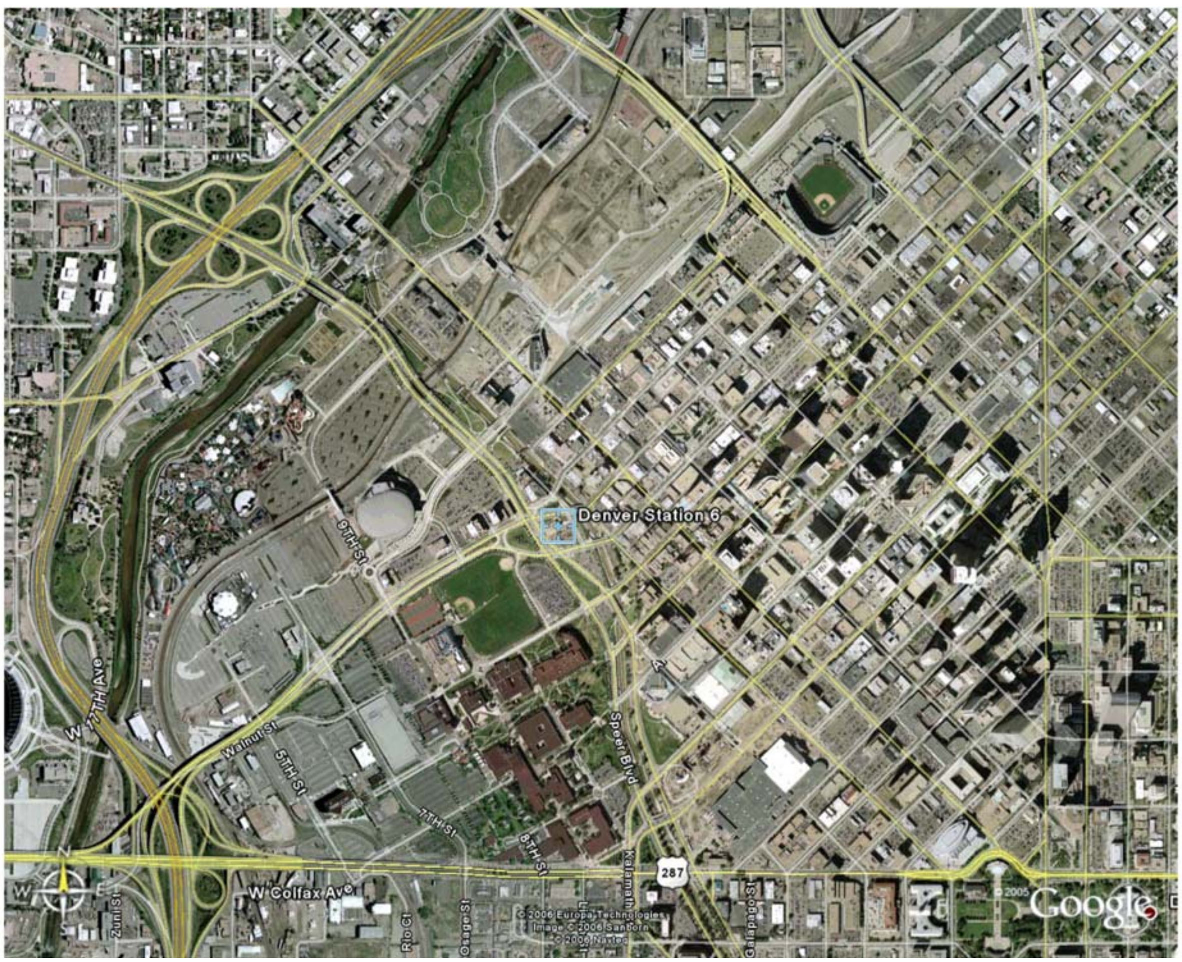
Chapter 5
Coverage in the Urban Inner City – Denver Fire Station 06

Area Description

The City of Denver is very typical of many large urban cities. The first study was from Denver Fire Station 06, which lies between the dense urban portion of the city and the tall buildings and skyscrapers, and the lower urban part of the city with the sprawl of Auraria Community College. The buildings are a mixture of old and new construction. Picture 5.1 is a satellite view[1] of the area. The downtown can be seen to the east, and the Auraria campus to the southwest.



Picture 5.1 – Satellite Image of Denver Fire Station 06 and Downtown Denver

[1] Satellite Imagery from Google Earth Pro, Registered to KNS Communications, Ltd.

Picture 5.2 – Looking NORTH from Station 06

Picture 5.3 – Looking WEST from Station 06

Picture 5.4 – Looking EAST from Station 06

Picture 5.5 – Looking SOUTH from Station 06

Summary of Results

The propagation in an urban area was significantly different from that found in the mountainous areas or the suburban areas. The urban area was characterized by a dense concentration of buildings that were side by side without open areas between them. Denver Fire Station 06 is on the edge of a dense urban area (to the east), and a less dense urban area bounded by Auraria Community college to the west.

It was expected that the dense buildings might have a "waveguide" effect upon the propagation – and might, in certain instances, result in a "better than theoretical" performance, where the free space path losses would be less than theoretical calculations would show, and the receive signal levels better than theoretical calculations would show. It was also expected that the buildings would act as obstructions, blocking the signals. What was not known was how pronounced these effects would be, and how many "streets" over beyond a line of sight path would still have coverage, and how far down those streets that coverage would extend.

There were two studies done from Denver Fire Station, which were examined in this chapter. The first study used beta version radios and the performance was disappointing. The second study used production models of the Proxim 4900 AP's, and the performance was as expected, with some areas performing better than the theoretical calculations showed. There was also coverage at least one block in each direction from the clear line of sight paths

Installation at Station 06

Denver Fire Station 6 is a typical fire station with a hose tower. There is existing equipment already mounted on the hose tower, so the antennas for the installation were side mounted to the existing tower. It was not possible to mount the antennas with exact 90° separation because of the existing antennas.

This was a temporary installation and all cable routing was temporary just for the drive test. Proxim 60° 5054-SA60-17 Antennas were mounted at approximately 60 feet above ground level at 32°, 165°, 230°, and 230° true north. The nominal antenna gain was measured by Pericle Communications at 16.5 dBi at the 4.9 GHz frequency range.

Picture 5.6 – Denver Fire Station 06

Picture 5.7 – Antennas on Hose Tower

Picture 5.8 – Close up of Antennas

Picture 5.9 – Picture of Hose Tower with Antennas

Study 1

Test Parameters: 10 MHz Bandwidth / Maximum Throughput Auto fallback
Denver Fire Station 06 – Test 0032
Beta Test Units – Proxim 60° Sector Antennas

Project Name	The Colorado 4.9 GHz Project					
Test Date	November 2005					
Study Area	Denver Station 06					
Test Description	Test 32					
MAC Address for Fixed AP	Multiple					
Deployment Number	9					
Frequency	4950	MHz				
Sector Azimuth	multiple	Degrees				
Site 1						
Latitude	39° 44' 53.89" N					
Longitude	105° 00' 08.42" W					
Elevation	5195.4	Feet AMSL				
Elevation	60	Feet AGL				
Site 2	Mobile					
Transmitter	**No BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	**_**	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	1	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	0	0.00		dB
Coax - dB loss/100 ft	LDF4-50A	-0.73	12	(0.09)		dB
Antenna	Proxim 60° Sector 5054-SA60-17	15.9	1	15.90		dBi
			EIRP	**32.11**		**dBm**

Table 5.1 – Denver Fire Station 06 – Test 32 Parameters

Table 5.1 shows the transmitter parameters for Denver Fire Station 06. The EIRP was 32.11 and not BDA was used in the installation. Table 5.3 shows the parameters for the mobile receiver used in the drive test. No BDA was used in the mobile receiver. The auto fallback[2]

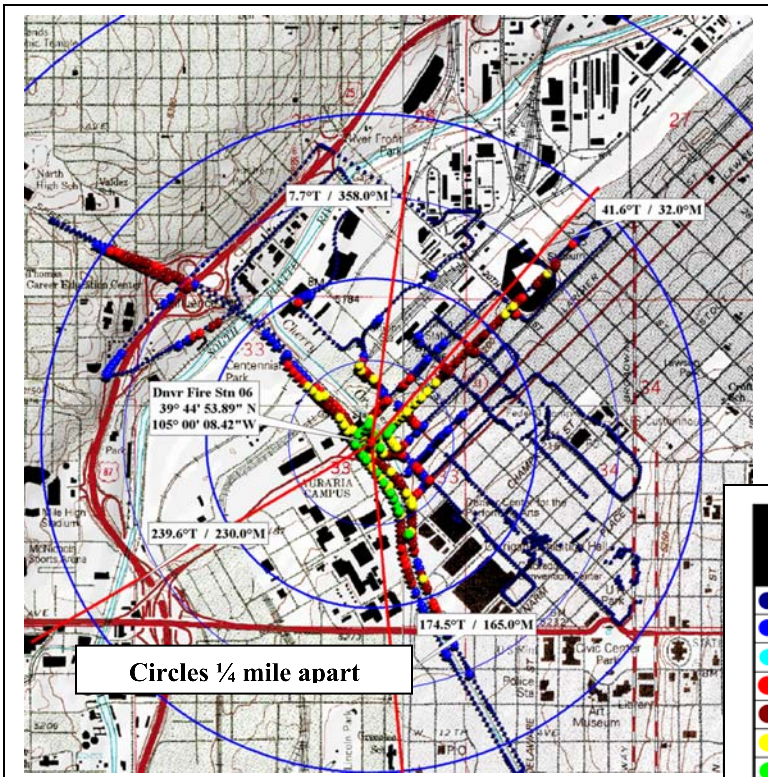
Receiver						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**		**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated [see C1, pg. 6]			(90.00)		dBm
	Maximum Path Loss [see C1, pg. 7]			**129.41**		**dB**
	Maximum Range Assuming LOS, - [see C1, pg.8]			**8.86**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated [see C1, pg. 6]			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**9.41**		**dB**

Table 5.2 – Denver Fire Station 06 – Test 32 - Receiver Specifications

Map 5.1 shows the results of drive test 32 around Denver Fire Station 06. The dark blue circles are every ½ mile, while the lighter blue circles are at ¼-mile intervals. Older beta version AP's were used for this test, so the coverage is not as good as in later tests. The maximum distance was 1 mile for reliable coverage, and high-speed coverage was available within ¼ mile of the station.

[2] The throughput rate will automatically drop to a lower rate if the field strength drops. This allows the radio to perform at the highest throughput for the given field strength, but to drop to a lower rate if necessary.

The coverage was considerably less than expected for this test. The antennas used were Proxim 60° degree sectors. Although these were out of band (5 GHz) antennas, bench testing confirmed that they performed only 1 dB below specifications at 4.9 GHz.



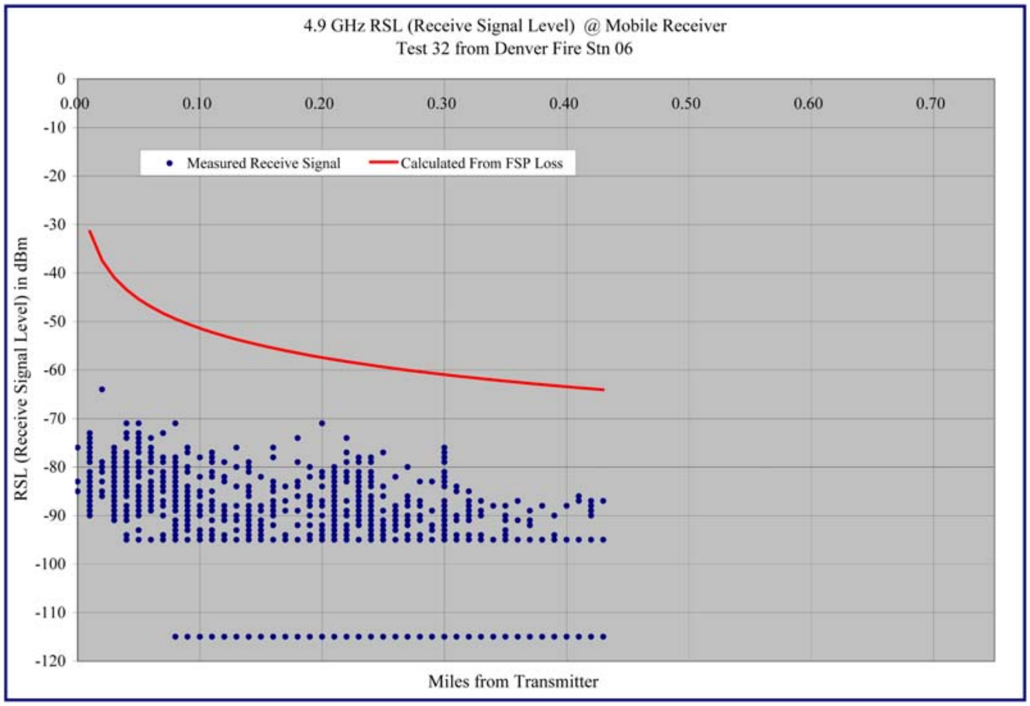
Map 5.1 – Denver Fire Station 06 – Test 32

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

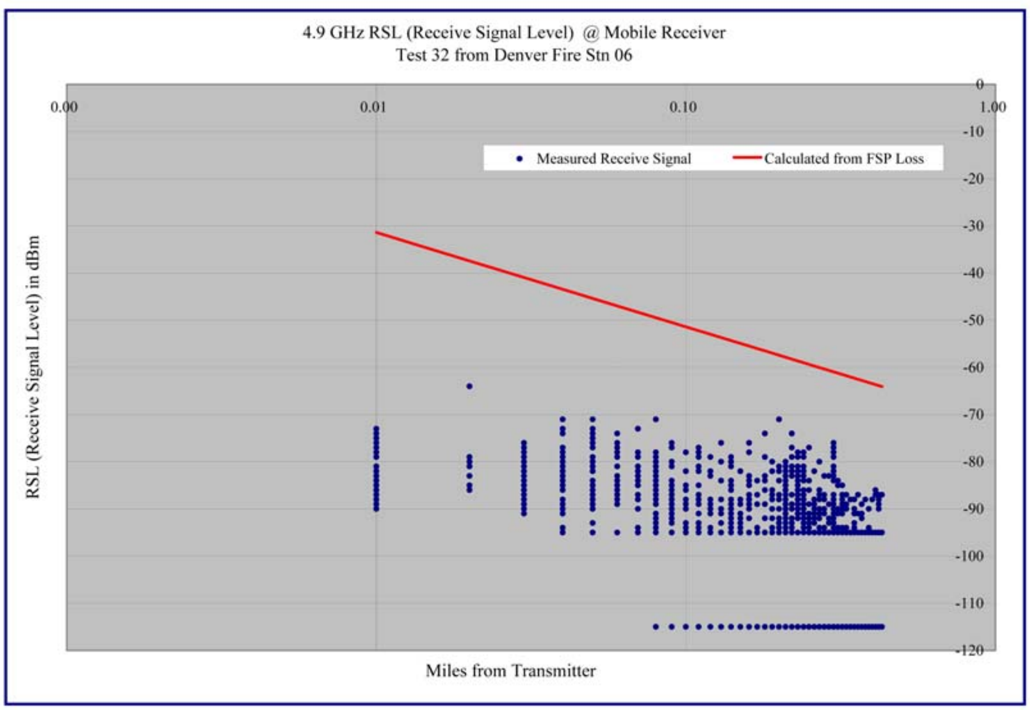
Table 5.3 – Map Legend Denver Fire Station 06 Map

There was excellent coverage within the first ¼ mile, and marginal coverage out to ½ mile from the station. There were hot spots between ½ and 1 mile.

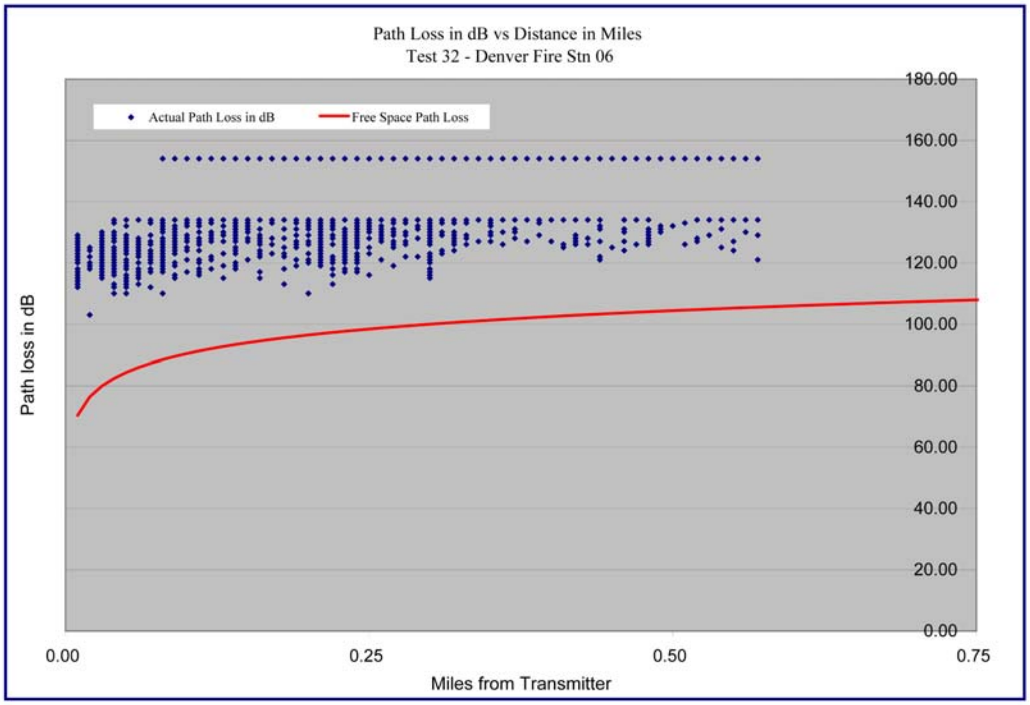
Graphs 5.1 and 5.2 show the receive signal level versus distance. The signals are 12 to 25 dB below theoretical, and are less than expected for this test. Graphs 5.3 and 5.4 show path loss versus distance. The signals are 8 to 20 dB below the theoretical and are less than expected for this test.



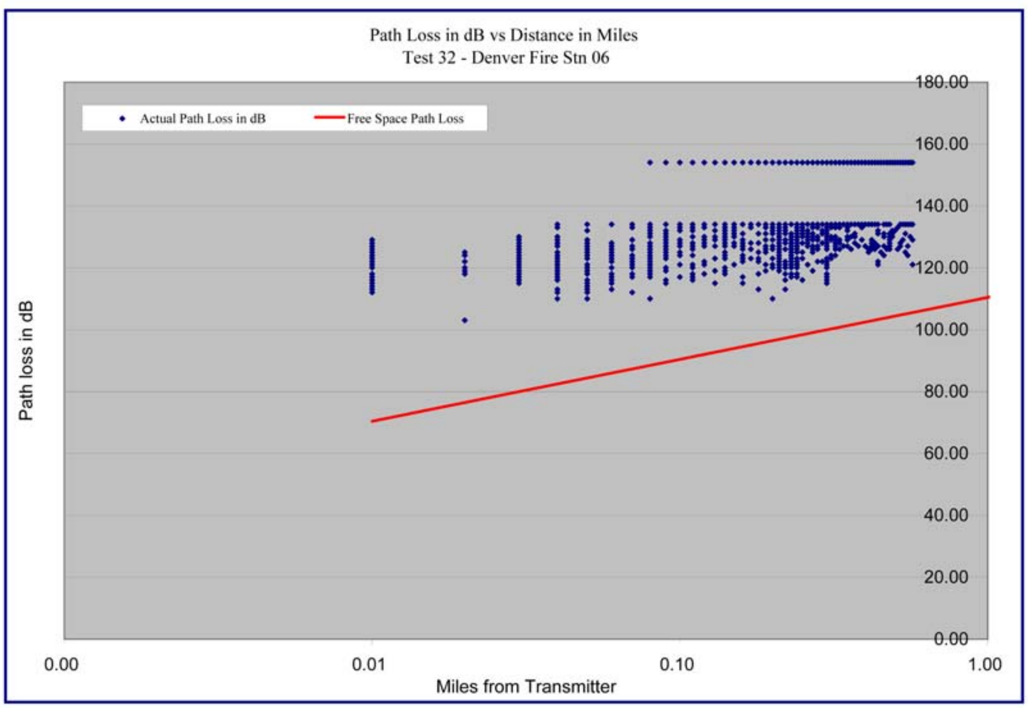
Graph 5.1 – Receive Signal versus Distance – Station 06 Test 32



Graph 5.2 – Receive Signal versus Distance – Station 06 Test 32 – Log-Log Format



Graph 5.3 – Denver Fire Station 06 - Path Loss versus Distance



Graph 5.4 – – Station Fire Station 06 - Path Loss versus Distance– Log-Log Format

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Study 2

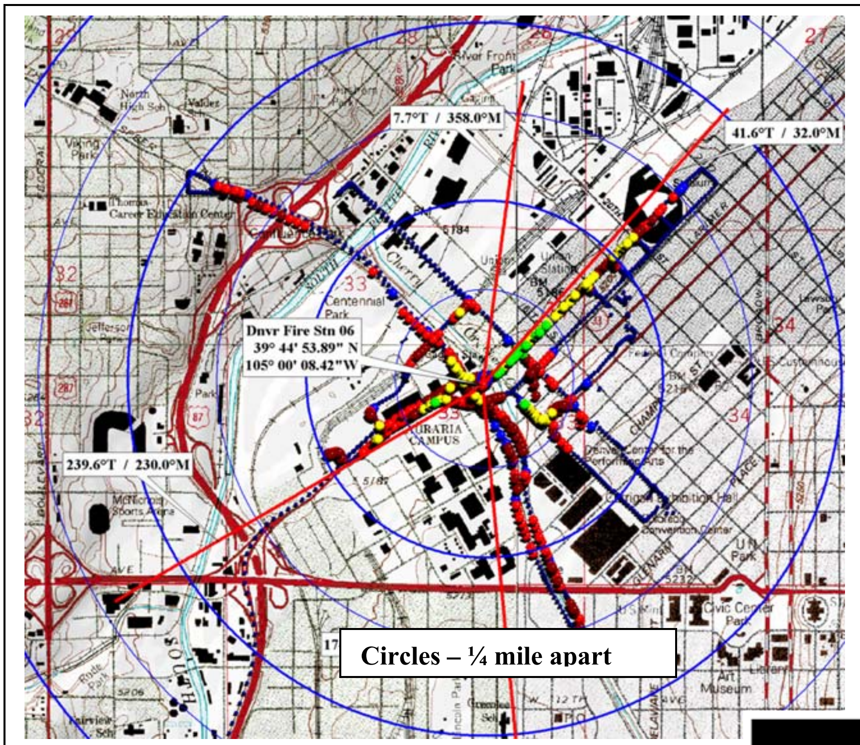
Test Parameters: 10 MHz Bandwidth / Maximum Throughput Auto Fallback

Denver Fire Station 06 – Test 0121 and 0122

Site	Denver Fire Station 06					
Latitude	39° 44' 53.89" N					
Longitude	105° 00' 8.42" W					
Elevation	5195.0	Feet AMSL				
Elevation	60	Feet AGL				

Transmitter	**No BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	0	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	0	0.00		dB
Coax - dB loss/100 ft	LDF4-50A	-0.73	12	(0.09)		dB
Antenna	Til-Tek 90° Sector - TA 4904-14-90	14.9	1	14.90		dBi
			EIRP	**31.11**		**dBm**
Receiver						
	Description	**Value in dB**	**Qty.**	**Gain/Loss**	_	**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**128.41**		**dB**
	Maximum Range Assuming LOS			**7.90**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**8.41**		**dB**

Table 5.4 – Parameters for Test 120 and 121 – Denver Fire Station 06



Map 5.2 – Test 0120 and 0121 – Denver Fire Station 06

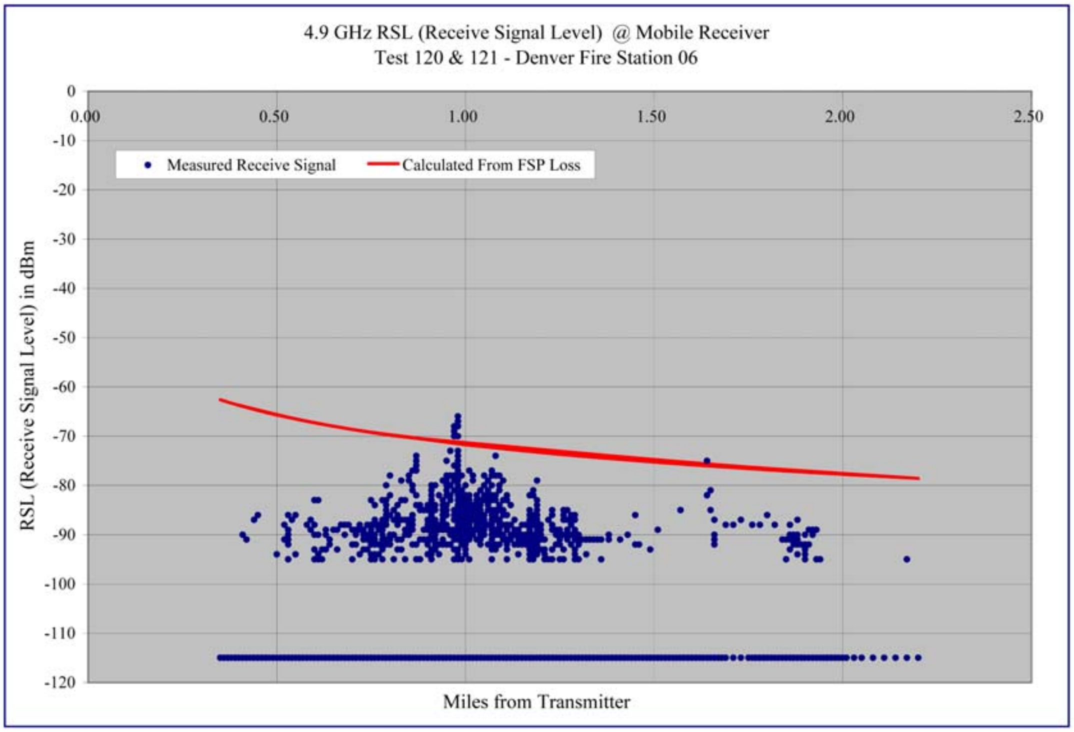
Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 5.5 Legend for Map

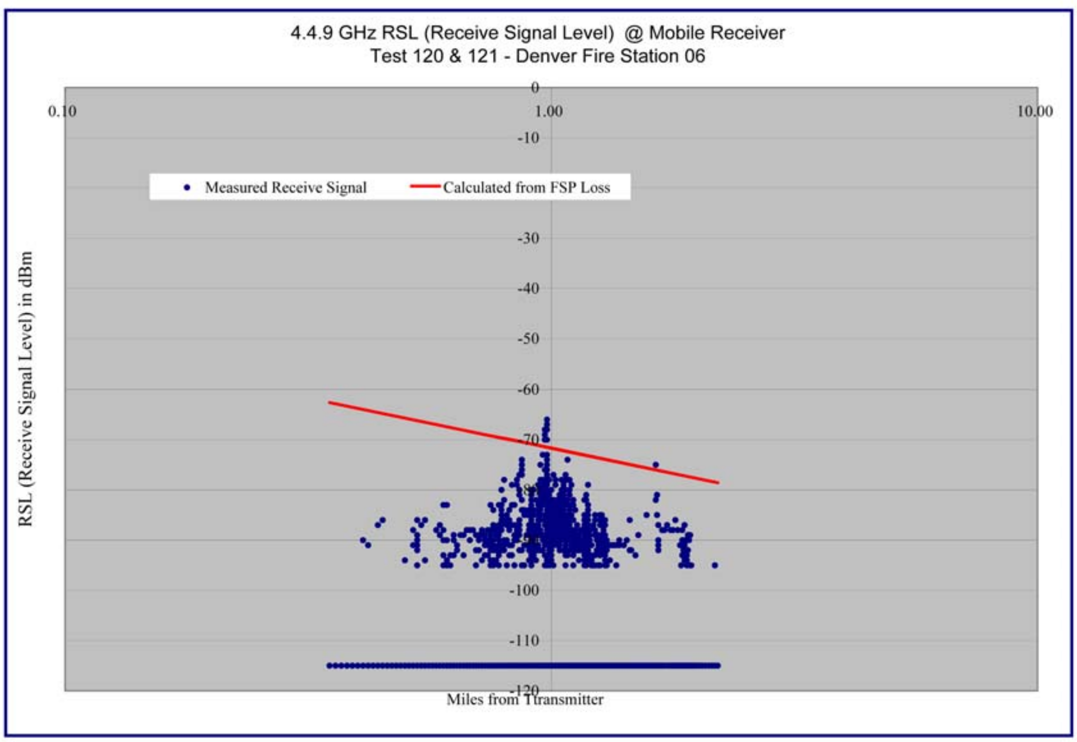
Test 0120 and 0121 used the new production model Proxim AP4900. The resulting performance was improved, with high throughput up to ¼ mile and good throughput up to ½ mile. Hot spot locations were up to 1 mile from the transmitter

Reliable coverage was as far as a mile where there were no obstructions from buildings (down the streets from the site). Reliable coverage was also seen ¼ mile in every direction, with high-speed coverage on the streets that have an unobstructed view of the site.

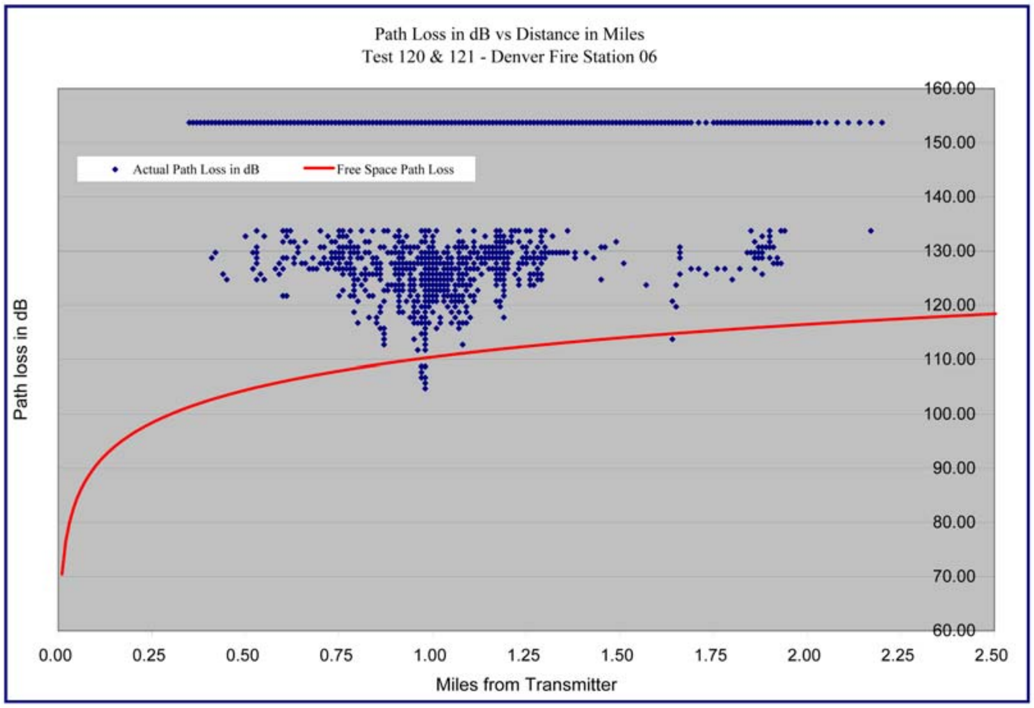
Graphs 5.5 and 5.6 show the Receive Signal Level versus Distance. Graphs 5.7 and 5.8 show the Path Loss versus Distance. At 1 mile the receive signal level is above the theoretical and the path loss is less than theoretical.



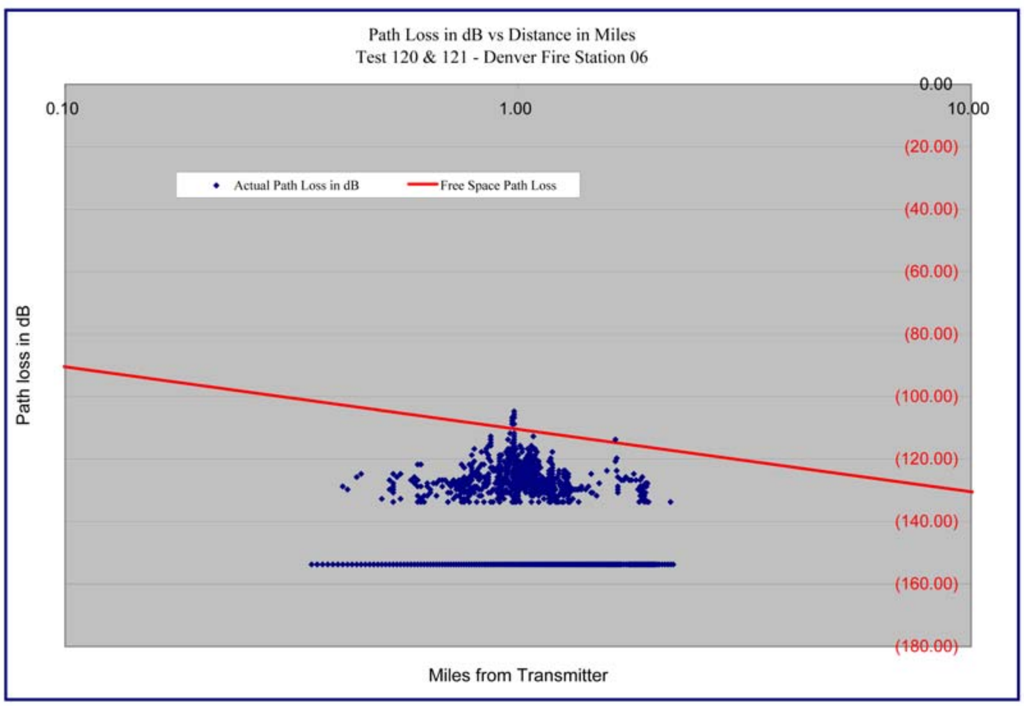
Graph 5.5 – Receive Signal Level versus Distance - Denver Fire Station 06



Graph 5.6 – Receive Signal Level versus Distance – Denver Fire Station 06



Graph 5.7 – Path Loss versus Distance – Denver Fire Station 06



Graph 5.8 – Path Loss versus Distance – Log-Log Format – Denver Fire Station 06

Test Numbers	32	0120, 0121
Study No for this Chapter	**Study 1**	**Study 2**
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	32.11 dBm	31.11 dBm
Antennas	no downtilt 60°	no downtilt 90°
Topography	urban	urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	60	60
Distance for Hot-spots		
Maximum	0.9	0.8
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	16	-8*
Maximum	40	20
Backhaul		
feasibility	microwave in place	microwave in place
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	yes	yes
Ad Hoc or Mesh	yes	yes
Site Comparison		
Overall Coverage	Very Good	Good
Comment	*Note - Study 2 has Less path loss than theoretical in several places	

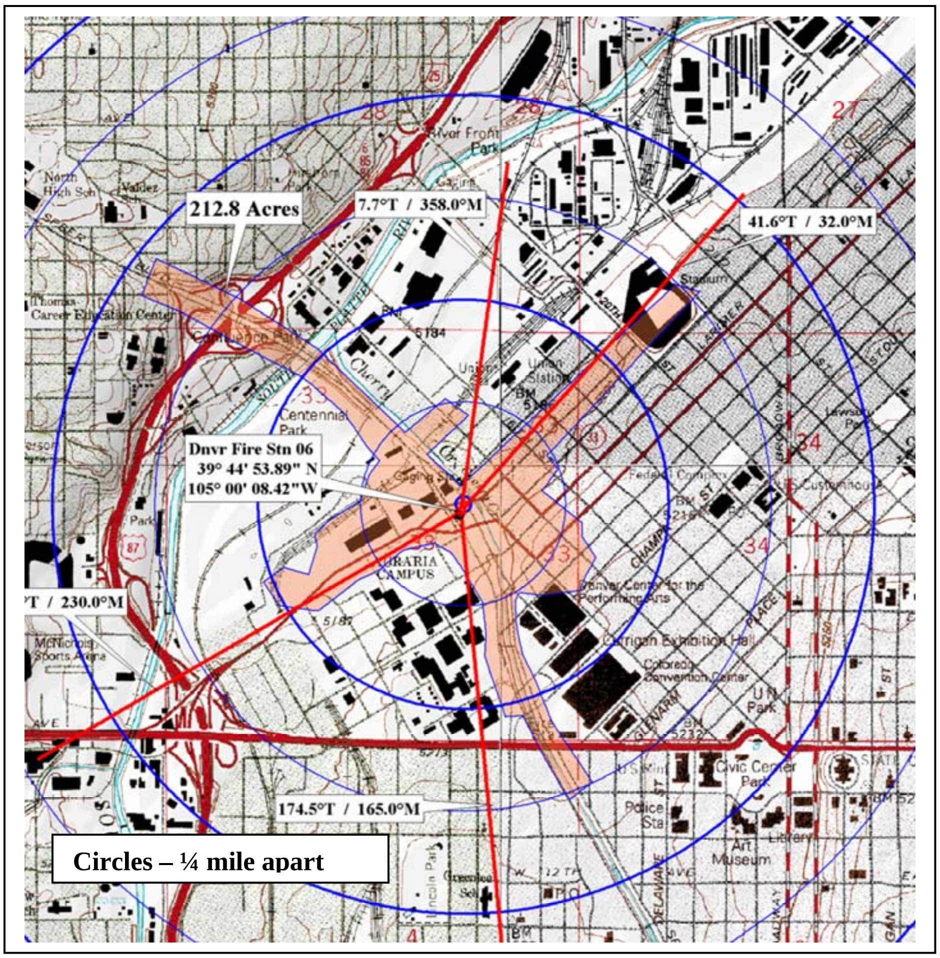
Table 5.6 – Site Comparisons

Summary and Conclusions

Map 5.3 shows a footprint of approximately 213 acres from the four AP's at Denver Fire Station 06. A single AP with a BDA (Bidirectional Amplifier) and an omni antenna would have approximately the same EIRP (Effective Radiated Power) and should have a similar footprint.

The current system has an EIRP above that currently allowed by the FCC for loose-mask radios. The FCC is strongly encouraged to revisit the current EIRP limitations for loose mask radios. The cost of deployment with a tight mask proprietary radio is considerably more than an off the shelf loose mask unit.

The coverage is encouraging, and a properly deployed system should be able to provide mobile broadband coverage for the emergency responders.



Map 5.3 – Footprint from Station 06

Checklist for deployment in the urban setting:

Evaluate potential sites

- Choose a higher sight clear of clutter for a larger area of coverage
- Choose a lower sight for local hotspots and localized coverage
- Make sure backhaul is available to the site.
- In an urban setting, the predictive tools are helpful only if the topography is rolling hills or rough terrain. If this is the case, the tools should be used to evaluate limitations caused by the topography. Longley-Rice or Bullington would be acceptable. If the terrain is relatively flat, such as in the Denver deployment, these tools will not provide much insight into the coverage because the buildings are the primary limiting factor.

Before final deployment set up a temporary deployment and drive test the area and record the results. The results should be recorded with software that takes many readings per seconds so that the multipath and effects of Raleigh fading can averaged into a reading, which is more reflective of the actual results.

Proper and professional installation is critical to satisfactory performance.

Networking of the system is CRITICAL. Routing must be done with a Level 3 router to prevent spanning tree issues.

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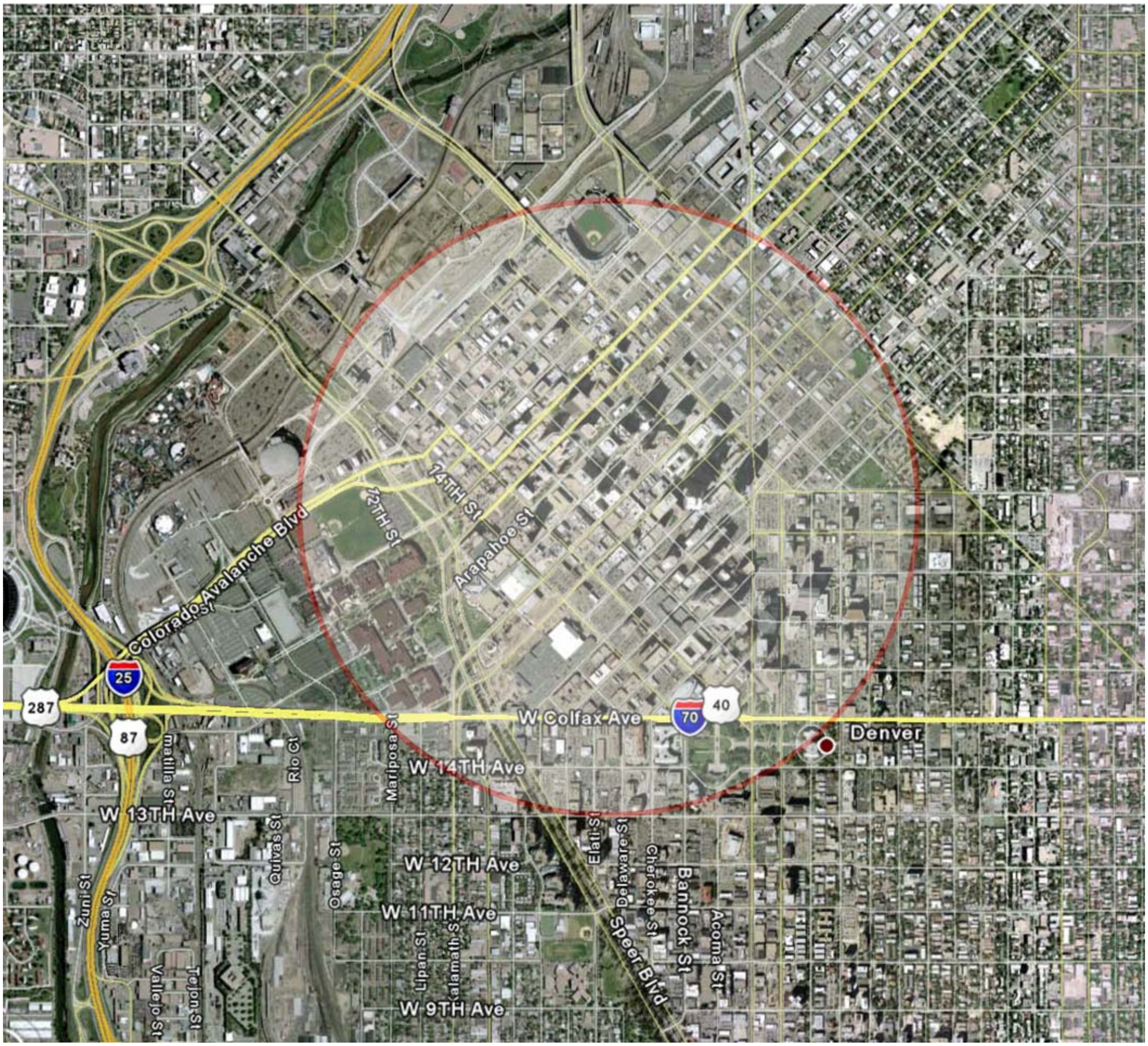
Chapter 6
Dense Urban – Downtown Denver

Area Description



Picture 6.1 – Satellite View of Downtown Denver

Picture 6.1 shows a satellite photo of the downtown Denver area[1]. The red circle shows the downtown area, which has the dense urban characteristics – skyscrapers and little open space. Picture 6.2 shows an enlarged view of the downtown area.

Picture 6.2 – Enlarged Satellite Image of Downtown Denver

There were 12 tests performed in the downtown Denver area. The tests were run in groups of two – with two tests being run simultaneously, so they could be compared side by side. Each test was designed to show characteristics of dense urban coverage, but the site locations were varied.

[1] Google Earth Pro Satellite Imagery, Registered to KNS Communications, Ltd.

Table 6.1 describes the tests that were run. Tests with the same number were run simultaneously, with the A designating a test with a BDA on each end, and B designating tests without a BDA.

Table 6.1 - Dense Urban Deployment - Description					
Test #	Portal Location Mobile Command Post	Mobile Command Post Antennas	BDA Locations Mobile Command Post	BDA Locations Mobile Receiver	Description
105-A	20th and Broadway	Omni at 35 ft AGL	Yes	Yes	intersection
105-B	20th and Broadway	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	intersection
106-A	20th and Stout	Omni at 35 ft AGL	Yes	Yes	intersection
106-B	20th and Stout	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	intersection
107-A	18th and Broadway	Omni at 35 ft AGL	Yes	Yes	intersection
107-B	18th and Broadway	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	intersection
108-A	18th and Stout	Omni at 35 ft AGL	Yes	Yes	mid block
108-B	18th and Stout	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	mid block
109-A	15th and Court Place	Omni at 35 ft AGL	Yes	Yes	mid block
109-B	15th and Court Place	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	mid block
110-A	Broadway South of Colfax	Omni at 35 ft AGL	Yes	Yes	mid block
110-B	Broadway South of Colfax	90° Sectors - 2 at 35 ft AGL, 2 at 28 ft AGL	no	no	mid block

The A tests used two omni antennas – one at the portal unit which was located in Denver's Mobile Command Post, and one in the mobile which had the mesh AP or subscriber unit. Picture 6.3 shows the mobile command post as it was deployed in these tests. The omni antenna can be seen at the end of the arrow. Both the Portal AP and the mobile AP were equipped with a Lynx BDA (bidirectional amplifier).

The B tests were run using four AP's at the command post – each AP connected to a 90° Til-Tek Sector Antenna (Til-Tek TA4904-14-90). The sectors were mounted at 90° from each other. Sector 1 pointed toward the front of the vehicle, Sector 2 pointed to the rear, Sector 3 pointed to the right, and Sector 4 pointed to the left. Since the streets in downtown Denver do not run north, the directions of the antennas will parallel the street on which the mobile command post was parked. There were no amplifiers used in the B tests.

Picture 6.4 shows the mobile command post, and the sector antennas can be seen more clearly in this photo. This picture also compares the height of the antennas to a light pole, since light poles will often be used in this type of deployment

.

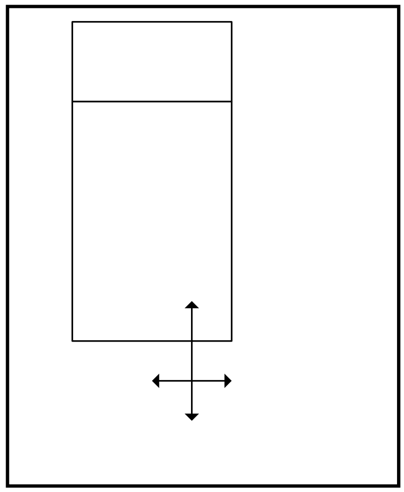


Figure 6.1 – Sector Configuration on MCP

omni antenna

Picture 6.3 – Mobile Command Post

Sector antennas

Picture 6.4 – Mobile Command Post next to Light Post

Project Name	The Colorado 4.9 GHz Project					
Test Date	February 2006					
Study Area	Downtown Denver					
Test Description	A Tests - Mobile Command Post - Omni					
MAC Address for Fixed AP						
Deployment Number	16					
Frequency	4950	MHz				
Sector Azimuth	219.4	Degrees				
Site 1						
Latitude	varied					
Longitude	varied					
Elevation	varied	Feet AMSL				
Elevation	35	Feet AGL				
Site 2	Mobile					
Transmitter – A Test	**With BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**		**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	1	10.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	1	(0.10)		dB
Coax - dB loss/100 ft	LDF4-50A	-0.073	10	(0.73)		dB
Antenna	Omni	6	1	6.00		dBi
			EIRP	**31.47**		**dBm**

Table 6.2 – Transmitter Parameters for the "A" Tests – MCP Omni with BDA

Table 6.2 gives the parameters for the transmitter in the A series of test and Table 6.3 gives the parameters for the transmitters in the B series of tests. The EIRP (Effective Isotropic Radiated Power) for the two tests are less than ½ dB different (31.47 dBm for the A series of tests 30.97 dBm for the B series of tests). This was on purpose, so the power out would be essentially the same for both tests. This allowed comparisons to be made between the tests without having to contribute the differences to a difference in EIRP.

The mobile AP used in Test A had a BDA, The mobile AP used in test B did not have a BDA. B. Since only the downlink was being tested, and since the EIRP's were essentially the same in both tests, <u>the differences that are noted can be contributed to the increased receiver sensitivity that results when the BDA was added to the mobile receiver[2]</u>.

The desense[3] in the mobile units, caused by the proximity of the two omni antennas on the vehicle, was measured at approximately 2 dB. This measurement was overseen by Frank Pratte, P.E., of Pericle Communications, and was done during the course of the downtown testing.

Project Name	The Colorado 4.9 GHz Project					
Test Date	February 2006					
Study Area	Downtown Denver					
Test Description	B Tests - Mobile Command Post - Omni					
MAC Address for Fixed AP						
Deployment Number	16					
Frequency	4950	MHz				
Sector Azimuth	219.4	Degrees				
<u>Site 1</u>						
Latitude	varied					
Longitude	varied					
Elevation	varied	Feet AMSL				
Elevation	28 ft at 35 ft	Feet AGL				
<u>Site 2</u>	Mobile					
Transmitter – B Test	**Without BDA**					
	<u>Description</u>	**<u>Value in dB</u>**	**<u>Qty.</u>**	**<u>Gain/Loss</u>**	_	**<u>Units</u>**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	0	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	1	(0.10)		dB
Coax - dB loss/100 ft	LDF4-50A	-0.073	10	(0.73)		dB
Antenna	90° Sector - Til-Tek 4904-14-90	15.5	1	15.50		dBi
			EIRP	**30.97**		**dBm**

Table 6.3 – Transmitter Parameters for B Series of Test – MCP 90° Sector Antennas – No BDA

---

[2] Bench level testing conducted by KNS and overseen by Frank Pratte., P.E. of Pericle Communications confirmed that the BDA increased the receiver sensitivity by 2 dB.

[3] "Desense" is a reduced sensitivity in the receivers. The amount of the desense was 2 dB, which means that the weakest signal the receiver can receive and decode must be 2 dB stronger than would be required without the desense.

Tables 6.4 and 6.5 show the receiver parameters for the mobile AP's used in all downtown Denver tests. If there were line-of-sight and nothing else that would affect signal propagation, the maximum path range was 10.36 miles with a BDA in the receiver and only 7.36 miles without out a BDA in the receiver. In effect, there would be a 30% reduction in coverage if there were no BDA used in the receiver to improve its sensitivity.

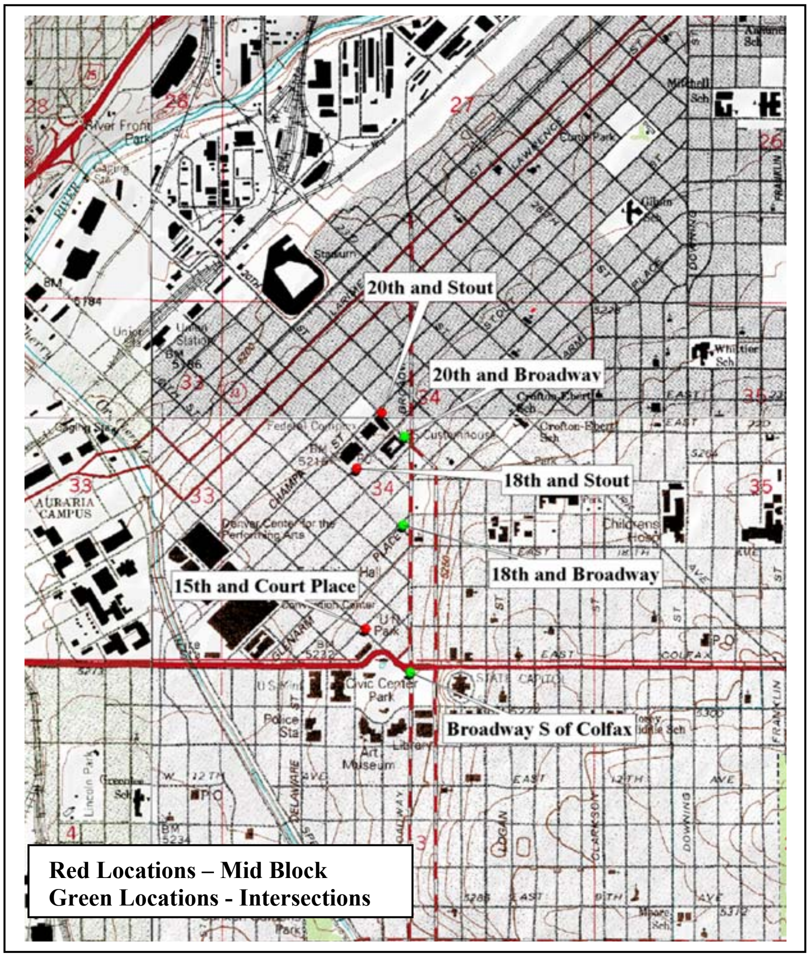
Receiver	**With BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**		**Units**
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated [see C1, pg. 6]			(92.00)		dBm
	Maximum Path Loss			**130.77**		**dB**
	Maximum Range Assuming LOS			**10.36**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**10.76**		**dB**

Table 6.4 – A Test - Receiver Parameters – With BDA

Receiver - B Tests	without BDA					
	Description	Value in dB	Qty.	Gain/Loss		Units
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**128.27**		**dB**
	Maximum Range Assuming LOS			**7.77**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated [see C1, pg. 6]			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**8.26**		**dB**

Table 6.5 – B Test – Receiver Parameters – Without BDA

108 and 109 were setup in the middle of the blocks to simulate installations that have a vantage point of only the street on which they are installed, but no cross streets.



Map 6.1 – Test Site Locations

The dense urban setting is characterized by the dense building structure and by the heights of the buildings. Because RF (radio frequency waves) are part of the electromagnetic spectrum, and because the 4.9 GHz frequencies are relatively high, it was felt that many of the characteristics of the propagation would be similar to that of light. This means that it was anticipated that multipath or reflections that would occur.

What was not known was the extent to which these reflections would occur, and whether the result would be constructive and cause improved signals, or destructive.

- It was expected that deployments at intersections would result in better coverage on adjacent parallel streets than deployments in the middle of the block.

- It was expected that coverage one block to either side of the street on which the portal was deployed would have some coverage.

- It was expected that coverage beyond one block to either side of the street on which the portal was deployed would not have coverage.

- It was expected that the streets with the tall buildings might have a "waveguide" effect which would result in better than theoretical coverage down the street where the deployment is occurring.

- It was expected that the BDA would enhance the performance of the mobile receiver, and that this would increase the coverage area.

Summary of Results

- As expected, deployments at the intersection resulted in substantially more coverage in adjacent streets parallel to the two streets, which intersect at the deployment location.

- An unexpected result was that mid-block deployments sometimes resulted in better coverage and propagation than the deployments near the intersections.

- As expected there was coverage in the block to either side of the streets on which the portal was deployed – however, it was surprising to see that the coverage often went beyond that, to two or three streets to either side.

- As expected, there was a "waveguide" effect, and field strengths greater than the theoretical were experienced in these deployments.

- As expected, the "waveguide" effect resulted in free space path loss less that than the theoretical.

- Downtown deployments appear to have better than expected coverage and performance because of the effects of the buildings.

- Each individual deployment should be tested before a final deployment is installed.

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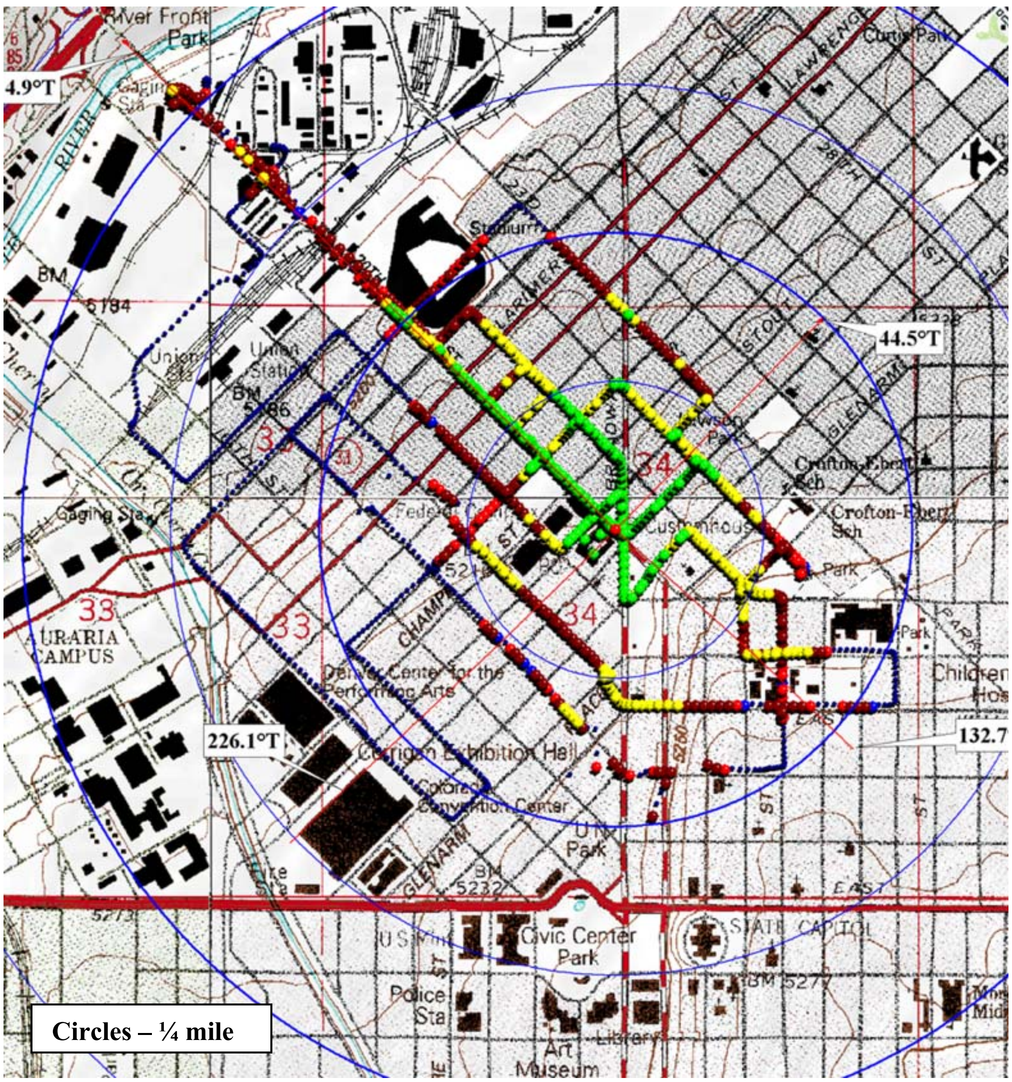
Study 1
Test 105A – Mobile Command Post with Omni
BDA at Portal and Mobile
20th and Broadway - Intersection



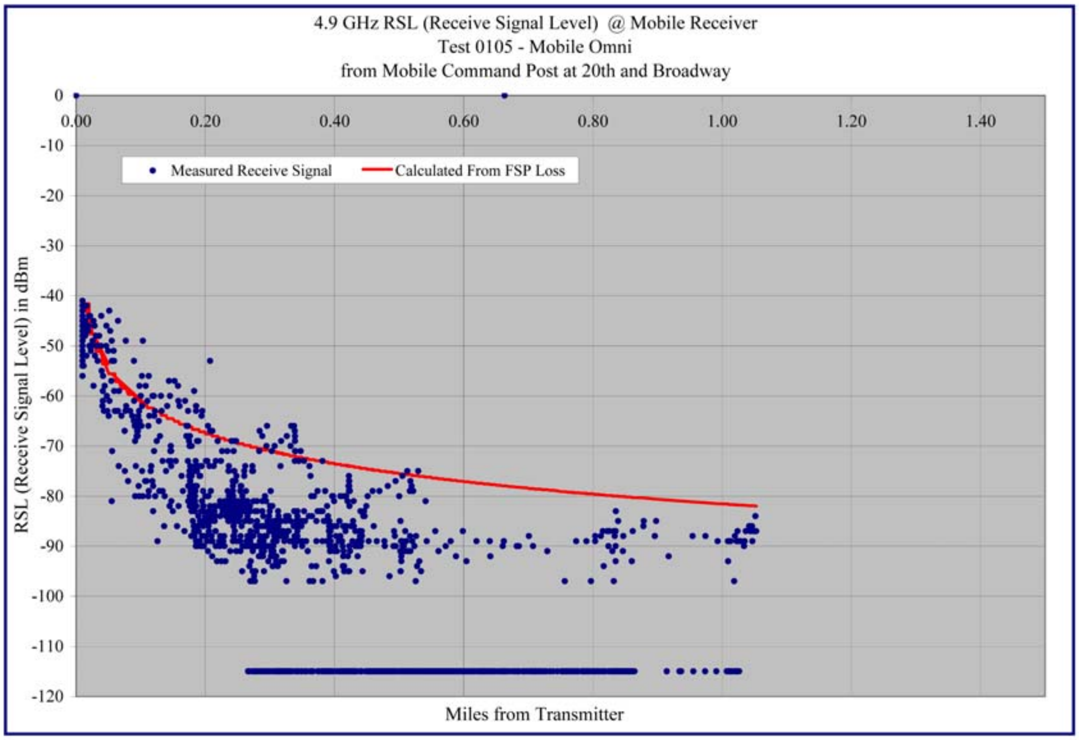
Map 6.2 – 20th and Broadway Omni with BDA

Deployment Summary:

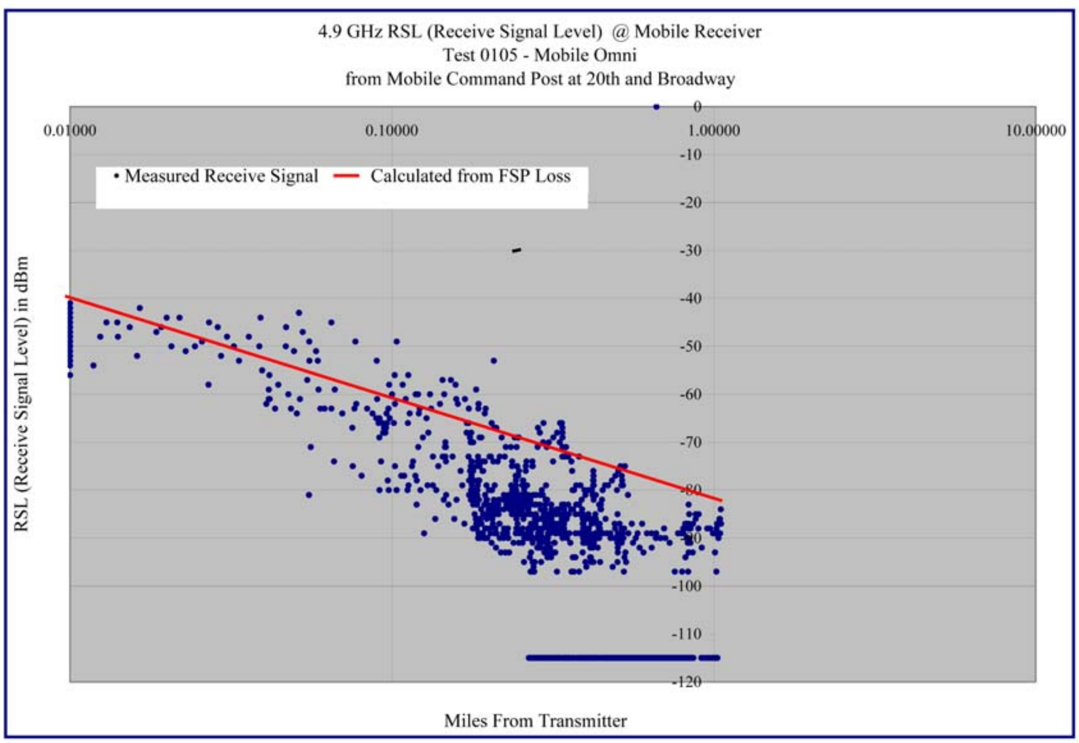
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL

20th and Broadway is on the northeastern edge of the dense urban area. It borders less dense urban areas to the east and high-density urban areas to the west.

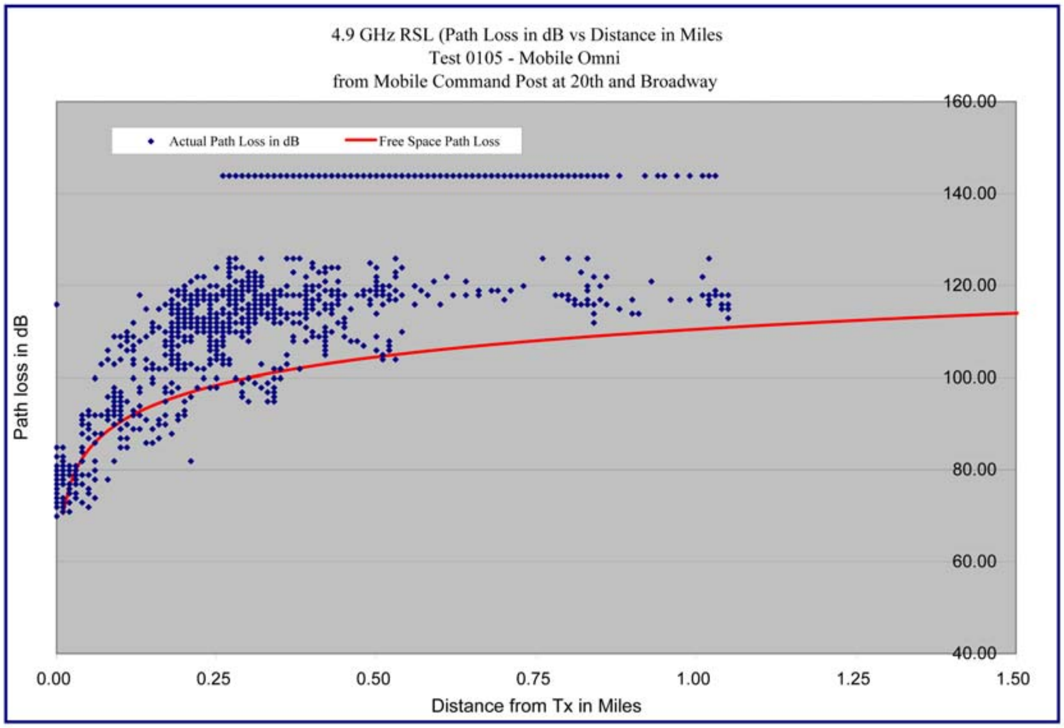
Table 6.6 – Map Legend



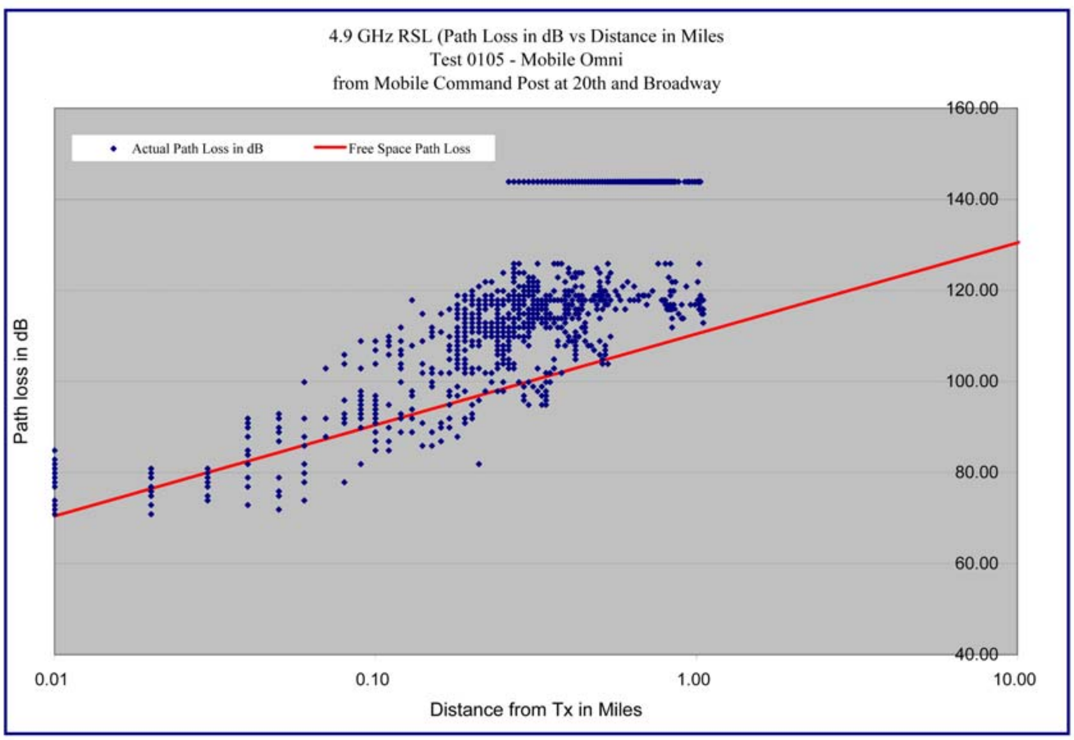
Graph 6.1 – Receive Signal Level versus Distance – Test 105 Omni with BDA



Graph 6.2 – Receive Signal Level versus Distance – Test 105 Omni with BDA – Log-Log Format



Graph 6.3 – Path Loss versus Distance – Test 105 Omni with BDA



Graph 6.4 – Path Loss versus Distance – Test 105 Omni with BDA – Log-Log Format

Picture 6.5 – 20th and Broadway looking NW

Picture 6.6 – MCP at 20th and Broadway

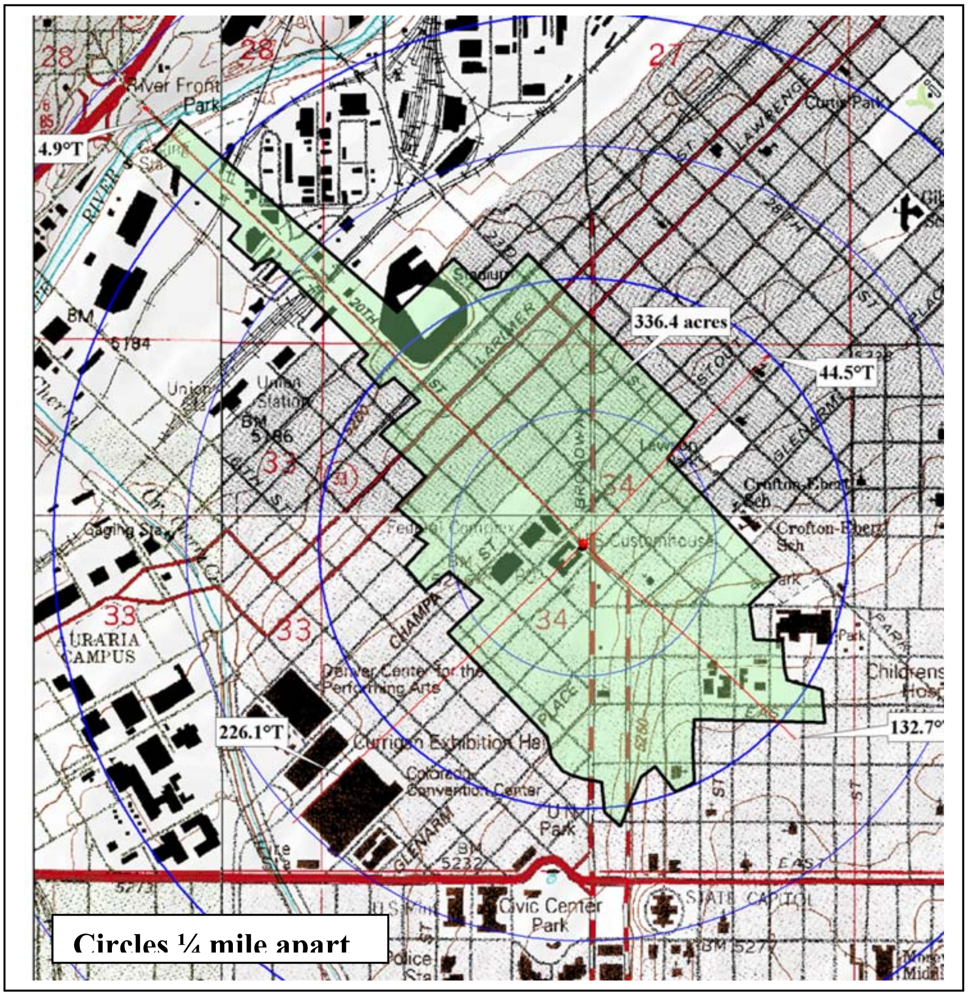
Picture 6.7 – Satellite Image of 20th and Broadway

The satellite photo clearly shows that the 20th and Broadway deployment is on the edge of the dense urban downtown area. The shadows of the large buildings to the south are seen in the photo.

This location also has a view of Broadway (which runs north and south) and 20th, which runs diagonally to Broadway.

The results of Study 1 were impressive and better than expected. Graphs 6.1 and 6.2 show that the receive signal level was consistently better than the calculated theoretical – a phenomena probably explained by the “waveguide[1]” effect of the buildings. Graphs 6.3 and 6.4 show that the actual path loss is less than the calculated path loss, also probably a result of the “waveguide” effect.

Map 6.2 shows the footprint of the coverage from this site. The BDA in the mobile receiver increases the mobile sensitivity by 2 dB. This site covers 336.4 acres.



Map 6.3 – Footprint for Test 105 with Omni antenna and BDA

[1] A “waveguide” effect means that the signal behaves as it does in waveguide, where the free space path losses are mitigated by the constructive interference caused by the wave fronts combining constructively along the waveguide.

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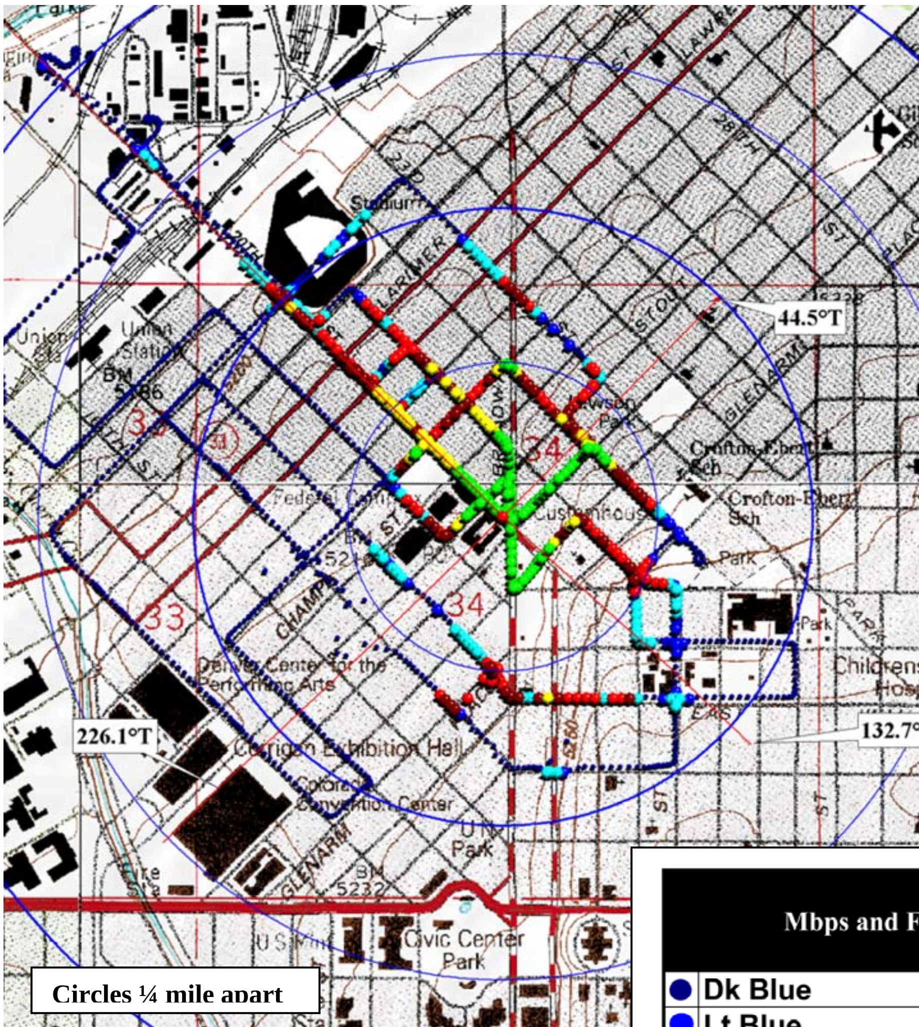
Study 2
Test 105B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
20th and Broadway – Intersection



Map 6.4 – Mobile Command Post with 90° Sectors no BDA

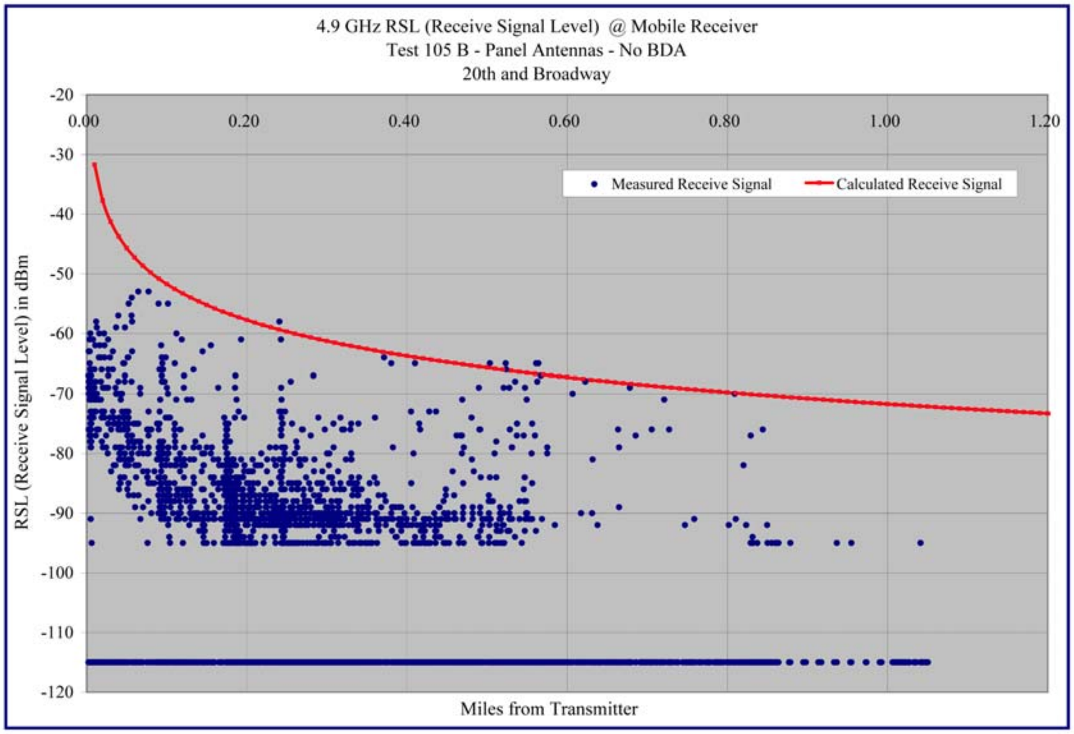
Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

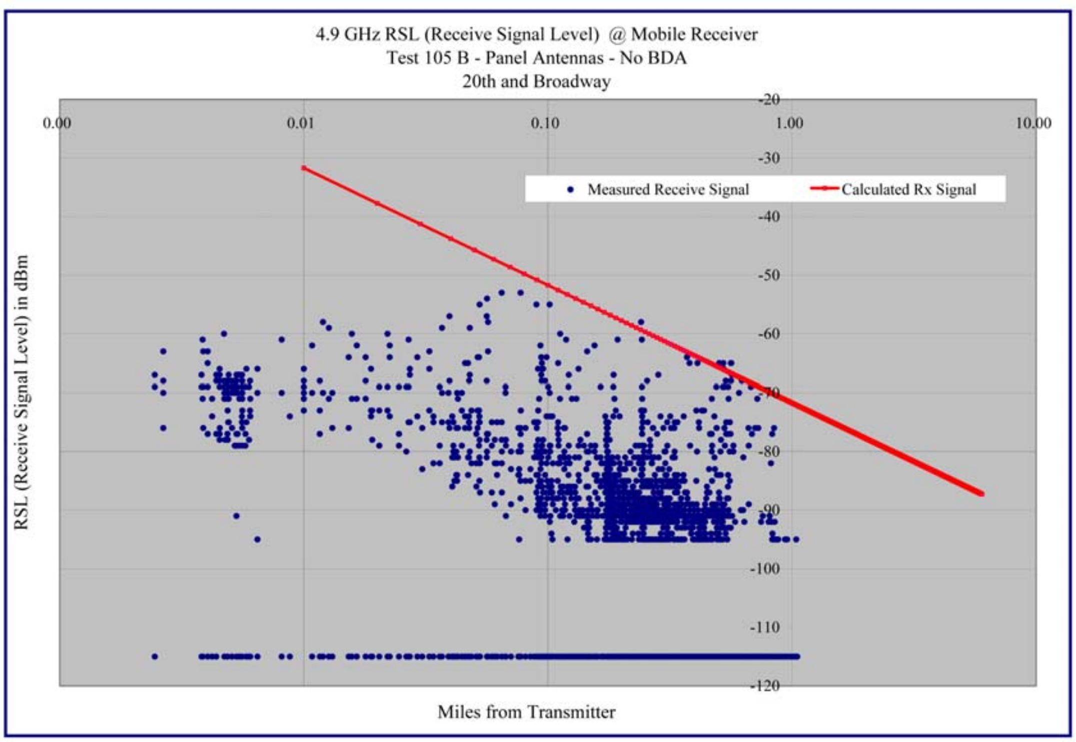
20th and Broadway is on the northeastern edge of the dense urban area. It borders less dense urban and high density urban areas.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

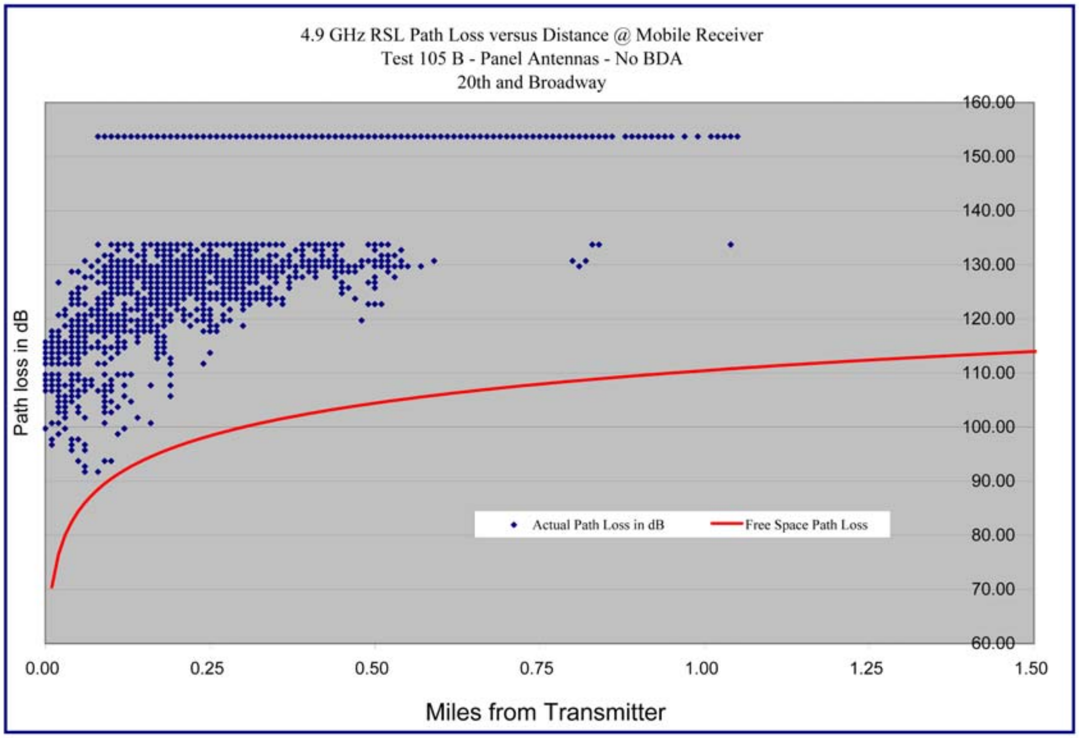
Table 6.7 – Map Legend



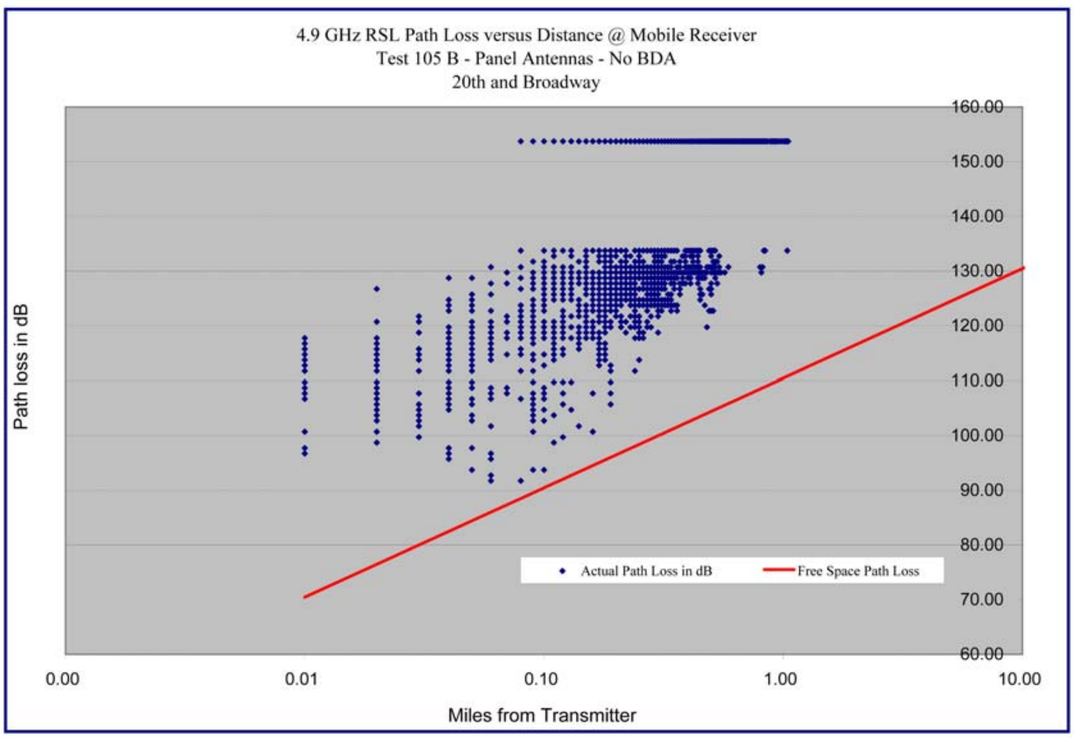
Graph 6.5 – Receive Signal Level versus Distance – Test 105B – Panel Antennas no BDA



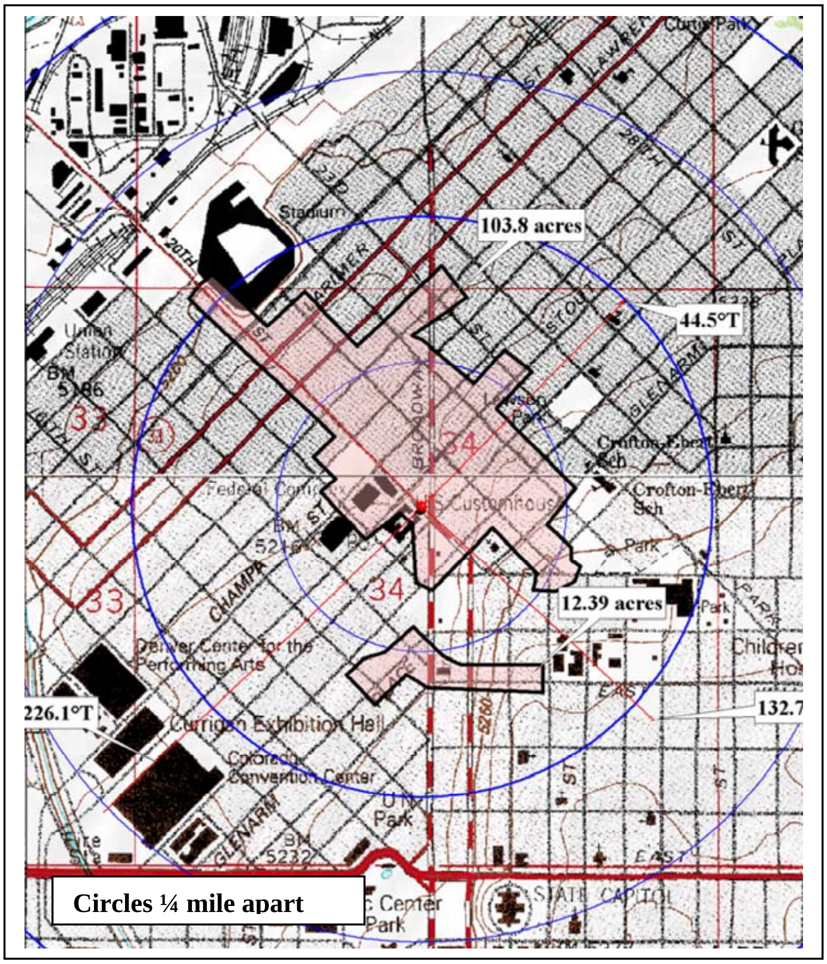
Graph 6.6 – Receive Signal Level versus Distance – Test 105B – Panel Antennas no BDA – Log-Log Format



Graph 6.7 – Path Loss versus Distance – Test 105B – Panel Antennas no BDA



Graph 6.8 – Path Loss versus Distance – Test 105B – Panel Antennas no BDA – Log-Log Format



Map 6.5 – Footprint for Test 105 with 90° Sector Antennas and no BDA

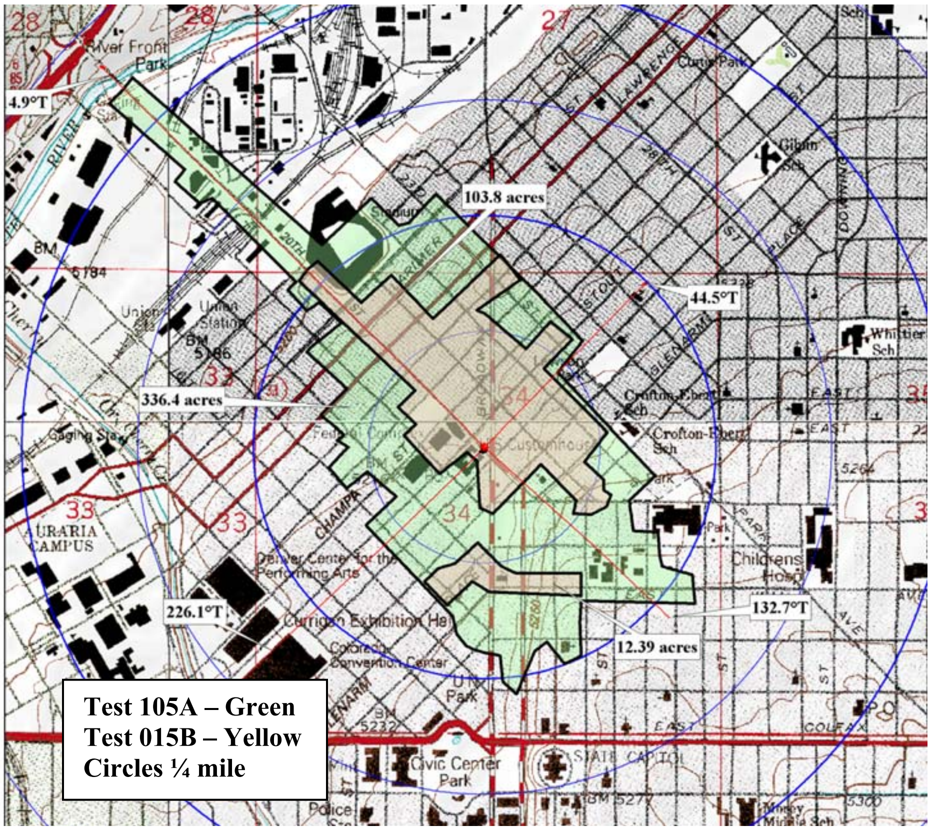
The results of this study were somewhat surprising. Initially it was felt that with the panel antennas would perform better than the omni antenna on the mobile command post, even though the omni antenna test (Test 105A) had BDA's in the system. That was not the case, however, and the footprint was 30% less than with the omni antenna.

The 30% less is consistent with the predictions for the receivers shown in the Tables 6.4 and 6.5, These tables showed that the receiver without the BDA have a range that was 30% less than the one with the BDA.

The total footprint was 116.29 acres, compared with 336.4 acres for the deployment with BDA's.

Map 6.6 in the Summary which follows, compares the two footprints.

Summary of Test Results – Test 105A and Test 105B
20th and Broadway - Intersection



Map 6.6 – Comparison of Footprints between Test 105A and Test 105B

Deployment Summary

Test 105A –Omni Antenna with BDA (Green)
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 336.4 acres

Test 105B – Panel Antennas without BDA (Yellow)

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
Two antennas - 35 ft AGL
Two antennas - 28 ft AGL
Footprint – 116.19 acres

20th and Broadway is on the northeastern edge of the dense urban area. It borders less dense urban and dense urban areas.

Tests 105A and 105B were conducted simultaneously with the same receive vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 105A had an EIRP of 31.47 dBm and test 105B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests can be assumed to be almost the same.

Test 105A resulted in a footprint of 336.4 acres while Test 105B has a footprint of only 116.19 acres, roughly 30% less than the size of the footprint from Test 105A.

The difference was that in the 105A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive

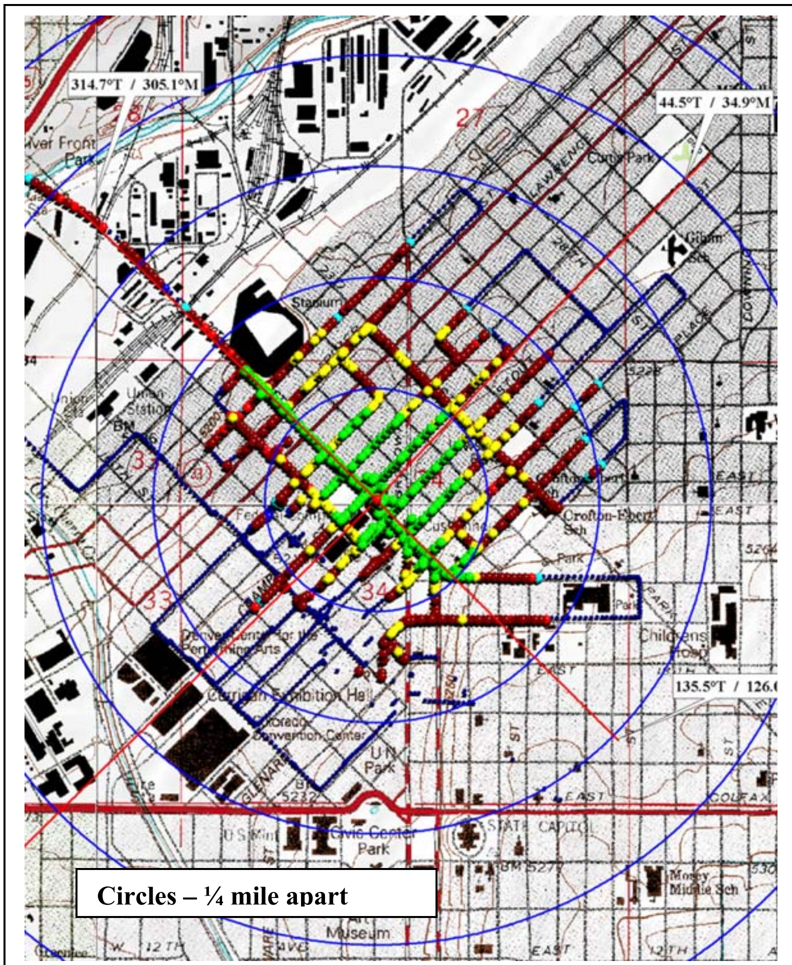
signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E. of Pericle Communications confirmed that the BDA increased the receiver sensitivity by 2 dB.

It appears that the addition of a mobile BDA has a dramatic effect on the coverage area, not because of the increase in EIRP or the effective isotropic radiated power, but because of the increase in receiver sensitivity.

Test Numbers	20th and Broadway 105A	20th and Broadway 105B
Study No for this Chapter	**Study 1**	**Study 2**
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	1.2	.6
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-26*	3
Maximum	1	25
Backhaul		
feasibility	None at this time	None at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	No	no
Ad Hoc or Mesh	yes	yes
Test Comparison		
Footprint Size	336.4 acres	116.19 acres
Comment	Study 1 shows less path loss than theoretical	

Table 6.8 – Comparison of Test 105A and Test 105B

Study 3
Test 106A – Mobile Command Post with Omni
BDA at Portal and Mobile
20th and Stout – Mid-block



Map 6.7 – 18th and Stout Coverage

Deployment Summary

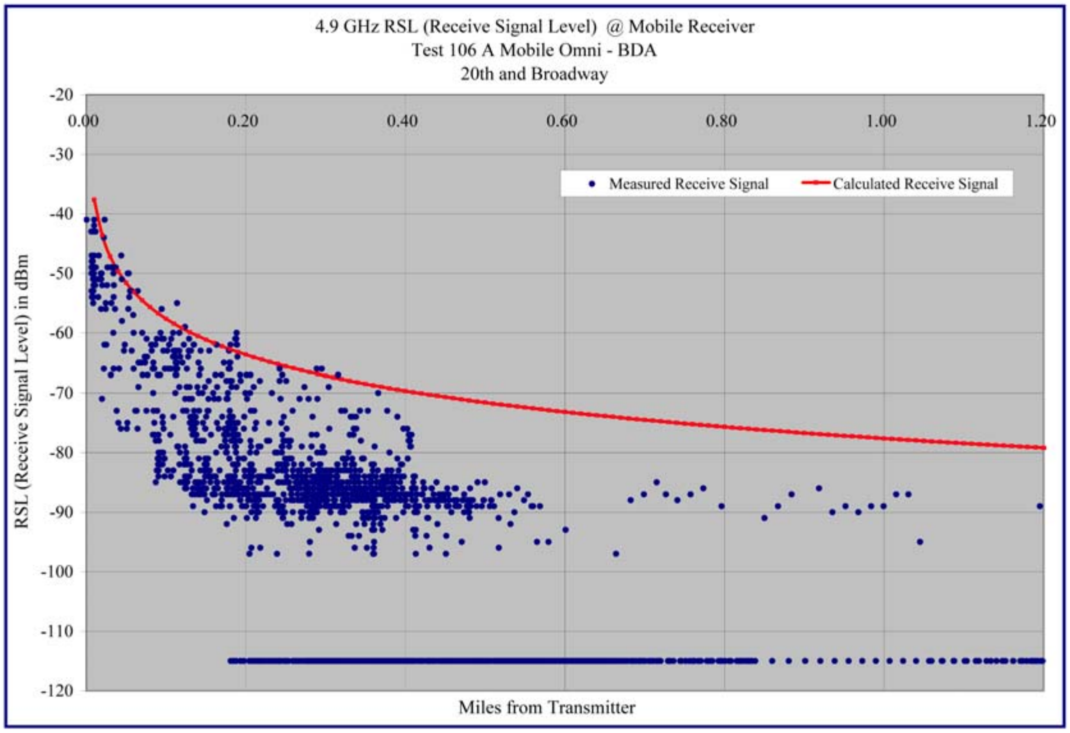
Test 105A

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 336.4 acres

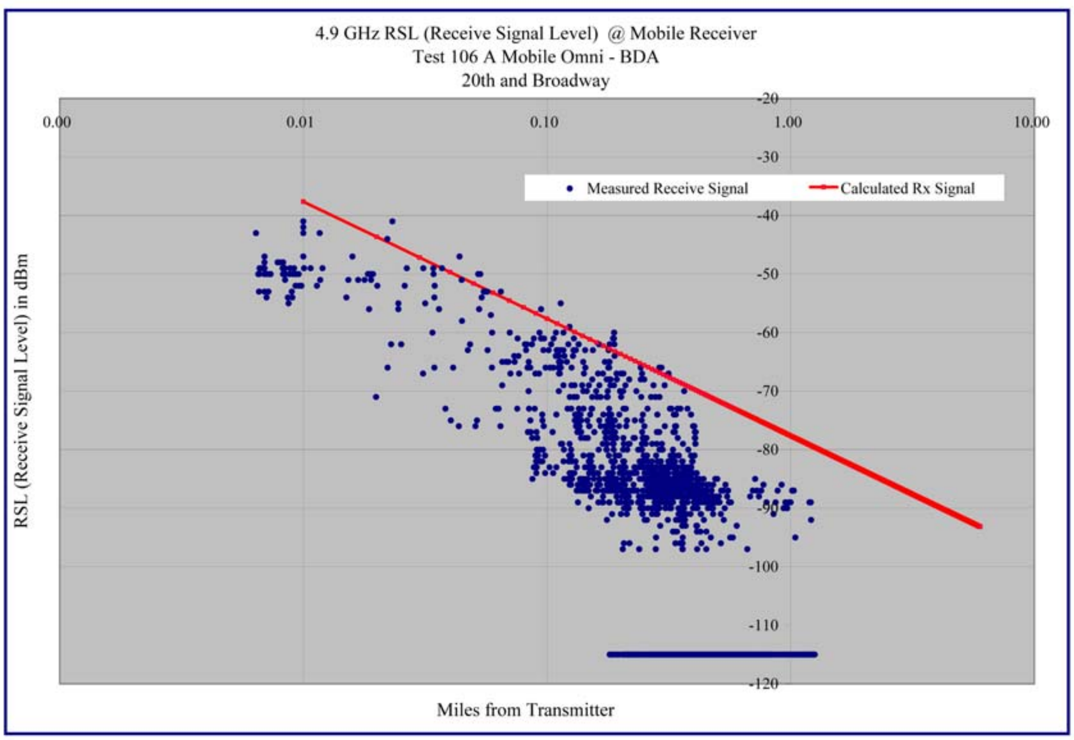
20th and Stout is on the northeastern edge of the dense urban area. It borders less dense urban and dense urban areas The Mobile Command Post was located mid-block.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

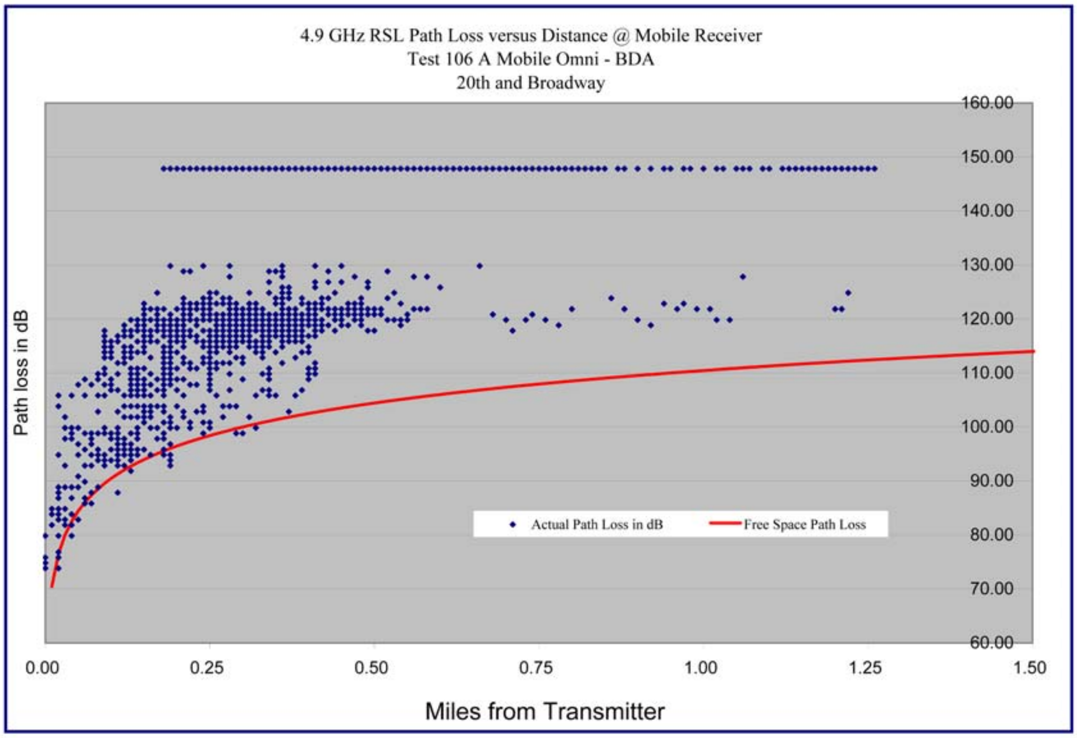
Table 6.9 - Map Legend



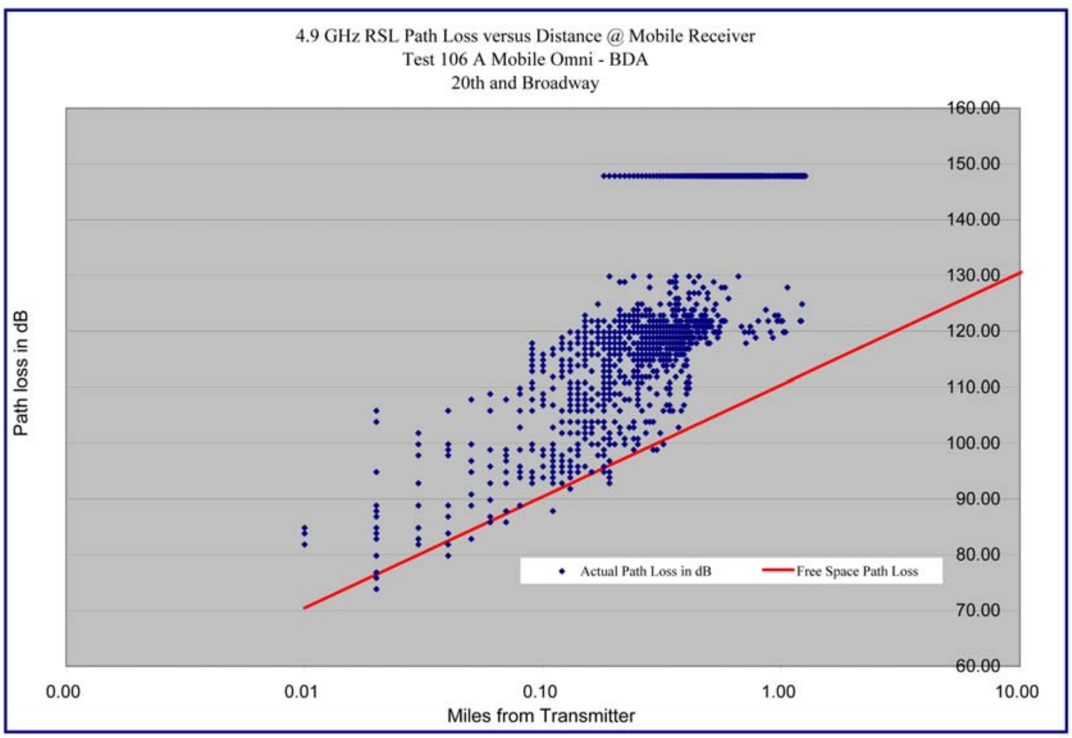
Graph 6.9 – Receive Signal versus Distance – 20th and Broadway



Graph 6.10 – Receive Signal versus Distance – 20th and Broadway – Log-Log Format



Graph 6.11 Path Loss versus Distance – 20th and Broadway

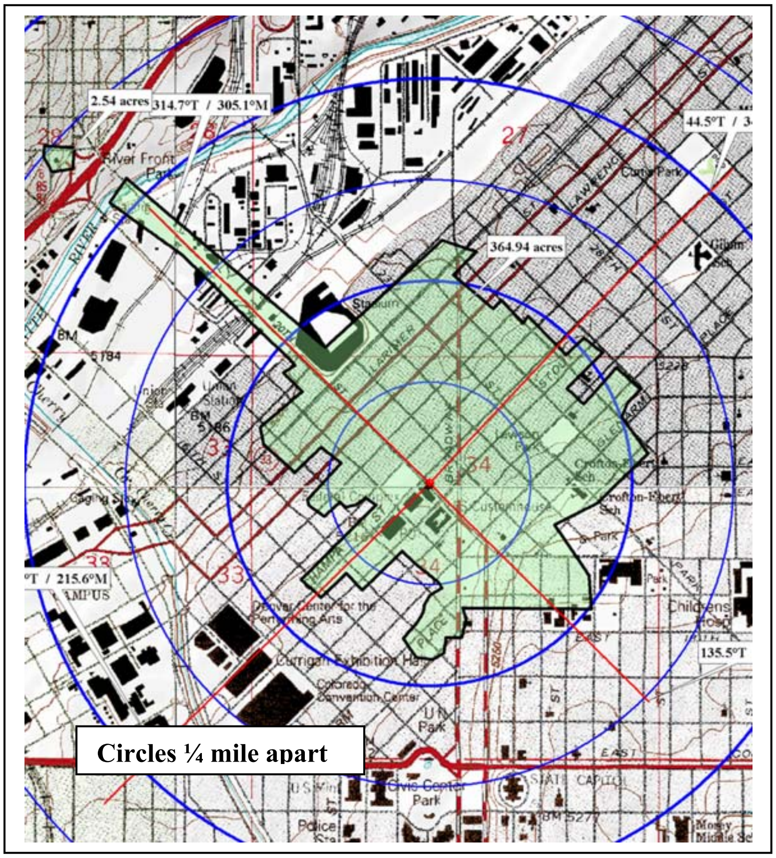


Graph 6.12 Path Loss versus Distance – 20th and Broadway- Log-Log Format

Picture 6.8 – Satellite – 20th and Stout

Picture 6.9 – 20th and Stout

Picture 6.10 – 20th and Stout



Map 6.8 –18th and Stout Coverage Footprint

The results of this study were surprising, since it was expected that mid-block coverage would be less than the coverage from a portal located in an intersection.

The coverage from this mid-block location resulted in 364.94 acres, the coverage from 18th and Broadway (at an intersection) had a footprint of 336.4 acres.

18th and Stout is only 2 blocks from 18th and Broadway.

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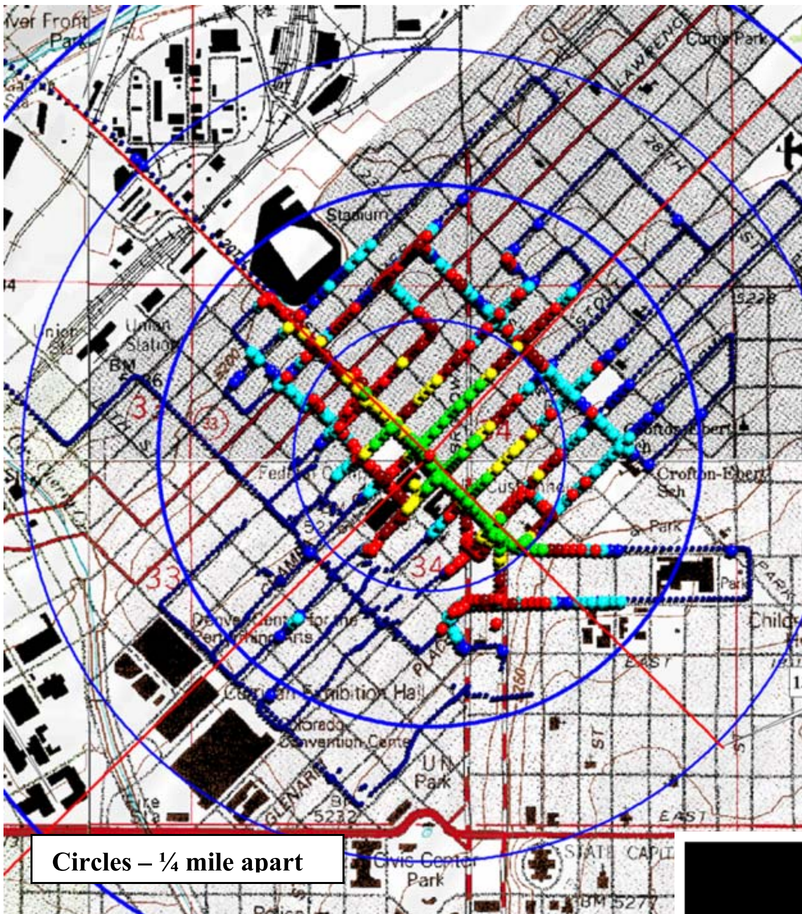
Study 4
Test 106B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
20th and Stout – Mid-block



Map 6.9 - 18th and Stout Coverage Map

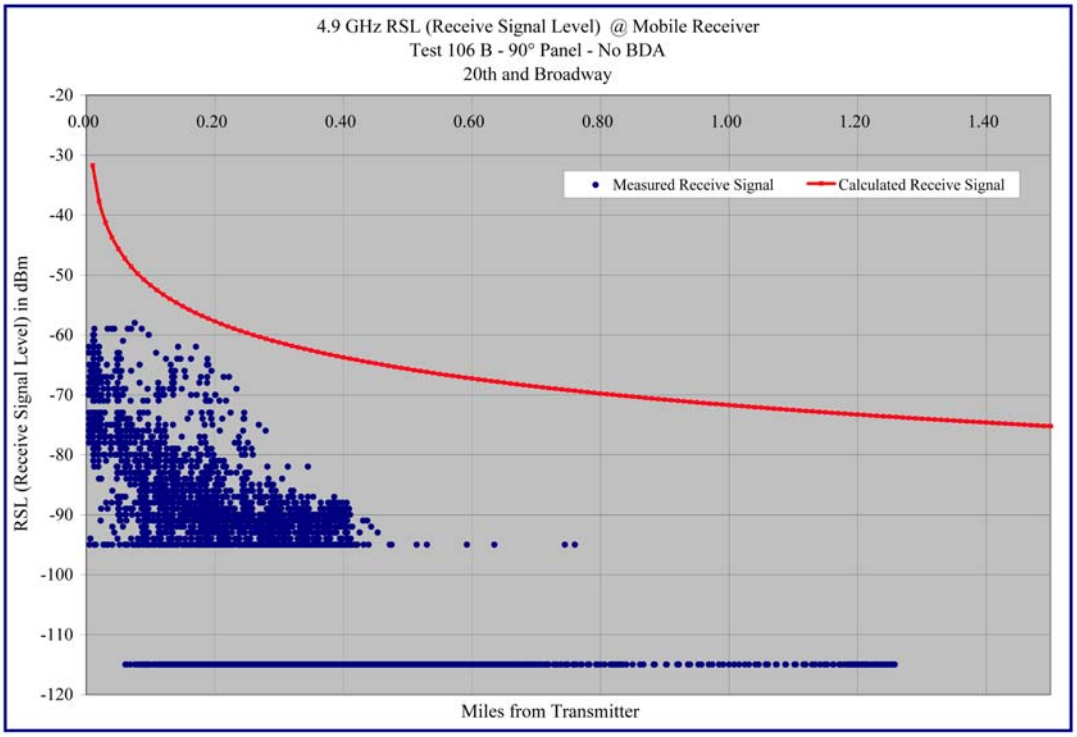
Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

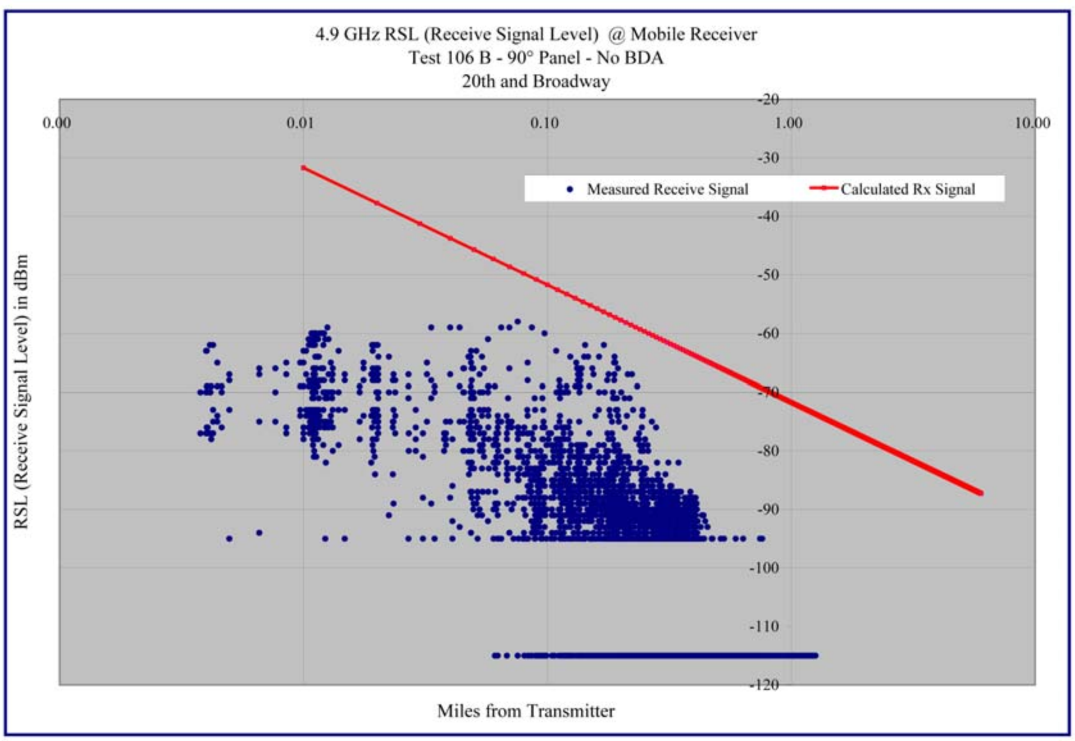
20th and Stout is on the northeastern edge of the dense urban area. It borders less dense urban and high-density urban areas. The Mobile Command Post was located mid-block.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

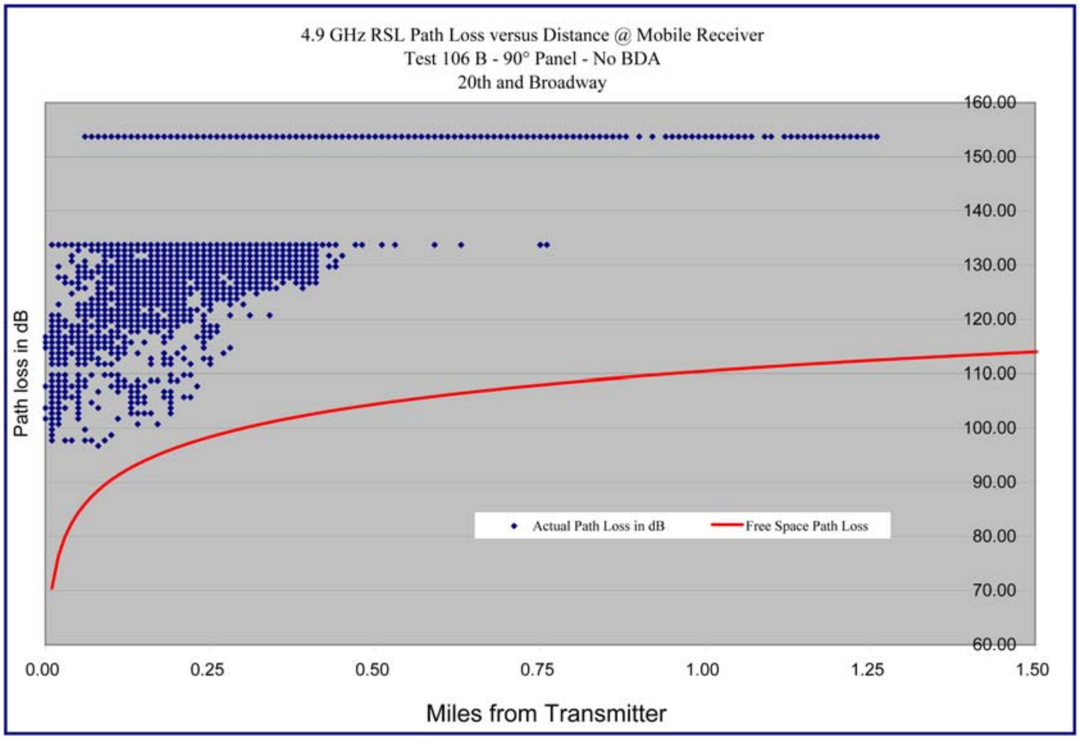
Table 6.10 Map Legend



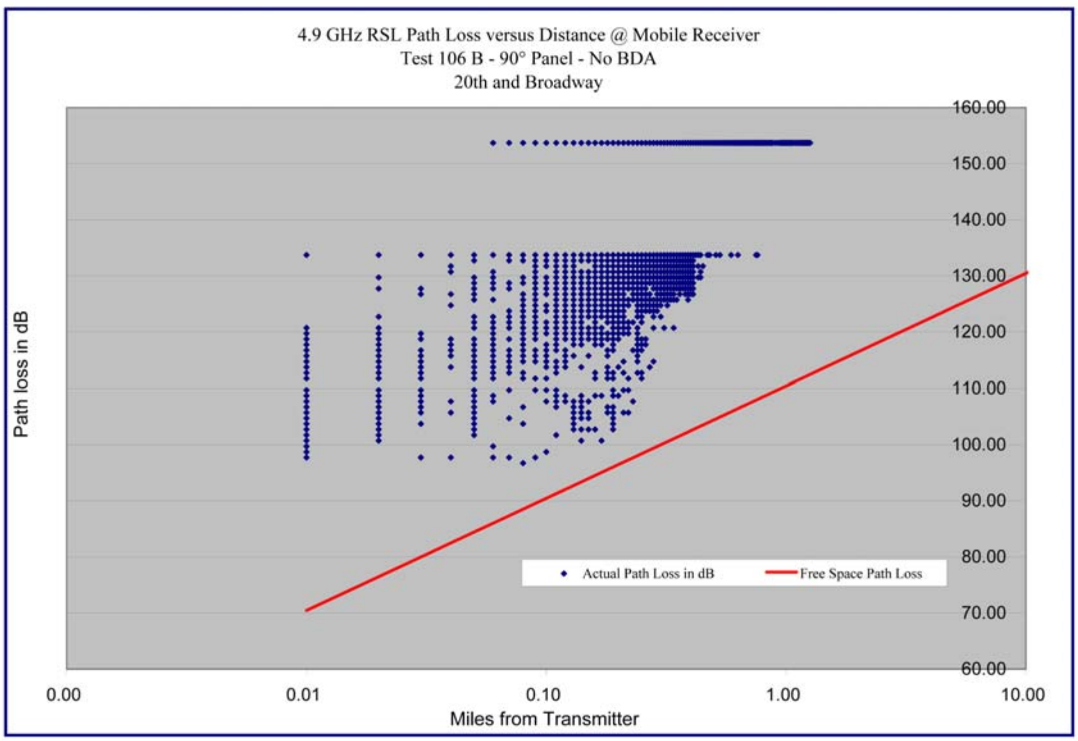
Graph 6.13 – Receive Signal Level versus Distance – 20th and Broadway Test B



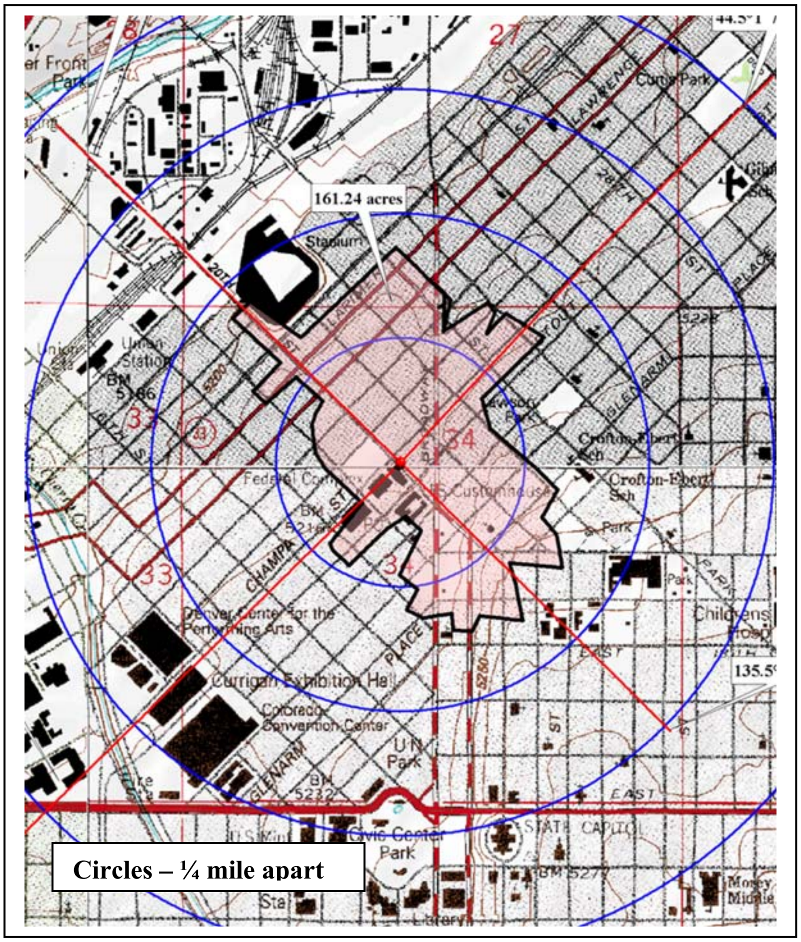
Graph 6.14 – Receive Signal Level versus Distance – 20th and Broadway Test B – Log-Log Format



Graph 6.15 – Path Loss versus Distance – 20th and Broadway Test B



Graph 6.16 – Path Loss versus Distance – 20th and Broadway Test B – Log-Log Format



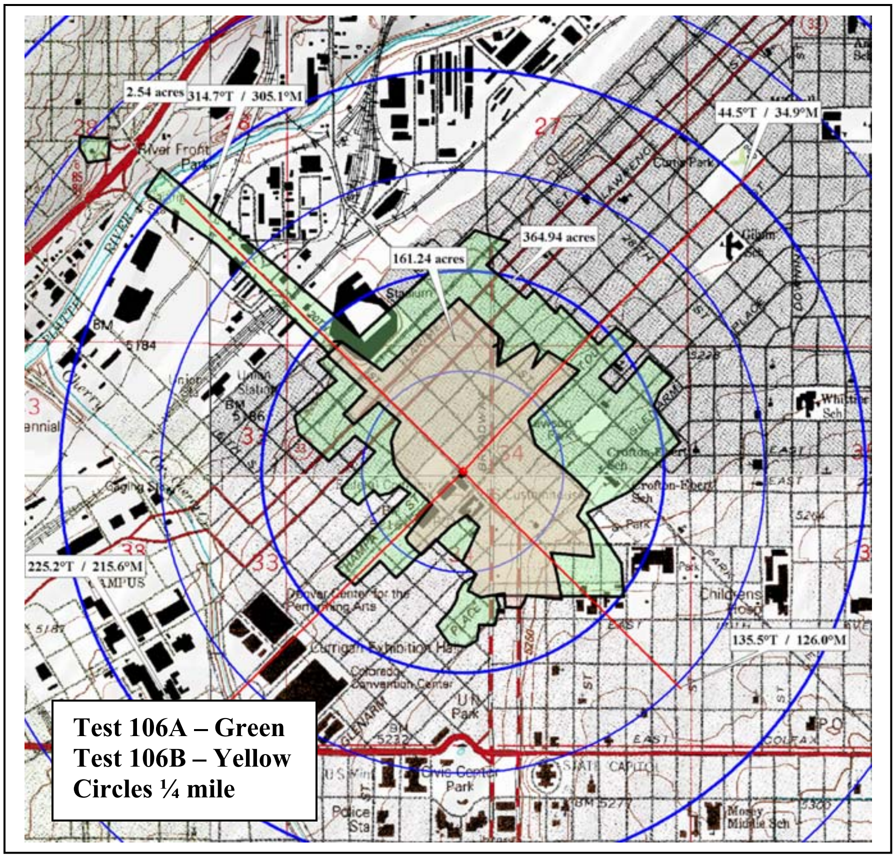
Map 6.11 - 18th and Stout Coverage Footprint

The results of this study were surprising, since it was expected that mid-block coverage would be less than the coverage from a portal located in an intersection.

The coverage from this mid-block location resulted in 161.24 acres, the coverage from 18th and Broadway (at an intersection) had a footprint of 116.29 acres. The 18th and Broadway footprint was 28% less than the footprint from 18th and Stout.

18th and Stout is only 2 blocks from 18th and Broadway.

Summary of Test Results – Test 106A and Test 106 B
20th and Stout – Mid-Block



Map 6.11 Comparisons of Footprints – 20th and Stout

Deployment Summary

Test 106A – Omni Antenna with BDA (Green)
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 364.94 acres

Test 106B – Panel Antennas without BDA (Yellow)
EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
Two antennas - 35 ft AGL
Two antennas - 28 ft AGL
Footprint – 161.24 acres

20th and Stout is on the northeastern edge of the dense urban area. It borders less dense urban and dense urban areas. The Mobile Command Post was located mid-block.

Tests 106A and 106B were conducted simultaneously with the same receive vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 106A had an EIRP of 31.47 dBm and test 106B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests can be assumed almost the same.

Test 106A resulted in a footprint of 364.94 acres while Test 105B has a footprint of only 164.24 acres, roughly 1/3 of the size of the footprint from Test 106A.

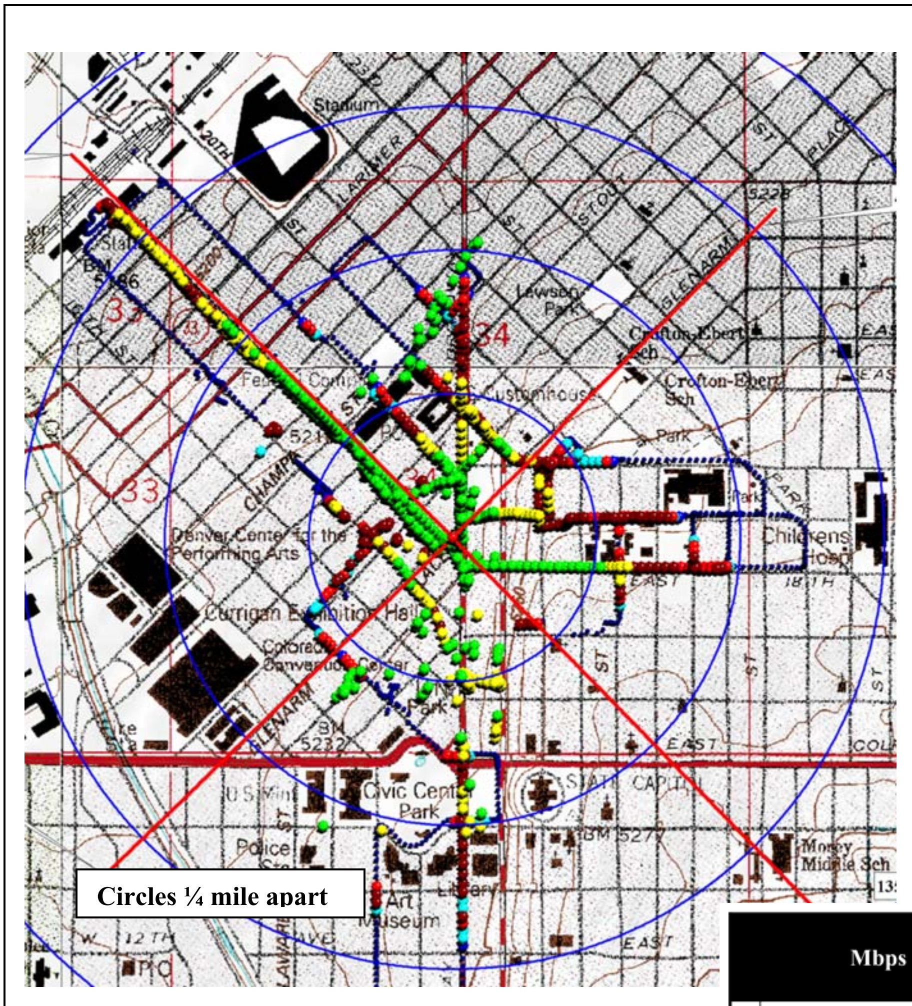
The difference was that in the 105A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E. of Pericle Communications confirmed that the BDA increased the receiver sensitivity by 2 dB.

It appears that the addition of a mobile BDA had a dramatic effect on the coverage area, not because of the increase in EIRP, but because of the increase in receiver sensitivity.

Test Numbers Study No for this Chapter	20th and Stout 106A Study 3	20th and Stout 106B Study 4
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	1.2	7/16
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-3	4
Maximum	9	24
Backhaul		
feasibility	none at this time	none at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	no	no
Ad Hoc or Mesh	yes	yes
Site Comparison		
Footprint	364.94 acres	161.24
Comment	Study 1 shows less path loss than theoretical	

Table 6.11 Comparison of Test 106A and Test 106B

Study 5
Test 107A – Mobile Command Post with Omni
BDA at Portal and Mobile
18th and Broadway – Intersection



Map 6.12 – Coverage 18th and Broadway

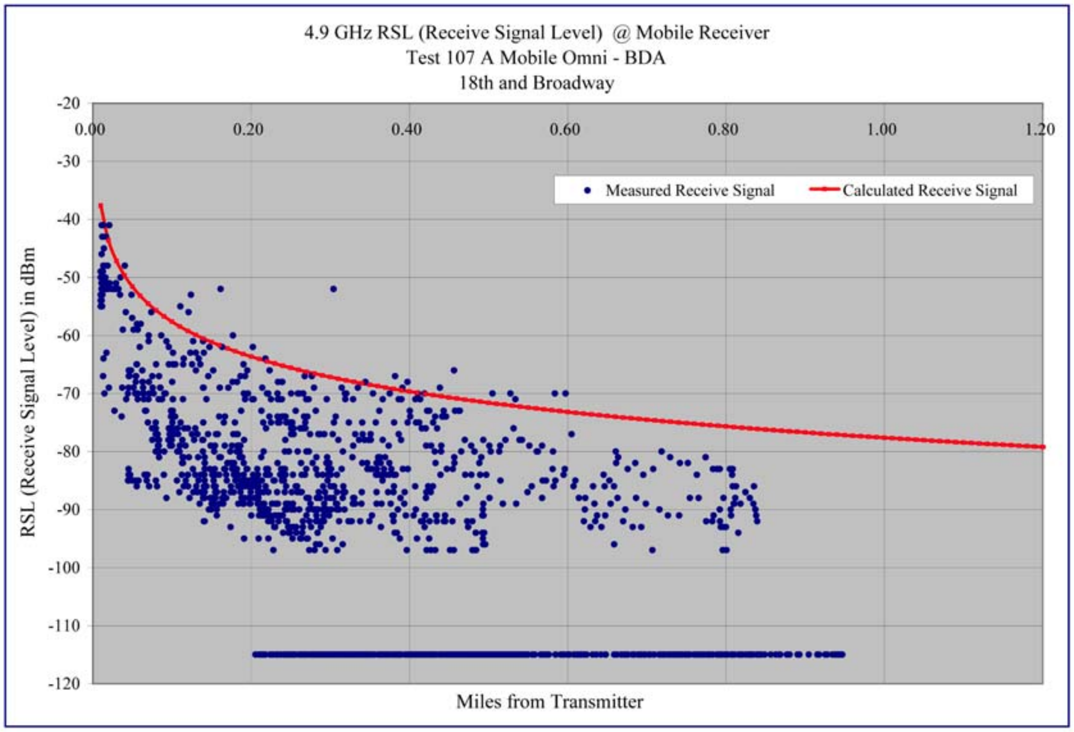
Deployment Summary:

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL

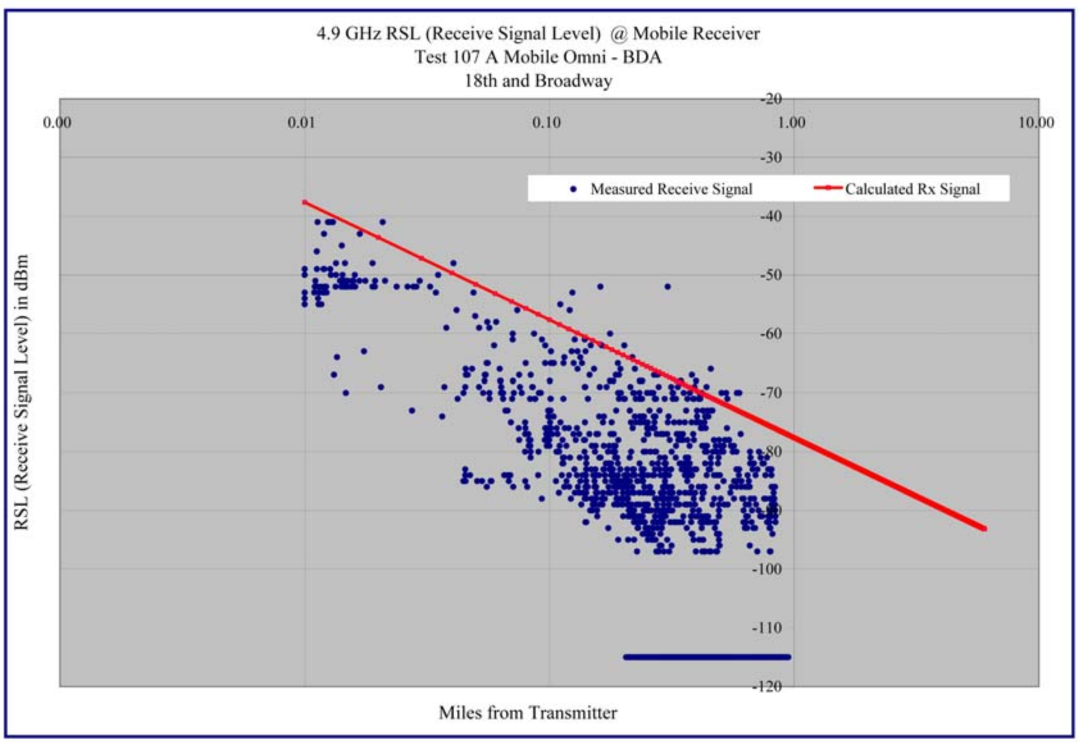
18th and Broadway is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was at an intersection looking down 18th street.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

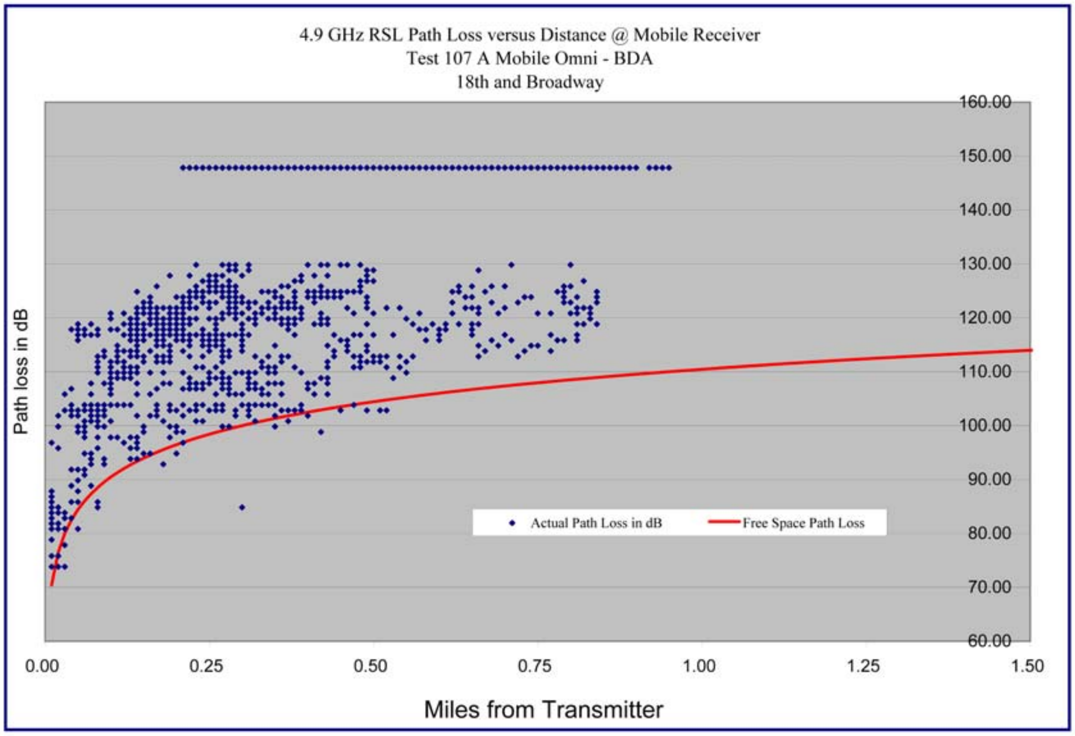
Table 6.12 – Map Legend



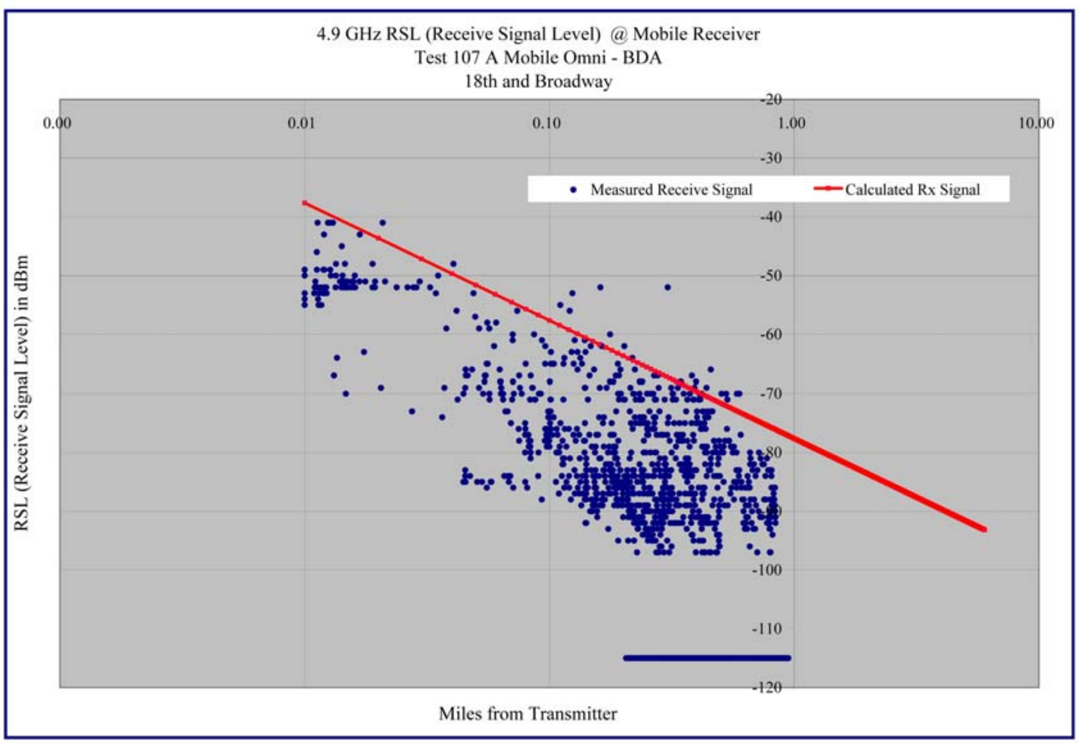
Graph 6.17 – Receive Signal Level versus Distance – Test 107 - 18th and Broadway



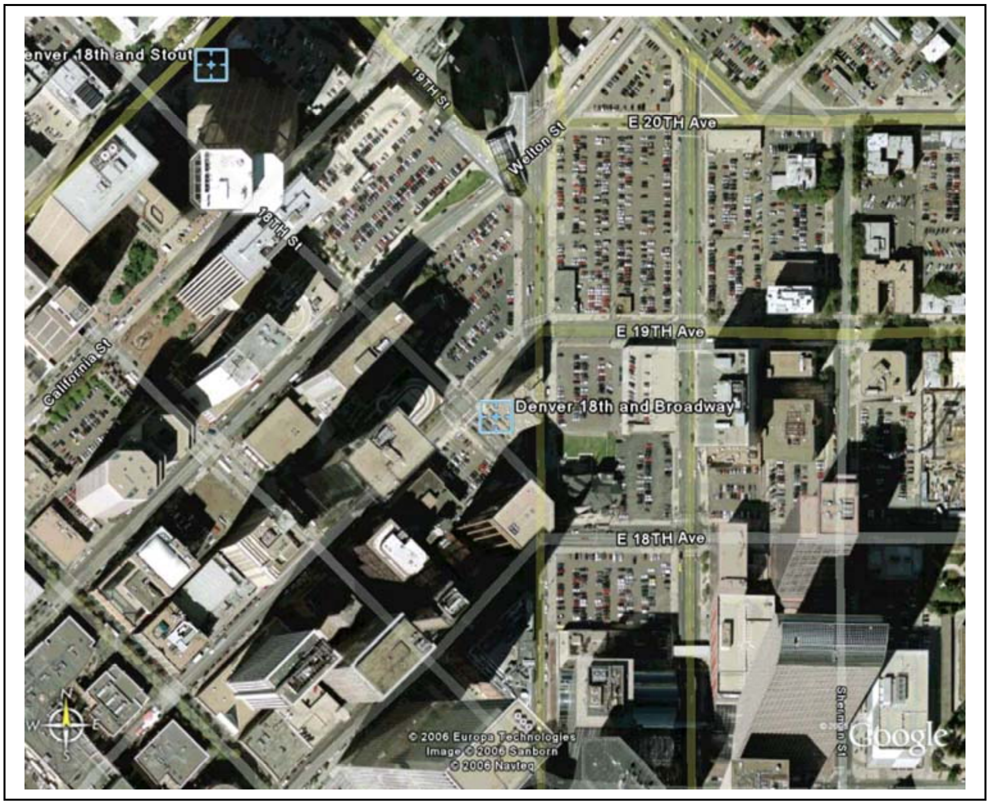
Graph 6.18 – Receive Signal Level versus Distance – Test 107 - 18th and Broadway – Log-Log Format



Graph 6.19 – Path Loss versus Distance – Test 107 - 18th and Broadway

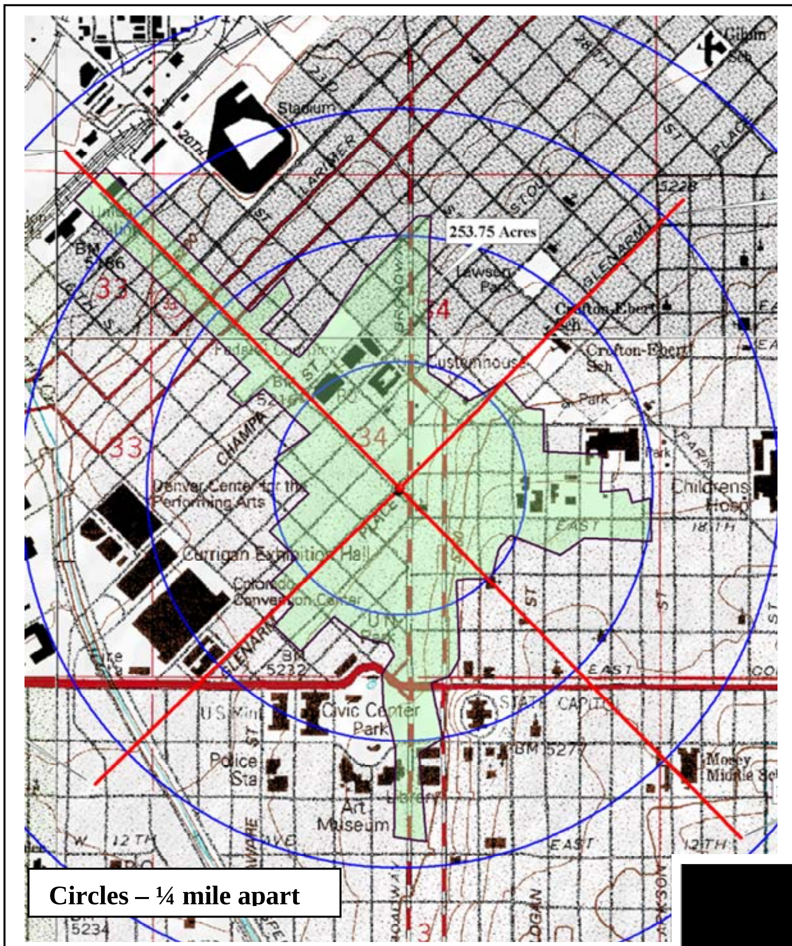


Graph 6.20 – Path Loss versus Distance – Test 107 - 18th and Broadway – Log-Log Format



Picture 6.11 – Satellite Imagery – 18th and Broadway

Picture 6.12 – 18th and Broadway



Map 6.13 – 18th and Broadway Footprint

The coverage at 18th and Broadway was 253.75 acres, in addition to some areas where there was hot-spot coverage beyond the footprint.

The scatter graphs closely follow the theoretical predictions. There were cases where the receive signal level exceeded the theoretical predicted calculations and the free space path loss was less than the theoretical predicted calculations.

This indicated a possible waveguide effect from the buildings, resulting in better than predicted performance.

There was coverage 3 to four blocks in any direction, as well converge up to almost a mile from the access point where there was line of site.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

Table 6.13 – Map Legend

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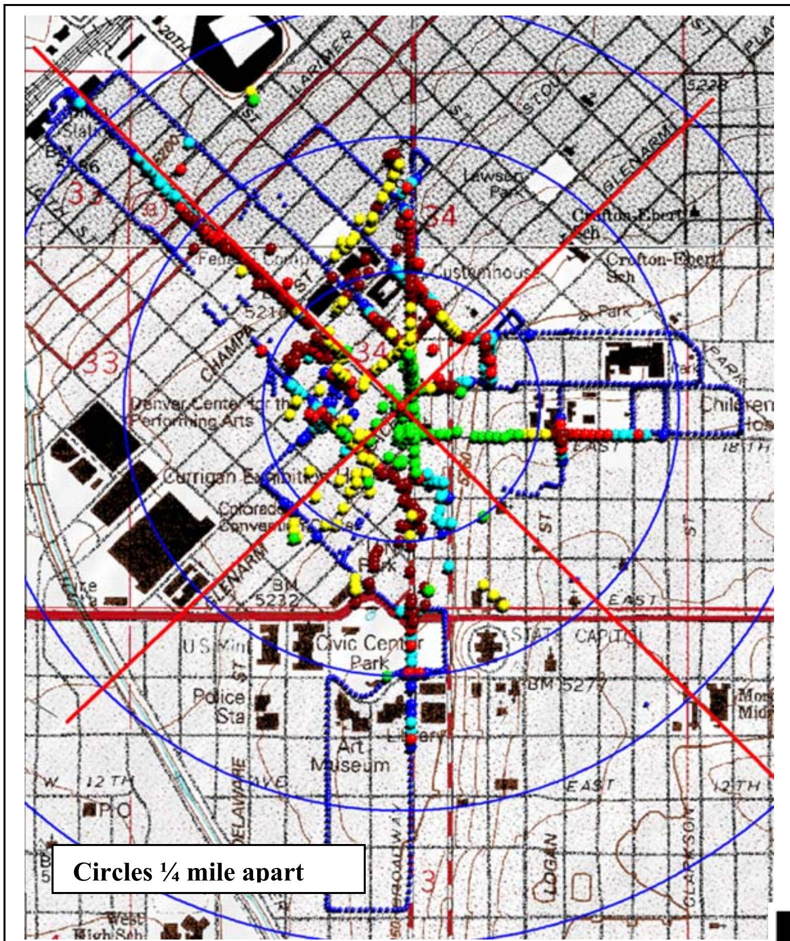
Study 6
Test 107B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
18th and Broadway - Intersection



Map 6.14 – Coverage – 20th and Broadway

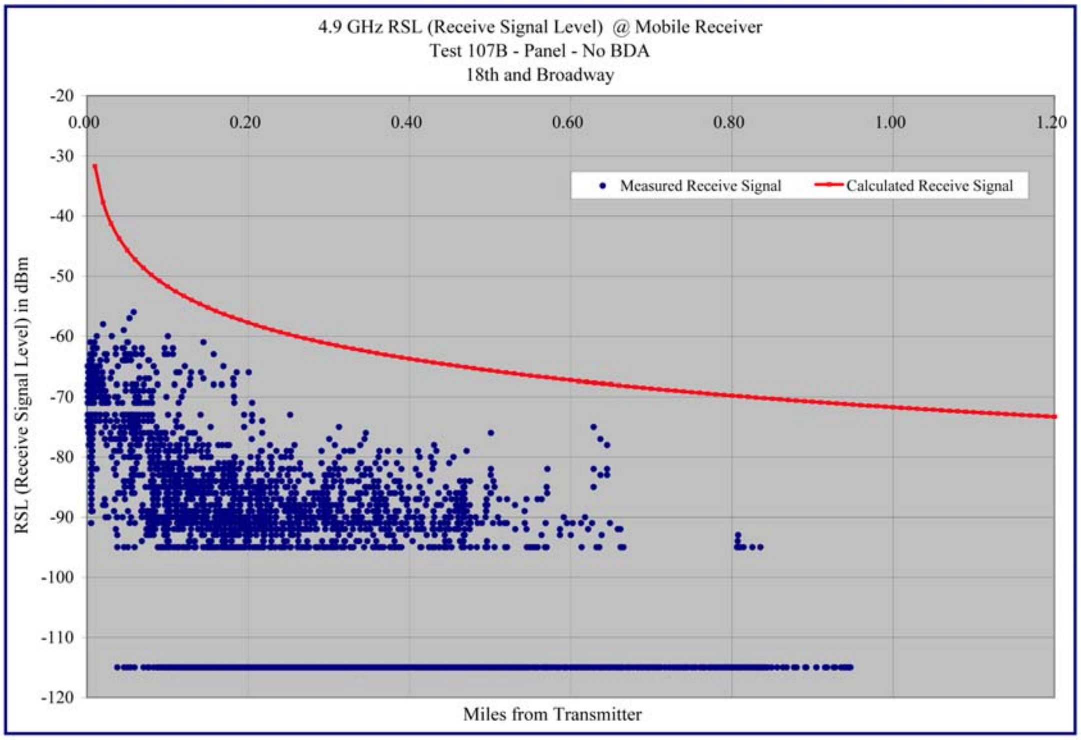
Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

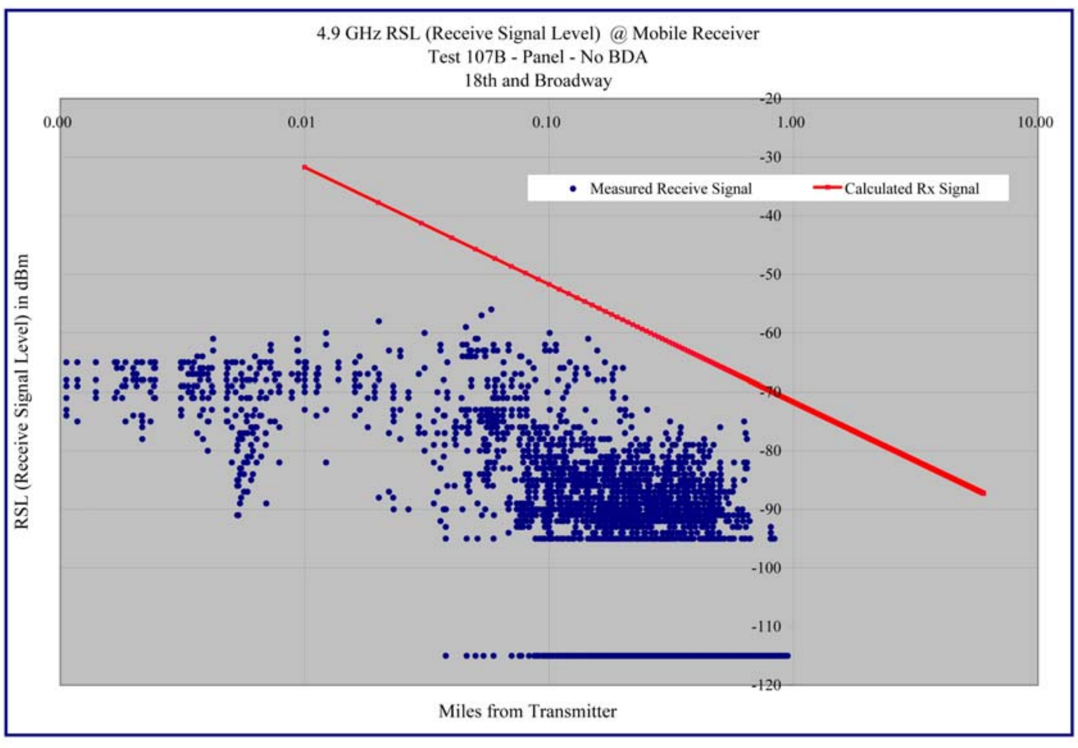
18th and Broadway is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was at an intersection looking down 18th Street

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

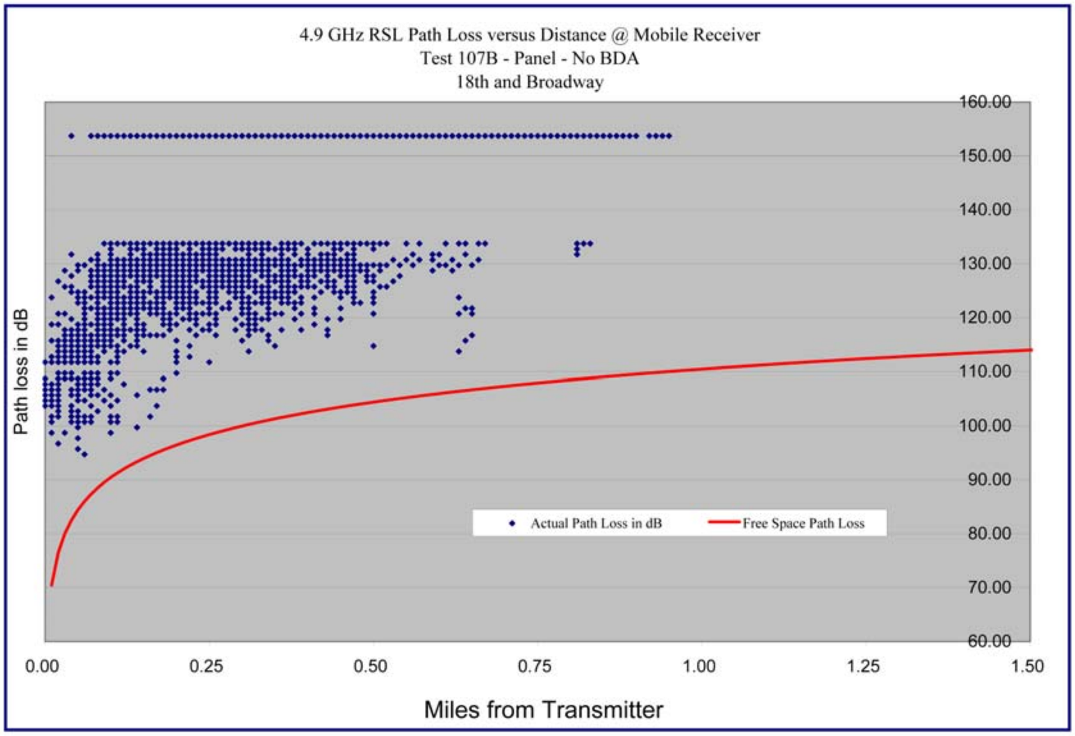
Table 6.14 – Map Legend



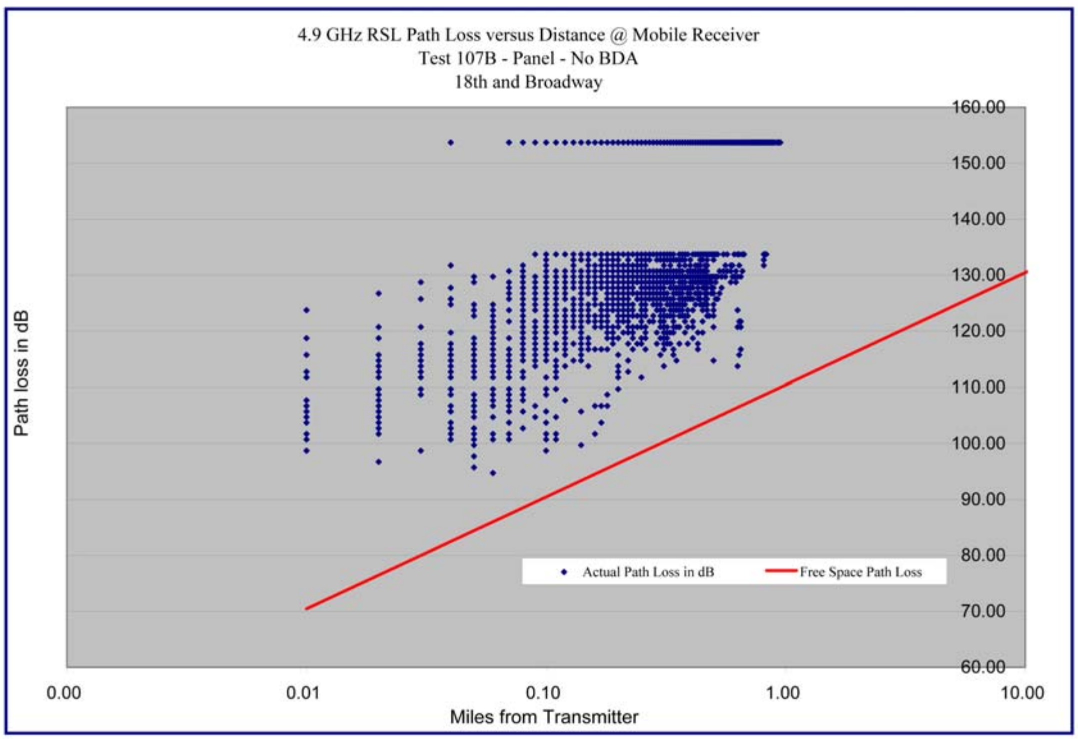
Graph 6.21 – Receive Signal Level versus Distance – Test 107B – 18th and Broadway



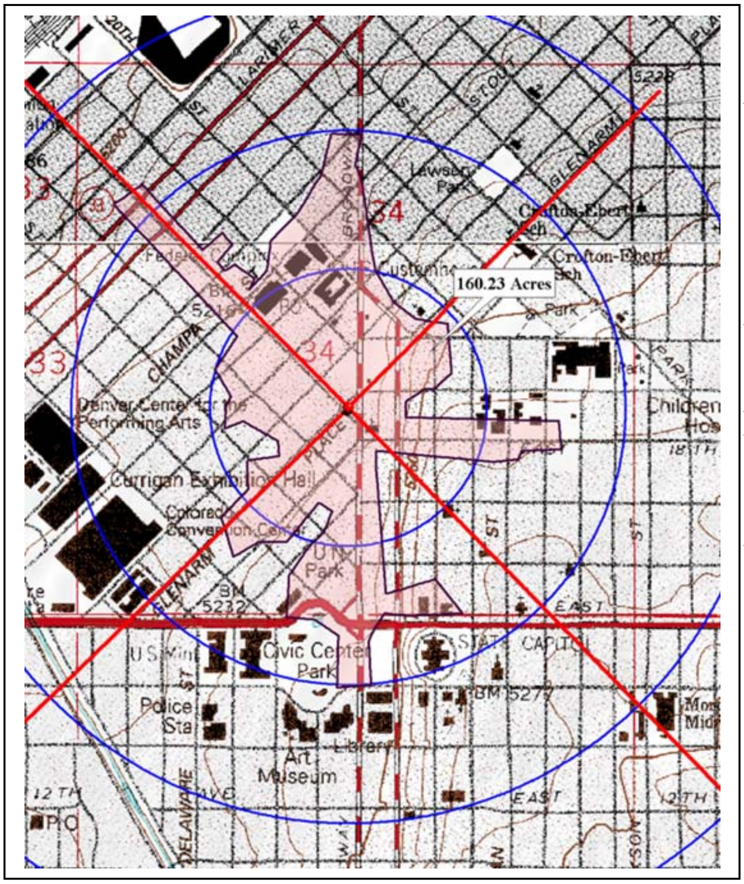
Graph 6.22 – Receive Signal Level versus Distance – Test 107B – 18th and Broadway – Log-Log Format



Graph 6.23 – Path Loss versus Distance – Test 107B – 18th and Broadway



Graph 6.24 – Path Loss versus Distance – Test 107B – 18th and Broadway – Log-Log Format



Map 6.15 – 18th and Broadway Coverage Footprint – Test 107B

The coverage at 18th and Broadway for Test 107B was 160.23 acres. The coverage with the BDA (Test 107A) was 253.75 acres – over 47% better.

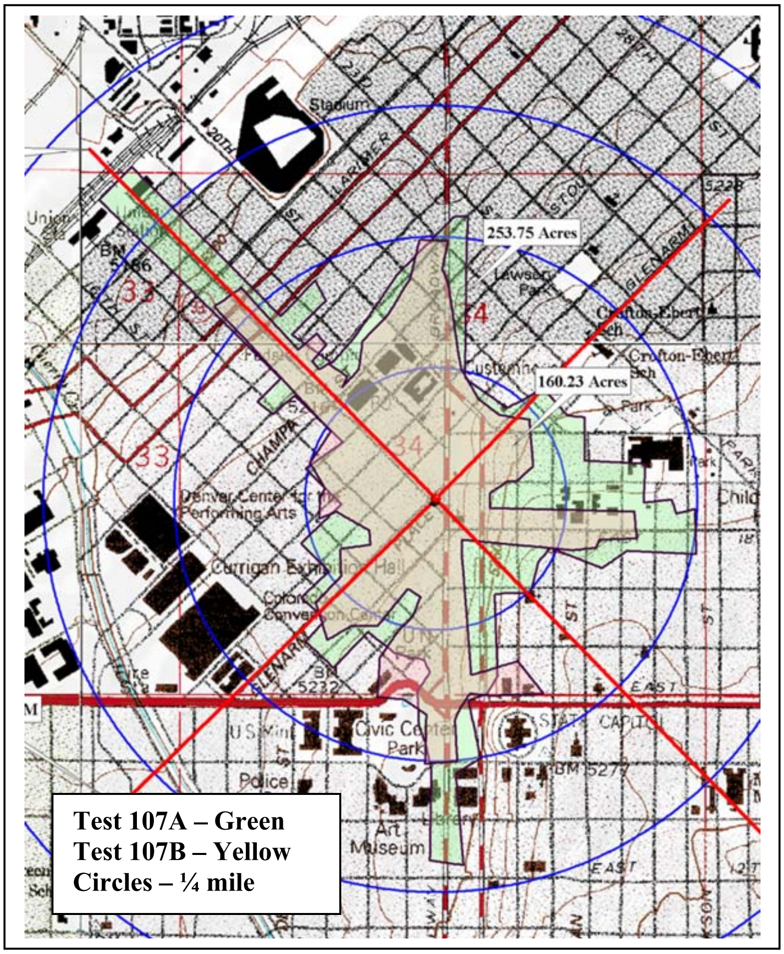
The EIRP was almost the same for both deployments – but the increased receiver sensitivity from the BDA greatly increased the coverage.

Although the scattergraphs follow the theoretical, with some receive, signal levels are greater than the theoretical predicted calculations and some path losses less than the theoretical predicted calculations.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 6.15 – Map Legend

Summary of Test Results – Test 107A and 107B
18th and Broadway - Intersection



Deployment Summary:

Test 107A – Omni Antenna with BDA (Green)
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 253.75 Acres

Test 107B – Panel Antennas without BDA (Yellow)
EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL
Footprint 160.23 Acres

18th and Broadway is in the middle of the high density urban setting, and is surrounded by skyscrapers. The site chosen was at an intersection looking down 18th street

Map 6.16 – Comparison of Footprints – 18th and Broadway

Tests 107A and 107B were conducted simultaneously with the same receive vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 107A had an EIRP of 31.47 dBm and test 107B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests can be assumed to be almost the same.

Test 107A resulted in a footprint of 253.75 acres while Test 105B has a footprint of only 160.23 acres, roughly 47% of the size of the footprint from Test 106A.

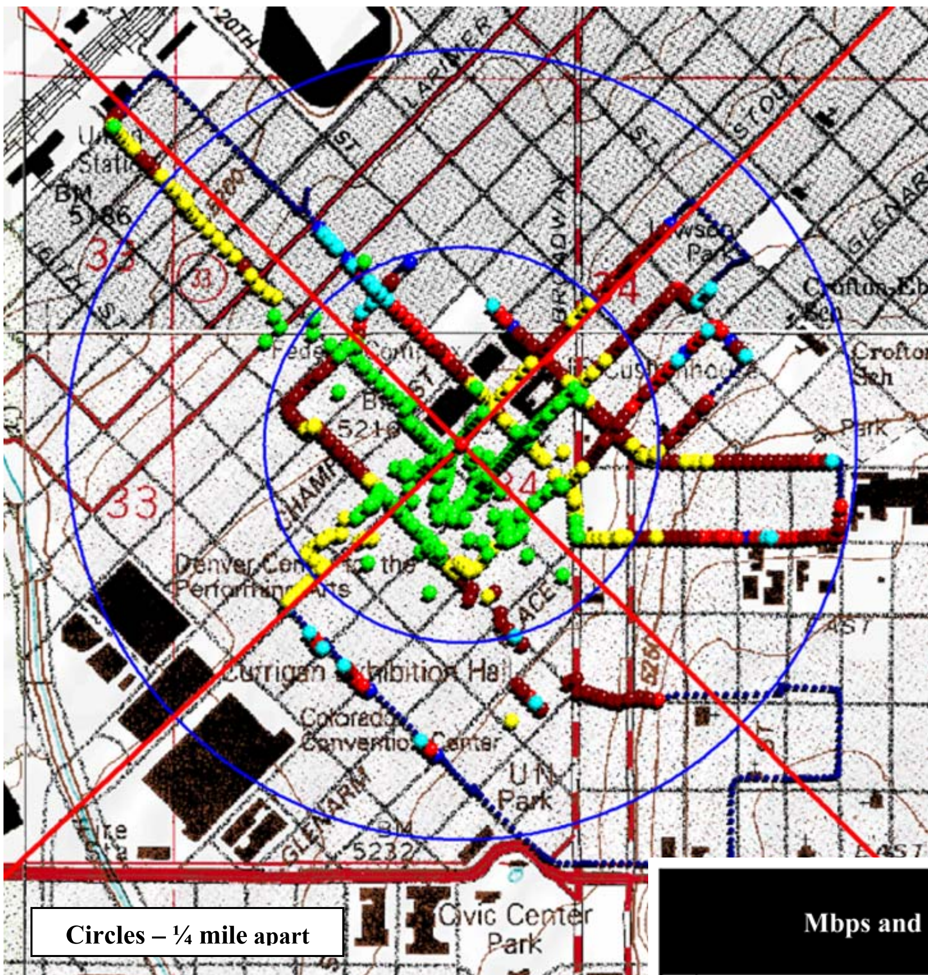
The difference was that in the 107A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E., of Pericle Communications, confirmed that the BDA increased the receiver sensitivity by 2 dB.

It appears that the addition of a mobile BDA has a dramatic effect on the coverage area, not because of the increase in EIRP, but because of the increase in receiver sensitivity.

Test Numbers **Study No for this Chapter**	**107A** **Study 5**	**107B** **Study 6**
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	7/8 mile	5/8 mile
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-14*	9
Maximum	6	21
Backhaul		
feasibility	none at this time	none at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	no	no
Ad Hoc or Mesh	yes	yes
Site Comparison		
Footprint	253.75 acres	160.23 acres

Table 6.16 – Comparison of Test 107A and Test 107B

Study 7
Test 108A – Mobile Command Post with Omni
BDA at Portal and Mobile
18th and Stout



Map 6.17 – Coverage at 18th and Stout

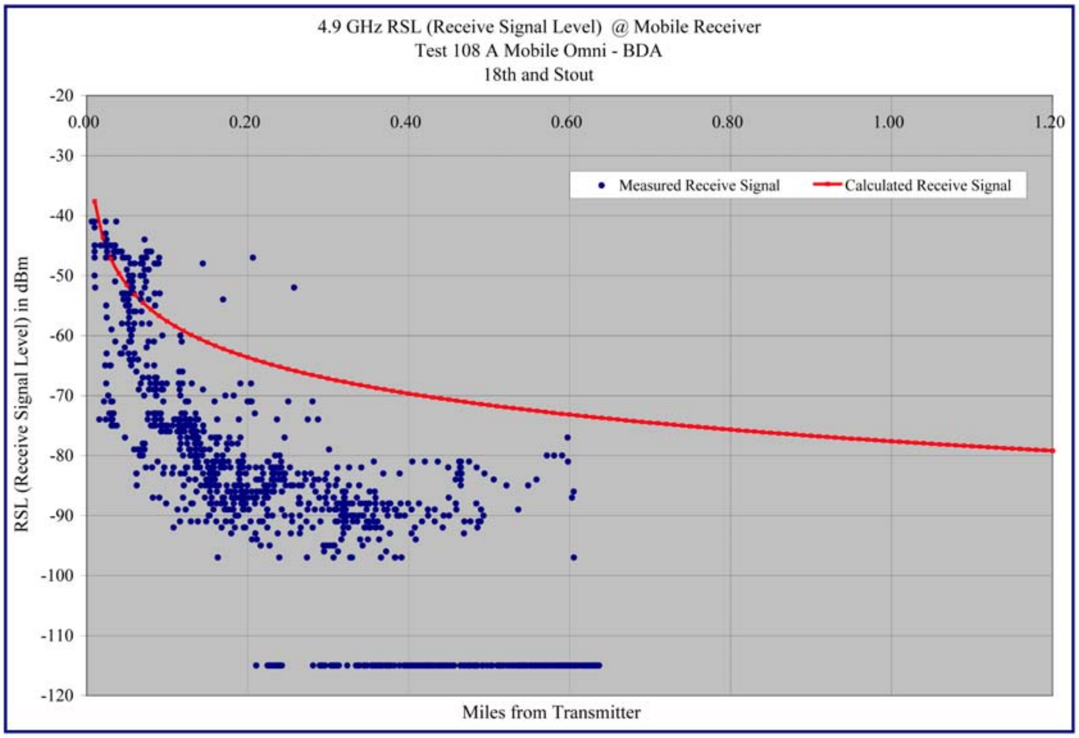
Deployment Summary:

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL

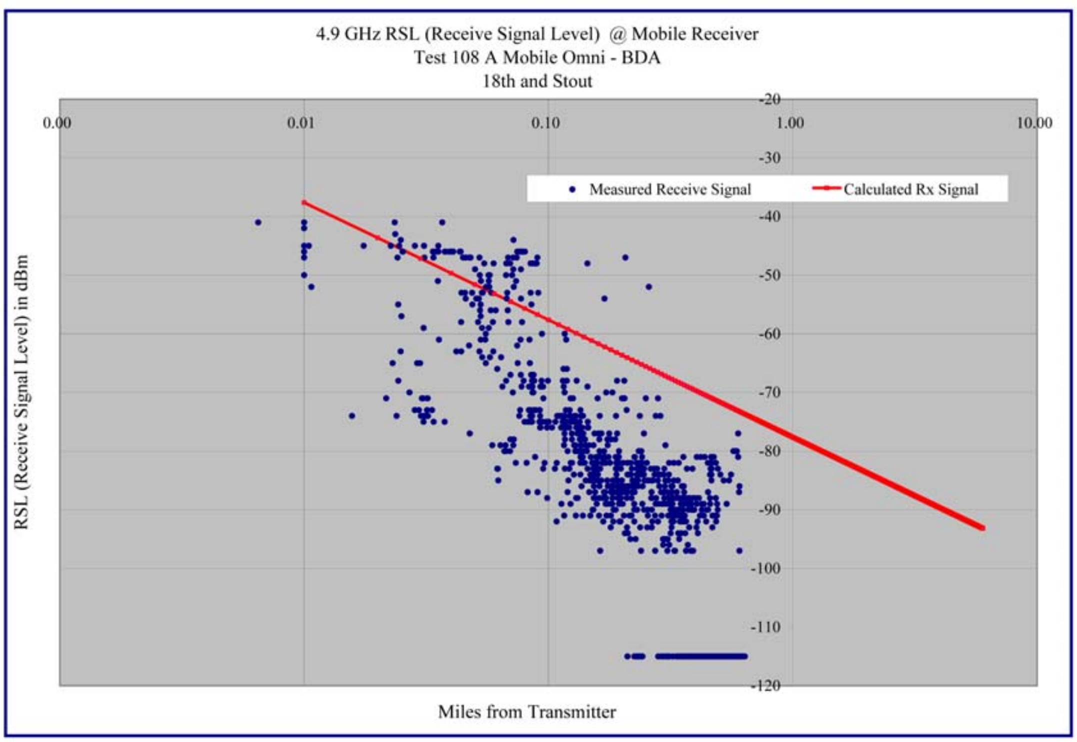
18th and Stout is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 18th street.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

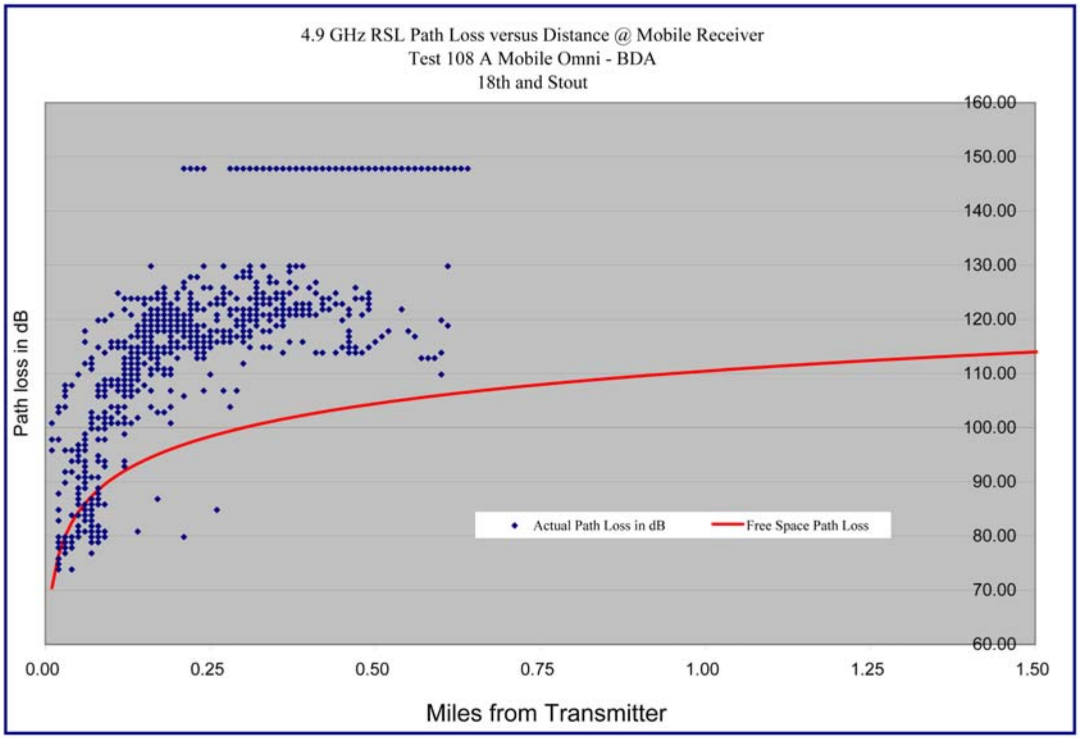
Table 6.17 Map Legend



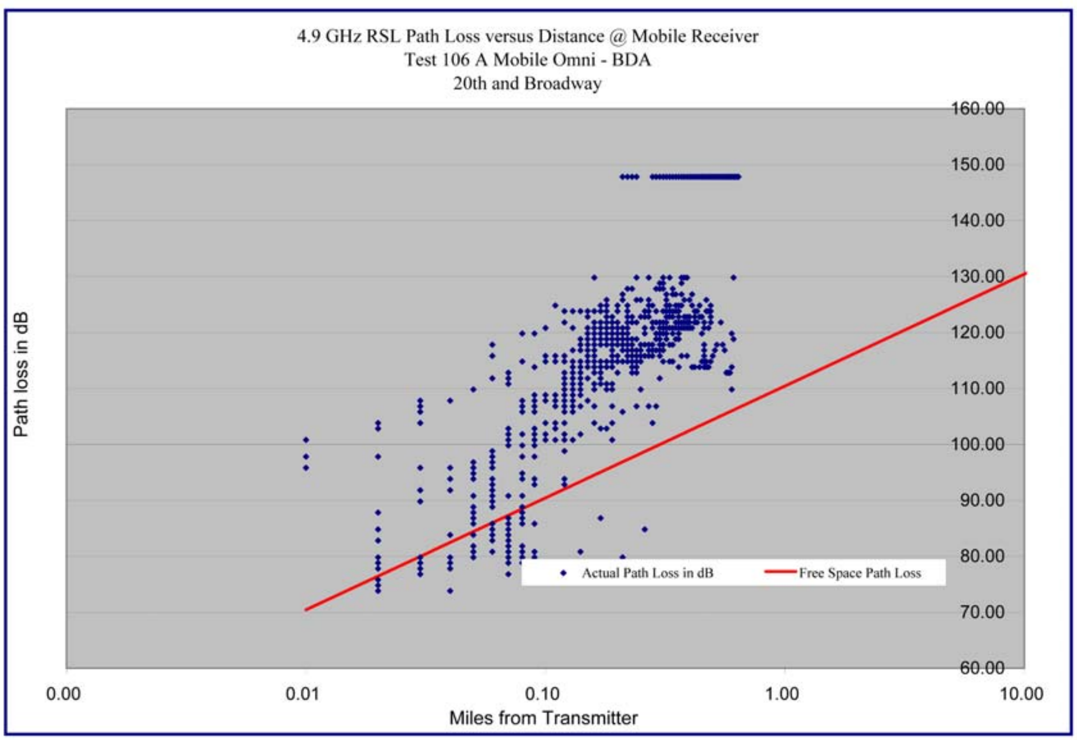
Graph 6.25 – Receive Signal Level versus Distance – 18th and Stout



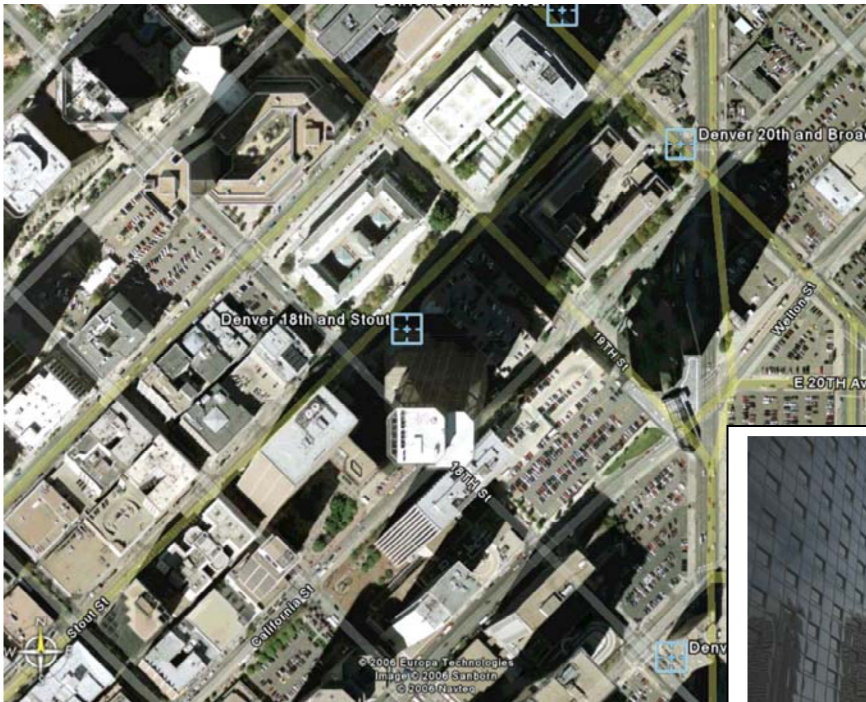
Graph 6.26 – Receive Signal Level versus Distance – 18th and Stout – Log-Log Format



Graph 6.27 – Path Loss versus Distance – 18th and Stout



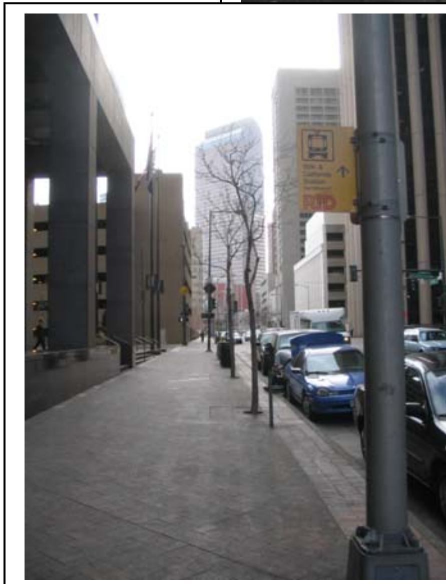
Graph 6.28 – Path Loss versus Distance – 18th and Stout – Log-Log Format



Picture 6.13 – Satellite – 18th and Stout

Picture 6.14
18th and Stout

Picture 6.15 – 18th and Stout

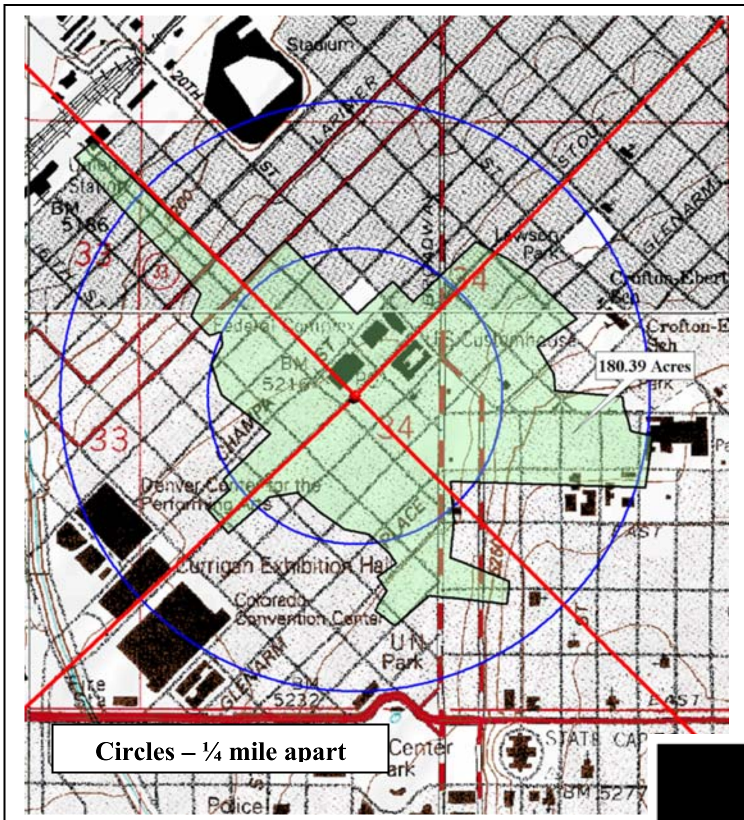


Picture 6.16 – 18th and Stout

The coverage at 18th and Stout was limited in comparison with some of the other tests – but there was still a footprint of 180.39 acres.

The scatter graphs closely followed the theoretical predictions, and actually performed better than the theoretical predicted coverage. The coverage reaches 3 blocks in either direction from the portal unit at the Mobile Command Post.

Considering the dense buildings, the coverage is excellent. It is apparent that the signals are reflected into areas where there was not line of sight from the portal at the Mobile Command Post.



Map 6.18 – 18th and Stout Footprint

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

Table 6.18 – Map Legend

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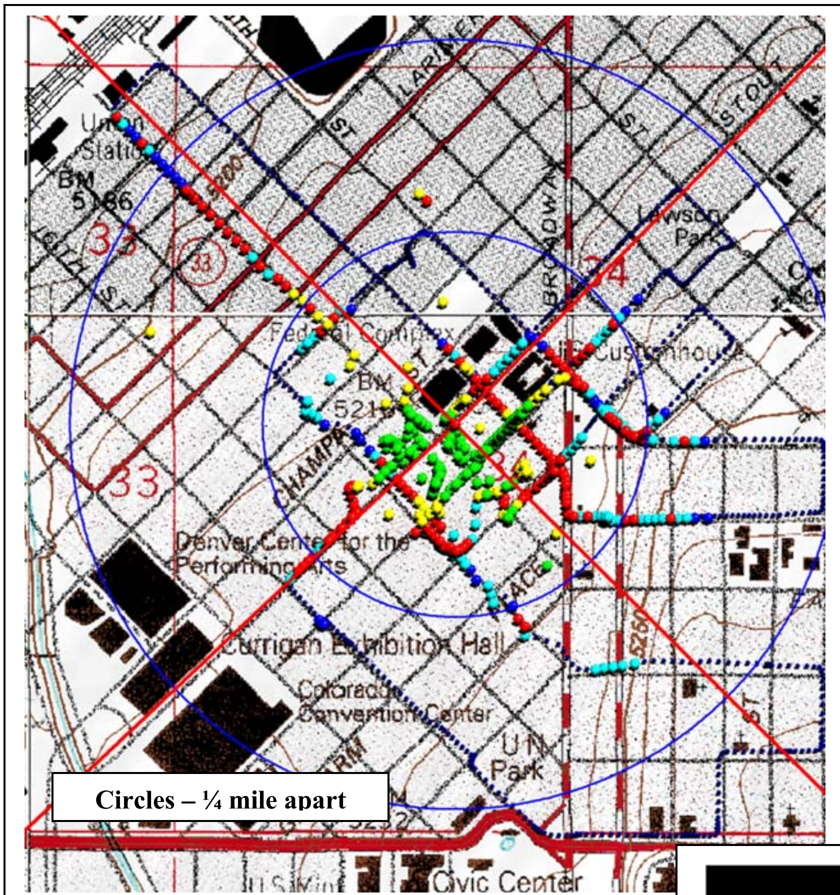
Study 8
Test 108B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
18th and Stout – Mid-Block



Map 6.19 – Coverage – 18th and Stout

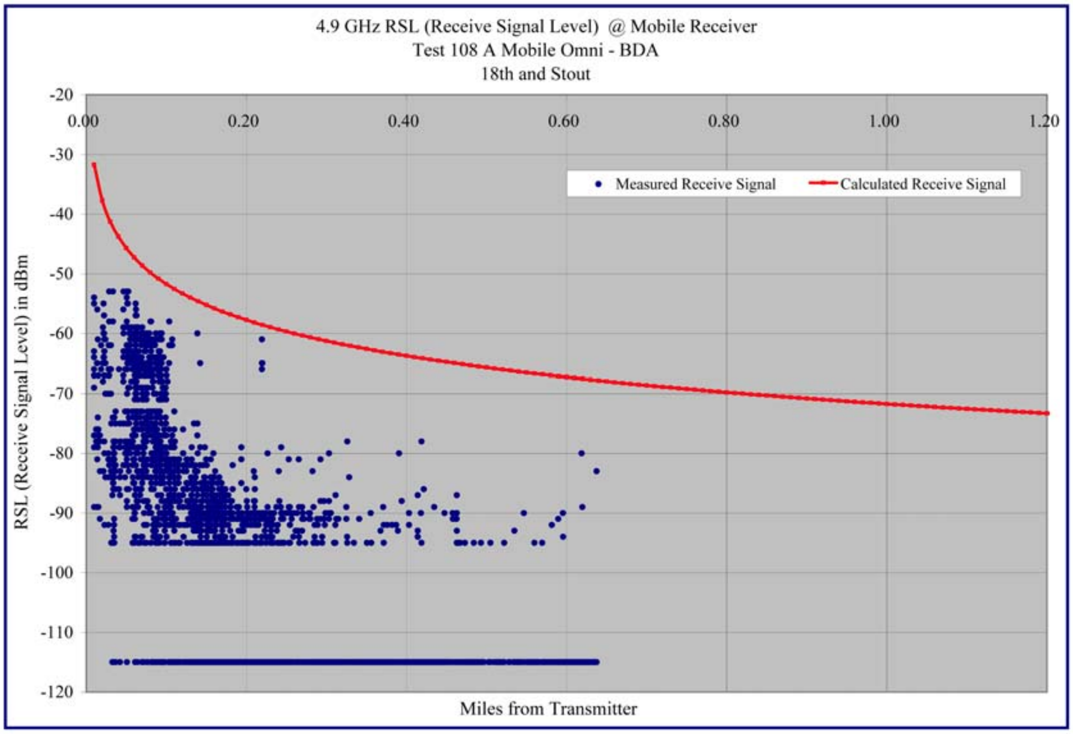
Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

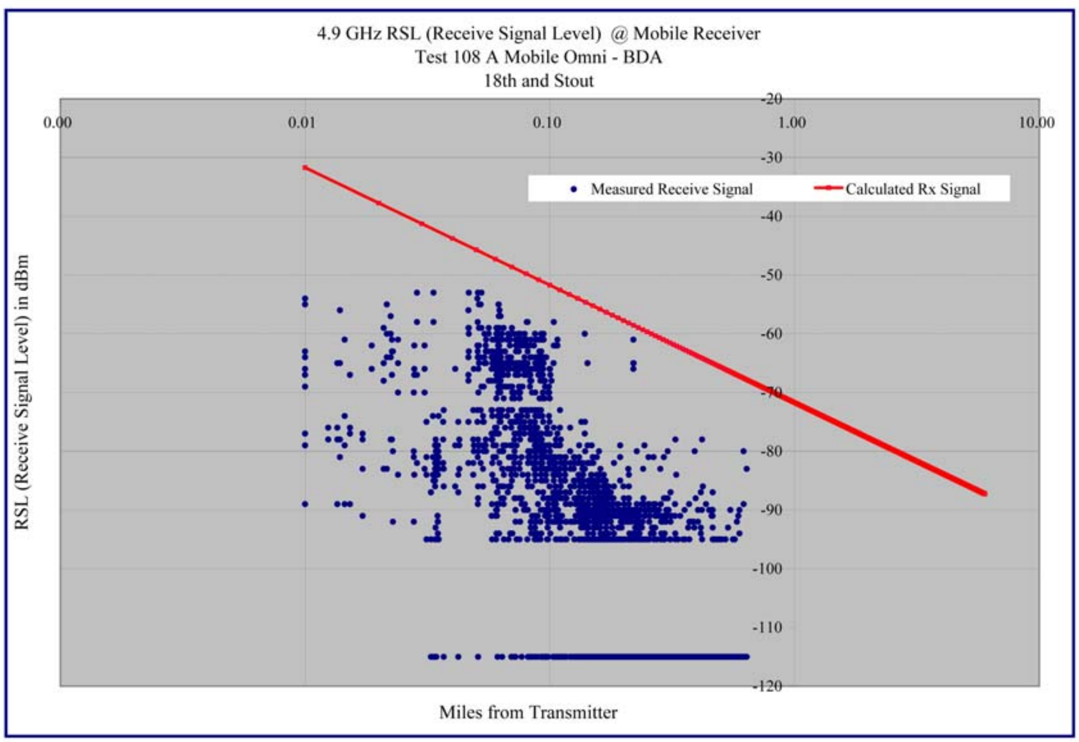
18th and Stout is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 18th street.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

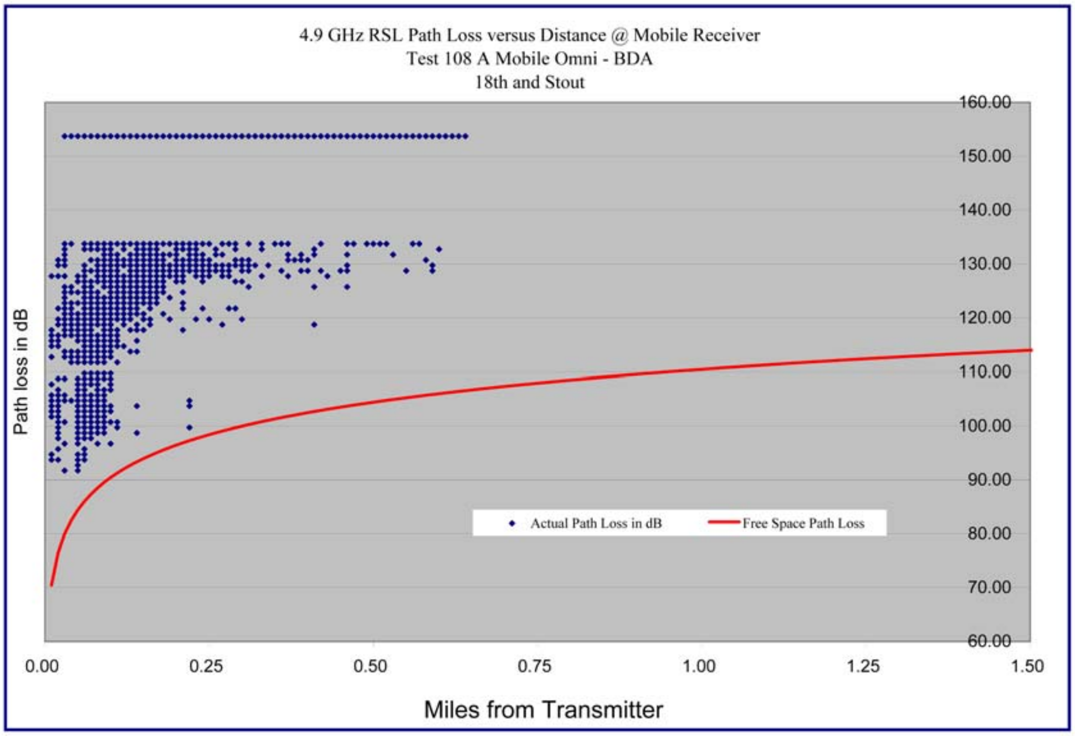
Table 6.19 Map Legend



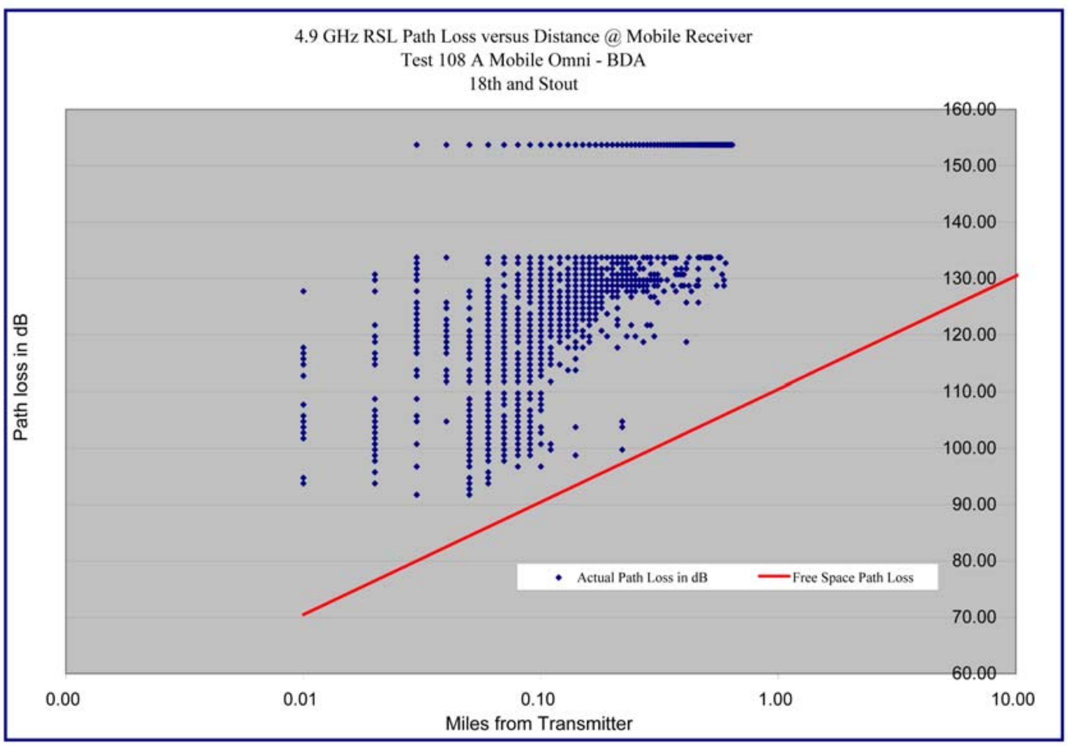
Graph 6.29 Receive Signal Level versus Distance – 18th and Stout



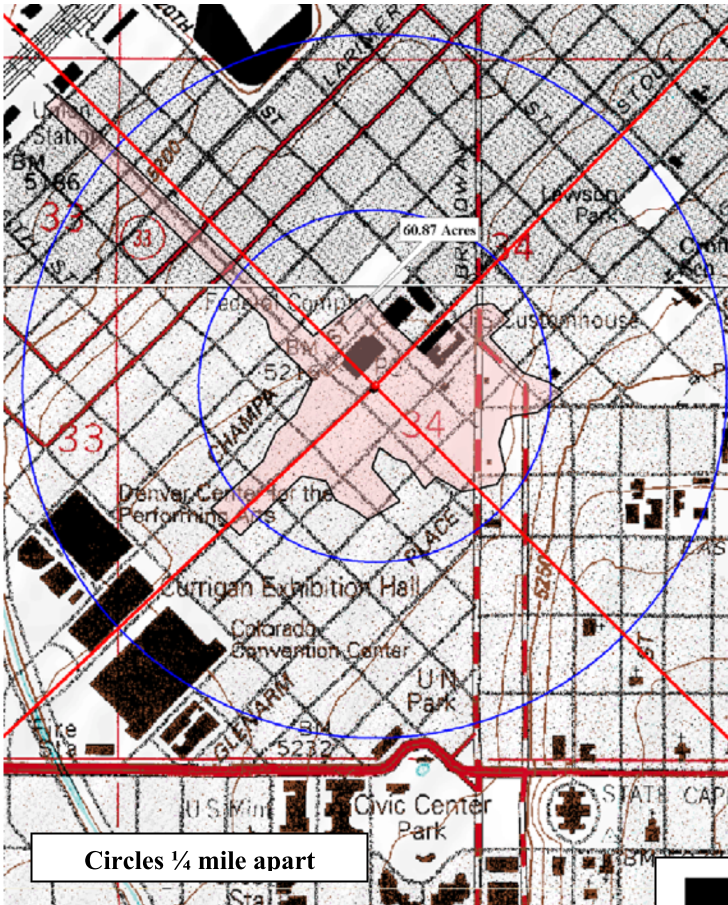
Graph 6.30– Receive Signal Level versus Distance – 18th and Stout – Log-Log Format



Graph 6.31 - Path Loss versus Distance – 18th and Stout



Graph 6.32 – Path Loss versus Distance – 18th and Stout – Log-Log Format



Map 6.20 - Footprint – 18th and Stout

The coverage at 18th and Stout was limited in comparison with some of the other tests (60.87 acres). Test 108B (without the BDA's) had a footprint of about 1/3, that of the Test 108B which used the BDA's (180.39 acres).

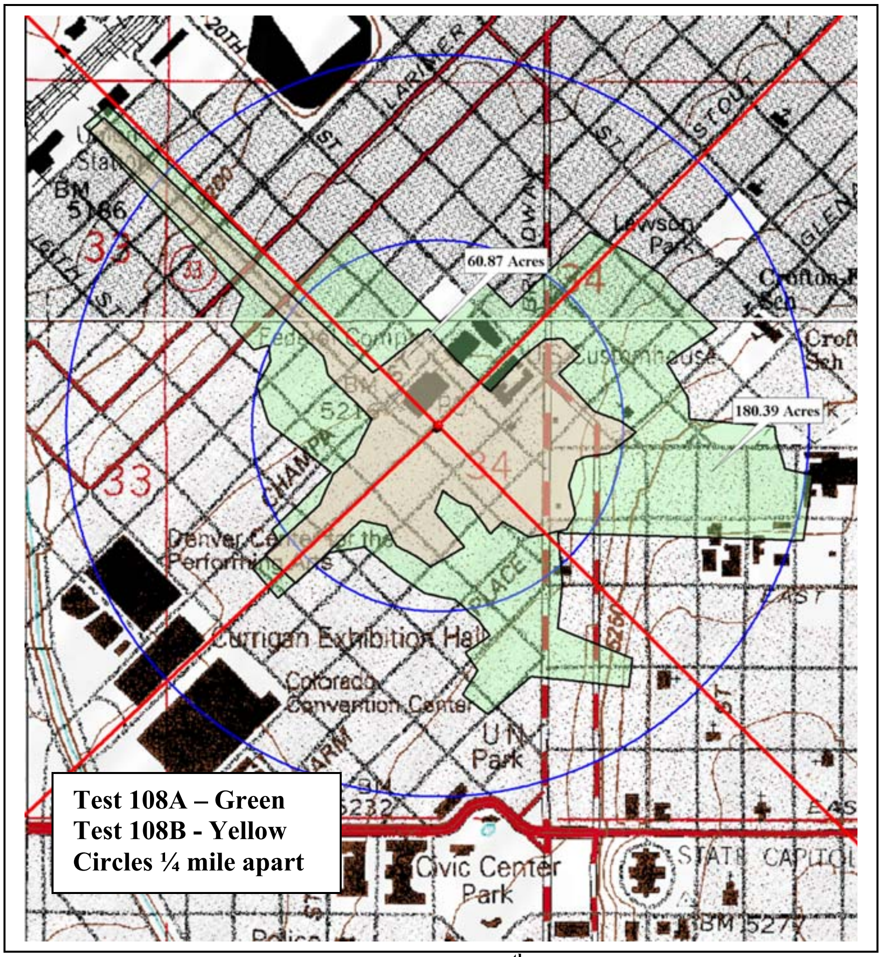
While the scatter graphs closely follow the theoretical predictions, none of them exceeds the performance of the theoretical predicted calculations. .

There is a one to two block radius where there is coverage, but in general, the coverage is much more limited than the coverage was when the BDA was used.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 6.20 – Map Legend

Summary of Test Results – Test 108A and 108B
18th and Stout – Mid-block



Map 6.21 – Footprint Comparison – 18th and Stout

Deployment Summary:

Test 108A – Omni Antenna with BDA (Green)
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 180.39 acres

Test 108B – Panel Antennas without BDA (Yellow)
EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL
Footprint – 60.87 acres

18th and Stout is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 18th street.

Tests 108A and 108B were conducted simultaneously from the same receive vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 108A had an EIRP of 31.47 dBm and test 108B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests can be assumed almost the same.

Test 108A resulted in a footprint of 180.39 acres while Test 105B has a footprint of only 60.87 acres, roughly 1/3 of the size of the footprint from Test 106A.

The difference was that in the 108A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive

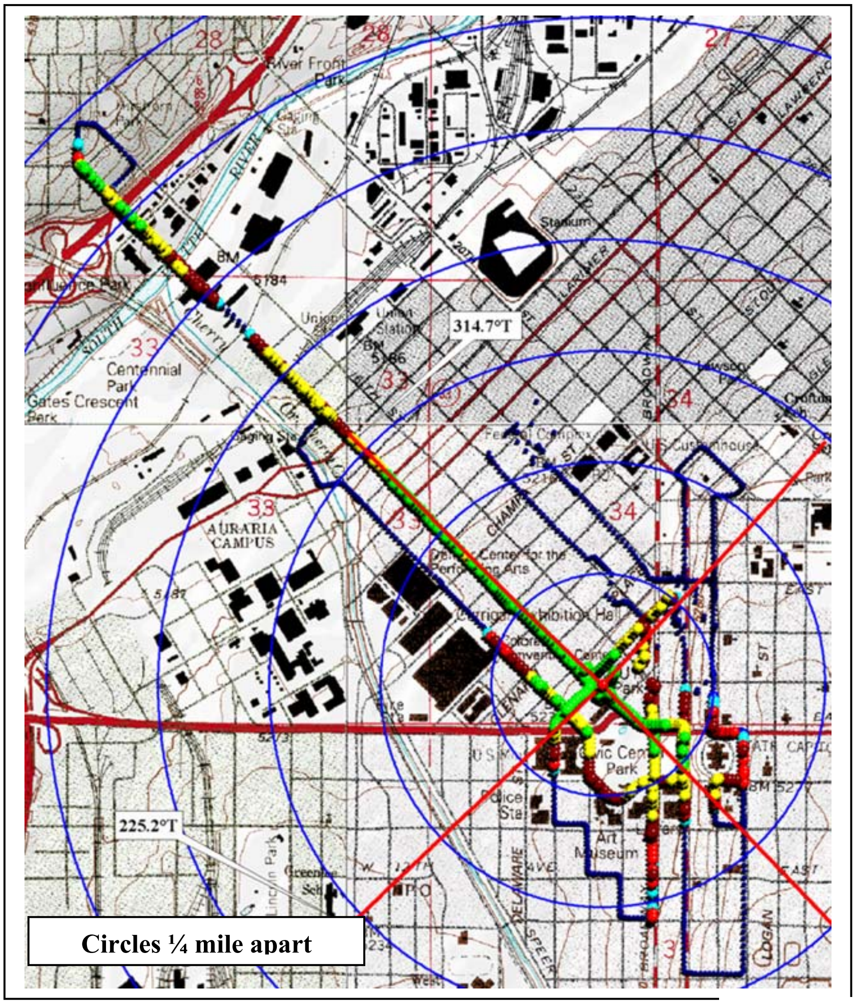
signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E., of Pericle Communications, confirmed that the BDA increased the receiver sensitivity by 2 dB.

It appears that the addition of a mobile BDA has a dramatic effect on the coverage area, not because of the increase in EIRP, but because of the increase in receiver sensitivity.

Test Numbers	108A	108B
Study No for this Chapter	Study 7	Study 8
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	5/8 mile	5/8 mile
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-18	2
Maximum	4	23
Backhaul		
feasibility	none at this time	none at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	no	no
Ad Hoc or Mesh	yes	yes
Site Comparison		
Footprint	180.39 acres	60.87 acres
Comment	Study 1 shows less path loss than theoretical	

Table 6.21 Comparison of Studies at 18th and Stout

Study 9
Test 109A – Mobile Command Post with Omni
BDA at Portal and Mobile
15th and Court Place



Map 6.22 – Coverage 15th and Court Place

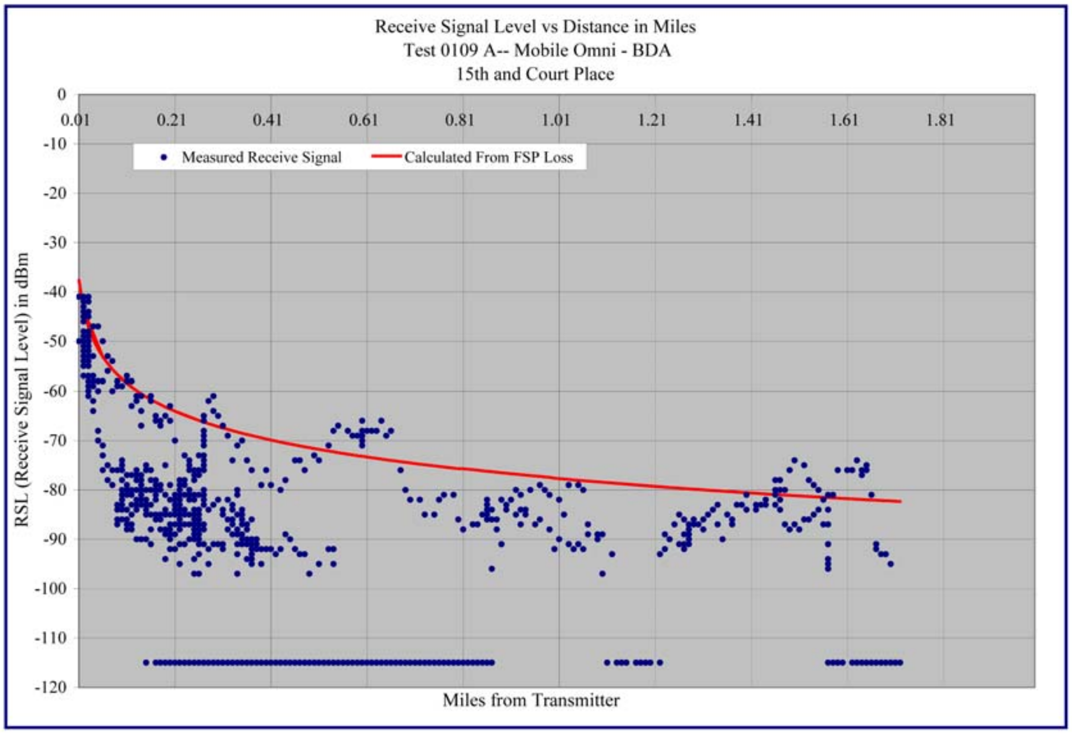
Deployment Summary:

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL

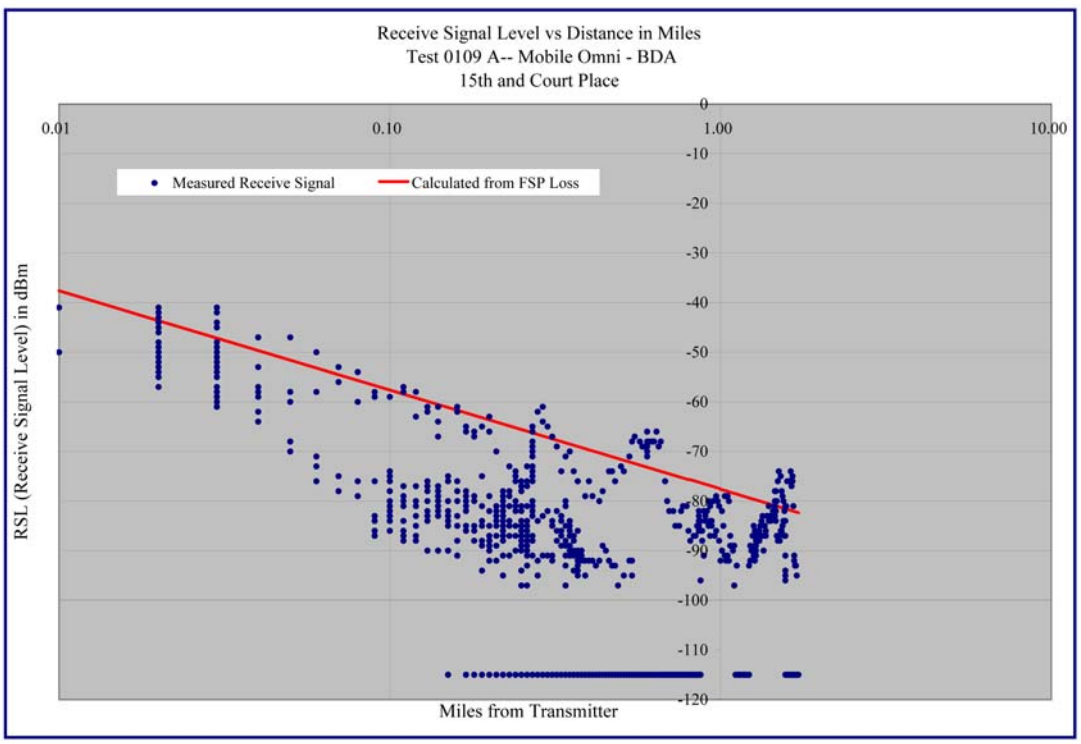
15th and Court is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 15th Street.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

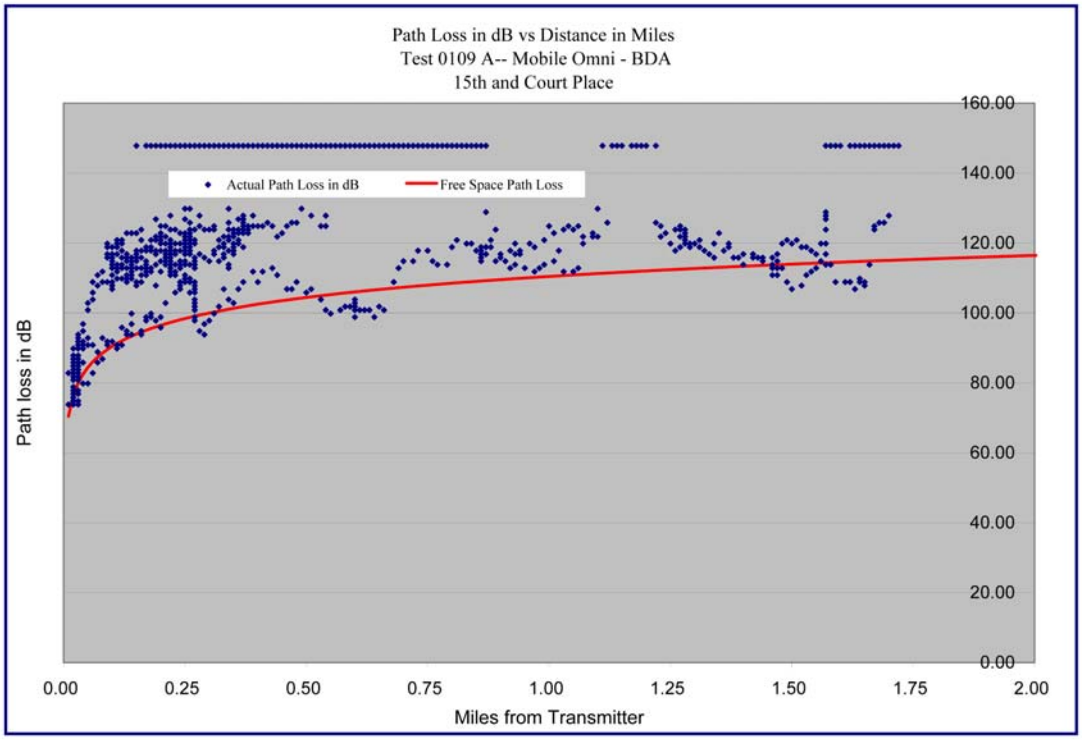
Table 6.22 Map Legend



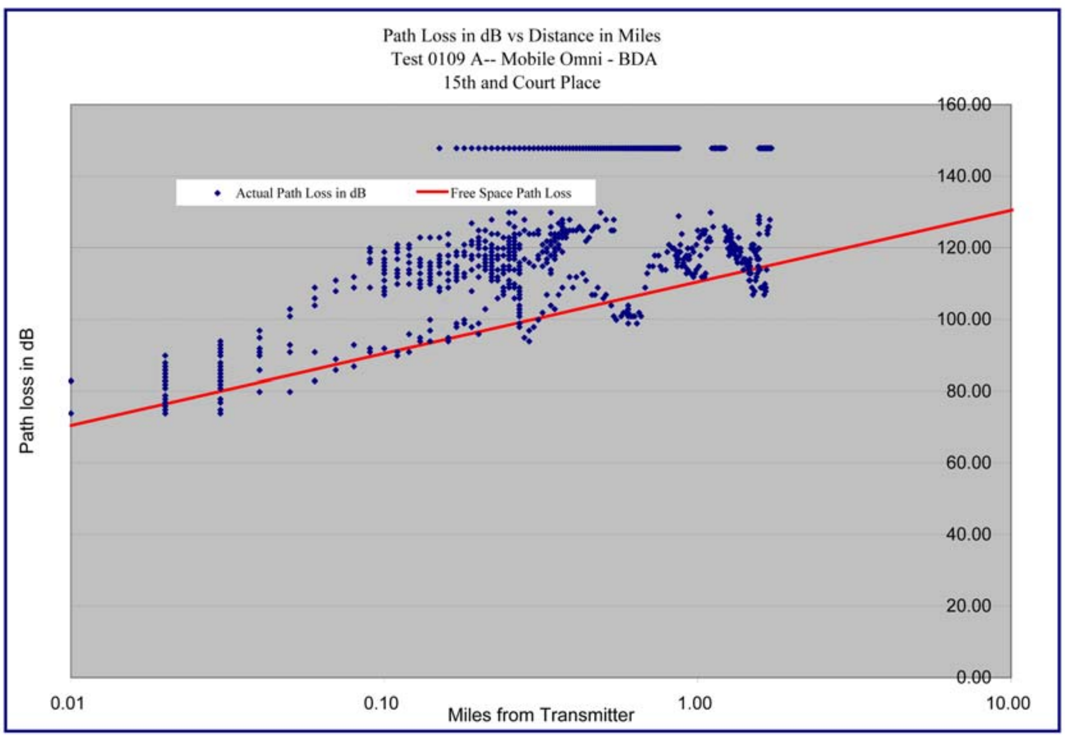
Graph 6.33 – Receive Signal Level versus Distance – 15th and Court Place



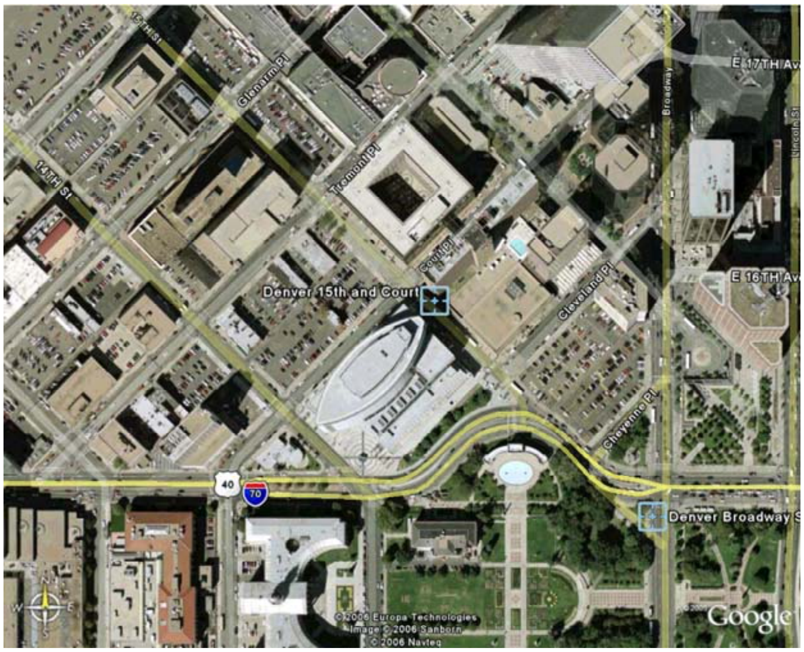
Graph 6.34 – Receive Signal Level versus Distance – 15th and Court Place – Log-Log Format



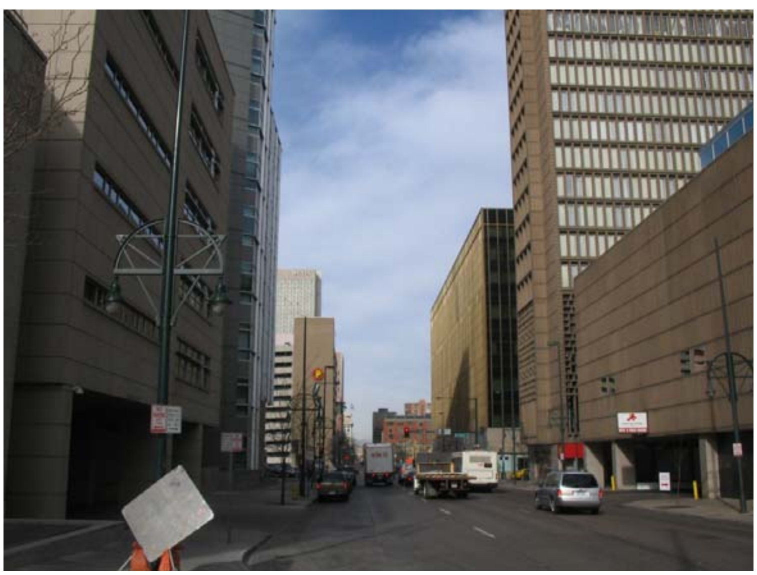
Graph 6.35 – Path Loss versus Distance -15th and Court Place



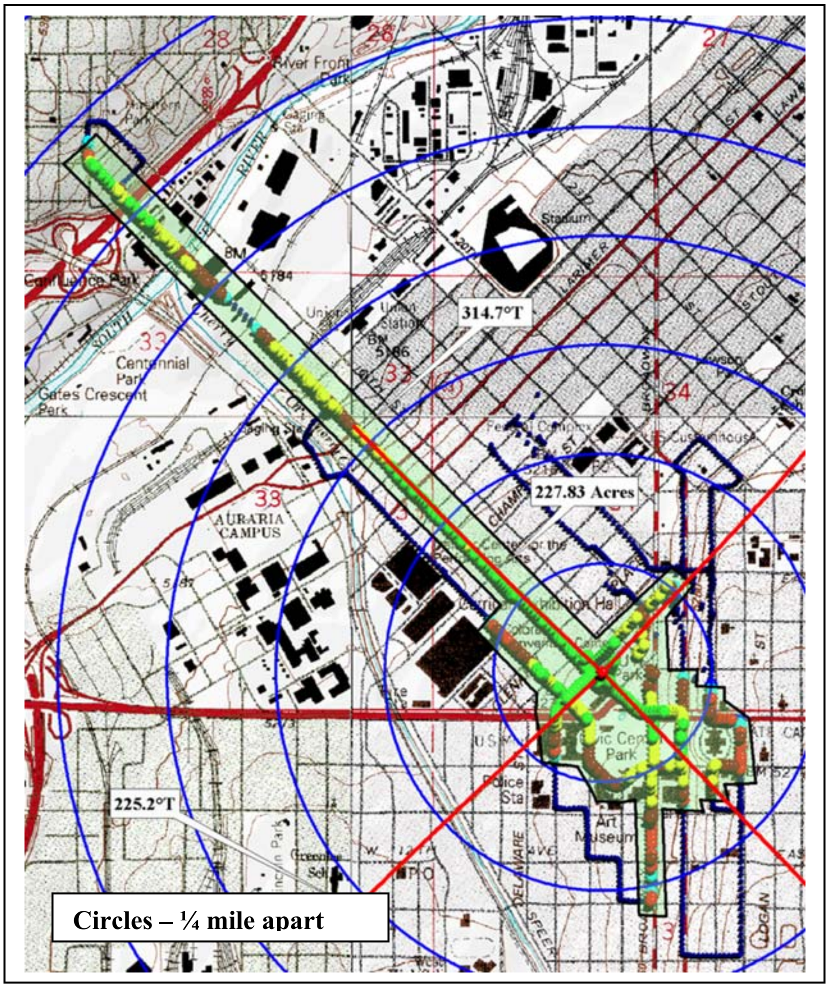
Graph 6.36 – Path Loss versus Distance – 15th and Court Place – Log-Log Format



Picture 6.17 – Satellite Image – 15th and Court Place



Picture 6.18 – 15th and Court



Map 6.23 – Footprint 15th and Court Place

The coverage from 15th and Court showed a footprint of 227.83 acres. The majority of the coverage was within the line-of-site path up Court Place. There was only 1 to 2 blocks coverage adjacent to the site.

The path loss of the system was better than the theoretical predicted calculations showed. The receive signal was greater, in some instances, than the theoretical predicted calculations showed..

Where there was coverage the system sometimes performed better than the theoretical calculations showed.

Table 6.23 – Map Legend

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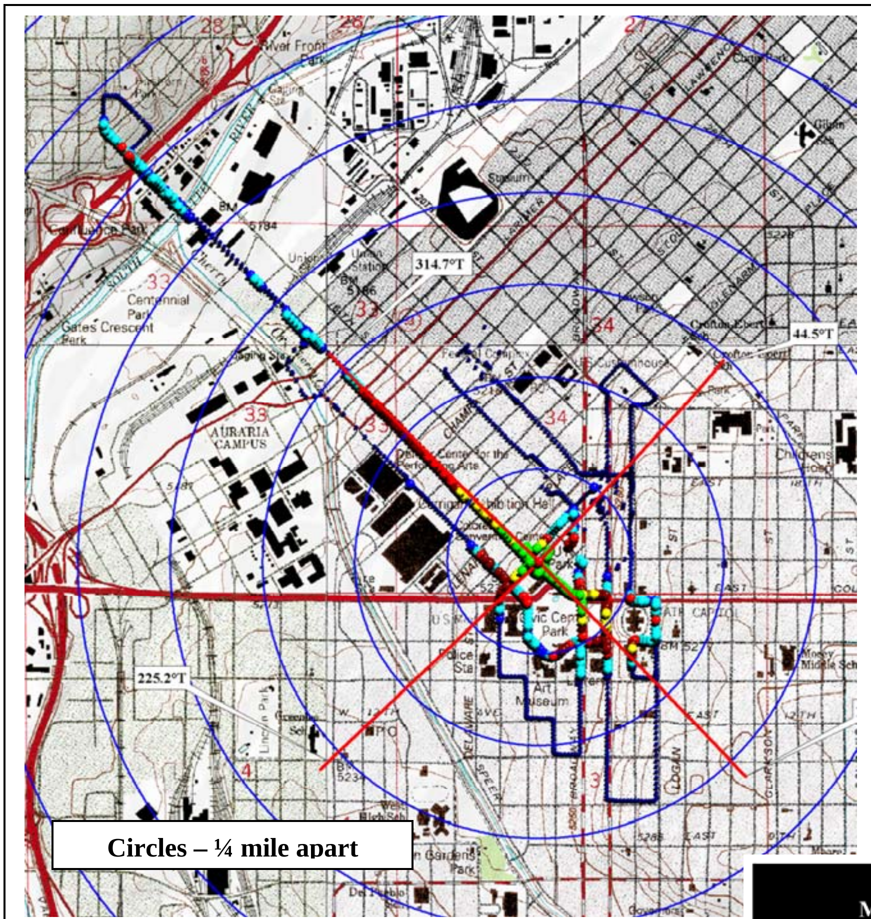
Study 10
Test 109B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
15th and Court – Mid-Block



Map 6.24 – Coverage – 15th and Court Place

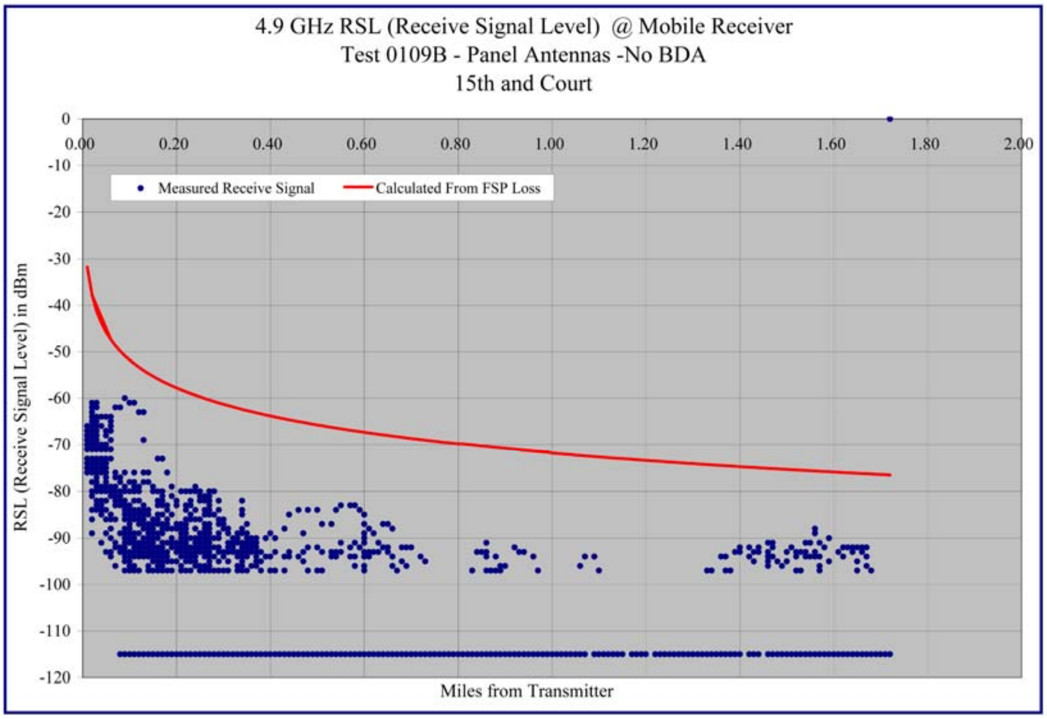
Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

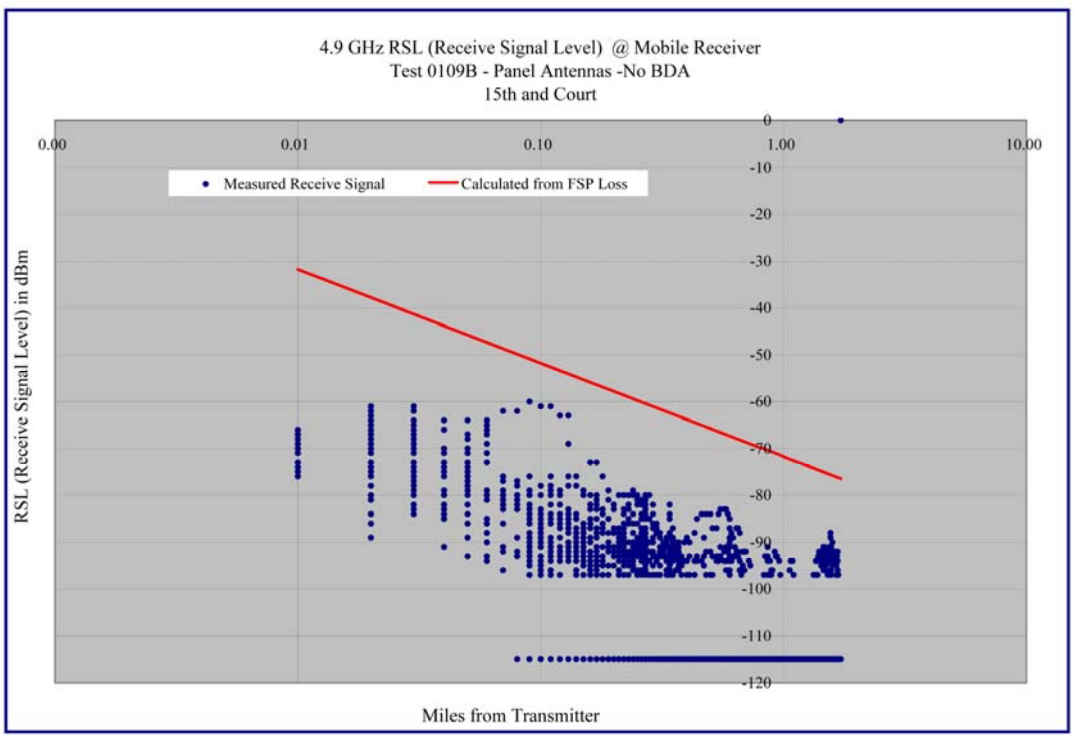
15th and Court is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 15th Street.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

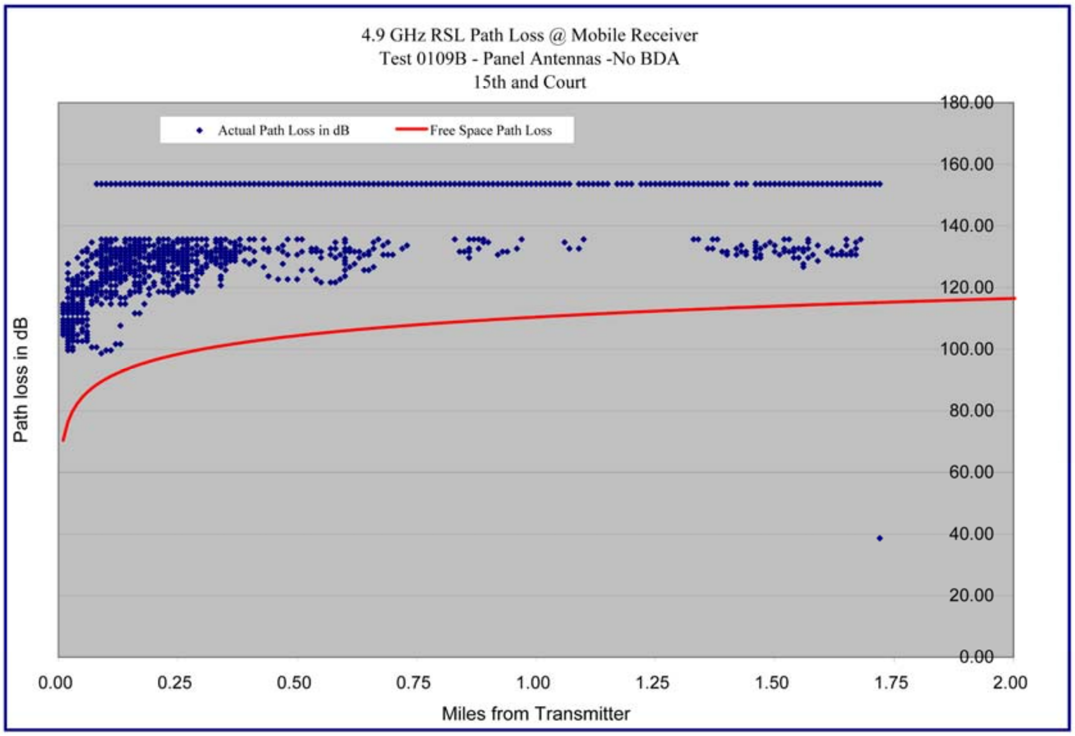
Table 6.24 – Map Legend



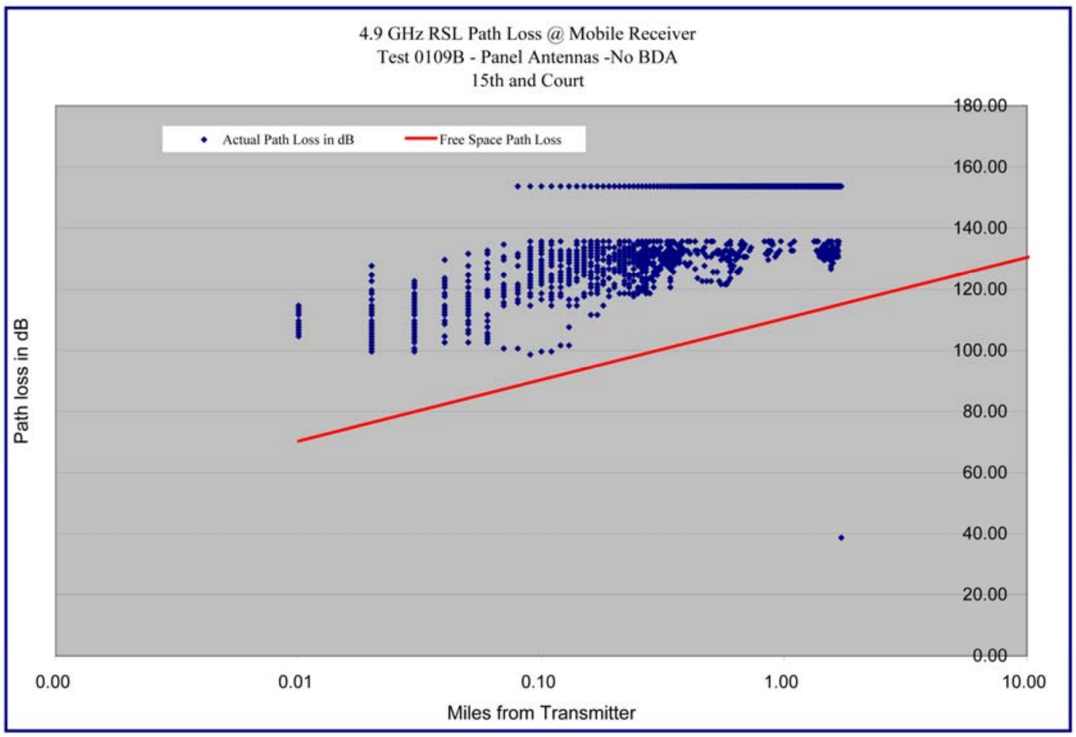
Graph 6.37 Receive Signal Level versus Distance – 15th and Court Place



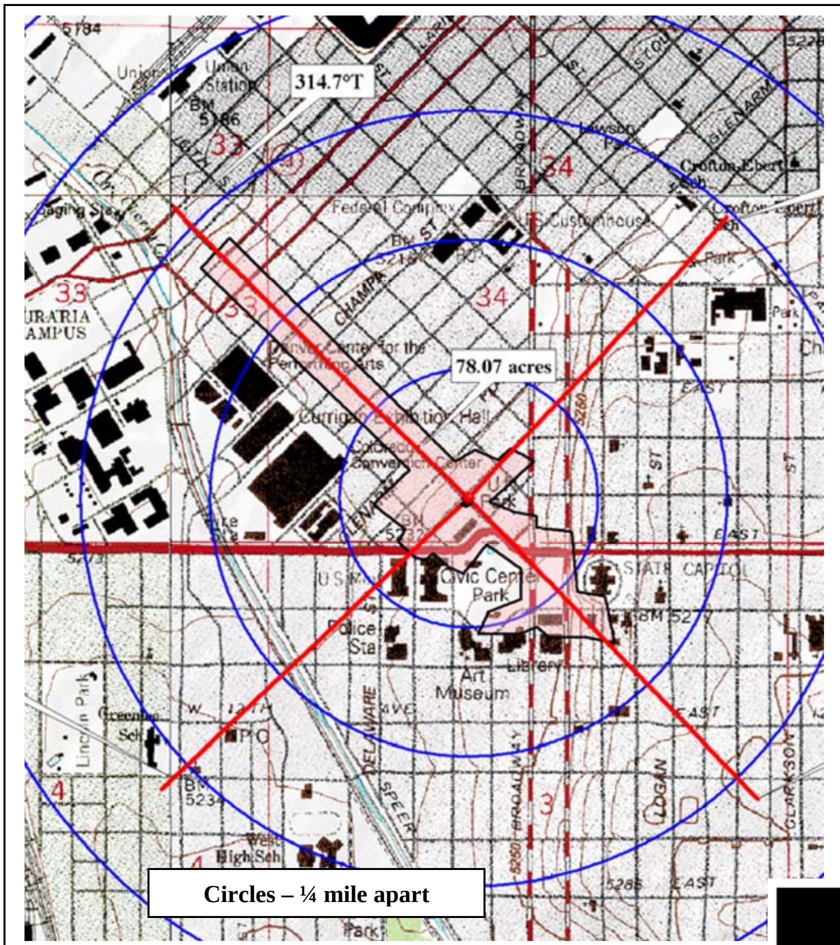
Graph 6.38 Receive Signal Level versus Distance – 15th and Court Place – Log-Log Format



Graph 6.39 Path Loss versus Distance – 15th and Court Place



Graph 6.40 Path Loss versus Distance – 15th and Court Place – Log-Log Format



Map 6.25 - 15th and Court Place Footprint

The coverage from 15th and Court showed a footprint of 78.07 acres. The coverage is limited to the line of sight path up Court Place, and to within a block or two in other directions. The area to the southeast is more open, and has some coverage.

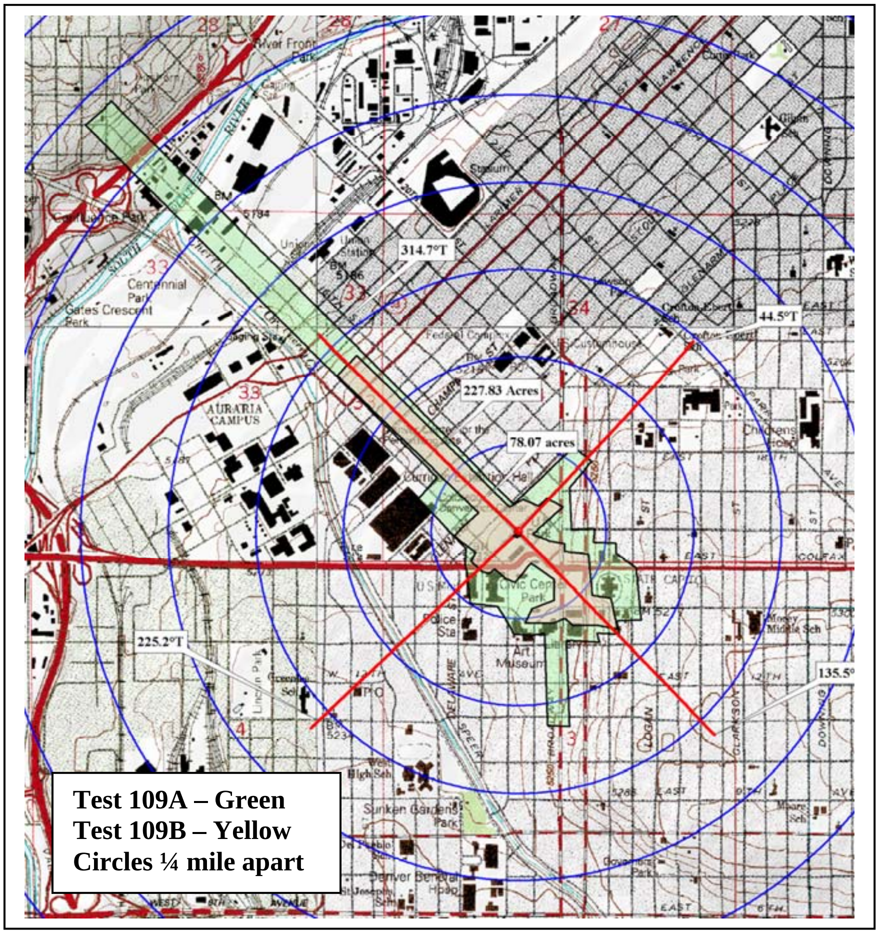
This mid-block deployment was in very dense urban – with tall buildings on all sides.

The footprint is ¼ that of the coverage, which was experienced in Test 109A, which had a BDA on each end and omni antennas on each end (227.83 acres) .

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 6.25 – Map Legend

Summary of Test Results – Test 109A and 109B
15th and Court Place – Mid-block



Map 6.26 – Comparison of Footprints at 15th and Court Place

Deployment Summary:

Test 109A – Omni Antenna with BDA (Green)
EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL
Footprint – 227.83 acres

Test 109B – Panel Antennas without BDA (Yellow)
EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL
Footprint – 78.07 acres

15th and Court is in the middle of the very dense urban setting, and is surrounded by skyscrapers. The site chosen was mid-block looking down 15th

Tests 109A and 109B were conducted simultaneously with the same vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 108A had an EIRP of 31.47 dBm and test 108B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests can be assumed to be almost the same.

Test 109A resulted in a footprint of 227.83 acres while Test 109B has a footprint of only 78.08 acres, roughly 1/4 of the size of the footprint from Test 109A

The difference was that in the 109A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive

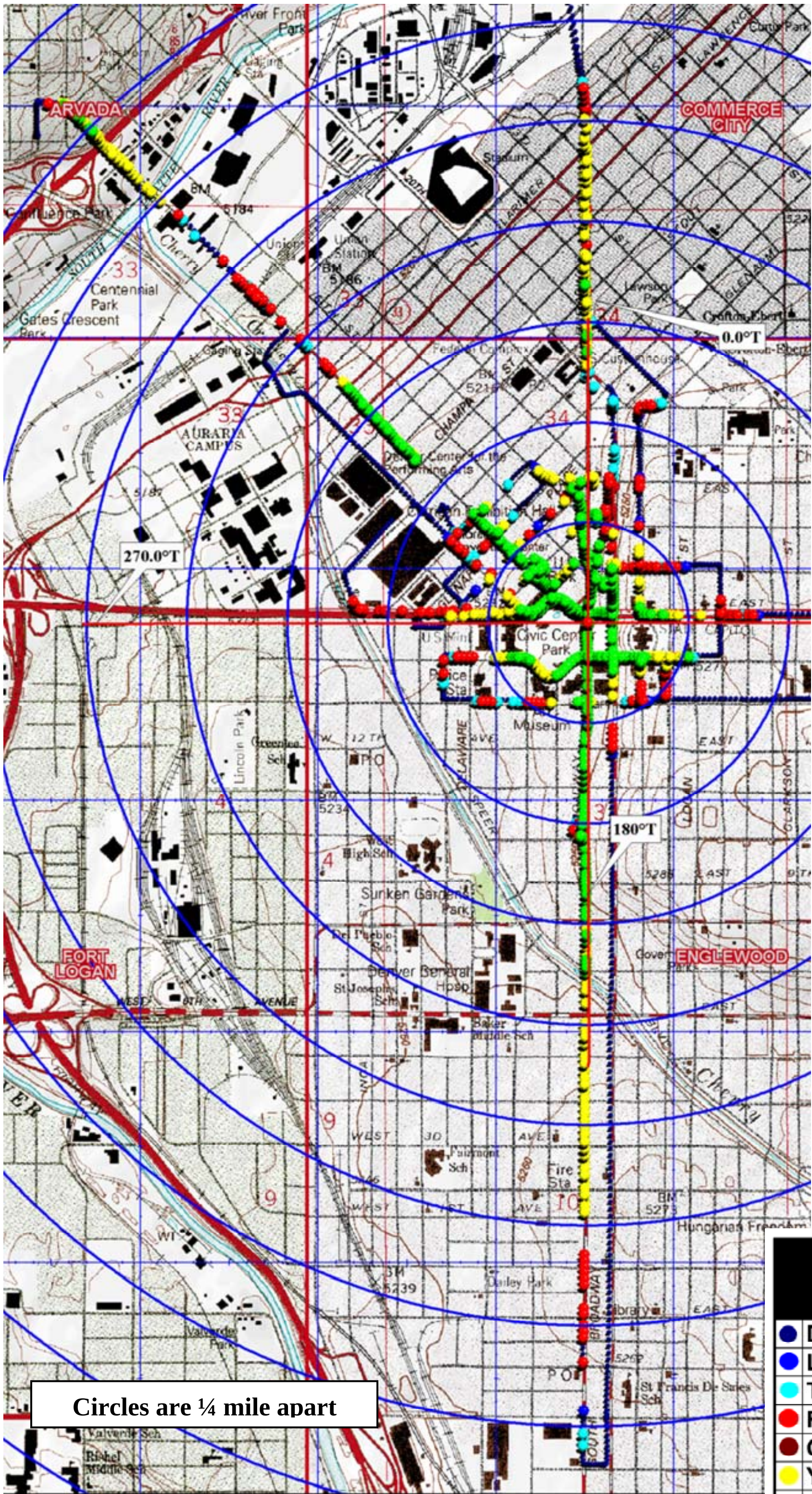
signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E., of Pericle Communications, confirmed that the BDA increased the receiver sensitivity by 2 dB.

It appears that the addition of a mobile BDA has a dramatic effect on the coverage area, not because of the increase in EIRP, but because of the increase in receiver sensitivity.

Test Numbers	109A	109B
Study No for this Chapter	**Study 9**	**Study 10**
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	1-5/8 mile	1-5/8 mile
Minimum	0	
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-10	10
Maximum	8	25
Backhaul		
feasibility	none at this time	none at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	no	no
Ad Hoc or Mesh	yes	yes
Site Comparison		
Footprint	227.83 acres	78.07 acres
Comment	Study 1 shows less path loss than theoretical	

Table 6.26 Comparison of Tests at 15th and Court Place

Study 11
Test 110A – Mobile Command Post with Omni
BDA at Portal and Mobile
Broadway South of Colfax



Map 6.27 – Coverage – Broadway south of Colfax

Deployment Summary:

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
Elevation 35 feet AGL
Mobile Antenna – Omni
Elevation 6 feet AGL

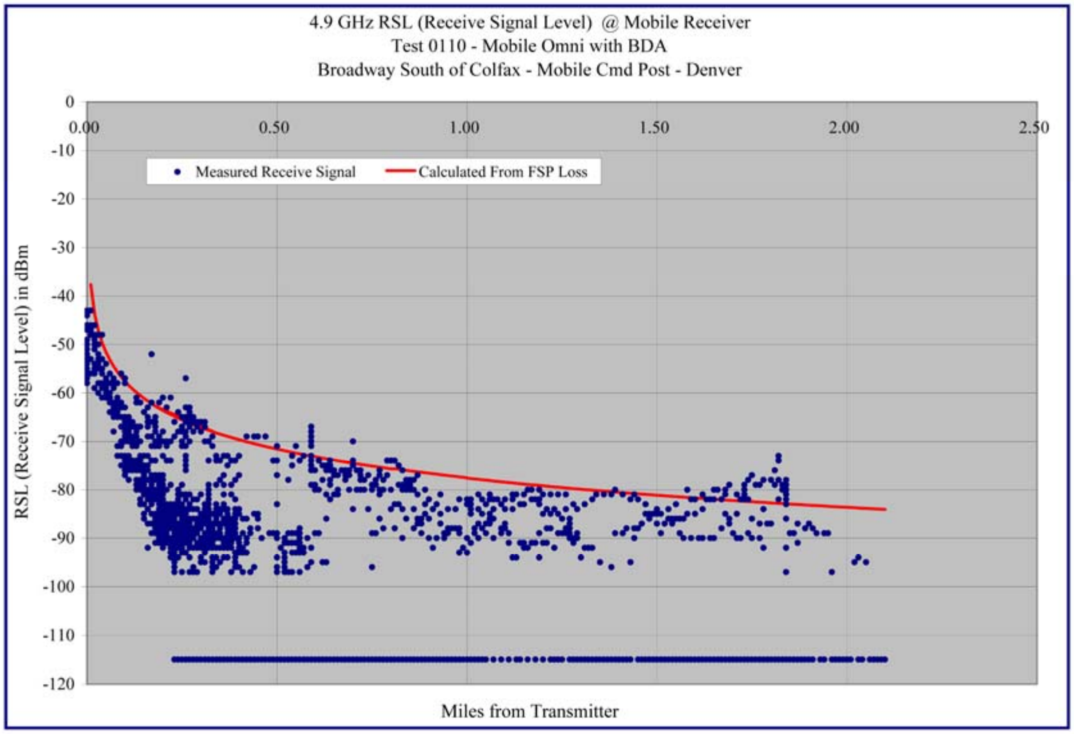
The location on Colfax south of Broadway is in front of the State Capitol. This is on the southeastern edge of the Dense Urban Area.

The Northwest is dense urban, southeast is urban sprawl with a mixture of building construction types. The south is urban, but with few skyscrapers, some office buildings, and some one or two story buildings.

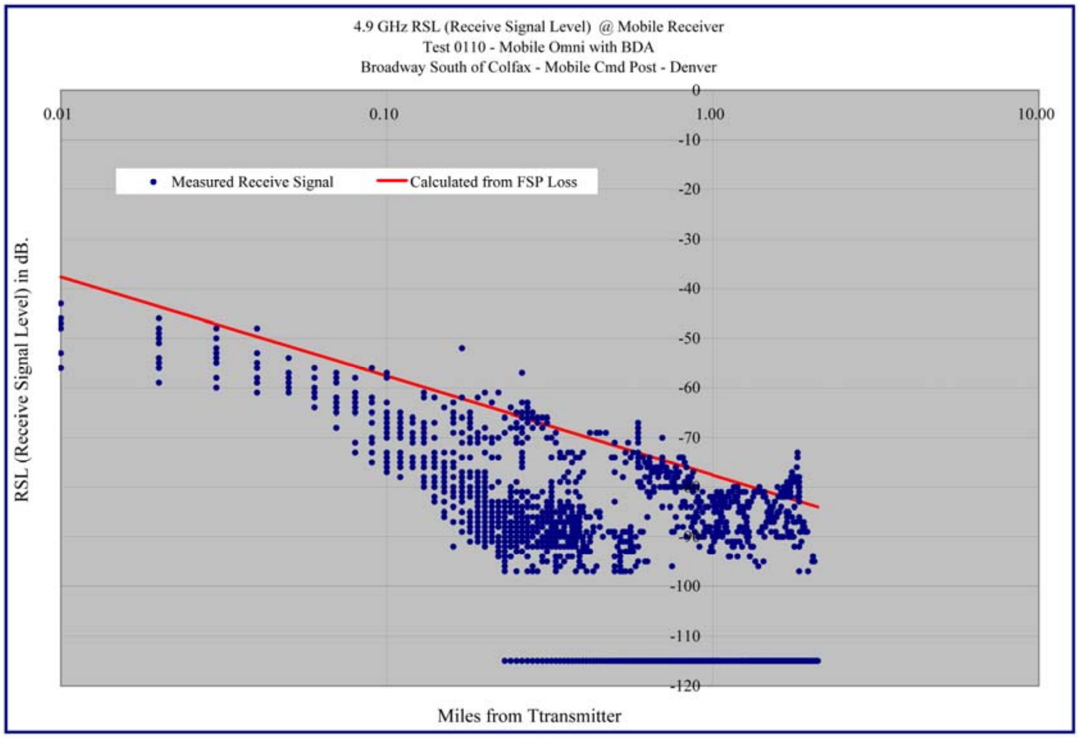
There is a large open area by the State Capitol.

Map Legend Mbps and Field Strength - With BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-97
Turquoise	marginal	1-4	-96 to -92
Red	3 to 4.5	4-7	-92 to -89
Orange/Brown	6 to 8	7-12	-89 to -84
Yellow	12 to 18	12-18	-84 to -78
Green	24 to 27	>18	> -78

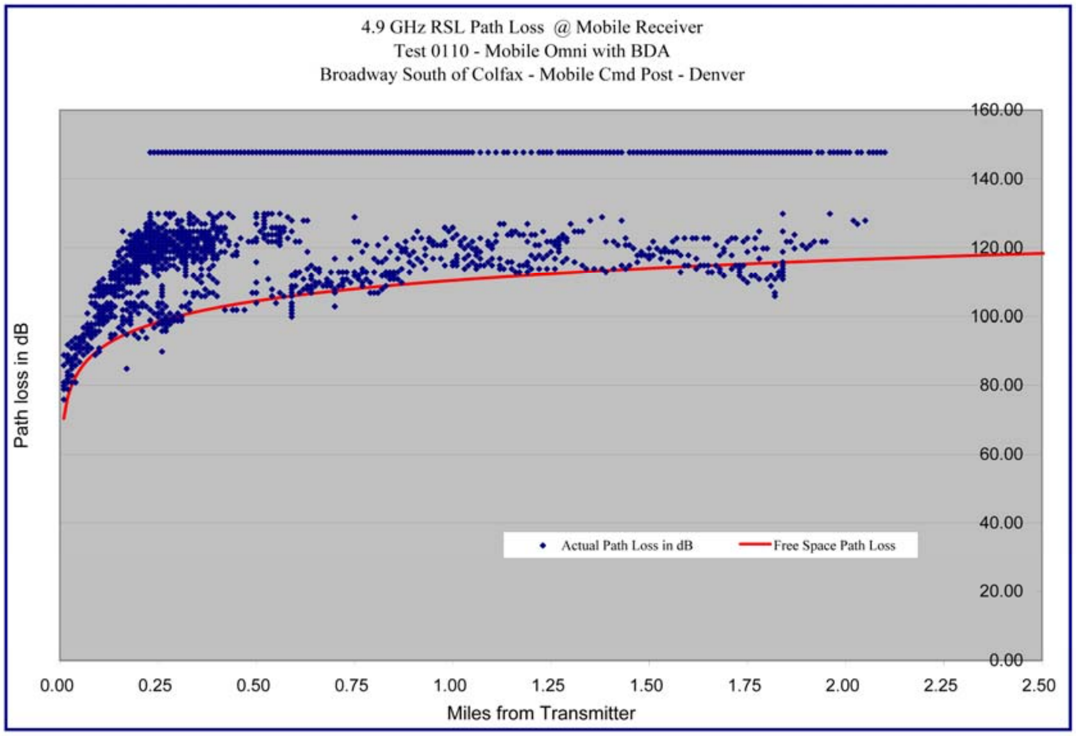
Table 6.27 Map Legend



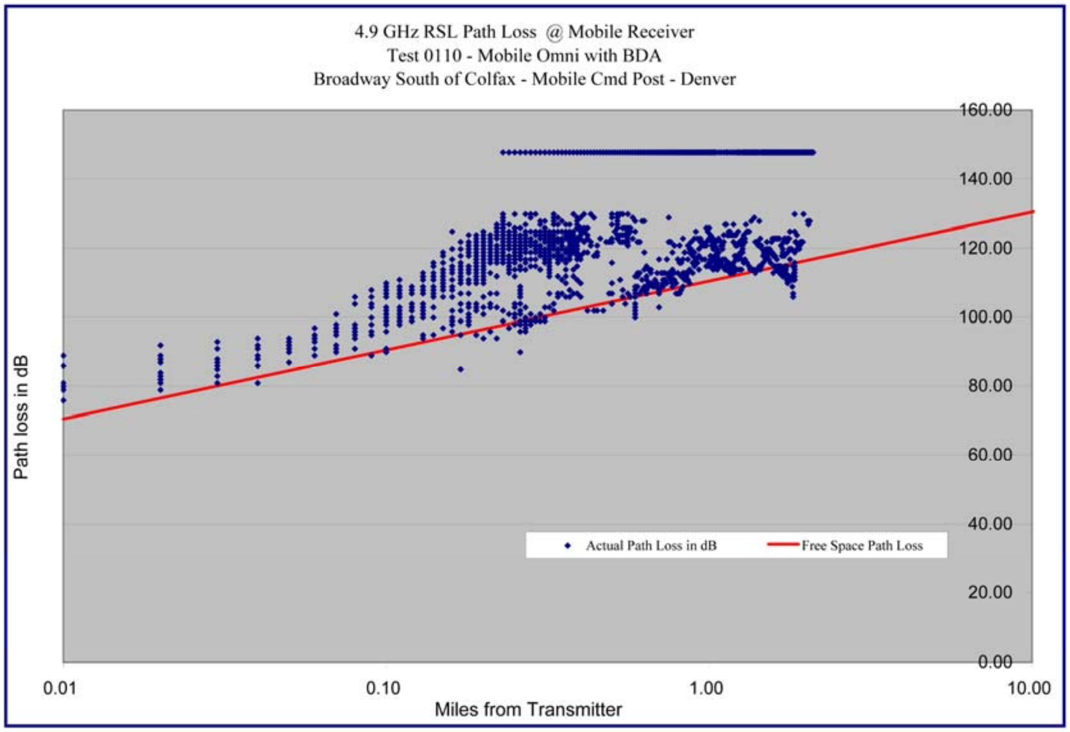
Graph 6.41 Receive Signal Level versus Distance – Broadway South of Colfax



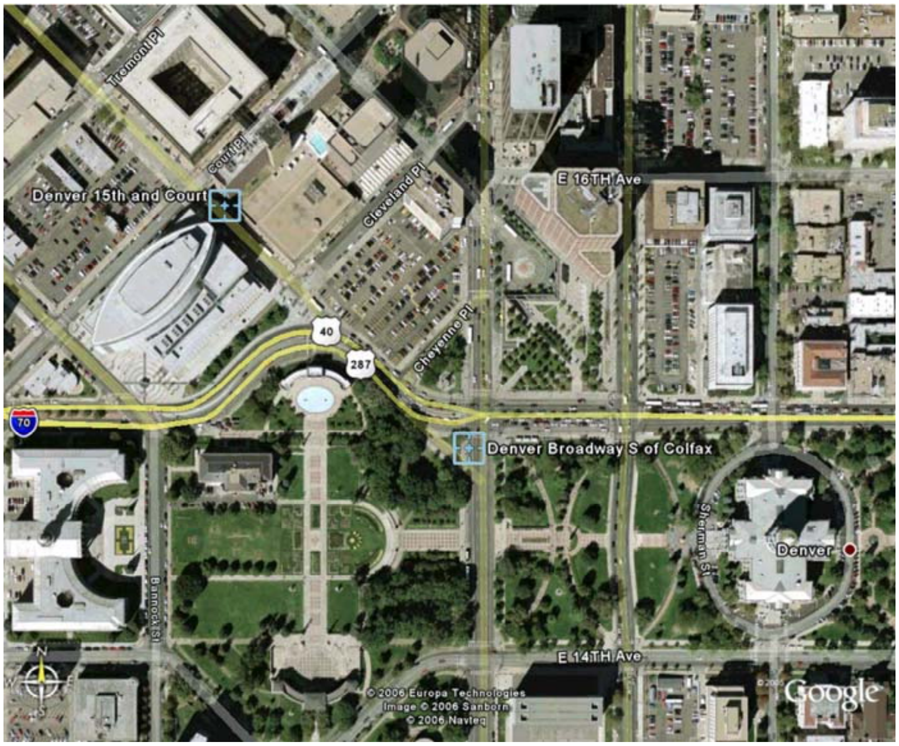
Graph 6.42 Receive Signal Level versus Distance – Broadway South of Colfax – Log-Log Format



Graph 6.43 Path Loss versus Distance – Broadway South of Colfax



Graph 6.44 Path Loss versus Distance – Broadway South of Colfax – Log-Log Format

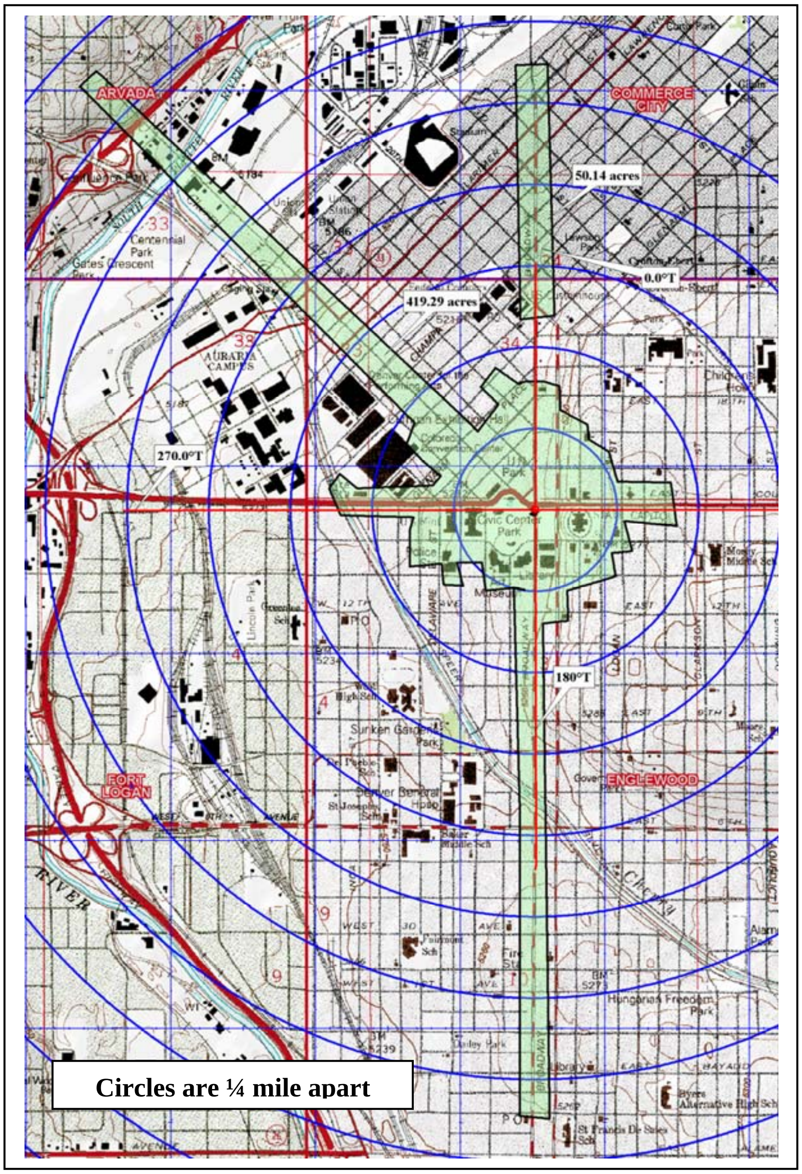


Picture 6.19 – Satellite Image – Broadway South of Colfax

Picture 6.20 – Broadway South of Colfax

Picture 6.21 – Broadway South of Colfax

Picture 6.22 – Broadway South of Colfax Looking Towards the Capitol



Map 6.28 – Footprint for Broadway South of Colfax

The coverage went north on Broadway until the crest of a hill was reached, then south on Broadway until the crest of a hill was reached, and finally northeast on 15th until a hill was reached. There is a loss of coverage on Broadway for a couple of blocks where the elevation of topography decreassed and line of sight was lost. The maximum distance where there was coverage was 2-7/8 miles south on Broadway.

The coverage was impressive with a 3 to four block radius around the portal. The total footprint for this portal was 469.43 acres – the best coverage of any of the tests which were run in the downtown area.

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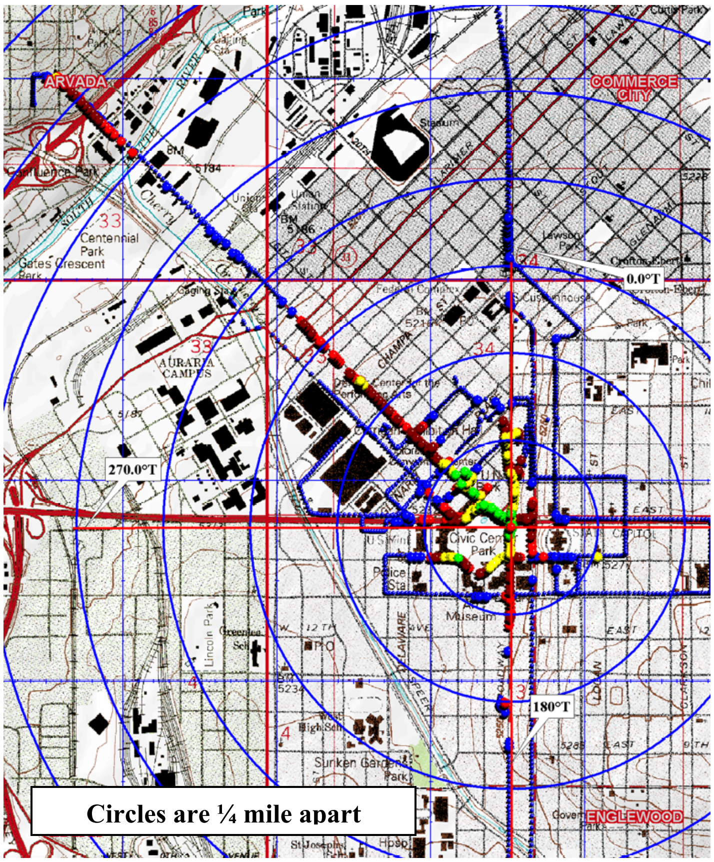
Study 12
Test 110B – Mobile Command Post with Four 90° Sector Antennas
No BDA at Portal or Mobile
Broadway South of Colfax



Map 6.29 – Coverage Colfax South of Broadway Test 110B

Deployment Summary

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted at 90° from each other
Elevation
2 antennas - 35 ft AGL
2 antennas - 28 ft AGL

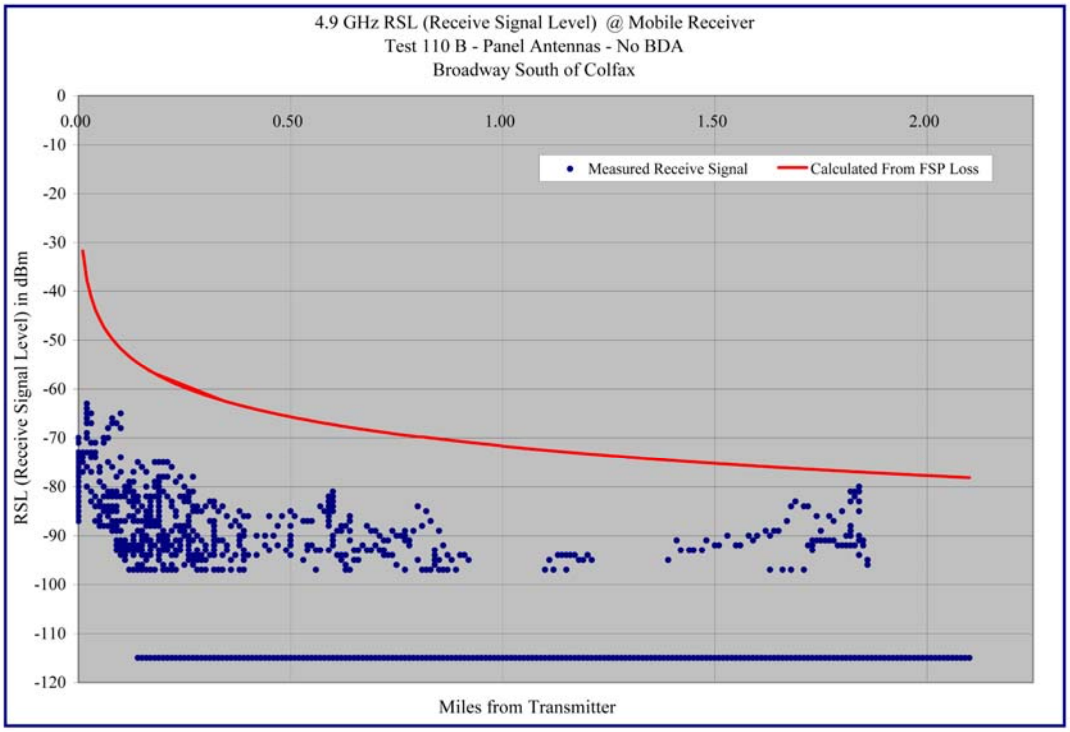
The location on Colfax south of Broadway is in front of the State Capitol. This is on the southeastern edge of the Dense Urban Area.

The Northwest is dense urban, southeast is urban sprawl with a mixture of building construction types, and the south would is urban with few skyscrapers, lower buildings, and some office buildings.

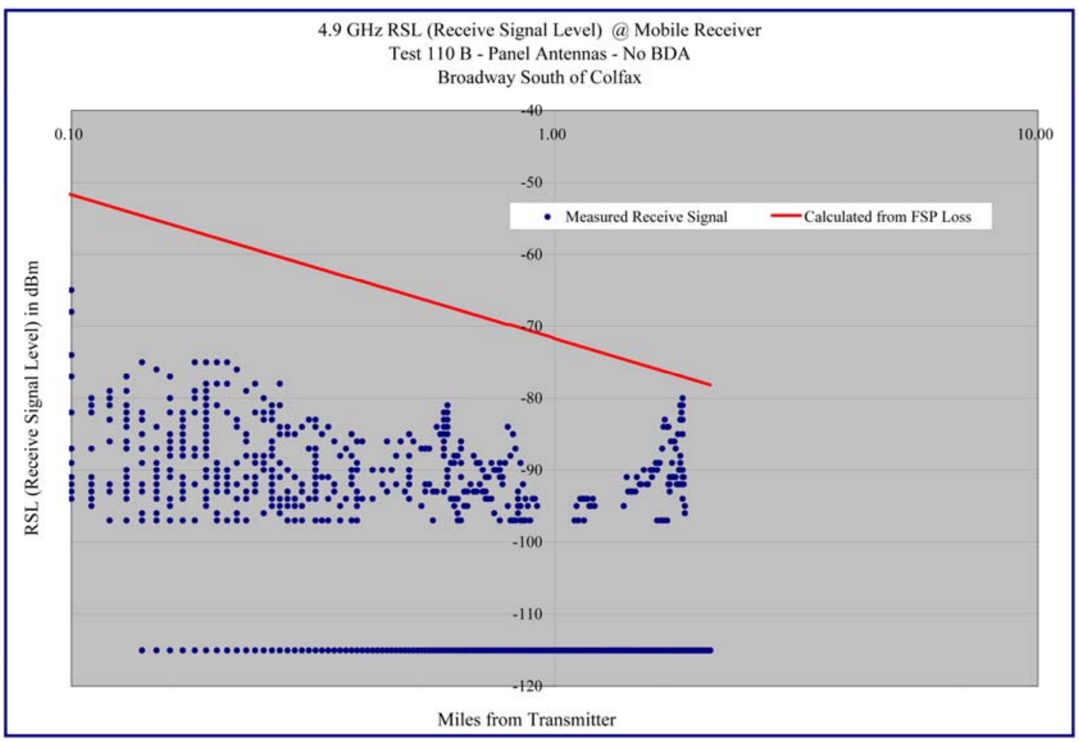
There is a large open area by the capitol.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

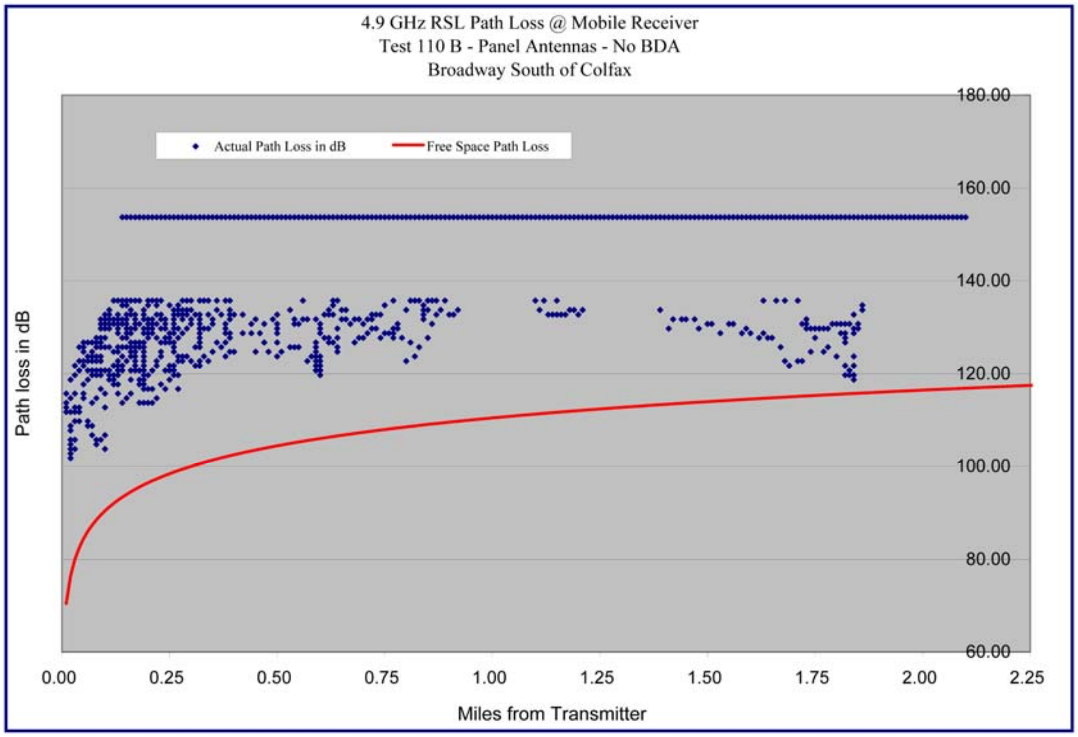
Table 6.28 – Map Legend



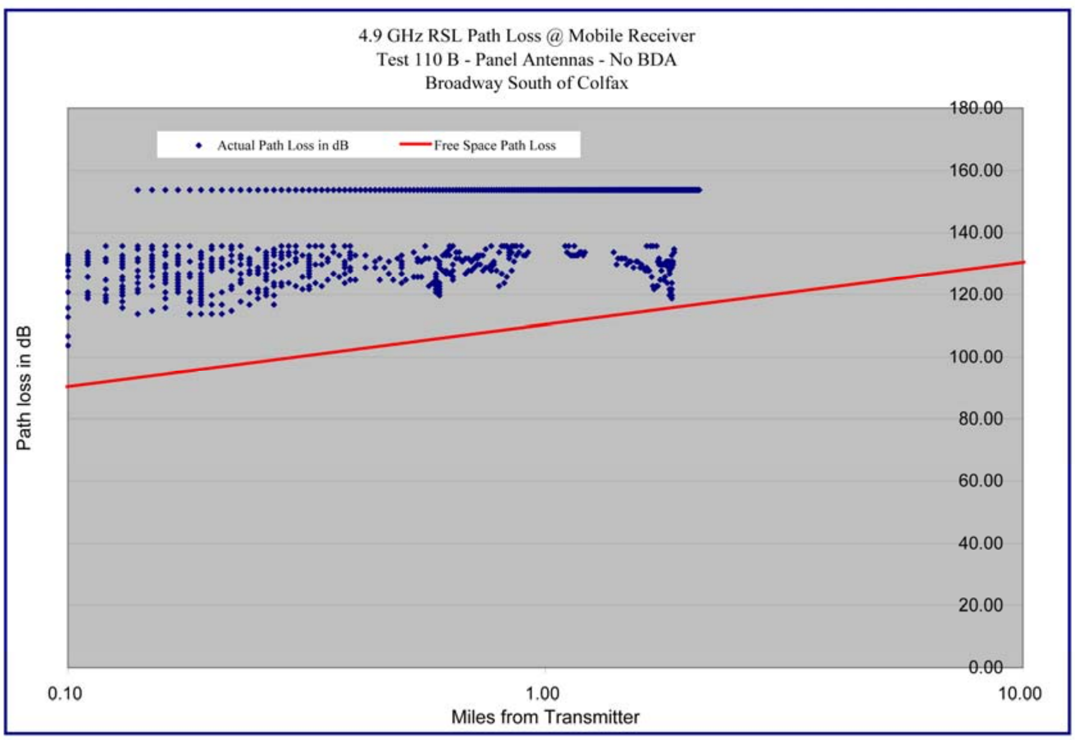
Graph 6.45 Receive Signal Level versus Distance – Broadway South of Colfax



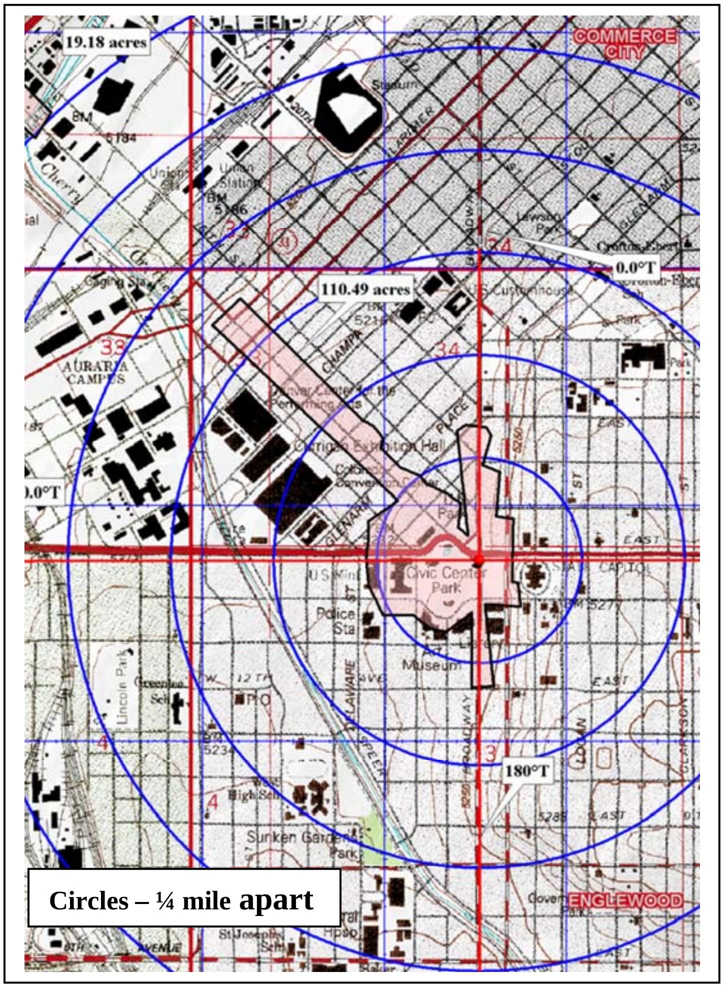
Graph 6.46 Receive Signal Level versus Distance – Broadway South of Colfax – Log-Log Format



Graph 6.47 Path Loss versus Distance – Broadway South of Colfax



Graph 6.48 Path Loss versus Distance – Broadway South of Colfax – Log-Log Format



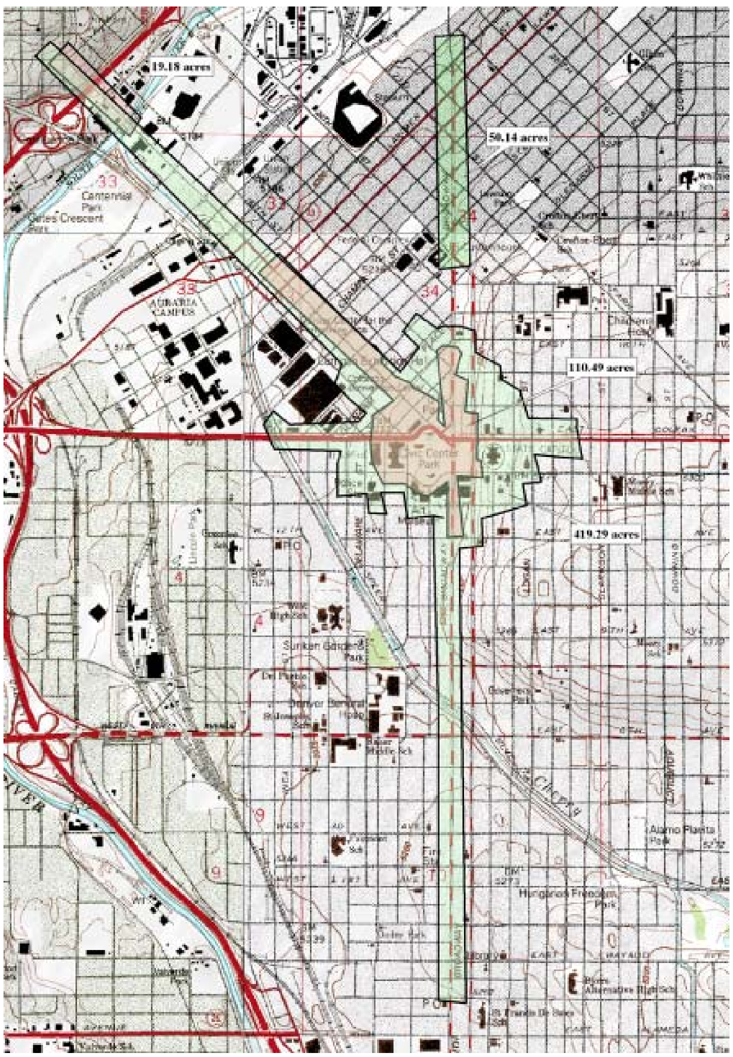
Map 6.30 – Footprint for Colfax South of Broadway Test 110B

The coverage footprint for Test 110B was only 110.49 acres, while Test 110A (with the BDA's in line and the omni antennas) had a footprint of 469.43 acres. The coverage without the BDA was 24% that of the coverage with the BDA!

The EIRP's of both tests were essentially the same. The difference in coverage is due to the improved receiver sensitivity in the mobile BDA.

The portal covered a one to three-block radius plus some of the distance up 15th Court. It's coverage up and down Broadway was considerably less than that of Test 110A.

Summary of Test Results – Test 110A and 110B
Broadway South of Colfax - Intersection



Map 6.31 – Coverage Broadway South of Colfax – Test 110B

Deployment Summary

Test 110A – Omni Antenna with BDA

EIRP = 31.47 dBm
Portal has BDA
Mobile has BDA
Portal Antenna – Omni
  Elevation 35 feet AGL
Mobile Antenna – Omni
  Elevation 6 feet AGL
<u>Footprint – 469.43 acres</u>

EIRP – 30.97 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
  Four 90° Til-Tek 4904-14-90
  Mounted at 90° from each other
  Elevation
    2 antennas - 35 ft AGL
    2 antennas - 28 ft AGL
<u>Footprint – 110.49 acres</u>

The location of Colfax south of Broadway is in front of the State Capitol. This is on the southeastern edge of the Dense Urban Area.

The Northwest is dense urban, southeast is urban sprawl with a mixture of building construction types, and the south would be urban, but with lower buildings and fewer skyscrapers.

There is a large open area by the capitol that can be seen in the satellite view of the area, shown in the summary for tests 110A and 110B.

Tests 109A and 109B were conducted simultaneously with the same receive vehicle. The measured desense effect of having two antennas closely mounted on the vehicle was 2 dB. Test 108A had an EIRP of 31.47 dBm and test 108B had an EIRP of 30.97 dBm, less than ½ dB difference. The Effective Radiated Power for both tests is almost the same.

Test 109A resulted in a footprint of 227.83 acres while Test 109B has a footprint of only 78.08 acres, roughly 1/4 of the size of the footprint from Test 109A

The difference was that in the 109A, the receive vehicle also had a mobile BDA. While the mobile BDA does increase the EIRP of the receive vehicle, the test was only measuring receive signal (or the downlink), not the effects of the uplink. Bench testing conducted by Frank Pratte, P.E., of Pericle Communications, confirmed that the BDA increased the receiver sensitivity by 2 dB. It appears that the addition of a mobile BDA has a dramatic effect on the coverage area, not because of the increase in EIRP, but because of the increase in receiver sensitivity.

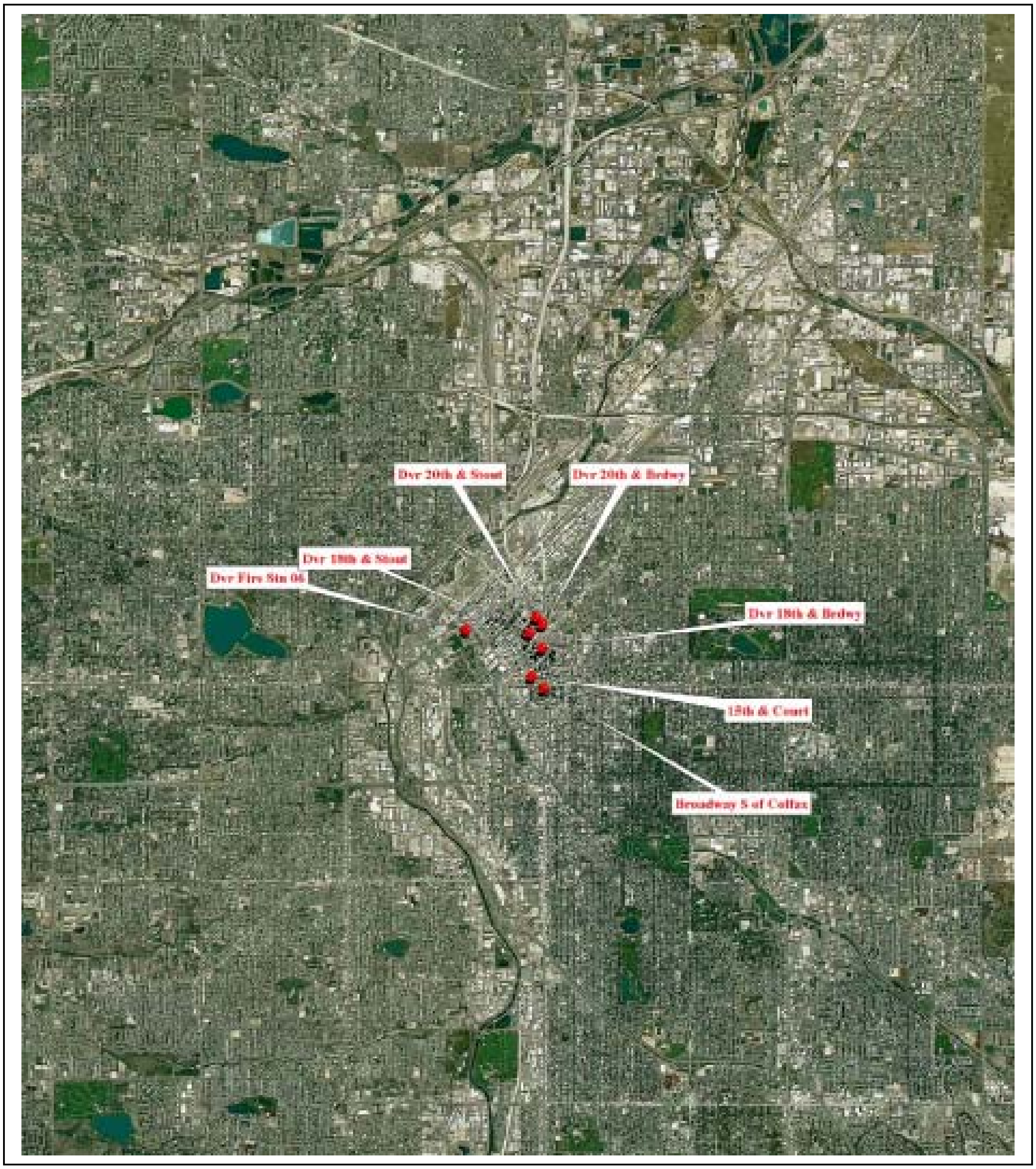
Picture 6.23 - Myron Kissinger
(Denver's Electronic Engineering Bureau)
and the Mobile Command Post used for Downtown Denver Testing

Picture 6.24 – View from MCP to Capitol

Test Numbers Study No for this Chapter	110A Study 11	110B Study 12
Deployment Parameters		
Bandwidth	10 MHz	10 MHz
Max Throughput Setting	Auto Fallback	Auto Fallback
EIRP	31.47	30.97
Antennas	omni	four 90° sectors
Topography	dense urban	dense urban
Vegetation	almost none	almost none
Climate	arid	arid
Vantage Point	35 ft AGL	28 and 35 ft AGL
Distance for Hot-spots in miles		
Maximum	2-7/8 miles	1-3/4 miles
Minimum	0	0
Throughput - Mbps		
Maximum	24 to 27	24 to 27
Minimum	3 to 4.5	3 to 4.5
Path Loss Above Theoretical in dB		
Minimum	-14	4
Maximum	14	30
Backhaul		
feasibility	none at this time	none at this time
Deployment Type		
Point to Multipoint	yes	yes
Hot-Spot	no	no
Ad Hoc or Mesh	yes	yes
Site Comparison		
Footprint	469.43 acres	110.49 acres
Comment	Study 1 shows less path loss than theoretical	

Table 6.29 Comparison of Tests at Broadway South of Colfax

Summary of Downtown Denver Dense Urban Testing
Tests 105 to 110



Picture 6.25 – Satellite Overview of Downtown Denver Sites

The Downtown Denver Dense Urban testing was structured to test several variables.

- Deployment near intersections versus mid-block deployments
- Omni versus Sector Antennas
- The effects of a BDA on the receiver sensitivity
- Effects of the tall buildings on propagation
- The effects of reducing power from tested power to 26 dBm (the FCC Limit for loose mask products)

Summary of results:

- Mid-block deployments performed very well. In some instances, they outperformed deployments near intersections, in some instances they did not. Testing should be done to determine optimum deployment locations.

- When an omni antenna is used, only 1 AP is required at the Portal location. Without a BDA, the power would have been less than 26 dBm (less than the FCC limitations for loose mask) for this deployment. Newer AP's have higher power, and the end user should check to make sure they EIRP is at least 26 dBm.

- Sector antennas are directional, but testing of individual AP's on sectors indicated that the coverage supported by these antennas is wider than the beamwidth specified at the 3 dB point.[1] Til-Tek has provided a white paper since this study that indicates that three 90° sector will provide 360° coverage, and will provide that coverage better than if four 90° sectors are used. Contact the antenna manufacturer for specifics on deploying AP's with sector antennas.

- The addition of a BDA to the mobile receiver increased the sensitivity of that receiver by 2 dB. This increase was confirmed by extensive bench testing. The receiver calculations that were shown on pages 171 through 173 of this report, showed that a receiver with a BDA has 30% better coverage than one without a BDA.

  This is exactly what was seen in the testing. Some of the tests showed a larger increase in coverage – however this additional coverage increase is probably due to the "waveguide" effect of the buildings, and the multipath and reflections that caused constructive combining of the signals.

[1] The 3 dB point is the point, in the antenna's horizontal pattern, where the gain is 3 dB down from the rated gain of the antenna. For instance, if the antenna is pointed due north (0°), and it has a gain of 16 dBi, and is a 90° sector, the gain at 45° or NE will only be 14 dBi, and the gain at 315° will only be 14 dBi.

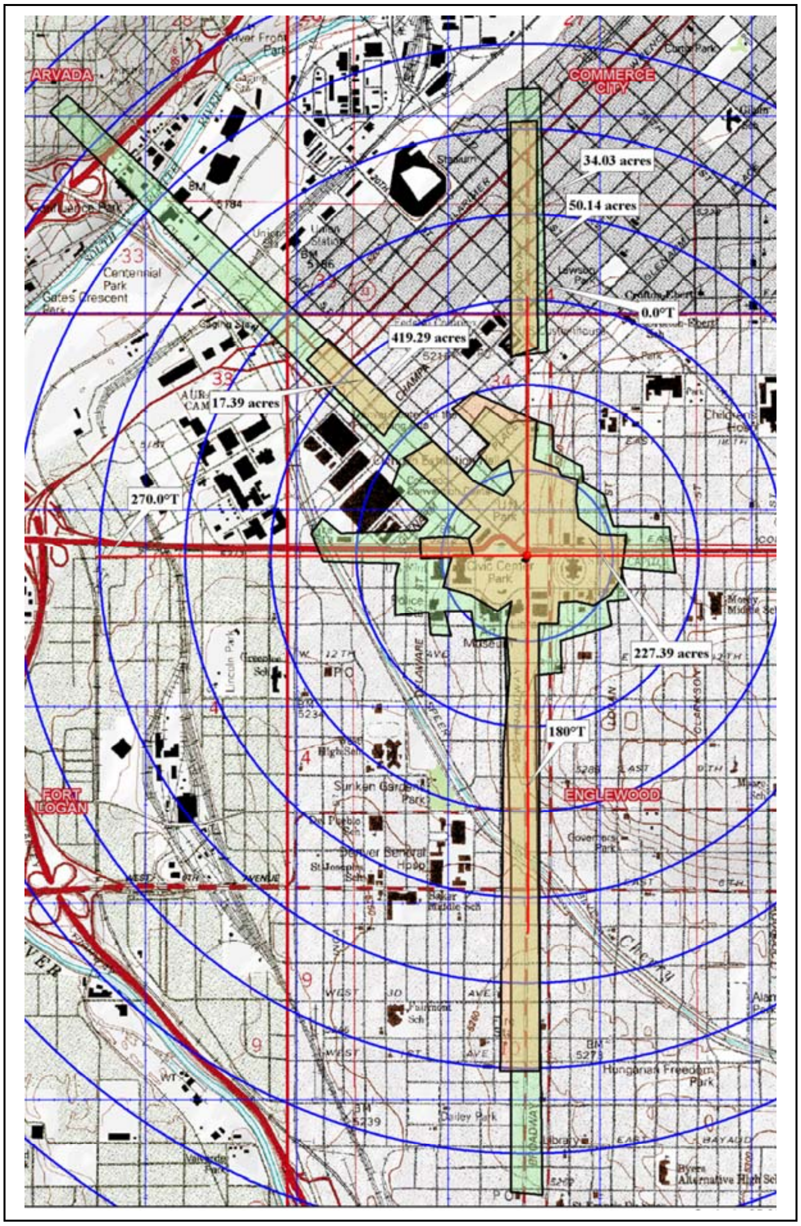
- In many of the downtown tests, the system performance was actually better than the predicted theoretical calculations. These predicted calculations use the free space loss formula to calculate losses for an unobstructed signal. With the exception of line-of-sight point-to-point microwave systems, real life deployments usually exhibit losses greater than these calculated losses.

  During the downtown Denver testing, however, this was not the case. There was a constructive effect where the signal strength was greater than would be expected, and the path loss was less than would be expected. One theory is that this is because of the "waveguide" effect of the tall buildings. Another theory would be that the reflections caused constructive rather than destructive interference. Regardless of the reason, the downtown urban environment appears to be very conducive to this type of deployment.

- Test 110 was replotted with a 6 dB drop across the board in field strength. This would equate to dropping the Power from the 31 dBm to 26 dBm, the FCC limits for loose mask radios.

  At 31 dBm, the footprint was 469.34 acres. At 26 dBm, the coverage footprint was reduced to 280.79 acres – a 40% reduction in coverage! Map 6.32 shows the comparison.

One of most important observations from these tests was that a BDA in the mobile receiver greatly improves system performance, regardless of the EIRP. The second conclusion was that the FCC limitations of 26 dBm reduce coverage substantially. Finally, the effects of the tall buildings seem to enhance deployment down the line-of-sight corridors, and result in reflections that cover adjacent streets even where there is not line-of-sight.



Map 6.32 – Comparison between 31 dBm and 26 dBm

Checklist for deployment in Dense Urban:

 Evaluate potential sites

- Choose a site that is lower – street-lamp height.
- Make sure the AP's are above the clutter of vehicles, trees in the area, etc.
- Make sure backhaul is available to the site.

- Use predictive model such as Bullington or Longley Rice to the maximum footprint for the coverage. These models are tools that help evaluate topography. If there are obstruction files for the area (for buildings), this will increase the accuracy of the model. Note that these models do not present an accurate map of the final coverage, but are simply one of many tools that can be used to help in the final planning process.

Before final deployment set up a temporary deployment and drive test the area and record the results. The results are best recorded with software that takes many readings per seconds so that the multipath and effects of Rayleigh fading can averaged into a reading that is more reflective of the actual results.

Proper and professional installation is critical to satisfactory performance.

Networking of the system is CRITICAL. Multiple sites require a Layer 3 router to prevent spanning tree issues.

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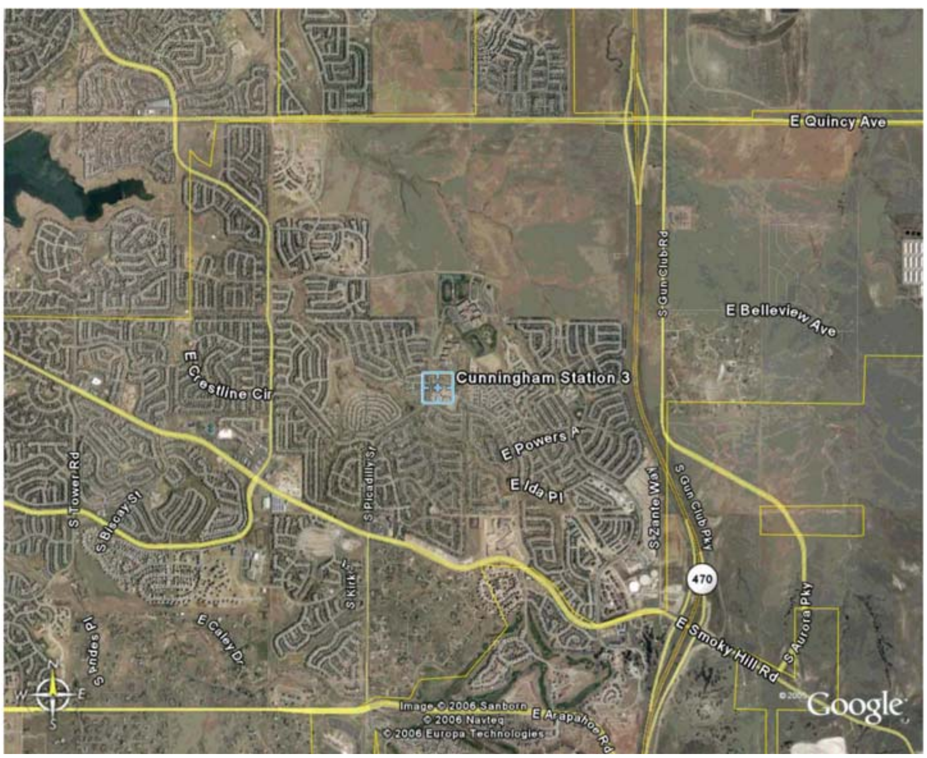
Chapter 7
Coverage in the Plains / Suburban
Cunningham Fire Station 3

Cunningham Fire Station 3 is located in a flat region in a typical suburban housing area. Picture 7.1 and 7.2 are satellite photos of the area and give a good indication of the type of topography and housing that is found in the area.

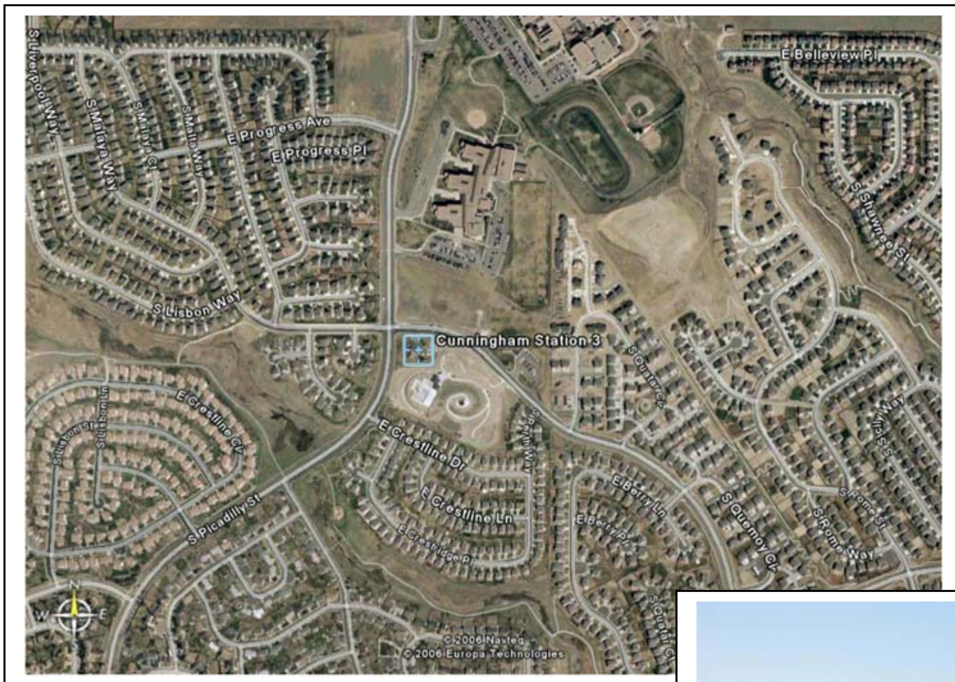
Summary

It was expected that the houses and trees would cause attenuation of the signal and limit the range for the AP, but it was not known how much impact would be seen.

The footprint was been very similar to what has been seen in other deployments without BDA's in the system – approximately 2 to 3 blocks radius around the AP, and then extended coverage in the line-of-sight directions down the streets. The study was done using an EIRP of about 31 dBm, with four 90° Til-Tek TA7904-14-90 sector antennas.



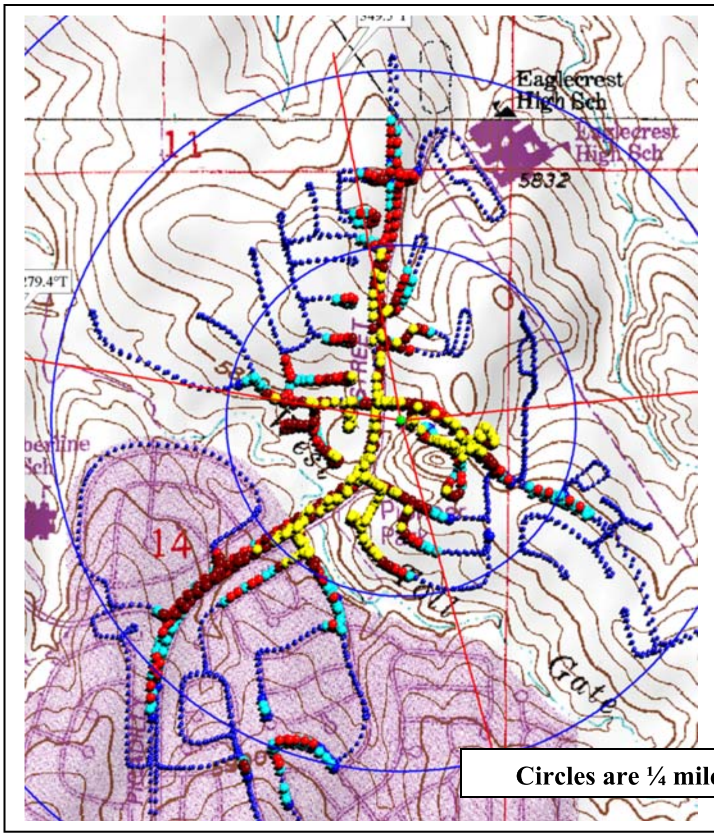
Picture 7.1 – Area around Cunningham Fire Station 03



Picture 7.2 – Zoomed in View of Cunningham Station 03

Picture 7.3 – Housing around Cunningham Station 06

Picture 7.4 – Housing around Cunningham Station 06



Circles are ¼ mile apart

Map 7.1 – Coverage around Cunningham Station 06

Deployment Summary

EIRP – 30.11dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted as shown in Map 7.1
Elevation – 25 feet AGL

Area is relatively flat with typical 2 story suburban housing.

Map Legend Mbps and Field Strength - Without BDA	Mbps	S/N	dBm
Dk Blue	no signal		-115
Lt Blue	unusable		<-95
Turquoise	marginal	1-4	-94 to -90
Red	3 to 4.5	4-7	-90 to -87
Orange/Brown	6 to 8	7-12	-87 to -82
Yellow	12 to 18	12-18	-82 to -76
Green	24 to 27	>18	> -76

Table 7.1 Map Legend

Project Name	The Colorado 4.9 GHz Project	
Test Date		
Study Area	Cunningham Fire Station 06	
Test Description	Test 156 and 157	
MAC Address for Fixed AP	multiple	
Deployment Number		
Frequency	4950	MHz
Sector Azimuth	multiple	Degrees
Site 1		
Latitude	39° 37' 7.4" N	
Longitude	104° 44' 17.09" W	
Elevation	5872.6	Feet AMSL
Elevation	25	Feet AGL

Table 7.2 – Site Information – Cunningham Fire Station 06

Transmitter	No BDA					
	Description	Value in dB	Qty.	Gain/Loss		Units
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	1	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrestor	Polyphaser	-0.1	0	0.00		dB
Coax - dB loss/100 ft	Eupen 1/2"	-0.0543	20	(1.09)		dB
Antenna	TA-5204-14-90-SP1 - 90° Sector	14.9	1	14.90		dBi
			EIRP	**30.11**		**dBm**

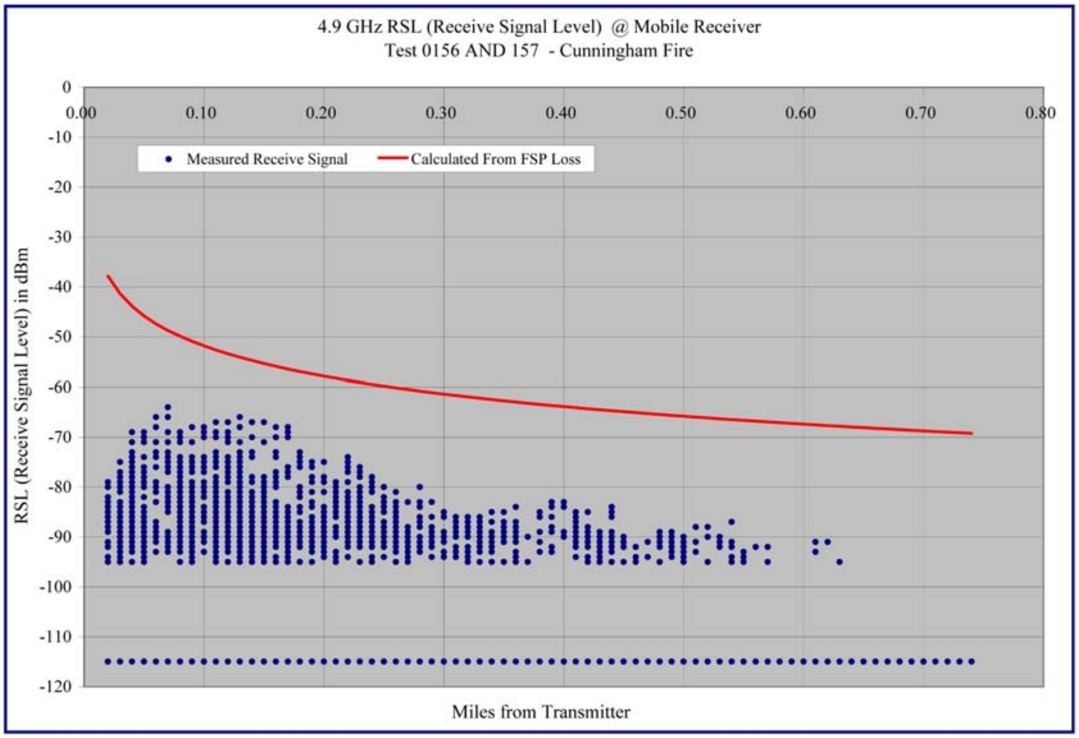
Table 7.3– Transmitter Specifications – Cunningham Fire Station 06

Receiver	No BDA					
	Description	Value in dB	Qty.	Gain/Loss		Units
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**127.41**		**dB**
	Maximum Range Assuming LOS			**7.04**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**7.41**		**dB**

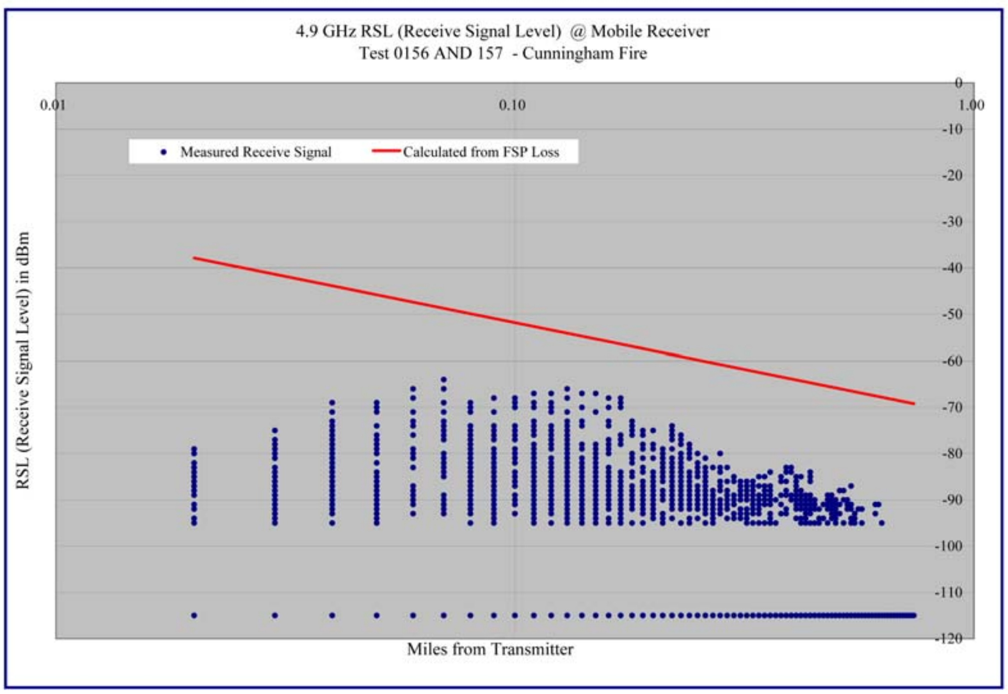
Table 7.4 – Receiver Specifications – Cunningham Fire Station 06

Graphs 7.1 and 7.2 show the receive signal level versus distance. Graphs 7.3 and 7.4 show path loss versus distance.

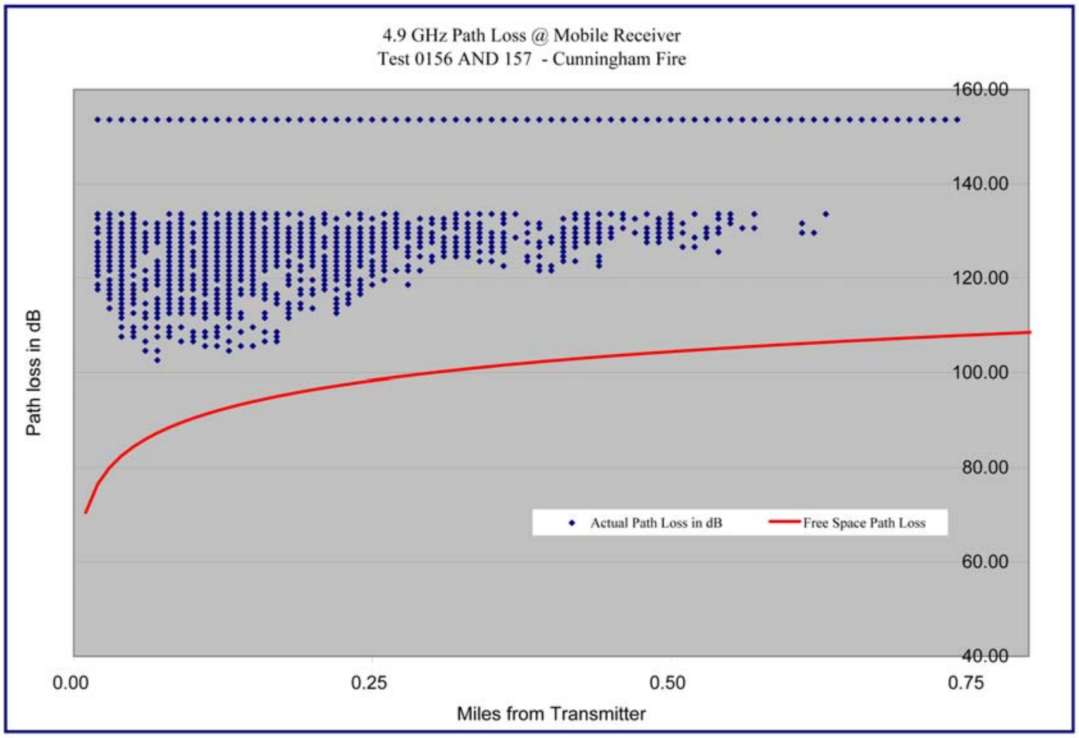
Graphs 7.3 and 7.4 are equipment independent and can be used in estimating path loss for similar installations.



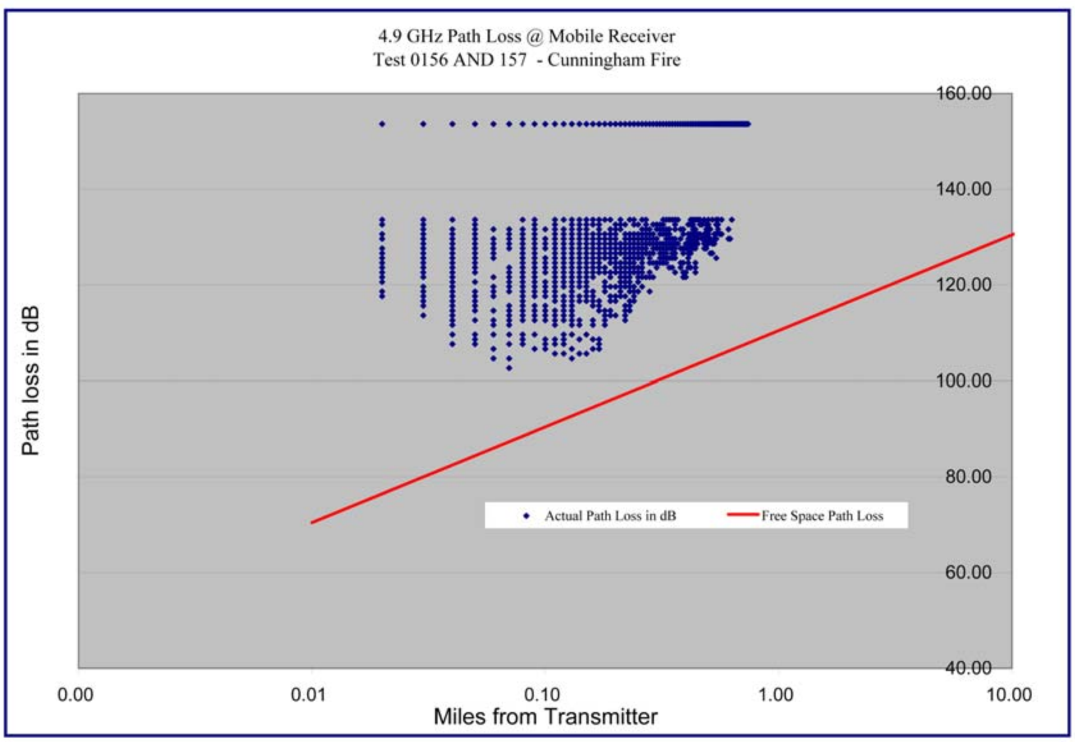
Graph 7.1 – Receive Signal Level versus Distance – Cunningham Station 06



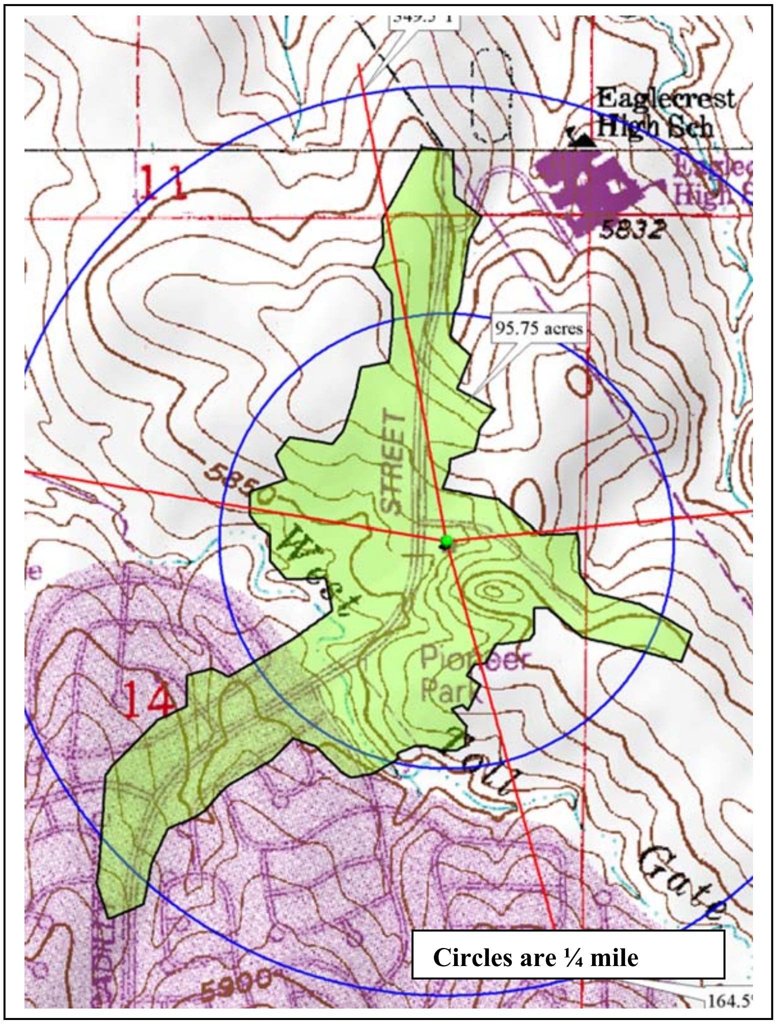
Graph 7.2 – Receive Signal Level versus Distance – Cunningham Station 06 – Log-Log Format



Graph 7.3 – Path Loss versus Distance – Cunningham Station 06



Graph 7.4 – Path Loss versus Distance – Cunningham Station 06 – Log-Log Format



Map 7.2 - Footprint from Cunningham Station 06

Map 7.2 shows the footprint for Cunningham Fire Station 06. The area covered is about 95.75 acres. This area is much smaller than was seen in the downtown dense-urban deployments in Denver, even though the elevations and EIRP were similar.

This deployment used high-gain Til-Tek 90° sector antennas and this increased the EIRP to an EIRP similar to the Denver Mobile Command Post deployment which also used sector antennas. Like the Denver deployment, no BDA's were used.

The trees and houses caused considerable attenuation, and after a few blocks, only line of sight coverage occured.

The majority of the coverage was within ¼ mile, although there was some coverage up to ½ mile from the portal location.

Summary

The coverage was very limited without the use of higher power access points and BDA's. Even without a BDA, this system exceeded the FCC EIRP for loose mask units. A 30% to 40% decrease in coverage would be expected if the EIRP were lowered from 31 to 26 dBm to meet current FCC regulations. An increase in coverage would be expected if BDA's were added to the receiver, as in the tests in downtown Denver. (Chapter 6).

Test Numbers	Station 03 156-157
Study No for this Chapter	**Study 1**
Deployment Parameters	
Bandwidth	10 MHz
Max Throughput Setting	Auto Fallback
EIRP	31.47
Antennas	omni
Topography	dense urban
Vegetation	almost none
Climate	arid
Vantage Point	35 ft AGL
Distance for Hot-spots in miles	
Maximum	9/16 mile
Minimum	0
Throughput - Mbps	
Maximum	24 to 27
Minimum	3 to 4.5
Path Loss Above Theoretical in dB	
Minimum	8
Maximum	24
Backhaul	
feasibility	may have backhaul
Deployment Type	
Point to Multipoint	yes
Hot-Spot	yes
Ad Hoc or Mesh	yes
Site Comparison	
Footprint	95.75 acres

Table 7.5 – Site Parameter Summary

Checklist for deployment in Suburban and Plains Setting:

- For deployment in suburban neighborhoods

  - Choose a sitethat higher – the top of a taller building, if possible
  - Do not expect ubiquitous coverage unless the density of the AP's in increased and they are deployed on street lights or something similar.
  - Make sure the AP's are above the clutter of the trees.
  - Make sure backhaul is available to the site.

- For deployment in plains or open areas

  - Choose a high site or hill that has a good vantage point
  - Make sure the AP's are above any clutter such as trees
  - Make sure backhaul is available to the site
  - Plan for hot-spot locations if needed

- Use predictive model such as Bullington or Longley Rice to the maximum footprint for the coverage. These models are tools that help evaluate topography. If there are obstruction files for the area (for buildings), this will increase the accuracy of the model. Note that these models do not present an accurate map of the final coverage, but are simply one of many tools that can be used to help in the final planning process.

  Before final deployment set up a temporary deployment and drive test the area and record the results. The results are best recorded with software that takes many readings per seconds so that the multipath and effects of Raleigh fading can averaged into a reading that is more reflective of the actual results.

  Proper and professional installation is critical to satisfactory performance.

  Networking of the system is CRITICAL. Multiple sites require a Layer 3 router to prevent spanning tree issues.

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Chapter 8
Coverage in the Plains and Foothills
Parker Fire Protection District

The studies at Parker Fire were designed to perform applications testing and to test the feasibility of a deployment with multiple overlapping sites and with ad-hoc or meshing, as a supplement to existing coverage.

Parker Fire Protection District lies in the foothills of the Rocky Mountains. It has rolling hills, flat areas, and was bordered by bluffs on the west and a ridge to the north and east. In the center of the district Bradbury Hill, a high point in the center of the District.

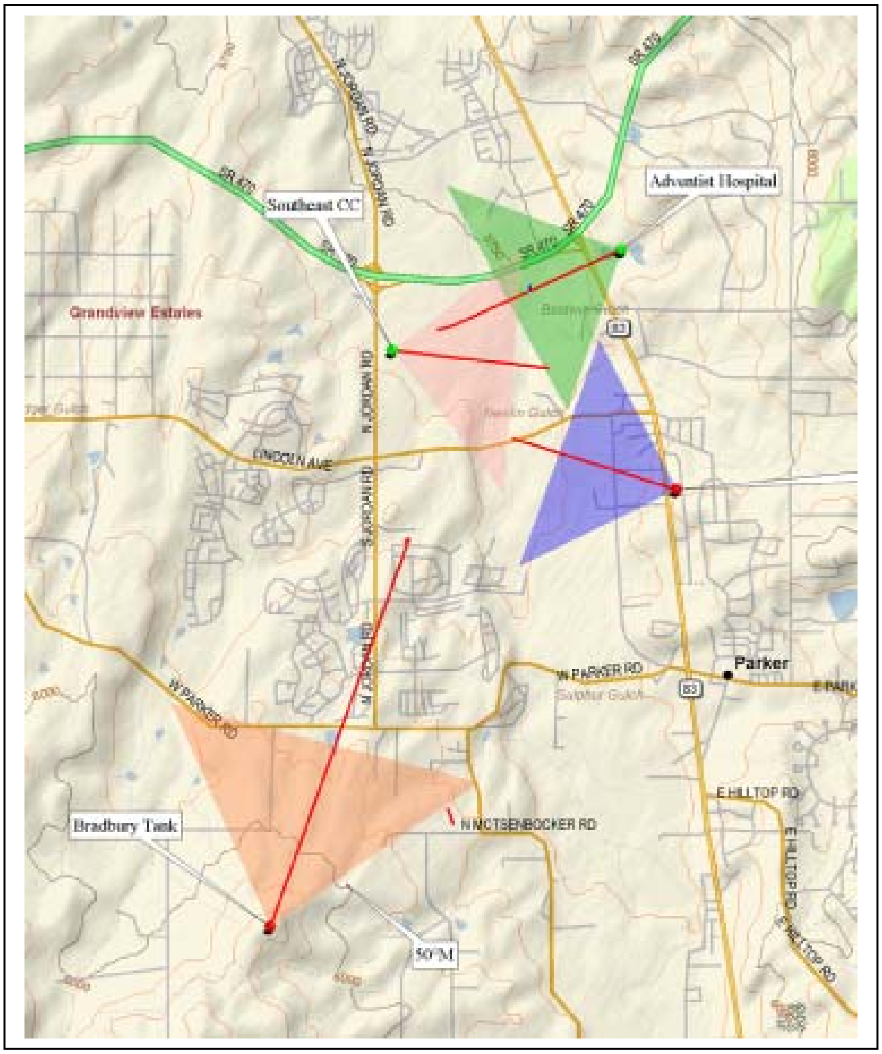
The District is bounded by I-25 on the west. E470 passes through the northern third of the District. Parker Road is the main north-south thoroughfare in the District, and Lincoln Avenue is the main east-west thoroughfare. The District would like to have coverage on E470, Parker Road, and Lincoln Avenue. To the West of the District between the populated area and I-25 is a series of bluffs.

The main approach to Centennial Regional Airport is over these bluffs, and for some reason, there have been a large number of small plane crashes in these bluffs. Currently there are no roads or communications in this area. One of the goals of this portion of the testing is to see if ad-hoc or mesh coverage can be used to reach these inaccessible areas and provide a way to get video back to the mobile command post. It is not feasible to try to install permanent coverage in this large uninhabited area – but temporary coverage is needed for these incidents.

Picture 8.1 shows a satellite photo of the entire area. There were four sites included in the study for the portal units: Parker Administration Headquarters, Bradbury Tank, Southeast Christian Church, and Parker Adventist Hospital. Antennas for these four sites were pointed in toward the center of the district, and only one 90° Sector antenna per site was tested during the composite coverage tests. This area was driven twice – once with a BDA (Study 1) and once without a BDA (Study 2).

Summary

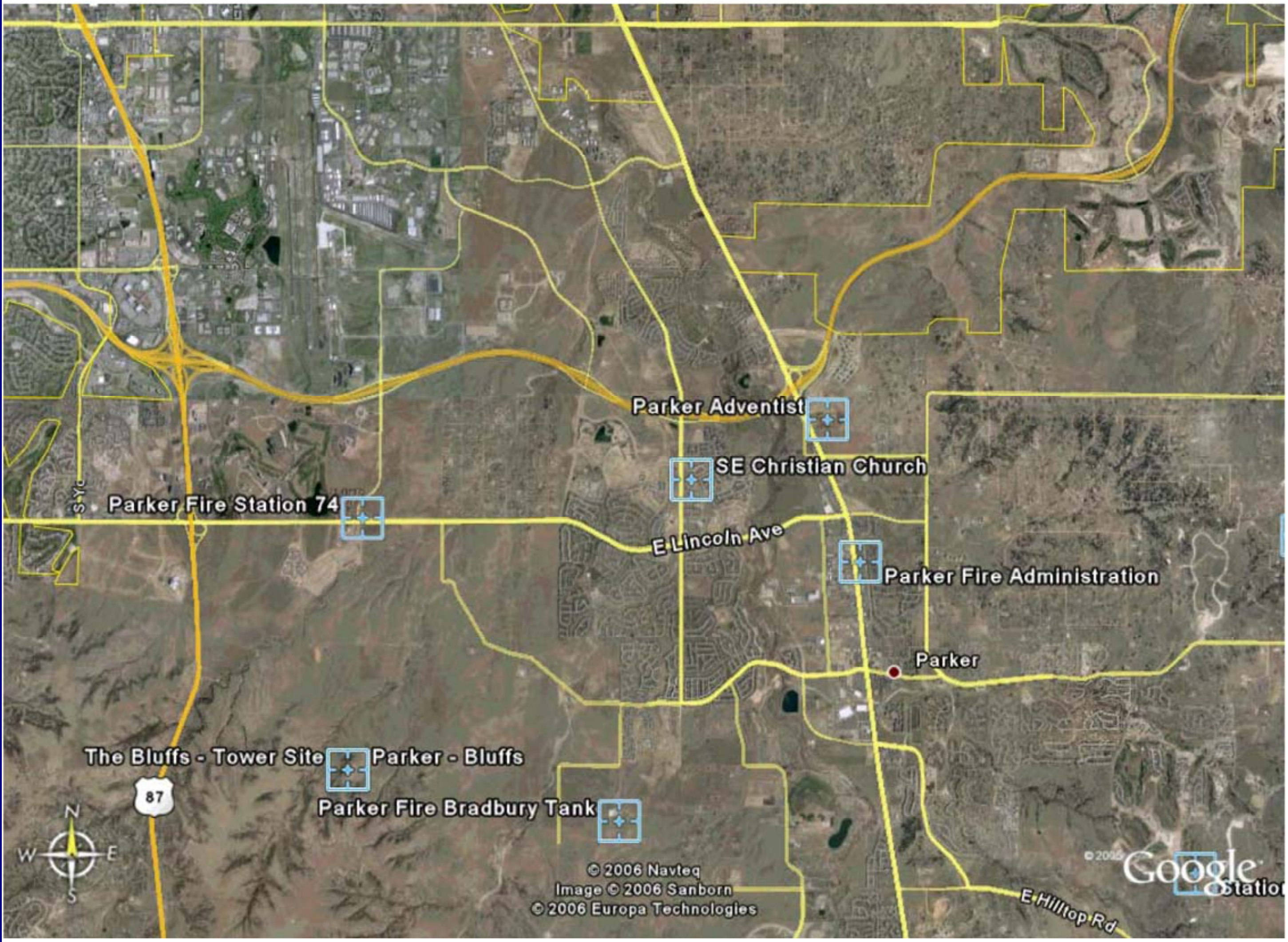
During the drive tests, the mobile AP was able to record information simultaneously from all portal access points at the four different locations. Two composite coverage maps (one with mobile BDA and one without the mobile BDA) were prepared to show what the coverage was from these four sites provide for the target area. Since the effect of having a BDA on both ends was studied in the downtown Denver testing, this test was run with a BDA only in the mobile unit.



Map 8.1 – Parker Application Testing – Final 90° Sector Deployment

Most of the target area was residential with two and three story homes, townhouses, and apartments. There were some light industrial as well as shopping areas. There were also large open spaces, which have no construction. Picture 8.2 is a satellite photo of the area.

It was expected that the four sites would cover a substantial portion of the target area collectively, since each site looks into the area from a different direction. It was hoped that this would mitigate some of the losses caused by the homes and trees, since each portal would have a different antenna azimuth. The four sites were chosen because of their height and location.



Picture 8.1 – Satellite Photo of Parker Fire Protection District

Initial Coverage Testing – Studies 1 and 2

The initial test plan was to use the existing 5.8 GHz unlicensed backhaul to bring the signals back into the headquarters building to a temporary server which was separate from the Department's secure network. The purpose was to determine how completely the test area could be covered from the four sites (Bradbury Tank, Administration, Southeast Christian Church, and Parker Adventist Hospital).

Study 1 was done using a mobile BDA, Study 2 was done over the same area without a mobile BDA. In both studies, the drive test data was simultaneously collected from all four AP's. Then the data points were aggregated into one map showing the coverage. The best coverage for each point was the top layer, so the result was a composite map, which showed collective coverage from all four sites.

As expected, the target area was very well blanketed. During Initial drive tests with the BDA in the mobile, one of the AP's was almost always actively associated, and frequently more than one of the AP's were associated. As expected, coverage decreased. What was a surprise was the magnitude of difference. With the mobile BDA 6.82 square miles had coverage. Without the mobile BDA only 3.00 square miles had coverage.

The test without the BDA in the mobile had a footprint that was only 44% of the size of the footprint with the BDA in the mobile. Since the downlink was the same in both tests, the difference was due to the increased receiver sensitivity in the mobile that was caused by the BDA. This increase in sensitivity was documented by bench testing done by KNS under the supervision of Frank Pratte, P.E., of Pericle Communications.

Unexpected Problem flags importance of IT Department Involvement

One unexpected event occurred which should alert all potential users about how important it is to have the IT department's involvement in the system network development.

Because the coverage was better than expected, the mobile AP was able to respond to multiple portals at one time – the result was a spanning tree problem. In simple terms, a spanning tree problem occurs when the network gets multiple inputs from the same unit through different routes. There is no "time to live" limitation on these Ethernet packets, so they end up in a continuous loop, causing a broadcast storm, which eventually overwhelms and shuts the entire network down.

The IT department evaluated the problem and it was determined that layer 3 routers would be required to solve the issue. These were not included in the grant equipment, so an alternate plan for testing was implemented. This plan would simulate the first test, but would require post-processing of the collected data to determine the coverage footprint.

Application Testing

The final six studies were designed to test the feasibility of various applications, including tested the ability of the system to transfer large files and streaming video, the ability to handle the Fire Manager Database program files on line, and the ability to access to the internet. Both 10 MHz and 20 MHz bandwidths were tested.

While the 20 MHz bandwidth provided much faster throughput, its range was severely limited and would be appropriate only for hot spot type applications. The system easily handled all of these applications at the 10 MHz bandwidth, including one file that was over 54 megabytes in size.

Testing Ad-hoc (Mesh) for Applications

The final application testing was the ad-hoc or mesh testing. The purpose of this testing was to determine if the system could be successfully extended beyond the coverage area by the use of ad-hoc or mesh, and still handle the various applications. Ad-hoc or meshing is where one mobile AP transmits to another mobile AP, which transmits to another mobile AP, etc.

The number of hops that could be sustained through meshing was not known, although it was know that each hop would result in a throughput reduction of 50% plus overhead from the throughput of the previous hop. What other limitations would be encountered was not know.

During testing it was discovered was that, the equipment limited the hops to four hops. More surprising was the fact that if one of the antennas on either end was less than 10 feet above ground, the distance of that hop was severely limited to less than .2 or .3 of a mile. Some research through IEEE's papers resulted in a paper by Green and Obaidat. In this paper, they discuss the problem with antenna height and the reduced path length distances. They proposed a new formula to calculate path loss for Ad-Hoc propagation in Wireless LAN (WLAN) devices.[1]

$$P_{Loss} = 40 \log_{10} + 20 \log_{10} F - 20 \operatorname{Log}_{10} H_t H_R$$

The decreased path length based upon the height of the antennas was certainly consistent with what was observed during the testing.

Regardless of which hop was studied, if the antennas were high off the ground, the distance of the hops varied, but one hop was over 4.74 miles in length, with the subsequent hop being .19

[1] Green, D. and Obaidat, M., *An Accurate Line of Sight Propagation Model for Ad-Hoc 802.11 Wireless LAN(WLAN) Devices.* 2002. Manmouth University. W Long Beach NJ.

miles because both antennas were vehicle mounted. Where the antennas were both off the ground, one of the 3rd hops in the ad-hoc system was a length of 2.05 miles. The fourth hop was .35 miles, again because both antennas were vehicle mounted and close to the ground.

The third observation was that the AP's were intelligent enough to determine link costs (losses), and dynamically reconfigure as the AP's moved from location to location, to chose the least cost routing. This reconfiguring did not affect performance and occurred seamlessly without any operator intervention.

In conclusion, it is obvious that for ad-hoc systems to work, at least one of the antennas must be raised at least 10 feet above ground level. Otherwise, the cost is a severe reduction in range.

Point to Point Testing

A microwave point to point was also test to see how the backhaul would work. Ceragon provided the microwave link and MWave provided the microwave antennas. The system worked seamlessly.

Since the point-to-point links are secondary[2] to the point-to-multipoint mobile systems and ad hoc systems, it was important to know if a point-to-point system would cause interference to the mobile units.

A narrow beam-width mWave microwave dish was mounted on one end of the link and a sector antenna on the other end of the link. The entire path was driven with a mobile AP to see if there was any interference or degradation to the mobile AP. None was observed.

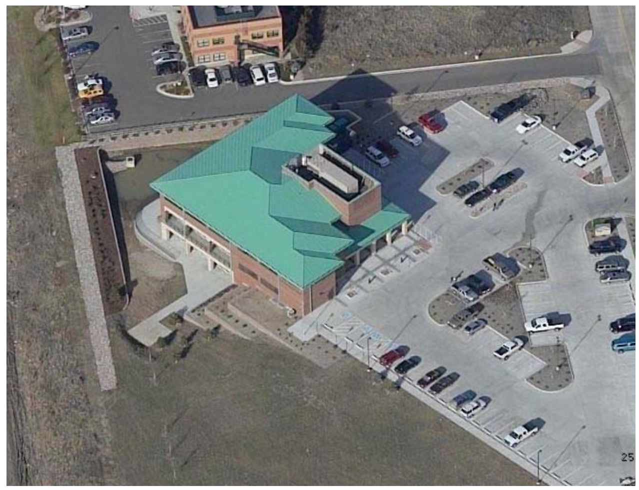
It is recommended that only microwave dishes be used for point-to-point links unless it is a temporary installation deployed for an incident. This will provide isolation and help mitigate any interference. The FCC requires site by site licensing for any permanent point-to-point microwave links. Only temporary links are allowed under the general 4.9 GHz license.

[2] A secondary system must mitigate any interference caused to the primary system, or the FCC will require that its use be discontinued. Since point-to-point 4.9 GHz links are secondary, they must be configured so they will not cause interference to mobile systems.

Parker Installation and Deployments

The Parker Deployment was by far the most challenging. Brett Bonomo donated countless hours on behalf of Proxim in an effort to make The 4.9 GHz Colorado Project a success.

Picture 8.2 - Brett Bonomo
Proxim Field Service Engineer



Picture 8.3 – Parker Admin Roof Deployment

Picture 8.4 – Antennas, Administration Roof

Picture 8.5 – View from Parker Administration

Picture 8.6 – Parker Adventist Hospital

Picture 8.7 – View from Parker Adventist Hospital

Picture 8.8 – Bradbury Tank

Transmitter	**No BDA**					
	Description	**Value in dB**	**Qty.**	**Gain/Loss**		**Units**
Power Out	Proxim AP4900 M			16.50		dBm
Amplifier Gain	Linx BDA	10	0	0.00		dB
Connector Loss		-0.1	2	(0.20)		dB
Lightning Arrrrestor	Polyphaser	-0.1	1	(0.10)		dB
Coax - dB loss/100 ft	LMR-600 6	-0.066	6	(0.40)		dB
Antenna	Til-Tek 90 Sector TA-4904-14-90	NA	NA	14.90		dBi
			EIRP	**30.70**		**dBm**

Table 8.1 – Portal Specifications

Receiver	With BDA					
	Description	Value in dB	Qty.	Gain/Loss	_	Units
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				8.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(92.00)		dBm
	Maximum Path			**140.00**		**dB**
	Maximum Range Assuming LOS			**30.00**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**20.00**		**dB**

Table 8.2 – Receiver Specifications with BDA

Receiver	Without BDA					
	Description	Value in dB	Qty.	Gain/Loss	_	Units
Antenna Gain	Mobile Mark EC09-4900PT			7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0	1	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP				10.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA				10.00	dB
Required S/N for lowest bit rate	From 802.11 standard				4.00	dB
Receiver Sensitivity	Calculated			(90.00)		dBm
	Maximum Path Loss			**138.00**		**dB**
	Maximum Range Assuming LOS			**23.83**		**miles**
Path Loss and Loss Margin						
Path Length				3.00		miles
Free Space Path Loss	Calculated			120.01		dB
	Excess Path Loss Margin [Fade Margin]			**18.00**		**dB**

Table 8.3 – Receiver Specifications without BDA

Table 8.1 gives the transmitter parameters for the four AP's which were deployed in Parker for the final testing. Table 8.2 gives the specifications of the mobile receiver with a BDA, and Table 8.3 gives the specifications of the mobile receiver without a BDA. For the receiver with the BDA, the maximum line of sight (LOS) coverage is 30 miles, while the maximum line of sight for the receiver without the BDA was only 23 miles. This is a difference of approximately 33%, and is consistent with the calculations for the Denver testing.

During the testing, this difference in coverage was confirmed. The receiver with the BDA had a coverage footprint of 6.82 square miles, while the receiver without the BDA had a coverage footprint of 3 square miles.

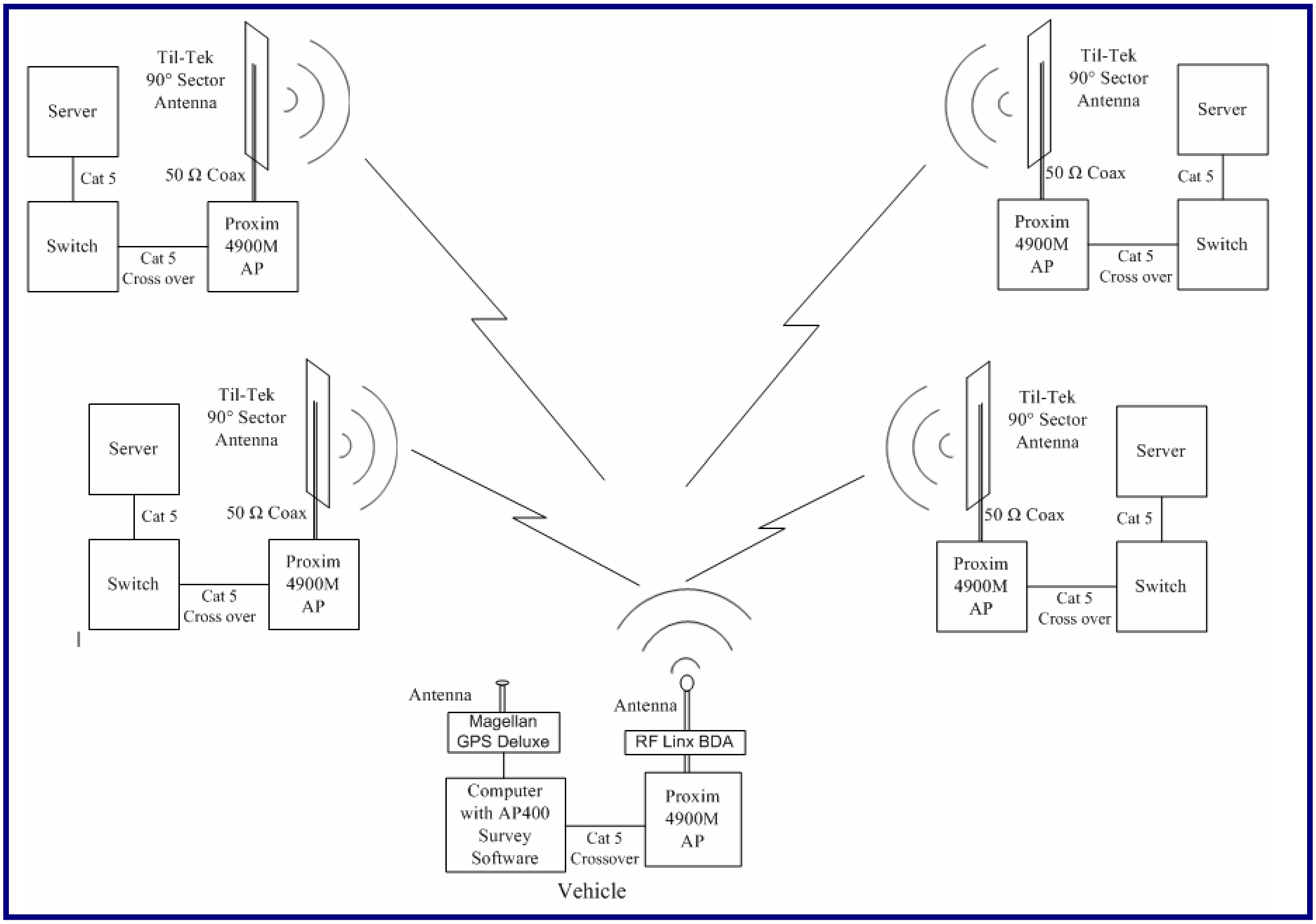


Figure 8.1 – System Diagram showing Deployment During Study 1 and Study 2

Data Collection

The drive test data was collected using proprietary software[1], which records SNMP readings received by the mobile AP. Although many readings were collected using the MIB's in the AP's software, the RSSI reading was specifically collected to measure the field strength. Considerable bench testing was done to confirm the nature of the "RSSI" reading.

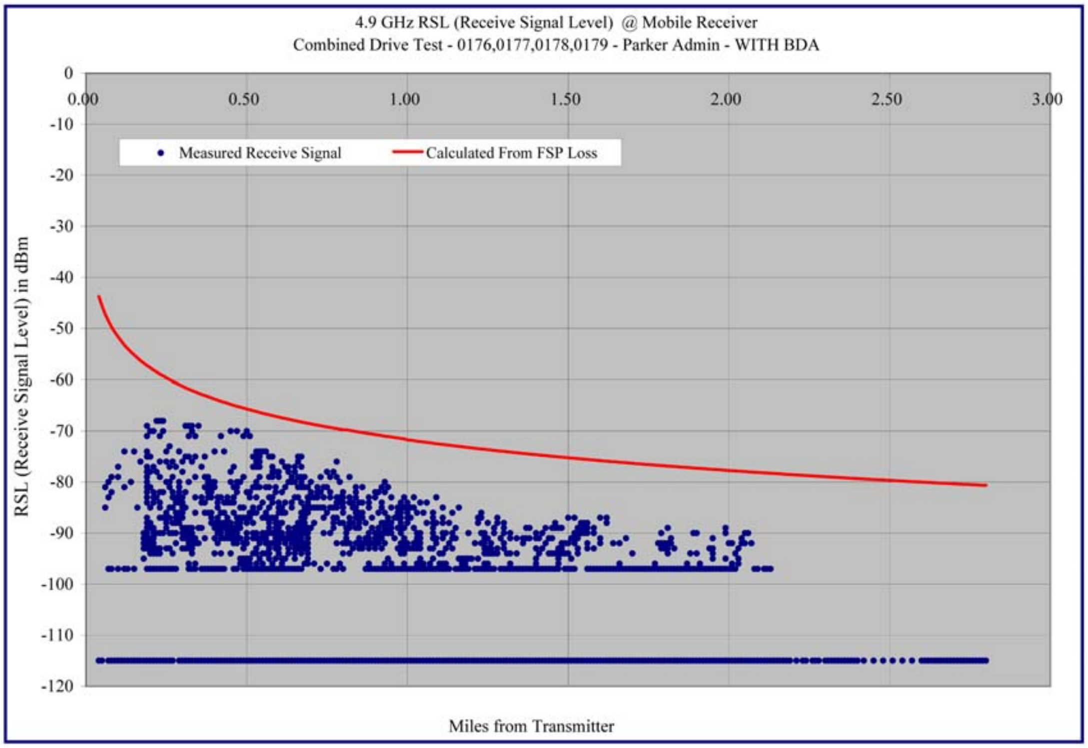
After consulting with Atheros (the chipset manufacturer) and with Proxim (the AP manufacturer), and after evaluating the bench-test measurements, it was determined that the RSSI readings approximated SNR (signal to noise ratio). Extensive bench test measurements[2] determined two algorithms to use to convert the RSSI to field strength measurements in dBm.

With a BDA: SNR = ((.9679)(pwr in dBm) + 94.186)
Without a BDA: SNR = ((.9679)(pwr in dBm) + 92.186)

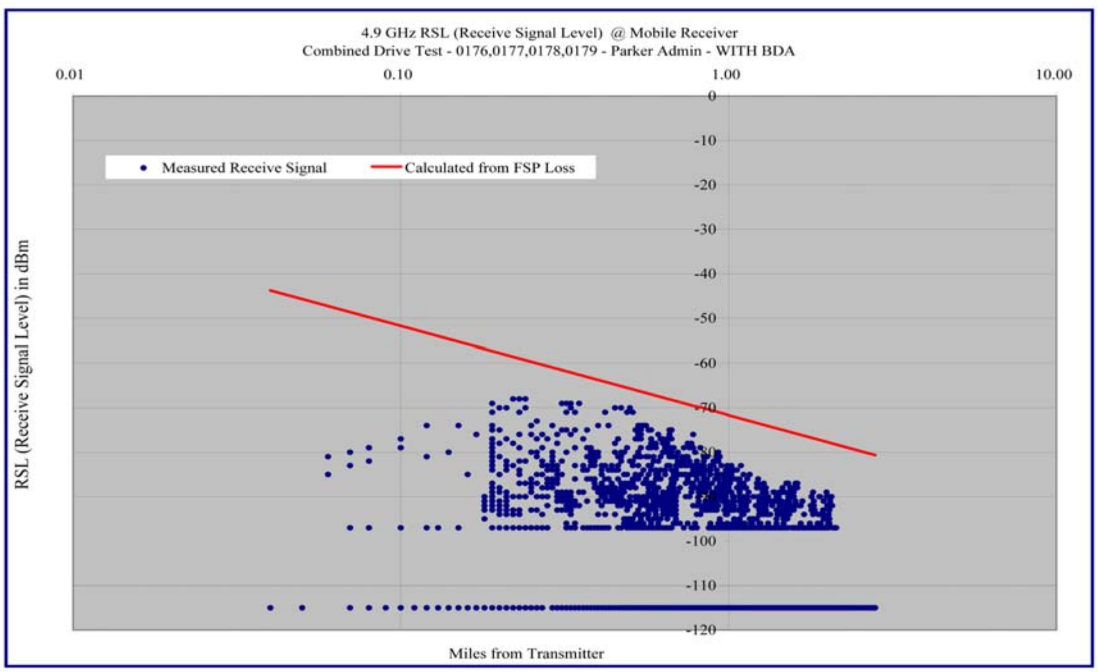
The AP Survey Software can take simultaneous readings from multiple AP's. The scan rate is adjustable, and for the purposes of this test, the scanning was done every 20 ms. The raw RSSI readings were recorded and logged. A Magellan Deluxe 5 GPS was connected to the computer, and the GPS time stamp, the computer time stamp, and the GPS coordinates, the RSSI readings, and multiple other readings including the MAC address of the transmitter are recorded in a comma delimited file.

Scatter graphs from the Parker Administration building has been shown below. The scatter graphs follow the predicted theoretical performance closely.

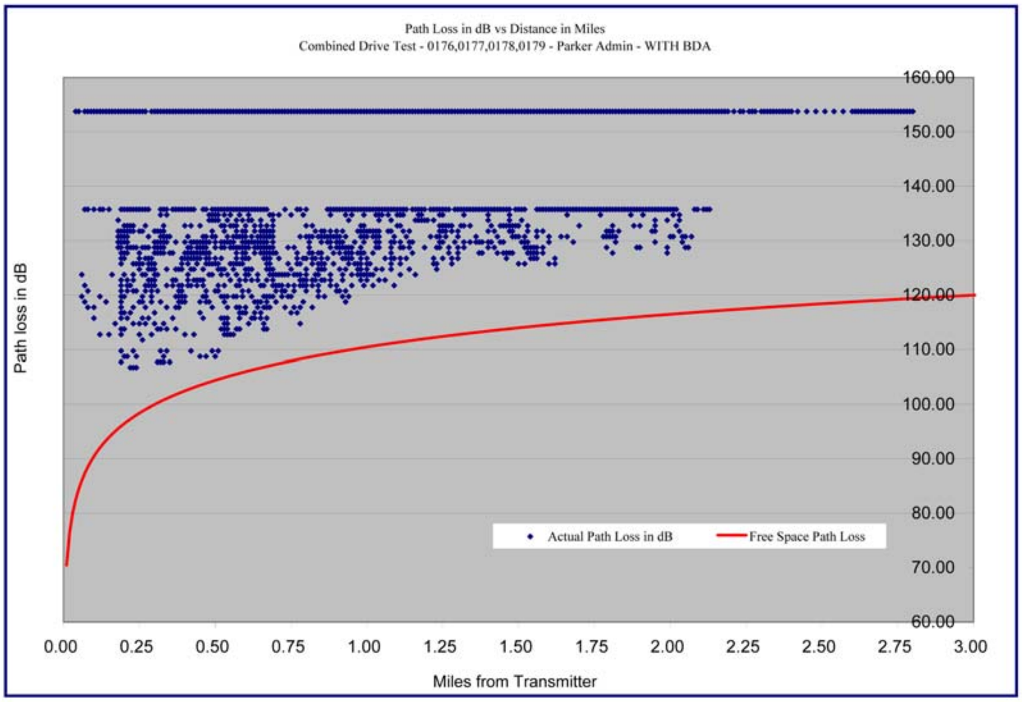
[1] owned by Pericle Communications.
[2] See the engineering evaluation report for detailed testing specifications.



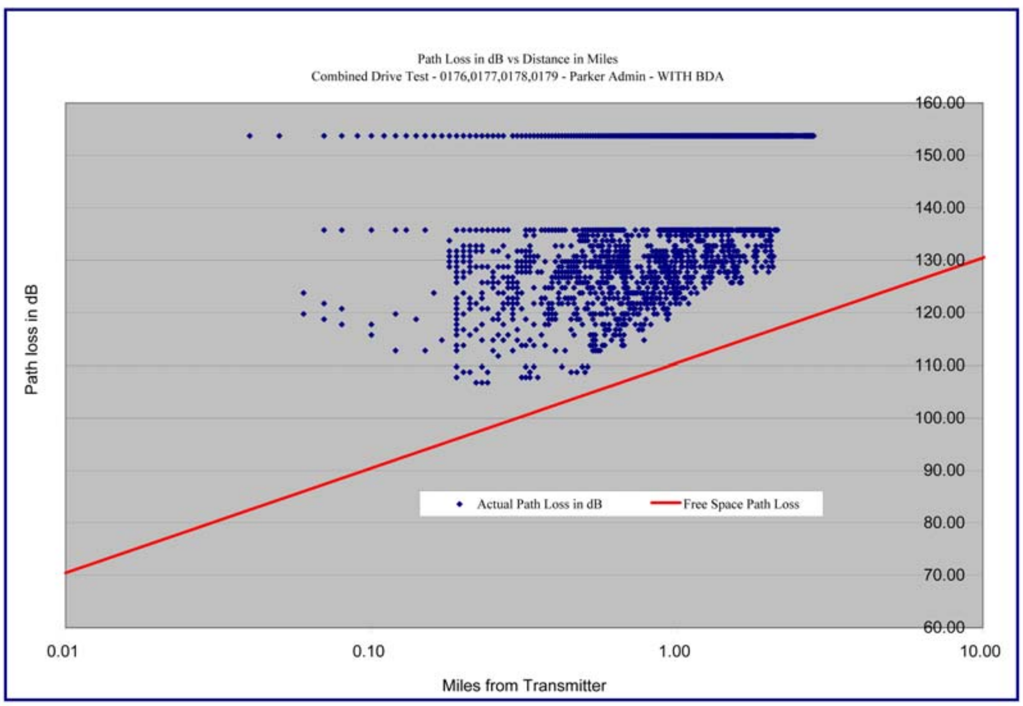
Graph 8.1 - Field Strength vs Distance-With mobile BDA - Parker Administration Bldg.



Graph 8.2 - Field Strength vs Distance-with mobile BDA – Log-Log Format - Parker Administration Bldg.



Graph 8.3 – Free Space Path Loss vs Distance – Parker Administration



Graph 8.4 – Free Space Path Loss versus Distance – Log-Log Format – Parker Administration

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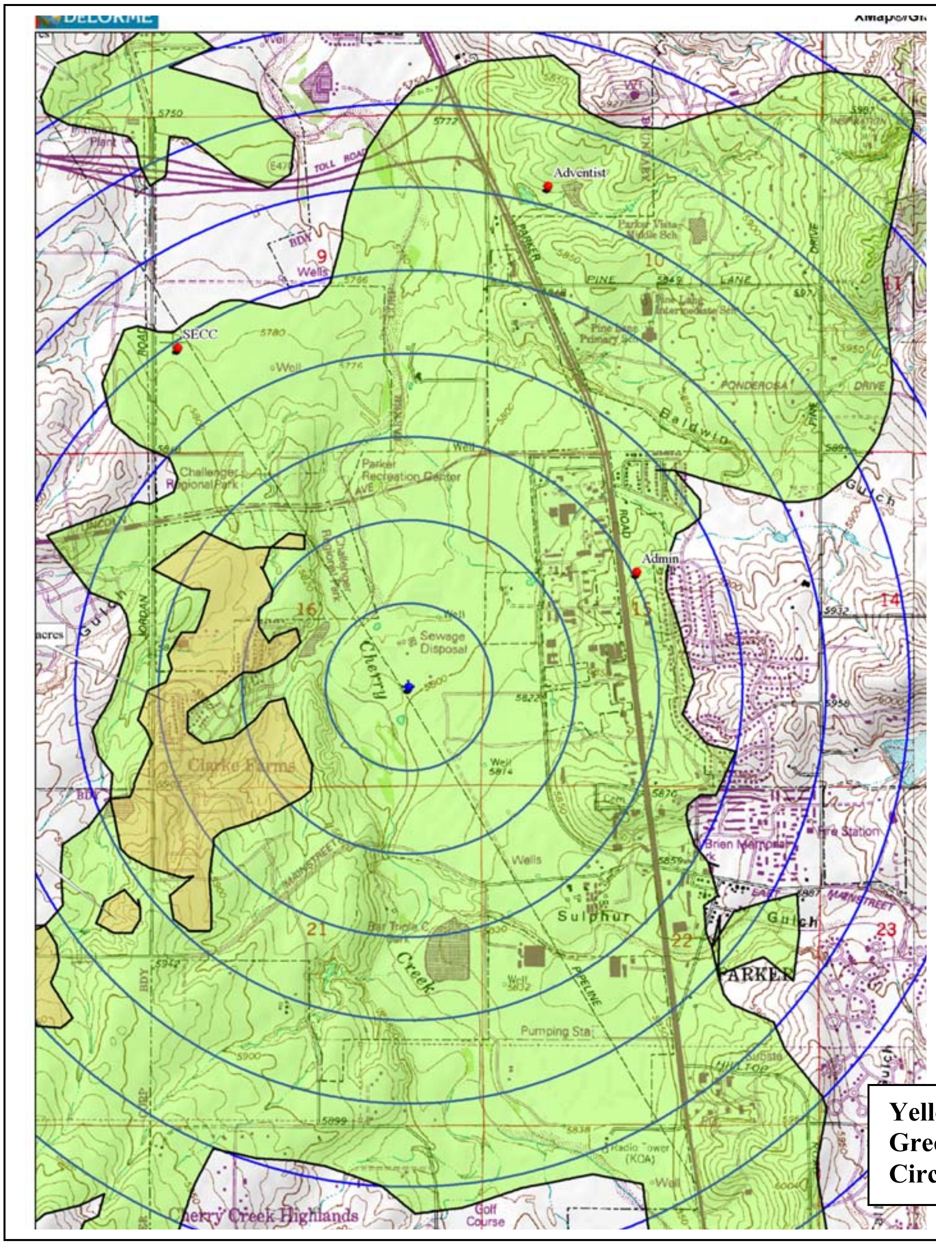
Study 1
Coverage with BDA in the Mobile – 4 Fixed AP's
Parker Fire Protection District



Map 8.2– Coverage Footprint – Parker Composit

Yellow – No Coverage
Green – Coverage
Circles – ¼ mile

Deployment Summary

EIRP – 30.70 dBm
Portal has no BDA
Mobile has BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted
Parker Administration – 45 ft AGL
Bradbury Tank – 12 ft AGL
Adventist Hospital – 75 ft AGL
Southeast Christian – 40 ft AGL

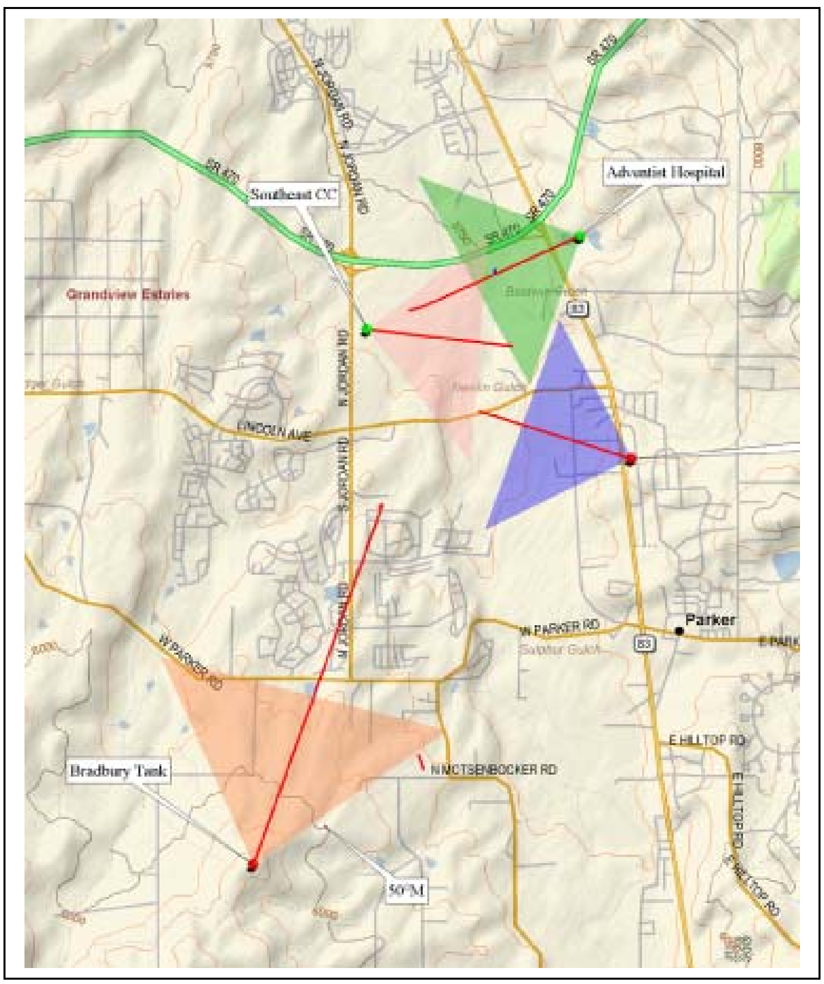
Footprint: 6.82 square miles

The four AP's working together provided considerable coverage for the District. All AP's had high advantageous locations and overlooked a large valley or bowl.

The areas that did not have coverage were within the residential housing where the streets twisted and turned rather than running straight toward one of the AP's.

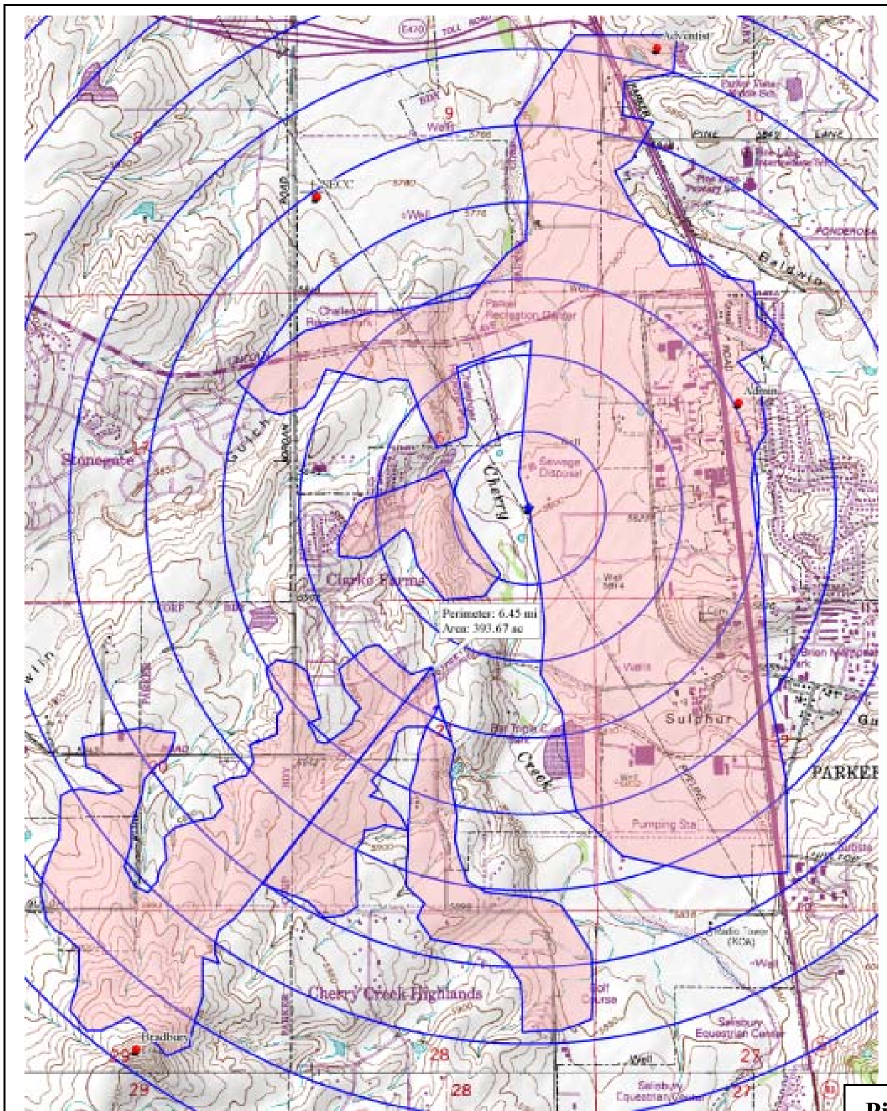
The testing for Study 1 involved AP's located at the Administration Building, Bradbury Tank, Southeast Christian Church, and Parker Adventist Hospital. For this test, a BDA was installed in the mobile. The four locations had the same SSID or network identification, and only one AP from each site was used. The antenna configuration is shown in Map 8.2. Each AP had a Til-Tek 90° sector deployed. The colored triangles show the 3 dB beamwidth for the antennas, and the orientation of the antennas for the testing.

The footprint was 6.82 square miles. The only areas where coverage was an issue was within some of the residential neighborhoods where the streets twisted and turned, and so prevented any of the four portal AP's from having coverage.



Map 8.3– Antenna Orientation for Parker Drive Testing

Study 2
Coverage without BDA in the Mobile – 4 Fixed AP’s
Parker Fire Protection District



Map 8.4 Coverage footprint for Mobile without BDA

Pink – Coverage
Circles – ¼ mile

Deployment Summary

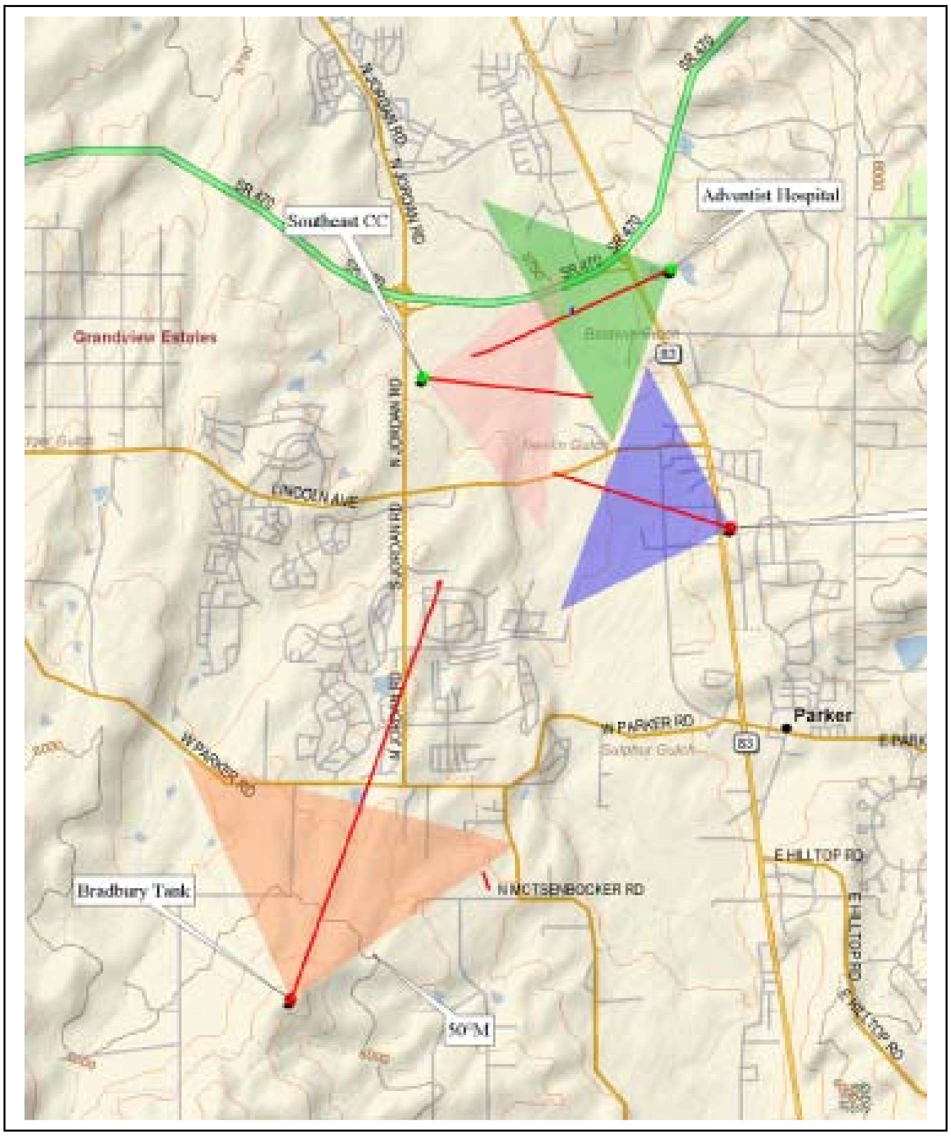
EIRP – 30.70 dBm
Portal has no BDA
Mobile has no BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted
Parker Administration – 45 ft AGL
Bradbury Tank – 12 ft AGL
Adventist Hospital – 75 ft AGL
Southeast Christian – 40 ft AGL

Footprint: 3.00 square miles

The four AP’s working together provided considerable coverage for the District. It must be remembered that all AP’s had high locations and overlooked the valley.

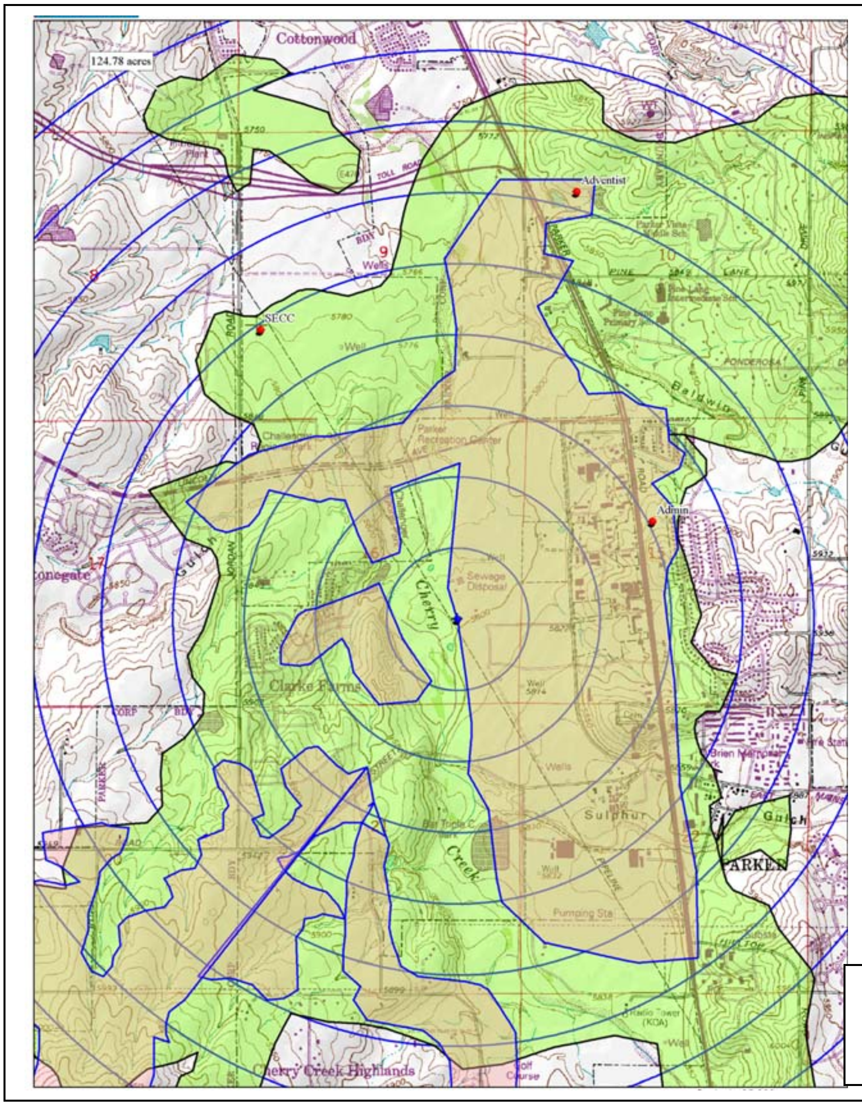
The coverage without the mobile BDA was less than ½ of the coverage with the mobile BDA!

The loss in coverage when the area was driven without a mobile BDA was dramatic! The new footprint is less than ½ the size of the footprint with the mobile BDA. The same equipment at the portal was used for both tests, so the EIRP for the downlink was the same. Since this is only testing the downlink, <u>the loss in coverage is not due to the amplification of the transmitter in the mobile unit, but to the decreased receiver sensitivity because of the BDA was not present</u>. This receiver sensitivity change was documented with bench testing done by KNS under the supervision of Frank Pratte, P.E., of Pericle Communications..



Map 8.5 – Antenna Deployment for Test 1 (with BDA) and Test 2 (without BDA)

Summary of Study 1 and 2
Coverage with BDA in the Mobile – 4 Fixed AP's
Parker Fire Protection District



Green with mobile BDA
Yellow – without mobile BDA
Circles – ¼ mile

Map 8.5 – Footprint of Coverage in Parker

Deployment Summary

EIRP – 30.70 dBm
Portal has no BDA
Mobile has BDA
Portal Antennas - Sectors
Four 90° Til-Tek 4904-14-90
Mounted
Parker Administration – 45 ft AGL
Bradbury Tank – 12 ft AGL
Adventist Hospital – 75 ft AGL
Southeast Christian – 40 ft AGL

Footprint with mobile BDA
6.82 square miles
Footprint without mobile BDA
3.00 square miles

The four AP's working together provided considerable coverage for the District. It must be remembered that all AP's had higher elevations and overlooked the valley.

The coverage without the mobile BDA was less than 50% of the coverage with the mobile BDA!

The coverage without the BDA in the mobile was 50% that of the coverage with the BDA in the mobile. Since the EIRP was the same for both tests, and the tests were measuring the downlink, it was obvious that the 2 dB improvement in receiver sensitivity in the mobile was responsible for the dramatic coverage difference.

Test 110A was plotted with EIRP at 26 dBm (the FCC levels) and with an EIRP at 31 dBm. The loss in coverage was over 50%!. If the power were reduced in this test from the 30.7 dBm to 26 dBm, a similar loss in coverage would be expected.

The low EIRP for the loose mask radio does not provide enough power to provide sufficient coverage to allow cost-effective deployments. If the proprietary tight mask radios are used, the cost is also much higher. Because the purpose of this spectrum is to enable emergency responders to be able to deploy broadband wireless, it would make sense to enable this deployment by allowing off-the-shelf non-proprietary loose-mask radios to be used. The economies of scale will allow widespread deployment.

Several times in this document the NPSTC study has been referred to, which clearly states that the loose mask will not cause a significant degradation in performance.

The FCC is urged to reconsider their current EIRP restrictions on the loose-mask radio.

Application Testing

Application Testing Goals

The stated objectives for the 4.9 GHz Colorado Project include the evaluation of whether the 4.9 GHz mobile broadband can be successfully deployed for use by emergency-responders and public safety personnel, and what criteria need to be considered for a successful system deployment.

The propagation characteristics of the 4.9 GHz frequency band were documented in a number of different scenarios, including mountainous terrain, foothills, and plains, urban and suburban environments. The final testing specifically is addressing the following issues:

- The ability of the 4.9 GHz Access Points to mesh from one to another
- The ability to "extend" the coverage from the portal AP to other AP's which are not within the coverage area of the portal AP through the meshing algorithms.
- The embedded intelligence in the AP's which enables them to choose "best route" and to evaluate path costs.
- Hop latencies
- Throughput costs for each additional hop when meshing is enabled
- The maximum number of hops
- The effects of antenna elevations on the hop performance and distance
- The effects of field strength on the size of file which can be transferred
- Evaluate quality of streaming video
- What sizes of files which the system can handle, and approximate time to open these files

The final application testing was done in the Parker Fire Protection District. Based upon the propagation studies done in the other environments and topographic regions, the results from the application testing can be extended to the other environments and topographic types. Each of the different studies looked not only at terrain and topography, but also at specific characteristics of 4.9 GHz propagation.

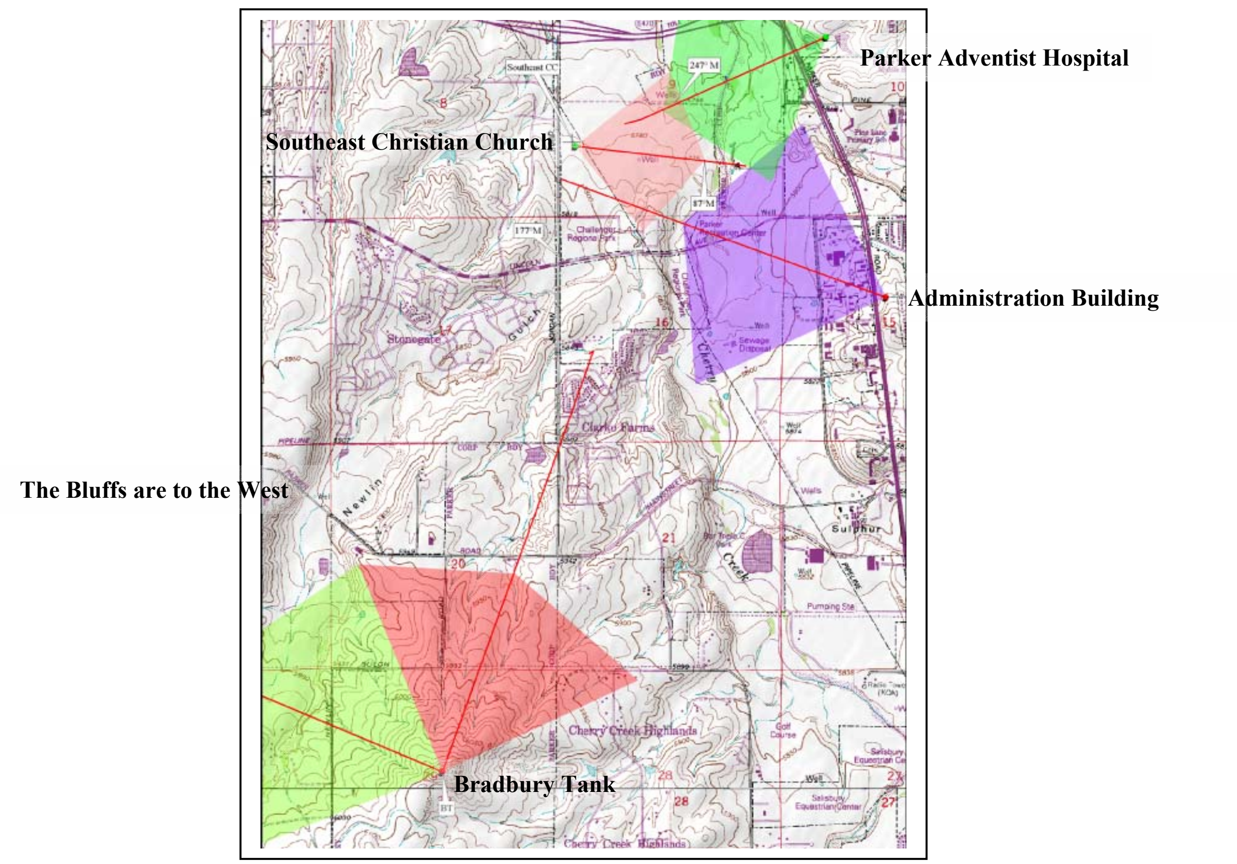
Methods:

AP Deployment:

Five (5) AP's were deployed in the Parker Fire Protection District area of coverage.

- One was deployed at the Administration building where the server is located
- One was deployed at Parker Adventist Hospital.
- One was deployed at Southeast Christian Church.
- Two were deployed at the Bradbury Tank

Two antennas were deployed at Bradbury Tank because it is the closest to "The Bluffs", in the approach pattern for Centennial Airport. The Bluffs have had numerous small airplane crashes n this approach pattern. The Bluffs are very remote and have no roads or electricity. Broadband coverage is badly needed in this area to help with incident management. .



Map 8.5 – Antenna Deployment for Application and Ad Hoc Testing

During the mesh testing, the two AP's at Bradbury tank mesh together by RF[1] over the air, rather than by a physical connection

The testing was designed to check the ad-hoc meshing capabilities of the system. The final group of tests was designed to test specific applications unique to emergency responders and to see if the applications can be successfully opened and used over the wireless network.

Deployment Details:

Detailed deployment information for all tests is listed in Appendix A.

Test Descriptions:

There were 6 subtests, which were run to help determine the various capabilities of the system. The following diagram is a basic representation of the setup used for these tests. There will be variations in the number of hops, and in one test the second and third AP's in the hop are actually fixed AP's located at Bradbury Tank. Maps will be used to demonstrate the details of each test.

The camera was located in Vehicle 3.

For two vehicles to "mesh" together, either one of the vehicles must have a connection back to the Portal AP, directly, or through other hops that mesh together. When no vehicle has a connection back to the portal unit (which was located in the Administration building for these tests), then they were no longer able to mesh together.

Figures 2 and 3 show two of the ways in which the system worked during the testing.

In order to test the ad-hoc or mesh coverage in the Parker Area there were two AP's installed at the Bradbury Tank site. The first antenna points toward the Parker Administration building and the 2nd antenna at Bradbury Tank points west toward The Bluffs.. The Bluffs is a remote area that has no roads nor infrastructure to support fixed AP's, so it was an excellent area to test the ad-hoc capabilities of the 4.9 GHz mesh system.

All of the Application testing was done using 10 MHz bandwidth. The portal AP was located at the Parker Administration Building or Headquarters. It had one 90° Til-Tek Panel Antenna, and an EIRP of 31.45 dBm. The two antennas at the Bradbury Tank have the same parameters. All AP's were powered over Ethernet.

[1] RF – Radio Frequency, or the propagated radio signal.

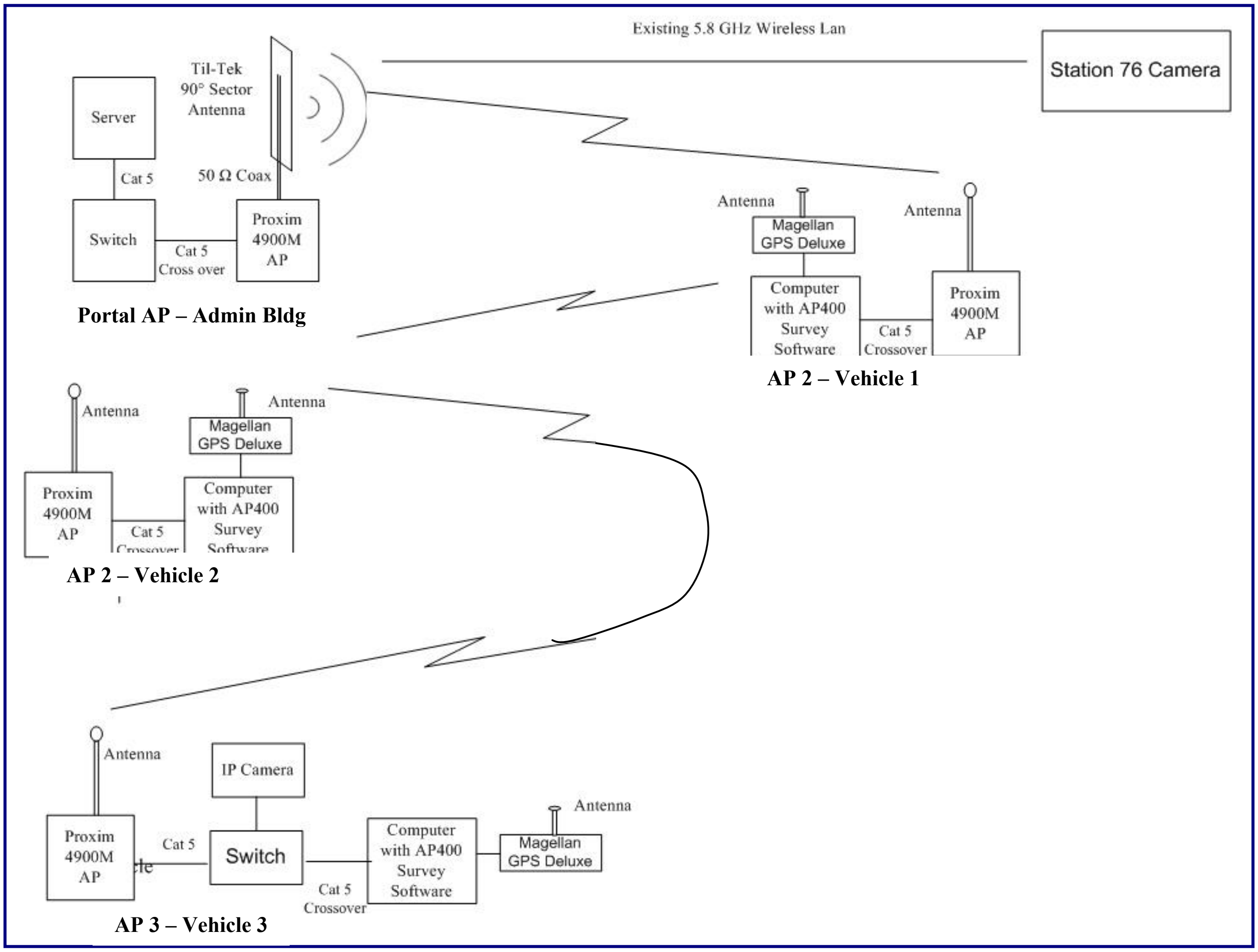


Figure 8.2 – Ad Hoc Testing Configuration

Figures 8.2 and 8.3 show two configurations, which were used during the testing. Not all sites were used in all testing, so refer to each individual application test, and to the satellite photo, to determine the final test configuration.

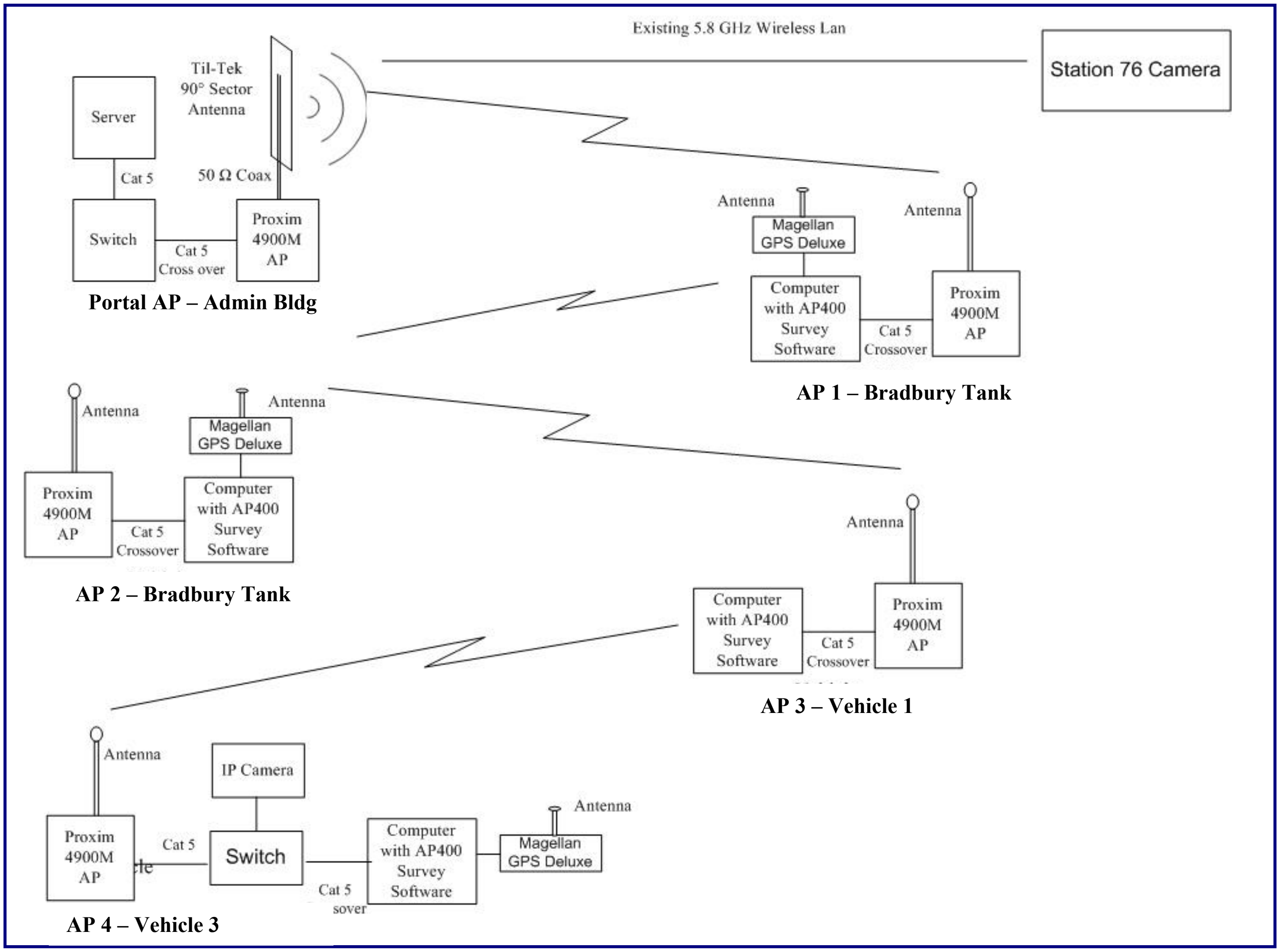
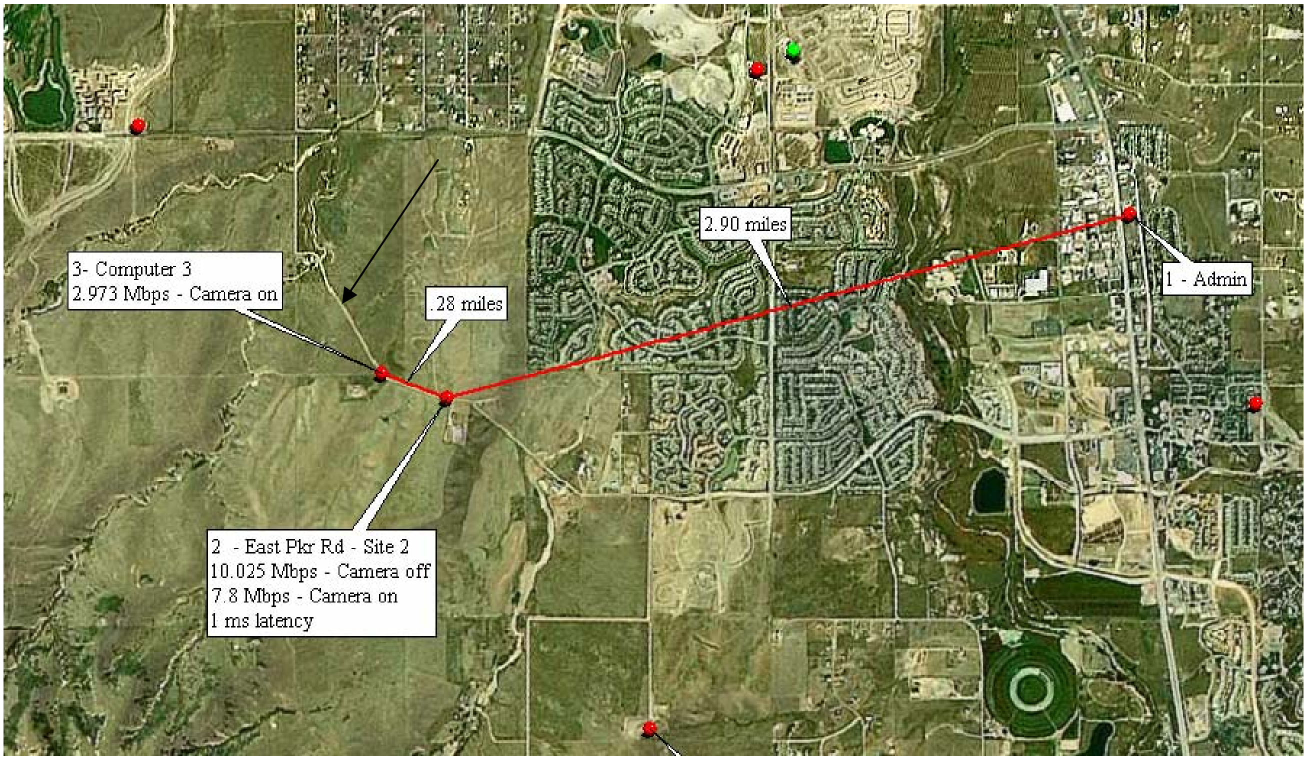


Figure 8.3 – Ad Hoc Testing Configuration

Application Test 1
Measure the Throughput and Latency for One Hop



Picture 8. 9 – Satellite Photo – Application Test 1
(See Figure 8.2 for Configuration)

- Vehicle 1 was on East Parker Road, of 2.9 miles from Administration Building.
- Vehicle 3 (with the camera) moved westbound on East Parker Road
- Bradbury Tank was not visible from this location, so the vehicle 1 the portal at Admin, a line of sight path.
- The AP in Vehicle 1 and Vehicle 3 were able to communicate with Parker Admin.
- The camera in Vehicle 3 was turned on, and sending video.
    - Measured throughput from Admin to Vehicle 1 was 7.8 Mbps When the camera was turned off, the throughput increased to 10.025 Mbps

- The throughput and latency were measured with QCheck. No video throughput was tested at this site, but the camera was associated with the Admin Portal AP

- The camera in Vehicle 3 was turned off.
    - Measured throughput from Admin to Vehicle 1 was 10.025 Mbps.

- Vehicle 3 attempted to drive to the point where line of sight from Vehicle 1 was lost (see black arrow on the map).

- Vehicle 3 was unable to associate until it reached the point shown on the map, a few tenths of a mile.

- Coordinates

Administration	39° 31' 53.70" N; 104° 45' 57.72" W
Vehicle (#1) on East Parker Road	39° 31' 14.40" N; 104° 49' 06.60" W

Summary Application Test 1:

- A hop path of 2.79 miles was achieved for the first hop.

- The second hop would not even go line of sight. Later testing will confirm that this problem is caused the elevation of the antennas on the mobile vehicles. If one of the two antennas is less than 10 feet above ground, the length of the hop is severely limited.

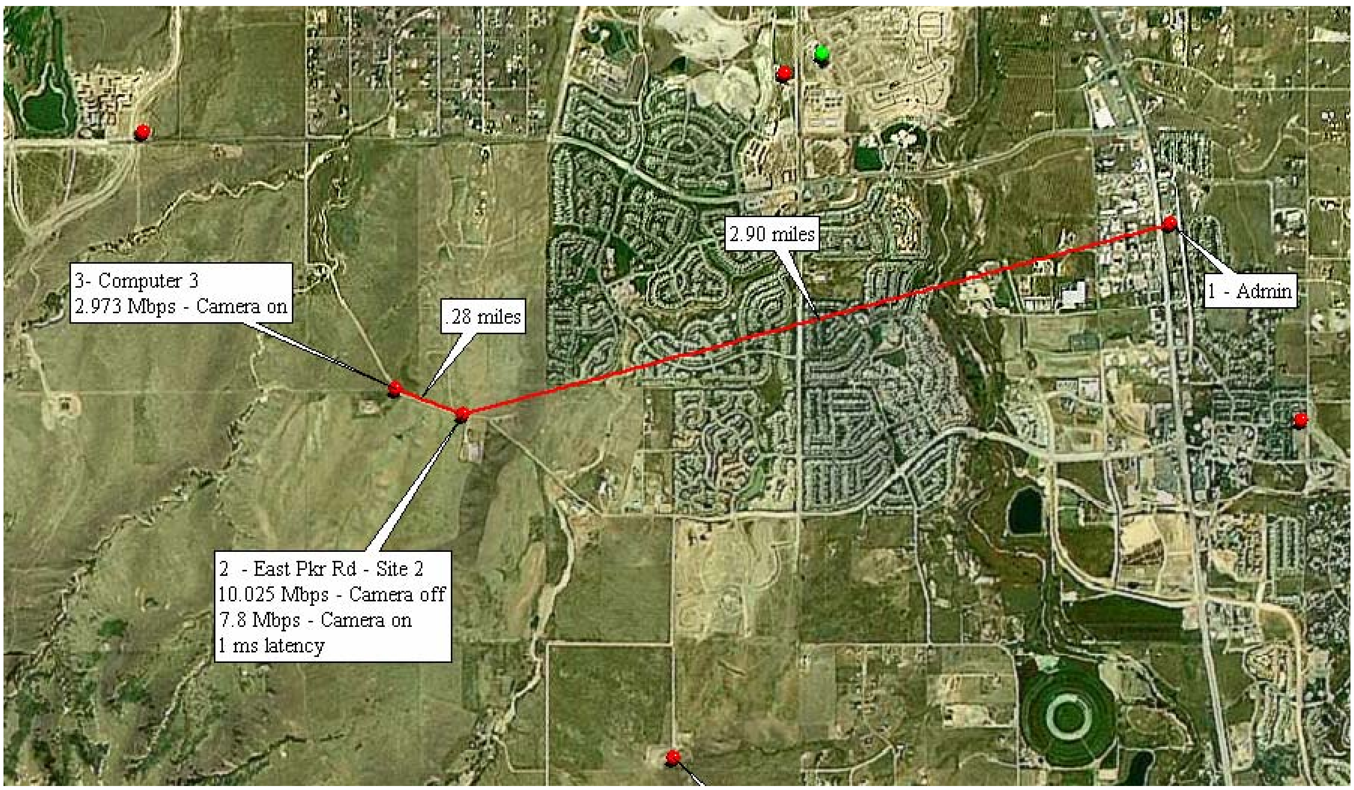
- Even when no video was being sent, the association of the AP with the Camera turned on caused a decrease in throughput of approximately 2.225 Mbps from Admin to Vehicle 1

Application Test 2
Measure the Throughput and Latency for Two Hops.

- Vehicle 1 remained on East Parker Road – a distance of 2.9 miles from the Parker Administration Building.

- Vehicle 2 west on East Parker Road. The goal was to drive until vehicle #2 reached the curve and hill where the line of site to Vehicle 1 would be blocked (4000 feet or .76 miles from Vehicle 1).

- Even with line of site Vehicle 2 lost connection as it traveled to this location. Vehicle 2 returned east on East Parker Road and connection was regained at location 2
- Vehicle 3 kept the camera on during this test.



Picture 8.10 – Satellite Photo – Application Test 2
(See Figure 8.2 for Configuration)

- The distance from Admin to Vehicle 1 was 2.90 miles,
- The distance from Vehicle 2 to Vehicle 3 was .28 miles.
- The total cumulative distance of both hops is 3.18 miles.
- The throughput to Vehicle 1 was measured at 7.8 Mbps
- Throughput to Vehicle 2 with the camera on was 2.973 Mbps.

- Vehicle 3, with the camera, was not meshed during this test, so video throughput was not tested.

- Coordinates

Hop 1		
From Administration	39° 31' 53.70" N;	104° 45' 57.72" W
Vehicle (#1) on East Parker Road	39° 31' 14.40" N;	104° 49' 06.60" W
Hop 2		
to Vehicle (#2)	39° 31' 19.60" N;	104° 49' 24.60" W

<u>Summary of Application Test 2</u>:

- The first meshed hop was 2.90 miles
- The second meshed hop was .28
- Total cumulative hop length was 3.18 miles
- The throughput was 7.9 Mbps from Admin to Vehicle 1, and 2.973 Mbps from Admin to Vehicle. The throughput to from Admin to Vehicle 2 was 38% of that from Admin to Vehicle 1
- Each hop will reduce the throughput by 50% PLUS overhead.
- The reduced throughput from Admin to Vehicle 2 is consistent with this principal, and the overhead appeared to be about 12%

Application Test 3
Measure Two Hops with Mesh

- Vehicle 1 was moved to the edge of The Bluffs – 4.74 miles from line-of-sight from Admin.

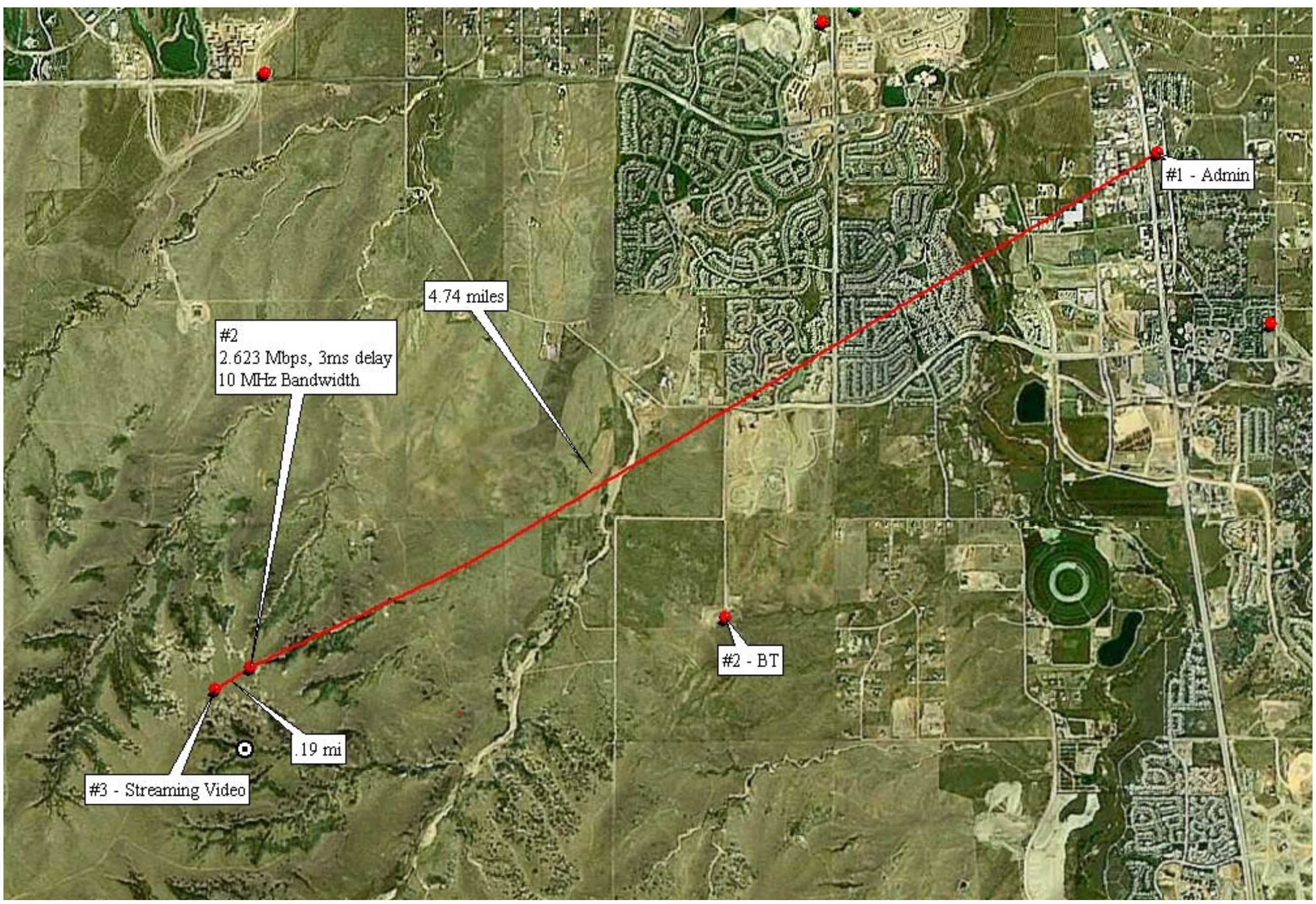
- Vehicle 1's AP associated with Admin.

- Bradbury Tank is closer than Admin, but it is not line of sight.

- Vehicle 3 did not have line-of-sight to Admin or to Bradbury Tank

- Vehicle 3 was moved as far away from Vehicle 1 until line-of-sight was lost.

- Then Vehicle 3 moved toward Vehicle 1 until the two AP's associated.
- The camera was on in Vehicle 3
- Throughput at vehicle #1 with the camera on was 2.623 Mbps and latency was 3 ms.
- Good streaming video was observed in Vehicle #1 from Vehicle #3.
- Parker Fire Chief, Daniel Qualman, was able to observe good quality streaming video at test server in the Admin Building. He reported no degradation of the video.
- Vehicle 2 was not involved in this test.



Picture 8.11 – Satellite Photo – Application Test 3
(See Figure 8.2 for Configuration)

- Coordinates

  Hop 1

  Hop 1 – Admin to The Bluffs - 4.74 miles

Administration	39° 31' 53.70" N;	104° 45' 57.72" W
The Bluffs - Vehicle 1 :	39° 29' 52.00" N;	104° 50' 36.00" W

  Hop 2: The Bluffs (#Vehicle 1) to Vehicle (#3) – 019 miles

Bluffs – Vehicle 3	39° 29' 46.80" N;	104° 50' 46.90" W

<u>Summary of Application Test 3</u>

- A path length of 4.74 miles was achieved in the first hop, from Admin to Vehicle 1.

- A path length of .19 miles was the maximum distance that could be achieved from Vehicle 1 to Vehicle 3, even though there was still line-of-sight at greater distances.

- The cumulative distance for both hops was 4.93 miles.

- Vehicle 1 had a throughput to Admin of 2.623 Mbps. This lower bandwidth is consistent with a reduced field strength from test 1, because of the increased free space path loss which results in a lower receive signal level.

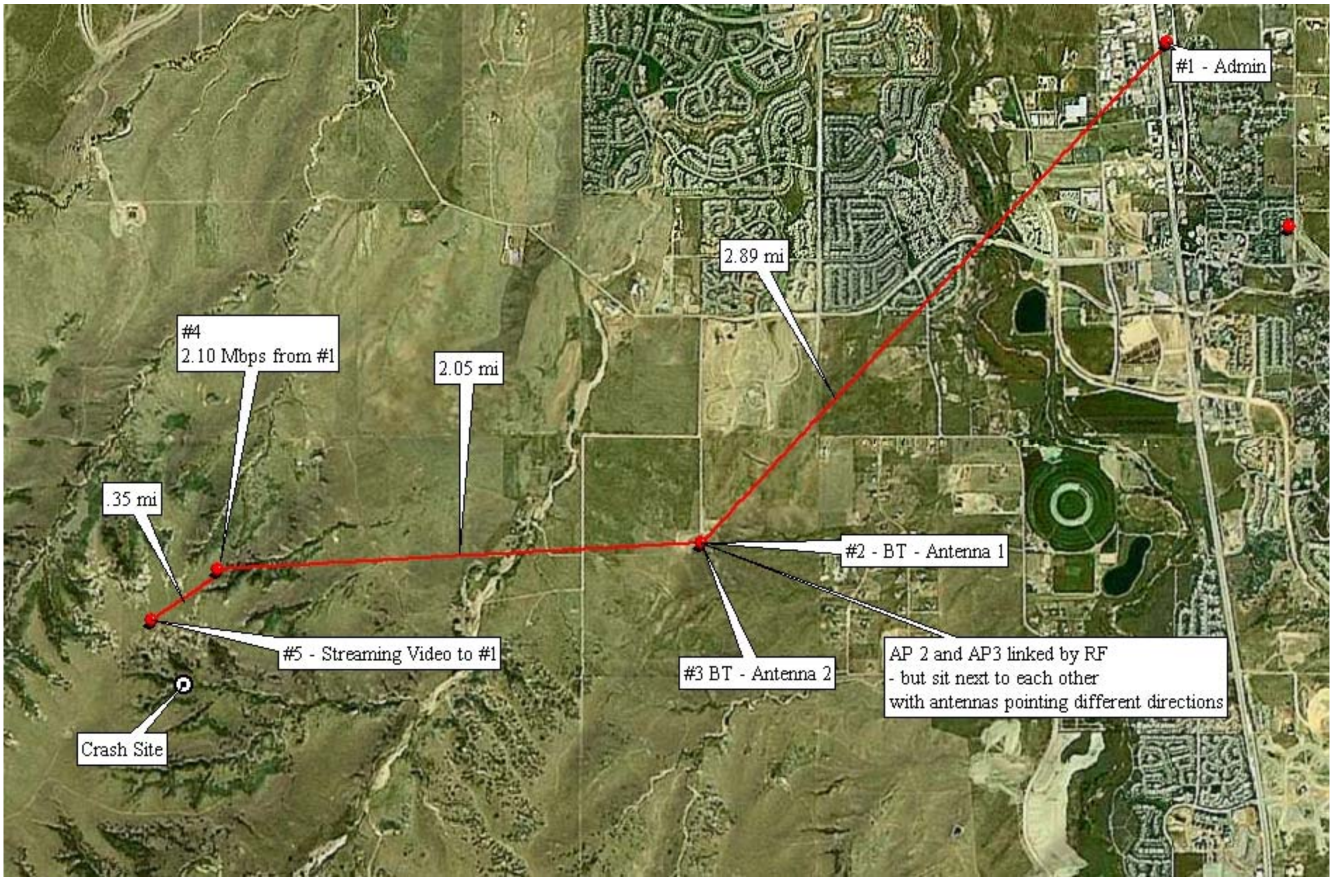
- Throughput was not measured at Vehicle 3, but it could not exceed 1.3 Mbps, and was probably less because of the overhead.

- Even with a decreased bandwidth because Vehicle 3 was the 2nd hop, the camera was able to send well streaming video that was observed both in Vehicle 1 and at the Admin test server.

- So far in the testing, the 2nd hop has had its distance severely limited to less than .3 of a mile, even though line of sight is much further.

- The question is whether this is a characteristic of additional hops, or whether something else might be causing this. Application Test 4 will address this question.

Application Testing 4
Measure Throughput, Test multiple hops, Test Antenna Elevation Effects



Picture 8.12 – Satellite Photo – Application Test 4
(See Figure 8.3 for Configuration)

- Application Test 4 is testing four hops:
  - Hop 1 - Admin to Bradbury Tank AP 1
  - Hop 2 - Bradbury Tank AP 1 to Bradbury Tank AP 2
  - Hop 3 - Bradbury Tank AP 3 to Vehicle 1 on the Bluffs
  - Hop 4 - Vehicle 1 on the Bluffs to Vehicle 3 and/or Vehicle 2 on the Bluffs

- Antenna Elevations for AP's
    - Admin – 45 feet AGL
    - Bradbury Tank 1 – 12 ft AGL
    - Bradbury Tank 2 – 12 ft AGL
    - Vehicle 1 – 6 ft AGL
    - Vehicle 2 – 6 ft AGL
    - Vehicle 3 (Truck) – 8 ft AGL

All four hops listed above were tested. <u>The distinguishing difference between this test and the previous test is that both antennas at the Bradbury tank are above 10 ft AGL</u> Therefore:

- Hop 1 from Admin to Bradbury Tank 1 has both antennas above 10 ft AGL
- Hop 2 from Bradbury Tank 1 to Bradbury Tank 2 has both antennas above 10 ft AGL
- Hop 3 from Bradbury Tank to Vehicle 1 has one antenna above 10 ft AGL
- Hop 4 has all antennas mounted to vehicles at less than 10 ft AGL

Comments about the testing

- In Tests 1,2 and the, the second hop was limited to less than .3 of a mile, which was, in all cases, less than line-of-sight.
- The Portal AP is at Admin
- Vehicle 2 was began the test with a line-of-sight and association with Admin.
- Vehicle 2 drove until it lost line-of-sight with Admin.
- Vehicle 2 immediately associated with Bradbury Tank when it came into line of sight, and immediately meshed back and showed association with Admin
- The path length for hop 1 from Admin to Bradbury was 2.89 miles
- The path length for hop 2 from Bradbury AP 1 to Bradbury AP 2 was 0 miles, but they did associate via RF and not with a hard connection
-
- The path length for hop 3 from Bradbury AP 2 to Vehicle 1 was 2.05 miles
- The path length for hop 4 from Vehicle 1 to Vehicle 3 was .35 miles

- At different times during the testing, it was observed that vehicles 2 and 3 both meshed to vehicle 1.

  - Both Vehicle 2 and Vehicle 3 could simultaneously mesh to Vehicle 2,

  - Vehicle 2 and Vehicle 3 did not associate with each other because they were both further from Bradbury Tank than Vehicle 1, and neither had an association with the portal AP.

  - There was a limit of 4 possible hops in the meshing configuration, so there was only one hop possible beyond Vehicle 1.

  - The intelligent meshing was dynamic, and as the AP's move, the associations changed without the necessity of operator intervention, based upon best-cost routing.

  - No subscriber AP's are able to mesh together UNLESS one of them is meshed to the Portal AP.

- Coordinates:

  - Hop 1: Administration to The Bradbury Tank 1 – 2.89 miles
    Administration 39° 31' 53.70" N; 104° 45' 57.72" W
    To Bradbury Tank Antenna 1 39° 30' 03.68" N; 104° 48' 10.44" W

  - Hop 2: Bradbury Tank 1 to Bradbury Tank 2 – 0 miles
    To Bradbury Tank Antenna 2 39° 30' 03.68" N; 104° 48' 10.44" W

  - Hop 3: Bradbury Tank 2 to Vehicle 1 on the Bluffs– 2.05 miles
    To Vehicle 2 39° 29' 57.80" N; 104° 50' 28.3" W

  - Hop 4 – Vehicle 1 to Vehicle 2 on the Bluffs - .35 miles
    To Vehicle 3 39° 29' 46.80" N; 104° 50' 46.9" W

Test 4 Summary

- Antenna height above ground (AGL) had a direct affect on path length.

- Even if hop 2 is ignored (from Bradbury Tank 2 to Bradbury Tank 3), the next hop in the system was 2.05 miles
- The longest previous 2nd hop was less than .3 mile.

- The total cumulative path distance from Admin to Vehicle 1, through the Bradbury Tank was 5.29 miles.
- Throughput at Vehicle 1 was 2.010 Mbps
- Vehicle 3 was able to mesh to vehicle 2 – Cheryl L. Poage, Grant Manager, was able to observe good streaming video from Vehicle 3 through Vehicle 1, through Bradbury 2 Through Bradbury 2 to the Administration Building. She reported that it was good quality streaming video[2]
- The effects of antenna elevation on propagation of wireless links have been documented in an IEEE's paper presented by Green and Obaidat. In this paper, they discuss the problem with antenna height and the reduced path length distances. This is discussed in more detail on page 267 of this report.
- The decreased path length based upon the height of the antennas was certainly consistent with what was observed during the testing.

Application Testing 5
Measure the time to open at 59.656 MB file

- The AP's were set at 10 MHz Bandwidth
- Vehicle 2 was driven to a line of site location .6 miles from the administration building.
- At this location we had a throughput of 5.04 Mbps while opening at 59.646 MB PDF file.
    - It took 115 seconds to open the file.
    - 27 seconds of which were required to open the application on the mobile laptop.

[2] Video was being sent at 30 frames per second.

- The remaining time of 87 seconds was the actual time to open the application.

- After the file was open on the laptop, it took 10 seconds to zoom in

Picture 8.13 – Satellite Photo – Application Test 5
(See Figure 8.3 for Configuration)

Test Summary

- The system was able to open a 59 MB file in less than 115 seconds. This time included the 27 seconds it took to open the application.

- The system had a throughput of over 5 Mbps while the file was being opened.

- The 10 MHz bandwidth was adequate, even for a file of this size.

- Bandwidth will decrease as distance increases, because the field strength will decrease with distance.

Application Testing 6

Parker Fire Application Tests Performed by the End User

The final tests were run by Steve Macaulay, Parker IT Department. The purpose of these tests was to see if the system worked as would be expected by an end user. The following input was given:

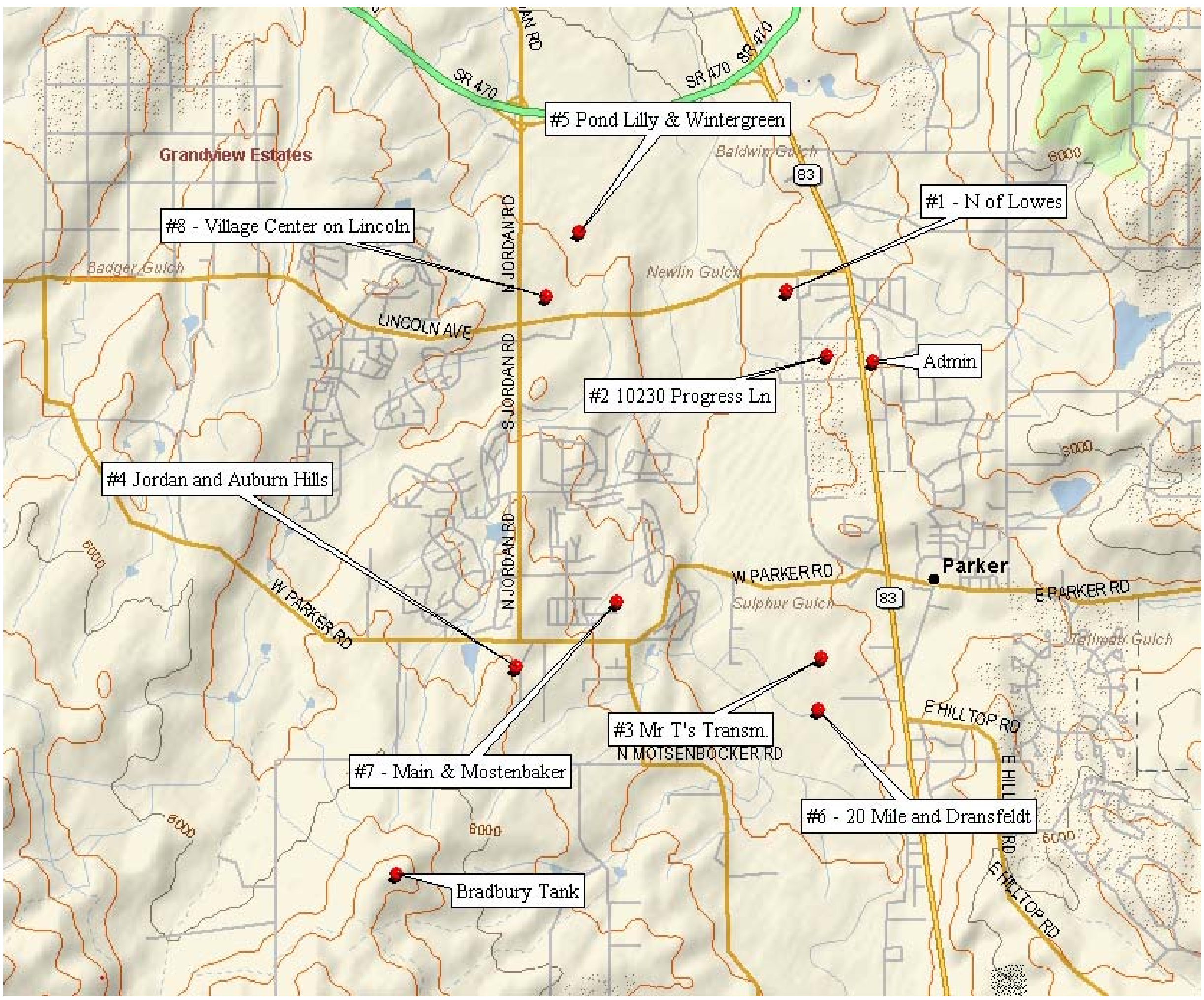
- When there was a good signal, a throughput of 2 Mb was seen and access was good.
- The 59 Megabyte PDF file and the 53 Megabyte DWG files opened as expected.
- The camera feed[3] from station 76 showed good streaming video when viewed. (see Figure 3.2)
- Access to Firemanager was as expected and the application does a good job of not having to transmit a lot of data
- Downloading the image files from within the application (Fire Manager) worked well.
- The system would quickly reacquire and connect as the vehicle moved from location to location.

Test Methodology

- The portal AP was located at Admin.
- Eight different sites were chose to perform the application testing.
  - The sites were determined by reviewing system coverage maps provided by KNS Communications.
  - Two sites were purposely chosen that showed no coverage.
- At each the following was attempted:
  - Open a DWG file
  - Open a PDF file

[3] The camera at station 76 is set at 30 frames per second.

- View a video from the server
- Open Fire Manager, a database used by the Department
- View streaming video from station 76
- Run a QCheck test of the throughput.



Map 8.6 – Locations for End-User Application Testing

Site No	Location	Distance from Admin (miles)	Test Description					
			DWG File (53 MB) Min:Sec	PDF File (59 MB) Min:Sec	Play Video file (26 MB)	Qcheck results	Fire manager access Sec	*Video camera from station 76
1	North side of Lowes / Dranfeldt	0.46	1:45	4:20	5	2.0 MB	15 sec	4
2	10230 Progress LN	0.18	1:00	1:50	5	4.2 MB	10 sec	5
3	Dransfeldt / Next to Mr. Transmission	1.25	5:00	**	***	400 Kb	****	3
4	Jordan/Auburn Hills	1.93	1:30	3:10	5	2.0 MB	20 sec	4
5	Pond Lilly / Wintergreen	1.32	1:30	2:40	5	3.0 MB	16 sec	4
6	20 Mile / Dransfeldt RD	1.45	1:20	1:55	5	5.3 MB	10 Sec	5
7	Main / Motsenbaker	1.45	No Signal					
8	Village Center / Lincoln	1.37	No Signal					

Table 8.4 – Results of End User Application Testing

*The video quality was rated 1 is bad, 5 is good

- At the Dransfeld Site (#3) by Mr. T's Transmission
  - QCheck showed 400 Kb of throughput.
  - The large PDF file would not open
  - The slightly smaller DWG file opened in 5 minutes.
  - The 26 MB Video file would not play
  - Fire manager could not be accessed

- Location 7 had no signal (Main / Mostenbaker)

- Location 8 had no signal (Village Center and Lincoln)

- Location 3 had marginal coverage from Admin according to early drive tests, Location 7, and 8 showed no coverage during the drive testing from the Admin building.

- Proper deployment and good system design can result in a mobile broadband system that will perform most tasks the emergency responders need, including large file download, access to server databases, streaming video, and other high-speed access applications.

Application Testing – Final Summary

The deployment of 4.9 GHz system must be made by carefully studying the topography and obstructions. 4.9 GHz behaves is very much line of sight, although some very limited non-line of-sight communications or obstructed communications do occur.

System performance is dependent upon quality of installation (short high quality feedline, good connectors, and quality antennas), good network design, evaluation of topography, evaluation of obstructions and evaluation vegetation. If testing is done in the winter, the system may fail in the summer when the trees leaf out.

The 4.9 GHz broadband mobile system can perform very well – but only if there is careful system engineering **and** testing up front.

The purpose of this report is to provide some examples of various types of topography (mountains, plains, and foothills) and varying environments (Urban and Suburban). Each different environment showed different results. The application testing which was done here was done in foothills and plains and in a suburban setting.

Chapter 9
Project Summary and Guidelines for System Deployment

The project studied how to deploy a mobile broadband network in the 4.9 GHz frequency band. The 4.9 GHz frequencies are a block of frequencies, which can be licensed to government agencies.

The details of the studies are contained in the previous chapters, so the purpose of this chapter is to summarize what was learned in the study.

Comparison of deployments in different types of areas:

Map 9.1 details the locations of all of the sites which were used in the testing.

Mountainous - Long distances can be achieved for hot-spot coverage, but in general the coverage is limited by the topographic obstructions and by the vegetation.

Suburban Foothills - Fairly long distances can be achieved if the AP's are placed advantageously. The coverage is limited by the topographic obstructions, by buildings, and by vegetation.

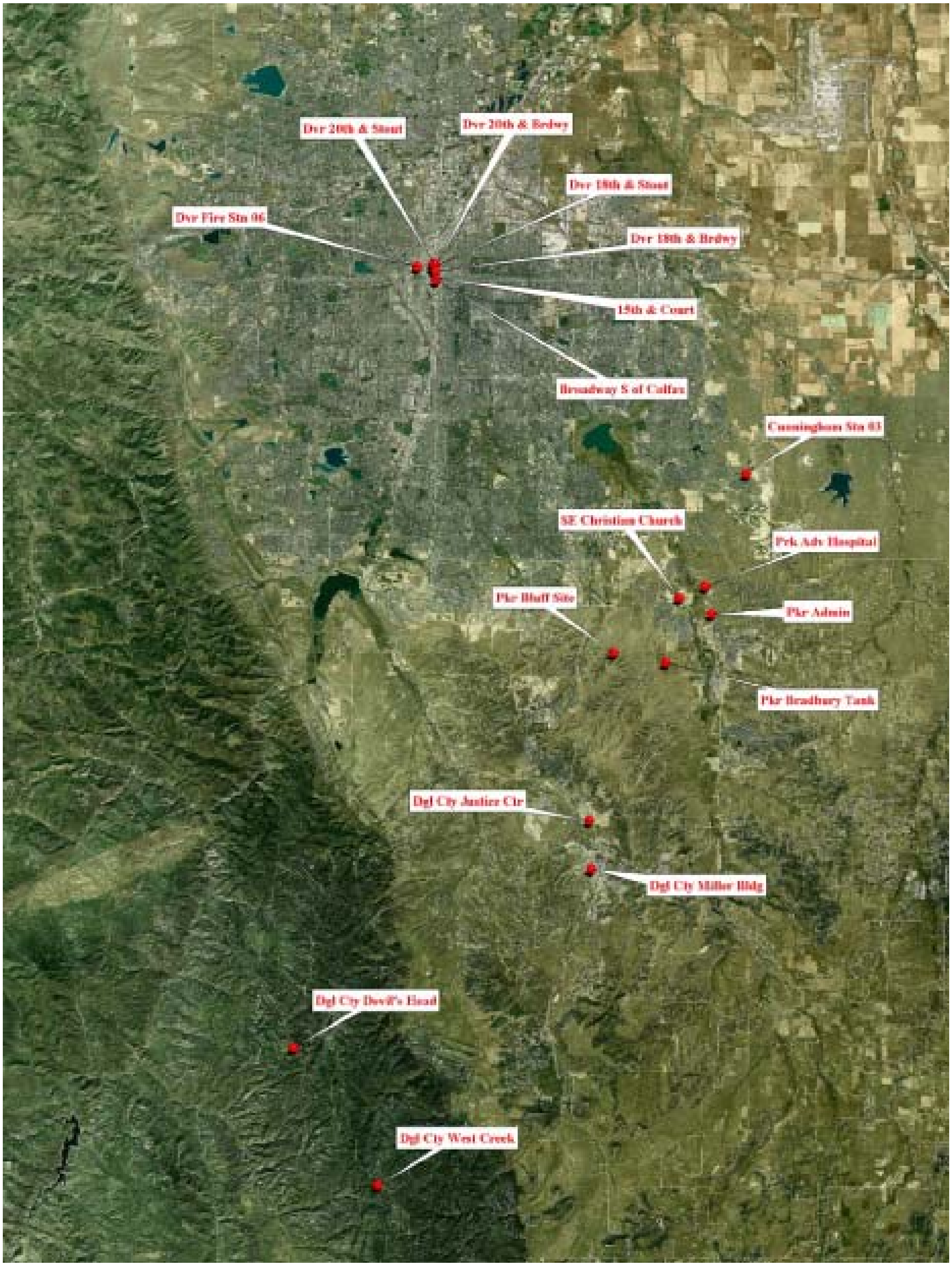
Urban – Coverage is limited by the buildings and obstructions. The streets, which are lined with buildings, which are side by side, tend to channel the signals. Adjacent blocks, which are not line of site, were also covered.

Dense Urban - Coverage is limited as well as enhanced by the tall buildings and obstructions. The buildings tend to have a waveguide effect, and sometimes the receive signal is greater than would be calculated, while the path loss is less than that which would be calculated.

Plains and Suburban – Coverage is limited by the houses and vegetation. The signal will traverse 1 to 2 blocks in any direction from the portal, but travels reliably only through the streets which are "seen" by the AP. This type of deployment was much more limited in distance than any of the other deployments studied. It might be noted that the "plains" were all covered by suburban sprawl.

Plains and Foothills – Here some of the plains were open, and the result was excellent propagation in those areas where there was a line of sight view. The foothills allow for advantageous location of the portal units, and coverage was seen up to 4 miles away from the AP. The ad-hoc and application testing was done in this environment. Over 6 square miles were covered by 4 portal Access Points.

Map 9.1 – The 4.9 GHz Colorado Project Test Sites



Picture 9.1 – Satellite View of The 4.9 GHz Colorado Project Test Sites

What was Learned about Propagation

How Effective Radiated Power affects Propagation – The study dramatically showed that the FCC limits on EIRP for the loose mask radio severely restrict propagation at the 4.9 GHz frequencies. Most of the tests were done with an EIRP of approximately 30 to 31 dBm. It is reasonable to assume that most deployments will either intentionally or unintentionally have at least this amount of power, because most of the antennas being produced for this frequency are high gain antennas.

In the summary of the Dense Urban deployment, one study was plotted for the 31 dBm and for 26 dBm (the current FCC limit for the tight mask). There was a 40% decrease in coverage!

The Effect of a BDA on the Receiver Sensitivity – Bench testing under the guidance of Frank Pratte, P.E., of Pericle Communications, confirmed that the addition of a Lynx BDA to an access point increased its receiver sensitivity by 2 dB. All of the dense urban testing (Downtown Denver) included two simultaneous tests – one without BDA's, and the second with a BDA at both the Portal and at the mobile. The EIRP of both systems were within .5 dB of each other – so the systems could be considered to have virtually the same EIRP.

Table 9.1 compares the footprints of the two systems in acres. Four of the test sites showed a 3:1 ratio, with the receiver BDA's increasing the coverage in a ratio of 3 to 1. Although the second system did not have a BDA, the EIRP's were virtually the same, so the difference in performance must be attributed to receiver sensitivity.

Table 8.1 also compares the difference in performance between 31 dBm and 26 dBm. There is a 1.7 to 1 ratio – or almost 40% of loss in coverage by reducing the EIRP by 5 dB.

Finally 8.1 compares the difference between two drive tests in Parker – one with a mobile BDA, but no Portal BDA, the other with no BDA's in the system. Since the EIRP of the transmitter is the same in both instances, the differences in coverage must be attributed to the mobile BDA. The difference is 2.3 to 1.

The conclusions are:

- The use of a BDA in both the portal and mobile improve receiver sensitivity will improve coverage substantially. Four of the six tests showed a 3 to 1 difference in area of coverage.
- The use of a BDA in the mobile only will also improve coverage. In the testing which was done in parker the improvement was 2.3 to 1.

- <u>Increase in EIRP substantially increases coverage</u>. The use of a BDA to achieve this increase has the side benefit of increasing the receiver sensitivity as well – which also increases coverage substantially.

	Coverage Footprint in acres		
	A	B	
Test	With TX and Rx BDA	With No BDA	A/B
Test 105A & B - 20th and Broadway	336.4	116.2	2.9
Test 106A & B - 20th and Stout	364.9	161.2	2.9
Test 107A & B - 18th and Broadway	253.8	160.2	2.3
Test 108A & B - 18th and Stout	180.4	60.9	1.6
Test 109A & B - 15th and Court	227.8	78.1	3.0
Test 110A & B - Broadway S of Colfax	469.4	110.5	2.9
	EIPR 3 dBm	EIRP 26 dBm	
Broadway South of Colfax	469.3	280.8	1.7
	Coverage Footprint in square miles		
	Mobile BDA	No Mobile BDA	
Parker Application Testing	6.8	3.0	2.3

Table 9.1 – Comparisons of different EIRP's and use of BDA's

Effect of Antenna Height on Propagation in 802.11 WLAN devices and on ad-hoc meshing - The effect of antenna height on the propagation was an unexpected result in the study. An ad-hoc path could be up to 4 miles long and still work well. However, if the antennas two antennas were less than 10 feet above ground level, the distances covered were reduced to less than 1/10 of a mile! This has significant implication in the deployment of an ad-hoc network. Antennas must be higher than the roof of a typical vehicle to work well.

Other Issues Affecting System Performance

Choosing a Bandwidth – While choosing a higher bandwidth initially sounds good, remember that it comes with a cost! Table 8.2 shows the effects of going from 10 MHz bandwidth to 20 MHz bandwidth. The table assumes an EIRP of 30.70 dBm.

Receiver	Description	Gain/Loss		Units	Gain/Loss		Units
Antenna Gain	Mobile Mark EC09-4900PT	7.30		dBi	7.30		dBi
Cable loss	included in antenna [+9dbi-1.7db=7.3]	0.00		dB	0.00		dB
Equivalent Noise Bandwidth	bandwidth from AP		10.00	MHz		20.00	MHz
Composite Noise Figure	10 dB w BDA, 8 dB w/o BDA		10.00	dB		10.00	dB
Required S/N for lowest bit rate	From 802.11 standard		4.00	dB		4.00	dB
Receiver Sensitivity	Calculated	(90.00)		dBm	(86.99)		dBm
	Maximum Path Loss	**128.00**		**dB**	**94.29**		**dB**
	Maximum Range Assuming LOS, - [see C1, pg.8]	**7.53**		**miles**	**5.33**		**miles**
Path Loss and Loss Margin							
Path Length		3.00		miles	3.00		miles
Free Space Path Loss	Calculated	120.01		dB	120.01		dB
	Excess Path Loss Margin [Fade Margin]	**8.00**		**dB**	**4.99**		**dB**

Table 9.2 – Effects of Changing Bandwidth from 10 to 20 MHz

Note that the receiver sensitivity is decreased by 3 dB. A 2 dB decrease in receiver sensitivity during the project testing resulting it a decrease in the area covered of up to 67%. Three dB will cause an even larger decrease in coverage.

The maximum range is decreased by over 2 miles. The fade margin is decreased by 3 dB. The maximum path loss is increased by 35 dB. Even with 10 MHz bandwidth, the tests were able to upload huge files (as large as 59 Mb), access the internet, and download streaming video at over 30 frames per second. The other consideration is that there is only 50 MHz of bandwidth allocated – 20 MHz reduces the number of channels, which are available for use by the system.

***File Transfers*:** While files can be transferred simply by choosing the file and beginning a download, this is not the most efficient way to do a mobile file transfer. The use of an FTP protocol allows faster file transfers, but more importantly, it allows the system to pick up where it left off if the connection is lost. This allows larger file transfers in a more reliable manner.

File Transfer Rates were only tested using 10 MHz bandwidth. It can be assumed that at higher bandwidth the transfer rates would increase in proportion to the increase in bandwidth, less the overhead.

Wireless Backhaul and Backbone – If the wireless backhaul is deployed with good high performance dish antennas that have a narrow beamwidth, the 4.9 GHz can be used for backhaul as well. One of the tests performed was to see if a backhaul interfered with or caused interference to the mobile AP. No degradation in performance of either was noted during the testing.

The 4.9 GHz backhaul is secondary to mobile applications, so it is important to use high-performance dishes in the implementation of the 4.9 as a backhaul.

Ad-Hoc and Meshing – The ad-hoc tests demonstrated the ability to have very long ad-hoc hops (one of over 4 miles was tested). If one antennas was less than 10 feet above the ground (such as vehicle-to-vehicle), the distance will be drastically reduced. Project testing showed a maximum range of .2 to .3 of a mile. Throughput in each hop will be cut by half, plus some overhead

. ***Importance of Networking Expertise -*** If these systems are deployed to allow for mobile broadband coverage, then the IT department must play a critical role in proper routing of the signals. It is likely that a mobile AP will be able to respond to more than one portal at a time. If both of these responses go into the network without proper routing, then the network will experience a spanning tree problem and/or a broadcast storm. This can cause the entire network to fail.

Planning for Implementation

Propagation Modeling – Propagation modeling provided help only to the extent that it helped determine topographic limitations. The difficulty of adding obstruction files which would include all buildings, trees, etc., made the feasibility of using the modeling for more detailed studies difficult. Propagation modeling such as Bullington or Longley-Rice can be used as a "first pass" tool to determine line-of-sight limitations for the propagation. From that point, the obstructions need to be observed, and reasonable estimates made on how to proceed with deployment.

Testing – Testing prior to deployment is critical. Drive testing software must be capable of taking large numbers of readings from multiple sites simultaneously, and correlating those readings to GPS coordinates. These results can be plotted to determine anticipated coverage and location for the AP's.

Frequency Reuse – There is only 50 MHz of bandwidth available in the 4.9 GHz channel band. It is important to deploy the frequencies so that self-interference does not occur.

Regulatory Issues

Licensing 4.9 GHz **–** The 4.9 GHz frequencies can be licensed to any non-federal government agency. The full range of available frequencies is issued on a license, and the license is granted to a governmental entity. Licenses may overlap. For instance, a county might have a license, cities within that county might have licenses, and fire districts within the same county might have licenses. The Regional Planning Committees have been tasked with overseeing the deployment of these frequencies among the various users.

Permanent Point-to-Point 4.9 GHz licenses must be licensed by site. The general 4.9 GHz license does not cover permanent point-to-point installations.

FCC Regulations – The regulations governing the use of the 4.9 GHz Band are contained in Title 47 Part 90 Subpart Y of the Code of Federal Regulations. Appendix A has a copy of these regulations. Appendix B is a Memorandum Opinion and Order, which modified the original regulations. Appendix C discusses the Regional Planning Committees, and their roles in the deployment of the 4.9 GHz by various entities.

Deployment

What questions need to be asked, and what needs to be done to oversee a successful deployment after the initial testing and system design has been done.

Installation**:** The little things make a big difference in installations at this frequency range. The best connectors should be used, adapters should be avoided, and loss cable should be used. Waterproofing of all cables is important, as is good grounding and lightning protection. If the AP is not rated for outdoor use, Nema 4x boxes should be used for installation.

Antennas should be good quality and should perform as rated. For antennas, which have coaxial cables already connected to them, be sure to check to see if the stated gains include the loss in the cables. If not, the manufacturer should provide this loss. It is important to have as much gain as is legally acceptable, and there is often 1.5 to 2 dB loss in a cable. By having the correct information, the access point power can be adjusted to stay within FCC limits. Cables must be as short as possible to mitigate losses.

Unlike typical voice radios, which may have 5, 10, or even 100 watts, these radios have power ratings of less than a watt. Every dB is critical to a good system. This study has already clearly demonstrated that a 2 dB system loss can reduce coverage by as much as 60%. Installations should be done by qualified personnel with the best of materials

System Performance Criteria - Performance criteria needs to be established with the vendor prior to the purchase or installation of equipment. Some of the issues that should be discussed include:

- **AP Specifications**

  - ✓ ***Power Out***

  - ✓ ***Receiver Sensitivity*** (This is very important. The better the sensitivity, the better the system performance.) A minimum acceptable sensitivity would be -90 or -92 dBm. (-92 is a better sensitivity than -90). Receiver sensitivity is a measure of how weak a signal the unit can receive and decode.

  - ✓ ***Bandwidth settings*** which are available
    - 5 MHz provides low throughput, but will go longer distances
    - 10 MHz provides a good balance between coverage and throughput
    - 20 MHz provides high throughput, but has limited coverage

  - ✓ ***Emissions mask***

    - ▪ ***Loose Mask*** – these radios are developed from the existing wireless access points in the 5 GHz frequencies. They will be less expensive because of the economies of scale. Extensive testing by NPSTC has confirmed that the small amount of interference caused by the loose mask emissions causes insignificant effects on the performance of the radio.

    - ▪ ***Tight Mask*** – these radios are still proprietary. As such, they are more expensive and are not interoperable with other tight mask radios. There is less interference, but the radios are considerably more expensive.

- **Antenna Specifications –** There is considerable confusion about how antennas work. The function of an antenna is to receive incoming RF signals, and to shape the outgoing RF signals. An RF signal behaves just like light, and if you imagine a light bulb – the light coming from that light bulb is analogous the RF signal coming from an Omni (Omnidirectional) antenna. An Omni antenna receives RF signals from all directions – so it is more susceptible to interference.

  An antenna with gain is simply an antenna that redirects the RF signal. According to the laws of physics, a gain in one direction will always be offset by a loss in another direction. It is important to understand that a high-gain antenna is beneficial **only** if the gain is in the direction you need it. For instance, a high gain antenna on a mountaintop often directs the RF signal over the area where the coverage is needed, and there is a loss down toward the base of the mountain.

If you imagine a balloon as the RF signal around an antenna, and you imagine squeezing the balloon, you now have more signal in one direction than in another – but you still have the same amount of signal.

Often sales people push for high gain antennas because the client feels that a high gain antenna always equates to better performance. As an educated purchaser, it is important to understand that this is not true. High gain antennas can actually degrade the system performance.

This being said, lets look at some of the decisions you will be required to make.

- ✓ ***Fixed Installations for Point to Multipoint – Options***
  - Omni Antenna
    - Pros – Only one antenna required, can be an excellent choice
    - Cons – lower EIRP, beamwidth is not as directed

  - Sector or Panel Antenna – The *Til-Tek Sector antennas* used in the testing performed very well.
    - Pros – Higher EIRP, directed beamwidth, both vertical and horizontal, more flexibility in directing the signal in desired direction
    - Cons – One AP is required for each Antenna, so there is more cost

- ✓ ***Mobile Installation –*** most mobile antennas are omni antennas, so the choice that must be made is what gain is needed for good system performance. Most of the testing was done using the 9 dBi gain antenna. Be sure to consider the coaxial cable loss when calculating the EIRP for the mobile installation. Mobile Mark antennas were used in the testing and performed well.
    - 3 dBi gain is a low gain antenna that can be used where coverage is good.

- 6 dBi gain is a medium gain antenna.

- 9 dBi gain is a high gain antenna.

✓ ***Point-to-Point Installations*** must be done with narrow beamwidth antennas to prevent interference both to other units and from other units. Remember that all point-to-point installations are **secondary** to the mobile applications. This means that if there is interference, the burden of resolving the interference is placed upon the fixed installation. If the interference cannot be resolved, the fixed station must be taken out of service.

- Do not use panel, sector antennas, or omni antennas. They have wide beamwidths, which will greatly increase the chance interference from the mobile AP's. It will also increase the chance of interference to mobile AP's.

- Dish antennas, such as the MWave antennas used in the testing, provide high performance, and perform very well.

- If interference occurs with the dish antennas, a high-performance shroud should be added to provide further protection. Because these are licensed frequencies, the interference should be minimal, and this is probably not necessary.

- **Fixed Equipment Installation** is the most important part of the deployment. Most Agencies are used to installation of voice systems, which operate at VHF, UHF, or 800 MHz frequencies. At these frequencies the installation quality is important, but the effects of poor installation cause premature failures, but do not affect performance as drastically as at microwave frequencies such as the 4.9 GHz.

  At 4.9 GHz, poor installations will result in dramatically reduced levels of performance. This is because the radios are much lower power (less than a watt) and cannot tolerate losses as easily, and because of the propagation characteristics of 4.9 GHz.

  If your vendor does not have certified and experienced radio technicians on staff, they should not be doing the installations! A certified radio technician will own expensive test equipment such as service monitors, and will be able to maintain your voice radio system, or your microwave backbone.

Many of the systems are being sold by vendors with computer expertise, but without proper RF expertise. Proper installation is the heart of your system, and this point is not even an option! Poor installations will often work, but will be plagued by intermittent and substandard performance.

- ✓ The **Access Point must be outdoor rated** or mounted in a Nema 4X box. If a Nema box is used, its seals must be maintained so the 4X rating is not compromised. The box should be large enough to dissipate any heat that might occur, and in cold climates, a heater may be necessary.

- ✓ **Options for getting the RF Signal to the antenna** must be evaluated in terms of losses, which are induced into the system.

    - **Coaxial Cable** has high loss characteristics at this frequency. The runs must be kept very short (10 to 12 feet) and good cable such as Andrew LDF4-5A should be used. Smaller higher loss cables must be avoided.

    - **Power injectors** provide an excellent alternative to Coaxial Cable. These allow you to keep the Access Point at the bottom of the tower and use category 5 cable to power the access point.

- ✓ **Connectors should be the highest quality available**, and must be properly terminated. At microwave frequencies, there is no room for sloppy installation of connectors. A poorly terminated connector will result in intermittent and poor performance.

- ✓ **Adapters are not acceptable in the system.** All cables should be terminated with the connector, which is required. If there are adapters, then the vendor is taking an unacceptable short-cut. Adapters cause additional losses and are an additional point of failure.

- ✓ **Careful routing of cables is essential** . All cables, jumpers, and coax must be neatly routed, and proper tie-downs should be used. You should be able to open the cabinet and see a professional installation. Jumbled wires and cables are difficult and expensive to troubleshoot later.

    Routing of cables of the tower must be done carefully and neatly, they should be tied down with clamps or tie downs designed for this. You should not see wire used to tie cables in place

✓ **Grounding and surge protection** is very important.

- An **in-line surge protector**, such as a Polyphaser, must be put in all coaxial cables between the cable and the Access Point.

- **The surge protector must be grounded**! If it is not properly grounded, it does no good. It should be grounded to earth ground or a good building ground with a #4 AWG copper wire or larger.

  Surge protectors should not be grounded to the equipment cabinet. If a lightning strike occurs, all equipment in the cabinet will be compromised.

- **AC Surge protection is also essential**. High quality power strips with surge protection should be used.

✓ **BDA Installation** – The BDA is mounted between the access point and the antenna. There BDA should be mounted with very short high-quality jumper cables, and no adapters should be used.

✓ **Power Cables** – Often power connections have transformers in them. These need to be mounted so they are stable. It is very common for the heavy transformers to fall out because of their weight. Common sense will tell you if these are mounted properly.

• **Mobile Equipment Installation** - Mobile equipment installations are critical to system performance. Because the vehicle is in constant motion, equipment and connections must be stabilized so they do not become loose or disconnected. Poor installations are one of the most common sources of failures in a mobile radio.

✓ **Antenna cables** should be routed inside headliner of the vehicle and down to AP.

✓ **Connectors and terminations** should go directly the BDA or AP.

✓ **No adapters** should be used in the installation.

✓ **Power connections** should be hardwired to the battery.

✓ **All cables should be carefully routed**. Any penetrations through the firewall or where there is metal should have be protected with grommets or cable loom.

- ✓ **Cables should not be run where they can be stepped** on or where they can be caught or compromised by the user.

- ✓ **If a BDA is used**, it should be mounted in the same location as the Access Point. The jumper should be very short and high quality. No adapters should be used.

- ✓ The **Access Point and BDA (if used) should be mounted in a secure location** and the connector and terminations should be protected so they are not stressed.

System Acceptance

- **FCC Compliance** is your responsibility, not that of the vendor. If there are issues, your agency is held responsible by the FCC. Require EIRP calculations for both fixed and mobile installations, and verify that the EIRP does not exceed that which is mandated under current FCC regulations. The calculations should be very similar to those shown throughout this report.

  The FCC web site is www.fcc.gov, or you can call 1-888-CALLFCC for assistance in determining the what the current regulations are.

- **System performance** should be what was agreed upon before the system was purchased. The initial testing should show you where there would be dead spots. Very few systems will have 100% coverage – but your coverage should be what was agreed upon and described in the initial testing.

- **System Installation** – use the checklists given above to make sure the system is installed properly.

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Equipment used in the project testing.

- ***Proxim 4900AP –*** Proxim furnished all of the AP's for this project, plus antennas and substantial engineering support. The AP's performances have been documented by this project. After the project was completed, Proxim produced an outdoor rated AP for use in these applications.

- ***Power Injectors*** were used in many of the installations to shorten the feedline required. When a power injector is used, the AP can be powered over the category 5 cable. This is an excellent way to deploy the system.

- ***Antenna Types.*** There were several types of antennas used in the project: All of the antennas were tested under the direction of Frank Pratte, P.E., of Pericle Communications. They all performed within a few tenths of a dB of their specifications.

  - ✓ Mobile Omni – The Mobile Mark Omni antennas were rated at six and nine dBi. The feedline measured a 1.7 dB loss, so the net gain was 4.3 dBi and 7.3 dBi. These antennas worked very well and were used in all mobile testing.

  - ✓ Proxim 60° Sector Antennas (5054-SA60-17) – these antennas were used in testing and performed very well.

  - ✓ Til-Tek 90° Sector Antennas (TA 4904-14-90) – these antennas were used in testing and performed very well. The Til-Tek web site has excellent information on how to configure the antennas for optimum performance. Three 90° Sectors will provide 360° or omni coverage.

  - ✓ MWave Microwave Dish – the dish performed well and at the specified gain.

  - ✓ Proxim Omni – Proxim also furnished some omni antennas for the fixed sites. These performed well.

- ***BDA*** **–** The Lynx Bidirectional Amplifier was used extensively during the testing. The performance of the system was enhanced considerably by the use of the amplifier. Not only does it increase the power out, it also improved the receiver sensitivity by 2 dB.

AP's function in several ways:

The fixed AP's serve as portals for point to multipoint connections.

They can also serve as ad-hoc backhaul to connect together or with other mobiles.

For permanent backhaul, it is recommended that the AP's be configured in WDS mode in a point-to-point configuration. The WDS mode allows only two radios to connect to each other and it is designed for backhaul

For hot-spot configuration the Fixed AP's are portals and in a point to multipoint configuration.

Mobile AP's are configured in mesh mode.

Basic Terms

BDA - Bidirectional amplifier. The bidirectional amplifier amplifies the RF signal. In our testing the bidirectional amplifier increased the outgoing signal by 10 dB. The incoming receiver sensitivity was increased by 2 dB.

***EIRP* –** Effective Isotropic Radiated Power is a calculation of the effective power being radiated. It is calculated by taking the power out of the transmitter, adding the antenna gain, adding the gain from the BDA, and subtracting the losses from the cable, jumpers, connectors, and lightning arrestor. The maximum EIRP is regulated by the FCC, and varies for different emission masks.

***Hysteresis* –** In order to keep the radios constantly connecting, disconnecting, and reconnecting, the units have a built in hysteresis. It was noted that once the connection was lost, it took 6 dB of signal above the minimum required signal for connection, before the connection was re-established.

Receiver Sensitivity – Is a measure of the radio's capability to receive and decode a signal. The better the sensitivity, the weaker the signal that can be received and decoded. For instance, -92 dBm is better than -90 dBm.

Independent Engineering Evaluation

The 4.9 GHz Colorado Project was evaluated by Pericle Communications. Jay Jacobsmeyer, P.E., President evaluated all the testing procedures, oversaw bench verification of the equipment specifications and parameters, and wrote the independent engineering evaluation of the project. This evaluation has been published under separate cover.

Chapter 10
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Appendix A
4.9 GHz Site Locations

		Coordinates												Elevation	AGL
Jurisdiction	Site Name	Latitude						Longitude						(feet)	ft
Parker	Administration	39	°	31	'	53.70	"	104	°	45	'	57.72	"	5886	45
Parker	Bradbury Tank	39	°	30	'	3.68	"	104	°	48	'	10.44	"	6137	16
Parker	Parker Adventist	39	°	32	'	54.05	"	104	°	46	'	15.65	"	5821	75
Parker	SE Christian Church	39	°	32	'	28.76	"	104	°	47	'	30.61	"	5784	40
Parker	The Bluffs - Tower Site	39	°	30	'	25.50	"	104	°	50	'	39.90	"	6305	30
Cunningham	Cunningham Station 03	39	°	37	'	7.40	"	104	°	44	'	17.09	"	5873	30
Douglas County	Justice Center	39	°	24	'	8.05	"	104	°	51	'	51.08	"	6162	75
Douglas County	Miller Building	39	°	22	'	19.52	"	104	°	51	'	44.39	"	6195	45
Douglas County	Devil's Head	39	°	15	'	37.50	"	105	°	6	'	4.40	"	9748	12
Douglas County	West Creek	39	°	10	'	28.00	"	105	°	2	'	2.30	"	9196	80
Denver	Station 6	39	°	44	'	53.89	"	105	°	0	'	8.42	"	5195	60
Denver	20th and Broadway	39	°	44	'	57.00	"	104	°	59	'	15.50	"	5225	35 / 28
Denver	18th and Stout	39	°	44	'	52.40	"	104	°	59	'	24.30	"	5217	35 / 28
Denver	20th and Stout	39	°	45	'	0.46	"	104	°	59	'	19.76	"	5222	35 / 28
Denver	18th and Broadway	39	°	44	'	44.30	"	104	°	59	'	15.80	"	5225	35 / 28
Denver	15th and Court	39	°	44	'	29.30	"	104	°	59	'	22.70	"	5236	35 / 28
Denver	Broadway S of Colfax	39	°	44	'	23.00	"	104	°	59	'	14.40	"	5243	35 / 28

Appendix B
Detailed Deployment Information for Parker Application Testing
AP Locations and Antenna Configurations

1) Parker Adventist Hospital
    - Coordinates: 39° 32’ 54.05” N; 104° 46’ 15.65” W,
    - Elevation 5820.75 ft MSL; 75 ft AGL on Roof
    - Antenna Til-Tek TA-4904-14-90, serial number 51027.1
    - Azimuth 283.4°T
    - AP Proxim 4900 M AP, Serial Number 05UT-486-00308 ;
    - Build 1100
    - MAC Address: 00:20:A6:5D:7C:99

2) Parker Administration Building
    - Coordinates: 39° 31’ 53.70” N; 104° 45’ 57.72” W,
    - Elevation 5885.12 ft MSL; 45 ft AGL on Roof
    - Antenna Til-Tek TA-4904-14-90, serial number 50686.4,
    - Azimuth 285.4°T
    - AP Proxim 4900 M AP, Serial Number 05UT-48570297;
    - Build 1100
    - MAC Address: 00:20:A6:5D:9E:66

3) Bradbury Tank – Antenna 1
    - Coordinates: 39° 30’ 3.68” N; 104° 48’ 10.44” W,
    - Elevation 6137.09 ft MSL; 12 ft AGL on Roof
    - Antenna Til-Tek TA-4904-14-90, serial number 50686.6
    - Azimuth 54.4°T
    - AP Proxim 4900 M AP, Serial Number 05UT-48600238;
    - Build 1100
    - MAC Address: 00:20:A6:5D:7B:C7

4) Bradbury Tank – Antenna 2 (toward the Bluffs)
    - Coordinates: 39° 30’ 3.68” N; 104° 48’ 10.44” W,
    - Elevation 6137.09 ft MSL; 12 ft AGL on Roof
    - Antenna Til-Tek TA-4904-14-90, serial number 51027.3
    - Azimuth 279.4°T
    - AP Proxim 4900 M AP, Serial Number 05UT-48570367;
    - Build 1100
    - MAC Address: 00:20:A6:5D:9F:38

5) Southeast Christian Church

- Coordinates: 39° 32' 28.76" N;
  104° 47' 30.61" W,
- Elevation 5783.63 ft MSL; 75 ft AGL on Roof
- Antenna Til-Tek TA-4904-14-90, serial number 50686.3
- Azimuth 96.4°T
- AP Proxim 4900 M AP, Serial Number 05UT-48570372 ;
- Build 1 100
- MAC Address: 00:20:A6:5D:9F:47

Appendix C

FCC Regulations Governing the Use of 4.9 GHz Frequencies

Appendix C
FCC Regulations Governing Use of 4.9 GHz Frequencies

Subpart Y—Regulations Governing Licensing and Use of Frequencies in the 4940–4990 MHz Band

SOURCE: 68 FR 38639, June 30, 2003, unless otherwise noted.

§ 90.1201 Scope.

This subpart sets out the regulations governing use of the 4940–4990 MHz (4.9 GHz) band. It includes eligibility requirements, and specific operational and technical standards for stations licensed in this band. The rules in this subpart are to be read in conjunction with the applicable requirements contained elsewhere in this part; however, in case of conflict, the provisions of this subpart shall govern with respect to licensing and operation in this band.

§ 90.1203 Eligibility.

(a) Entities providing public safety services as defined under section 90.523 are eligible to hold a Commission license for systems operating in the 4940–4990 MHz band. All of the requirements and conditions set forth in that section also govern authorizations in the 4940–4990 MHz band.

(b) 4.9 GHz band licensees may enter into sharing agreements or other arrangements for use of the spectrum with entities that do not meet these eligibility requirements. However, all applications in the band are limited to operations in support of public safety.

§ 90.1205 Permissible operations.

(a) Unattended and continuous operation is permitted.

(b) Voice, data and video operations are permitted.

(c) Aeronautical mobile operations are prohibited.

§ 90.1207 Licensing.

(a) A 4940–4990 MHz band license gives the licensee authority to operate on any authorized channel in this band within its licensed area of operation. *See* § 90.1213. A 4940–4990 MHz band license will be issued for the geographic area encompassing the legal jurisdiction of the licensee or, in case of a nongovernmental organization, the legal jurisdiction of the state or local governmental entity supporting the nongovernmental organization.

(b) Subject to § 90.1209, a 4940–4990 MHz band license gives the licensee authority to construct and operate any number of base stations anywhere within the area authorized by the license, except as follows:

(1) A station is required to be individually licensed if:

(i) International agreements require coordination;

(ii) Submission of an environmental assessment is required under § 1.1307 of this chapter; or

(iii) The station would affect areas identified in § 1.924 of this chapter.

(2) Any antenna structure that requires notification to the Federal Aviation Administration (FAA) must be registered with the Commission prior to construction under § 17.4 of this chapter.

(c) A 4940–4990 MHz band license gives the licensee authority to operate base and mobile units (including portable and handheld units) and operate temporary (1 year or less) fixed stations anywhere within the area authorized by the license. Such licensees may operate base and mobile units and/or temporary fixed stations outside their authorized area to assist public safety operations with the permission of the jurisdiction in which the radio station is to be operated. Base and temporary fixed stations are subject to the requirements of paragraph (b) of this section.

(d) A 4940–4990 MHz band license does not give the licensee authority to operate permanent fixed point-to-point stations. Licensees choosing to operate such fixed stations must license them individually on a site-by-site basis. Such fixed operation will be authorized only on a secondary, non-interference basis to base, mobile and temporary fixed operations.

[68 FR 38639, June 30, 2003, as amended at 69 FR 17959, Apr. 6, 2004]

§ 90.1209 Policies governing the use of the 4940–4990 MHz band.

(a) Channels in this band are available on a shared basis only and will not be assigned for the exclusive use of any licensee.

(b) All licensees shall cooperate in the selection and use of channels in order to reduce interference and make the most effective use of the authorized facilities. Licensees of stations suffering or causing harmful interference are expected to cooperate and resolve this problem by mutually satisfactory arrangements. If licensees are unable to do so, the Commission may impose restrictions including specifying the transmitter power, antenna height, or area or hours of operation of the stations concerned. Further, the Commission may prohibit the use of any 4.9 GHz channel under a system license at a given geographical location when, in the judgment of the Commission, its use in that location is not in the public interest.

(c) Licensees will make every practical effort to protect radio astronomy operations as specified in § 2.106, footnote US311 of this chapter.

(d) There is no time limit for which base and temporary fixed stations authorized under a 4940–4990 MHz band license must be placed in operation. Fixed point-to-point stations which are licensed on a site-by-site basis must be placed in operation within 18 months of the grant date or the authorization for that station cancels automatically.

§ 90.1211 Regional plan.

(a) To facilitate the shared use of the 4.9 GHz band, each region may submit a plan on guidelines to be used for sharing the spectrum within the region. Any such plan must be submitted to the Commission within 12 months of the effective date of the rules.

(b) Such plans must incorporate the following common elements:

(1) Identification of the document as a plan for sharing the 4.9 GHz band with the region specified along with the names, business addresses, business telephone numbers and organizational affiliations of the chairperson(s) and all members of the planning committee.

(2) A summary of the major elements of the plan and an explanation of how all eligible entities within the region were given an opportunity to participate in the planning process and to have their positions heard and considered fairly.

(3) An explanation of how the plan was coordinated with adjacent regions.

(4) A description of the coordination procedures for both temporary fixed and mobile operations, including but not limited to, mechanisms for incident management protocols, interference avoidance and interoperability.

(c) Regional plans may be modified by submitting a written request, signed by the regional planning committee, to the Chief, Wireless Telecommunications Bureau. The request must contain the full text of the modification, and a certification that all eligible entities had a chance to participate in discussions concerning the modification and that any changes have been coordinated with adjacent regions.

EFFECTIVE DATE NOTE: At 69 FR 51959, Sept. 23, 2004, paragraph (a) of § 90.1211 was stayed indefinitely.

§ 90.1213 Band plan.

The following channel center frequencies are permitted to be aggregated for channel bandwidths of 5, 10, 15 or 20 MHz. Channel numbers 1 through 5 and 15 through 18 are 1 MHz channels and channels numbers 6 through 14 are 5 MHz channels.

Center frequency (MHz)	Channel Nos.
4940.5	1
4941.5	2
4942.5	3
4943.5	4
4944.5	5
4947.5	6
4952.5	7
4957.5	8
4962.5	9
4967.5	10
4972.5	11
4977.5	12
4982.5	13
4985.5	14
4986.5	15
4987.5	16
4988.5	17
4989.5	18

§ 90.1215 Power limits.

The transmitting power of stations operating in the 4940–4990 MHz band must not exceed the maximum limits in this section.

(a) The peak transmit power should not exceed:

Channel bandwidth (MHz)	Low power peak transmitter power (dBm)	High power peak transmitter power (dBm)
1	7	20
5	14	27
10	17	30
15	18.8	31.8
20	20	33

High power devices are also limited to a peak power spectral density of 21 dBm per one MHz. High power devices using channel bandwidths other than those listed above are permitted; however, they are limited to a peak power spectral density of 21 dBm/MHz. If transmitting antennas of directional gain greater than 9 dBi are used, both the peak transmit power and the peak power spectral density should be reduced by the amount in decibels that the directional gain of the antenna exceeds 9 dBi. However, high power point-to-point or point-to-multipoint operation (both fixed and temporary-fixed rapid deployment) may employ transmitting antennas with directional gain up to 26 dBi without any corresponding reduction in the transmitter power or spectral density. Corresponding reduction in the peak transmit power and peak power spectral density should be the amount in decibels that the directional gain of the antenna exceeds 26 dBi.

(b) Low power devices are also limited to a peak power spectral density of 8 dBm per one MHz. Low power devices using channel bandwidths other than those listed above are permitted; however, they are limited to a peak power spectral density of 8 dBm/MHz. If transmitting antennas of directional gain greater than 9 dBi are used, both the peak transmit power and the peak power spectral density should be reduced by the amount in decibels that the directional gain of the antenna exceeds 9 dBi.

(c) The peak transmit power is measured as a conducted emission over any interval of continuous transmission calibrated in terms of an RMS-equivalent voltage. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. The measurement results shall be properly adjusted for any instrument limitations, such as detector response times, limited resolution bandwidth capability when compared to the emission bandwidth, sensitivity, etc., so as to obtain a true peak measurement conforming to the definitions in this paragraph for the emission in question.

(d) The peak power spectral density is measured as conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements are made over a bandwidth of one MHz or the 26 dB emission bandwidth of the device, whichever is less. A resolution bandwidth less than the measurement bandwidth can be used, provided that the measured power is integrated to show total power over the measurement bandwidth. If the resolution bandwidth is approximately equal to the measurement bandwidth, and much less than the emission bandwidth of the equipment under test, the measured results shall be corrected to account for any difference between the resolution bandwidth of the test instrument and its actual noise bandwidth.

[70 CFR 28467, May 18, 2005]

§ 90.1217 RF Hazards.

Licensees and manufacturers are subject to the radiofrequency radiation exposure requirements specified in §§ 1.1307(b), 2.1091 and 2.1093 of this chapter, as appropriate. Applications for equipment authorization of mobile or portable devices operating under this section must contain a statement confirming compliance with these requirements for both fundamental emissions and unwanted emissions. Technical information showing the basis for this statement must be submitted to the Commission upon request.

Subpart Z—Wireless Broadband Services in the 3650–3700 MHz Band

SOURCE: 70 FR 24726, May 11, 2005, unless otherwise noted.

Appendix D
Memorandum Opinion and Order
WT Docket 00-32
Adopted November 9, 2004

Reconsideration of Technical Rules for 4.9 GHz
as requested by
NPSTC (National Public Safety Telecommunications Council)

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	WT Docket No. 00-32
	)	
The 4.9 GHz Band Transferred from	)	
Federal Government Use	)	

MEMORANDUM OPINION AND ORDER

Adopted: November 9, 2004 **Released: November 12, 2004**

By the Commission:

I. INTRODUCTION

1. In this *Memorandum Opinion and Order* (*MO&O*), we consider a Petition for Reconsideration (Petition) filed on July 30, 2003, by the National Public Safety Telecommunications Council (NPSTC).[1] NPSTC requests us to reconsider certain of the technical rules in the *Memorandum Opinion and Order and Third Report and Order*, in which the Commission adopted licensing and service rules for the 4940-4990 MHz (4.9 GHz) band.[2] Herein, we grant the NPSTC petition in part by adopting new 4.9 GHz emission masks – one for high power operations (the DSRC-C mask)[3], and one for low power operations (the DSRC-A mask).[4] We also reaffirm our decisions in the *Third R&O* not to adopt a technology standard, and not to make regional planning[5] mandatory in the 4.9 GHz band.

[1] *See* Petition at 1. NPSTC is a federation of public safety associations that encourages and facilitates the implementation of recommendations of the Public Safety Wireless Advisory Committee (PSWAC) and the 700 MHz Public Safety National Coordination Committee (NCC).

[2] The 4.9 GHz Band Transferred from Federal Government Use, *Memorandum Opinion and Order and Third Report and Order*, 18 FCC Rcd 9152 (2003) (*Third R&O*).

[3] The DSRC (Dedicated Short Range Communications) masks A and C are contained in the ASTM International Standard E 2213-03, *Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems-5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications*. The ASTM standard was adopted in Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz band (5.9 GHz band), *Report and Order*, 19 FCC Rcd 2458 (2004). *See* 47 C.F.R. §§ 90.379, 95.1509.

[4] *Id*.

[5] Under a regional planning scheme, the country is divided into regions that have autonomy to develop plans that appropriately meet their different communications needs. To facilitate the shared use of the 4.9 GHz band, each region may (but not must) submit guidelines to be used for sharing the spectrum within their respective regions. *See* 47 C.F.R. § 90.1211.

II. BACKGROUND

2. The 4.9 GHz band was transferred from Federal Government to non-Federal Government use in 1999, in accordance with the provisions of the Omnibus Budget Reconciliation Act.[6] In 2000, the Commission released a *Notice of Proposed Rulemaking* proposing to allocate the 4.9 GHz band to non-Government fixed and mobile services, and to allow flexible use of this band.[7] In 2002, the Commission adopted the fixed and mobile allocation, designated the band for use in support of public safety, and sought comment on the establishment of licensing and service rules for the 4.9 GHz band.[8] In the *Third R&O,* the Commission adopted service rules for use of this band and addressed petitions for reconsideration of its decision to prohibit aeronautical mobile operations in this band.[9]

3. The current NPSTC Petition urges us to adopt two different emission masks, one mask for low power operations, the other for high power operations.[10] NPSTC also proposes a technology standard for general and interoperability use in the 4.9 GHz band,[11] and seeks mandatory regional planning and the inclusion of a conflict resolution process in regional plans.[12] We received comments on the NPSTC proposals from equipment manufacturers, standards organizations, public safety licensees and others.[13]

4. In the *Second R&O and FNPRM,* the Commission sought comment on whether technical standards should be adopted for the 4.9 GHz band, and, if so, what standards would be appropriate.[14] The Commission then adopted a flexible band plan suited to emerging broadband technologies that could enhance public safety operations.[15] It also adopted an emission mask to minimize out-of-band emissions that could result in interference between 4.9 GHz devices.[16] This mask, currently incorporated into Section 90.210 of the Rules,[17] is referred to herein as the *Section 90.210 Mask*. The parameters of this

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[6] Omnibus Budget Reconciliation Act of 1993, Pub. L. No. 103-66, 107 Stat. 312 (OBRA-93).

[7] The 4.9 GHz Band Transferred from Federal Government Use, *Notice of Proposed Rulemaking*, 15 FCC Rcd 4778 (2000).

[8] The 4.9 GHz Band Transferred from Federal Government Use, *Second Report and Order and Further Notice of Proposed Rule Making*, 17 FCC Rcd 3955 (2002) (*Second R&O and FNPRM*).

[9] *See Third R&O,* 18 FCC Rcd at 9152.

[10] *See* Petition at 5. In the *Third R&O*, the Commission adopted a single emission mask. *Third R&O,* 18 FCC Rcd at 9174.

[11] *See* Petition at 11, 18. "Interoperability" is an essential communications link within public safety and public service wireless communication systems, which permits units from two or more different entities to interact with one another, exchanging information according to a prescribed method, in order to achieve predictable results. *See* 47 C.F.R. § 90.7.

[12] *See* Petition at 5.

[13] *See generally* comments of: PacketHop; the New York State Office for Technology Statewide Wireless Network; Motorola Inc.; Proxim Corporation; Cisco Systems, Inc.; and IEEE 802.18 Group. The IEEE 802.18 Group is the Radio Regulatory Technical Advisory Group within the IEEE Local and Metropolitan area Networks Standards Committee (IEEE 802 and LMSC IEEE 802). IEEE 802 functions as a consensus-based industry-standards body, producing standards for wireless networking devices, including wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless metropolitan area networks (Wireless MANs).

[14] *See Second R&O and FNPRM,* 17 FCC Rcd at 3981¶ 63.

[15] *See Third R&O,* 18 FCC Rcd at 9172 ¶ 48.

[16] *Id.* at 9174 ¶ 54.

[17] 47 C.F.R. § 90.210.

mask were derived from recommendations from the two parties commenting on the emission mask, Motorola, Inc. (Motorola) and the Association of Public-Safety Communications Officials-International, Inc. (APCO).[18]

III. DISCUSSION

A. Emission Mask

5. *Background.* In the instant Petition, NPSTC submits that the *Section 90.210 Mask* is unnecessarily restrictive and would add significantly to the cost of 4.9 GHz equipment, thereby potentially delaying public safety's use of the band.[19] It argues that public safety must leverage currently available (*i.e.,* "commercial-off-the-shelf" (COTS)) technologies used in adjacent bands, such as the 5.4 GHz Unlicensed National Information Infrastructure (U-NII) unlicensed band[20] and the Intelligent Transportation System (ITS) band.[21] NPSTC indicates that the current mask would prohibit any significant transfer of technology from the equipment used in these bands. For example, NPSTC contends that the more restrictive mask would hamper the ability of 4.9 GHz equipment to use chipsets employed in equipment designed for the U-NII or ITS bands.[22]

6. As a substitute for the *Section 90.210 Mask*, NPSTC recommends that the Commission adopt the DSRC-A and DSRC-C masks applicable to ITS equipment.[23] It proposes the DSRC-A mask for low power 4.9 GHz devices with transmitter output power of 20 dBm or less, and recommends the DSRC-C mask for higher power 4.9 GHz devices with transmitter power output greater than 20 dBm. It also contends that adoption of these emission masks could enable manufacture of devices that could operate in the 4.9 GHz band, the ITS band and the U-NII band, thus providing the public safety community access to these bands using a single, low-cost, device.[24]

7. In its comments, PacketHop, Inc. (PacketHop), a supplier of mobile broadband *ad hoc* networking and applications for public safety, states that adopting NPSTC's recommendations would create incentives for IEEE 802.11 manufacturers[25] to leverage their current technical skills and

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[18] Motorola recommendations include emissions masks for the 5, 10, 15 and 20 MHz channels. *See* Motorola *ex parte* presentation dated Jan. 15, 2003. APCO recommends an emission mask for one megahertz channels. *See* APCO *ex parte* presentation dated Feb. 4, 2003.

[19] *See* Petition at 4.

[20] *See* Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5.4 GHz band, *Report and Order*, 18 FCC Rcd 24484 (2003). Part 15 of our Rules sets forth the technical requirements for U-NII technology and applications. *See* 47 C.F.R. §§ 15.401-15.407. These rules employ spectral power density limits, rather than emission masks, to limit in-band and out-of-band power. *See* 47 C.F.R. §15.407.

[21] ITS or Dedicated Short Range Communications (DSRC) systems operate in the 5.850-5.925 GHz band. *See* Amendment of the Commission's Rules Regarding Dedicated Short-Range Communication Services in the 5.850-5.925 GHz band (5.9 GHz band), *Report and Order*, 19 FCC Rcd 2458 (2004).

[22] Petition at 5.

[23] *Id.* at 6. *See also* NPSTC further comments filed Oct. 2, 2003. See also 47 C.F.R. § 90.379 and § 95.1509.

[24] Petition at 5-11.

[25] By use of this term, we refer to manufacturers that produce equipment compliant with IEEE 802.11. IEEE 802.11 is a family of specifications developed by the IEEE for wireless local area network (LAN) technology. 802.11 specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. There are several specifications in the 802.11 family, including: 802.11, 802.11a and 802.11j. 802.11 applies to (continued….)

manufacturing techniques to develop new, low cost, reliable devices, built to a nationwide uniform technical standard. These devices, PacketHop claims, would give the public safety community access to affordable and interoperable equipment.[26] The IEEE 802.18 Group[27] submits that:

> The mask identified in the amended Rules 90.210 (l) [47 C.F.R. § 90.210] will explicitly preclude the use of widely available equipment compliant with IEEE 802.11a standards and that to meet the mask as currently specified would require the redesign of existing chipsets and equipment specifically for use in this band, creating a niche market that will result in much higher equipment costs with virtually no benefit to the Public Safety community.[28]

It further indicates:

> Use of the IEEE 802.11a channel mask [which is identical to the DSRC-A mask] will have minimal effect on in-band interference between channels and will permit the use of IEEE 802.11a compliant equipment.[29]

8. Motorola initially favored the use of the DSRC-C mask at power levels of 0 dBm or more, indicating that there are relatively straightforward and inexpensive ways to meet standards such as the *Section 90.210 Mask* and the DSRC-C mask, while still being able to take advantage of COTS technology.[30] It offered simulations purporting to show that use of the DSRC-A mask at power levels up to 20 dBm would result in excessive interference when multiple 4.9 GHz devices are used at the site of an incident.[31] Later, however, Motorola reached a consensus with NPSTC that the DSRC-A and DSRC-C masks were a reasonable regulatory substitute for the *Section 90.210 Mask,*[32] and that the DSRC-A mask should be used for low power devices while the more restrictive DSRC-C mask should be used for high power devices. However, NPSTC and Motorola reached no consensus on the definition of "high power" and "low power" in this context. Motorola argued that devices using powers greater than 8 dBm should be classified as high power; whereas NPSTC maintained that devices should be classified as "low power" if they employed powers of 20 dBm or less.[33]

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wireless LANs and provides 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum or direct sequence spread spectrum. 802.11a is an extension to 802.11 that applies to wireless LANs and provides up to 54 Mbps in the 5 GHz band. 802.11a uses an orthogonal frequency division multiplexing (OFDM) encoding scheme. The 802.11j standard incorporates Japanese regulatory extensions to the 802.11 standard. It provides performance resembling 802.11a, but uses a different part of the 5 GHz spectrum.

[26] *See* PacketHop comments at 1.

[27] For a definition, *see* note 13, *supra.*

[28] *See* IEEE 802.18 Group comments at 2.

[29] *Id.* The IEEE 802.18 Group indicates that the DSRC-A mask proposed by NPSTC is identical to the 802.11a mask. IEEE 802.18 Group comments at 2. The technical standard for 802.11a equipment, IEEE Standard. 802.11a-1999, contains identical emission mask requirements.

[30] *See* Motorola comments at 5, including Appendix A.

[31] *Id.* Appendix B.

[32] *See* Motorola *ex parte* letter dated Sept. 13, 2004 at 1.

[33] *See* NPSTC reply comments at 12.

9. Ultimately, on September 10, 2004, NPSTC filed an *ex parte* document that included a set of recommended rules that put the "high power" breakpoint at 20 dBm.[34] On the next business day, Motorola filed an *ex parte* letter stating that while it continued to believe that an 8 dBm breakpoint was more appropriate, "Motorola and NPSTC concur on the rules needed if a 20 dBm breakpoint is used."[35]

10. *Decision.* We recognize that benefits would accrue to public safety agencies if they could use 4.9 GHz devices adapted from COTS technologies in nearby bands. In particular, leveraging such technologies could result in savings for state and local governments and provide the potential for deployment of dual-band devices that make Internet access available via the U-NII band adjacent to the 4.9 GHz band. We are persuaded by the comments submitted that we may safely adopt the DSRC-A and DSRC-C masks[36] in lieu of the *Section 90.210 Mask* currently in our Rules, and, therefore, will not burden public safety agencies with unnecessary costs for 4.9 GHz devices.

11. We are encouraged that Motorola and NPSTC reached consensus on the rules proposed by NPSTC.[37] However, after review of the submissions by all parties, we believe that 20 dBm is, in fact, the appropriate breakpoint. This power level strikes a reasonable balance between interference avoidance and 4.9 GHz equipment affordability.[38]

12. Our decision to adopt a 20 dBm breakpoint is also grounded on the fact that even consumer equipment in this frequency range is relatively tolerant of interference. The DSRC-A mask is identical to the mask defined in the widely-used 802.11 "Wi-Fi" standard for equipment used for in-home wireless LANs and found in consumer "hotspots" in businesses ranging from coffee shops to airports. The adjacent channel rejection (ACR) of an 802.11 receiver, using Orthogonal Frequency Division Multiplexing (OFDM), is defined by data throughput as a function of the level of adjacent channel interference. For example, an 802.11 receiver can sustain data throughput of 48 Mbits/s in the presence of an equal-power adjacent channel signal and a throughput of 6 Mbits/s when the adjacent channel signal is 16 dB higher.[39] Thus, adjacent channel interference in these systems is a "graceful degradation" of data throughput, although loss of service can eventually result at higher levels of adjacent channel interference. Moreover, the potential for interference can be anticipated and taken into account in the placement of 4.9 GHz devices at the scene of an incident.

13. In assessing the proper breakpoint for requiring the more restrictive emission mask, we were mindful that, although 4.9 GHz equipment operating at power levels of 8 dBm or less may be adequate for consumer applications, the reliability requirements of public safety communications favor

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[34] *See* NPSTC *ex parte* letter dated Sept. 10, 2004 at 1-2.

[35] *See* Motorola *ex parte* letter dated Sept. 13, 2004 at 1.

[36] *See* comments of: PacketHop at 1; the New York State Office for Technology Statewide Wireless Network at 4; Cisco Systems, Inc. at 2; and IEEE 802.18 Group at 2.

[37] *See* Motorola *ex parte* letter dated Sept. 13, 2004 at 1.

[38] Motorola indicates that incorporating a more restrictive emission mask for 4.9 GHz devices would cost only about $3.00 per device for additional components. *See* Motorola *ex parte* filing, Aug. 19, 2004 at 19; *see also Motorola* ex parte letter dated Aug. 30, 2004. We note, however, that component cost is not the only factor which affects the ultimate cost of such devices. We note that Motorola does not take into account factors such as design expense, testing, retooling, inventory management, and the loss of economies of scale inherent in producing specialized equipment for a public safety market, which, although significant, is substantially smaller, by orders of magnitude, than the general consumer market. *See, e.g.*, 4.9 GHz Open Standards Coalition *ex parte* filing, Aug. 23, 2004.

[39] *See* IEEE Std 802.11a-1999, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, High-speed physical layer in the 5 GHz Band, available for download on the IEEE website, http://standards.ieee.org/.

higher power levels, especially given propagation characteristics at these frequencies. Accordingly, were we to preclude use of higher power on affordable units using the DSRC-A mask, such devices could have so few applications that they might be unattractive to public safety agencies, which then would have to resort to specialized higher power units employing the DSRC-C mask -- if they could afford such units. By comparison, allowing the DSRC-A mask to be used for low-cost 4.9 GHz devices at power levels up to 20 dBm would provide enhanced reliability -- notably when obstructions are present between devices -- albeit with the possibility of some degradation in throughput if multiple systems are operated on adjacent channels in close proximity to one another. In sum, technical, economic and operational considerations have informed our decision that the DSRC-A mask should be permitted for power levels of 20 dBm and less, and that the DSRC-C mask should apply to all power levels in excess of 20 dBm**.**

B. Compatible Technology Standards

14. NPSTC contends that technology standards are necessary to provide roaming capability[40] and requests us to develop a "clear path" toward identification and adoption of a technology standard for general and interoperability use within the 4.9 GHz band.[41] NPSTC believes a standard could be developed within the next eighteen months[42] and that, once the standard is established, users should be given approximately three years, to migrate to the standard.[43]

15. In the *Second R&O and FNPRM,* the Commission sought comment on the adoption of two widely contemplated broadband standards available for wireless: LAN-IEEE standard 802.11a, and European Telecommunications Standardization Institute (ETSI) Broadband Radio Access Network (BRAN) High Performance Local Area Network number two (HiperLAN2).[44] In the comments, some parties recommended the adoption of the 802.11a standard because of its utility for mobile applications,[45] and others urged adoption of a flexible band plan that would accommodate other emerging broadband technologies.[46] Previously, the Commission found that considerations of minimal regulation and licensee flexibility outweighed any benefits that adoption of a single standard would confer.[47] It thus declined to adopt technology standards and stated that potential interference between devices using different standards could be minimized if licensees cooperated in the selection and use of channels.[48] NPSTC asks us to revisit that determination because, they maintain, differing technologies operating at the same site could generate interference that could disrupt communications. NPSTC believes this interference could be avoided by use of Internet Protocol-based (IP) applications that would allow users to "roam seamlessly across infrastructures (their own and others), with their traffic routed appropriately to its destination across an Internet-type backbone."[49]

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[40] *See* Petition at 14-15.

[41] *Id.* at 11.

[42] *Id.* at 15.

[43] *Id.* at 16.

[44] *Second R&O and FNPRM*, 17 FCC Rcd 3955, 3982 ¶ 65 (2002).

[45] *See Third R&O*, 18 FCC Rcd at 9172 ¶ 48.

[46] *Id*.

[47] *Id*.

[48] *See* 47 C.F.R. § 90.1209.

[49] *See* Petition at 14-15. Motorola also supports the development of a 4.9 GHz technology standard, claiming it would allow various equipment vendors to provide interoperable products. However, as Motorola concedes no (continued….)

16. *Decision.* We believe that there is an insufficient record to justify adoption of technical standards that would provide interoperability in the 4.9 GHz band. Moreover, the band is likely to be used for a variety of services that do not readily lend themselves to standardization or interoperability. Thus, for example, users may consider a fixed video camera and a mobile data terminal as distinctly separate applications without a need to interoperate: the video camera cannot display data and the mobile data terminal would not normally be used to display video from the camera. Also, were we to adopt a standard, it likely would cement the 4.9 GHz band in 2004 technology such that public safety would be denied the benefits of emerging broadband technologies. Finally, even were a standard realizable in eighteen months, as NPSTC suggests, we see no point in depriving the public safety community the use of the 4.9 GHz band in the interim in the hope that a useful standard could be adopted by that time.[50] We therefore reaffirm our determination in the *Third R&O* that interoperability technical standards for the 4.9 GHz band would be counterproductive.

C. Regional Planning

17. NPSTC supports mandatory regional planning and the inclusion of a conflict resolution process in regional plans. We disagree and reaffirm our decision in the *Third R&O.*[51] Our primary rationale for rejecting mandatory regional planning lies in the shared-use structure we have established for the 4.9 GHz band. Applicants that meet eligibility criteria will be granted a geographic area license for the entire fifty MHz of 4.9 GHz spectrum over a geographical area defined by the boundaries of their jurisdiction -- city, county, state, etc.[52] Licensees are required to coordinate their operations in the shared band to avoid interference, a common practice when joint operations are conducted.[53]

18. The functions served by Regional Planning Committees (RPCs)[54] in the public safety segments of the 700 MHz and 800 MHz bands entail the long-term planning for the use of specific channels by discrete licensees, in bands where public safety agencies are not granted a blanket license for the entire spectrum. Nonetheless, the Commission directed each 700 MHz RPC to consider coordination procedures for the 4.9 GHz band, and that each may submit to the Commission such a plan.[55] It envisioned that the plans would specify best practices for efficient use of the 4.9 GHz band, including, for example, procedures to allow an incident commander to take control of emergency communications

standard has emerged that would provide the mix of frequency band, center frequencies, interoperability and detailed security features needed for 4.9 GHz band operations.

[50] *See* Petition at 15-16. Although NPSTC suggests that users of the 4.9 GHz band should be given three years to migrate to a new standard, it is questionable whether the typical user would invest in 4.9 GHz equipment that would be rendered obsolete within just a few years. *See id.*

[51] *Third R&O*, 18 FCC 9152 (2003).

[52] *Id.* at 9164 ¶¶ 27-28.

[53] *Id.* at 9164 ¶ 28.

[54] *See* note 5, *supra.*

[55] *Third R&O*, 18 FCC at 9169 ¶ 40. The due date for such plans was originally one year after the effective date of the current rules. *See id.* As the rules became effective on June 26, 2003, RPC plans were originally due on July 30, 2004. *See* The 4.9 GHz Band Transferred from Federal Use, *Order,* 19 FCC Rcd 152270 ¶ 1 (2004) (*Stay*). However, on June 26, 2004, the National Association of Regional Planning Committees (NARPC) filed a request to stay the July 30, 2004 deadline until twelve months after the Commission resolves the current Petition. *See* Letter dated June 24, 2004 from Chairman, Stephen T. Devine, Chairman, National Association of Regional Planning Committees (NARPC) to Marlene H. Dortch, FCC. On August 2, 2004, 2004, we released an order granting this stay until six months after the release date of the instant decision. *See Stay,* 19 FCC Rcd at 15270 ¶ 9.

pursuant to compacts made with adjacent and overlapping jurisdictions.[56] In the event an RPC does not submit such a plan, licensees must cooperate in the selection and use of channels in order to reduce interference and make the most effective use of authorized facilities.[57]

19. *Decision.* We continue to believe that the technical expertise resident in the RPCs may be quite useful to new 4.9 GHz licensees, and we encourage dialog between them. However, we have not been shown that coordination of 4.9 GHz operations will be facilitated by requiring 4.9 GHz licensees to make mandatory use of the RPCs. The principal task of RPCs is to coordinate selection of specific channels for use at static base stations (and their associated mobiles). However, given the whole-band licensing structure that we have established and the likelihood that deployment of 4.9 GHz equipment is likely to be dynamic rather than static, it would appear impractical to formulate, in advance, an optimum distribution of channel assignments that would be universally suitable for each incident. This is not to suggest that agencies should not coordinate use of channels at an incident, or not have a process for doing so. However, we believe that that task is best undertaken by local jurisdictions, and we thus are not prepared to mandate use of RPCs for a purpose markedly different from that for which they were formed.

20. Our decision essentially renders moot NPSTC's request that we require RPCs to establish procedures for resolving disputes over the use of 4.9 GHz frequencies. However, we are aware that 700 MHz and 800 MHz RPCs do have procedures for resolution of disputes among licensees using those bands. Accordingly, these RPCs may be well-equipped to mediate disputes arising between 4.9 GHz licensees, should such licensees voluntarily elect to submit such disputes to mediation. We do not believe, however, that the possibility of such requests for voluntary mediation is a sufficient reason to require RPCs to develop 4.9 GHz dispute resolution procedures and, accordingly, we decline NPSTC's request to do so.

IV. PROCEDURAL MATTERS

A. Final Regulatory Flexibility Certification

21. As required by the Regulatory Flexibility Act (RFA), *see* 5 U.S.C. § 604, the Commission has prepared a Final Regulatory Flexibility Certification for this *Memorandum Opinion and Order* and is included as Appendix A.

B. Ordering Clauses

22. ACCORDINGLY, IT IS ORDERED that Part 90 of the Commission's Rules is amended as specified in Appendix B, effective 60 days after publication of this Memorandum Opinion and Order in the Federal Register.

23. IT IS FURTHER ORDERED pursuant to Sections 4(i), 303(r), and 405 of the Communications Act of 1934, as amended, 47 U.S.C. §§ 154(i), 303(r), 405, and Section 1.429 of the Commission's Rules, 47 C.F.R. § 1.429, that the petition for reconsideration filed by the National Public Safety Telecommunications Council is GRANTED IN PART and DENIED IN PART, to the extent set forth above.

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[56] *Id.* at 9169 ¶ 41.

[57] *Third R&O*, 18 FCC at 9169.

24. IT IS FURTHER ORDERED that the Commission's Consumer and Governmental Affairs Bureau, Reference Information Center, SHALL SEND a copy of this *Memorandum Opinion and Order*, including the Final Regulatory Flexibility Certification, to the Chief Counsel for Advocacy of the Small Business Administration.

FEDERAL COMMUNICATIONS COMMISSION

Marlene H. Dortch
Secretary

APPENDIX A

FINAL REGULATORY FLEXIBILITY CERTIFICATION

1. As required by the Regulatory Flexibility Act (RFA),[58] a Final Regulatory Flexibility Analysis (FRFA) was incorporated in the *Third R&O.*[59] In view of the fact that we have adopted further rule amendments in this *Memorandum Opinion and Order (MO&O)*, we have included this Final Regulatory Flexibility Certification. This Certification conforms to the RFA.[60]

2. The RFA requires that regulatory flexibility analysis be prepared for rulemaking proceedings unless the agency certifies that "the rule will not, if promulgated, have a significant economic impact on a substantial number of small entities." The RFA generally defines "small entity" as having the same meaning as the term "small business," "small organization," and "small governmental jurisdiction." In addition, the term "small business" has the same meaning as the term "small business concern" under the Small Business Act. A small business concern is one which: (1) is independently owned and operated; (2) is not dominant in its field of operation; and (3) satisfies any additional criteria established by the Small Business Administration (SBA).

3. This *MO&O* relaxes the technical emission limits adopted in the *3rd R&O* for devices operating in the band 4940-4990 MHz, to be used exclusively for public safety services. Our action may affect equipment manufacturers since technical equipment parameters are being changed. However, as service rules for the 4.9 GHz band have been recently adopted,[61] equipment has not yet been developed and certified under the Commission's rules.

4. Therefore, we certify that the requirements of this *MO&O* will not have a significant economic impact on a substantial number of small entities. The Commission will send a copy of the *MO&O,* including a copy of this final certification, in a report to Congress pursuant to the Congressional Review Act, *see* U.S.C. § 801(a)(1)(A). In addition, the *MO&O* and this certification will be sent to the Chief Counsel for Advocacy of the Small Business Administration, and will be published in the Federal Register. *See* U.S.C. § 605(b).

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[58] *See* 5 U.S.C. § 603. The RFA (*see* 5 U.S.C. § 601 – 612) has been amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), Pub. L. No. 104-121, Title II, 110 Stat. 857 (1996).

[59] The 4.9 GHz Band Transferred from Federal Government Use, *Memorandum Opinion and Order and Third Report and Order*, 18 FCC Rcd 9152 (2003) (*Third R&O*).

[60] *See* 5 U.S.C. § 604.

[61] *Third R&O,* 18 FCC Rcd 9152 (2003).

APPENDIX B

FINAL RULES

Part 90 of Title 47 of the Code of Federal Regulations, is revised to read as follows:

PART 90 – PRIVATE LAND MOBILE RADIO SERVICES

1. The authority citation for Part 90 continues to read as follows:

AUTHORITY: Sections 4(i), 11, 303(g), 303(r) and 332(c)(7) of the Communications Act of 1934, as amended, 47 U.S.C. 154(i), 161, 303(g), 303(r), 332(c)(7).

2. Section 90.210 is amended specifically by amending the entry in the table for the 4940-4990 MHz frequency band in the undesignated paragraph, by replacing paragraph (l), redesignating paragraphs (m) and (n) as paragraphs (n) and (o) and by adding a new paragraph (m) to read as follows:

§ 90.210 Emission masks.

Frequency band (MHz)	Mask for equipment with audio low pass filter	Mask for equipment without audio low pass filter
* * * * *	* * * * *	* * * * *
4940-4990 MHz	L or M……………	L or M
* * * * *	* * * * *	* * * * *

* * * * *

(l) *Emission Mask L*. For low power transmitters (20 dBm or less) operating in the 4940-4990 MHz frequency band, the power spectral density of the emissions must be attenuated below the output power of the transmitter as follows:

(1) On any frequency removed from the assigned frequency between 0 - 45 % of the authorized bandwidth (BW): 0 dB.

(2) On any frequency removed from the assigned frequency between 45 – 50 % of the authorized bandwidth: 219 log (% of (BW) / 45) dB.

(3) On any frequency removed from the assigned frequency between 50 - 55 % of the authorized bandwidth: 10 + 242 log (% of (BW) / 50) dB.

(4) On any frequency removed from the assigned frequency between 55 – 100 % of the authorized bandwidth: 20 + 31 log (% of (BW) / 55) dB attenuation.

(5) On any frequency removed from the assigned frequency between 100 – 150 % of the authorized bandwidth: 28 + 68 log (% of (BW) / 100) dB attenuation.

(6) On any frequency removed from the assigned frequency above 150 % of the authorized bandwidth: 50 dB.

(7) The zero dB reference is measured relative to the highest average power of the fundamental emission measured across the designated channel bandwidth using a resolution bandwidth of at least one percent of the occupied bandwidth of the fundamental emission and a video bandwidth of 30 kHz. The power spectral density is the power measured within the resolution bandwidth of the measurement device divided by the resolution bandwidth of the measurement device. Emission levels are also based on the use of measurement instrumentation employing a resolution bandwidth of at least one percent of the occupied bandwidth.

(m) *Emission Mask M*. For high power transmitters (greater that 20 dBm) operating in the 4940-4990 MHz frequency band, the power spectral density of the emissions must be attenuated below the output power of the transmitter as follows:

(1) On any frequency removed from the assigned frequency between 0 - 45 % of the authorized bandwidth (BW): 0 dB.

(2) On any frequency removed from the assigned frequency between 45 – 50 % of the authorized bandwidth: 568 log (% of (BW) / 45) dB.

(3) On any frequency removed from the assigned frequency between 50 - 55 % of the authorized bandwidth: 26 + 145 log (% of BW / 50) dB.

(4) On any frequency removed from the assigned frequency between 55 – 100 % of the authorized bandwidth: 32 + 31 log (% of (BW) / 55) dB.

(5) On any frequency removed from the assigned frequency between 100 – 150 % of the authorized bandwidth: 40 + 57 log (% of (BW) / 100) dB.

(6) On any frequency removed from the assigned frequency between above 150 % of the authorized bandwidth: 50 dB or 55 + 10 log (P) dB, whichever is the lesser attenuation.

(7) The zero dB reference is measured relative to the highest average power of the fundamental emission measured across the designated channel bandwidth using a resolution bandwidth of at least one percent of the occupied bandwidth of the fundamental emission and a video bandwidth of 30 kHz. The power spectral density is the power measured within the resolution bandwidth of the measurement device divided by the resolution bandwidth of the measurement device. Emission levels are also based on the use of measurement instrumentation employing a resolution bandwidth of at least one percent of the occupied bandwidth.

(Note: Low power devices may as an option, comply with paragraph (m).)

* * *

3. Section 90.1215 is amended to read as follows:

§ 90.1215 Power limits.

The transmitting power of stations operating in the 4940-4990 MHz band must not exceed the maximum limits in this section.

(a) The peak transmit power should not exceed:

Channel Bandwidth (MHz)	Low power peak transmitter power (dBm)	High power peak transmitter power (dBm)
1	7	20
5	14	27
10	17	30
15	18.8	31.8
20	20	33

(a) High power devices are also limited to a peak power spectral density of 21 dBm per one MHz. High power devices using channel bandwidths other than those listed above are permitted; however, they are limited to a peak power spectral density of 21 dBm/MHz. If transmitting antennas of directional gain greater than 9 dBi are used, both the peak transmit power and the peak power spectral density should be reduced by the amount in decibels that the directional gain of the antenna exceeds 9 dBi. However, high power point-to-point or point-to-multipoint operation (both fixed and temporary-fixed rapid deployment) may employ transmitting antennas with directional gain up to 26 dBi without any corresponding reduction in the transmitter power or spectral density. Corresponding reduction in the peak transmit power and peak power spectral density should be the amount in decibels that the directional gain of the antenna exceeds 26 dBi.

(b) Low power devices are also limited to a peak power spectral density of 8 dBm per one MHz. Low power devices using channel bandwidths other than those listed above are permitted; however, they are limited to a peak power spectral density of 8 dBm/MHz. If transmitting antennas of directional gain greater than 9 dBi are used, both the peak transmit power and the peak power spectral density should be reduced by the amount in decibels that the directional gain of the antenna exceeds 9 dBi.

(c) The peak transmit power is measured as a conducted emission over any interval of continuous transmission calibrated in terms of an RMS-equivalent voltage. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. The measurement results shall be properly adjusted for any instrument limitations, such as detector response times, limited resolution bandwidth capability when compared to the emission bandwidth, sensitivity, etc., so as to obtain a true peak measurement conforming to the definitions in this paragraph for the emission in question.

(d) The peak power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements are made over a bandwidth of one MHz or the 26 dB emission bandwidth of the device, whichever is less. A resolution bandwidth less than the measurement bandwidth can be used, provided that the measured power is integrated to show total power over the measurement bandwidth. If the resolution bandwidth is approximately equal to the measurement bandwidth, and much less than the emission bandwidth of the equipment under test, the measured results shall be corrected to account for any difference between the resolution bandwidth of the test instrument and its actual noise bandwidth.

APPENDIX C

LIST OF PLEADINGS

Petition for Reconsideration

National Public Safety Telecommunications Council (NPSTC)

Comments

Cisco Systems, Inc. (Cisco)

Institute of Electrical and Electronics Engineering 802.18 Radio Regulatory Technical Advisory Group (IEEE 802 Group)

Motorola, Inc. (Motorola)

National Public Safety Telecommunications Council (NPSTC)

PacketHop, Inc. (PacketHop)

Proxim Corporation (Proxim)

`Reply Comments

National Public Safety Telecommunications Council (NPSTC)

New York State Office for Technology Statewide Wireless Network (SWN)

Ex Parte

Association of Public-Safety Communications Officials International, Inc. (APCO)

Motorola, Inc. (Motorola)

National Public Safety Telecommunications Council (NPSTC)

Appendix E
Proxim 4900M Access Point

ORiNOCO AP-4000

For Mobile Enterprise and Metro-Area Network Applications

APPLICATIONS

- **Metro Wi-Fi outdoor deloyments**
  Broad coverage for public safety, business and residential usage
- **Large corporations**
  Mobile access to improve employee, contractor and customer efficiency
- **Universities**
  Flexible, immediate, mobile faculty and student connectivity in dorms, classrooms, libraries and campus quads
- **Hospitals and medical clinics**
  Real time information system wide for better patient care and reduced errors
- **Local, state and federal agencies**
  Fast access to information to serve constituencies better

Highest-Performance Access Point Delivers Scalability for Large Wi-Fi Deployments

The ORiNOCO AP-4000 Access Point is the flagship solution in Proxim's next-generation line of access points supporting enterprise voice and video applications. The AP-4000 delivers enterprise-scale security, management and QoS features, and is pre-configured with tri-mode for best-in-class performance and flexibility in large deployments. The AP-4000 is perfect for large production Wi-Fi and metro-Wi-Fi networks.

- Tri-mode and AP-to-AP communication for deployment in large or hard-to-reach areas
- Unique 802.11a scalability – external antenna connector for increased transmit distance, and maximum system gain on B/B radio for repeating configurations
- Twice the memory of competing APs, ensuring software upgrade capacity
- Industry-leading throughput with 802.11g and 802.11a simultaneous operation, and new Super Mode
- New level of intelligent rogue access point and client detection
- Sophisticated hotspot interfaces with RADIUS integration
- Pre-standard IEEE 802.11e quality of service support for latency-sensitive applications

Proactive Security Measures to Protect Your Network

ORiNOCO access points support the latest security standards, including IEEE 802.11i and AES encryption, and add proactive security measures.

- IEEE 802.1X mutual authentication
- Dynamic per-user, per-session rotating keys
- Rogue access point detection, notification
- Secure management interfaces: SNMPv3, SSL and SSH
- Intra-cell blocking to prevent client-to-client snooping

Easy to Deploy and Manage

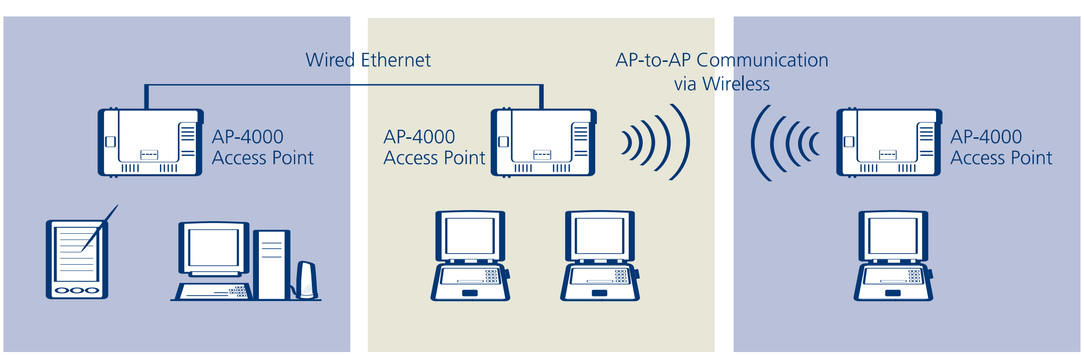
Ease of deployment and integration with the wired network are critical factors in a successful, profitable wireless LAN rollout. ORiNOCO access points excel with key capabilities that simplify WLAN deployment.

- Tools to speed installation and optimization: automatic channel selection, adjustable transmit power, external antenna connectors
- Wireless repeating functionality in areas without Ethernet wiring
- Remote management via SNMP, HTTP and Telnet
- Extensive RADIUS accounting support
- Powerful group configuration, software updates and automatic alerts via Proxim Wavelink Mobile Manager

Reliable by Design

With over 10 years of experience in the design and manufacture of wireless LANs, Proxim understands that service providers and enterprises require the same uptime and reliability in a wireless network as in a wired network. ORiNOCO access points offer:

- Robust features for enterprise, public access – compared to consumer grade APs
- Automatic reconfiguration of security policy in the event of power loss
- Dual firmware image support – for rollback in the event of software or configuration change problems
- IEEE 802.3af Power-over-Ethernet, plenum rating, built-in Kensington lock and external antenna connectors**



**Not available on all models

ORiNOCO AP-4000 Specifications

About Proxim

Proxim Corporation is a global leader in wireless networking equipment for Wi-Fi and broadband wireless networks. Proxim provides solutions for mobile enterprise applications, security and surveillance, last mile access, voice and data backhaul, public hot spots, and metropolitan area networks. Product families include ORiNOCO Wi-Fi products, Tsunami Ethernet bridges, and Lynx point-to-point digital radios.

ADDITIONAL FEATURES

Tri-mode 802.11b, 802.11g and 802.11a support	Pre-configured, simultaneous 802.11b, 802.11g and 802.11a support
Field upgradeable	Software upgradeable to support new standards
IEEE 802.11i and AES encryption	Highest authentication and encryption methods including mutual authentication, message integrity check (MIC), per-packet keys initialization vector hashing and broadcast key rotation
Rogue AP and Client Detection	Detects, alerts and stops unauthorized rogue Access Points and clients in both the 2.4 and 5 GHz bands[1]
Secure Management Interfaces	SNMPv3 and SSL protect against unauthorized AP changes via the management interface
Multiple VLAN Support with different security settings	Up to 16 separate VLANs per radio each able to support a different security setting
Auto configuration via DHCP	Ensures new APs automatically receive correct configuration and prevents security vulnerabilities with deliberate resets
Central management and configuration	Allows centralized management of AP settings including group updates of firmware[1]
Assured Software Upgrades	Guarantees new AP configuration file is valid before deleting current image - dual image support
Quality of Service	Draft IEEE 802.11e along with 802.1p and 802.1q improve performance of video and voice applications
High Output Power	+20 dBm for 802.11b, +18 dBm for 802.11g and 802.11a
Transmit Power Control	Supports settable transmit power levels to adjust coverage cell size
Automatic Channel Selection	Simplifies installation by choosing best possible channel upon installation
RADIUS Support	Extensive RADIUS Accounting support, intra-cell blocking to prevent client-to-client snooping, multiple VLAN support with different security modes
Super Mode	Delivers greater than 30 Mbps throughput for ORiNOCO and Atheros-based clients while simultaneously compatible with non-Atheros clients
Designed for Metro Wi-Fi	AP-to-AP communication for extension of wireless LAN to areas without Ethernet wiring (parking lots, long corridors, etc) for 802.11b, 802.11g and 802.11a
Advanced Filtering Capabilities	IEEE 802.1d bridging with static MAC address filtering, network protocol filtering, Proxy ARP, multicast/broadcast storm threshold filtering,TCP/UDP port filtering, intra-cell traffic filtering, and Spanning Tree support
IEEE 802.3af and AC Power	Decreases installation costs up to $1000 per AP when Power over Ethernet is available
Integrated diversity 2.4 and 5 GHz antennas with horizontal and vertical polarization	Delivers optimum coverage in any mounting position and excellent performance in high multipath environments
External antenna connectors for 802.11b/g and 802.11a	Allows use of shaped and higher gain antennas to design for most efficient AP placement[2]
Plenum rated	Meets safety and insurance requirements when installed in air spaces
Wi-Fi Certified	Industry certification guarantees interoperability with other Wi-Fi certified clients

INTERFACE

Wired Ethernet	10/100 base-T Ethernet (RJ-45)
Wireless Ethernet	1 integrated 802.11b/g radio and 1 integrated 802.11a radio
RS-232	Unit configuration

HARDWARE SPECIFICATION

Memory	32 MB SDRAM; 8 MB Flash

PHYSICAL SPECIFICATIONS

Dimensions	11.375 x 9.25 x 2.75 in (29 x 23.5 x 7 cm)
Weight	2.05 lbs (0.93 kg)

ENVIRONMENTAL SPECIFICATIONS

Temperature	Operating	0°C to 55°C
	Storage	-10°C to 70°C
Humidity	Operating	95% (non-condensing)
	Storage	95% (non-condensing)

POWER SUPPLY

Types	Integrated module Autosensing 100/240 VAC; 50/60 Hz IEEE 802.3af Active Ethernet for power over Ethernet

LEDS

Type:	Power, Ethernet LAN Activity Wireless 802.11b/g Activity Wireless 802.11a Activity

MANAGEMENT

- SNMPv1, SNMPv2c and secure SNMPv3 management
- Standard & ORiNOCO traps
- ORiNOCO MIB, Etherlike MIB, 802.11 MIB, Bridge MIB, MIB-II
- TFTP support
- Telnet CLI, Serial Port CLI (no proxy required)
- HTTPS (SSL) server for secure web-based management
- Proxim WaveLink Mobile Manager for group management (not included)
- Syslog
- DHCP Server and Client

WARRANTY

1 year (on parts and labor)

PACKAGE CONTENTS

- AP-4000 tri-mode access point with built-in 802.11b/g and 802.11a radios
- Power supply and support for Active Ethernet and IEEE 802.3af
- Software and documentation
- Cable cover and mounting bracket

RELATED PRODUCTS

Wavelink Mobile Manager, Ekahau Site Survey and RF Prediction Software, ORiNOCO 11a/b/g ComboCard, Dual Band Range Extender Antenna

1 In conjunction with Proxim Wavelink Mobile Manager

2 8670-AU, 8670-EU2 and 8670-US2 do not include external antenna connectors for 802.11a

For detailed technical specifications,please go to http://www.proxim.com/products/wifi/ap/ap4000/techspecs.html

Wi-Fi CERTIFIED abg

Proxim Corporation
2115 O'Nel Drive
San Jose, CA 95131

tel: 800.229.1630
tel: 408.731.2700
fax: 408.731.3675

www.proxim.com

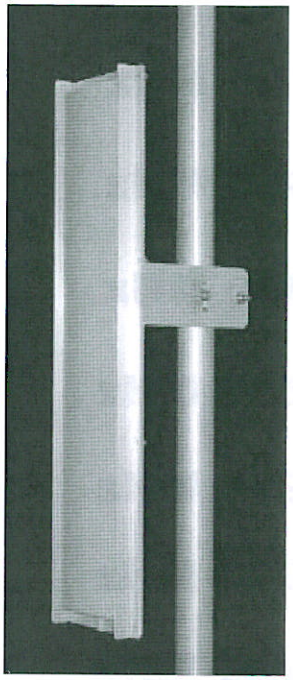
proxim WIRELESS NETWORKS

OD37-0904

Appendix F
Til-Tek Antennas

TA-4904-14-90 Sector

4940 - 4990 MHz



The TA-4904-14-90 is a vertically polarized 90 degree sectoral antenna. The antenna consists of a printed dipole array enclosed in an aluminum base with a UV stabilized radome for superior weatherability. The antenna is at DC ground to aid in lightning protection.

Electrical Specifications

Frequency Range: 4940 - 4990 MHz
Gain: 15.5 dBi typ.
VSWR: 2:1 max.
Front to Back Ratio: 25 dB min.
Polarization: Vertical
Power Rating: 5 Watts
H-Plane Beamwidth: 90 degrees
E-Plane Beamwidth: 5 degrees
Cross Pol. Discrimination: 20 dB min.
Impedance: 50 ohms nominal
Termination: N female

Typical mid band values. (For details , contact factory)

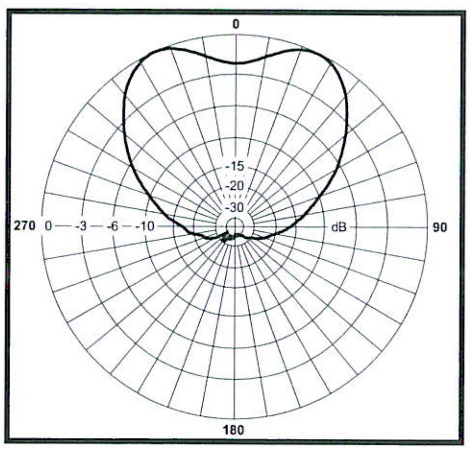
Mechanical Specifications

Length: 26.5 in. (673 mm)
Width: 6.25 in. (159 mm)
Depth: 2.0 in. (51 mm)
Weight (incl. Clamps): 6 lb. (2.72 kg)
Rated Wind Velocity: 125 mph (200 km/h)
Hor. Thrust at rated wind: 72 lb. (32.6 kg)
Mechanical Tilt: 0+/-16 degrees
Mounting (O.D.): 0.75 - 2.0 in. (19 - 51 mm)

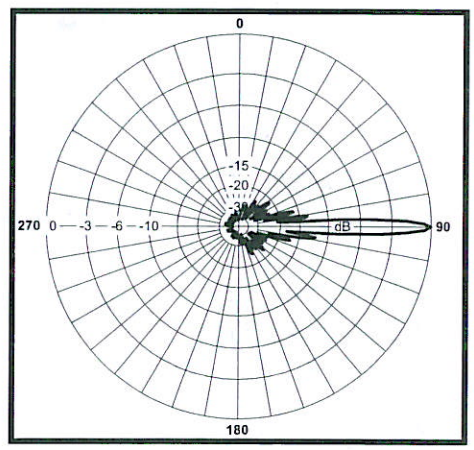
Materials

Radiating Elements: Plated copper on PCB
Reflector: Irridited aluminum
Radome: Gray UV stabilized ASA
Clamps: Aluminum and stainless steel

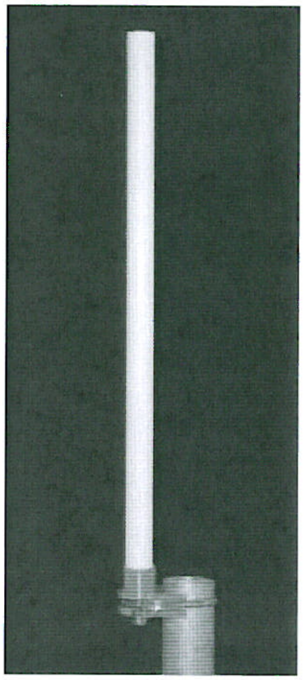
H-Plane



E-Plane



TA-4952 Omnidirectional
4940-4990 MHz



The TA-4952 is a 10 dBi omnidirectional antenna consisting of end fed collinear dipoles in a UV stabilized fiberglass radome. The antenna is designed for severe weather conditions and is at DC ground to aid in lightning protection. The TA-4952 has been developed in response to customer requests specifically with and for the Public Safety Band in mind which demands optimal performance and reliability at an affordable price.

Electrical Specifications

Frequency Range: 4940-4990 MHz
Gain: 10 dBi typ.
VSWR: 1.7:1 max.
Polarization: Vertical
Power Rating: 75 Watts
H-Plane Beamwidth: 360 degrees
E-Plane Beamwidth: 5 degrees
Cross Pol. Discrimination: 20 dB min.
Impedance: 50 ohms nominal
Termination: N female

Typical mid band values. (For details , contact factory)

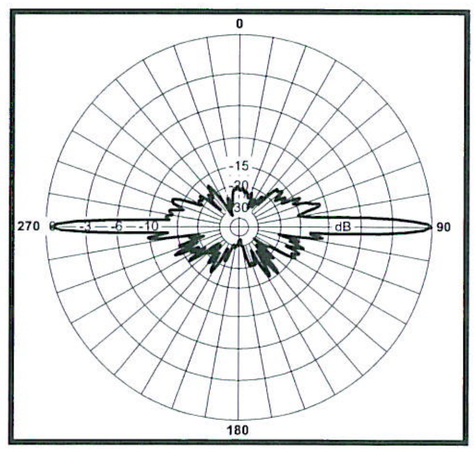
Mechanical Specifications

Length: 34 in. (864 mm)
Diameter: 1.0 in. (25 mm)
Weight (Incl. Clamps): 1.2 lb. (0.544 kg)
Rated Wind Velocity: 125 mph (200 km/h)
Hor. Thrust at rated wind: 9.3 lb. (4.2 kg)
Mounting (O.D.): 0.75 - 3.0 in. (19 - 76 mm)

Materials

Radiating Elements: Plated Copper on PCB
Radome: White UV stabilized fiberglass
Clamps: Stainless steel

E-Plane



Appendix G
RF Linx Bidirectional Amplifier

ANTENNAFIER™ 4900-5800 S SERIES

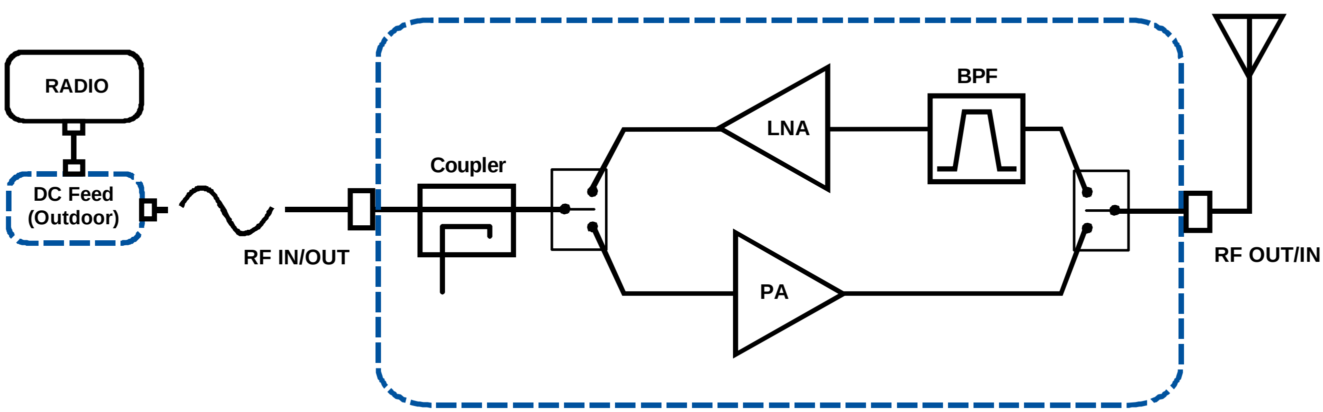
RF LINX CORPORATION

The Antennafier™ 4900-5800 S series Bi-Directional Amplifiers will significantly improve link reliability and operating range by providing Low Noise Amplification during Receive, and Spectrally Clean Power Amplification during Transmit. These fixed gain devices housed in a rugged machined aluminum chassis and are available in either indoor or outdoor models covering 4.9 to 5.8GHz in five popular bands.

Featured Highlights:

- Rugged Machined Aluminum Housing
- Fixed TX & RX Gains
- Transmit P1dBm = +30dBm (1W)
- Low 2.5dB RX Noise Figure
- High Dynamic Range
- 802.11a compatible
- TX/RX LED Indicator
- Automatically senses incoming RF signal

ANTENNAFIER™ 4900-5800 S SERIES
BLOCK DIAGRAM



The marketing, sale, and use of power amplification devices are governed by and subject to Part 15 of the Rules and Regulations of the Federal Communications Commission. Such devices may only be sold to parties assembling certified RF transmission systems consisting of an intentional radiator, an external radio frequency power amplifier, and an antenna.

9017 Cincinnati Columbus Rd.
West Chester, Ohio 45069
PH: 513-777-2774

FAX: 513-777-2115
http://www.rflinx.com

Typical Performance Parameters

Frequency Bands:	Public Safety:	4.940-4.990 GHz
	U-NII Lower:	5.15-5.25 GHz
	U-NII Middle:	5.25-5.35 GHz
	CEPT:	5.47-5.725 GHz
	U-NII Upper :	5.725-5.825 GHz
Supply Voltage:	+12 VDC +/- 5%	(Outdoor Version) DC from Center of coax (Indoor Version) DC from Power Jack on side of amp, 2.1mm I.D. (+), 5.5mm O.D. (-)
Receive:	Gain:	10 dB +/- 2 dB (SE Indoor) 12 dB +/- 2 dB (SX Outdoor)
	Noise Figure:	2.5 dB
	Supply Current:	< 250 mA
	TX to RX Switching:	< 500nSec
Transmit:	Gain :	9 dB +/- 2 dB (SE Indoor) 12 dB +/- 2 dB (SX Outdoor)
	Compression Point:	P1dBm = +30dBm (1W) (we recommend 6dB back-off for OFDM)
	OFDM 802.11a Power Output	+24dBm (250mW yields 54Mbs) +27dBm (500mW yields 36Mbs)
	RF Input Power for Turn-On:	> 1 dBm
	Harmonic Rejection:	2fo > 50 dBc, 3fo >73dBc @ Power Output
	Supply Current:	< 900 mA
	RX to TX Switching:	< 500Sec
Maximum Ratings:	Pin (Radio Port)	+30 dBm
	Pin (Antenna Port)	+27 dBm
Size:	2.88" x 3.00"x 1.01"	
Weight:	< 12 oz	
Chassis:	Machined Aluminum with durable black anodize finish CCA is protected with a conformal coating compound	
Indicator LED:	Green LED -Receive Mode, Red LED-Transmit Mode	
Lightning Suppression:	1/4 wavelength short	

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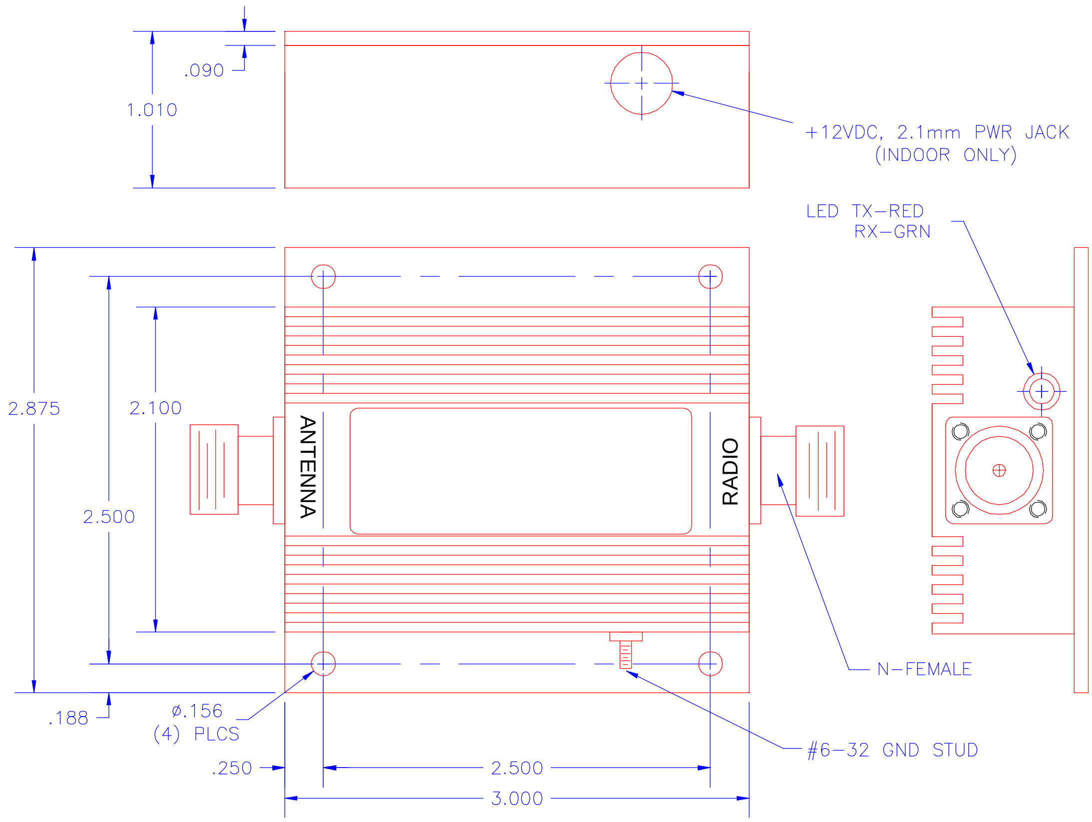
Mechanical Envelope:



9017 Cincinnati Columbus Rd.
West Chester, Ohio 45069
PH: 513-777-2774
FAX: 513-777-2115
http://www.rflinx.com

Ordering Guide:

Indoor Series	Freq Band	Description
4900 SE	4940-4990 GHz Public Safety Band	Includes: Amplifier, Heat Sink, Cable Stays & 12VDC Wall Mount Power Supply.
5200 SE	5.15-5.25GHz U-NII Lower Band	
5300 SE	5.25-5.35 GHz U-NII Middle Band	
5600 SE	5.47-5.725 GHz CEPT	
5800 SE	5.725-5.825GHz U-NII Upper Band	

Outdoor Series	Freq Band	Description
4900 SX	4940-4990 GHz Public Safety Band	For Outdoor applications where DC is sent via center conductor of RF Coax to power Amplifier. Includes: Amplifier, DC injector, mounting bracket with stainless steel hardware, Heat Sink, Cable Stays & 12VDC Wall Mount Power Supply
5300 SX	5.25-5.35 GHz U-NII Middle Band	
5600 SX	5.47-5.725 GHz CEPT	
5800 SX	5.725-5.825GHz U-NII Upper Band	

- Use designator “U” in tail end of Part Number to denote user specified gains. Specify TX and RX gain in dB when ordering.

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West Chester, Ohio 45069
PH: 513-777-2774
FAX: 513-777-2115
http://www.rflinx.com

Appendix H
Mobile Mark Antennas

Magnetic Mount

New Models!

Trunk Lip Mount

ECO Series Mobile Antennas

Models For 2.4 - 6 GHz

- Models available in Magnetic Mount and Trunk Lip mount
- Groundplane independent designs can be used on any surface.
- Available in models with 5 dBi - 9 dBi gain
- Elevated Feed Magnetic versions provide additional clearance for light bars

Mobile Mark's new ECO Mobile series are high frequency antennas designed for new technology applications in the 2.4 - 6 GHz bands. There are individual models for the most popular systems: WiFi, WiMAX, 3.5 GHz, Public Safety 4.9 GHz, 5 GHz Broadband and DSRC 5.9 GHz.

These antennas are free space designs and are ground plane independent. High gain coupled with low loss cable compensates for the losses that occur at higher bands. All antennas use low loss RF-195 cable to improve efficiency. The vertical radomes are black fiberglass with an ABS base assembly. All antennas are weatherproof.

The magnetic mount models have a 2.6" (6.7 cm) base, and use a strong commercial magnet. They provide a scratch resistant covering on the bottom. The cable exits out of the side of the base. Special "EF" elevated feed versions are available. These models have the radiating element located higher in a longer radome, providing more clearance of lightbars on police vehicles.

Trunk lip units mount securely to vehicle trunk lip with set screws. An allen wrench is provide for attaching the mount. A cable guide routes the cable around the mounting bracket and through the trunk molding into the vehicle, where the radio is typically located.

Magnetic Mount Models

Frequency	Gain	Height	Model
2.4 - 2.5 GHz	5 dBi	12.0 in/31 cm	ECOM5-2400
3.4 - 3.7 GHz	6 dBi	14.0 in/36 cm	ECOM6-3500
4.8 - 5.0 GHz	6 dBI	10.0 in/26 cm	ECOM6-4900
4.8 - 5.0 GHz	9 dBI	14.0 in/36 cm	ECOM9-4900
5.0 - 6.0 GHz	6 dBi	10.0 in/26 cm	ECOM6-5500
5.0 - 6.0 GHz	9 dBi	14.0 in/36 cm	ECOM9-5500

Magnetic Mount Elevated Feed Models

Frequency	Gain	Height	Model
4.8 - 5.0 GHz	6 dBi	14.5 in/37 cm	ECOM6-4900TEF
5.0 - 6.0 Ghz	6 dBi	14.5 in/37 cm	ECOM6-5500TEF

Trunk Lip Mount Models

Frequency	Gain	Height	Model
2.4 - 2.5 GHz	5 dBi	12.0 in/31 cm	ECOT5-2400PT
3.4 - 3.7 GHz	6 dBi	15.0 in/38 cm	ECOT6-3500PT
4.8 - 5.0 GHz	6 dBI	11.5 in/29 cm	ECOT6-4900PT
4.8 - 5.0 GHz	9 dBI	15.0 in/38 cm	ECOT9-4900PT
5.0 - 6.0 GHz	6 dBi	11.5 in/29 cm	ECOT6-5500PT
5.0 - 6.0 GHz	9 dBi	15.0 in/38 cm	ECOT9-5500PT

The desired connector should be requested at time of order. Cables are 10 ft (3 meters) but can be provided differently upon request.

Specifications

Frequency:	See above	**Trunk Mount Size:**	1"H x 3"L x 2.75"W (2.4 cm x 7.6 cm x 7.0 cm)
Gain:	See above		
Bandwidth:	See above @2:1 SWR	**Trunk Mount Method:**	Dual set screws, allen wrench supplied
Impedance:	50 Ohm nominal		
Maximum Power:	10 Watts	**Cable Length/type:**	10 ft of RF-195 (3 meters)
Radome:	Black Fiberglass	**Connector:**	Male TNC, N or SMA. Specifiy at time of order.
Base/Mount:	ABS plastic & steel		
MAG Base Size:	2.6" D (6.7 cm)		

H2

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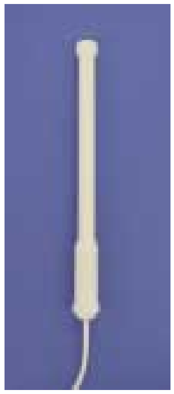
ECO Series Omni Antennas (Pat.Pend.)

for all 2.4 - 6.0 GHz Systems

ECO Series 3 - 5 GHz
Models with N female



"PT" pigtail cable
option for all models

- Gain configurations from 5 dBi to 12 dBi
- Economical, weatherproof and durable design for both indoors and outdoors
- Standard mounting kit includes all hardware needed for pole or wall mount
- Optional drop ceiling mount, as well as mobile magnetic & trunk lip mount

Mobile Mark's new ECO Series Omni antennas are designed for all new data & broadband systems, including WiFi, 802.11 & 802.16 systems being planned. Using the latest PCB technology, these antennas improve highspeed broadband system performance in an economical package.

The Omni antennas provide uniform horizontal pattern and excellent frequency response. The ECO Series are free space antennas; no ground plane is required. Because they are also low profile and durable, they can even be used in a mobile application. Mounting hardware is available for a variety of uses. Standard hardware includes pole/wall mount.

The antenna element is enclosed in an extremely tough white fiberglass radome. The low profile radome is only 0.63 inches (1.6 cm) diameter, and 0.9 in (2.3 cm) at the base. Windloading on the antenna is insignificant. The antenna terminates with an integrated N-female. A "PT" pigtail cable option also provides a direct coax into the antenna and can be outfitted with a variety of connectors, such as Reverse polarity TNC or SMA. For direct male N mounting, series “RN” can be chosen.

These antennas can withstand the harshest outdoor environments, yet are quite attractive for indoor use. The antennas are supplied with hardware for pole or surface mount. Other mount options include flush ceiling, drop ceiling and mobile mounts.

Model Numbers

Model	Description	Frequency
ECO5-2400PT	5 dBi Omni, Pigtail	2.4 - 2.5 GHz
ECO6-3500	6 dBi Omni	3.4 - 3.7 GHz
ECO9-3500	9 dBi Omni	3.4 - 3.7GHz
ECO6-4900	6 dBi Omni	4.9 - 5.0 GHz
ECO9-4900	9 dBi Omni	4.9 - 5.0 GHz
ECO6-5500	6 dBi Omni	5.0 - 6.0 GHz
ECO9-5500	9 dBi Omni	5.0 - 6.0 GHz
ECO12-5800	12 dBi Omni	5.7 - 6.0 GHz

add "PT" Pigtail Direct Cable Option with N male connectors, others available

add “RN” Direct mount version with Male N connector, example ECO6-4900RN

Special configurations may be available upon request. Please consult factory for more information.

Specifications

Frequency/Gain:	See above	**Mounting:**	Pole or surface mount, mounts up to 2" (5cm)
Bandwidth@2:1 VSWR:	See above		
Impedance:	50 Ohm nominal	**Antenna Length:**	
Max Power:	25 Watts	ECO5-2400PT	11 in (28.0 cm)
ECO5 Beamwidth:	30° El, 360° Az	ECO6-3500	15 in (38.1 cm)
ECO6 Beamwidth:	25° El, 360° Az	ECO9-3500	19 in (48.3 cm)
ECO9 Beamwidth	14° El, 360° Az	ECO6-4900	11 in (28.0 cm)
ECO12 Beamwidth:	7° El, 360° Az	ECO9-4900	15 in (38.1 cm)
Lightning Protection:	External recommended	ECO6-5500	11 in (28.0 cm)
Max Wind Velocity:	100 mph, all models	ECO9-5500	15 in (38.1 cm)
Material:	White fiberglass radome,	ECO12-5800	19 in (48.3 cm)
Weight:	<0.75 lbs (< 0.340 kg)	**Connector (standard):**	N female direct
Antenna Diameter:	0.63 in (1.6 cm) Radome, 0.9 in (2.3 cm) at the base	**PT Pigtail Option:**	1ft cable (0.3 meters) & N male, others available

H3

Appendix I
mWave Microwave Antennas

4.940-5.850 GHz Parabolic Antennas

Features:

- Linear Polarization (field adjustable for horizontal or vertical polarization) & Dual Polarization
- Sturdy aluminum construction reflector and pipe mount
- All corrosion resistant materials, galvanized and stainless steel hardware.
- Fine azimuth and elevation adjustment
- Type N Female Connector, 50 Ohm impedance
- Mounts to 1.9-4.5" OD pipe (48-114mm)
- Optional ABS radome available

Electrical Specifications

Model No.	Frequency GHz	Pol.	Size ft.	Size m	Notes	Gain, nominal dBi	HPBW Deg.	Xpol dB	F/B dB	VSWR max	R.L. dB
RP2-54-N	4.940-4.990	H or V	2	0.6	-	26.7	7.0	28	32	1.5:1	14.0
	5.250-5.850	H or V	2	0.6	-	28.5	6.2	28	35	1.5:1	14.0
RP3-56-N	5.250-5.850	H or V	3	0.9	-	31.4	4.0	30	38	1.5:1	14.0
RP4-56-N	5.250-5.850	H or V	4	1.2	-	34.5	3.0	30	42	1.5:1	14.0
RP2-58-N	5.725-5.850	H or V	2	0.6	-	28.8	6.0	30	38	1.5:1	14.0
RP3-58-N	5.725-5.850	H or V	3	0.9	-	32.0	4.0	30	40	1.5:1	14.0
RPD2-54-N	4.940-4.990	Dual	2	0.6	-	26.5	7.0	28	35	1.5:1	14.0
	5.250-5.850	Dual	2	0.6	-	28.3	6.2	28	38	1.5:1	14.0
RPD3-56-N	5.250-5.850	Dual	3	0.9		31.2	4.0	30	40	1.5:1	14.0
RPD4-56-N	5.250-5.850	Dual	4	1.2		34.3	3.0	30	42	1.5:1	14.0

All specifications are subject to change without notice.

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Appendix J
Ceragon FibeAir

FibeAir® 4800 Family

Fast Ethernet & nxT1/E1 License Exempt Radio

Broadband Wireless Network Solutions

System Overview

FibeAir® 4800 product family is a carrier-class, high capacity, low cost point-to-point wireless broadband system. It operates in the license-exempt 2.4 - 5.x GHz bands and is suitable for service providers and enterprises that require immediate deployment and quick return on investment.

FibeAir® 4800 product family carries Fast Ethernet and TDM services over license-exempt bands, effectively connecting voice and data over a single link. The system ensures low BER, as well as low latency and full compliance with E1/T1 interface jitter and wander requirements.

FibeAir® 4800 enables direct connection of existing equipment, such as LANs and PBX systems, thus eliminating the need for additional external equipment. FibeAir® 4800 product family is a split-mount system consisting of an IDU, ODU and antenna on each side of the link.

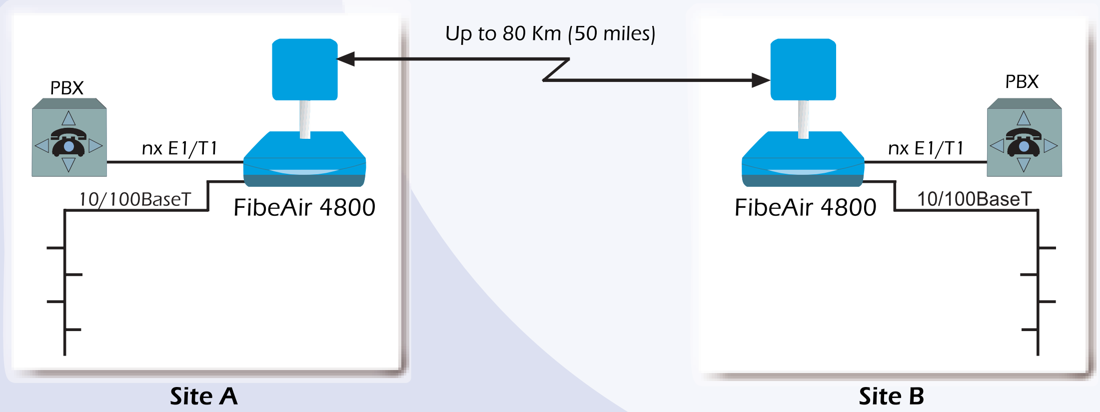
Two types of IDUs are available: IDU-E with 1 x 10/100BT and 1,2 x E1/T1, or IDU-C (Carrier Class) with 2 x 10/100BT and 1, 2, 4, 6 x E1/T1, power redundancy, and optional 1+1 protection.

Two types of ODUs are available: ODU with integrated 1 ft antenna, or ODU with N-type connector for external antenna.

Features

- High data rate up to 48 Mbps
- License-exempt radio operation at:

  2.400-2.4835 GHz
  4.940-4.990 GHz
  5.250-5.350 GHz
  5.470-5.725 GHz
  5.725-5.850 GHz
- Configurable modulation schemes: QPSK, 16 QAM, 64 QAM
- Integrated Fast Ethernet and nxE1/T1 interfaces
- Operational range of up to 50 miles (80 km)
- Carrier-class grade
- Excellent performance and reliability
- Complete SNMP-based local and remote management
- Complies with ETSI, FCC, IC, ITU-T and IEEE standards and frequency plans, for operation worldwide
- Cost-effective Ethernet link



private networks mobile backbone telecom infrastructure

Applications

Campus Connectivity: Transparent connection of enterprise LAN and PBX systems across campuses, which reduces communication costs, operating expenses, and maintenance requirements.

Wireless ISP Backhaul: Wireless Internet Service Providers (WISPs) use backhaul to connect their Point of Presence (POP) to their network operation centers. Using FibeAir 4800, WISPs have a higher capacity, with a range of up to 80 km, and bundled connectivity, within the same cost-effective package.

Wi-Fi and WiMax Backhauling: Provides a robust and cost-effective wireless alternative to leased lines, for the last mile connection between the Wi-Fi/WiMax access point and the data network.

Technical Specifications

Configuration

Architecture:
Indoor Unit (IDU-E or IDU-C) and
Outdoor Unit (ODU)
IDU to ODU Interface
Outdoor CAT-5 cable;
Maximum length of 100 m

Radio

Frequency:
2.400-2.4835 GHz
4.940-4.990 GHz
5.250-5.350 GHz
5.470-5.725 GHz
5.725-5.850 GHz
Data Rate: Configurable up to 48 Mbps
Channel BW: 20 MHz
Channel Setting Resolution: 5 MHz
Duplex Technique: TDD
Modulation: OFDM - BPSK, QPSK, 16 QAM, 64 QAM
Transmit Power: Up to 18 dBm (configurable in 1dB steps)
The max value will be limited in accordance with standard regional regulations.
Received Dynamic range: > 60 dB
Error Correction: FEC k=1/2, 2/3, 3/4
Encryption: AES 128

LAN Interface

Type: 10/100BaseT interface auto-negotiation.
Number of ports: 1, 2
Framing Coding: IEEE 802.3/U
Bridging: Self-learning up to 2047 MAC addresses IEEE 802.1
Traffic Handling: MAC layer bridging, self-learning
Data Latency: 3 msec typical
Line Impedance: 100W'
VLAN Support: Transparent
Connector: RJ-45

E1/T1 Interface

Framing: Unframed (Transparent)
Number of ports: 1, 2, 4, 6
Compliance to standards: G.703,G.826.
Timing: Plesiochronous (independent Tx and Rx timing)
Line Code: E1: HDB3; **T1:** AMI /B8ZS
Latency: 8 msec
Impedance: E1: 120W', balanced
T1: 100W', balanced
Connector: RJ-45
Jitter & Wander: ITU-T G.823, G.824

Management

Protocol: SNMP based protocol
Network Management: SNMPc based
Upgrade Capabilities: Local and remote software download

Diagnostics: Local and remote loopbacks
Management interface: 10/100 BaseT
Connector: RJ-45

Mechanical

ODU Dimensions:
24.5 cm (H) x 13.5 cm (W) x 4.0 cm (D)
Weight: 1.0kg/2.2 lb
IDU-E Dimensions:
16.5 cm (H) x 23.6 cm (W) x 4.5 cm (D)
Weight: 0.5kg/1.1lb
IDU-C Dimensions:
43 cm (H) x 29 cm (W) x 4.5 cm (D)
Weight: 1.5Kg/3.3lb

General

Power Feeding:
110/220 VAC, -48 VDC, 50/60 Hz,
Power Consumption:
FibeAir 4800 with IDU-E: 10W Max
FibeAir 4800 with IDU-C: 14W Max
Mounting: Pole or wall mounting

Environmental

Outdoor Unit Enclosure: All-weather cases
ODU Temperatures: -35°C - 60°C / -31°F - 140°F
IDU Temperatures: -5°C - 45°C / 23°F - 113°F
Humidity: Up to 90% non-condensing

Antenna Characteristics

	FibeAir 4824	FibeAir 4849	FibeAir 4853	FibeAir 4854	FibeAir 4858
Frequency Band	2.400-2.4835 GHz	4.940-4.990 GHz	5.250-5.350 GHz	5.470-5.725 GHz	5.725-5.850 GHz
Integrated Antenna 1 ft					
Gain	17dBi	21dBi	22dBi	22dBi	22dBi
Beam Width	20°	9°	9°	9°	9°
Polarization	Linear	Linear	Linear	Linear	Linear
External Antenna 2 ft					
Gain	24dBi	28dBi	28dBi	28dBi	28dBi
Beam Width	10°H/14°V	4.5°	4.5°	4.5°	4.5°
Polarization	Linear	Linear	Linear	Linear	Linear

*** Higher gain antennas are available upon request**

Standards & Regulations

	FibeAir 4824	FibeAir 4849	FibeAir 4853	FibeAir 4854	FibeAir 4858
Frequency Band	2.400-2.483 GHz	4.940-4.990 GHz	5.250-5.350 GHz	5.470-5.725 GHz	5.725-5.85 GHz
Radio					
FCC 47CFR Part 15	Sub-part C	Sub-part C	Sub-part E	Sub-part E	Sub-part C
IC	RSS-210		RSS-210		RSS-210
ETSI	EN 300 328			EN300 216 V1.2.1	EN300 440 V1.3.1
Dynamic Frequency Selection and Transmission Power Control (DFS/TPC)				EN 301 893 V1.2.2	
Safety					
TUV	60950, according to UL 60950				
CAN-CSA	C22.2 No.60950				
EMC					
FCC	47CFR Part 15, Sub-part B				
ETSI	EN 301 489-1				
Environment					
ETSI	IEC 60721-3-4 Class 4M5 IP67				

About Ceragon Networks Ltd.

Ceragon Networks Ltd. (NASDAQ: CRNT), a pacesetter in broadband wireless networking systems, enables rapid and cost-effective high-capacity network connectivity for mobile cellular infrastructure, fixed networks, private networks and enterprises. Ceragon's modular FibeAir® product family operates across multiple frequencies, supports integrated high-capacity services over SONET/SDH, ATM and IP networks, and offers innovative built-in add/drop multiplexing and encryption functionality to meet the growing demand for value -added broadband services. Ceragon's FibeAir® product family complies with North American and international standards and is installed with over 150 customers in more than 60 countries. More information is available at **www.ceragon.com**.

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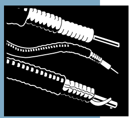
Appendix K
Andrew LDF4-50A



1/2" Foam Dielectric, LDF Series – *50-ohm*

LDF4-50A

Description	Type No.
Cable Ordering Information	
Standard Cable	
1/2" Standard Cable, Standard Jacket	**LDF4-50A**
Fire Retardant Cables	
1/2" Fire Retardant Jacket (CATVX)	**LDF4RN-50A**
1/2" Fire Retardant Jacket (CATVR)	**LDF4RN-50A**
Low VSWR and Specialized Cables	
1/2" Low VSWR, specify operating band	**LDF4P-50A-(**)**
Phase Stabilized and Phase Measured Cable	See page 590
Jumper Cable Assemblies – See page 584	

** Insert suffix number from "Low VSWR Specifications" table, page 498

Characteristics

Electrical	
Impedance, ohms	50 ± 1
Maximum Frequency, GHz	8.8
Velocity, percent	88
Peak Power Rating, kW	40
dc Resistance, ohms/1000 ft (1000 m)	
Inner	0.45 (1.48)
Outer	0.58 (1.90)
dc Breakdown, volts	4000
Jacket Spark, volts RMS	8000
Capacitance, pF/ft (m)	23.1 (75.8)
Inductance, µH/ft (m)	0.058 (0.19)

Mechanical	
Outer Conductor	Copper
Inner Conductor	Copper-Clad Aluminum
Diameter over Jacket, in (mm)	0.63 (16)
Diameter over Copper Outer Conductor, in (mm)	0.55 (14)
Diameter Inner Conductor, in (mm)	0.189 (4.6)
Nominal Inside Transverse Dimensions, cm	1.11
Minimum Bending Radius, in (mm)	5 (125)
Number of Bends, minimum (typical)	15 (50)
Bending Moment, lb-ft (N•m)	2.8 (3.8)
Cable Weight, lb/ft (kg/m)	0.15 (0.22)
Tensile Strength, lb (kg)	250 (113)
Flat Plate Crush Strength, lb/in (kg/mm)	110 (2.0)

Attenuation and Average Power Ratings

Frequency MHz	Attenuation dB/100 ft	Attenuation dB/100 m	Average Power, kW
0.5	0.045	0.149	40.0
1	0.064	0.211	35.8
1.5	0.079	0.259	29.2
2	0.091	0.299	25.3
10	0.205	0.672	11.3
20	0.291	0.954	7.93
30	0.357	1.17	6.46
50	0.463	1.52	4.98
88	0.619	2.03	3.73
100	0.661	2.17	3.49
108	0.688	2.26	3.36
150	0.815	2.67	2.83
174	0.880	2.89	2.62
200	0.946	3.10	2.44
300	1.17	3.83	1.97
400	1.36	4.46	1.70
450	1.45	4.75	1.59
500	1.53	5.02	1.51
512	1.55	5.08	1.49
600	1.69	5.53	1.37
700	1.83	6.01	1.26
800	1.97	6.46	1.17
824	2.00	6.56	1.15
894	2.09	6.85	1.10
960	2.17	7.12	1.06
1000	2.22	7.28	1.04
1250	2.51	8.23	0.921
1500	2.77	9.09	0.833
1700	2.97	9.74	0.777
1800	3.07	10.1	0.753
2000	3.25	10.7	0.710
2100	3.34	11.0	0.691
2200	3.43	11.2	0.673
2300	3.52	11.5	0.657
3000	4.09	13.4	0.565
3400	4.39	14.4	0.526
4000	4.82	15.8	0.479
5000	5.49	18.0	0.421
6000	6.11	20.1	0.378
8000	7.26	23.8	0.318
8800	7.69	25.2	0.300

Standard Conditions:
For attenuation. VSWR 1.0, ambient temperature 20°C (68°F).
For Average Power, VSWR 1.0, ambient temperature 40°C (104°F), inner conductor temperature 100°C (212°F), no solar loading.

ANDREW®

Revised 9/00

Appendix L
Times Microwave LMR400

TIMES MICROWAVE SYSTEMS

A Smiths Group plc company

LMR®-400
Flexible Low Loss Communications Coax

Ideal for...

- Drop-in replacement for RG-8/9913 Air-Dielectric type Cable
- Jumper Assemblies in Wireless Communications Systems
- Short Antenna Feeder runs
- Any application (e.g. WLL, GPS, LMR) requiring an easily routed, low loss RF cable

• **LMR®** standard is a UV Resistant Polyethylene jacketed cable designed for 20-year service outdoor use. The bending and handling characteristics are significantly better than air-dielectric and corrugated hard-line cables.

• **LMR®- DB** is identical to standard LMR plus has the advantage of being watertight. The addition of waterproofing compound in and around the foil/braid insures continuous reliable service should the jacket be inadvertently damaged during installation or in the future.

• **LMR®- FR** is a non-halogen (non-toxic), low smoke, fire retardant cable designed for in-building runs that can be routed anywhere except air handling plenums. LMR-FR has a UL/NEC & CSA rating of 'CMR/MPR' and 'FT4' respectively.

• **LMR®- FR-PVC** is a general-purpose indoor cable and has a UL/NEC & CSA rating of 'CMR/MPR' and 'FT4' respectively. It is less expensive than LMR-FR, however it emits toxic fumes (HCL) and greater smoke density when burned.

• **LMR®- PVC** is designed for low loss general-purpose indoor/outdoor applications and is somewhat more flexible than the standard polyethylene jacketed LMR.

• **LMR®- PVC-W** is a white-jacketed version of LMR-PVC for marine and other indoor/outdoor applications where color compatibility is desired.

• **Flexibility** and bendability are hallmarks of the LMR-400 cable design. The flexible outer conductor enables the tightest bend radius available for any cable of similar size and performance.

• **Low Loss** is another hallmark feature of LMR-400. Size for size LMR has the lowest loss of any flexible cable and comparable loss to semirigid hard-line cables.

• **RF Shielding** is 50 dB greater than typical single shielded coax (40 dB). The multi-ply bonded foil outer conductor is rated conservatively at > 90 dB (i.e. >180 dB between two adjacent cables).

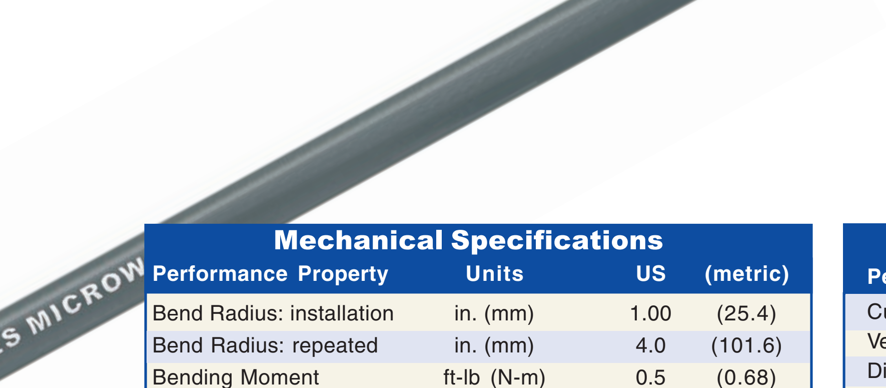
• **Weatherability**: LMR-400 cables designed for outdoor exposure incorporate the best materials for UV resistance and have life expectancy in excess of 20 years.

• **Connectors**: A wide variety of connectors are available for LMR-400 cable, including all common interface types, reverse polarity, and a choice of solder or non-solder center pins. Most LMR connectors employ crimp outer attachment using standard hex crimp sizes.

• **Cable Assemblies**: All LMR-400 cable types are available as pre-terminated cable assemblies. Refer to the section on FlexTech for further details.

Part Description				Stock
Part No.	Application	Jacket	Color	Code
LMR-400	Outdoor	PE	Black	54001
LMR-400-DB	Outdoor/Watertight	PE	Black	54091
LMR-400-FR	Indoor -Riser CMR	FRPE	Black	54030
LMR-400-FR-PVC	Indoor -Riser CMR	FRPVC	Black	54073
LMR-400-PVC	Indoor/Outdoor	PVC	Black	54218
LMR-400-PVC-W	Indoor/Outdoor	PVC	White	54204

Construction Specifications			
Description	Material	In.	(mm)
Inner Conductor	Solid BCCAl	0.108	(2.74)
Dielectric	Foam PE	0.285	(7.24)
Outer Conductor	Aluminum Tape	0.291	(7.39)
Overall Braid	Tinned Copper	0.320	(8.13)
Jacket	(see table above)	0.405	(10.29)



TIMES MICROWAVE SYSTEMS

A Smiths Group plc company

LMR-400

Mechanical Specifications

Performance Property	Units	US	(metric)
Bend Radius: installation	in. (mm)	1.00	(25.4)
Bend Radius: repeated	in. (mm)	4.0	(101.6)
Bending Moment	ft-lb (N-m)	0.5	(0.68)
Weight	lb/ft (kg/m)	0.068	(0.10)
Tensile Strength	lb (kg)	160	(72.6)
Flat Plate Crush	lb/in. (kg/mm)	40	(0.71)

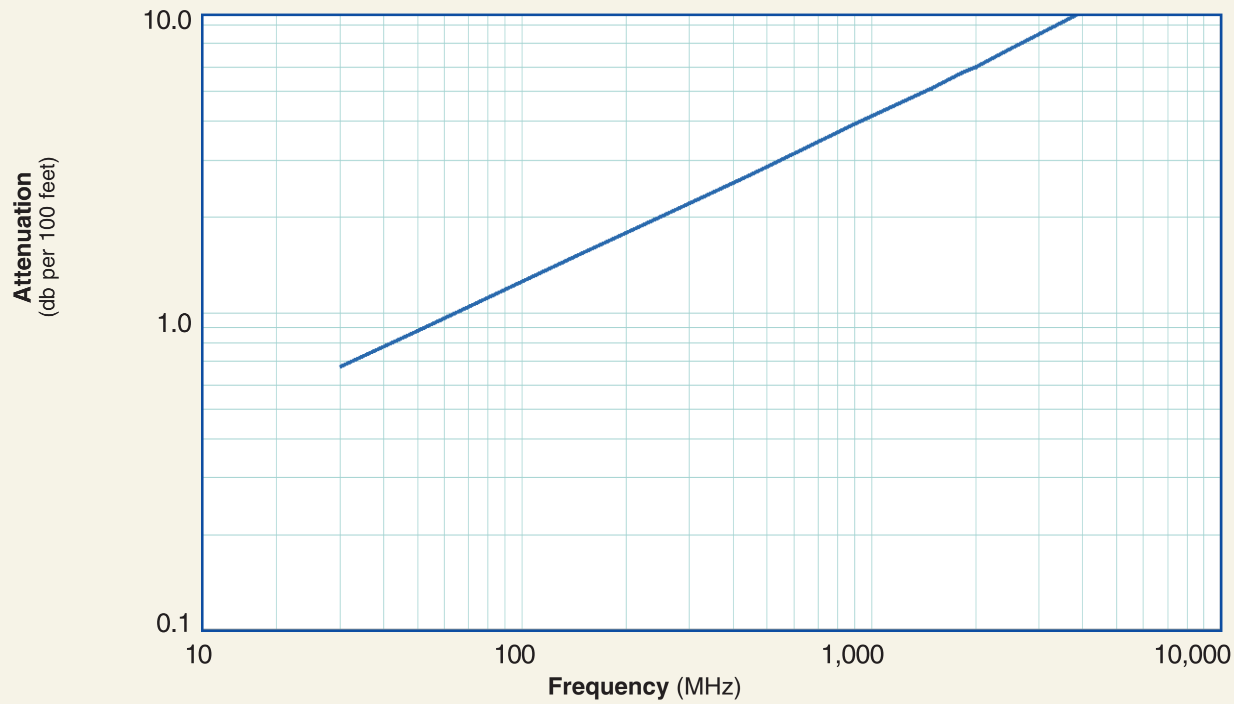
Environmental Specifications

Performance Property	°F	°C
Installation Temperature Range	-40/+185	-40/+85
Storage Temperature Range	-94/+185	-70/+85
Operating Temperature Range	-40/+185	-40/+85

Electrical Specifications

Performance Property	Units	US	(metric)
Cutoff Frequency	GHz	16.2	
Velocity of Propagation	%	85	
Dielectric Constant	NA	1.38	
Time Delay	nS/ft (nS/m)	1.20	(3.92)
Impedance	ohms	50	
Capacitance	pF/ft (pF/m)	23.9	(78.4)
Inductance	uH/ft (uH/m)	0.060	(0.20)
Shielding Effectiveness	dB	>90	
DC Resistance			
Inner Conductor	ohms/1000ft (/km)	1.39	(4.6)
Outer Conductor	ohms/1000ft (/km)	1.65	(5.4)
Voltage Withstand	Volts DC	2500	
Jacket Spark	Volts RMS	8000	
Peak Power	kW	16	

Attenuation vs. Frequency (typical)



Frequency (MHz)	30	50	150	220	450	900	1500	1800	2000	2500	5800
Attenuation dB/100 ft	0.7	0.9	1.5	1.9	2.7	3.9	5.1	5.7	6.0	6.8	10.8
Attenuation dB/100 m	2.2	2.9	5.0	6.1	8.9	12.8	16.8	18.6	19.6	22.2	35.5
Avg. Power kW	3.33	2.57	1.47	1.20	0.83	0.58	0.44	0.40	0.37	0.33	0.21

Calculate Attenuation =

$(0.122290) \bullet \sqrt{FMHz} + (0.000260) \bullet FMHz$ (interactive calculator available at http://www.timesmicrowave/telecom)

Attenuation:

VSWR=1.0 ; Ambient = +25°C (77°F)

Power:

VSWR=1.0; Ambient = +40°C; Inner Conductor = 100°C (212°F); Sea Level; dry air; atmospheric pressure; no solar loading

Appendix M
Post Processing Software

Post Processing of ApSurvey Data

Introduction

The PostProcessApSurvey.jar program performs post-processing of data collected with the ApSurvey (data collection) software. It associates logged readings with extra information describing the access point and antenna deployment, and generates a separate output file for each access point with this and additional information. In addition, the post-processing can average readings over a specified distance and suppress "aged" readings where the link has been broken, but the access point is still reported as being connected, albeit with no changes in RSSI values.

Distance and Azimuth Calculations

The program uses Vincenty's algorithm for geographic distance and azimuth calculations. A description of various models, including ellipsoidal models, can be found in an article titled "Geographic Distance and Azimuth Calculations" by Andy McGovern, April 28, 2000.

The WGS84 reference ellipsoid is used for geographic calculations.

Earth Radius (meters)	***Flattening***
6378137.0	1.0 ---------------------- 298.2572235630

Portions of the source code are derived from the DIRCT1 routine found in the FORWRD3D program found at ftp://ftp.ngs.noaa.gov/pub/pcsoft/for_inv.3d/source/forwrd3d.for.

RSSI to dBm Calculations

The program converts the signal and noise RSSI values returned by the access point into dBm values using an interpolation table specified by the "-dbmtable=*FILENAME*" parameter. Values are linearly interpolated between the closest two points in the table. If you want to be accurate, generate a table with RSSI values from -1 to 100, covering every possible RSSI value. (An RSSI of -1 is used for "aged" readings, as described below.)

Averaging

The ApSurvey data collection software can log data faster than the GPS receiver can provide updated position information. Therefore the post processing program allows you go average readings over a specified distance. This averaging distance is specified by the "-avg=N" parameter, where N is the number of meters over which you want to average readings. Specifying "-avg=-1" disables averaging, and specifying "-avg=0" will all average readings with identical GPS coordinates.

When averaging readings, the following fields are averaged:

Latitude
Longitude
Altitude
Signal RSSI
Noise RSSI
Age
GPS Timestamp
Computer Timestamp

The signal and noise dBm values are recalculated based on the averaged RSSI values. All other fields are arbitrarily taken from the first of the averaged readings.

Suppression of "Aged" Readings

During testing, we noticed that the access points will sometimes report the last known data for a connection, even after the connection has been dropped. The post processing program can identify such readings based on a combination of the "Age" field and an analysis to determine whether the signal RSSI value is changing.

For all readings with an "Age" value greater than a threshold *X* (e.g., 5 seconds), if a run of at least *N* consecutive readings are detected with the same signal RSSI value, set the signal RSSI value of all but the first reading in the run to -1. When used with the RSSI->dBm lookup table, this allows you to assign a "noise floor" value to these readings.

You can specify the age and number of consecutive readings without change values by specifying the "-age=X" and "num=N" parameters as input to the program.

Association with Access Point and Antenna Deployment Information

The program will associate access point connections with additional information describing the remotely connected access point and various antenna deployment information. This information is stored in two separate files, one containing access point information and one containing antenna deployment information. These files can be specified with the "-apfile=*FILENAME*" and "-deployfile=*FILENAME*" parameters.

The antenna deployment file in particular contains the antenna latitude, longitude, elevation, and height above ground data used for calculating distance and algorithms.

Colorado 4.9 GHz Project

April 30, 2006

Lead Agency:

Parker Fire Protection District
10795 South Pine Drive
Parker, CO 80138
(303) 841-8783 Business
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http://www.parkerfire.org

Parker Fire Project Manager: Cheryl Poage

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Colorado 4.9 GHz Project

1.0 Executive Summary

In October of 2004, the Parker Fire Protection District received an NTIA TOP grant for the purpose of investigating the feasibility of using 4.9 GHz for public safety applications. At the time of the grant award, the 4.9 GHz band was new and unproven. The study was conducted as a series of field trials using 4.9 GHz radios furnished by Proxim Wireless. Over 40 fixed and mobile Access Points were deployed in urban, suburban, rural plains, foothills, and mountain areas along the Colorado front range. Thousands of field measurements were collected during more than 139 mobile and fixed equipment trials. The project was completed on April 30, 2006.

Several wide-area computer networks were configured and tested over 4.9 GHz radio links using conventional and mesh networking. Many public safety applications were successfully demonstrated, including email, database query, file download, remote video monitoring, and streaming video.

The major findings of the study are the following:

- Open Standards are Best for Public Safety. Public safety agencies have a long history of using proprietary protocols for their voice radio networks. Proprietary equipment is expensive and typically lags the state-of-the-art. Wireless data is a new application for public safety and it creates an opportunity to adopt industry standard devices and enjoy the innovation and low cost created by economies of scale. This project would not have been possible if we were forced to wait for proprietary radios. Instead, Proxim was able to quickly modify its existing IEEE 802.11 radios to operate in the 4.9 GHz band, making this entire project feasible.

- Range is Limited. Radio waves at 4.9 GHz behave very much like visible light. If the Access Point antenna is not visible, the likelihood of maintaining a reliable connection is low, especially at the low power levels mandated by the FCC for 802.11-compatible devices. Range depends on many factors, but coverage in downtown Denver was limited to roughly 1.0 mile with an antenna height of 30 feet. This dense urban performance was actually better than expected. In open rural areas, some mobile links connected at 4.6 miles when the path was not obstructed. High power devices would increase range significantly.

- FCC Power Limitations Unnecessarily Hamper Performance. The FCC allows two types of radios to operate in the 4.9 GHz band: Low power devices, up to 20 dBm (100 mW), may use a “loose” emission mask, compatible with industry-standard IEEE 802.11 devices. High power devices, up to 33 dBm (2 W), must comply

with a “tight” emission mask which is not compatible with existing 802.11 devices. Studies by NPSTC show conclusively that the small amount of adjacent channel interference created by 802.11 devices creates a negligible loss in performance for public safety applications [22]. Our study shows that the range of low power devices is severely limited. The public interest would be served if the FCC relaxes its rules and allows 802.11 radios, with their “loose” emission mask, to operate at the higher power levels allowed today only for proprietary “tight mask” radios.[1]

- Propagation Conditions Drive Practical Network Configurations. For mobile applications where the mobile antenna height is low, range is typically limited to less than 2.0 miles. Quite simply, one cannot replace a VHF radio operating through a mountain top repeater with 4.9 GHz radio using voice over IP (VoIP). The coverage areas are dramatically different. On the other hand, point-to-point links or airborne links with line-of-sight can reach as far as 30 miles or more (with high power devices). Consequently, one practical configuration for 4.9 GHz is to deploy a “hot spot” via a mobile command post with a point-to-point link back to a fixed location. In some cases, an intermediate relay will be needed. For rural fire fighting applications, it may be wise to maintain the relay at a high location in hot standby configuration and activate it when deployed. Mobile users connect through the hot spot and exploit high data rates (> 3 Mbps) for a variety of public safety applications.

- Propagation Conditions Limit Practical Applications. The mobile radio channel is a hostile environment for communications. Multipath fading wreaks havoc on broadband signals, resulting in high error rates, multiple re-transmissions, or lost connections. This study showed that fixed links can support nearly all public safety applications envisioned, but mobile links are unlikely to support true real-time applications such as VoIP unless physical airlink standards and network protocols are improved.

- 20 MHz Channels are Not Optimal. In the 4.9 GHz band, the FCC authorizes channel bandwidths of 1, 5, 10, and 20 MHz. Existing IEEE 802.11 standards specify channel bandwidths of 10 and 20 MHz, but some vendors also offer 5 MHz channels. Both 10 and 20 MHz channels were tested during this study. We find that 10 MHz is the preferred channel size for several reasons: It creates more flexible channel plans because five channels are available rather than 2.5, the 10 MHz radio has greater sensitivity by a factor of 2 (3 dB), and the 10 MHz radio is more robust in the presence of delay spread, which is prevalent on mobile radio channels.

[1] This recommendation assumes that manufacturers of 802.11 chip sets and amplifiers cannot solve the emission mask problem without resorting to proprietary solutions. We have not seen a non-proprietary solution to this problem in the 18 months since the FCC adopted the current emission mask limits.

- Regional Cooperative Networks are Preferred. FCC rules for licensing and deploying 4.9 GHz networks have poor interference protection. Essentially, the rules follow existing practice for the 2.4 GHz and 5 GHz unlicensed radio bands. For this reason, public safety agencies should pool their resources and share a common network in each region. Modern hardware and software allow networks to be partitioned without sacrificing throughput or security. In fact, traffic engineering theory shows that the spectrum is used most efficiently if all users share a single resource rather than dividing the resource among many users.

- Mesh Networking Holds Promise. Mesh networking creates a path back to the network server through intermediate nodes when wireline connections are infeasible or cost-prohibitive. Mesh networking solves an important problem for public safety agencies that must deploy to rural locations with no infrastructure. An obvious deployment example is a large wildfire, like the Hayman Fire of June, 2002. Most manufacturers of 802.11 Access Points have mesh capability and the 802.11 committee is currently drafting a standard, 802.11s, for mesh networking. This study successfully demonstrated a mesh network and revealed some practical rules for employing mesh networks.

The remainder of this report describes the methods used and the results achieved during this study.

2.0 Introduction

This project was funded by the National Telecommunications and Information Administration (NTIA) under a Technology Opportunities Program (TOP) grant. The grant period was October 1, 2004 through April 30, 2006.

The purpose of this project was to investigate the feasibility of using 4.9 GHz radio spectrum for a variety of public safety applications. Over 40 fixed and mobile Access Points (APs) were deployed in urban, suburban, rural plains, and mountainous areas along the front range of Colorado. Several test vehicles were equipped and thousands of field measurements were collected during more than 70 mobile and fixed equipment trials.

Several wide-area computer networks were configured and tested over 4.9 GHz radio links using conventional and *ad hoc* (mesh) networking. Many public safety applications were successfully demonstrated, including email, database query, file download, remote video monitoring, and streaming video.

2.1 Problem Statement & Project Objectives. Public safety agencies nationwide are clamoring for reliable broadband wireless services. The traditional narrowband public safety radio channels cannot support the high bit rates needed for modern computer and telephony applications. Many agencies have resorted to commercial wireless data services over third generation (3G) cellular radio networks. Although these commercial services do provide high speed data, high recurring costs, potential for security breaches, and lack of network availability during a crisis make this approach unacceptable in the long term. Public safety agencies need their own spectrum for broadband wireless services.

Recognizing this problem, the Federal Government recently allocated 50 MHz of new spectrum between 4.94 and 4.99 GHz exclusively for licensed public safety use [19].

This new public safety spectrum creates a number of opportunities, but it also raises many implementation challenges. Before the spectrum can be put to use in operational environments, several questions must be answered:

- Public safety radio systems typically operate in the VHF (150-174 MHz), UHF (450-512 MHz) and 800 MHz (806-869 MHz) bands. Unlike these bands, radio propagation at 4.9 GHz is similar to visible light. If the path is not line-of-sight, path losses will be severe and the signal may be unusable. Previous uses of this band were limited to point-to-point microwave links. Will the physical limitations of the frequency band preclude wide-area mobile use? What is the maximum range of practical systems in different propagation environments?

- Public safety agencies seek to exploit off-the-shelf, standards-based products whenever possible to realize economies of scale, achieve interoperability, and promote innovation. In the 4.9 GHz band, this means the use of IEEE 802.11 standards. But the loose emission mask of 802.11 radios caused the FCC to limit their use to low transmitter power, between 13 dB and 30 dB (20 and 1000 times) below high power limits. To qualify for high power, products must comply with the tight emission mask. At the time of this writing, these high power devices are not compatible with 802.11 and are available only in proprietary products. With this handicap, can 802.11 devices create sufficient coverage to be useful for public safety applications? What are the tradeoffs between low-cost, standards-based, low power radios and expensive, proprietary, high power radios? Are tight mask radio necessary to use the spectrum efficiently, or can low-cost 802.11 radios achieve comparable spectrum efficiencies?

- Given that the 802.11 standard was not optimized for mobile radio, is the protocol capable of supporting all envisioned public safety applications? How does mobility affect throughput? If the physical layer 802.11 protocol works well, are certain link layer and transport layer protocols preferred on this wireless channel (e.g., UDP vs. TCP/IP)?

- Given that 802.11 is a non-real time packet radio network and that mobility may disrupt the connection and introduce latency, can 802.11 radios support multimedia applications such as VoIP and streaming video?

- What is the role of *ad hoc* or *mesh* networking in 4.9 GHz networks? Can mesh networks solve the sparse node problem and reduce infrastructure costs by eliminating the need for landline connections at intermediate nodes?

The goal of this project was to provide specific answers to as many of these questions as possible.

2.2 Project Participants - Roles and Responsibilities. The Colorado 4.9 GHz Project main participants were Proxim, KNS Communication Consultants, Communications Systems, Inc., Pericle Communications Company, the Douglas County Sheriffs Office, Parker Fire Protection District, Cunningham Fire Protection District, and the City and County of Denver. The lead agency for this grant is the Parker Fire Protection District.

As a leading manufacturer of wireless broadband products, Proxim donated in-kind equipment and engineering services for the test bed.

KNS Communication Consultants provided the testing services and worked closely with Pericle Communications Company to refine the procedures to ensure accurate, unambiguous results. KNS Communications worked with the other partners to determine the location of Access Points, and then conducted computer coverage studies of these locations. KNS performed field testing of the sites, and revised their computer models to reflect actual field test results, compile data, and provide preliminary reports for engineering review by Pericle.

Communications Systems, Inc. (CSI) installed the fixed and mobile Proxim Access Points and provided technical support. This support included installing Access Points, climbing towers, installing mobile units, and repairing equipment as needed. CSI has FCC and PCIA certified technicians on staff, as well as installation personnel.

Pericle Communications Company provided test and evaluation services for the project, furnished test equipment for bench and field testing, supervised all testing, developed survey and post processing software, and prepared the final report.

The Douglas County Sheriff's office was the test site for law enforcement testing of the hardware and software in mountain, foothills, and suburban environments. We should note that northern portions of the Douglas County suburban environment already experience interference in the unlicensed radio bands (2.4 and 5 GHz) that affects public safety systems. Thus, a licensed system at 4.9 GHz will be a welcome replacement.

Cunningham Fire Protection District provided suburban and rural plains testing environments for fire and ambulance personnel.

The City and County of Denver provided a dense urban environment for measurements. A Denver fire station was used for a fixed AP location and Denver provided their mobile command post for testing in downtown Denver.

Parker Fire Protection District provided the fire and ambulance service testing area for suburban coverage. Parker Fire was the lead grant agency and managed the overall project and controlled the finances.

3.0 Regulatory Background

Starting in 2003, 50 MHz of new radio spectrum between 4.940 MHz and 4.990 MHz was made available by the Federal Government for public safety use. This spectrum is designated for fixed and mobile broadband wireless services. Communications in this new band must support the protection of life, health, or property. Proposed uses include the following:

- Wireless local area networks (LANs) for incident management
- Mobile data
- Video security
- Voice over Internet Protocol (VoIP)
- Connectivity for Personal Digital Assistants (PDAs)
- Hotspots
- T-1 line replacement

Although permanent point-to-point fixed installations are allowed with certain restrictions, the main purpose of the band is for temporary point-to-point links and mobile operations, which take priority over permanent fixed installations.

Prior to 2003, the 4.9 GHz band (4.940-4.990 GHz) was allocated in the United States to Federal Government fixed and mobile services. The band was used for fixed services such as conventional point-to-point microwave, tactical radio relay, high power tropospheric scatter systems, and for mobile services such as control of remote piloted vehicles, video and data telemetry links, target drone control links, fleet defense systems, and tethered aerostat systems.

In 1999, the 4.9 GHz band was transferred from Federal Government to non-Government use in accordance with the provisions of the Omnibus Budget Reconciliation Act. In 2000, the FCC released a Notice of Proposed Rulemaking that proposed to allocate the 4.9 GHz band to non-Government fixed and mobile services, excluding aeronautical mobile service, on a co-primary basis and to allow for flexible use of the band. The FCC also tentatively concluded *not* to designate the band exclusive for public safety use. The Second Report and Order (R&O) adopted the fixed and mobile allocation proposal [19]. However, the Commission also concluded in this second R&O that the public interest would be best served by designating the 4.9 GHz band for public safety use. Many state, county, local government and national public safety associations successfully argued that a public safety designation would enable responders to carry out critical and urgent missions more effectively, and would provide a safer environment for emergency responders. Further, the Commission believed that such an approach would further its statutory obligation to oversee wire and radio communications "... for the purpose of promoting safety of life and property through the use of wire and radio communication."

The FCC issued a Third R&O in May of 2003 that defined additional rules for eligibility and use of the 4.9 GHz band and for the first time allowed public safety agencies to apply for and receive licenses to operate in the band [20]. FCC rules governing the 4.9 GHz band are found in Part 90 of Title 47 the Code of Federal Regulations [15]. Some sections of Part 90 relevant to the 4.9 GHz band are the following: Part 90.523 defines who is eligible to hold a 4.9 GHz license, Part 90.1213 defines the channelization of the 4.9 GHz band, Part 90.1215 defines the power limits for radios operating in the band, and Part 90.210 defines the emission masks for the band. Excerpts of the relevant Part 90 rules are found in Appendix C.

The FCC allows channels to be aggregated to channel bandwidths of 1, 5, 10, 15, or 20 MHz. The maximum channel size is 20 MHz. The FCC channels are listed in Table 1.

An *emission mask* defines the how much spectrum the signal may occupy. In November of 2004, the FCC defined two masks for use in the 4.9 GHz band: Emission Mask *L* for low power devices, and Emission Mask *M* for high power devices. The *M* mask is "tighter" and provides better adjacent channel protection. It was selected first. The *L* mask is nearly identical to the mask defined in the IEEE 802.11 standards. It was chosen to allow public safety agencies and equipment vendors to exploit the economies of scale created by existing 5 GHz commercial off-the-shelf devices and to reduce time to market. Higher power devices will of course extend the range and reliability of 4.9 GHz networks, so from that perspective, Emission Mask *M* is preferred.

Emission mask, transmitter power and effective isotropic radiated power (EIRP) are tightly coupled in the FCC rules. Part 90.1215 creates a relatively complicated set of power limitations that we will summarize here.

Table 1 - FCC Channels in 4.9 GHz Band		
Channel	**Center Frequency (MHz)**	**Bandwidth (MHz)**
1	4940.5	1
2	4941.5	1
3	4942.5	1
4	4943.5	1
5	4944.5	1
6	4947.5	5
7	4952.5	5
8	4957.5	5
9	4962.5	5
10	4967.5	5
11	4972.5	5
12	4977.5	5
13	4982.5	5
14	4985.5	1
15	4986.5	1
16	4987.5	1
17	4988.5	1
18	4989.5	1

Both transmitter power and EIRP are limited by Part 90.1215. The power limits for low and high power devices are listed in Table 2. Note that within each category, the *power density* (dBm/MHz) is the same regardless of channel bandwidth. The power density limit for low power devices is 7 dBm /MHz and the power density limit for high power devices is 20 dBm/MHz.

Table 2 - FCC Power Limits at 4.9 GHz		
Channel Bandwidth	**Low Power Device (FCC Mask L)**	**High Power Device (FCC Mask M)**
1 MHz	7 dBm	20 dBm
5 MHz	14 dBm	27 dBm
10 MHz	17 dBm	30 dBm
15 MHz	18.8 dBm	31.8 dBm
20 MHz	20 dBm	33 dBm

EIRP is the product of transmitter power and antenna gain (relative to isotropic). Assuming that the receiving station is operating in the main lobe of the transmitting antenna, EIRP determines the power received, not transmitter power. For example, a 30 dBm transmitter operating with a 10 dBi antenna has an EIRP of 40 dBm, but a 27 dBm transmitter operating with a 13 dBi antenna also has an EIRP of 40 dBm and both systems will result in the same receive power if the receiving station is in the main lobe of the transmitting antenna.

Both low power and high power devices may use omnidirectional or directional antennas with gains up to 9 dBi at maximum transmitter power.

Low power devices may use directional antennas with gains greater than 9 dBi if both transmitter power and power spectral density are reduced dB-for-dB by the amount the directional antenna gain exceeds 9 dBi.

High power devices used for point-to-point or point-to-multipoint operation (fixed or temporary) may use directional antennas with gain up to 26 dBi at maximum authorized power. Directional antenna gain may exceed 26 dBi if both transmitter power and power spectral density are reduced dB-for-dB by the amount the directional antenna gain exceeds 26 dBi.

EIRP limits for directional antenna systems are summarized in Table 3.

Table 3 - FCC EIRP Limits at 4.9 GHz
(Directional Antennas)

Channel Bandwidth	Low Power Device (FCC L Mask)	High Power Device (FCC M Mask)
1 MHz	16 dBm	46 dBm
5 MHz	23 dBm	53 dBm
10 MHz	26 dBm	56 dBm
15 MHz	27.8 dBm	57.8 dBm
20 MHz	29 dBm	59 dBm

The emission mask was a contentious issue in 2003 and 2004. The original FCC mask, "Emission Mask *M*," also known as the "tight" mask, was originally the sole emission mask authorized. Neither IEEE 802.11a or 802.11j radios could meet this emission mask, so there was no industry-standard 4.9 MHz product available to public safety agencies.

The National Public Safety Telecommunications Council (NPSTC) and other agencies filed comments with the FCC objecting to the FCC emissions mask on the grounds it would preclude the use of industry-standard 802.11 radios and would result in expensive, proprietary devices that would stifle innovation. The FCC relented and eventually adopted two masks for 4.9 GHz, the original *M* mask for high power devices and the *L* mask for low power devices [15]. Thus, the prohibition on the 802.11a mask has been lifted, but the power limitations of the "loose" *L* mask create an incentive to use "tight" mask devices.

Both emission masks are plotted in Figure 1 for a 10 MHz channel.

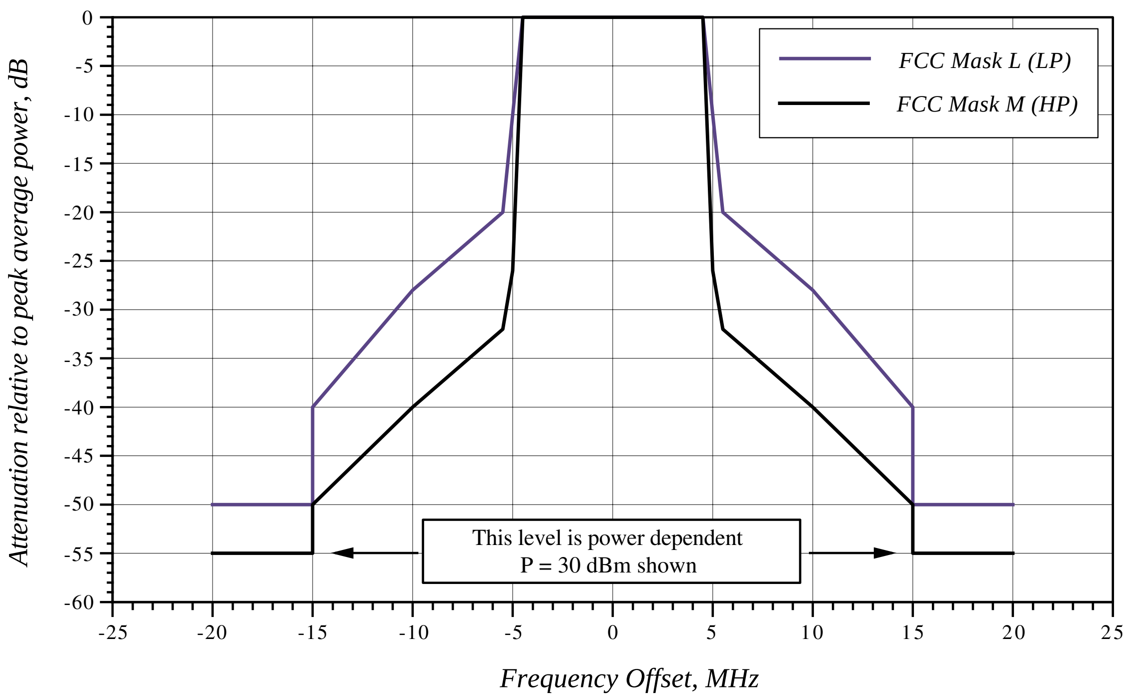

Figure 1 - FCC 10 MHz Emission Masks
(Masks scale proportionately for 5 MHz and 20 MHz channels)

4.0 Radio Propagation at 4.9 GHz

The bulk of this project involved measuring packet radio performance in the 4.9 GHz band over a variety of topographical conditions for both mobile and fixed deployments. Before we describe the test approach in Section 6.0, it is important that we understand two important topics:

- The physics of fixed and mobile radio propagation at 4.9 GHz, the subject of this section.
- The strengths and weaknesses of the 802.11 protocols when used on the 4.9 GHz channel, the subject of Section 5.0.

Let's begin with the case of fixed radios:

4.1 Fixed Radios and Basic Concepts. Fixed radio is the traditional use of frequencies above 2 GHz, including the 4.9 GHz band. Fixed radios can be used in point-to-point networks or point-to-multipoint networks. Most fixed radio links are configured so the path is line-of-sight, meaning there are no obstructions within a distance of 0.6 F_1 of a line drawn between the transmit and receive antennas, where F_1 is the first Fresnel zone radius, given by

$$F_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}, \tag{1}$$

where λ is the wavelength of the radio carrier, d_1 is the distance from the transmit antenna to the point of observation and d_2 is the distance from the point of observation to the receive antenna. The maximum value of F_1 occurs at mid path.

Note that lower frequencies (longer wavelengths) have a larger value of F_1 and therefore are more susceptible to diffraction losses from obstacles in the path. For more information on Fresnel diffraction, see [1].

Two exceptions to the line-of-sight requirement for fixed radios are *tropospheric scatter* paths and *knife edge diffraction* paths which are purposely beyond the horizon. Path losses on these systems are very high and they are not practical for the low-cost, low power devices under consideration for 4.9 GHz.

Assuming the fixed radio path is line-of-sight, the receive signal at the receiver is given by the following expression [1]:

$$P_r = \frac{EIRP G_r \lambda^2}{(4\pi r)^2}, \tag{2}$$

where EIRP is the effective isotropic radiated power, G_r is the receive antenna gain (relative to isotropic), λ is the wavelength of the radio carrier, and r is the path distance.

Embedded in this equation is an important factor called the *free space loss*. It can be written as

$$L_{fs} = \frac{(4\pi r)^2}{\lambda^2} \tag{3}$$

Or, in decibels,

$$L_{fs} = 21.98 + 20\log_{10}\left(\frac{r}{\lambda}\right) \tag{4}$$

In most cases, free space loss is the minimum loss we will encounter. In fact, many channel models use the concept of *excess path loss* to model path losses that exceed free space loss. One exception to this rule is the urban corridor where continuous tall buildings near the street create an effect similar to waveguide and the path loss is sometimes less than free space loss.

Another concept we will use for both fixed and mobile radio paths is *maximum path loss*, L_{max}. Maximum path loss is a useful way to compare radio systems that employ different transmitter powers, antenna gains and receiver sensitivities. The maximum path loss is the loss that attenuates the transmitted signal to the point where the received signal is exactly equal to the receiver threshold, P_{th}. In decibels, it is given by

$$L_{\max} = EIRP + G_r - P_{th} \tag{5}$$

Note that P_{th} is referenced to the antenna port on the receive antenna and therefore includes the effects of the antenna amplifier (if used) and cable losses. Also, P_{th} is defined for a particular level of service (e.g., bit rate) and there may be more than one value of P_{th} for a particular radio.

A final concept for this section is the *path loss exponent*. The path loss exponent describes the attenuation of the signal as a function of distance. It is a simplification, but a useful one when predicting the maximum range of a particular link. From (4), we see that the line-of-sight path has a path loss exponent of 2, or equivalently, 20 dB per decade. In mobile radio, a path loss exponent approaching 4 (40 dB per decade) is common. The path loss exponent is only valid starting at some non-zero distance from the transmitting site. Because most transmit antennas are installed above clutter, it is common to assume a path loss exponent of 2 until clutter is encountered and then an exponent greater than 2 in the clutter. This is an example of a two-slope model.

4.2 Mobile Radios. Unlike fixed radios, mobile radios must deal with non-line-of-sight conditions. We know that the higher the radio frequency, the more closely the propagation resembles visible light. In other words, higher frequency signals do not penetrate materials well and have high diffraction losses when bending over or around obstacles. Traditionally, frequencies above 2 GHz were used exclusively for fixed point-to-point radio links with highly directional transmit and receive antennas. Over the past decade, the demand for additional mobile radio spectrum resulted in fixed point-to-multipoint systems and mobile systems at 1.9 GHz (PCS), 2.4 GHz (Wi-Fi), 2.5 GHz (MMDS), and 5 GHz (Wi-Fi). Of these, only the 1.9 GHz band is truly a mobile radio band today, but there are plans to provide mobile radio services at 2.5 GHz and users routinely operate Wi-Fi radios from vehicles despite the weaknesses of the 802.11 protocol in this environment (see Section 5.0 for more on this subject).

The 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. Using central limit theorem arguments, these fluctuations are modeled as Rayleigh fading with Rayleigh-distributed amplitude and uniformly distributed phase [1]. Figure 2 is a plot of amplitude versus time for a typical Rayleigh fading mobile radio channel.

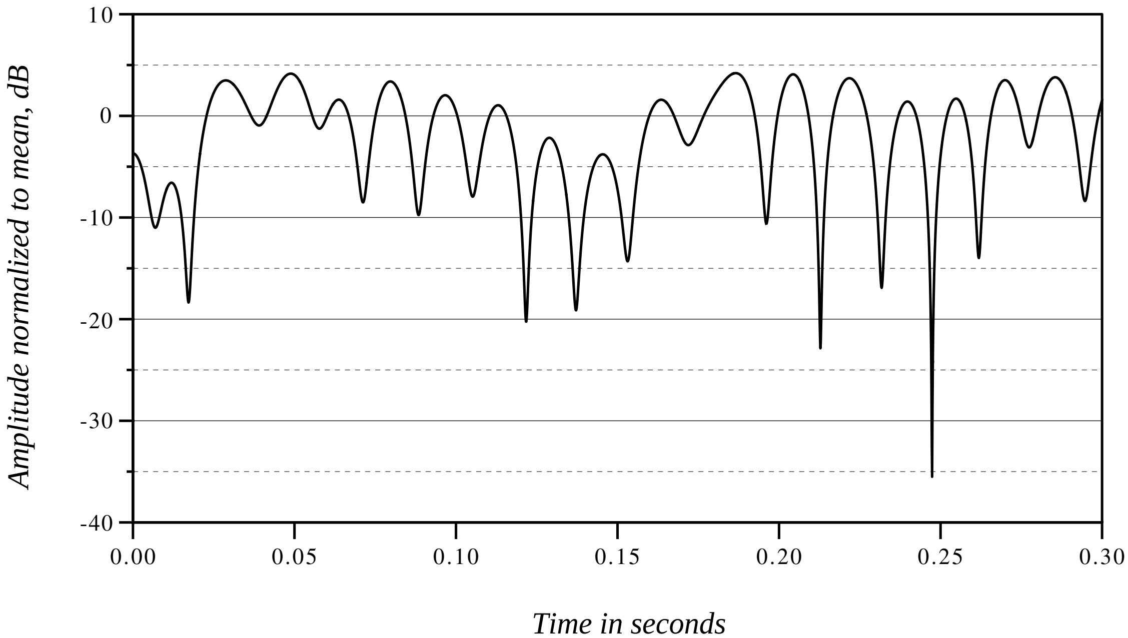

Figure 2 - Time-Varying Amplitude on Rayleigh Fading Channel
(V = 5 mph, f_c = 4950 MHz)

The local mean of the Rayleigh fading signal varies more slowly than the instantaneous amplitude and is commonly referred to as *shadow loss*. The most widely used statistical model of shadow loss assumes that the loss is log-normally distributed. In other words, if the signal level is given in decibel form (e.g., dBm), the received signal level, Y, has the normal probability density function,

$$f_Y(y) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{(y-\mu)^2}{2\sigma^2}} \tag{6}$$

where μ is the mean, and
σ is the standard deviation.

Mobile and portable receivers are usually specified to operate with a minimum local mean in the presence of Rayleigh fading. Thus, for a measurement survey to be a useful indicator of receiver performance, we want to estimate the local mean, *not* the instantaneous time-varying signal. Estimating the local mean requires that we average subsample measurements over some distance. The preferred distance is 40λ (8 feet at 4.95

GHz) as it adequately smoothes the Rayleigh fading [5], [6]. Long distances tend to include changes in the local mean due to location variability and are therefore not desirable. However, there is no ironclad rule on the maximum averaging distance when conducting field surveys.

Some minimum number of samples are required to accurately estimate the mean of the time-varying, Rayleigh-distributed signal amplitude. A rule of thumb used in mobile radio is that the number of samples should be sufficient to guarantee a 90% confidence interval of +/- 1 dB. Test receivers usually deliver readings in units of power or the logarithm of power (dBm). One can show that power on a Rayleigh fading channel is exponentially distributed [4] and the confidence interval for an exponential random variable is described by a Chi-squared distribution with $2n$ degrees of freedom where n is the number of samples [13]. We won't repeat the derivation here, but we will note that under the assumption of exponentially distributed power samples, one can show that roughly 50 samples are needed for a 90% confidence interval of +/- 1 dB.

With few practical exceptions, good estimators are *unbiased*, meaning that the expected value of the estimator equals the expected value of the random variable being sampled. Although the arithmetic mean of power samples is unbiased, the arithmetic mean of the logarithm of power samples has a -2.5 dB bias and therefore should not be used [5]. In other words, if the receiver delivers samples in units of dBm, each sample should be converted to milliwatts, summed, and the sum converted back to dBm. This is the method used by the data collection software for this project.

Because the composite signal is the vector sum of many delayed versions of the original signal, overlapping symbols at the receiver will create *intersymbol interference* (ISI). The extent of the problem depends on the delay, which is a random variable. The usual measure of delay is the *rms delay spread*, given by

$$S = \left[\frac{\sum_{k=1}^{N} (t_k - d)^2 P(t_k)}{\sum_{k=1}^{N} P(t_k)} \right]^{1/2} \tag{7}$$

where

$$d = mean \;\; delay = \frac{\sum_{k=1}^{N} t_k P(t_k)}{\sum_{k=1}^{N} P(t_k)} \tag{8}$$

and N is the number of discrete resolvable signals, t_k is the delay of the k^{th} discrete signal and $P(t_k)$ is the power of the k^{th} discrete signal.

Modern narrowband radios mitigate the effects of delay spread through the use of adaptive equalizers. An adaptive equalizer continuously measures the time-varying impulse response of the channel and attempts to correct to a flat frequency response across the channel bandwidth. However, 802.11 radios currently operating at 4.9 GHz are broadband and equalizers for broadband channels are considered by many to be either impractical or ineffective [2]. Instead, IEEE 802.11 radios use a modulation technique called Orthogonal Frequency Division Multiplexing (OFDM). The 802.11 version of OFDM employs 64 narrowband carriers and multiplexes each carrier's output at the receiver to recover the broadband signal.[2] Each carrier is narrow enough that the designer assumes the frequency response is flat and therefore no ISI should occur.

OFDM is only effective for relatively short delay spreads, however, and was not intended for outdoor use where long delay spreads can occur. Thus, one objective of this study was to determine if 4.9 GHz OFDM radios can maintain high throughput in the presence of real-world multipath environments.

5.0 Wireless Data Airlink Standards & Multiple Access Techniques

The Institute of Electrical and Electronics Engineers (IEEE) publishes a series of interoperability standards under the IEEE 802.11 series (wireless Ethernet). These standards greatly accelerated the growth of the wireless LAN market and today, nearly all wireless data products in the 2.4 GHz and 5 GHz bands are 802.11-compliant. Table 4 is a list of some of the 802.11 standards relevant to this project. IEEE 802.11 standards are available for free download from *http://standards.ieee.org/getieee802/download/802.11d-2001.pdf.*

Table 4 - Partial List of IEEE 802.11 Standards

Standard	Description
802.11-1999	Original Standard, Frequency Hopping & DSSS
802.11a-1999	OFDM up to 54 Mbps in 5 GHz Band, 20 MHz Channel
802.11b-1999	DSSS up to 11 Mbps in 2.4 GHz Band, 20 MHz Channel
802.11g-2003	OFDM up to 54 Mbps in 2.4 GHz Band, 20 MHz Channel
802.11i-2004	Security
802.11j-2004	OFDM up to 54 Mbps in 4.9 GHz Band, 10 and 20 MHz Channels (Japan)
802.11s-TBD	Mesh Networking (Still in Committee)

[2]Actually, only 52 of the 64 carriers are used. See Section 5.0 for further explanation.

Note that 802.11j was motivated by needs in Japan where the 4.9 GHz band was first cleared for wireless data use. This standard is also being used by vendors of 4.9 GHz radios on the United States.

To date, most offered 4.9 GHz products are adapted versions of 802.11a or 802.11j radios operating in the 5 GHz and 4.9 GHz bands, respectively. These products operate under the FCC low power rules, using the *L* or "loose" emission mask. Although 802.11j specifies 10 and 20 MHz channels, some vendors have successfully scaled their product bandwidths to operate at 5 MHz. Unfortunately, 802.11 products, scaled or not, do not meet the *M* or "tight" emission mask. Today, only proprietary implementations are available in high power, tight emission mask products.

802.11a and 802.11j employ algorithms for automatically adjusting the instantaneous bit rate to the measured channel conditions. The bit rate is adjusted by varying both the signal constellation and the code rate of an error-correcting code. Table 5 lists the required signal-to-noise ratio for each discrete bit rate for an 802.11j radio. Note that Table 5 assumes static conditions. A time-varying multipath fading channel will put greater stress on the receiver and performance will generally be worse for the same average signal-to-noise ratio.[3]

Table 5 - IEEE 802.11j Rate Dependent Parameters
(Required S/N Assumes Static Conditions)

Modulation	Code Rate	Required S/N, dB	10 MHz Channel Data Rate (Mbps)	20 MHz Channel Data Rate (Mbps)
BPSK	1/2	4	3	6
BPSK	3/4	5	4.5	9
QPSK	1/2	7	6	12
QPSK	3/4	9	9	18
16-QAM	1/2	12	12	24
16-QAM	3/4	16	18	36
64-QAM	2/3	20	24	48
64-QAM	3/4	21	27	54

IEEE 802.11a and 802.11j radios employ OFDM with 64 carriers. Of these, 48 are used for transporting user data and 4 are pilot carriers used for synchronization. Twelve additional carriers exist in an algorithmic sense, but have no power. They are needed to ensure the total number of carriers is a power of 2.

Two channel bandwidths are specified in 802.11j: 10 MHz and 20 MHz. The channel bandwidth is fixed for a particular session and does not change automatically. Although the 10 MHz bit rates are exactly half the 20 MHz bit rates, the 10 MHz channel has one-half

[3] Signal and noise are measured across the same bandwidth. The *S/N* is equal to the ratio of the energy per symbol to noise spectral density, E_s/N_0.

the equivalent noise bandwidth of the 20 MHz channel and therefore has 3 dB better sensitivity. This improved sensitivity translates into longer range.

Another advantage of the 10 MHz channel is that its ability to mitigate delay spread is improved by a factor of two. Goldsmith shows in [2] that the 20 MHz channel has an inherent delay spread mitigation of no more than 0.8 microseconds (μs). Although this level of performance is helpful, outdoor delay spreads in this band have been measured above 2.0 μs. Thus, the delay spread robustness realized by using the 10 MHz channel (1.6 μs) could prove powerful in mobile receivers. Similarly, a 5 MHz channel (available from some vendors) will double the delay spread mitigation again and also provide 3 dB greater sensitivity than the 10 MHz channel.

The 802.11 standard uses a method called carrier sense multiple access with collision avoidance (CSMA/CA) to enable multiple users to access a common medium. In this protocol, the station receiver listens to the channel for a period of time to determine if another station is transmitting. If another station is transmitting on the channel, the station wishing to transmit will wait for a random length of time before checking the channel again. If the channel is clear, the station will proceed to transmit. The station that is transmitting will reserve the channel for a specified period of time, so that the entire frame can be transmitted with minimum risk of a collision. A station will break the data message into frames, with each frame constituting a separate transmit request. The receiving station will issue an acknowledgement to the frame just received. If an acknowledgement is not received, the transmitting station will try to transmit the frame again.

The 802.11 standard also allows for a point coordination function, in which one station acts as a point coordinator that keeps track of which station has permission to transmit. This function is only used on an infrastructure network connection.

6.0 Measurement Approach

The propagation characteristics of the 4.9 GHz band were quantified in a number of different environments or *clutter categories*, including urban, mountains, foothills, plains, and suburban. Specifically, fixed APs were installed at the locations shown in Figure 3.

The fixed AP locations corresponding to each clutter category are the following:

- Urban (6 AP Locations): Downtown Denver, including Fire Station 6, 20th & Broadway, 20th & Stout, 18th & Stout, 18th and Broadway, 15th and Court, and Broadway just south of Colfax.

- Mountains (2 AP Locations): Devils Head, West Creek.

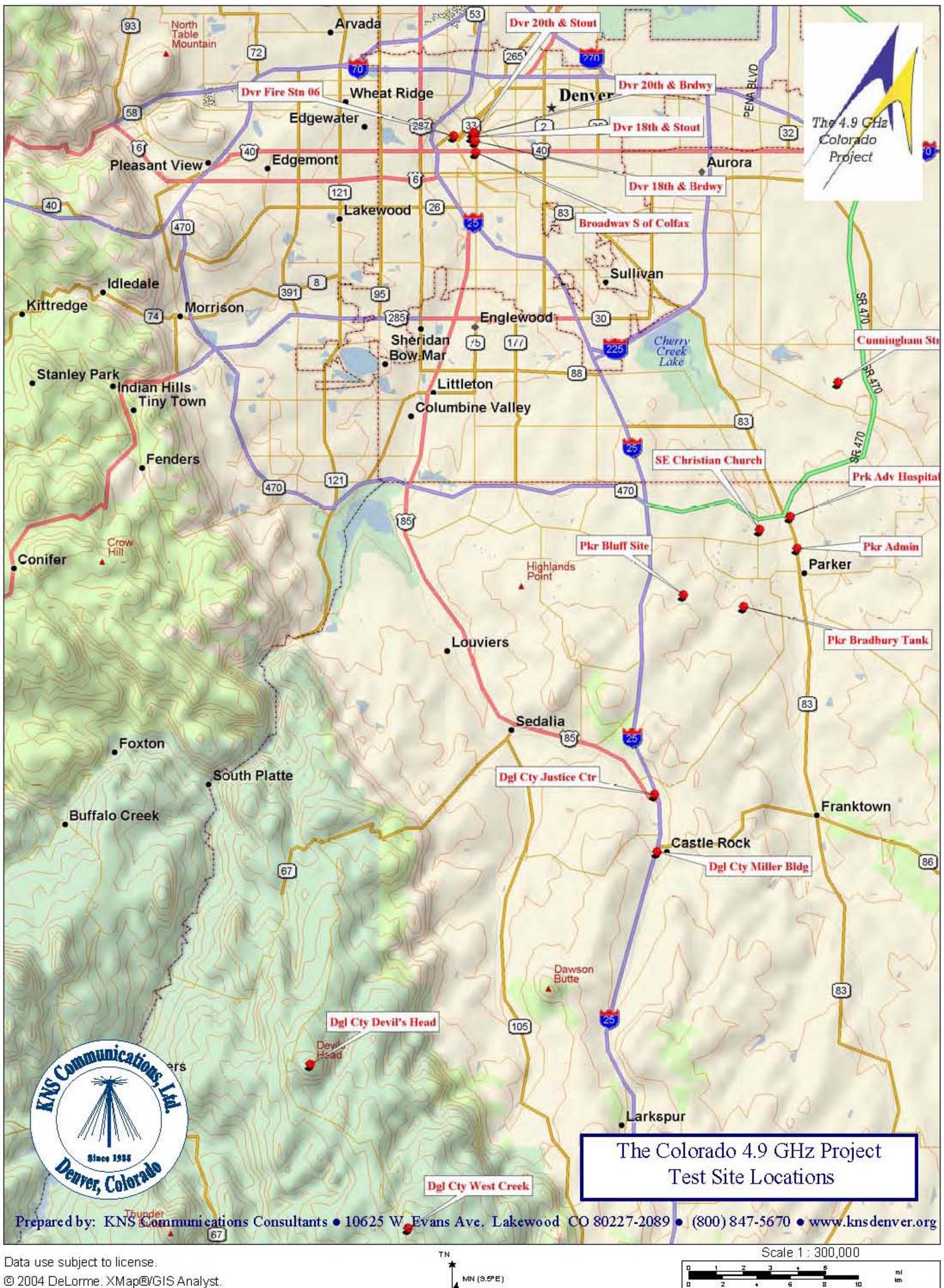

Figure 3 - Test Site Locations

- Foothills (2 AP Locations): Two buildings in Castle Rock near I-25: Douglas County Justice Center and the Miller Building.

- Plains (1 AP Location): Cunningham Fire Station 3.

- Suburban (4 AP Locations): Four locations in Parker, Colorado: Parker Fire Protection District Administration Building, Bradbury Water Tank, Parker Adventist Hospital, and Southeast Christian Church.

Each fixed AP location hosted multiple sectors and therefore multiple APs because one AP is required for each sector antenna. A total of 40 fixed and mobile Access Points were deployed through the course of the project.

We should note that the clutter categories are somewhat arbitrary and antenna height may be a stronger factor in performance than the particular clutter category. For example, foliage loss was the main factor at the two mountain sites, not terrain. In Parker, man-made clutter (houses and other buildings) was the main attenuation source. Parker was built on the plains and has relatively new construction, so tree cover is practically non-existent. Cunningham is similar to Parker with the distinction that the terrain is relatively flat while Parker has rolling hills. The two Castle Rock sites were categorized as foothills due to the rolling hills and mesas. However, most of the Castle Rock measurements were collected on I-25 and U.S. Highway 85 where terrain and other clutter effects were small.

The Proxim Model AP-4900 Access Point was used as the test instrument and was deployed in vehicles with an omnidirectional, rooftop magnetic-mount antenna (G = 9 dBi). Although a subscriber card was considered briefly for this role, much less data was stored in the subscriber card and Proxim postponed further development of the card until after this project was completed. Internal to the AP are registers holding relevant performance data such as the MAC address of the AP, MAC address of the AP at the distant end, signal-to-noise ratio, etc. These registers are organized in a block of memory called the Management Information Block (MIB).

Bear in mind that unlike a test receiver or spectrum analyzer, the AP does not report signal level unless a connection is maintained.

A Proxim AP-4900 can be configured in one of two basic operating modes, Mesh and Wireless Distribution System (WDS). In Mesh mode, the APs have a built-in hysteresis of roughly 6 dB to keep the radios from rapidly alternating between service and no service (the "ping-pong" effect). This hysteresis is similar to techniques used in cellular phone handoff algorithms. This effect interfered with accurate measurement of signal strength at relatively weak levels, so the WDS mode was used instead for all propagation measurements. Mesh mode was used during application testing to test the mesh algorithm.

One of the most difficult tasks undertaken during this project was to extract reliable and accurate signal strength information from the MIB. Significant time and expertise of the equipment vendor (Proxim) and the chip set manufacturer (Atheros) were needed to fully understand exactly how signal strength was estimated by the hardware and how it was stored in the MIB. Every assertion was tested independently on the lab bench. In the end, we discovered that the parameter labeled "RSSI" was in fact the logarithm of the signal-plus-noise-to-noise ratio, $(S+N_1)/N_2$, where N_1 is the noise power measured during the sampling period when the signal is active and N_2 is the noise power measured during a quiet period.[4] If the only source of noise is thermal noise in the receiver (the laboratory case), then $N_1=N_2$. Ideally, the MIB would have a register for signal level and a level for noise, but only the "RSSI" register was available and it was actually a signal-to-noise ratio.[5] Interestingly, "noise" is measured during quiet periods and only the weakest measurement of noise is recorded over some sampling period. The actual value of the noise power is not provided in the MIB.

Once this MIB information was finally available and understood, Pericle put several APs on the bench, recorded the reported signal level as a function of known input signal from signal levels from -100 dBm to 0 dBm. Signal level was derived from the signal-to-noise ratio reported by the MIB by assuming that the noise level, which was essentially thermal noise in the receiver, is constant under bench test conditions. This information was assembled in a table that was included in the post-processing software (developed by Pericle) so signal level could be reported in units of dBm.

Figure 4 is a plot of reported signal-to-noise ratio versus input signal level from the benchtop calibration measurements. Measured values are the average of six production units. Note that the receiver appears to have a noise figure of 10 dB when operating with a 10 MHz channel. Thus, the sensitivity for a 10 MHz channel at the lowest rate of 3 Mbps (S/N = 4 dB) should be -174 + 70 + 10 + 4 = -90 dBm.[6] The sensitivity for a 20 MHz channel at the lowest rate of 6 Mbps should be -87 dBm. The Linx bidirectional amplifier (BDA) improved receiver sensitivity by 2 dB.

[4] RSSI = Received Signal Strength Indicator. It is normally defined as signal level, not a signal-to-noise ratio.

[5] The register labeled "noise" has a value of -100 dBm and it never changes. It was ignored.

[6] Noise floor = kTB where k is Boltzman's constant, T is °K, and B is bandwidth in Hz. The factor -174 dBm/Hz is kT for T=290°K. The factor of 70 dB is 10log(10,000,000) and assumes a 10 MHz equivalent noise bandwidth.

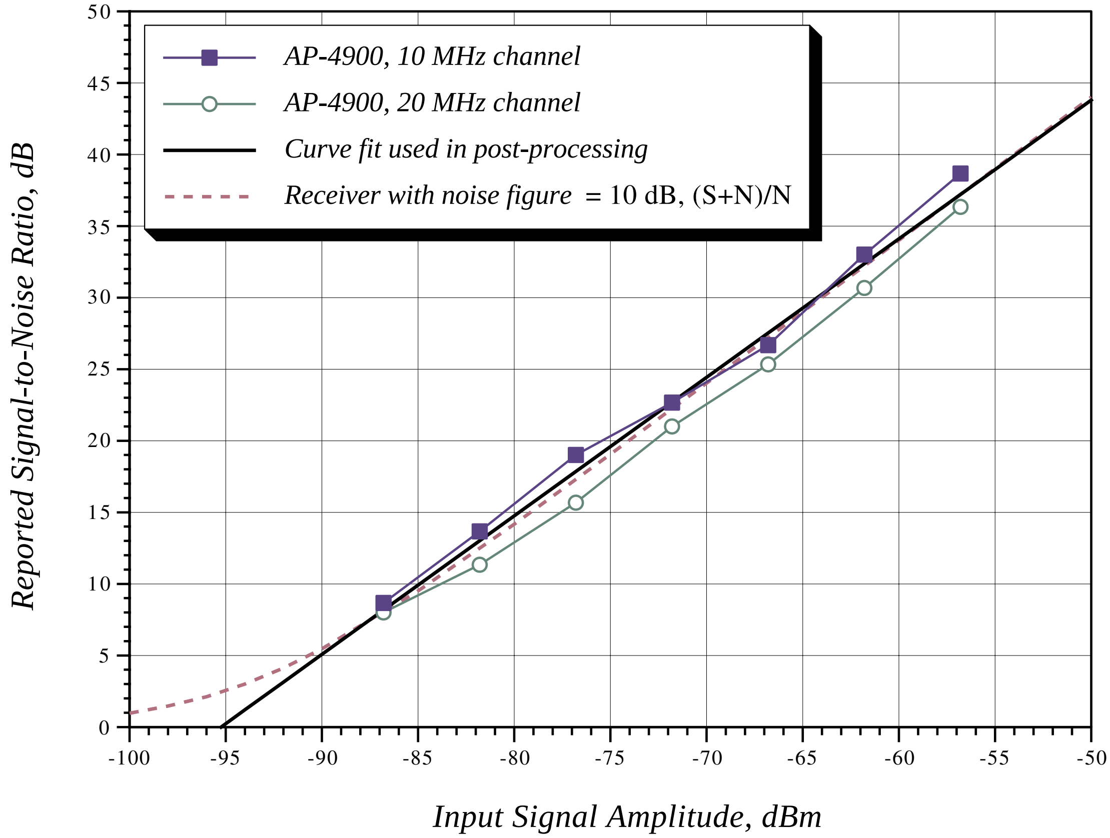

Figure 4 - Signal Level in dBm Versus Reported RSSI from AP-4900 (Static conditions)

No survey software for the AP-4900 existed at the beginning of the project, so Pericle developed new survey software to read data from the MIB and process it on-the-fly before storing 40 wavelength (minimum) average values in a log file on the computer hard drive. The sampling rate is set in milliseconds (ms), and it ranges from 20 to 1,000 ms. The header of each log file, as shown in Figure 5, gives basic information about the test.

```
#@PROGRAM=AP-4000 Survey
#@PROGRAM_VERSION=0.99
#@LOGFILE=C:\Documents and Settings\Administrator\My Documents\ShopTest\
        Test\2006-02-03 - Test0105 - CmdPOmni.log
#@ACCESS_POINT=AP-4900M v3.1.0(1069)  SN-05UT48600238 v3.1.0
#@MODE=STATION
#@RSSI_DBM_TABLE=0,-95.6 10,-85.3 20,-75.1 30,-64.8 40,-54.5 50,-44.3 60,-34.0
        70,-23.7 80,-13.5 90,-3.2 100,7.1
#@TIME=Feb 3, 2006 9:48:49 AM
```

Figure 5 - Header Information from Survey Log File

Each second, a new GPS header is put in front of the collected data. As one can see from Figure 6, the GPS header lists coordinates (decimal degrees) and other relevant parameters. The last number is the number of seconds since midnight. This is translated into time during post-processing of the log file. The date is included in the header of the file and is taken from the computer clock. There are additional parameters in the software that will be filled in when these values become available in the AP MIB files. In other words, we have place holders in the survey software for fields that are not available today, but may be available in future version of the AP firmware. Unfortunately the “Data Rate” parameter was one of these empty fields. The noise field is constant at -100 dBm, even when external interference is injected on the bench, so we did not consider this field reliable.

```
#@GPS=1,39.528983,-104.769300,1785.4,10,1.0,200218
39.528983,-104.769300,1785.4,0,00:20:a6:5d:9e:66,-91.5,-100.0,0,
,"00:20:a6:5d:9e:66",4,0,A,mesh,102,
3123,56,1528,0,48,724,221287,56502,480,61,584,0,0,10
```

For legibility — the line above is shown below with the appropriate headers:

#Latitude,	Longitude,	Altitude, Channel,	MAC Address,	Signal(dBm),	Noise(dBm),	DataRate
39.528983,	-104.769300,	1785.4,0,	00:20:a6:5d:9e:66,	-91.5,	-100.0,	0.0,

AP_Name,	Signal(RSSI),	Noise(RSSI),	Protocol,	StationType,	Age,
00:20:a6:5d:9e:66",	4,	0,	A,	mesh,	0

Figure 6 - Log File Data in Comma-Delimited Format

An important feature in the drive test software is the ability to detect and record the time when a connection is lost. This feature is needed because the MIB will continue to report the last good signal level even if the AP has lost its connection. By introducing a variable called AGE, we are able to count the number of samples since the last good signal measurement. The AGE variable is used in post-processing to flag samples that correspond to no connection. Although these samples are useless for measuring signal level, they are important indicators of the availability of the link. Under mobile conditions, the link connection can be lost even when the mean signal level is relatively strong.

Figure 7 is a screen shot of the collection window of the survey software. The font size is purposely large so the test engineer or technician can see the display from a distance (e.g., while driving).

As one can see from Figure 7, literally thousands of samples were taken during each drive test. The “A” under Protocol indicates 802.11a. The software build version number is also displayed on the bottom of the screen next to the GPS coordinates. Note that the particular test captured in Figure 7 indicates the AP is simultaneously collecting measurements from four fixed APs, but three of the APs have relatively large AGE values which means there is no active connection. The value stored in the AGE field is the number of seconds since the connection was lost. As the vehicle drives in and out of coverage, the test AP will automatically re-connect with the fixed APs and the AGE value resets to 0.

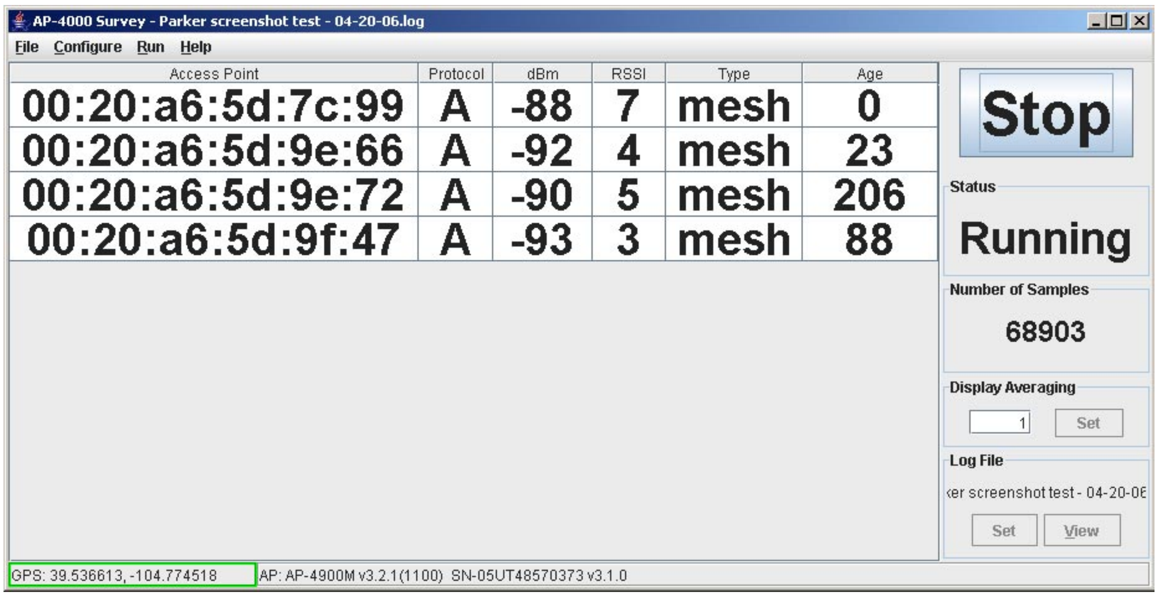

Figure 7 - Screen Shot of Survey Software Window

The AP-4900 operates with an output power (at the output coaxial cable connector) of 16.5 dBm (45 milliwatts). For most tests, the EIRP of the fixed AP was +31 dBm when sector antenna gain and cable losses were included. Because of cable losses, the EIRP varied between sectors and between sites, but the actual EIRP was measured/calculated in each case and the these actual values were used in all post-processing of the measured data.

The EIRP of a fixed AP is affected by the transmitter power, use of a BDA, antenna gain, and cable losses. The EIRP was calculated for each installation and this calculated value was used in a all post-processing. Most fixed APs without a BDA operated at an approximate EIRP of 31 dBm. Assuming an effective receive antenna gain of 7.3 dBi (including cable loss), the maximum path loss for a non-BDA installation is 128.3 dB (10 MHz channel).

Table 6 lists the EIRP, receiver sensitivity and maximum path loss for each of the link configurations used. Note that when BDAs were used at the fixed AP, a 6 dBi omnidirectional antenna was used and this configuration was only employed in downtown Denver. Otherwise, the BDA was used at the mobile or not at all.

Table 6 - EIRP, Sensitivity & Maximum Path Loss (Typical) (Effective Gain of Mobile Omni Antenna = 7.3 dBi, Sector Antenna = 14.9 dBi)					
Forward Link (Fixed to Mobile)	**EIRP**	**10 MHz Channel**		**20 MHz Channel**	
		Sensitivity	**Maximum Path Loss**	**Sensitivity**	**Maximum Path Loss**
No BDA, Panel TX, Omni RX	31 dBm	-90 dBm	128.3 dB	-87 dBm	125.3 dB
Panel TX, Omni RX, BDA at RX	31 dBm	-92 dBm	130.3 dB	-89 dBm	127.3 dB
BDA at Both Ends, Omni TX, RX	33 dBm	-92 dBm	132.3 dB	-89 dBm	129.3 dB
Reverse Link (Mobile to Fixed)	**EIRP**	**10 MHz Channel**		**20 MHz Channel**	
		Sensitivity	**Maximum Path Loss**	**Sensitivity**	**Maximum Path Loss**
No BDA, Omni TX, Panel RX	24 dBm	-90 dBm	128.9 dB	-87 dBm	125.9 dB
Omni TX, Panel RX, BDA at TX	34 dBm	-90 dBm	138.9 dB	-87 dBm	135.9 dB
BDA at Both Ends, Omni TX, RX	34 dBm	-92 dBm	132.0 dB	-89 dBm	129.0 dB

All antennas used in the project were calibrated for effective gain through the use of an unobstructed line-of-sight link. The 90 degree sector antennas showed very close agreement with the manufacturer's specifications (G=14.9 dBi). The two magnetic mount antennas showed a 1.7 dB loss from the manufacturer's specification, but the measurements included the connecting coaxial cable, which easily accounts for this loss. Figure 8 is a plot of the measured gain variation in dB for one of the sector antennas as a function of the sample number.

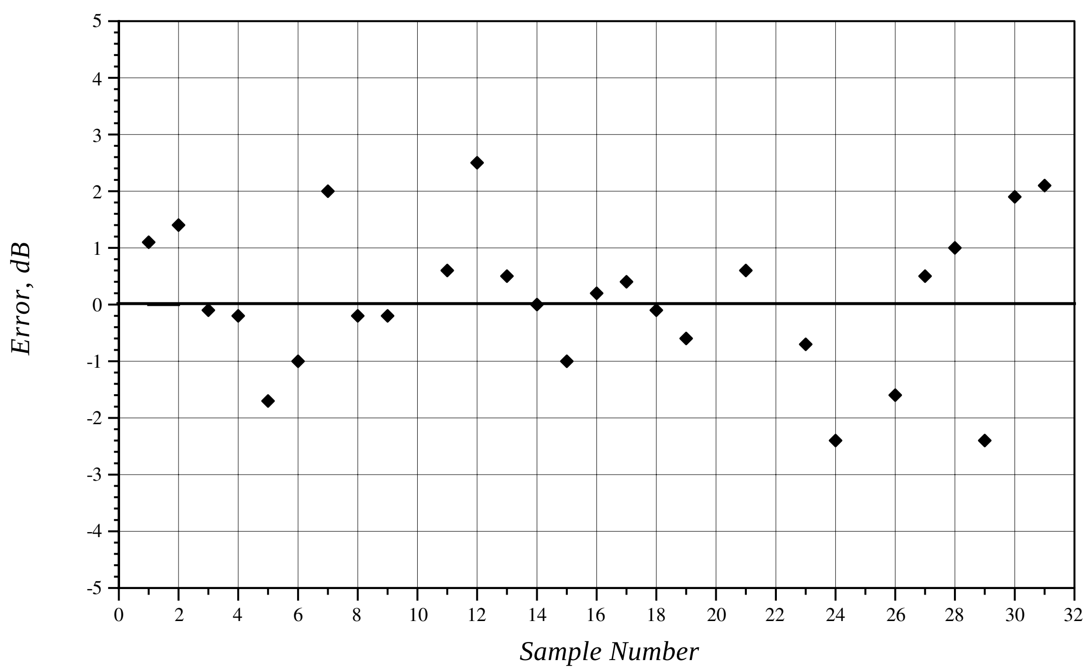

Figure 8 - Antenna Calibration Results (0=mfr. spec.)
(Mean Error = 0.1 dB, Standard Deviation = 1.3 dB)

The antenna gain measurements showed some variation about the mean despite the static nature of the line-of-sight link, but the mean value was always within a few tenths of a dB of the manufacturer's specification.

In addition to the antenna verification, Pericle and KNS measured and recorded the output power of every AP used in the project. Typical output power is 16.5 dBm (45 mW).

In the next section, several coverage maps will be presented to show coverage in each of the five topographical categories studied. In each case, the legend shown in Table 7 is used.

Table 7 - Legend for Coverage Maps
(10 MHz Channel)

Color	S/N Range	Nominal Throughput	Comment
Green	>18 dB	24-27 Mbps	Strong Signal
Yellow	12-18 dB	12-18 Mbps	Medium Signal
Orange	7-12 dB	6-9 Mbps	Weak Signal
Red	4-7 dB	3-4.5 Mbps	Minimum Signal Required
Light Blue	< 4 dB	0 Mbps	Connection May Be Intermittent
Dark Blue	<< 4 dB	0 Mbps	Lost Connection

Note from Table 7 that both light blue and dark blue indicates measured levels below the minimum threshold for reliable service. In the case of light blue, the connection has not yet been broken, but the instantaneous reading indicates a signal-to-noise ratio less than 4 dB. Dark blue, on the other hand, indicates that a lost connection has been confirmed. The throughput values are the nominal 802.11j performance levels and correspond to the case of a stationary receiver. A moving receiver is not likely to maintain these data rates due to multipath fading effects.

7.0 Radio Propagation Tests

The purpose of radio propagation testing was to characterize the performance of the 4.9 GHz AP in a variety of topologies. Specifically, we were interested in the path loss as a function of distance, achievable throughput, effect of power on range and coverage area, and circuit availability.

Drive tests were conducted in five locations: downtown Denver (*Urban*), Rampart Range Road (*Mountains*), Castle Rock (*Foothills*), Cunningham Fire Station 3 (*Plains*), and Parker, Colorado (*Suburban*). The results are summarized in the following subsections.

7.1 Urban - Downtown Denver. Eight tests were conducted in downtown Denver. Tests 022 and 032 were run from Denver Fire Station 6 with sector antennas 45 feet above the immediate clutter. (Fire Station 6 is just west of the downtown area.) Four 60 degree sectors antennas were installed at Fire Station 6 oriented at 30°, 165°, 230° and 358°.

Tests 105-110 were conducted from the Denver mobile command post. See Figures 9 and 10. For this series of tests, four 90 degree sector antennas and one omni antenna were installed on the telescoping mast and five corresponding APs were operating simultaneously. One mobile AP and the omni sector employed BDAs with a gain of 10 dB. A second mobile AP (without BDA) operated from the same vehicle and it communicated with the four fixed APs operating from the panel antennas. Two different SSIDs were used, one for the omnidirectional to omnidirectional link and one for the four panel antennas to omnidirectional links.

Tests 105, 107, and 110 employed fixed APs at intersections whereas tests 106, 108, and 109 employed fixed APs in the middle of the block. In all of these cases, the fixed AP sector antennas were at approximately 30' AGL and below clutter, meaning that the buildings in the immediate vicinity of the sector antennas were strictly higher than the antenna.

The test parameters for the urban area drive tests are listed in Table 8.

Table 8 - Urban Area Drive Tests
(O=Fixed AP Omni, P=Fixed AP Panel)

Test	Date	Fixed AP Antenna	AP Location	BDA?	Latitude	Longitude
022P	10/20/05	Proxim 15.9 dBi	Denver FS 6	No	-105.002338	39.748302
032P	11/2/05	Proxim 15.9 dBi	Denver FS 6	No	-105.002338	39.748302
105O	2/3/06	Proxim 6 dBi	20th & Broadway	Yes	-104.987638	39.749166
105P	2/3/06	TA 4904-14-90	20th & Broadway	Mobile	-104.987638	39.749166
106O	2/3/06	Proxim 6 dBi	20th & Stout	Yes	-104.988822	39.750127
106P	2/3/06	TA 4904-14-90	20th & Stout	Mobile	-104.988822	39.750127
107O	2/3/06	Proxim 6 dBi	18th & Broadway	Yes	-104.987722	39.745638
107P	2/3/06	TA 4904-14-90	18th & Broadway	Mobile	-104.987722	39.745638
108O	2/3/06	Proxim 6 dBi	18th & Stout	Yes	-104.990083	39.747888
108P	2/3/06	TA 4904-14-90	18th & Stout	Mobile	-104.990083	39.747888
109O	2/4/06	Proxim 6 dBi	15th & Court	Yes	-104.989638	39.741472
109P	2/4/06	TA 4904-14-90	15th & Court	Mobile	-104.989638	39.741472
110O	2/4/06	Proxim 6 dBi	Bdway, S. of Colfax	Yes	-104.987333	39.739722
110P	2/4/06	TA 4904-14-90	Bdway, S. of Colfax	Mobile	-104.987333	39.739722

The maximum path loss for the omnidirectional antenna with the BDA and the panel antennas without the BDA were nearly identical, but the coverage results were quite different. The omnidirectional antenna at the fixed AP created more than 30% greater coverage area than the composite coverage from the four panel antennas. One can speculate that in the scattering environment of downtown, illuminating a wider range of vertical and horizontal look angles creates a more favorable propagation scenario.

Figure 9 - Denver Mobile Command Post Vehicle

Figure 10 - Antenna Mast on Mobile Command Post

Figure 11 below is a scatter plot of the measured path loss versus distance from Test 105 in downtown Denver. Included in Figure 11 is a plot of the free space path loss and a linear curve fit to measurements. Note that the curve fit has a slope very close to the free space loss case (26 dB vs. 20 dB per decade), but there is an additional loss of roughly 18 dB (at 0.1 miles) that is unexplained.

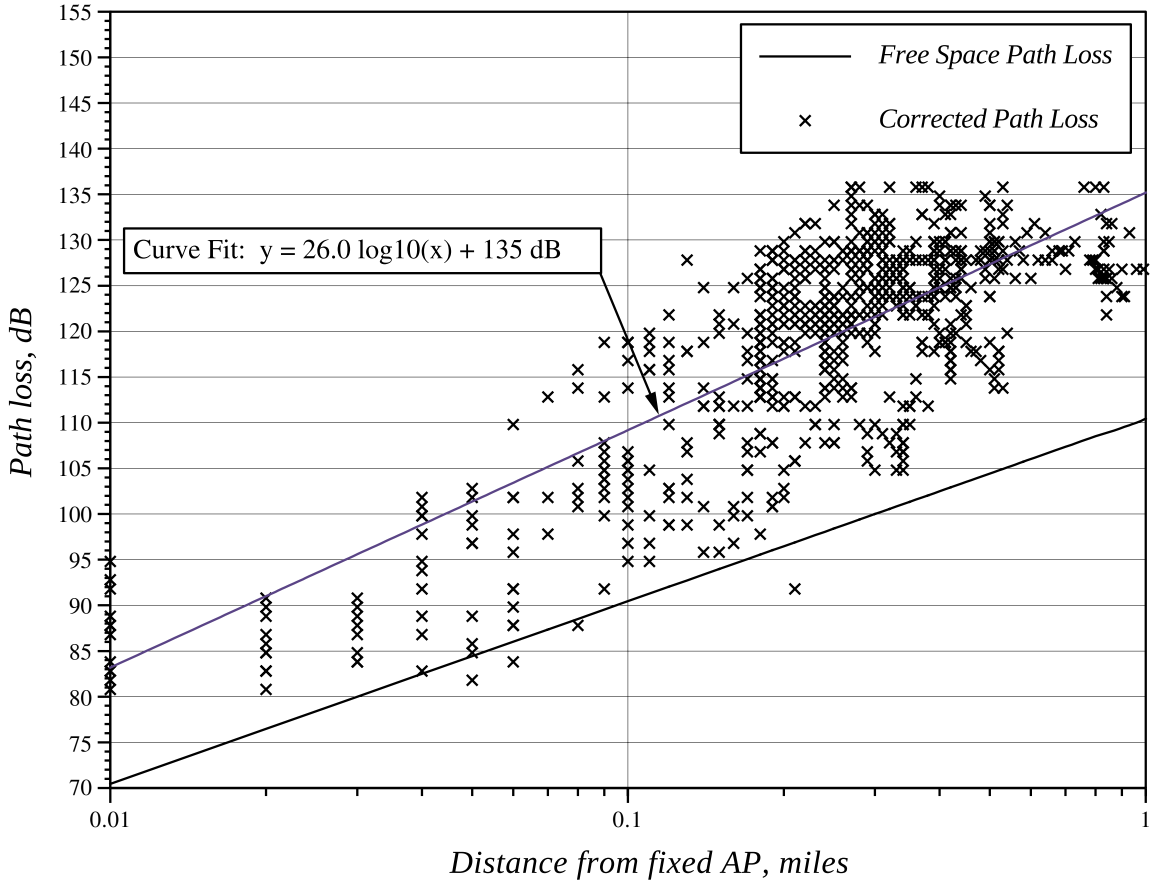

Figure 11- Path Loss Versus Distance for Test 105
(Downtown Denver, Omni TX & RX Antennas, BDA at Each End)

Please note that the maximum path loss for Test 105, corresponding to the receiver sensitivity of -92 dBm, is 131 dB. The receiver sometimes reports weaker signal levels without losing the connection partly because of the random nature of the signal amplitude and partly because of measurement error.

Coverage for Test 105 is shown in Figure 12 using the legend of Table 7. Surprisingly, the signal penetrated the urban environment quite well for an antenna height of 30 feet which was well below clutter. From Figure 12, one can see that the signal reached three blocks perpendicular to the direction of illumination.

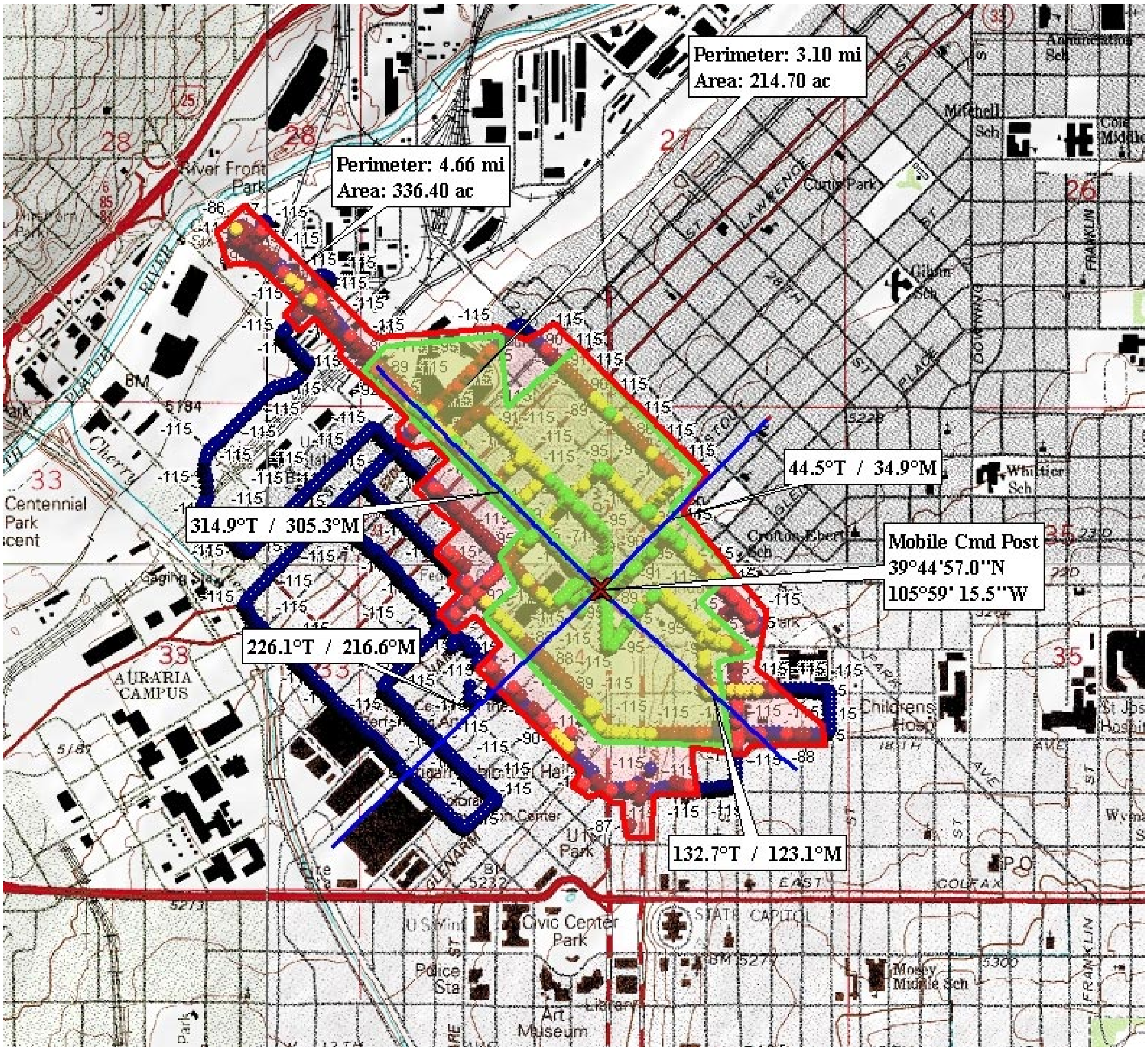

Figure 12 - Downtown Denver Coverage, Test 105 Omnidirectional, Legend in Table 7
(Note Difference Between Standard AP (Green Shading) and BDA Coverage)

The MIB did not report bit rate, but it is possible to estimate throughput at the transport layer (vice physical layer) using various utility software. One such software program is IXIA (*www.ixiacom.com*). Using this program, we first measured throughput on the bench under static conditions as a function of signal-to-noise ratio. We then used the IXIA program to measure throughput on several of the test runs in downtown Denver. The results for Test 110 are plotted in Figure 13.

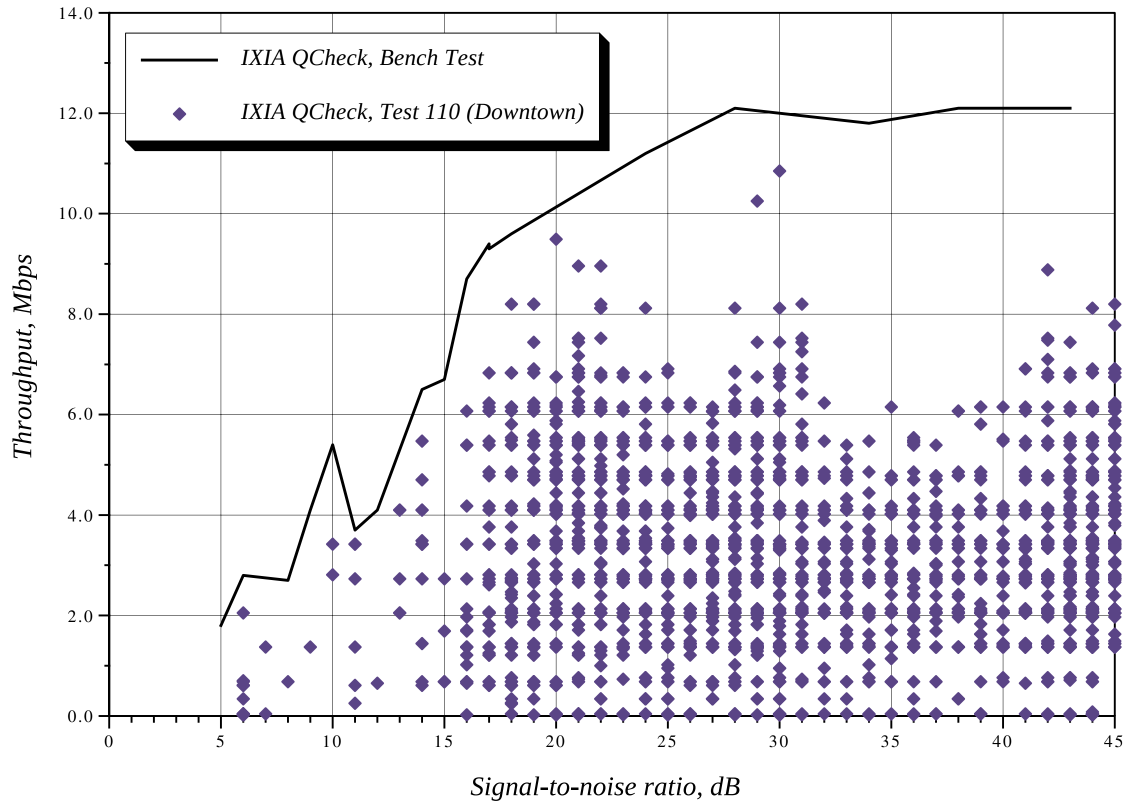

Figure 13 - Transport Layer Throughput, AP-4900, 10 MHz Channel

Note that under mobile conditions, the throughput as a function of signal-to-noise ratio is highly variable, and on average much lower than throughput in static conditions. We can speculate why this is true. There are several possibilities:

- The throughput ceiling of 12 Mbps versus 27 Mbps (for 10 MHz channels) is most likely due to overhead inherent in TCP/IP.

- In flat fading, the bit error rate may be high due to burst errors that the receiver cannot correct. The probability of packet re-transmissions is high and throughput suffers.

- When present, delay spread may create an irreducible error floor that increases the likelihood of at least one uncorrectable error per packet to nearly 100%. In other words, the frame-error rate (FER) is nearly 1.0. Thus, each packet must be retransmitted at least once and throughput suffers.

- The auto fallback algorithm used to estimate the channel conditions and select a rate may encounter several problems: The algorithm may not select the most reliable rate on a time-varying channel due to channel estimation errors; the algorithm may try and fail to negotiate the rate, causing down time; and the algorithm may be conservative and simply select a lower rate than is necessary.

- TCP/IP is an inefficient protocol on channels with frequent packet errors. Typically, the throughput assuming a single re-transmission is much less than 50% because of this inefficiency. The User Datagram Protocol (UDP) is much more efficient on wireless channels, but the user software application must be capable of using this protocol and must be configured to do so. TCP/IP certainly does not preclude the effective use of 4.9 GHz; it simply makes the use less efficient and prone to latency.

Although the throughput in an urban mobile environment appears to be much lower than in a static laboratory environment, we shall see in Section 9.0 that most public safety applications, even video, do not require user throughput greater than about 1.5 Mbps. Perhaps the greater concern is the bursty nature of the channel. This burstiness will create latency and negatively affect real-time, two-way communications such as VoIP.

7.2 Mountains - Devils Head & West Creek. The Colorado Rockies are densely forested with rugged terrain. At 4.9 GHz, both tree cover and terrain shadowing have a dramatic negative effect on radio coverage. Below tree line (subalpine), the mountains are mostly covered with conifers of various types in old growth areas and aspens in new growth areas. The dominant tree species below 8,000 feet is the Ponderosa Pine while the dominant tree type above 8,000 feet is the fir, especially the Douglas Fir. The only common deciduous tree at altitude is the Aspen. Two sites were used for mountain drive test surveys, Devil's Head and West Creek. Both sites are accessible from Rampart Range Road. The study elevations varied between 8,000 feet and 9,750 feet AMSL.

No BDAs were used at Devil's Head or West Creek, so the EIRP from the fixed AP was 31 dBm, the receiver sensitivity was -92 dBm (BDA at mobile), the mobile receive antenna gain was 7.3 dBi and the maximum path loss was 128.3 dB.

Devil's head fire lookout tower is located at 9,748 feet AMSL. Three sectors were installed on the tower with all antennas well above tree height. Antennas were installed with a 3° downtilt to reach the Rampart Range Road below the site which varies in elevation from 8,400 feet to 9,000 feet AMSL. Figures 14 and 15 show the antenna installations at Devil's Head.

Figure 14 - Devil's Head Fire Lookout Tower (AP Sector Antennas in Foreground)

Figure 15 - Devil's Head Third Sector Antenna

Figure 16 shows the coverage from Devil's Head. Some isolated coverage was seen at points as far as 4.6 miles from the site, but most of the useful locations were within 2.5 miles of the site. Despite the relatively steep lookdown angle, the tree cover created significant attenuation and coverage was limited mostly to line-of-sight locations.

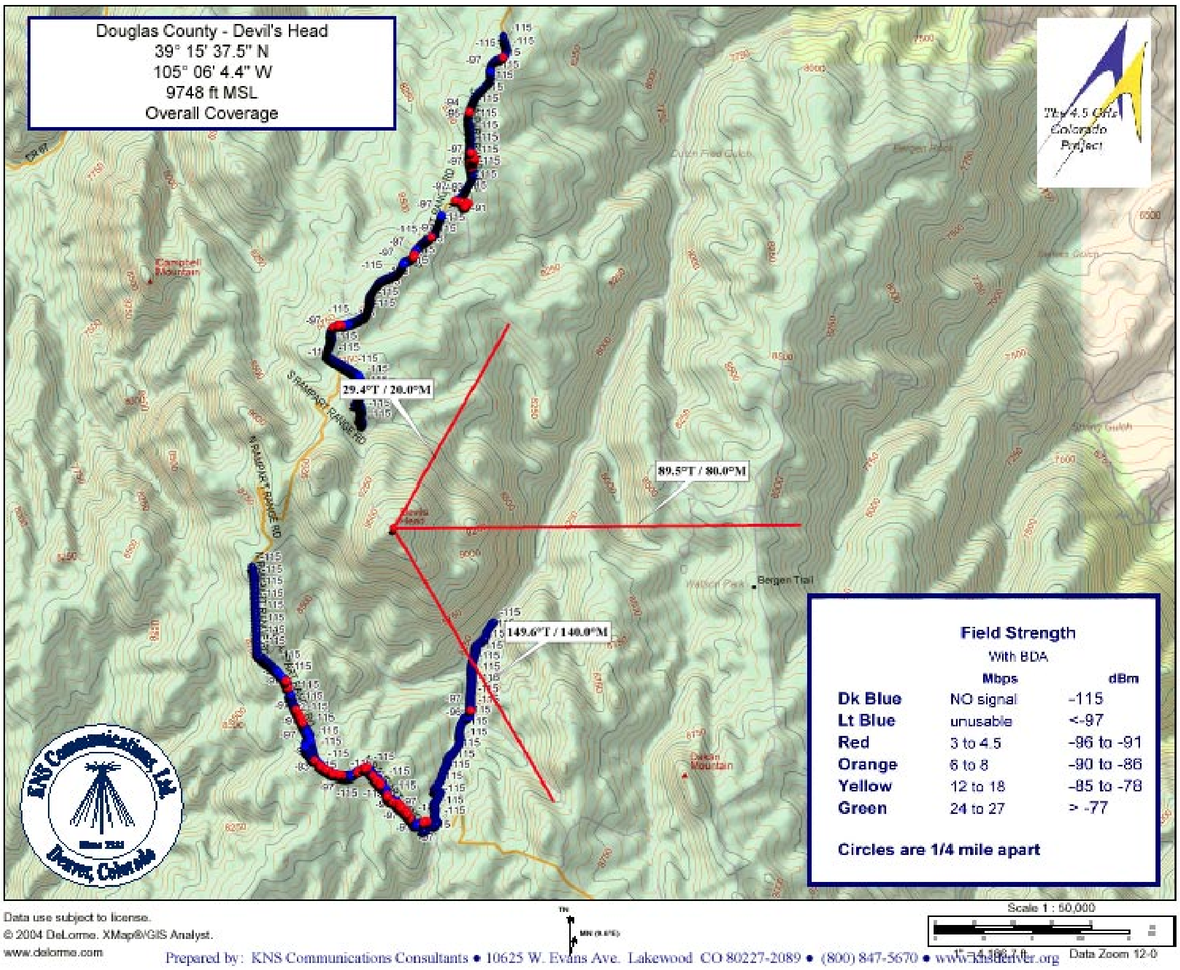

Figure 16 - Devil's Head Coverage (EIRP = 31 dBm)

West Creek is an existing tower site on Rampart Range Road between Colorado Springs and Sedalia. It is south of Devil's Head at an elevation of 9,195 feet AMSL. At West Creek, the APs were mounted at 40 feet AGL and were powered over the CAT/5 Ethernet cable. The terrain and vegetation is similar to Devils Head, but the antenna height is lower relative to the tree cover, so greater attenuation due to vegetation was expected.

Figure 17 - West Creek Towers From Rampart Range Road (September, 2005)

Figure 18 - West Creek Towers
(AP Sector Antenna on Left Side at 40' AGL)

The measured coverage from this site is shown in Figure 19.

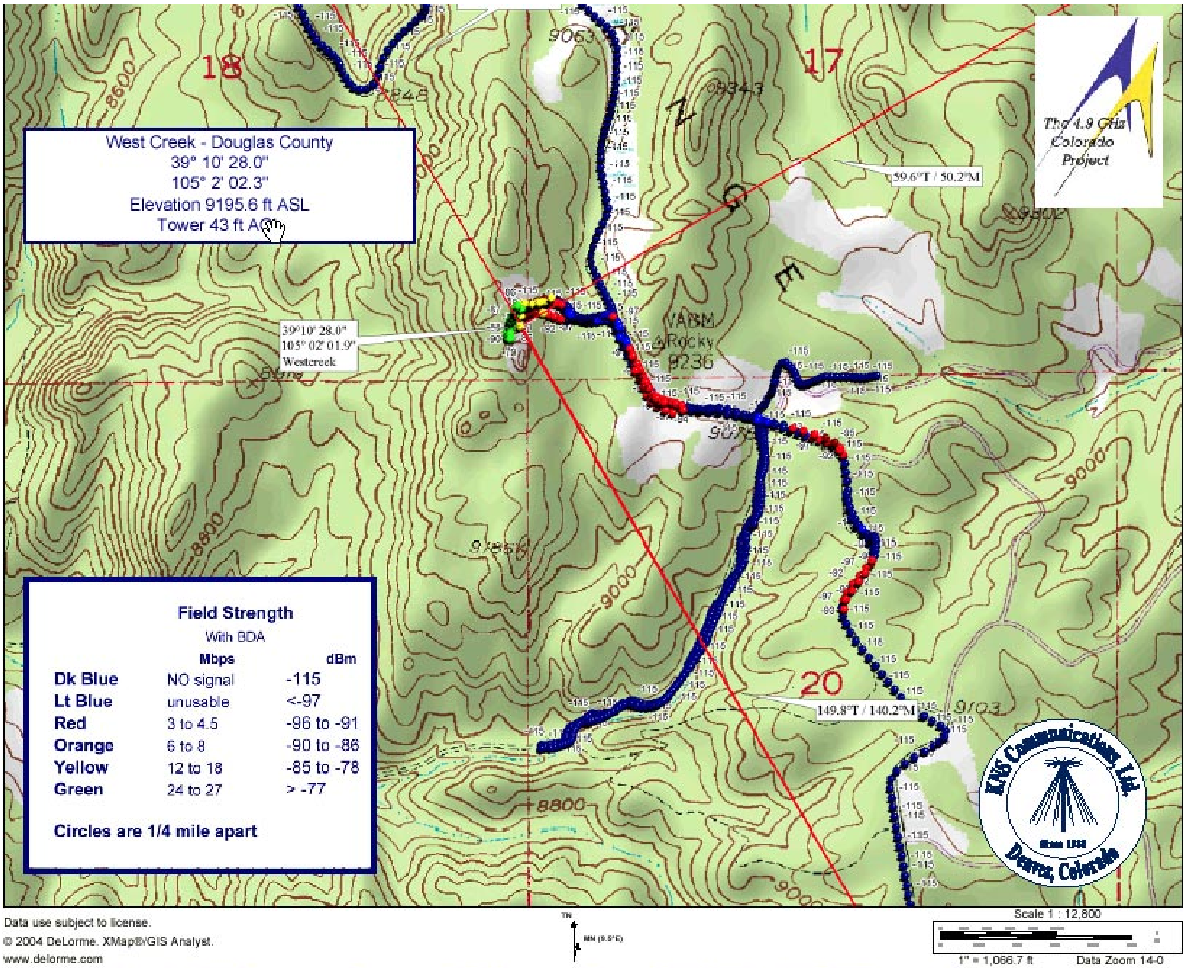

Figure 19 - West Creek Coverage (EIRP = 31 dBm)

7.3 Foothills - Castle Rock. Two fixed AP sites were used in Castle Rock, the Douglas County Justice Center and the Miller Building. The Justice Center employed four 90 degree panel antennas at 0°, 90°, 180°, and 270°. The Miller Building employed three 60 degree panel antennas at 0°, 180° and 270°. No BDAs were used.

Thirteen test runs were made in Castle Rock, seven with 10 MHz channels and six with 20 MHz channels. These were the only 20 MHz drive tests conducted in this study. All others were 10 MHz. Each run was conducted with a different fixed bit rate, ranging from 3 Mbps to 24 Mbps. Composite coverage from these two sites for a 10 MHz channel and fixed rate of 3 Mbps is shown in Figure 20. Note that starting from the south on I-25 and driving north, the drive routes split at the northern edge of Castle Rock. The left fork is U.S. Highway 85 and the right fork is I-25.

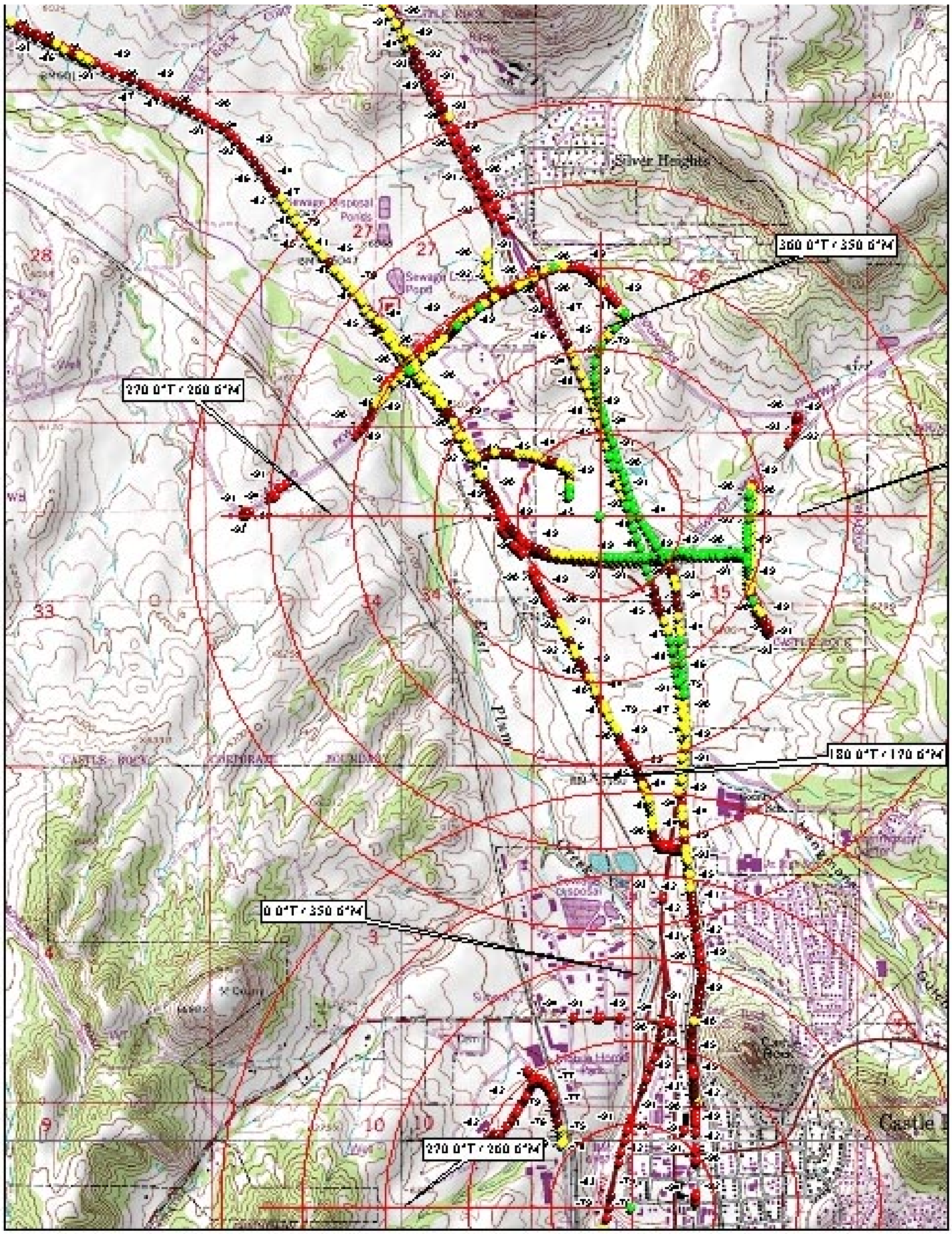

Figure 20 - Castle Rock Composite 2-Site Coverage, Test 039 (10 MHz)
(Rate Fixed at 3 Mbps, EIRP = 31 dBm, Concentric Circles are 1/4 Mile Apart)

The Castle Rock tests revealed some important shortfalls of both the 20 MHz channel and autoranging data rates in mobile environments. Both the channel availability and the mean bit rate were lower using 20 MHz channels than with 10 MHz channels. Some of this performance shortfall was due to the 3 dB loss in basic sensitivity, but we also found that when a connection was made, the autoranging algorithm caused the 20 MHz channel to operate at a lower mean bit rate than 10 MHz. We also found that the connection was more reliable for both 20 MHz and 10 MHz channels if the data rate was fixed at the lowest rate rather than allowing the AP to autorange. Some performance loss is likely due to weaker delay spread mitigation at 20 MHz, but we can only speculate because delay spread was not measured directly.

7.4 Plains - Cunningham Fire Station 3. Two test runs were conducted using an AP installed at Cunningham Fire Station 3. Coverage from this site is shown in Figure 21.

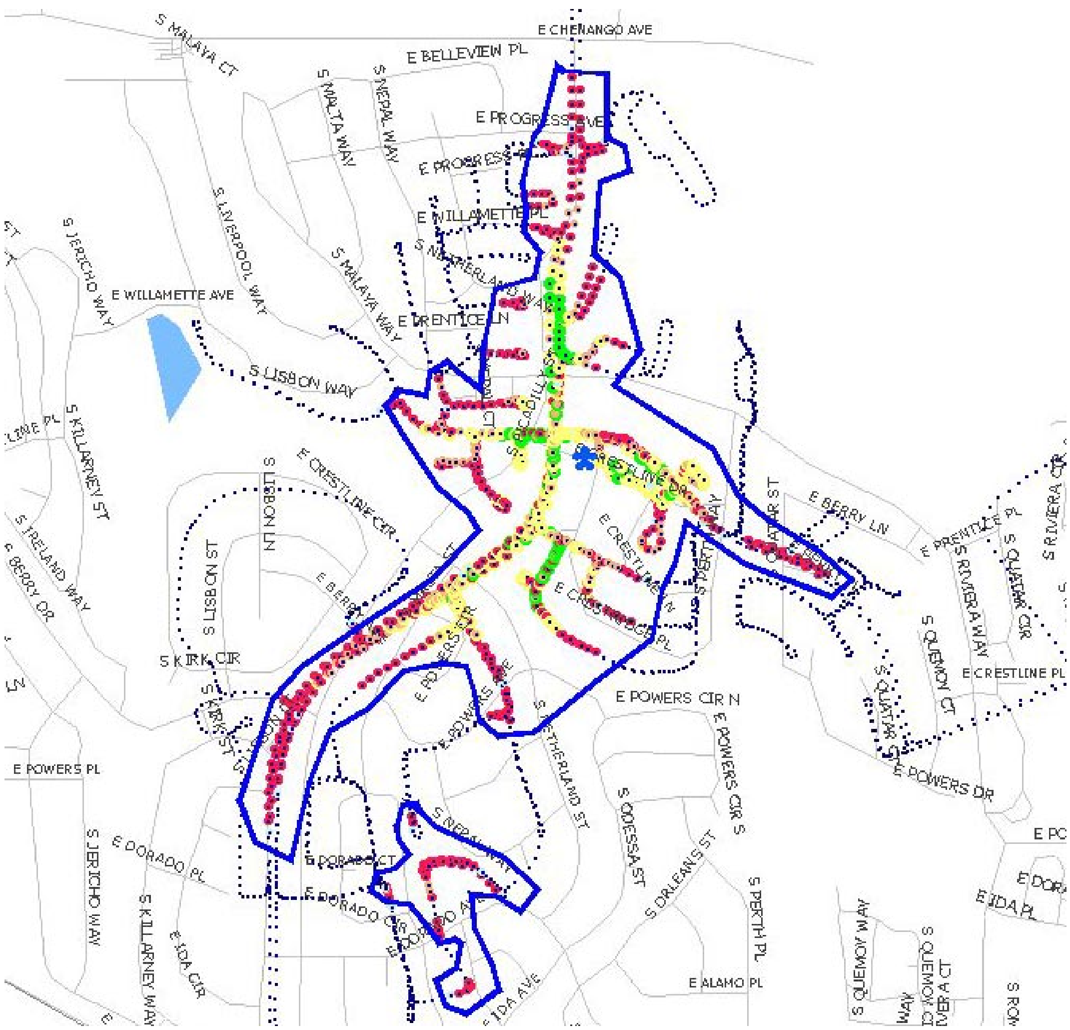

Figure 21 - Cunningham Fire Station 3 Coverage
(Blue Outline Indicates Limit of Coverage)

7.5 Suburban - Parker, Colorado. The most sophisticated network configuration was was installed in Parker, Colorado with a network server at the Parker Fire Administration Building. Four sites were constructed and unlike the other locations, the Parker network was maintained throughout the study period and is still in place at the time of this writing. Composite coverage from the four sites is shown in Figure 22.

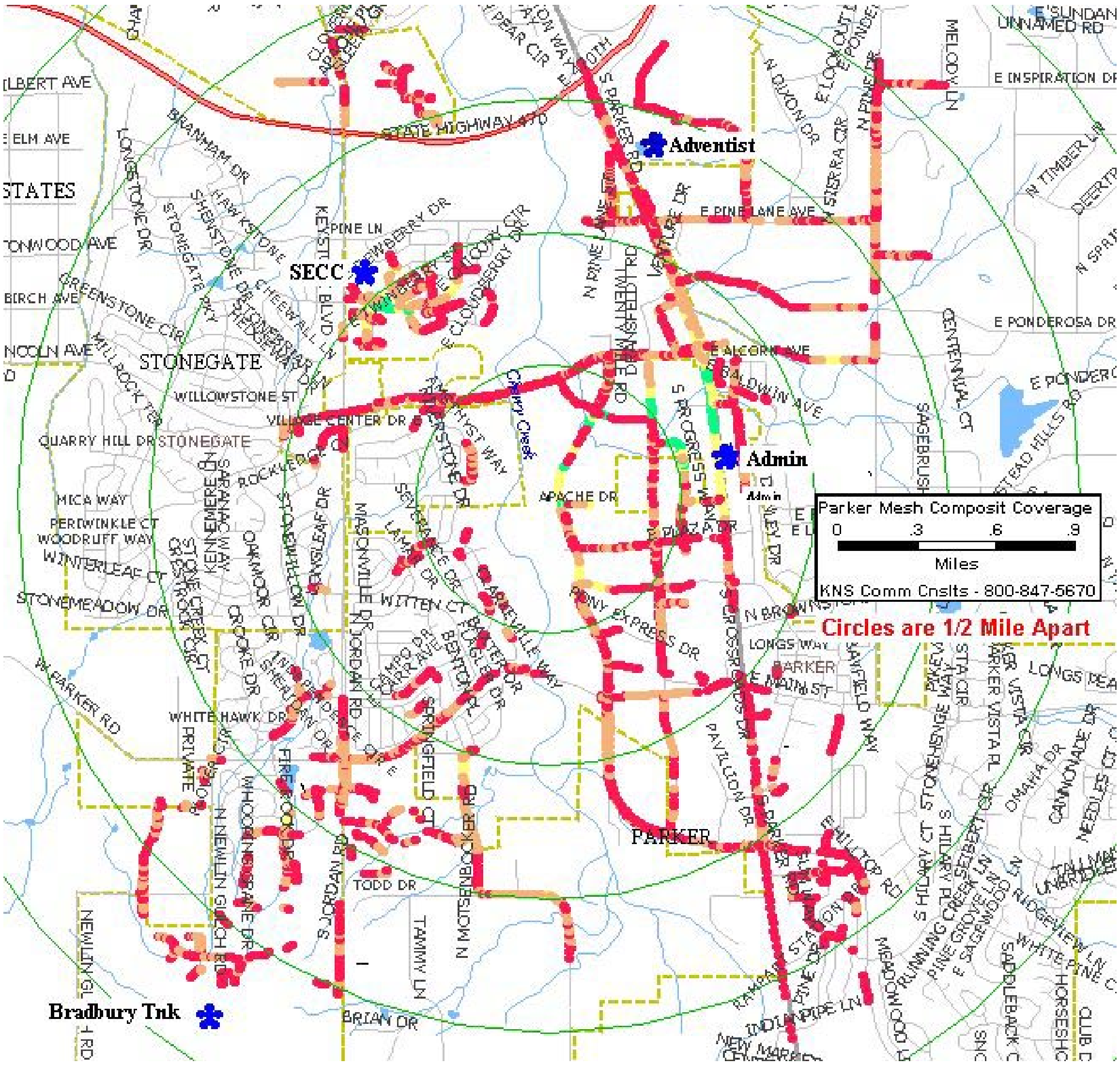

Figure 22 - Parker Fire Network Composite Coverage (4 Sites)
(See Table 7 for Legend)

8.0 Mesh Networks

An important enabling technology for 4.9 GHz networks is *ad hoc* networking, also known as *mesh* networking. Much of the basic research in this area was funded by the Defense Advanced Research Projects Agency (DARPA) and this research already appears in many commercial products. IEEE 802.11 wireless LANs are the main commercial application of mesh technology today.

A typical 802.11 network requires that users connect to an Access Point that is connected in turn to a wired Ethernet computer network. Normally, APs talk to end users and to the wired network, but not to other APs. Mesh networks allow the AP to talk to other APs for the purpose of finding the "shortest path" to a wired connection and to save infrastructure costs. The principal advantage of mesh networking is lower installation costs for outdoor APs that are far from any wired infrastructure.

A mesh wireless network is a set of two or more devices equipped with radios and special networking capability. Each device is a network node capable of originating traffic or routing traffic to other network nodes. Each node can communicate with another node that is within radio range or one that is outside radio range. In the latter case, an intermediate node is used to relay or forward the packet from the source toward the destination [10]. Like many "smart" wireline networks, *ad hoc* wireless networks use shortest path algorithms to find the best path between source and destination.

The metric for optimizing the path is not necessarily physical distance. The "shortest" path may be the path that creates the highest throughput. Or, it might be the path that is expected to be the most reliable.

Mesh networks have two key features: they are *self-organizing* and *adaptive*. Mesh network nodes can detect the presence of other network nodes and perform the necessary handshaking to connect the link and ultimately create a reliable path between source and destination. Figure 23 illustrates a typical mesh network architecture.

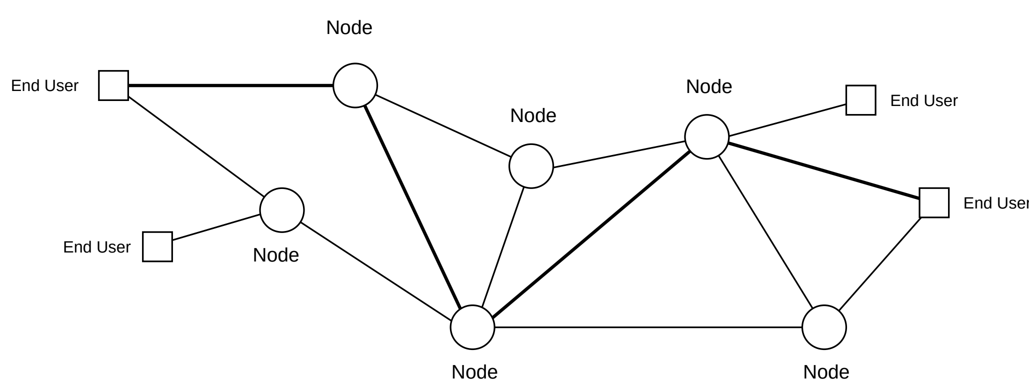

Figure 23 - Typical Network Topology with a Shortest Path Highlighted

The highlighted path in Figure 23 is an example of a shortest or best path between two end users. The network adaptively measures link conditions to pick the path that provides the most reliable link with the highest data rate.

Note from Figure 23 that connections exist between nodes only when the link can be closed. The absence of a connection between two nodes indicates that the distance is too great or perhaps interference makes the link unfeasible.

Several companies manufacture Access Points with ad hoc networking capability. Two early adopters are **Tropos Networks** and **Mesh Networks**. **Proxim**, the vendor partner for this project, also offers a mesh-capable AP and this AP was used during field testing near the end of the study period. We'll describe this testing in more detail in the next section of this report.

At the time of this writing, mesh protocols are proprietary, but several companies, including **Proxim,** sell mesh-capable APs that communicate with user devices using IEEE 802.11. A new standard for mesh networking, IEEE 802.11s, is in committee at the time of this writing.

9.0 Application and Mesh Tests

The purpose of application testing was to determine if the equipment was capable of handling real-world applications such as streaming video, large file transfers, Internet access, and fire-manager applications. Measurements were also collected to determine the effectiveness of mesh (*ad hoc*) networking between APs, the cost in throughput when using mesh, maximum distance per hop, and effects of antenna elevation on range.

Fixed AP Locations. The application testing was conducted in Parker, Colorado using the four sites previously employed for radio propagation drive test measurements. These four sites and the corresponding sector antennas are listed in Table 9.

Table 9 - Fixed AP Site Data for Application/Mesh Tests

Location	Sector Az.	Beam-width	Gain	EIRP
Parker Admin. Bldg.	285°	90°	14.9 dBi	31.5dBm
Adventist Hospital	283°	90°	14.9 dBi	31.5 dBm
SE Christian Church	96°	90°	14.9 dBi	31.5 dBm
Bradbury Tank #1	279°	90°	14.9 dBi	31.5 dBm
Bradbury Tank #2	54°	90°	14.9 dBi	31.5 dBm

The site locations and sector orientations are shown in Figure 24.

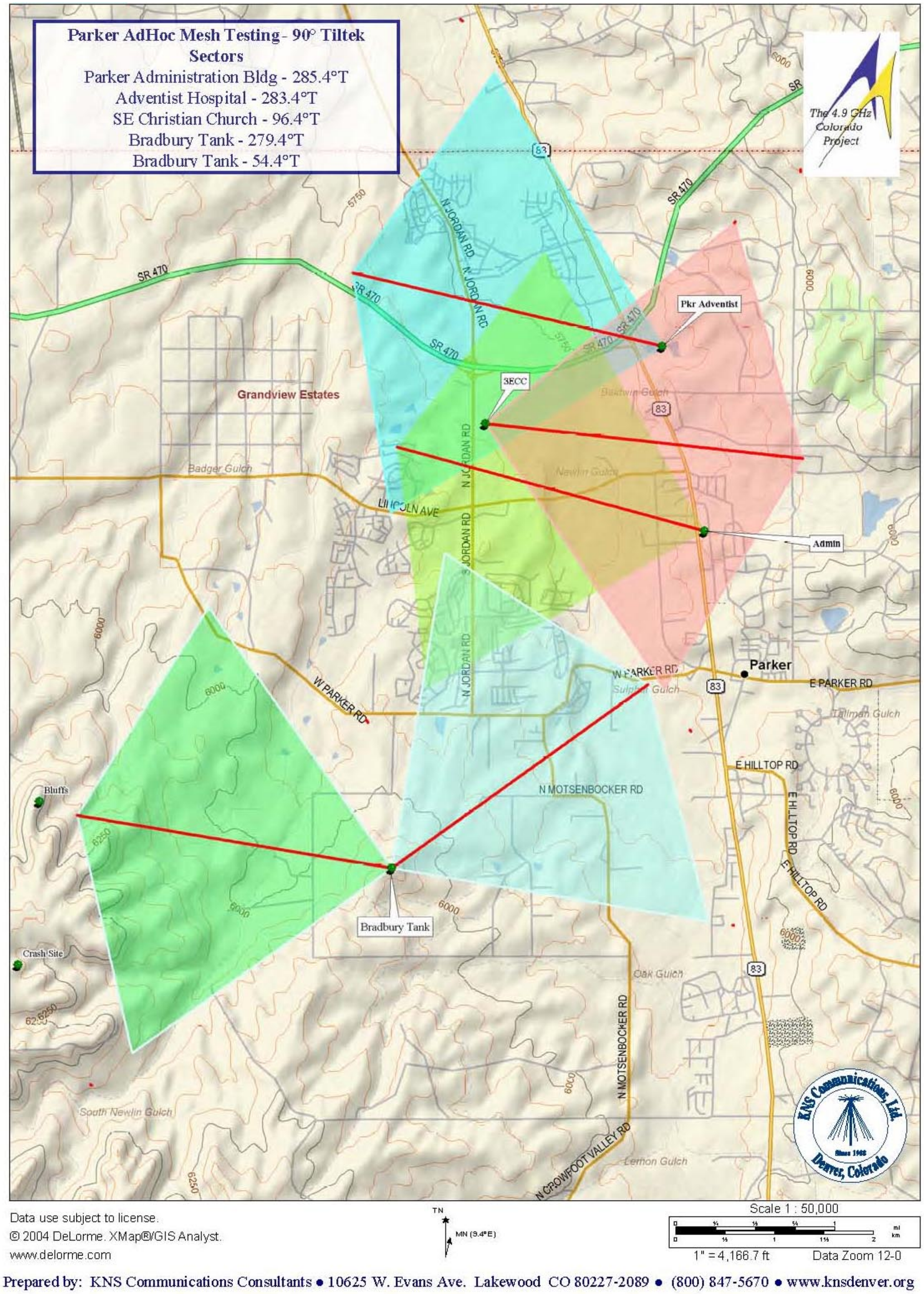

Figure 24 - Network Configuration for Mesh Network Application Testing

Backhaul. Backhaul connections were *initially* made with point-to-point microwave links as follows:

- Adventist Hospital to Parker HQ: Ceragon 4.9 GHz point-to-point link
- SE Christian Church to Parker HQ: Temporary 4.9 GHz point-to-point link to Fire Station 73, Fire Station 73 to Parker HQ via 5.8 GHz point-to-point.
- Bradbury Tank #2 to Bradbury Tank #1: Mesh
- Bradbury Tank to Parker Admin.: Existing 5.8 GHz point-to-point link

The original test plan envisioned Portal APs at each of the four fixed locations, with wireless links back to the server at the Parker Administration Building. The link from Parker Adventist Hospital to Parker HQ. was a Ceragon 4.9 GHz point-to-point link, and it worked seamlessly.

However, the portal at Southeast Christian Church used an existing 4.9 GHz link into Parker Fire Station 73, and then this link was carried over the existing 5.8 GHz wireless network into the Administration Building. The link from Bradbury Tank back to the Administration building was also over an existing 5.8 GHz wireless network. When the 4.9 GHz link was overlaid on top of the existing network, there were multiple points of access back to the server at the Administration Building. Mobile AP's saw more than one fixed AP, and the portal AP at Southeast Christian Church could also see the portal AP at the Administration Building. The result was a spanning tree problem or a broadcast "storm" which took down the entire Parker Fire network. After some investigation, the Parker IT director determined that a layer-3 switch or high-end router could solve this problem, but this solution was outside the scope of the project.

Consequently, the backhaul was abandoned for mesh testing and instead, APs on test vehicles were configured to test mesh networking protocols and performance.

Test Vehicle. The principal test vehicle operated in two runs for each of four tests conducted. The first test run was conducted without a BDA and the mobile EIRP was 24 dBm. The second test run was conducted with a 10 dB gain BDA and the EIRP was 34 dBm. The BDA also improved receiver sensitivity from -90 dBm to -92 dBm (10 MHz channel). In both cases, the antenna was an omnidirectional magnetic mount type with an effective gain of 7.3 dBi.

Two sectors were deployed at Bradbury Tank because it is the closest fixed AP to "The Bluffs" – a region where there have been numerous aircraft crashes in the Parker Fire District. The Bluffs lies in the approach pattern for Centennial Airport, and for some reason there are many small plane crashes in this approach pattern. Parker Fire Protection District responds to these emergencies. The Bluffs is remote and has no roads or electricity. The first and second AP at Bradbury Tank are connected through a mesh radio connection rather than a wireline connection and the two APs are connected back to the server through a point-to-point microwave link.

Two types of tests were conducted:

- Propagation measurements to show composite network coverage
- Application tests

To measure network coverage, the drive test was done anyway and all four AP's at all four sites were measured simultaneously during the drive test. Then the resulting propagation measurements were combined into one aggregate map showing system-wide coverage which will occur when the network issues are resolved. The four-site composite coverage is shown in Figure 22, presented in Section 7.5. Application testing is discussed below.

Application Testing. The objective of the application tests was twofold:

- Verify mesh capability
- Operate software applications over the mesh network.

Six subtests were run to help determine the various capabilities of the system. Some of the questions we sought to answer are the following: Is the equipment capable of meshing from one subscriber AP to another without having to go back through the Portal AP to get to that subscriber unit? Is there a limit in the number of hops, and is this limit due to equipment limitations, or transmission problems?

All application testing was done using a 10 MHz channel bandwidth. The portal AP was located at the Parker Administration building using a 90° Til-Tek Panel Antenna. The EIRP was 31 dBm. The two antennas at the Bradbury Tank had identical parameters to the Parker Administration Building ("Parker").

Application Test 1 – Measure the throughput and latency for one hop.

For the first test, a vehicle (Vehicle 1) was parked on East Parker Road, a distance of 2.9 miles west of the Parker Administration Building. An AP was installed in a second vehicle (Vehicle 2) and an AP *and* another camera were installed in a third vehicle (Vehicle 3). Vehicle 2 and 3 were co-located, roughly 0.28 miles northwest of Vehicle 1. The basic configuration is shown in Figure 25. Vehicles 2 and 3 were purposely position so they could see Vehicle 1, but not Parker HQ. The network self-configured with Vehicles 2 and 3 associating with Vehicle 1. Throughput was measured with a software utility called **QCheck**. With the camera turned off at Vehicle 3, video throughput from Vehicle 1 to Parker HQ was 10.025 Mbps. With the camera turned on but *not* transmitting video, Vehicle 1 throughput dropped to 7.8 Mbps. This loss in throughput was attributed to mesh networking overhead required to keep the network configured and connected. Latency was measured at 1 millisecond (ms).

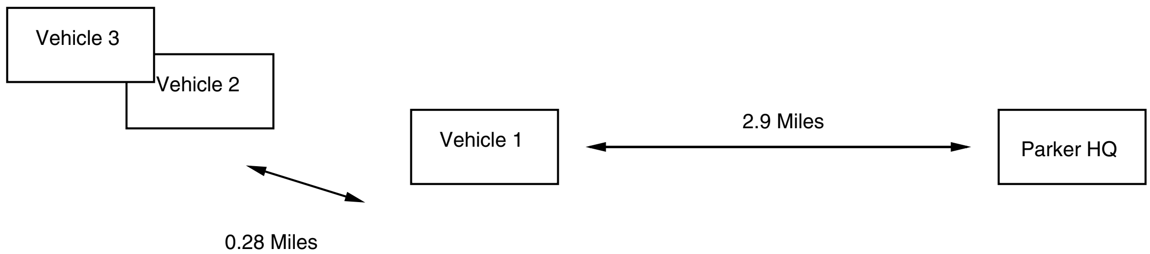

Figure 25 - Application Test #1

Application Test 2 – Throughput Effects Caused by Relaying

For the second test, Vehicle 1 remained in the same location on East Parker Road, 2.9 miles west of Parker HQ. Vehicle 2 drove west on East Parker Road. The goal was to drive until Vehicle #2 reached the curve and hill where line-of-sight to Vehicle 1 would be blocked (4,000 feet or 0.76 miles from Vehicle 1). Even with optical line-of-sight, Vehicle 2 lost connection as it traveled to this location. Vehicle 2 returned on East Parker Road and connection was regained at a location 0.28 miles from Vehicle 1 and co-located with Vehicle 2.

Throughput to Vehicle 2 with the Vehicle 1 camera transmitting with 7.8 Mbps, was 3.0 Mbps. In other words, Vehicle 2 saw less than half the throughput of Vehicle 1 because it was forced to mesh through Vehicle 1 to get to Parker HQ.

Application Test 3 – Measure two hops.

During Application Test 2, the 2nd hop was from vehicle to vehicle, each with an antenna elevation of 6 feet AGL. Test 3 also employed two hops, but now with the intermediate antenna at Bradbury Tank, at an elevation of approximately 12 feet AGL. The purpose of this test was to determine if the range of the second hop could be extended by increasing the antenna height to eliminated any Fresnel zone diffraction (not visible to the naked eye) on the first hop. In other words, maximize performance of the first hop.

For this test, Vehicle 1 was moved to the edge of The Bluffs — 4.7 miles from Parker HQ, but with line-of-sight over a large valley. Vehicle 3 was moved as far from Vehicle 1 as was possible and still maintain a connection with Vehicle 1. Vehicle 3 was not line-of-sight to Parker HQ. Although the line-of-sight path allowed for greater distance, the path length of the second hop was, again, very short (0.2 miles).

Throughput at Vehicle 1 with the camera on was 2.6 Mbps and latency was 3 ms. We were able to observe good streaming video in Vehicle 2 from Vehicle #3. A call was placed to Chief Qualman at the Administration Building. He was also able to observe the streaming video at this location. He reported no degradation of the video. Vehicle 2 was not involved in this test.

Total path distance was 4.7 miles for hop 1 and 0.2 miles for hop 2 — a total of 4.9 miles.

Application Test 4 – Measure throughput and test multiple hops.

In both of the previous two tests (3 and 2) the 2nd hop was limited in distance to ensure line-of-sight. One of the purposes of Test 4 was to determine if antenna elevation has any effect on hop length. In addition, we attempted to determine if there was a limit to the number of hops which can be effectively maintained. The Proxim equipment supports a maximum of 4 hops and Test 4 determined what happens when there are 4 active hops.

The Portal AP remained at Parker HQ. Vehicle 2 was driven out of the line-of-sight to Parker HQ and immediately meshed with Bradbury Tank as soon as it came into the line-of -sight with it. At different times during the test, it was observed that Vehicles 2 and 3 both meshed to vehicle 2. However, when vehicle 3 moved past vehicle 2 (where the distance was further to vehicle 1 than to vehicle 2), Vehicle 3 would mesh with Vehicle 2, and Vehicle 2 would mesh to Vehicle 1, which in turn meshed to Bradbury Tank 2, which meshed to Bradbury Tank 1, which meshed to the Parker HQ, (a total of four active hops). The equipment appears to be able to evaluate the cost and choose the best route back to the Portal.

Please note that no subscriber APs can mesh together unless at least one of them is connected to the Portal AP.

It appears that antenna height does have a strong a effect on path length. The antennas at Bradbury were both 12 feet AGL. Path 1, from Parker HQ to Bradbury Tank (2.89 miles), Path 2 was from Bradbury Tank AP 1 to Bradbury Tank AP 2 (0 miles), Path 3 was from Bradbury Tank AP 2 to Vehicle 1 on The Bluffs (2.05 miles), and path four was from Vehicle 1 on the Bluffs to Vehicle 2 and to Vehicle 3. Vehicle 3 and 2 would both mesh to Vehicle 2 – but Vehicle 3 would not mesh to Vehicle 2. The distance of path 3 or four was over 2 miles – a distance that was not achievable when antennas were vehicle roof-mounted at both ends of the path.

The total path distance from Parker HQ through four hops to Vehicle 2 was 5.29 miles. Throughput at Vehicle 1 was 2.01 Mbps. Vehicle 3 was able to mesh to vehicle 2 and good quality streaming video was passed back to the Parker HQ. Cheryl L. Poage was able to observe the video on the server at Parker HQ and reported good quality streaming video.

A good rule of thumb is that all mesh nodes must be line-of-sight for a connection to be feasible. Each additional path cuts the throughput roughly in half plus some overhead. Also, the current revision of Proxim hardware limits the number of hops in an end-to-end connection to four.

Application Test 5 – Measure Time to Open a 59.7 MByte file.

Vehicle 2 was driven to a line-of-sight location 0.6 miles from Parker HQ. At this location, we observed a throughput of 5.04 Mbps (measured by iperf) while opening at 59.7 MB pdf file. It took 87 seconds to open the file after the software application was running locally on the laptop.

Application Test 6 – Parker Fire Application End User Tests.

The final tests were run by Steve Macaulay of the Parker Fire IT Department. The purpose of these tests was to see if the system met end user expectations for a variety of software applications. Mr. Macaulay made the following observations:

- When there was a good signal, 2 Mbps of throughput was seen and access was good.
- The 59 Megabyte pdf file and the 53 Megabyte .dwg files opened as expected.
- The camera feed from Fire Station 76 showed good streaming video when viewed.
- Access to **Firemanager** was good and we were able to effectively download image files.
- The system would quickly re-acquire and connect as the vehicle moved from location to location.

Eight different sites were chosen to perform the application testing. The locations are shown in Figure 26. The sites were selected after reviewing 4.9 GHz coverage maps provided by KNS Communications. Two sites were purposely chosen that showed no coverage.

At each site, we attempted to open an AutoCAD file (.dwg), a pdf file, view a video from the server, open Fire Manager, view streaming video from Fire Station 76, and run a QCheck test of the throughput.

At the Dransfeld Site, QCheck showed 400 kByte/s of throughput. We were unable to open the pdf file, although we were able to download the slightly smaller .dwg file in five minutes. We were unable to play the 26 MByte video file and we were unable to access Firemanager. The video quality was rated as 3 (with one being bad and 5 being good).

Neither location 7 nor location 8 (Main & Mostenbaker and Village Center & Lincoln) had any signal.

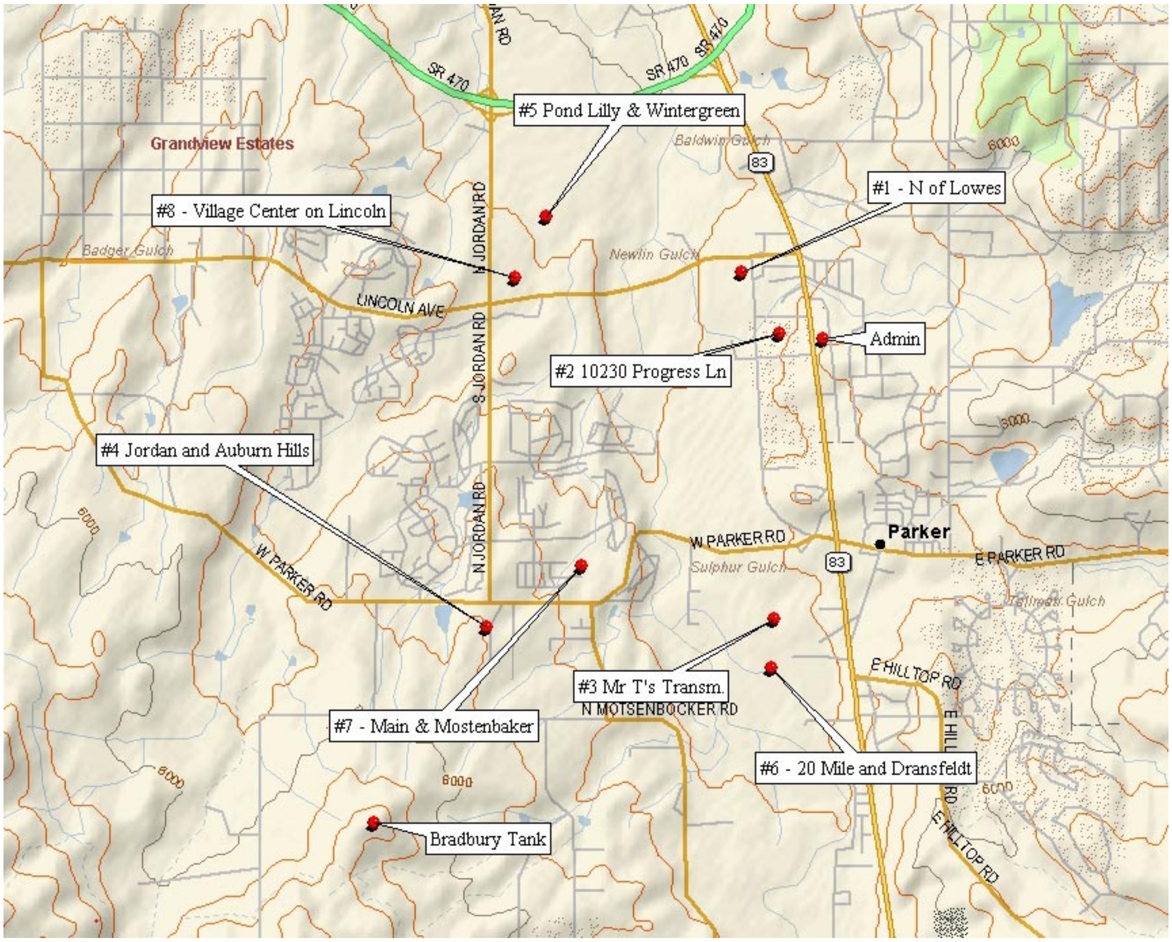

Figure 26 - Locations for Application Test #6

The application testing shows that the system will work for many typical first reponder and public safety requirements as long as the APs are deployed properly and the system is designed with some attention to detail.

10.0 Acknowledgements

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Term of Grant: October 1, 2005 through April 30, 2006

Governmental Partners:

City and County of Denver – (In-kind, facilities and vehicles for testing)
Douglas County Sheriff - (In-kind, facilities for testing)
Cunningham Fire Protection District - (In-kind, facilities for testing)
Parker Fire Protection District – Lead Agency - (Monetary, in-kind, facilities for testing)

Commercial Partners:

Communications Systems, Inc. – (Services, in-kind)
KNS Communications Ltd. – (Testing, Report Preparation Services, in-kind)
Pericle Communications – (Professional Engineering Services, Independent Project Evaluation, Test Equipment, Test Software, in-kind)
Proxim – (Equipment for testing, Software, Engineering Services, Other Services)

Federal Support

Technology Opportunity Program – Matching Funds
Institute for Telecommunications Sciences (ITS) – technical and scientific support

The project was funded by a 50-50 match with the partners providing 50% of the funding and TOP providing the matching 50% of the funding.

Each public safety agency partner provided in-kind donations of time, oversight, and equipment to the project. Parker Fire, the lead agency, provided monetary donations, in-kind donation of labor, computer equipment, an IP camera, IT support, and facilities for use during the testing. Cunningham Fire provided two laptop computers, an in-kind donation of labor, and use of their facilities for use during testing. The City and County of Denver provided in-kind donation of labor and the use of their mobile command post for testing in downtown Denver, as well as other facilities for testing. Douglas County provided an in-kind donation of labor, laptop computers, and facilities for testing.

Proxim Corporation who donated all the APs used in the study and also provided significant engineering support.

KNS Communications Consultants provided in-kind donations of labor and also paid for some of the software development to help process the data. In addition, KNS designed each installation, performed all of the drive testing and data collection, post-processed the collected data, did gain and loss calculations for all of the tests, prepared maps showing radio coverage, and prepared the spreadsheets and graphs showing received signal versus distance and path loss versus distance. KNS also worked under Pericle's direction to complete the bench tests and field tests which measured both AP and antenna performance.

Communications Systems, Inc. did all of the fixed antenna deployment, vehicle deployments, programming of the APs, software configuration for deployment testing, and handled any repairs or maintenance issues which arose during testing.

Pericle Communications Company provided in-kind donation of labor, loan of test equipment, and developed the AP survey software and post-processing software. Also, Jay Jacobsmeyer, President of Pericle Communications Company, authored this report.

Additional equipment was donated or loaned to the project by several vendors. Til-Tek donated sector antennas for use at the fixed AP locations and on the mobile command post. Mobile-Mark donated mobile antennas for testing. mWave, LLC provided a 4.9 MHz microwave dish antenna for use during testing. RF Linx provided mobile bidirectional amplifiers for use during testing. Cerragon provided a pair of 4.9 MHz point-to-point radios for testing

Additional fixed facilities for testing made available by Parker Water and Sanitation District, Southeast Christian Church, Parker Adventist Hospital.

11.0 Contact Information

Local Government Agencies

Parker Fire Protection District, Lead Agency
10235 Parkglenn Way
Parker, CO 80138
(303) 841-2608
www.parkerfire.org
Daniel Qualman, Chief, *dqualman@parkerfire.org*
Cheryl L. Poage, Grant Manager, *cpoage@parkerfire.org*
Rob Krause, IT Department, *rkrause@parkerfire.org*
Steve Macaulay, IT Department, *sgmacaulay@parkerfire.org*

Cunningham Fire Protection District
2250 South Emporia Street
Denver, CO 80231
(303) 755-9202
www.cfpd.org
Ira Rhodes, Chief, *irhodes,@cfpd.org*
David Markham, Assistant Chief, *dmarkham@cfpd.org*

City and County of Denver
1930 35th Street
Denver, CO 80216
(303) 295-4381

www.denvergov.org/Electronic_Engineering_Bureau/default.asp
Myron Kissinger, Supervisor, Electronic Engineering Bureau
kissingerm@ci.denver.co.us

Douglas County
4000 Justice Way
Castle Rock, CO 80104
(303) 660-7536
www.douglas.co.us/countyadmin/emergencyservices
Mike Coleman, Administrative Chief, Communications, *mcoleman@douglas.co.us*
Allison Robenstein, Systems Analyst, *ARobenst@dcsheriff.net*
Kevin Layton, Network Engineer, Supervisor IT Dept, *klayton@douglas.co.us*
Tony Gerhardt, Network Engineer, *tgerhard@douglas.co.us*
Jeff Vaughn, Telecommunications Technician, *jvaughn@douglas.co.us*

Commercial Partners

Proxim Wireless
2115 O'Nel Drive
San Jose, CA 95131
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www.proxim.com
Michael Johnston, Systems Engineer, (602) 820-8549, *mjohnston@proxim.com*
Colby Carr, Regional Sales Manager, (303) 285-0021, *CCarr@proxim.com*

KNS Communications Ltd., (KNS Communications Consultants)
10625 W. Evans Avenue
Denver CO 80227-2089
(800) 847-5670 • (303) 989-1038
www.knsdenver.org
L. Sue Scott-Thomas, President, *suethomas@knsdenver.org*

Pericle Communications Company
1910 Vindicator Drive, Suite 100
Colorado Springs CO 80919
www.pericle.com
Jay Jacobsmeyer, P.E., President, (719) 548-10404, *jacobsmeyer@pericle.com*
Frank Pratte, P.E., (303) 594-0094, *fpratte@ieee.org*
Dan Mieszala, Vice President, (720) 344-9556, *mieszala@pericle.com*

Communications Systems, Inc.
1460 S. Wadsworth Blvd.
Lakewood CO 80243-5441
(877) 987-2680 • (303) 987-2680
www.csidenver.com
Ken Thomas, President, *kenthomas@csidenver.com*
John Thomas, Vice President of Operations, *john@csidenver.com*

Equipment Vendors Who Loaned or Donated Hardware

Proxim Wireless
2115 O'Nel Drive
San Jose, CA 95131
(800) 229-1630
www.proxim.com

Til-Tek (Sector Antennas)
P.O. Box 550
500 Van Buren Street
Kemptville, ON KOG 1JO, Canada
(613) 258-5928
www.tiltek.com
Doug Kerr, Regional Sales Manager, (707) 433-2477, *dkerr@tiltek.com*

Mobile Mark, Inc. (Mobile Antennas)
3900-B River Road
Schiller Park, IL 60176
(847) 671-6690 • (800) 648-2800
www.mobilemark.com
Ken Lukowski, Sales Manger, *ken@mobilemark.com*

mWAVE Industries, LLC (Microwave Dish Antennas)
28 Sanford Drive
Gorham, ME 04038 USA
(207) 857-3083
www.mwavellc.com
Mike Cahill, Vice President, Sales, *mcahill@Mwavellc.com*

RF Linx (Amplifiers)
9017 Cincinnati - Columbus Road
West Chester, Ohio 45069
(513) 777-2774
www.rflinx.com
Jerry Nauman, Sales Representative, *jnauman@rflinx.com*

Ceragon Networks, Inc.
10 Forest Avenue
Paramus, NJ 07652
(201) 845-6955
www.ceragon.com
Scott Sweetland, President, *ssweetland@ceragon-us.com*
Wendi Snyder, Director, Western Region, (602) 909-9538, *wendi@ceragon-us.com*

Additional Testing Facilities Provided By:

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19801 East Mainstreet
Parker CO 80138
(303) 847-4627

Southeast Christian Church
9650 Jordan Road
Parker, CO 80134
(303) 841-9292

Parker Adventist Hospital
9895 Crown Crest blvd
Parker CO 80138
(303) 269-4000

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[2] A. Goldsmith, Wireless Communications, Cambridge University Press, 2005.

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[4] M. M. Peritsky, "Statistical Estimation of Mean Signal Strength in a Rayleigh Fading Environment," *IEEE Transactions on Communications*, November, 1973, pp. 1207-1213.

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

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[9] B. O'Hara and A. Petrick, 802.11 Handbook, A Designer's Companion, IEEE, 1999.

[10] C.-K. Toh, Ad Hoc Mobile Wireless Networks, Prentice-Hall, 2002.

[11] S. M. Faccin, et al., "Mesh WLAN Networks: Concept and System Design," *IEEE Wireless Communications Magazine,* April, 2006, pp. 10-17.

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

[13] R. J. Larsen, M. L. Marx, An Introduction to Mathematical Statistics and its Applications, Prentice-Hall, 1986. (See problem 7.4.17 on page 338 for the derivation of the confidence interval for an exponential random variable.)

[14] ANSI/IEEE 802.11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 1999. Available for free download from the IEEE web site. Also see:

802.11a-1999	OFDM up to 54 Mbps in 5 GHz Band, 20 MHz Channel
802.11b-1999	DSSS up to 11 Mbps in 2.4 GHz Band, 20 MHz Channel
802.11g-2003	OFDM up to 54 Mbps in 2.4 GHz Band, 20 MHz Channel

802.11i-2004 Security
802.11j-2004 OFDM up to 54 Mbps in 4.9 GHz Band, 10 and 20 MHz Channels

[15] Title 47 of the U.S. Code of Federal Regulations, Part 15, Part 90, October 1, 2005.

[16] W. A. Arbaugh, et al., "Your 802.11 Wireless Network has no Clothes," *IEEE Wireless Communications*, December 2002.

[17] B. Rinehard, D. Eierman, "4.9 GHz Public Safety Broadband Spectrum - Overview of Technical Rules and Licensing Instructions," June 13, 2005. Available from NPSTC web site at *http://www.npstc.org/documents.jsp*.

[18] "Wireless Mesh Networking: Theories, Protocols, and Systems," *IEEE Wireless Communications*, Special Issue, April 2006.

Some FCC Decisions on 4.9 GHz:

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[20] Memorandum Opinion and Order & Third Report and Order, "In the Matter of the 4.9 GHz Band Transferred from Federal Government Use," WT Docket 00-32, Adopted April 23, 2003.

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[22] S. O'Hara, FCC Ex Parte Technical Filing, August 19, 2004, WT Docket 00-32. (This filing advocates approval of the loose mask in the 4.9 GHz band and supports this argument with detailed analysis on the adjacent channel interference effects of the loose mask versus the tight mask.)

13.0 Acronyms

AES	Advanced Encryption Standard
AM	Amplitude Modulation
AMPS	Advanced Mobile Phone System
AP	Access Point
APCO	Association of Public Safety Communications Officers
ARQ	Automatic Repeat-Request
AWGN	Additive White Gaussian Noise
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CSMA	Carrier Sense Multiple Access
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
dB	Decibels
dBd	Decibels relative to a half-wave dipole (for antenna gain)
dBi	Decibels relative to isotropic (for antenna gain)
dBm	Decibels relative to a milliwatt
DHCP	Dynamic Host Control Protocol
DSRC	Dedicated Short Range Communications
DSSS	Direct Sequence Spread Spectrum
EDGE	A high speed data service offered on GSM networks
EIRP	Effective Isotropic Radiated Power
EMS	Emergency Medical Services
ENBW	Equivalent Noise Bandwidth
ERP	Effective Radiated Power (relative to half-wave dipole)
FCC	Federal Communications Commission
FM	Frequency Modulation
GHz	Gigahertz (10^9 cycles per second)
GPRS	Wireless data service on GSM networks; will be replaced by EDGE
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ISI	Intersymbol Interference
iDEN	Proprietary Motorola airlink standard used by Nextel
IEEE	Institute of Electrical and Electronics Engineers
IPSec	Preferred protocol for VPNs
ISP	Internet Service Provider
ISM	Industrial, Scientific and Medical
ITAC	Interoperability Tactical Channel
ITFS	Instructional Television Fixed Service
LAN	Local Area Network
MAC	Medium Access Control

MHz	Megahertz (10^6 cycles per second)
MIB	Management Information Block
MMDS	Multi-Channel Multipoint Distribution System
NAMPS	Narrowband AMPS
NLEC	National Law Enforcement Channel
NPSPAC	National Public Safety Planning Advisory Committee
NPSTC	National Public Safety Telecommunications Council
OFDM	Orthogonal Frequency Division Multiplexing
PCS	Personal Communications Services
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
SHF	Super High Frequency (3 GHz to 30 GHz)
SMR	Specialized Mobile Radio
SP	Subscriber Point
SSID	Service Set Identifier
STA	Station, also called Subscriber Point (SP)
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
3G	Third Generation Wireless
TIA/EIA	Telecommunications/Electronic Industries Association
TKIP	Temporary Key Integrity Protocol
UHF	Ultra High Frequency (300 MHz to 3 GHz)
UDP	User Datagram Protocol
VHF	Very High Frequency (30 MHz to 300 MHz)
VPN	Virtual Private Network
WDS	Wireless Distribution System
WEP	Wired Equivalent Privacy
WiFi	Trade name for systems that comply with the IEEE 802.11 standards
WISP	Wireless Internet Service Provider
WLAN	Wireless Local Area Network
WPA	WiFi Protected Access

Appendix A - Manufacturer Data Sheets

ORiNOCO® AP-4900M

Public Safety Broadband Wireless Solutions

APPLICATIONS

- **Emergency services**
  Real-time computer-aided-dispatch on the move. Mobile office, voice, live-streaming video, and data connectivity for responder vehicles.
- **Metro Wi-Fi & 4.9 GHz public safety**
  Simultaneous 4.9 GHz Public Safety access and 2.4 GHz Metro Wi-Fi coverage on a single, dual-radio platform.

Highest-Performance Access Point Delivers Scalability for Large 4.9 GHz and Wi-Fi Deployments

Supporting both 4.9 GHz public safety and 2.4 GHz metropolitan Wi-Fi networks through dual 4.9/2.4 GHz radios, the ORiNOCO AP-4900M Access Point delivers the versatility and feature robustness required by today's demanding emergency response and metro Wi-Fi applications. The AP-4900M delivers unparalleled enterprise-scale security, management and QoS features, and is pre-configured with quad mode for best-in-class performance and flexibility in large deployments. The AP-4900M is perfect for large production public safety and metro Wi-Fi networks.

- Dual-radio, multi-band mesh system
- Quad-mode (4.9 GHz, 802.11a, 802.11b, and 802.11g) and dual radio AP-to-AP communication for deployment in large or hard-to-reach areas
- Unique scalability – external antenna connector for increased transmit distance, and maximum system gain on baseband radio for repeating configurations
- Twice the memory of competing APs, ensuring software upgrade capacity
- Industry-leading throughput with 802.11g and 802.11a/4.9 GHz operation, and new Super Mode
- New level of intrusion detection and prevention
- Sophisticated hotspot interfaces with RADIUS integration
- Pre-standard IEEE 802.11e quality of service support for latency-sensitive applications

Proactive Security Measures to Protect Your Network

ORiNOCO access points support the latest security standards, including IEEE 802.11i and AES encryption, and add proactive security measures.

- IEEE 802.1x mutual authentication
- Dynamic per-user, per-session rotating keys
- Rogue Access Point and client identification
- Secure management interfaces: SNMPv3, SSL and SSH
- Intra-cell blocking to prevent client-to-client snooping

Easy to Deploy and Manage

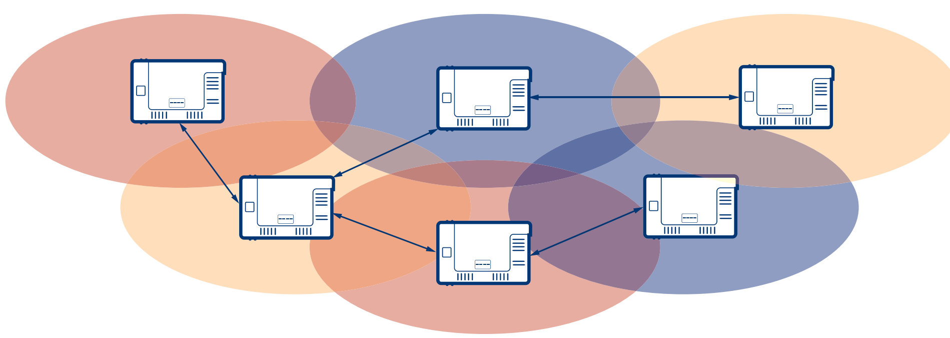
Ease of deployment and integration with the wired network are critical factors in a successful, profitable wireless LAN rollout. ORiNOCO access points excel with key capabilities that simplify WLAN deployment.

- Tools to speed installation and optimization: automatic channel selection, adjustable transmit power, external antenna connectors
- ORiNOCO Mesh Creation Protocol for maximum coverage, flexibility, reliability, and lowest infrastructure costs.
- Wireless repeating functionality in areas without Ethernet wiring
- Remote management via SNMP, HTTP and Telnet
- Extensive RADIUS accounting support
- Powerful group configuration, software updates and automatic alerts via Proxim Wavelink Mobile Manager

Reliable by Design

With over 25 years of experience in the design and manufacture of wireless LANs, Proxim understands that public safety, service providers, and enterprises require the same uptime and reliability in a wireless network as in a wired network

- Robust features for enterprise, public access – compared to consumer grade APs
- Automatic reconfiguration of security policy in the event of power loss
- Dual firmware image support – for rollback in the event of software or configuration change problems
- IEEE 802.3af Power-over-Ethernet, plenum rating, built-in Kensington lock and external antenna connectors



The ORiNOCO Mesh Creation Protocol uses one radio for simultaneous mesh backhaul and Wi-Fi coverage and the other radio for Wi-Fi coverage.

ORiNOCO AP-4900M Specifications

About Proxim Wireless

Proxim Wireless is a global leader in networking equipment for Wi-Fi and broadband wireless networks. Proxim provides solutions for enterprise applications, last mile access, municipal broadband networks, and cellular backhaul. Product families include ORiNOCO and TeraStar Wi-Fi products; Tsunami, TeraBridge, Gigalink, and TeraOptic Ethernet bridges, and Lynx point-to-point digital radios.

ADDITIONAL FEATURES

Quad-mode 802.11b, 802.11g, 802.11a, and 4.9 GHz support	Pre-configured simultaneous 802.11b/g and 4.9 GHz support. May also be configured to support simultaneous 802.11b/g and 802.11a
Field upgradeable	Software upgradeable to support new standards
ORiNOCO Mesh Creation Protocol	AP mesh networking allows quick installation, expanded network coverage, and self-healing capabilities for maximum network reliability.
IEEE 802.11i and AES encryption	Highest authentication and encryption methods including mutual authentication, message integrity check (MIC), per-packet keys initialization vector hashing and broadcast key rotation
Intrusion Detection and Prevention	Detects, alerts, and stops unauthorized rogue Access Points and cleints in the 2.4, 4.9, and 5 GHz bands[1]
Secure Management Interfaces	SNMPv3 and SSL protect against unauthorized AP changes via the management interface
Multiple VLAN Support with different security settings	Up to 16 separate VLANs per radio, each able to support multiple different authentication and encryption algorithms simultaneously
Auto configuration via DHCP	Ensures new APs automatically receive correct configuration and prevents security vulnerabilities with deliberate resets
Central management and configuration	Allows centralized management of AP settings including group updates of firmware[1]
Assured Software Upgrades	Guarantees new AP configuration file is valid before deleting current image - dual image support
Quality of Service	Draft IEEE 802.11e along with 802.1p and 802.1q improve performance of video and voice applications
High Output Power	+20 dBm for 802.11b, +18 dBm for 802.11g, 802.11a, and 4.9 GHz
Transmit Power Control	Supports settable transmit power levels to adjust coverage cell size
Automatic Channel Selection	Simplifies installation by choosing best possible channel upon installation
RADIUS Support	Extensive RADIUS Accounting support, intra-cell blocking to prevent client-to-client snooping, multiple VLAN support with different security modes
Super Mode	Delivers greater than 30 Mbps throughput for ORiNOCO and Atheros-based clients while simultaneously compatible with non-Atheros clients
Designed for Metro 4.9 GHz & Wi-Fi	AP-to-AP communication for extension of wireless LAN to areas without Ethernet wiring (parking lots, long corridors, etc) for 802.11b, 802.11g, 802.11a, and 4.9 GHz public safety
Advanced Filtering Capabilities	IEEE 802.1d bridging with static MAC address filtering, network protocol filtering, Proxy ARP, multicast/broadcast storm threshold filtering,TCP/UDP port filtering, intra-cell traffic filtering, and Spanning Tree support
IEEE 802.3af and AC Power	Decreases installation costs up to $1000 per AP when Power over Ethernet is available
Integrated diversity 2.4 and 5 GHz antennas with horizontal and vertical polarization	Delivers optimum coverage in any mounting position and excellent performance in high multipath environments
External antenna connectors for 802.11b/g, 802.11a, and 4.9 GHz	Allows use of shaped and higher gain antennas to design for most efficient AP placement
Plenum rated	Meets safety and insurance requirements when installed in air spaces

INTERFACE

Wired Ethernet	10/100 base-T Ethernet (RJ-45)
Wireless Ethernet	1 integrated 802.11b/g radio and 1 integrated 802.11a/4.9 GHz radio
RS-232	Unit configuration

HARDWARE SPECIFICATION

Memory	32 MB SDRAM; 8 MB Flash

PHYSICAL SPECIFICATIONS

Dimensions	11.375 x 9.25 x 2.75 in (29 x 23.5 x 7 cm)
Weight	2.05 lbs (0.93 kg)

ENVIRONMENTAL SPECIFICATIONS

Temperature	Operating Storage	0°C to 55°C -10°C to 70°C
Humidity	Operating Storage	95% (non-condensing) 95% (non-condensing)

POWER SUPPLY

Types	Integrated module Autosensing 100/240 VAC; 50/60 Hz IEEE 802.3af Active Ethernet for power over Ethernet

LEDS

Type:	Power, Ethernet LAN Activity Wireless 802.11b/g Activity Wireless 802.11a/4.9 GHz activity

MANAGEMENT

- SNMPv1, SNMPv2c and secure SNMPv3 management
- Standard & ORiNOCO traps
- ORiNOCO MIB, Etherlike MIB, 802.11 MIB, Bridge MIB, MIB-II
- TFTP support
- Telnet CLI, Serial Port CLI (no proxy required)
- HTTPS (SSL) server for secure web-based management
- Proxim WaveLink Mobile Manager for group management (not included)
- Syslog
- DHCP Server and Client

WARRANTY

1 year (on parts and labor)

PACKAGE CONTENTS

- AP-4900M quad mode access point with built-in 802.11b/g and 802.11a/4.9 GHz radios
- Power supply and support for Active Ethernet and IEEE 802.3af
- Software and documentation
- Cable cover and mounting bracket

RELATED PRODUCTS

Wavelink Mobile Manager, Ekahau Site Survey and RF Prediction Software, ORiNOCO 11a/b/g ComboCard, Dual Band Range Extender Antenna

[1] In conjunction with Proxim Wavelink Mobile Manager

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OD39-0805

ORiNOCO AP-4900M

Technical Specifications

APPLICATIONS

- **Emergency services**
  Real-time computer-aided-dispatch on the move. Mobile office, voice, live-streaming video, and data connectivity for responder vehicles.
- **Metro Wi-Fi and 4.9 GHz public safety**
  Simultaneous 4.9 GHz Public Safety access and 2.4 GHz Metro Wi-Fi coverage on a single, dual-radio platform.

RADIO	Dual Radio Access Point with integrated radios:802.11a/4.9 GHz Public Safety + 802.11b/g	
DATA RATES SUPPORTED	4.9 GHz 10 MHz channels:	3, 4.5, 6, 9, 12, 18, 24, 27 Mbps
	4.9 GHz 20MHz channels:	6, 9, 12, 18, 24, 36, 48, 54 Mbps
	802.11b	1, 2, 5.5, 11 Mbps
	802.11g	1, 2, 5.5, 6, 9, 11, 12, 18, 24, 36, 48, 54 Mbps
	802.11a	6, 9, 12, 18, 24, 36, 48, 54 Mbps
NETWORK STANDARD	IEEE 802.11a IEEE 802.11b or IEEE 802.11g	
UPLINK	Autosensing 802.3 10/100BASE-T Ethernet	
FREQUENCY BAND	802.11b/g	2.412 to 2.462 GHz (FCC)
	802.11a	5.15 to 5.35 GHz (FCC UNII 1 and UNII 2), 5.725 to 5.85 GHz (FCC UNII 3/ISM)
	Public Safety 4.9GHz 4.94 to 4.99 GHz (FCC only)	
NETWORK ARCHITECTURE TYPE	Infrastructure mesh	
WIRELESS MEDIUM	802.11b or 802.11g	Direct sequence spread spectrum (DSSS); Orthogonal Frequency Division Multiplexing (OFDM)
	802.11a and 4.9 GHz	Orthogonal Frequency Division Multiplexing (OFDM)
MEDIA ACCESS PROTOCOL	Carrier sense multiple access with collision avoidance (CSMA/CA)	
MODULATION	OFDM	BPSK @ 6 and 9 Mbps QPSK @ 12 and 18 Mbps 16-QAM @ 24 and 36 Mbps 64-QAM @ 48 and 54 Mbps
	DSSS	DBPSK @ 1 Mbps DQPSK @ 2 Mbps CCK @ 5.5 and 11 Mbps
OPERATING CHANNEL	2.4 GHz Band	802.11b/g: 11 Channels
	5 GHz Band	FCC: 12
	4.9 GHz Band	10MHz channels, with the following center frequencies: 10 = 4.945 GHz (default) 20 = 4.950 GHz 30 = 4.955 GHz 40 = 4.960 GHz 50 = 4.965 GHz 60 = 4.970 GHz 70 = 4.975 GHz 80 = 4.980 GHz 90 = 4.985 GHz
		20MHz channels, with the following center frequencies: 20 = 4.950 GHz (default) 30 = 4.955 GHz 40 = 4.960 GHz 50 = 4.965 GHz 60 = 4.970 GHz 70 = 4.975 GHz 80 = 4.980 GHz
NON-OVERLAPPING CHANNELS	802.11a: 12; 802.11b/g: 3; 4.9 GHz 10 MHz: 5; 4.9 GHz 20 MHz: 2	
RADIO SPECIFICATIONS RF PERFORMANCE	The following tables show typical RF performance values for FCC-certified products (values may differ for products certified in other regulatory domains)	

802.11a RF Performance

802.11a Data Rates (Mbps)	54	48	36	24	18	12	9	6
Tx Power (dBm)	16	17	18	18	18	18	18	18
Receiver Sensitivity (dBm)	-70	-73	-78	-82	-84	-85	-86	-87
Antenna Gain (dBi)	0 (integrated diversity antennas; 5.15–5.85 GHz)							

ORiNOCO AP-4900M Technical Specifications

RADIO SPECIFICATIONS

RF PERFORMANCE

802.11b/g RF Performance

	G-only Rates								B-only Rates			
802.11b/g Data Rates (Mbps)	54	48	36	24	18	12	9	6	11	5.5	2	1
Tx Power (dBm)	17	18	18	18	18	18	18	18	20	20	20	20
Receiver Sensitivity (dBm)	-70	-73	-79	-82	-85	-88	-90	-91	-89	-91	-92	-93
Antenna Gain (dBi)	1 (integrated diversity antenna module; 2.4–2.5 GHz											

4.9 GHz 20 MHz Channel Public Safety RF Performance

Data Rates (Mbps)	54	48	36	24	18	12	9	6
Tx Power (dBm)	16	17	18	18	18	18	18	18
Receiver Sensitivity (dBm)	-70	-73	-78	-82	-84	-85	-86	-87
Antenna Gain (dBi)	N/A: Depends on external antenna							

4.9 GHz 10 MHz Channel Public Safety RF Performance

Data Rates (Mbps)	27	24	18	12	9	6	4.5	3
Tx Power (dBm)	16	17	17	17	17	17	17	17
Receiver Sensitivity (dBm)	-73	-76	-81	-85	-87	-88	-89	-90
Antenna Gain (dBi)	N/A: Depends on external antenna							

COMPLIANCE STANDARDS

Safety	UL 60950 CSA 22.2 No. 60950-00 IEC 60950 3rd Ed (1999)	
Radio Approvals	FCC Part 90	
EMI and Susceptibility (Class B)	FCC Part 15.107 ICES-003 (Canada)	
Security	802.1X and TKIP WPA AES and 802.11i	
Wireless Network Standards	IEEE 802.11b IEEE 802.11g IEEE 802.11a	
Other	FCC Bulletin OET-65C Wi-Fi Alliance Certification RSS-102 IEEE 802.3af	IEEE 802.1d spanning tree IEEE 802.11i Authentication/Encryption IEEE 802.11e QoS SSH, Telnet, SSL, HTTP, SNMPv3

SNMP COMPLIANCE

ORiNOCO; RFC1213; rfc1643; SNMPv2c; 802.11i-D3; IANAifType-MIB; MIB802

ANTENNA

2.4 GHz

Dual on-board antennas to support antenna and polarization diversity:

- One 3dBi vertically polarized omni antenna, 360 ° horizontal and 40° vertical beamwidths
- One 2dBi horizontally polarized omni antenna, 360° horizontal and 30° vertical beamwidths

Certified with:
Proxim 1086-REA
Proxim 1086-DA24-4
Proxim 1086-OA24-5
Proxim 1086-PA24-8.5
Proxim 1086-PA24-9.5

5 GHz

Dual on-board antennas to support antenna and polarization diversity:

- One 3dBi vertically polarized omni antenna, 360° horizontal and 40° vertical beamwidths
- One 2dBi horizontally polarized omni antenna, 360° horizontal and 30° vertical beamwidths

Certified with:
Proxim 1086-REA
Proxim 1086-PA50-7

2.4, 4.9, and 5GHz

Tri band (2.4, 4.9, and 5GHz) external Range Extender Antenna for use indoors

2.4, 4.9, and 5GHz

5054-SA120-14; 5054-SA60-17; Omnidirectional (Part# TBD); Directional (Part# TBD); Vehicle Mount (Part# TBD)

1086-OA49-8	360 degrees Omni-Directional Antenna
1086-OA49-10	360 degrees Omni-Directional Antenna
1086-PA49-10	45 degrees Directional Panel Antenna
21 dBi 4.9-5.0GHz	10 degrees Directional Panel Antenna

Proxim WIRELESS

ORiNOCO AP-4900M Technical Specifications

SECURITY ARCHITECTURE CLIENT AUTHENTICATION	Authentication	802.1X support including PEAP, EAP-TLS, EAP-TTLS EAP-SIM, and other EAP methods that conform to RFC 3748 to yield mutual authentication and dynamic per-user, per-session encryption keys RADIUS-based MAC address MAC address control list
	Encryption	802.11i support for CCMP/AES keys of 128 bits (WPA2) TKIP encryption enhancements (for WEP) with key hashing (per-packet keying) and broadcast key rotation (WPA) Support for WEP keys of 64 and 128 bits
	Message Authentication:	802.11i AES message authentication with 128 bit keys TKIP with 128 bit Michael Message Integrity Check
INTRUSION DETECTION	Rogue AP and client detection Detect switch port of rogue access point when used in conjunction with Wavelink Mobile Manager Detect MIC intrusion attacks	
STATUS LEDS	Four indicators on the top panel indicate power, wireless traffic, Ethernet traffic, and error conditions	
REMOTE CONFIGURATION SUPPORT	DHCP, Telnet, HTTP, TFTP, Boot P, and SNMP	
LOCAL CONFIGURATION	RS-232 Serial port, DB9 Female	
DIMENSIONS	Packaged	11.375 x 9.25 x 2.75 inches (289 mm x 235 mm x 70 mm)
	Unpackaged	7.8 x 4.75 x 1 inches (198 mm x 121 mm x 25 mm)
WEIGHT	Packaged weight	2.05 lbs (.92 kg)
	Unpackaged weight	.65 lbs (.29 kg) AP-only, .45 lbs (.20 kg) for power supply
ENVIRONMENTAL	Operating	0° to 55°C, 5-95% humidity non-condensing @ 5° to 55°C
	Storage	-20° to 85°C, 5-95% humidity non-condensing @ 5° to 85°C
PROCESSOR	220MHz MIPS 4000 processor	
SYSTEM MEMORY	16 Mbytes RAM 8 Mbytes FLASH	
INPUT POWER REQUIREMENTS	90 to 240 VAC ±10% (power supply) 48 VDC ±10% (device)	
POWER DRAW	10 watts, RMS	
WARRANTY	One year	
WI-FI CERTIFICATION	View Wi-Fi Interoperability Certificate for ORiNOCO AP-4000	
PART NUMBERS	8670-PS-US	Mesh access point – ORiNOCO AP-4900 US FCC-LMU; with Lower, Middle and Upper 802.11a bands; includes external antenna connectors for 802.11a, 4.9GHz, and 802.11b/g; includes one N-type male pigtail adapter.

[1] To achieve 802.11i security, the EAP method that is used must conform to both RFC 3748 and IETF draft-walker-ieee802-req-07 (Submitted as an Informational RFC). In RFC 3748, EAP- MD5-Challenge (Section 5.4), One-Time Password (Section 5.5) and Generic Token Card (Section 5.6), are non-compliant with the requirements specified in IETF draft-walker-ieee802-req-07 and thus do not support the 802.11i security claims when used with 802.11i.

Proxim Wireless Corporation
2115 O'Nel Drive
San Jose, CA 95131

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tel: 408.731.2700
fax: 408.731.3675

www.proxim.com

TS7-0805

ORiNOCO® AP-4900MR-LR

Public Safety Broadband Wireless Solutions

Outdoor Broadband Wireless Access

Proxim Wireless offers the industry's most complete suite of outdoor broadband wireless access products. This portfolio includes:

- **ORiNOCO® AP-4000MR-LR –** outdoor Wi-Fi mesh for service providers and municipalities
- **Tsunami® MP.11 –** capabilities of fixed and mobile WiMAX for U.S. and global markets
- **Tsunami® MP.16 –** WiMAX for the 3.5 GHz frequency band

Proxim Wireless is a global pioneer in scalable broadband wireless networking. From Wi-Fi to wireless Gigabit Ethernet – our WLAN, mesh, point-to-multipoint and point-to-point products are available through our extensive global channel network.

Highest-Performance Mesh Access Point Delivers Scalability for Large Public Safety and Wi-Fi Deployments

Supporting both 4.9 GHz public safety and 2.4 GHz metropolitan Wi-Fi networks through dual 4.9/2.4 GHz radios, the ORiNOCO AP-4900MR-LR tri-mode outdoor mesh access point delivers the versatility and feature robustness required by today's demanding emergency response and metro Wi-Fi applications.The AP-4900MR-LR delivers unparalleled enterprise-scale security, management and QoS features, and is pre-configured with tri mode for best-in-class performance and flexibility in large outdoor deployments. The ruggedized form factor is designed for outdoor installations enabling deployments in severe weather conditions.

- Outdoor, Dual Radio, multi-band mesh system
- Tri-mode (802.11b/g and 4.9GHz support) and a dual radio AP-to-AP communication for deployment in large or hard-to-reach areas
- Unique scalability – external antenna connectors for increased transmit distance, and maximum system gain on baseband radio for repeating configurations
- Industry-leading throughput with 802.11b/g and 4.9 GHz operation
- New level of intrusion detection
- Sophisticated hotspot interfaces with RADIUS integration
- Pre-standard IEEE 802.11e quality of service support for latency-sensitive applications
- Higher output power for extended range

Proactive Security Measures to Protect Your Network

ORiNOCO access points support the latest security standards, including IEEE 802.11i and AES encryption, and add proactive security measures.

- IEEE 802.1x mutual authentication
- Dynamic per-user, per-session rotating keys
- Rogue Access Point and client identification
- Secure management interfaces: SNMPv3, SSL and SSH
- Intra-cell blocking to prevent client-to-client snooping

Easy to Deploy and Manage

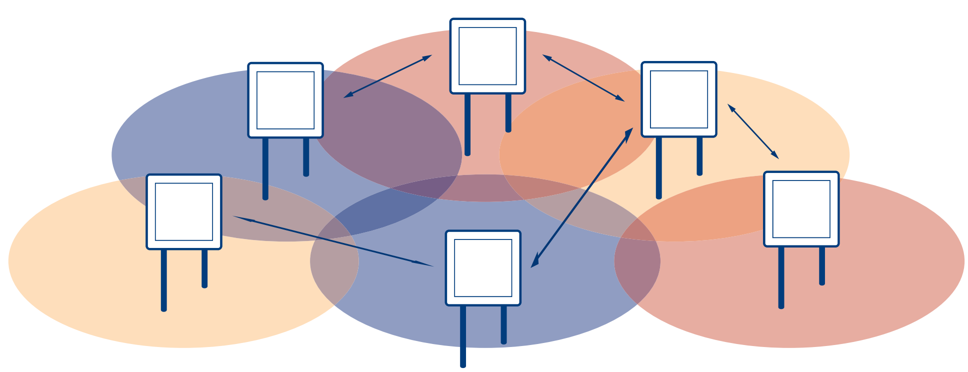
Ease of deployment and integration with the wired network are critical factors in a successful, profitable wireless LAN rollout. ORiNOCO access points excel with key capabilities that simplify WLAN deployment.

- Tools to speed installation and optimization: automatic channel selection, adjustable transmit power, external antenna connectors
- ORiNOCO Mesh Creation Protocol for maximum coverage, flexibility, reliability, and lowest infrastructure costs.
- Wireless repeating functionality in areas without Ethernet wiring
- Remote management via SNMP, HTTP and Telnet
- Extensive RADIUS accounting support

Reliable by Design

With over 25 years of experience in the design and manufacture of wireless LANs, Proxim understands that public safety, service providers, and enterprises require the same uptime and reliability in a wireless network as in a wired network

- Robust features for enterprise, public access – compared to consumer grade APs
- Automatic reconfiguration of security policy in the event of power loss
- Dual firmware image support – for rollback in the event of software or configuration change problems
- IEEE 802.3af Power-over-Ethernet for tower/rooftop installations and AC Power options for light pole installations



The ORiNOCO Mesh Creation Protocol uses one radio for simultaneous mesh backhaul and Wi-Fi coverage and the other radio for Wi-Fi coverage.

ORiNOCO AP-4900MR-LR Specifications

APPLICATIONS

- **Emergency services**
  Real-time computer-aided-dispatch on the move. Mobile office, voice, live-streaming video, and data connectivity for first responder vehicles.
- **Metro Wi-Fi & 4.9 GHz public safety**
  Simultaneous 4.9 GHz Public Safety access and 2.4 GHz Metro Wi-Fi coverage on a single, dual-radio platform.

ADDITIONAL FEATURES

Tri-mode 802.11b, 802.11g, and 4.9 GHz support	Pre-configured simultaneous 802.11b/g and 4.9 GHz support. May also be configured to support simultaneous 802.11b/g
Frequency Band	4.9 GHz; 2.4 GHz (802.11b/g)
Field Upgradeable	Software upgradeable to support new standards
ORiNOCO Mesh Creation Protocol	AP mesh networking allows quick installation, expanded network coverage, and self-healing capabilities for maximum network reliability.
IEEE 802.11i and AES encryption	Highest authentication and encryption methods including mutual authentication, message integrity check (MIC), per-packet keys initialization vector hashing and broadcast key rotation
Intrusion Detection	Detects and alerts unauthorized rogue Access Points and clients in the 2.4, 4.9, and 5 GHz bands
Secure Management Interfaces	SNMPv3 and SSL protect against unauthorized AP changes via the management interface
Multiple VLAN Support with different security settings	Up to 16 separate VLANs per radio, each able to support multiple different authentication and encryption algorithms simultaneously
Auto configuration via DHCP	Ensures new APs automatically receive correct configuration and prevents security vulnerabilities with deliberate resets
Multiple BSSID Support	Up to 4 Basic Service Set Identifiers (BSSIDs) per radio
Central management and configuration	Allows centralized management of AP settings including group updates of firmware[1]
Assured Software Upgrades	Guarantees new AP configuration file is valid before deleting current image - dual image support
Quality of Service	Draft IEEE 802.11e along with 802.1p and 802.1q improve performance of video and voice applications
Output Power	+24 dBm for 802.11b/g; +24 dBm for 4.9 GHz
Transmit Power Control	Supports settable transmit power levels to adjust coverage cell size
Automatic Channel Selection	Simplifies installation by choosing best possible channel upon installation
RADIUS Support	Extensive RADIUS Accounting support, intra-cell blocking to prevent client-to-client snooping, multiple VLAN support with different security modes
Super Mode	Delivers greater than 30 Mbps throughput for ORiNOCO and Atheros-based clients while simultaneously compatible with non-Atheros clients
Designed for Metro 4.9 GHz & Wi-Fi	AP-to-AP communication for extension of wireless LAN to areas without Ethernet wiring (parking lots, long corridors, etc) for 802.11b, 802.11g, and 4.9 GHz public safety
Advanced Filtering Capabilities	IEEE 802.1d bridging with static MAC address filtering, network protocol filtering, Proxy ARP, multicast/broadcast storm threshold filtering,TCP/UDP port filtering, intra-cell traffic filtering, and Spanning Tree support
External antenna connectors for 802.11b/g, and 4.9 GHz	Allows use of shaped and higher gain antennas to design for most efficient AP placement
Compliance	Wi-Fi, UL50, IP65
Remote Reboot System	Reboot or reset to factory default can be performed remotely via a power injector button
Fast boot-up in cold climate	Sophisticated heating technology automatically heats the system to shorten boot-up time
Near line of sight capable	Line of sight and near line of sight connectivity extends deployment flexibility in rural as well as high-density urban areas
Extended Operating Temperature	Rated for -35° to 60° Celcuis, can be deployed in hot or cold outdoor climates

INTERFACE

Wired Ethernet	10/100 base-T Ethernet (RJ-45)
Wireless Ethernet	1 integrated 802.11b/g radio and 1 integrated 4.9 GHz radio
RS-232	Unit configuration
Antenna Connector	2 Standard N-Female, 1 for each radio

HARDWARE SPECIFICATION

Memory	64 MB SDRAM; 8 MB Flash

PHYSICAL SPECIFICATIONS

Dimensions (unpackaged)	10.5 x 10.5 x 3.25 in (267 x 267 x 83 mm)
Weight (unpackaged)	6 lbs (2.49 kg)

ENVIRONMENTAL SPECIFICATIONS

Temperature	Operating -35°C to 60°C Storage -55°C to 80°C
Relative Humidity	Operating Max 95% (non-condensing) Storage Max 95% (non-condensing)
Wind Loading	125 mph
Water and dust proof	IP65

POWER SUPPLY

Power Injector	Input: 42 to 60 VDC Output: 48 VDC
Power Consumption	Maximum 20 Watts

LEDs

Type:	Power, Ethernet LAN Link
Line Feed:	Wireless Link

MANAGEMENT

- SNMPv1, SNMPv2c and secure SNMPv3 management
- Standard & ORiNOCO traps
- ORiNOCO MIB, Etherlike MIB, 802.11 MIB, Bridge MIB, MIB-II
- TFTP support
- Telnet CLI, Serial Port CLI (no proxy required)
- HTTPS (SSL) server for secure web-based management
- Proxim WaveLink Mobile Manager for group management (not included)
- Syslog
- DHCP Server and Client

MTBF AND WARRANTY

100,000 hours; 1 year on parts and labor

PACKAGE CONTENTS

ORiNOCO AP-4900MR-LR, wall/pole mounting bracket, PoE power injector, Cable termination kit, one mini-DIN to DB9 connector cable for serial connection, documentation and software CD-ROM. Available Options: AC Power Kit with twist lock power cord and Wide Pole Mounting Kit for light pole installation

RELATED PRODUCTS

Proxim Wireless CommUNITY is designed for metropolitan networks:

- Tsunami MP.11 for backhaul between groups of AP-4000MRs connected to each other through the ORiNOCO Mesh Creation Protocol
- Ekahau Site Survey to predict Wi-Fi coverage area after installation

Proxim Wireless Corporation
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Wi-Fi is a trademark of the Wireless Ethernet Compatibility Alliance, Inc.

DSUS_406_AP4900MRLR

ANTENNAFIER™ 4900-5800 S SERIES

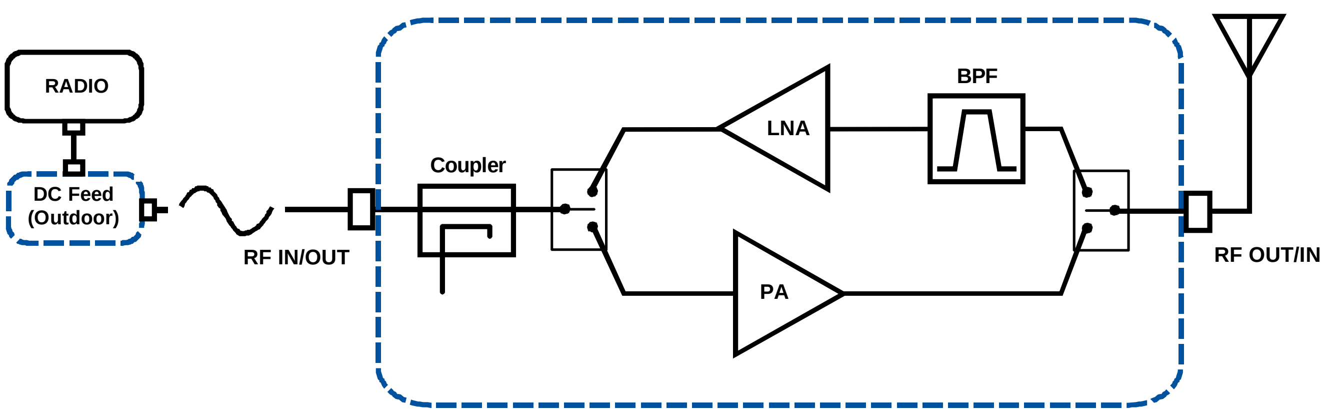
RF LINX CORPORATION

The Antennafier™ 4900-5800 S series Bi-Directional Amplifiers will significantly improve link reliability and operating range by providing Low Noise Amplification during Receive, and Spectrally Clean Power Amplification during Transmit. These fixed gain devices housed in a rugged machined aluminum chassis and are available in either indoor or outdoor models covering 4.9 to 5.8GHz in five popular bands.

Featured Highlights:

- Rugged Machined Aluminum Housing
- Fixed TX & RX Gains
- Transmit P1dBm = +30dBm (1W)
- Low 2.5dB RX Noise Figure
- High Dynamic Range
- 802.11a compatible
- TX/RX LED Indicator
- Automatically senses incoming RF signal

ANTENNAFIER™ 4900-5800 S SERIES
BLOCK DIAGRAM



The marketing, sale, and use of power amplification devices are governed by and subject to Part 15 of the Rules and Regulations of the Federal Communications Commission. Such devices may only be sold to parties assembling certified RF transmission systems consisting of an intentional radiator, an external radio frequency power amplifier, and an antenna.

9017 Cincinnati Columbus Rd.
West Chester, Ohio 45069
PH: 513-777-2774

FAX: 513-777-2115
http://www.rflinx.com

ANTENNAFIER™ 4900-5800 S SERIES

RF LINX CORPORATION

Typical Performance Parameters

Frequency Bands:	Public Safety:	4.940-4.990 GHz
	U-NII Lower:	5.15-5.25 GHz
	U-NII Middle:	5.25-5.35 GHz
	CEPT:	5.47-5.725 GHz
	U-NII Upper :	5.725-5.825 GHz
Supply Voltage:	+12 VDC +/- 5%	(Outdoor Version) DC from Center of coax (Indoor Version) DC from Power Jack on side of amp, 2.1mm I.D. (+), 5.5mm O.D. (-)
Receive:	Gain:	10 dB +/- 2 dB (SE Indoor) 12 dB +/- 2 dB (SX Outdoor)
	Noise Figure:	2.5 dB
	Supply Current:	< 250 mA
	TX to RX Switching:	< 500nSec
Transmit:	Gain :	9 dB +/- 2 dB (SE Indoor) 12 dB +/- 2 dB (SX Outdoor)
	Compression Point:	P1dBm = +30dBm (1W) (we recommend 6dB back-off for OFDM)
	OFDM 802.11a Power Output	+24dBm (250mW yields 54Mbs) +27dBm (500mW yields 36Mbs)
	RF Input Power for Turn-On:	> 1 dBm
	Harmonic Rejection:	2fo > 50 dBc, 3fo >73dBc @ Power Output
	Supply Current:	< 900 mA
	RX to TX Switching:	< 500Sec
Maximum Ratings:	Pin (Radio Port)	+30 dBm
	Pin (Antenna Port)	+27 dBm
Size:	2.88" x 3.00"x 1.01"	
Weight:	< 12 oz	
Chassis:	Machined Aluminum with durable black anodize finish CCA is protected with a conformal coating compound	
Indicator LED:	Green LED -Receive Mode, Red LED-Transmit Mode	
Lightning Suppression:	1/4 wavelength short	

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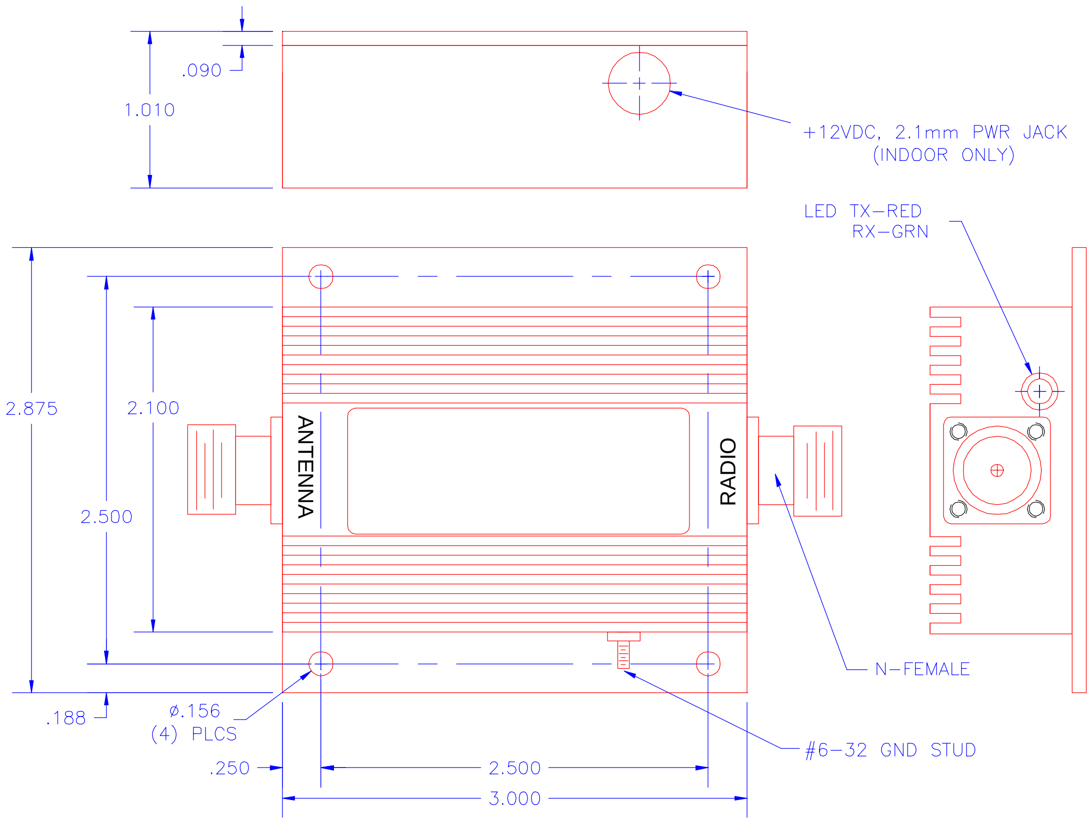
Mechanical Envelope:



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FAX: 513-777-2115
http://www.rflinx.com

Ordering Guide:

Indoor Series	Freq Band	Description
4900 SE	4940-4990 GHz Public Safety Band	Includes: Amplifier, Heat Sink, Cable Stays & 12VDC Wall Mount Power Supply.
5200 SE	5.15-5.25GHz U-NII Lower Band	
5300 SE	5.25-5.35 GHz U-NII Middle Band	
5600 SE	5.47-5.725 GHz CEPT	
5800 SE	5.725-5.825GHz U-NII Upper Band	

Outdoor Series	Freq Band	Description
4900 SX	4940-4990 GHz Public Safety Band	For Outdoor applications where DC is sent via center conductor of RF Coax to power Amplifier. Includes: Amplifier, DC injector, mounting bracket with stainless steel hardware, Heat Sink, Cable Stays & 12VDC Wall Mount Power Supply
5300 SX	5.25-5.35 GHz U-NII Middle Band	
5600 SX	5.47-5.725 GHz CEPT	
5800 SX	5.725-5.825GHz U-NII Upper Band	

- Use designator "U" in tail end of Part Number to denote user specified gains. Specify TX and RX gain in dB when ordering.

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TA-4904-14-90 Sector

4940 - 4990 MHz

The TA-4904-14-90 is a vertically polarized 90 degree sectoral antenna. The antenna consists of a printed dipole array enclosed in an aluminum base with a UV stabilized radome for superior weatherability. The antenna is at DC ground to aid in lightning protection.

Electrical Specifications

Frequency Range: 4940 - 4990 MHz
Gain: 15.5 dBi typ.
VSWR: 2:1 max.
Front to Back Ratio: 25 dB min.
Polarization: Vertical
Power Rating: 5 Watts
H-Plane Beamwidth: 90 degrees
E-Plane Beamwidth: 5 degrees
Cross Pol. Discrimination: 20 dB min.
Impedance: 50 ohms nominal
Termination: N female

Typical mid band values. (For details , contact factory)

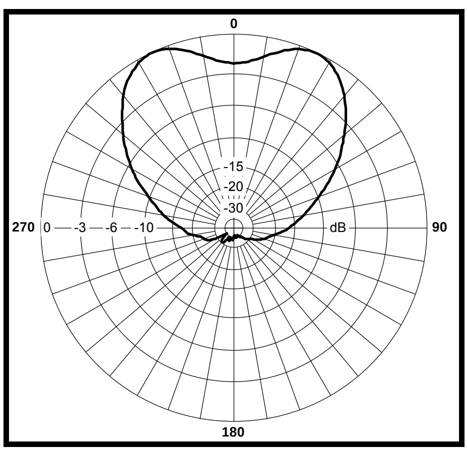
Mechanical Specifications

Length: 26.5 in. (673 mm)
Width: 6.25 in. (159 mm)
Depth: 2.0 in. (51 mm)
Weight (incl. Clamps): 6 lb. (2.72 kg)
Rated Wind Velocity: 125 mph (200 km/h)
Hor. Thrust at rated wind: 72 lb. (32.6 kg)
Mechanical Tilt: 0+/-16 degrees
Mounting (O.D.): 0.75 - 2.0 in. (19 - 51 mm)

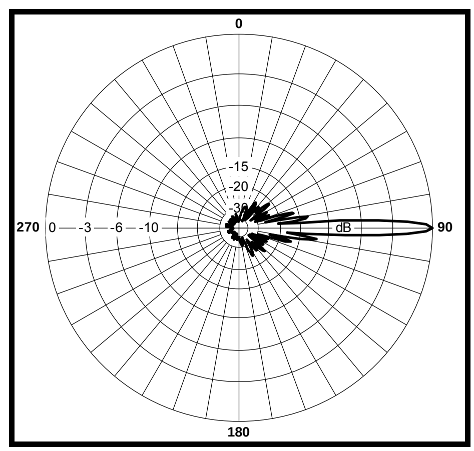
Materials

Radiating Elements: Plated copper on PCB
Reflector: Irridited aluminum
Radome: Gray UV stabilized ASA
Clamps: Aluminum and stainless steel

H-Plane



E-Plane

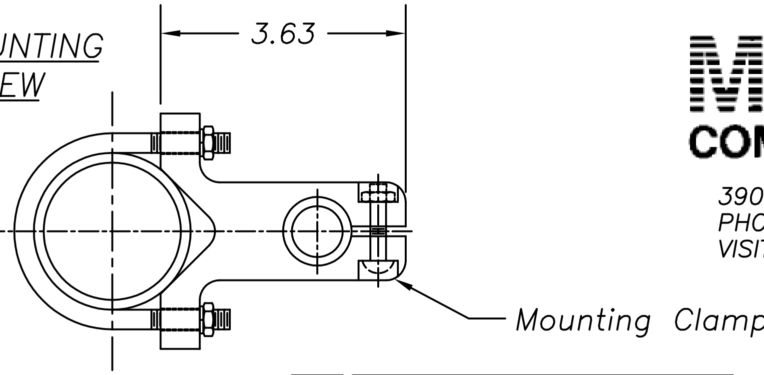


MOBILE MARK®
COMMUNICATIONS ANTENNAS

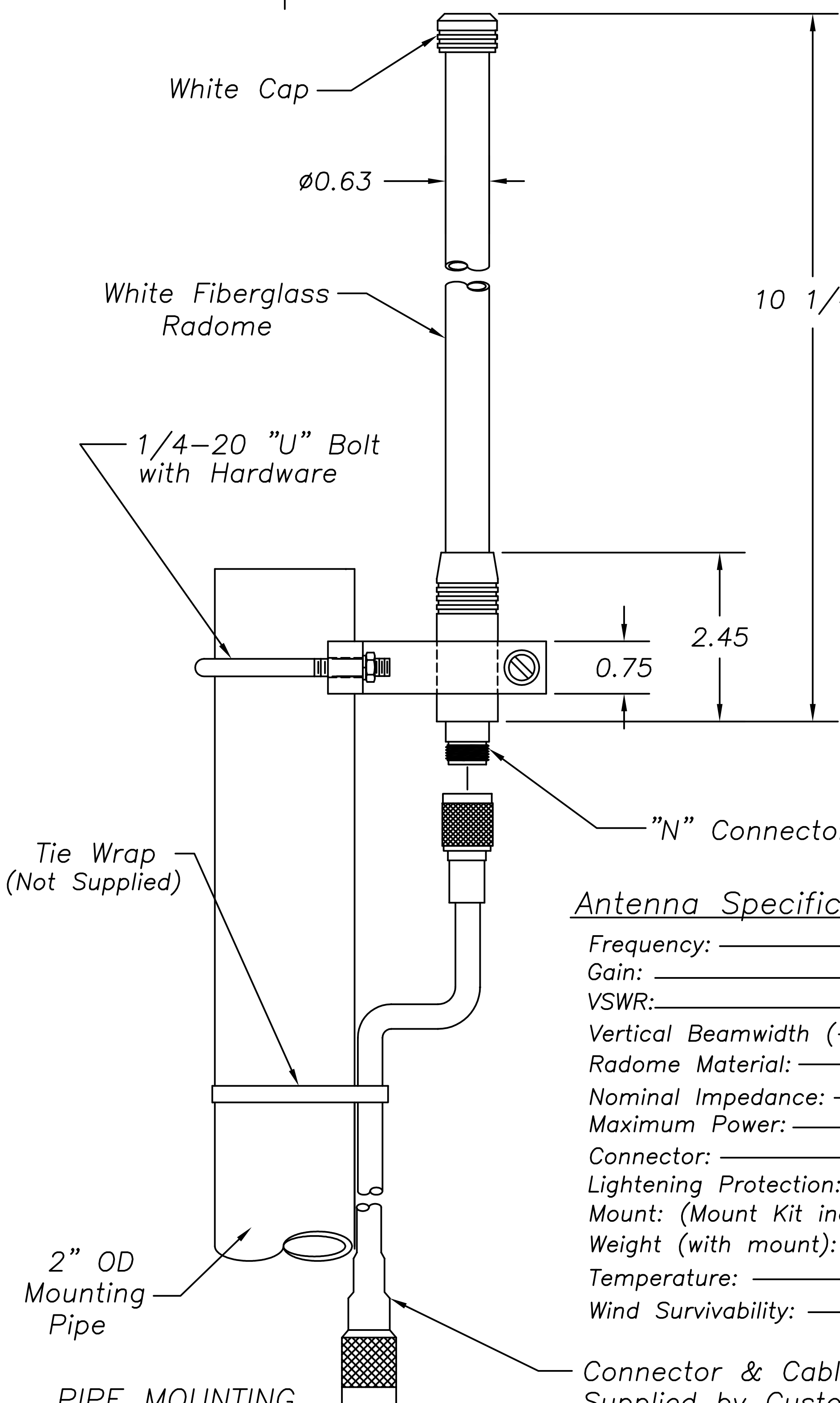
3900–B RIVER ROAD, SCHILLER PARK, IL 60176
PHONE: (847) 671–6690 * FAX (847) 671–6715
VISIT OUR WEBSITE AT WWW.MOBILEMARK.COM

ECO6-4900

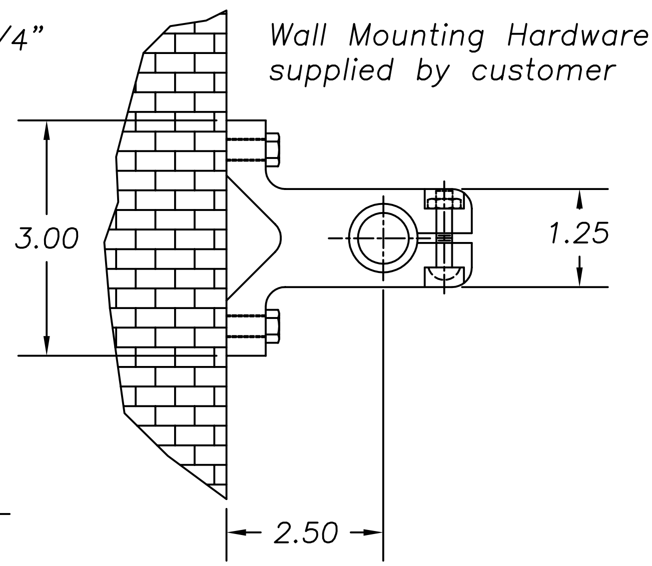
Omni Directional Antenna 6 dBi with Mounting Kit 4.9 - 5.0 GHz



PIPE MOUNTING TOP VIEW



PIPE MOUNTING



WALL MOUNTING TOP VIEW

Antenna Specifications:

Frequency:	4.9–5.0 GHz
Gain:	6 dBi
VSWR:	2:1 Max
Vertical Beamwidth (–3 dB)	20 degrees
Radome Material:	White Fiberglass
Nominal Impedance:	50 OHM Nominal
Maximum Power:	10 Watts
Connector:	"N" Female Termination
Lightening Protection:	External Recommended
Mount: (Mount Kit included)	Mounts up to 2" OD Pipe,
Weight (with mount):	5 oz.
Temperature:	–40C to +80C
Wind Survivability:	100 mph minimum 100 mph with 1/2" radial ice

Specifications subject to change without notice

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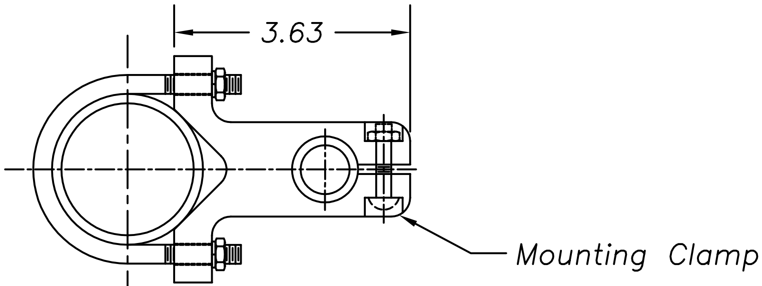
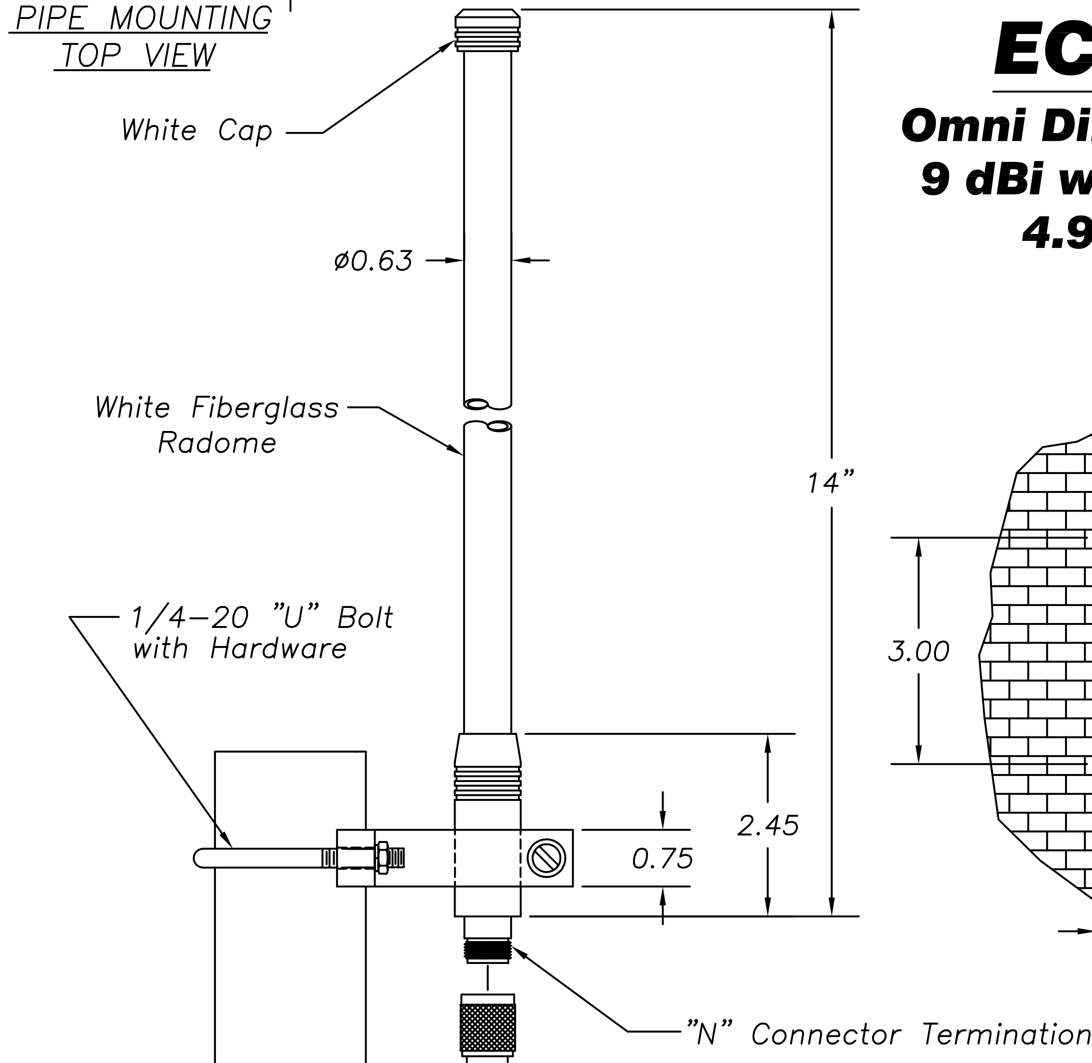
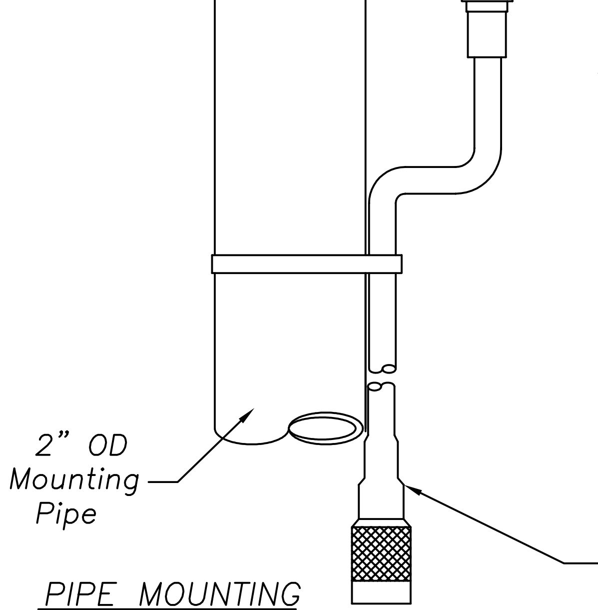
ECO9-4900

Omni Directional Antenna 9 dBi with Mounting Kit 4.9 - 5.0 GHz

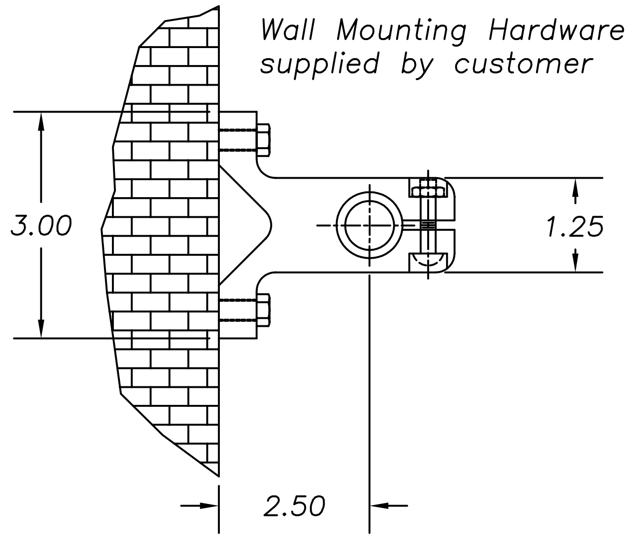


PIPE MOUNTING TOP VIEW





PIPE MOUNTING



WALL MOUNTING TOP VIEW

Antenna Specifications:

Frequency:	4.9–5.0 GHz
Gain:	9 dBi
VSWR:	2:1 Max
Vertical Beamwidth (–3 dB)	12 degrees
Radome Material:	White Fiberglass
Nominal Impedance:	50 OHM Nominal
Maximum Power:	10 Watts
Connector:	"N" Female Termination
Lightening Protection:	External Recommended
Mount: (Mount Kit included)	Mounts up to 2" OD Pipe,
Weight (with mount):	8 oz.
Temperature:	–40C to +80C
Wind Survivability:	100 mph minimum
	100 mph with 1/2" radial ice

Specifications subject to change without notice

Your Partner in Antenna Technology

4.940-5.850 GHz Parabolic Antennas

4.940-5.850 GHz Parabolic Antennas

Features:

- Linear Polarization (field adjustable for horizontal or vertical polarization) & Dual Polarization
- Sturdy aluminum construction reflector and pipe mount
- All corrosion resistant materials, galvanized and stainless steel hardware.
- Fine azimuth and elevation adjustment
- Type N Female Connector, 50 Ohm impedance
- Mounts to 1.9-4.5" OD pipe (48-114mm)
- Optional ABS radome available

Electrical Specifications

Model No.	Frequency GHz	Pol.	Size ft.	Size m	Notes	Gain, nominal dBi	HPBW Deg.	Xpol dB	F/B dB	VSWR max	R.L. dB
RP2-54-N	4.940-4.990	H or V	2	0.6	-	26.7	7.0	28	32	1.5:1	14.0
	5.250-5.850	H or V	2	0.6	-	28.5	6.2	28	35	1.5:1	14.0
RP3-56-N	5.250-5.850	H or V	3	0.9	-	31.4	4.0	30	38	1.5:1	14.0
RP4-56-N	5.250-5.850	H or V	4	1.2	-	34.5	3.0	30	42	1.5:1	14.0
RP2-58-N	5.725-5.850	H or V	2	0.6	-	28.8	6.0	30	38	1.5:1	14.0
RP3-58-N	5.725-5.850	H or V	3	0.9	-	32.0	4.0	30	40	1.5:1	14.0
RPD2-54-N	4.940-4.990	Dual	2	0.6	-	26.5	7.0	28	35	1.5:1	14.0
	5.250-5.850	Dual	2	0.6	-	28.3	6.2	28	38	1.5:1	14.0
RPD3-56-N	5.250-5.850	Dual	3	0.9		31.2	4.0	30	40	1.5:1	14.0
RPD4-56-N	5.250-5.850	Dual	4	1.2		34.3	3.0	30	42	1.5:1	14.0

mWAVE Industries, LLC
Gorham Industrial Park
28 Sanford Drive
Gorham, ME 04038 USA
www.mwavellc.com
info@mwavellc.com
phone: 207-857-3083
fax: 207-854-2287

FibeAir® 4800 Family

Fast Ethernet & nxT1/E1 License Exempt Radio

Broadband Wireless Network Solutions

System Overview

FibeAir® 4800 product family is a carrier-class, high capacity, low cost point-to-point wireless broadband system. It operates in the license-exempt 2.4 - 5.x GHz bands and is suitable for service providers and enterprises that require immediate deployment and quick return on investment.

FibeAir® 4800 product family carries Fast Ethernet and TDM services over license-exempt bands, effectively connecting voice and data over a single link. The system ensures low BER, as well as low latency and full compliance with E1/T1 interface jitter and wander requirements.

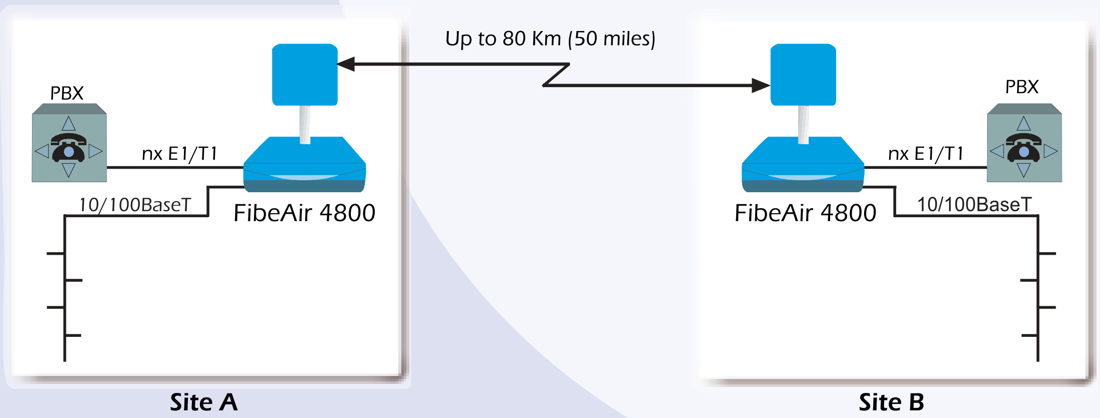
FibeAir® 4800 enables direct connection of existing equipment, such as LANs and PBX systems, thus eliminating the need for additional external equipment. FibeAir® 4800 product family is a split-mount system consisting of an IDU, ODU and antenna on each side of the link.

Two types of IDUs are available: IDU-E with 1 x 10/100BT and 1,2 x E1/T1, or IDU-C (Carrier Class) with 2 x 10/100BT and 1, 2, 4, 6 x E1/T1, power redundancy, and optional 1+1 protection.

Two types of ODUs are available: ODU with integrated 1 ft antenna, or ODU with N-type connector for external antenna.

Features

- High data rate up to 48 Mbps
- License-exempt radio operation at:
  2.400-2.4835 GHz
  4.940-4.990 GHz
  5.250-5.350 GHz
  5.470-5.725 GHz
  5.725-5.850 GHz
- Configurable modulation schemes: QPSK, 16 QAM, 64 QAM
- Integrated Fast Ethernet and nxE1/T1 interfaces
- Operational range of up to 50 miles (80 km)
- Carrier-class grade
- Excellent performance and reliability
- Complete SNMP-based local and remote management
- Complies with ETSI, FCC, IC, ITU-T and IEEE standards and frequency plans, for operation worldwide
- Cost-effective Ethernet link



private networks
mobile backbone
telecom infrastructure

IDU-E

IDU-C

Applications

Campus Connectivity: Transparent connection of enterprise LAN and PBX systems across campuses, which reduces communication costs, operating expenses, and maintenance requirements.

Wireless ISP Backhaul: Wireless Internet Service Providers (WISPs) use backhaul to connect their Point of Presence (POP) to their network operation centers. Using FibeAir 4800, WISPs have a higher capacity, with a range of up to 80 km, and bundled connectivity, within the same cost-effective package.

Wi-Fi and WiMax Backhauling: Provides a robust and cost-effective wireless alternative to leased lines, for the last mile connection between the Wi-Fi/WiMax access point and the data network.

Technical Specifications

Configuration

Architecture:
Indoor Unit (IDU-E or IDU-C) and
Outdoor Unit (ODU)
IDU to ODU Interface
Outdoor CAT-5 cable;
Maximum length of 100 m

Radio

Frequency:
2.400-2.4835 GHz
4.940-4.990 GHz
5.250-5.350 GHz
5.470-5.725 GHz
5.725-5.850 GHz
Data Rate: Configurable up to 48 Mbps
Channel BW: 20 MHz
Channel Setting Resolution: 5 MHz
Duplex Technique: TDD
Modulation: OFDM - BPSK, QPSK, 16 QAM, 64 QAM
Transmit Power: Up to 18 dBm (configurable in 1dB steps)
The max value will be limited in accordance with standard regional regulations.
Received Dynamic range: > 60 dB
Error Correction: FEC k=1/2, 2/3, 3/4
Encryption: AES 128

LAN Interface

Type: 10/100BaseT interface auto-negotiation.
Number of ports: 1, 2
Framing Coding: IEEE 802.3/U
Bridging: Self-learning up to 2047 MAC addresses IEEE 802.1
Traffic Handling: MAC layer bridging, self-learning
Data Latency: 3 msec typical
Line Impedance: 100W'
VLAN Support: Transparent
Connector: RJ-45

E1/T1 Interface

Framing: Unframed (Transparent)
Number of ports: 1, 2, 4, 6
Compliance to standards: G.703,G.826.
Timing: Plesiochronous (independent Tx and Rx timing)
Line Code: E1: HDB3; **T1:** AMI /B8ZS
Latency: 8 msec
Impedance: E1: 120W', balanced
T1: 100W', balanced
Connector: RJ-45
Jitter & Wander: ITU-T G.823, G.824

Management

Protocol: SNMP based protocol
Network Management: SNMPc based
Upgrade Capabilities: Local and remote software download

Diagnostics: Local and remote loopbacks
Management interface: 10/100 BaseT
Connector: RJ-45

Mechanical

ODU Dimensions:
24.5 cm (H) x 13.5 cm (W) x 4.0 cm (D)
Weight: 1.0kg/2.2 lb
IDU-E Dimensions:
16.5 cm (H) x 23.6 cm (W) x 4.5 cm (D)
Weight: 0.5kg/1.1lb
IDU-C Dimensions:
43 cm (H) x 29 cm (W) x 4.5 cm (D)
Weight: 1.5Kg/3.3lb

General

Power Feeding:
110/220 VAC, -48 VDC, 50/60 Hz,
Power Consumption:
FibeAir 4800 with IDU-E: 10W Max
FibeAir 4800 with IDU-C: 14W Max
Mounting: Pole or wall mounting

Environmental

Outdoor Unit Enclosure: All-weather cases
ODU Temperatures: -35°C - 60°C / -31°F - 140°F
IDU Temperatures: -5°C - 45°C / 23°F - 113°F
Humidity: Up to 90% non-condensing

Antenna Characteristics

	FibeAir 4824	FibeAir 4849	FibeAir 4853	FibeAir 4854	FibeAir 4858
Frequency Band	2.400-2.4835 GHz	4.940-4.990 GHz	5.250-5.350 GHz	5.470-5.725 GHz	5.725-5.850 GHz
Integrated Antenna 1 ft					
Gain	17dBi	21dBi	22dBi	22dBi	22dBi
Beam Width	20°	9°	9°	9°	9°
Polarization	Linear	Linear	Linear	Linear	Linear
External Antenna 2 ft					
Gain	24dBi	28dBi	28dBi	28dBi	28dBi
Beam Width	10°H/14°V	4.5°	4.5°	4.5°	4.5°
Polarization	Linear	Linear	Linear	Linear	Linear

*** Higher gain antennas are available upon request**

Standards & Regulations

	FibeAir 4824	FibeAir 4849	FibeAir 4853	FibeAir 4854	FibeAir 4858
Frequency Band	2.400-2.483 GHz	4.940-4.990 GHz	5.250-5.350 GHz	5.470-5.725 GHz	5.725-5.85 GHz
Radio					
FCC 47CFR Part 15	Sub-part C	Sub-part C	Sub-part E	Sub-part E	Sub-part C
IC	RSS-210		RSS-210		RSS-210
ETSI	EN 300 328			EN300 216 V1.2.1	EN300 440 V1.3.1
Dynamic Frequency Selection and Transmission Power Control (DFS/TPC)				EN 301 893 V1.2.2	
Safety					
TUV	60950, according to UL 60950				
CAN-CSA	C22.2 No.60950				
EMC					
FCC	47CFR Part 15, Sub-part B				
ETSI	EN 301 489-1				
Environment					
ETSI	IEC 60721-3-4 Class 4M5 IP67				

About Ceragon Networks Ltd.

Ceragon Networks Ltd. (NASDAQ: CRNT), a pacesetter in broadband wireless networking systems, enables rapid and cost-effective high-capacity network connectivity for mobile cellular infrastructure, fixed networks, private networks and enterprises. Ceragon's modular FibeAir® product family operates across multiple frequencies, supports integrated high-capacity services over SONET/SDH, ATM and IP networks, and offers innovative built-in add/drop multiplexing and encryption functionality to meet the growing demand for value -added broadband services. Ceragon's FibeAir® product family complies with North American and international standards and is installed with over 150 customers in more than 60 countries. More information is available at **www.ceragon.com**.

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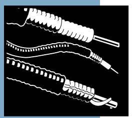

1/2" Foam Dielectric, LDF Series – *50-ohm*

LDF4-50A

Description	Type No.
Cable Ordering Information	
Standard Cable	
1/2" Standard Cable, Standard Jacket	**LDF4-50A**
Fire Retardant Cables	
1/2" Fire Retardant Jacket (CATVX)	**LDF4RN-50A**
1/2" Fire Retardant Jacket (CATVR)	**LDF4RN-50A**
Low VSWR and Specialized Cables	
1/2" Low VSWR, specify operating band	**LDF4P-50A-(**)**
Phase Stabilized and Phase Measured Cable	See page 590
Jumper Cable Assemblies – See page 584	

** Insert suffix number from “Low VSWR Specifications” table, page 498

Characteristics

Electrical	
Impedance, ohms	50 ± 1
Maximum Frequency, GHz	8.8
Velocity, percent	88
Peak Power Rating, kW	40
dc Resistance, ohms/1000 ft (1000 m)	
Inner	0.45 (1.48)
Outer	0.58 (1.90)
dc Breakdown, volts	4000
Jacket Spark, volts RMS	8000
Capacitance, pF/ft (m)	23.1 (75.8)
Inductance, µH/ft (m)	0.058 (0.19)
Mechanical	
Outer Conductor	Copper
Inner Conductor	Copper-Clad Aluminum
Diameter over Jacket, in (mm)	0.63 (16)
Diameter over Copper Outer Conductor, in (mm)	0.55 (14)
Diameter Inner Conductor, in (mm)	0.189 (4.6)
Nominal Inside Transverse Dimensions, cm	1.11
Minimum Bending Radius, in (mm)	5 (125)
Number of Bends, minimum (typical)	15 (50)
Bending Moment, lb-ft (N•m)	2.8 (3.8)
Cable Weight, lb/ft (kg/m)	0.15 (0.22)
Tensile Strength, lb (kg)	250 (113)
Flat Plate Crush Strength, lb/in (kg/mm)	110 (2.0)

Attenuation and Average Power Ratings

Frequency MHz	Attenuation dB/100 ft	Attenuation dB/100 m	Average Power, kW
0.5	0.045	0.149	40.0
1	0.064	0.211	35.8
1.5	0.079	0.259	29.2
2	0.091	0.299	25.3
10	0.205	0.672	11.3
20	0.291	0.954	7.93
30	0.357	1.17	6.46
50	0.463	1.52	4.98
88	0.619	2.03	3.73
100	0.661	2.17	3.49
108	0.688	2.26	3.36
150	0.815	2.67	2.83
174	0.880	2.89	2.62
200	0.946	3.10	2.44
300	1.17	3.83	1.97
400	1.36	4.46	1.70
450	1.45	4.75	1.59
500	1.53	5.02	1.51
512	1.55	5.08	1.49
600	1.69	5.53	1.37
700	1.83	6.01	1.26
800	1.97	6.46	1.17
824	2.00	6.56	1.15
894	2.09	6.85	1.10
960	2.17	7.12	1.06
1000	2.22	7.28	1.04
1250	2.51	8.23	0.921
1500	2.77	9.09	0.833
1700	2.97	9.74	0.777
1800	3.07	10.1	0.753
2000	3.25	10.7	0.710
2100	3.34	11.0	0.691
2200	3.43	11.2	0.673
2300	3.52	11.5	0.657
3000	4.09	13.4	0.565
3400	4.39	14.4	0.526
4000	4.82	15.8	0.479
5000	5.49	18.0	0.421
6000	6.11	20.1	0.378
8000	7.26	23.8	0.318
8800	7.69	25.2	0.300

Standard Conditions:
For attenuation. VSWR 1.0, ambient temperature 20°C (68°F).
For Average Power, VSWR 1.0, ambient temperature 40°C (104°F), inner conductor temperature 100°C (212°F), no solar loading.

ANDREW®

Revised 9/00

TIMES MICROWAVE SYSTEMS

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LMR®-400
Flexible Low Loss Communications Coax

Ideal for...

- Drop-in replacement for RG-8/9913 Air-Dielectric type Cable
- Jumper Assemblies in Wireless Communications Systems
- Short Antenna Feeder runs
- Any application (e.g. WLL, GPS, LMR) requiring an easily routed, low loss RF cable

- **LMR®** standard is a UV Resistant Polyethylene jacketed cable designed for 20-year service outdoor use. The bending and handling characteristics are significantly better than air-dielectric and corrugated hard-line cables.
- **LMR®- DB** is identical to standard LMR plus has the advantage of being watertight. The addition of waterproofing compound in and around the foil/braid insures continuous reliable service should the jacket be inadvertently damaged during installation or in the future.
- **LMR®- FR** is a non-halogen (non-toxic), low smoke, fire retardant cable designed for in-building runs that can be routed anywhere except air handling plenums. LMR-FR has a UL/NEC & CSA rating of 'CMR/MPR' and 'FT4' respectively.
- **LMR®- FR-PVC** is a general-purpose indoor cable and has a UL/NEC & CSA rating of 'CMR/MPR' and 'FT4' respectively. It is less expensive than LMR-FR, however it emits toxic fumes (HCL) and greater smoke density when burned.
- **LMR®- PVC** is designed for low loss general-purpose indoor/outdoor applications and is somewhat more flexible than the standard polyethylene jacketed LMR.
- **LMR®- PVC-W** is a white-jacketed version of LMR-PVC for marine and other indoor/outdoor applications where color compatibility is desired.

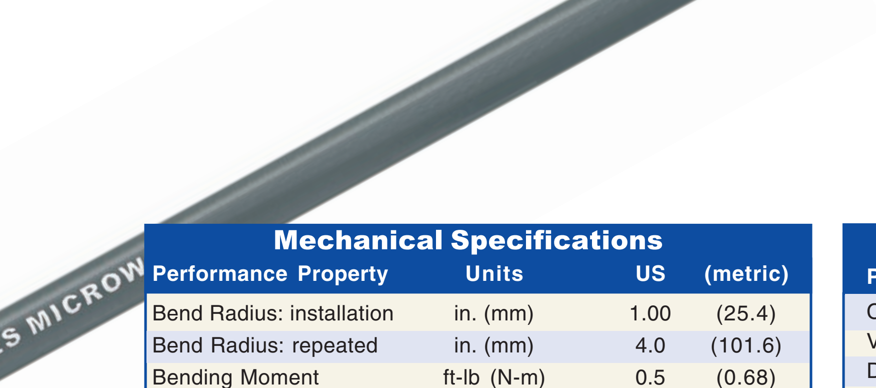
- **Flexibility** and bendability are hallmarks of the LMR-400 cable design. The flexible outer conductor enables the tightest bend radius available for any cable of similar size and performance.
- **Low Loss** is another hallmark feature of LMR-400. Size for size LMR has the lowest loss of any flexible cable and comparable loss to semirigid hard-line cables.
- **RF Shielding** is 50 dB greater than typical single shielded coax (40 dB). The multi-ply bonded foil outer conductor is rated conservatively at > 90 dB (i.e. >180 dB between two adjacent cables).
- **Weatherability**: LMR-400 cables designed for outdoor exposure incorporate the best materials for UV resistance and have life expectancy in excess of 20 years.
- **Connectors**: A wide variety of connectors are available for LMR-400 cable, including all common interface types, reverse polarity, and a choice of solder or non-solder center pins. Most LMR connectors employ crimp outer attachment using standard hex crimp sizes.
- **Cable Assemblies**: All LMR-400 cable types are available as pre-terminated cable assemblies. Refer to the section on FlexTech for further details.

Part Description

Part No.	Application	Jacket	Color	Stock Code
LMR-400	Outdoor	PE	Black	54001
LMR-400-DB	Outdoor/Watertight	PE	Black	54091
LMR-400-FR	Indoor -Riser CMR	FRPE	Black	54030
LMR-400-FR-PVC	Indoor -Riser CMR	FRPVC	Black	54073
LMR-400-PVC	Indoor/Outdoor	PVC	Black	54218
LMR-400-PVC-W	Indoor/Outdoor	PVC	White	54204

Construction Specifications

Description	Material	In.	(mm)
Inner Conductor	Solid BCCAl	0.108	(2.74)
Dielectric	Foam PE	0.285	(7.24)
Outer Conductor	Aluminum Tape	0.291	(7.39)
Overall Braid	Tinned Copper	0.320	(8.13)
Jacket	(see table above)	0.405	(10.29)



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Mechanical Specifications

Performance Property	Units	US	(metric)
Bend Radius: installation	in. (mm)	1.00	(25.4)
Bend Radius: repeated	in. (mm)	4.0	(101.6)
Bending Moment	ft-lb (N-m)	0.5	(0.68)
Weight	lb/ft (kg/m)	0.068	(0.10)
Tensile Strength	lb (kg)	160	(72.6)
Flat Plate Crush	lb/in. (kg/mm)	40	(0.71)

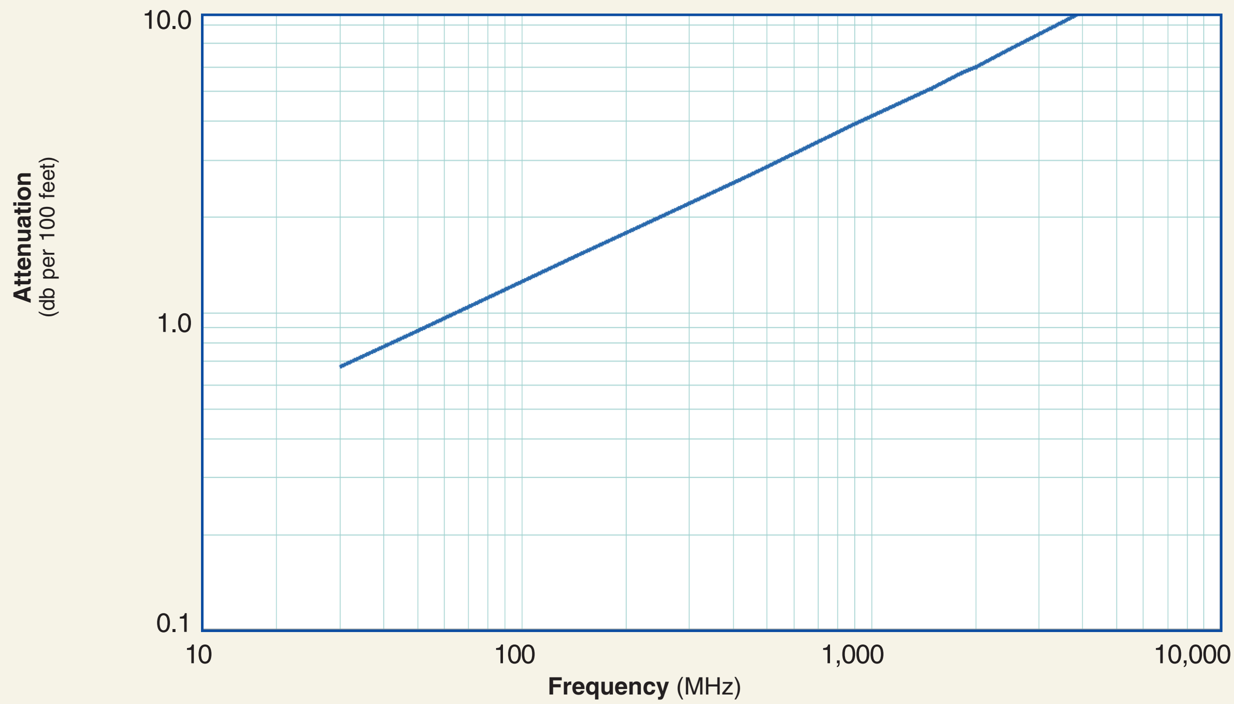
Environmental Specifications

Performance Property	°F	°C
Installation Temperature Range	-40/+185	-40/+85
Storage Temperature Range	-94/+185	-70/+85
Operating Temperature Range	-40/+185	-40/+85

Electrical Specifications

Performance Property	Units	US	(metric)
Cutoff Frequency	GHz	16.2	
Velocity of Propagation	%	85	
Dielectric Constant	NA	1.38	
Time Delay	nS/ft (nS/m)	1.20	(3.92)
Impedance	ohms	50	
Capacitance	pF/ft (pF/m)	23.9	(78.4)
Inductance	uH/ft (uH/m)	0.060	(0.20)
Shielding Effectiveness	dB	>90	
DC Resistance			
Inner Conductor	ohms/1000ft (/km)	1.39	(4.6)
Outer Conductor	ohms/1000ft (/km)	1.65	(5.4)
Voltage Withstand	Volts DC	2500	
Jacket Spark	Volts RMS	8000	
Peak Power	kW	16	

Attenuation vs. Frequency (typical)



Frequency (MHz)	30	50	150	220	450	900	1500	1800	2000	2500	5800
Attenuation dB/100 ft	0.7	0.9	1.5	1.9	2.7	3.9	5.1	5.7	6.0	6.8	10.8
Attenuation dB/100 m	2.2	2.9	5.0	6.1	8.9	12.8	16.8	18.6	19.6	22.2	35.5
Avg. Power kW	3.33	2.57	1.47	1.20	0.83	0.58	0.44	0.40	0.37	0.33	0.21

Calculate Attenuation =
(0.122290) • $\sqrt{FMHz}$ + (0.000260) • FMHz (interactive calculator available at http://www.timesmicrowave/telecom)
Attenuation:
VSWR=1.0 ; Ambient = +25°C (77°F)
Power:
VSWR=1.0; Ambient = +40°C; Inner Conductor = 100°C (212°F); Sea Level; dry air; atmospheric pressure; no solar loading

TIMES MICROWAVE SYSTEMS

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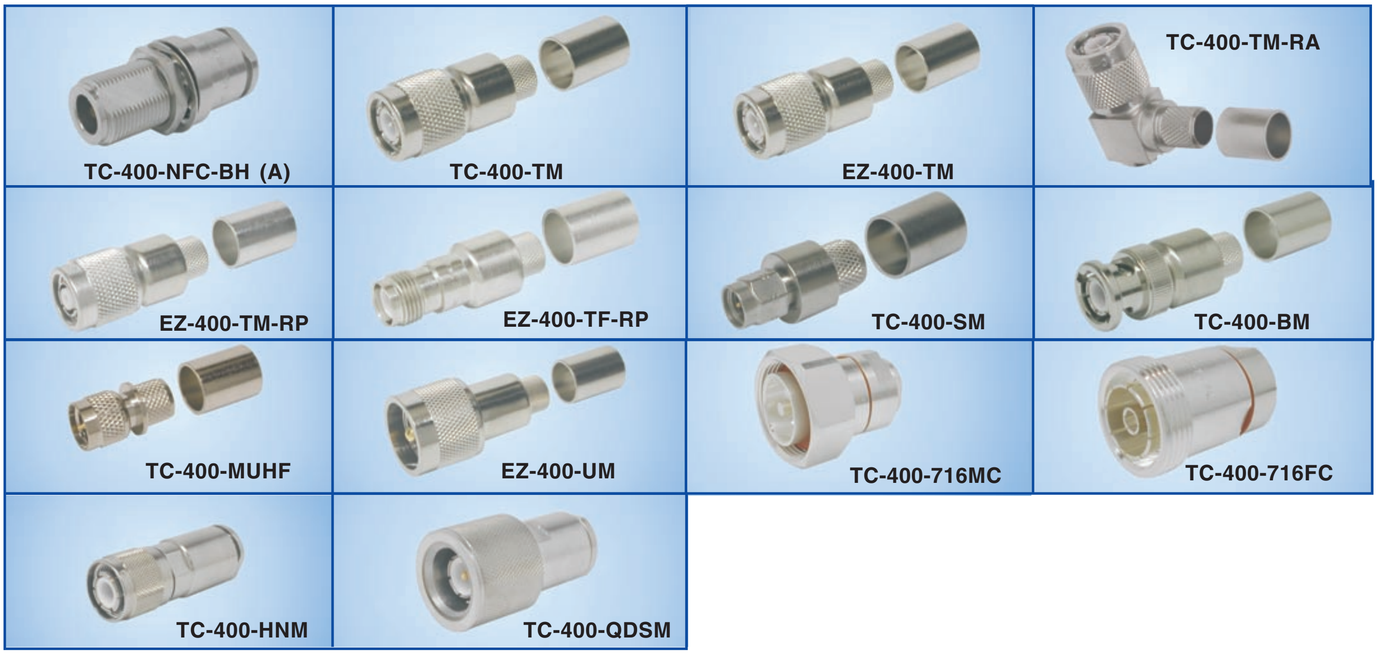
LMR®-400
Flexible Low Loss Communications Coax

Connectors

Interface	Description	Part Number	Stock Code	VSWR**	Freq. (GHz)	Coupling Nut	Inner Contact Attach	Outer Contact Attach	Finish* Body /Pin	Length in	Length (mm)	Width in	Width (mm)	Weight lb	Weight (g)
7-16 DIN Female	Straight Jack	TC-400-716-FC	3190-376	<1.25:1	(2.5)	NA	Solder	Clamp	S/S	1.6	(41)	1.13	(28.7)	0.281	(127.5)
7-16 DIN Male	Straight Plug	TC-400-716-MC	3190-279	<1.25:1	(2.5)	Hex	Solder	Clamp	S/S	1.4	(36)	1.40	(35.6)	0.268	(121.6)
7-16 DIN Male	Right Angle	TC-400-716MC-RA	3190-1671	<1.25:1	(<3)	Hex	Solder	Clamp	A/S	2.4	(61.5)	1.88	(47.8)	0.35	(159)
BNC Male	Straight Plug	TC-400-BM	3190-318	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/S	1.7	(43)	0.56	(14.2)	0.063	(28.6)
HN Male	Straight Plug	TC-400-HNM	3190-923	<1.25:	(<1)	Knurl	Solder	Clamp	S/G	2.3	(59.2)	0.88	(22.4)	0.25	(113.4)
QDS Male	Straight Plug	TC-400-QDSM	3190-620	<1.25:	(<3)	Knurl	Solder	Clamp	A/G	1.8	(46.6)	1.00	(25.4)	0.25	(113.4)
Mini-UHF	Straight Plug	TC-400-MUHF	3190-520	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/G	1.1	(28)	0.50	(12.7)	0.020	(9.1)
N Female	Straight Jack	TC-400-NFC	3190-299	<1.25:1	(2.5)	NA	Solder	Clamp	N/S	1.6	(41)	0.75	(19.1)	0.119	(54.0)
	Straight Jack	EZ-400-NF	3190-956	<1.25:1	(2.5)	NA	Spring Finger	Crimp	N/G	1.8	(45)	0.66	(16.8)	0.105	(47.6)
	Bulkhead Jack	EZ-400-NF-BH	3190-518	<1.25:1	(2.5)	NA	Spring Finger	Crimp	N/G	1.8	(46)	0.88	(22.4)	0.102	(46.3)
	Bulkhead Jack	TC-400-NFC-BH (A)	3190-872	<1.25:1	(2.5)	NA	Solder	Clamp	A/G	1.8	(46)	0.88	(22.4)	0.145	(65.8)
N Male	Straight Plug	SC-400-NM	3190-1454	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/G	1.5	(38)	0.75	(19.1)	0.090	(40.8)
	Straight Plug	TC-400-NM	3190-188	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/G	1.5	(38)	0.75	(19.1)	0.090	(40.8)
	Straight Plug	TC-400-NMC	3190-277	<1.25:1	(2.5)	Knurl	Solder	Clamp	N/G	1.5	(38)	0.75	(19.1)	0.121	(54.9)
	Straight Plug	EZ-400-NMH	3190-400	<1.25:1	(10)	Hex	Spring Finger	Crimp	S/G	1.5	(38)	0.89	(22.6)	0.113	(51.3)
	Straight Plug	TC-400-NMH	3190-552	<1.25:1	(10)	Hex	Solder	Crimp	S/G	1.5	(38)	0.89	(22.6)	0.113	(51.3)
	Straight Plug	EZ-400-NMK	3190-661	<1.25:1	(10)	Knurl	Spring Finger	Crimp	S/G	1.5	(38)	0.89	(22.6)	0.113	(51.3)
	Right Angle	TC-400-NMH-RA	3190-422	<1.35:1	(6)	Hex	Solder	Crimp	S/G	1.8	(46)	1.25	(31.8)	0.13	0(59.0)
	Right Angle	TC-400-NMC-RA (A)	3190-870	<1.35:1	(2.5)	Hex	Solder	Clamp	A/G	1.8	(46)	1.25	(31.8)	0.150	(68.0)
	Right Angle	EZ-400-NMH-RA	3190-761	<1.35:1	(2.5)	Hex	Spring Finger	Crimp	S/G	1.8	(46)	1.25	(31.8)	0.130	(59.0)
	Reverse Polarity	TC-400-NM-RP	3190-960	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/G	1.5	(38)	0.75	(19.1)	0.090	(40.8)
SMA Male	Straight Plug	TC-400-SM	3190-439	<1.25:1	(8)	Hex	Solder	Crimp	N/G	1.2	(29)	0.50	(12.7)	0.032	(14.5)
TNC Female	Reverse Polarity	EZ-400-TF-RP	3190-795	<1.25:1	(2.5)	NA	Spring Finger	Crimp	A/G	1.8	(46)	0.55	(14.0)	0.074	(33.6)
TNC Male	Straight Plug	TC-400-TM	3190-260	<1.25:1	(2.5)	Knurl	Solder	Crimp	N/S	1.7	(43)	0.59	(15.0)	0.074	(33.6)
	Straight Plug	EZ-400-TM	3190-650	<1.25:1	(2.5)	Knurl	Spring Finger	Crimp	N/S	1.7	(43)	0.59	(15.0)	0.074	(33.6)
	Right Angle	TC-400-TM-RA	3190-442	<1.35:1	(2.5)	Knurl	Solder	Crimp	N/G	1.7	(43)	0.59	(15.0)	0.085	(38.6)
	Reverse Polarity	EZ-400-TM-RP	3190-794	<1.25:1	(2.5)	Knurl	Spring Finger	Crimp	A/G	1.7	(43)	0.59	(15.0)	0.074	(33.6)
UHF Male	Straight Plug	EZ-400-UM	3190-997	<1.25:1	(2.5)	Knurl	Spring Finger	Crimp	N/G	1.9	(48)	0.80	(20.3)	0.090	(40.8)

* Finish metals: N=Nickel, S=Silver, G=Gold, SS=Stainless Steel, A=Alballoy **VSWR spec based on 3 foot cable with a connector pair



Hardware Accessories

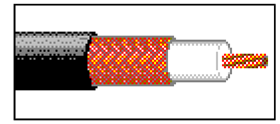
Type	Part Number	Stock Code	Description
Ground Kit	GK-S400T	GK-S400T	Standard Grounding Kit (each)
Hoisting Grip	HG-400T	HG-400T	Laced Type (each)

Install Tools

Type	Part Number	Stock Code	Description
Crimp Tool	HX-4	3190-200	Crimp Handle
Crimp Dies	Y1719	3190-202	.429" Hex Dies
Crimp Tool	CT-400/300	3190-666	Crimp tool for LMR 400 connectors
Crimp Rings	CR-400	3190-830	Crimp rings for TC/EZ-400 connectors (package of 10)
Strip Tool	ST-400C	3190-228	For Clamp Connectors
Strip Tool	ST-400EZ	3190-401	For Crimp Connectors
Deburr Tool	DBT-01	3190-406	Removes center conductor rough edges
Cutting Tool	CCT-01	3190-1544	Cable end flush cut tool
Replacement Blade	RB-01	3190-1609	Replacement blade for cutting tool
Tool Kit	TK-400EZ	3190-1602	Tool kit for LMR-400 Crimp Connectors (includes CCT-01, ST-400EZ, CT-400/300, DBT-01, Tool Pouch

Belden
1-800-BELDEN-1

MIL-Spec Coaxial Cable
RG213/U QPL
13 AWG



Trade Number Industry Stds.	Std. Lgth. (ft.)	Std. Units (lbs.)	AWG (strand) Type (dia.) Nom. D.C.R.	Core O.D. Nom. O.D.	Shields Nom. D.C.R.	Nom. Imp. (ohms)	Vel. of Prop.	Nom. Cap.
8267 UL AWM: 1354 NEC: CMX CEC: CMX	500 1000	57.4 111.1	13 (7x21) BC 0.089 in. 1.7 ohms/M'	0.285 in. 0.405 in.	97% BC Braid **Inner** 1.2 ohms/M'	50.0	66.0%	30.8 pF/ft
Metric	(Meters) 152.4 304.9	(Kg) 26.09 50.5	2.260 mm 5.6 ohms/km	7.239 mm 10.286 mm	**Inner** 3.9 ohms/km			101.0 pF/m

Description:

Insulation:	Polyethylene	Coaxial MIL Spec Cable to MIL-C-17G. 13 AWG stranded bare copper conductor with polyethylene insulation. Bare copper braid, 97% coverage. Black non-contaminating PVC jacket. MIL-C-17G M17/163-00001 (RG213/U) QPL Temperature Rating : 60°C Voltage Rating : 30 Volts (UL) Suggested Operating Temperature Range (Non-UL): -40°C to +85°C. Maximum Operating Voltage (Non-UL): 3700 Volts RMS. Un-swept version of RG-213
Jacket:	PVC-NC	
Plenum Version(s):	n/a	

Attenuation

Freq MHz	Nom. Atten. (dB/100ft)	Nom. Atten. (dB/100m)
1.0	0.18	.59
10.0	0.62	2.03
50.0	1.5	4.92
100.0	2.1	6.9
200.0	3.0	9.8

Attenuation

Freq MHz	Nom. Atten. (dB/100ft)	Nom. Atten. (dB/100m)
1000.0	8.2	26.9
4000.0	21.5	70.5

Appendix B - FCC License Issued to Parker Fire

(Call Sign WQAC428)

Federal Communications Commission
Wireless Telecommunications Bureau

Radio Station Authorization (Reference Copy)

This is not an official FCC license. It is a record of public information contained in the FCC's licensing database on the date that this reference copy was generated. In cases where FCC rules require the presentation, posting, or display of an FCC license, this document may not be used in place of an official FCC license.

Licensee: Parker Fire Protection District

ATTN Daniel H. Qualman, Chief
Parker Fire Protection District
10235 Parkglenn Way
Parker, CO 80138

FCC Registration Number (FRN):	
0010555266	
Call Sign: WQAC428	**File Number:**
Radio Service: PA - Public Safety 4940-4990 MHz Band	
Regulatory Status: PMRS	
Frequency Coordination Number:	

Grant Date	Effective Date	Expiration Date	Print Date
05/04/2004	05/04/2004	05/04/2014	06/20/2005

STATION TECHNICAL SPECIFICATIONS

Fixed Location Address or Mobile Area of Operation

Loc. 1 **Area of Operation**
Countywide

County	State
DOUGLAS	CO

Location 1 Special Conditon: Except for those stations requiring an individual license under Rule 90.1207(b), this license authorizes mobile and base stations anywhere within its authorized area.

Loc. 2 **Area of Operation**
Countywide

County	State
DOUGLAS	CO

Location 2 Special Conditon: Except for those stations requiring an individual license under Rule 90.1207(b), this license authorizes temporary fixed stations anywhere within its authorized area.

Antennas

Loc. No.	Ant. No.	Frequencies (MHz)	Sta. Cls.	No. Units	No. Pagers	Emmission Designator	Output Power (watts)	ERP (watts)	Ant. Ht./Tp meters	Ant. AAT meters	Construct Deadline Date
1	1	4940.00000-4990.00000			0						
2	1	4940.00000-4990.00000			0						

Control Points **Pt. No.**1

Address: 10235 Parkglenn Way

City: Parker **County:** DOUGLAS **State:** CO **Telephone Number:** (303)841-2608

Associated Call Signs
None

Waivers/Conditions
This license gives the licensee authority to operate on any authorized channel in the 4940-4990 MHz band only within its legal jurisdiction, or in the case of a non-governmental organization, the legal jurisdiction of the state or local government entity supporting the non-government organization.

Antenna structures for land, base and fixed stations authorized by the Wireless Telecommunications Bureau for operation at temporary unspecified locations may be erected without specific prior approval of the Commission where such antenna structures do not exceed a height of 60.96 meters (200 feet) above ground level; provided that the overall height of such antennas more than 6.10 meters (20 feet) above ground, including their supporting structures (whether natural formation or man-made), do not exceed any of the slope ratios set forth in Section 17.7(b). Any antenna to be erected in excess of the foregoing limitations requires prior Commission approval. Licensees seeking such approval should file application for modification of license. In addition, notification to the Federal Aviation Administration is required whenever the antenna will exceed 60.96 meters (200 feet) above the ground and whenever notification is otherwise required by Section 17.7 of the Commission's Rules. Such notification should be given by filing FAA Form 7460-1, Notice of Proposed Construction or Alteration, in duplicate, with the nearest office of the Federal Aviation Administration, which form is available from that office.

Base or Temporary Fixed stations that meet Rule 90.1207(b) must apply for a separate authorization.

Conditions
Pursuant to Section 309(h) of the Communications Act of 1934, as amended, 47 U.S.C. Section 309(h), this license is subject to the following conditions: This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term thereof nor in any other manner than authorized herein. Neither the license nor the right granted thereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934, as amended. See 47 U.S.C. Section 310(d). This license is subject in terms to the right of use or control conferred by Section 706 of the Communications Act of 1934, as amended. See 47 U.S.C. Section 706.

FCC 601 - LM
July 2002

CLOSE WINDOW

Appendix C - FCC Rule Excerpts, Part 90

bands that increase the station's authorized interference contour, will be acceptable for filing if the applicant utilizes channels with an authorized bandwidth exceeding 11.25 kHz, unless specified elsewhere or the operations meet the efficiency standards of § 90.203(j)(3). See § 90.187(b)(2)(iii) and (iv) for interference contour designations and calculations. Applications submitted pursuant to this paragraph must comply with frequency coordination requirements of § 90.175.

[60 FR 37263, July 19, 1995, as amended at 67 FR 41860, June 20, 2002; 68 FR 42314, July 17, 2003; 68 FR 54769, Sept. 18, 2003; 69 FR 39867, July 1, 2004; 69 FR 67837, Nov. 22, 2004; 70 FR 21661, Apr. 27, 2005; 70 FR 34693, June 15, 2005]

§ 90.210 Emission masks.

Except as indicated elsewhere in this part, transmitters used in the radio services governed by this part must comply with the emission masks outlined in this section. Unless otherwise stated, per paragraphs (d)(4), (e)(4), and (m) of this section, measurements of emission power can be expressed in either peak or average values provided that emission powers are expressed with the same parameters used to specify the unmodulated transmitter carrier power. For transmitters that do not produce a full power unmodulated carrier, reference to the unmodulated transmitter carrier power refers to the total power contained in the channel bandwidth. Unless indicated elsewhere in this part, the table in this section specifies the emission masks for equipment operating in the frequency bands governed under this part.

APPLICABLE EMISSION MASKS

Frequency band (MHz)	Mask for equipment with Audio low pass filter	Mask for equipment without audio low pass filter
Below 25[1]	A or B	A or C
25–50	B	C
72–76	B	C
150–174[2]	B, D, or E	C, D, or E
150 Paging-only	B	C
220–222	F	F
421–512[2]	B, D, or E	C, D, or E
450 Paging-only	B	G
806–809/851–854	B	H
809–824/854–869[3]	B	G
896–901/935–940	I	J
902–928	K	K
929–930	B	G
4940–4990 MHz	L or M	L or M.
5850–5925[4]		
All other bands	B	C

[1] Equipment using single sideband J3E emission must the requirements of Emission Mask A. Equipment using other emissions must meet the requirements of Emission Mask B or C, as applicable.

[2] Equipment designed to operate with a 25 kHz channel bandwidth must meet the requirements of Emission Mask B or C, as applicable. Equipment designed to operate with a 12.5 kHz channel bandwidth must meet the requirements of Emission Mask D, and equipment designed to operate with a 6.25 kHz channel bandwidth Must meet the requirements of Emission Mask E.

[3] Equipment used in this licensed to EA or non-EA systems shall comply with the emission mask provisions of § 90.691.

[4] DSRCS Roadside Units equipment in the 5850–5925 MHz band is governed under subpart M of this part.

(a) *Emission Mask A.* For transmitters utilizing J3E emission, the carrier must be at least 40 dB below the peak envelope power and the power of emissions must be reduced below the output power (P in watts) of the transmitter as follows:

(1) On any frequency removed from the assigned frequency by more than 50 percent, but not more than 150 percent of the authorized bandwidth: At least 25 dB.

(2) On any frequency removed from the assigned frequency by more than 150 percent, but not more than 250 percent of the authorized bandwidth: At least 35 dB.

(3) On any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth: At least 43 + 10 log P dB.

(b) *Emission Mask B.* For transmitters that are equipped with an audio low-pass filter, the power of any emission must be attenuated below the unmodulated carrier power (P) as follows:

(1) On any frequency removed from the assigned frequency by more than 50 percent, but not more than 100 percent of the authorized bandwidth: At least 25 dB.

(2) On any frequency removed from the assigned frequency by more than 100 percent, but not more than 250 percent of the authorized bandwidth: At least 35 dB.

(3) On any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth: At least 43 + 10 log (P) dB.

(c) *Emission Mask C*. For transmitters that are not equipped with an audio low-pass filter, the power of any emission must be attenuated below the unmodulated carrier output power (P) as follows:

(1) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 5 kHz, but not more than 10 kHz: At least 83 log (f_d/5) dB;

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 10 kHz, but not more than 250 percent of the authorized bandwidth: At least 29 log (f_d^2/11) dB or 50 dB, whichever is the lesser attenuation;

(3) On any frequency removed from the center of the authorized bandwidth by more than 250 percent of the authorized bandwidth: At least 43 + 10 log (P) dB.

(d) *Emission Mask D—12.5 kHz channel bandwidth equipment*. For transmitters designed to operate with a 12.5 kHz channel bandwidth, any emission must be attenuated below the power (P) of the highest emission contained within the authorized bandwidth as follows:

(1) On any frequency from the center of the authorized bandwidth f_0 to 5.625 kHz removed from f_0: Zero dB.

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 5.625 kHz but no more than 12.5 kHz: At least 7.27(f_d − 2.88 kHz) dB.

(3) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 12.5 kHz: At least 50 + 10 log (P) dB or 70 dB, whichever is the lesser attenuation.

(4) The reference level for showing compliance with the emission mask shall be established using a resolution bandwidth sufficiently wide (usually two to three times the channel bandwidth) to capture the true peak emission of the equipment under test. In order to show compliance with the emissions mask up to and including 50 kHz removed from the edge of the authorized bandwidth, adjust the resolution bandwidth to 100 Hz with the measuring instrument in a peak hold mode. A sufficient number of sweeps must be measured to insure that the emission profile is developed. If video filtering is used, its bandwidth must not be less than the instrument resolution bandwidth. For emissions beyond 50 kHz from the edge of the authorized bandwidth, see paragraph (m) of this section. If it can be shown that use of the above instrumentation settings do not accurately represent the true interference potential of the equipment under test, then an alternate procedure may be used provided prior Commission approval is obtained.

(e) *Emission Mask E—6.25 kHz or less channel bandwidth equipment*. For transmitters designed to operate with a 6.25 kHz or less bandwidth, any emission must be attenuated below the power (P) of the highest emission contained within the authorized bandwidth as follows:

(1) On any frequency from the center of the authorized bandwidth f_0 to 3.0 kHz removed from f_0: Zero dB.

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 3.0 kHz but no more than 4.6 kHz: At least 30 + 16.67(f_d − 3 kHz) or 55 + 10 log (P) or 65 dB, whichever is the lesser attenuation.

(3) On any frequency removed from the center of the authorized bandwidth by more than 4.6 kHz: At least 55 + 10 log (P) or 65 dB, whichever is the lesser attenuation.

(4) The reference level for showing compliance with the emission mask shall be established using a resolution bandwidth sufficiently wide (usually two to three times the channel bandwidth) to capture the true peak emission of the equipment under test. In order to show compliance with the emissions mask up to and including 50 kHz removed from the edge of the authorized bandwidth, adjust the resolution bandwidth to 100 Hz with the measuring instrument in a peak hold mode. A sufficient number of sweeps must be measured to insure that the emission profile is developed. If video filtering is used, its bandwidth must not be less than the instrument resolution bandwidth. For emissions beyond 50 kHz from the edge of the authorized bandwidth, see paragraph (m) of this

section. If it can be shown that use of the above instrumentation settings do not accurately represent the true interference potential of the equipment under test, then an alternate procedure may be used provided prior Commission approval is obtained.

(f) *Emission Mask F.* For transmitters operating in the 220–222 MHz frequency band, any emission must be attenuated below the power (P) of the highest emission contained within the authorized bandwidth as follows:

(1) On any frequency from the center of the authorized bandwidth f_o to the edge of the authorized bandwidth f_e: Zero dB.

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 2 kHz up to and including 3.75 kHz: 30 + 20(f_d -2) dB or 55 + 10 log (P), or 65 dB, whichever is the lesser attenuation.

(3) On any frequency beyond 3.75 kHz removed from the center of the authorized bandwidth $f_{d\leq}$ At least 55 + 10 log (P) dB.

(g) *Emission Mask G.* For transmitters that are not equipped with an audio low-pass filter, the power of any emission must be attenuated below the unmodulated carrier power (P) as follows:

(1) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 5 kHz, but no more than 10 kHz: At least 83 log (f_d/5) dB;

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 10 kHz, but no more than 250 percent of the authorized bandwidth: At least 116 log (f_d/6.1) dB, or 50 + 10 log (P) dB, or 70 dB, whichever is the lesser attenuation;

(3) On any frequency removed from the center of the authorized bandwidth by more than 250 percent of the authorized bandwidth: At least 43 + 10 log (P) dB.

(h) *Emission Mask H.* For transmitters that are not equipped with an audio low-pass filter, the power of any emission must be attenuated below the unmodulated carrier power (P) as follows:

(1) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of 4 kHz or less: Zero dB.

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 4 kHz, but no more than 8.5 kHz: At least 107 log (f_d/4) dB;

(3) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 8.5 kHz, but no more than 15 kHz: At least 40.5 log (f_d/1.16) dB;

(4) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 15 kHz, but no more than 25 kHz: At least 116 log (f_d/6.1) dB;

(5) On any frequency removed from the center of the authorized bandwidth by more than 25 kHz: At least 43 + log (P) dB.

(i) *Emission Mask I.* For transmitters that are equipped with an audio low pass filter, the power of any emission must be attenuated below the unmodulated carrier power of the transmitter (P) as follows:

(1) On any frequency removed from the center of the authorized bandwidth by a displacement frequency of more than 6.8 kHz, but no more than 9.0 kHz: At least 25 dB;

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency of more than 9.0 kHz, but no more than 15 kHz: At least 35 dB;

(3) On any frequency removed from the center of the authorized bandwidth by a displacement frequency of more than 15 kHz: At least 43 + 10 log (P) dB, or 70 dB, whichever is the lesser attenuation.

(j) *Emission Mask J.* For transmitters that are not equipped with an audio low-pass filter, the power of any emission must be attenuated below the unmodulated carrier power of the transmitter (P) as follows:

(1) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 2.5 kHz, but no more than 6.25 kHz: At least 53 log (f_d/2.5) dB;

(2) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz)

of more than 6.25 kHz, but no more than 9.5 kHz: At least 103 log (f_d/3.9) dB;

(3) On any frequency removed from the center of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 9.5 kHz: At least 157 log (f_d/5.3) dB, or 50 + 10 log (P) dB or 70 dB, whichever is the lesser attenuation.

(k) *Emission Mask K*—(1) *Wideband multilateration transmitters*. For transmitters authorized under subpart M to provide forward or reverse links in a multilateration system in the subbands 904–909.75 MHz, 921.75–927.25 MHz and 919.75–921.75 MHz, and which transmit an emission occupying more than 50 kHz bandwidth: in any 100 kHz band, the center frequency of which is removed from the center of authorized sub-band(s) by more than 50 percent of the authorized bandwidth, the power of emissions shall be attenuated below the transmitter output power, as specified by the following equation, but in no case less than 31 dB:

A=16+0.4 (D−50)+10 log B (attenuation greater than 66 dB is not required)

Where:

A = attenuation (in decibels) below the maximum permitted output power level

D = displacement of the center frequency of the measurement bandwidth from the center frequency of the authorized sub-band, expressed as a percentage of the authorized bandwidth B

B = authorized bandwidth in megahertz.

(2) *Narrowband forward link transmitters*. For LMS multilateration narrowband forward link transmitters operating in the 927.25–928 MHz frequency band the power of any emission shall be attenuated below the transmitter output power (P) in accordance with following schedule:

On any frequency outside the authorized sub-band and removed from the edge of the authorized sub-band by a displacement frequency (f_d in kHz): at least 116 log ((f_d+10)/6.1) dB or 50 + 10 log (P) dB or 70 dB, whichever is the lesser attenuation.

(3) *Other transmitters*. For all other transmitters authorized under subpart M that operate in the 902–928 MHz band, the peak power of any emission shall be attenuated below the power of the highest emission contained within the licensee's sub-band in accordance with the following schedule:

(i) On any frequency within the authorized bandwidth: Zero dB.

(ii) On any frequency outside the licensee's sub-band edges: 55 + 10 log(P) dB, where (P) is the highest emission (watts) of the transmitter inside the licensee's sub-band.

(4) In the 902–928 MHz band, the resolution bandwidth of the instrumentation used to measure the emission power shall be 100 kHz, except that, in regard to paragraph (2) of this section, a minimum spectrum analyzer resolution bandwidth of 300 Hz shall be used for measurement center frequencies with 1 MHz of the edge of the authorized subband. The video filter bandwidth shall not be less than the resolution bandwidth.

(5) Emission power shall be measured in peak values.

(6) The LMS sub-band edges for non-multilateration systems for which emissions must be attenuated are 902.00, 904.00, 909.5 and 921.75 MHz.

(l) *Emission Mask L*. For low power transmitters (20 dBm or less) operating in the 4940–4990 MHz frequency band, the power spectral density of the emissions must be attenuated below the output power of the transmitter as follows:

(1) On any frequency removed from the assigned frequency between 0–45% of the authorized bandwidth (BW): 0 dB.

(2) On any frequency removed from the assigned frequency between 45–50% of the authorized bandwidth: 219 log (% of (BW)/45) dB.

(3) On any frequency removed from the assigned frequency between 50–55% of the authorized bandwidth: 10 + 242 log (% of (BW)/50) dB.

(4) On any frequency removed from the assigned frequency between 55–100% of the authorized bandwidth: 20 + 31 log (% of (BW)/55) dB attenuation.

(5) On any frequency removed from the assigned frequency between 100–150% of the authorized bandwidth: 28 + 68 log (% of (BW)/100) dB attenuation.

(6) On any frequency removed from the assigned frequency above 150% of the authorized bandwidth: 50 dB.

(7) The zero dB reference is measured relative to the highest average power of the fundamental emission measured

across the designated channel bandwidth using a resolution bandwidth of at least one percent of the occupied bandwidth of the fundamental emission and a video bandwidth of 30 kHz. The power spectral density is the power measured within the resolution bandwidth of the measurement device divided by the resolution bandwidth of the measurement device. Emission levels are also based on the use of measurement instrumentation employing a resolution bandwidth of at least one percent of the occupied bandwidth.

(m) *Emission Mask M.* For high power transmitters (greater that 20 dBm) operating in the 4940–4990 MHz frequency band, the power spectral density of the emissions must be attenuated below the output power of the transmitter as follows:

(1) On any frequency removed from the assigned frequency between 0–45% of the authorized bandwidth (BW): 0 dB.

(2) On any frequency removed from the assigned frequency between 45–50% of the authorized bandwidth: 568 log (% of (BW)/45) dB.

(3) On any frequency removed from the assigned frequency between 50–55% of the authorized bandwidth: 26 + 145 log (% of BW/50) dB.

(4) On any frequency removed from the assigned frequency between 55–100% of the authorized bandwidth: 32 + 31 log (% of (BW)/55) dB.

(5) On any frequency removed from the assigned frequency between 100–150% of the authorized bandwidth: 40 + 57 log (% of (BW)/100) dB.

(6) On any frequency removed from the assigned frequency between above 150% of the authorized bandwidth: 50 dB or 55 + 10 log (P) dB, whichever is the lesser attenuation.

(7) The zero dB reference is measured relative to the highest average power of the fundamental emission measured across the designated channel bandwidth using a resolution bandwidth of at least one percent of the occupied bandwidth of the fundamental emission and a video bandwidth of 30 kHz. The power spectral density is the power measured within the resolution bandwidth of the measurement device divided by the resolution bandwidth of the measurement device. Emission levels are also based on the use of measurement instrumentation employing a resolution bandwidth of at least one percent of the occupied bandwidth.

NOTE TO PARAGRAPH m: Low power devices may as an option, comply with paragraph (m).

(n) *Other frequency bands.* Transmitters designed for operation under this part on frequencies other than listed in this section must meet the emission mask requirements of Emission Mask B. Equipment operating under this part on frequencies allocated to but shared with the Federal Government, must meet the applicable Federal Government technical standards.

(o) *Instrumentation.* The reference level for showing compliance with the emission mask shall be established, except as indicated in §§ 90.210 (d), (e), and (k), using standard engineering practices for the modulation characteristic used by the equipment under test. When measuring emissions in the 150–174 MHz and 421–512 MHz the following procedures will apply. A sufficient number of sweeps must be measured to insure that the emission profile is developed. If video filtering is used, its bandwidth must not be less than the instrument resolution bandwidth. For frequencies more than 50 kHz removed from the edge of the authorized bandwidth a resolution of at least 10 kHz must be used for frequencies below 1000 MHz. Above 1000 MHz the resolution bandwidth of the instrumentation must be at least 1 MHz. If it can be shown that use of the above instrumentation settings do not accurately represent the true interference potential of the equipment under test, then an alternate procedure may be used provided prior Commission approval is obtained.

[60 FR 37264, July 19, 1995, as amended at 61 FR 4235, Feb. 5, 1996; 61 FR 6155, Feb. 16, 1996; 61 FR 18986, Apr. 30, 1996; 62 FR 41214, July 31, 1997; 62 FR 52044, Oct. 6, 1997; 64 FR 66409, Nov. 26, 1999; 67 FR 63288, Oct. 11, 2002; 68 FR 38639, June 30, 2003; 69 FR 46443, Aug. 3, 2004; 69 FR 67838, Nov. 22, 2004; 70 FR 28466, May 18, 2005] controlling interests, has average gross revenues not to exceed $15 million for the preceding three years.

(2) A very small business is an entity that, together with its affiliates and controlling interests, has average gross revenues not to exceed $3 million for the preceding three years.

(c) A winning bidder that qualifies as a small business, as defined in paragraph (b)(1) of this section, or a consortium of small businesses may use the bidding credit specified in § 1.2110(f)(2)(ii) of this chapter. A winning bidder that qualifies as a very small businesses, as defined in paragraph (b)(2) of this section, or a consortium of very small businesses may use the bidding credit specified in § 1.2110(f)(2)(i) of this chapter.

[63 FR 40664, July 30, 1998, as amended at 67 FR 45379, July 9, 2002; 68 FR 43001, July 21, 2003]

Subpart Y—Regulations Governing Licensing and Use of Frequencies in the 4940–4990 MHz Band

SOURCE: 68 FR 38639, June 30, 2003, unless otherwise noted.

§ 90.1201 Scope.

This subpart sets out the regulations governing use of the 4940–4990 MHz (4.9 GHz) band. It includes eligibility requirements, and specific operational and technical standards for stations licensed in this band. The rules in this subpart are to be read in conjunction with the applicable requirements contained elsewhere in this part; however, in case of conflict, the provisions of this subpart shall govern with respect to licensing and operation in this band.

§ 90.1203 Eligibility.

(a) Entities providing public safety services as defined under section 90.523 are eligible to hold a Commission license for systems operating in the 4940–4990 MHz band. All of the requirements and conditions set forth in that section also govern authorizations in the 4940–4990 MHz band.

(b) 4.9 GHz band licensees may enter into sharing agreements or other arrangements for use of the spectrum with entities that do not meet these eligibility requirements. However, all applications in the band are limited to operations in support of public safety.

§ 90.1205 Permissible operations.

(a) Unattended and continuous operation is permitted.

(b) Voice, data and video operations are permitted.

(c) Aeronautical mobile operations are prohibited.

§ 90.1207 Licensing.

(a) A 4940–4990 MHz band license gives the licensee authority to operate on any authorized channel in this band within its licensed area of operation. *See* § 90.1213. A 4940–4990 MHz band license will be issued for the geographic area encompassing the legal jurisdiction of the licensee or, in case of a non-governmental organization, the legal jurisdiction of the state or local governmental entity supporting the non-governmental organization.

(b) Subject to § 90.1209, a 4940–4990 MHz band license gives the licensee authority to construct and operate any number of base stations anywhere within the area authorized by the license, except as follows:

(1) A station is required to be individually licensed if:

(i) International agreements require coordination;

(ii) Submission of an environmental assessment is required under § 1.1307 of this chapter; or

(iii) The station would affect areas identified in § 1.924 of this chapter.

(2) Any antenna structure that requires notification to the Federal Aviation Administration (FAA) must be registered with the Commission prior to construction under § 17.4 of this chapter.

(c) A 4940–4990 MHz band license gives the licensee authority to operate base and mobile units (including portable and handheld units) and operate temporary (1 year or less) fixed stations anywhere within the area authorized by the license. Such licensees may operate base and mobile units and/or temporary fixed stations outside their authorized area to assist public safety operations with the permission of the jurisdiction in which the radio station is to be operated. Base and temporary fixed stations are subject to the requirements of paragraph (b) of this section.

(d) A 4940–4990 MHz band license does not give the licensee authority to operate permanent fixed point-to-point stations. Licensees choosing to operate such fixed stations must license them individually on a site-by-site basis. Such fixed operation will be authorized only on a secondary, non-interference basis to base, mobile and temporary fixed operations.

[68 FR 38639, June 30, 2003, as amended at 69 FR 17959, Apr. 6, 2004]

§ 90.1209 Policies governing the use of the 4940–4990 MHz band.

(a) Channels in this band are available on a shared basis only and will not be assigned for the exclusive use of any licensee.

(b) All licensees shall cooperate in the selection and use of channels in order to reduce interference and make the most effective use of the authorized facilities. Licensees of stations suffering or causing harmful interference are expected to cooperate and resolve this problem by mutually satisfactory arrangements. If licensees are unable to do so, the Commission may impose restrictions including specifying the transmitter power, antenna height, or area or hours of operation of the stations concerned. Further, the Commission may prohibit the use of any 4.9 GHz channel under a system license at a given geographical location when, in the judgment of the Commission, its use in that location is not in the public interest.

(c) Licensees will make every practical effort to protect radio astronomy operations as specified in § 2.106, footnote US311 of this chapter.

(d) There is no time limit for which base and temporary fixed stations authorized under a 4940–4990 MHz band license must be placed in operation. Fixed point-to-point stations which are licensed on a site-by-site basis must be placed in operation within 18 months of the grant date or the authorization for that station cancels automatically.

§ 90.1211 Regional plan.

(a) To facilitate the shared use of the 4.9 GHz band, each region may submit a plan on guidelines to be used for sharing the spectrum within the region. Any such plan must be submitted to the Commission within 12 months of the effective date of the rules.

(b) Such plans must incorporate the following common elements:

(1) Identification of the document as a plan for sharing the 4.9 GHz band with the region specified along with the names, business addresses, business telephone numbers and organizational affiliations of the chairperson(s) and all members of the planning committee.

(2) A summary of the major elements of the plan and an explanation of how all eligible entities within the region were given an opportunity to participate in the planning process and to have their positions heard and considered fairly.

(3) An explanation of how the plan was coordinated with adjacent regions.

(4) A description of the coordination procedures for both temporary fixed and mobile operations, including but not limited to, mechanisms for incident management protocols, interference avoidance and interoperability.

(c) Regional plans may be modified by submitting a written request, signed by the regional planning committee, to the Chief, Wireless Telecommunications Bureau. The request must contain the full text of the modification, and a certification that all eligible entities had a chance to participate in discussions concerning the modification and that any changes have been coordinated with adjacent regions.

EFFECTIVE DATE NOTE: At 69 FR 51959, Sept. 23, 2004, paragraph (a) of § 90.1211 was stayed indefinitely.

§ 90.1213 Band plan.

The following channel center frequencies are permitted to be aggregated for channel bandwidths of 5, 10, 15 or 20 MHz. Channel numbers 1 through 5 and 15 through 18 are 1 MHz channels and channels numbers 6 through 14 are 5 MHz channels.

Center frequency (MHz)	Channel Nos.
4940.5	1
4941.5	2
4942.5	3
4943.5	4
4944.5	5
4947.5	6
4952.5	7
4957.5	8
4962.5	9
4967.5	10
4972.5	11
4977.5	12
4982.5	13
4985.5	14
4986.5	15
4987.5	16
4988.5	17
4989.5	18

§ 90.1215 Power limits.

The transmitting power of stations operating in the 4940–4990 MHz band must not exceed the maximum limits in this section.

(a) The peak transmit power should not exceed:

Channel bandwidth (MHz)	Peak transmitter power (dBm)
1	20
5	27
10	30
15	31.8
20	33

Devices are also limited to a peak power spectral density of 20 dBm per 1 MHz. Devices using channel bandwidths other than those listed above are permitted; however, they are limited to a peak power spectral density of 20 dBm/MHz. If transmitting antennas of directional gain greater than 9 dBi are used, both the peak transmit power and the peak power spectral density should be reduced by the amount in decibels that the directional gain of the antenna exceeds 9 dBi. However, point-to-point or point-to-multipoint operation (both fixed and temporary-fixed rapid deployment) may employ transmitting antennas with directional gain up to 26 dBi without any corresponding reduction in the transmitter power or spectral density. Corresponding reduction in the peak transmit power and peak power spectral density should be the amount in decibels that the directional gain of the antenna exceeds 26 dBi.

(b) The peak transmit power is measured as a conducted emission over any interval of continuous transmission calibrated in terms of an rms-equivalent voltage. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. The measurement results shall be properly adjusted for any instrument limitations, such as detector response times, limited resolution bandwidth capability when compared to the emission bandwidth, sensitivity, etc., so as to obtain a true peak measurement conforming to the definitions in this paragraph for the emission in question.

(c) The peak power spectral density is measured as a conducted emission by direct connection of a calibrated test instrument to the equipment under test. If the device cannot be connected directly, alternative techniques acceptable to the Commission may be used. Measurements are made over a bandwidth of 1 MHz or the 26 dB emission bandwidth of the device, whichever is less. A resolution bandwidth less than the measurement bandwidth can be used, provided that the measured power is integrated to show total power over the measurement bandwidth. If the resolution bandwidth is approximately equal to the measurement bandwidth, and much less than the emission bandwidth of the equipment under test, the measured results shall be corrected to account for any difference between the resolution bandwidth of the test instrument and its actual noise bandwidth.

§ 90.1217 RF Hazards.

Licensees and manufacturers are subject to the radiofrequency radiation exposure requirements specified in §§ 1.1307(b), 2.1091 and 2.1093 of this chapter, as appropriate. Applications for equipment authorization of mobile or portable devices operating under this section must contain a statement confirming compliance with these requirements for both fundamental emissions and unwanted emissions. Technical information showing the basis for this statement must be submitted to the Commission upon request.

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shall be accompanied by a statement signed by the applicant in which it is agreed that any authorization issued pursuant thereto will be accepted with the express understanding of the applicant that it is subject to change in any of its terms or to cancellation in its entirety at any time, upon reasonable notice but without a hearing, if, in the opinion of the Commission, circumstances should so require.

§ 90.517 Report of operation.

A report on the results of a developmental program shall be filed with and made a part of each application for renewal of authorization. In cases where no renewal is requested, such report shall be filed within 60 days of the expiration of such authorization. Matters which the applicant does not wish to disclose publicly may be so labeled; they will be used solely for the Commission's information, and will not be publicly disclosed without permission of the applicant. The report shall include comprehensive and detailed information on:

(a) The final objective.

(b) Results of operation to date.

(c) Analysis of the results obtained.

(d) Copies of any published reports.

(e) Need for continuation of the program.

(f) Number of hours of operation on each frequency.

This report is not required if the sole reason for the developmental authorization is that the frequency of operation is restricted to developmental use only.

Subpart R—Regulations Governing the Licensing and Use of Frequencies in the 764–776 and 794–806 MHz Bands

SOURCE: 63 FR 58651, Nov. 2, 1998, unless otherwise noted.

§ 90.521 Scope.

This subpart sets forth the regulations governing the licensing and operations of all systems operating in the 764–776 MHz and 794–806 MHz frequency bands. It includes eligibility, operational, planning and licensing requirements and technical standards for stations licensed in these bands. The rules in this subpart are to be read in conjunction with the applicable requirements contained elsewhere in this part; however, in case of conflict, the provisions of this subpart shall govern with respect to licensing and operation in these frequency bands.

§ 90.523 Eligibility.

This section implements the definition of public safety services contained in 47 U.S.C. § 337(f)(1). The following are eligible to hold Commission authorizations for systems operating in the 764–776 MHz and 794–806 MHz frequency bands:

(a) *State or local government entities.* Any territory, possession, state, city, county, town, or similar State or local governmental entity is eligible to hold authorizations in the 764–776 MHz and 794–806 MHz frequency bands.

(b) *Nongovernmental organizations.* A nongovernmental organization (NGO) that provides services, the sole or principal purpose of which is to protect the safety of life, health, or property, is eligible to hold an authorization for a system operating in the 764–776 MHz and 794–806 MHz frequency bands for transmission or reception of communications essential to providing such services if (and only for so long as) the NGO applicant/licensee:

(1) Has the ongoing support (to operate such system) of a state or local governmental entity whose mission is the oversight of or provision of services, the sole or principal purpose of which is to protect the safety of life, health, or property;

(2) Operates such authorized system solely for transmission of communication essential to providing services the sole or principal purpose of which is to protect the safety of life, health, or property; and

(3) All applications submitted by NGOs must be accompanied by a new, written certification of support (for the NGO applicant to operate the applied-for system) by the state or local governmental entity referenced in paragraph (b)(1) of this section.

(c) *All NGO authorizations are conditional.* NGOs assume all risks associated with operating under conditional authority. Authorizations issued to

NGOs to operate systems in the 764–776 MHz and 794–806 MHz frequency bands include the following condition: If at any time the supporting governmental entity (see paragraph (b)(1)) notifies the Commission in writing of such governmental entity's termination of its authorization of a NGO's operation of a system in the 764–776 MHz and 794–806 MHz frequency bands, the NGO's application shall be dismissed automatically or, if authorized by the Commission, the NGO's authorization shall terminate automatically.

(d) Paragraphs (a) and (b) notwithstanding, no entity is eligible to hold an authorization for a system operating in the 764–776 MHz and 794–806 MHz frequency bands on the basis of services, the sole or principal purpose of which is to protect the safety of life, health or property, that such entity makes commercially available to the public.

[63 FR 58651, Nov. 2, 1998, as amended at 65 FR 53645, Sept. 5, 2000]

§ 90.525 Administration of Interoperability channels

(a) States are responsible for administration of the Interoperability channels in the 764–776 MHz and 794–806 MHz frequency bands. Base and control stations must be licensed individually. A public safety entity meeting the requirements of § 90.523 may operate mobile or portable units on the Interoperability channels in the 764–776 MHz and 794–806 MHz frequency bands without a specific authorization from the Commission provided it holds a part 90 license. All persons operating mobile or portable units under this authority are responsible for compliance with part 90 of these rules and other applicable federal laws.

(b) License applications for Interoperability channels in the 764–776 MHz and 794–806 MHz frequency bands must be approved by a state-level agency or organization responsible for administering state emergency communications. States may hold the licenses for Interoperability channels or approve other qualified entities to hold such licenses. States may delegate the approval process for Interoperability channels to another entity, such as regional planning committees.

[66 FR 10635, Feb. 16, 2001]

§ 90.527 Regional plan requirements.

Each regional planning committee must submit a regional plan for approval by the Commission.

(a) *Common elements.* Regional plans must incorporate the following common elements:

(1) Identification of the document as the regional plan for the defined region with the names, business addresses, business telephone numbers, and organizational affiliations of the chairpersons and all members of the planning committee.

(2) A summary of the major elements of the plan and an explanation of how all eligible entities within the region were given an opportunity to participate in the planning process and to have their positions heard and considered fairly.

(3) A general description of how the spectrum would be allotted among the various eligible users within the region with an explanation of how the requirements of all eligible entities within the region were considered and, to the degree possible, met.

(4) An explanation as to how needs were assigned priorities in areas where not all eligible entities could receive licenses.

(5) An explanation of how the plan had been coordinated with adjacent regions.

(6) A detailed description of how the plan put the spectrum to the best possible use by requiring system design with minimum coverage areas, by assigning frequencies so that maximum frequency reuse and offset channel use may be made, by using trunking, and by requiring small entities with minimal requirements to join together in using a single system where possible.

(7) A detailed description of the future planning process, including, but not limited to, amendment process, meeting announcements, data base maintenance, and dispute resolution.

(8) A certification by the regional planning chairperson that all planning committee meetings, including subcommittee or executive committee meetings, were open to the public.