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# Colorado 4.9 GHz Project

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Lead Agency:

**Parker Fire Protection District**

10795 South Pine Drive

Parker, CO 80138

(303) 841-8783 Business

(303) 841-5961 FAX

<http://www.parkerfire.org>

Parker Fire Project Manager: Cheryl Poage

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# Colorado 4.9 GHz Project

## 1.0 Executive Summary

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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.<sup>1</sup>

- 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.

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<sup>1</sup>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**

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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.

<b>Table 3 - FCC EIRP Limits at 4.9 GHz (Directional Antennas)</b>		
<b>Channel Bandwidth</b>	<b>Low Power Device (FCC L Mask)</b>	<b>High Power Device (FCC M Mask)</b>
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.

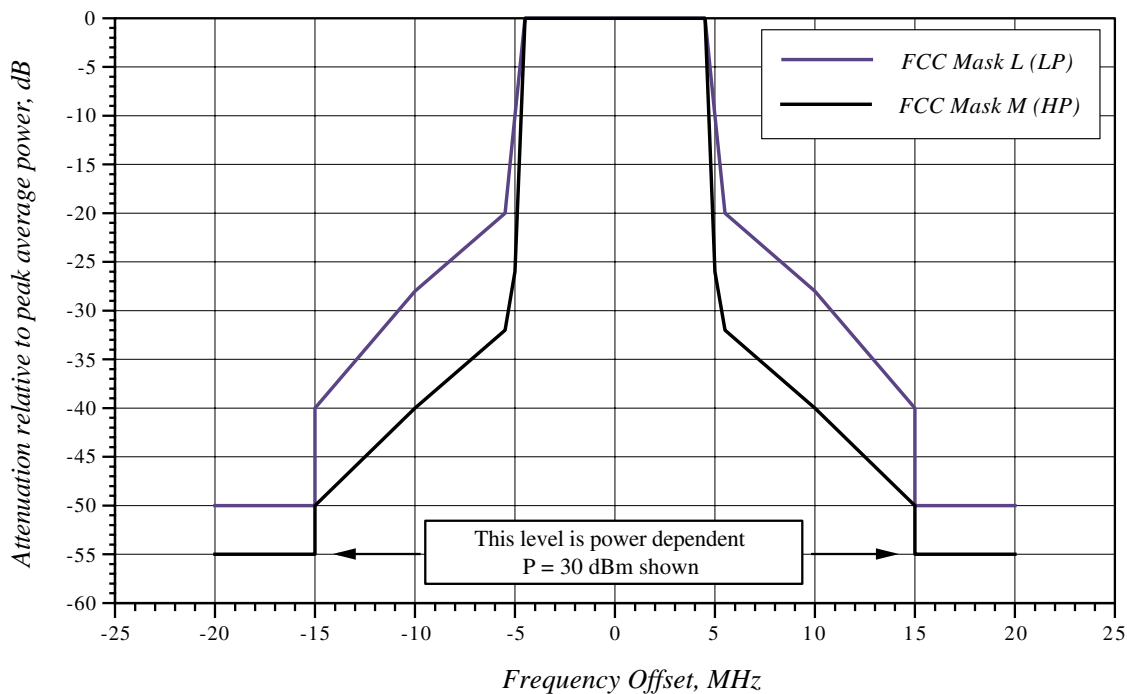


Figure 1 - FCC 10 MHz Emission Masks  
(Masks scale proportionately for 5 MHz and 20 MHz channels)

#### 4.0 Radio Propagation at 4.9 GHz

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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

$$F_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}, \quad (1)$$

where  $\lambda$  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]:

$$P_r = \frac{EIRP G_r \lambda^2}{(4\pi r)^2}, \quad (2)$$

where EIRP is the effective isotropic radiated power,  $G_r$  is the receive antenna gain (relative to isotropic),  $\lambda$  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

$$L_{fs} = \frac{(4\pi r)^2}{\lambda^2} \quad (3)$$

Or, in decibels,

$$L_{fs} = 21.98 + 20 \log_{10} \left( \frac{r}{\lambda} \right) \quad (4)$$

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

$$L_{max} = EIRP + G_r - P_{th} \quad (5)$$

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.

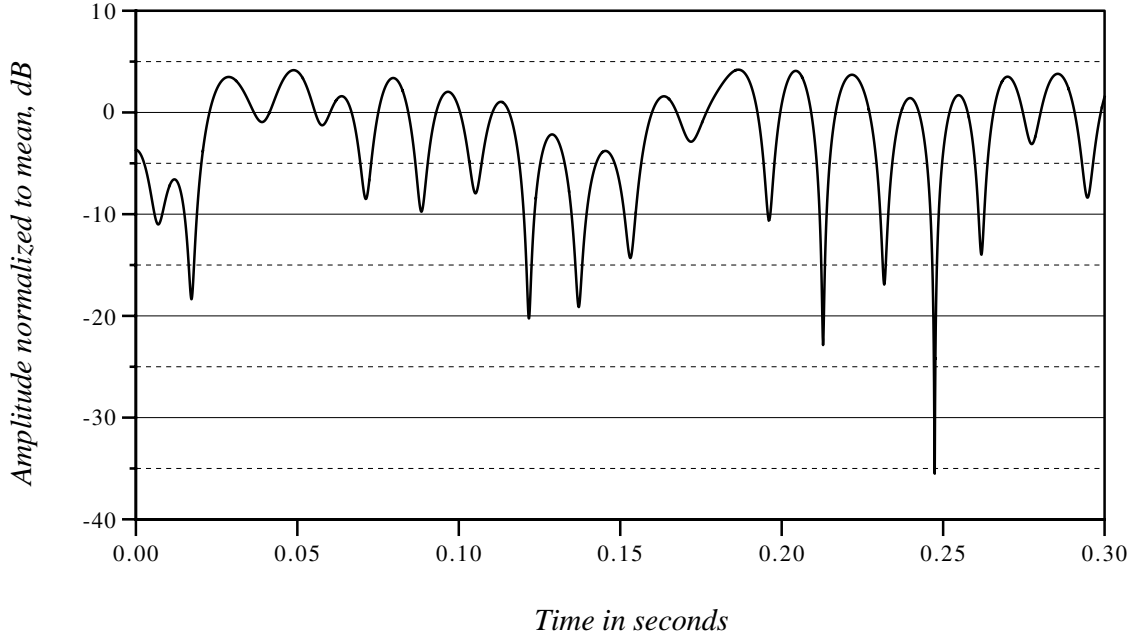


Figure 2 - Time-Varying Amplitude on Rayleigh Fading Channel  
( $V = 5$  mph,  $f_c = 4950$  MHz)

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,

$$f_Y(y) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{(y-\mu)^2}{2\sigma^2}} \quad (6)$$

where  $\mu$  is the mean, and  
 $\sigma$  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  $40\lambda$  (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

$$S = \left[ \frac{\sum_{k=1}^N (t_k - d)^2 P(t_k)}{\sum_{k=1}^N P(t_k)} \right]^{1/2} \quad (7)$$

where

$$d = \text{mean delay} = \frac{\sum_{k=1}^N t_k P(t_k)}{\sum_{k=1}^N P(t_k)} \quad (8)$$

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.<sup>2</sup> 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)

<sup>2</sup>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.<sup>3</sup>

<b>Table 5 - IEEE 802.11j Rate Dependent Parameters</b> (Required S/N Assumes Static Conditions)				
<b>Modulation</b>	<b>Code Rate</b>	<b>Required S/N, dB</b>	<b>10 MHz Channel Data Rate (Mbps)</b>	<b>20 MHz Channel Data Rate (Mbps)</b>
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

<sup>3</sup>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 ( $\mu\text{s}$ ). Although this level of performance is helpful, outdoor delay spreads in this band have been measured above 2.0  $\mu\text{s}$ . Thus, the delay spread robustness realized by using the 10 MHz channel (1.6  $\mu\text{s}$ ) 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

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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.



- 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.<sup>4</sup> 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.<sup>5</sup> 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.<sup>6</sup> 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.

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<sup>4</sup>RSSI = Received Signal Strength Indicator. It is normally defined as signal level, not a signal-to-noise ratio.

<sup>5</sup>The register labeled “noise” has a value of -100 dBm and it never changes. It was ignored.

<sup>6</sup>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  $T=290^\circ\text{K}$ . The factor of 70 dB is  $10\log(10,000,000)$  and assumes a 10 MHz equivalent noise bandwidth.

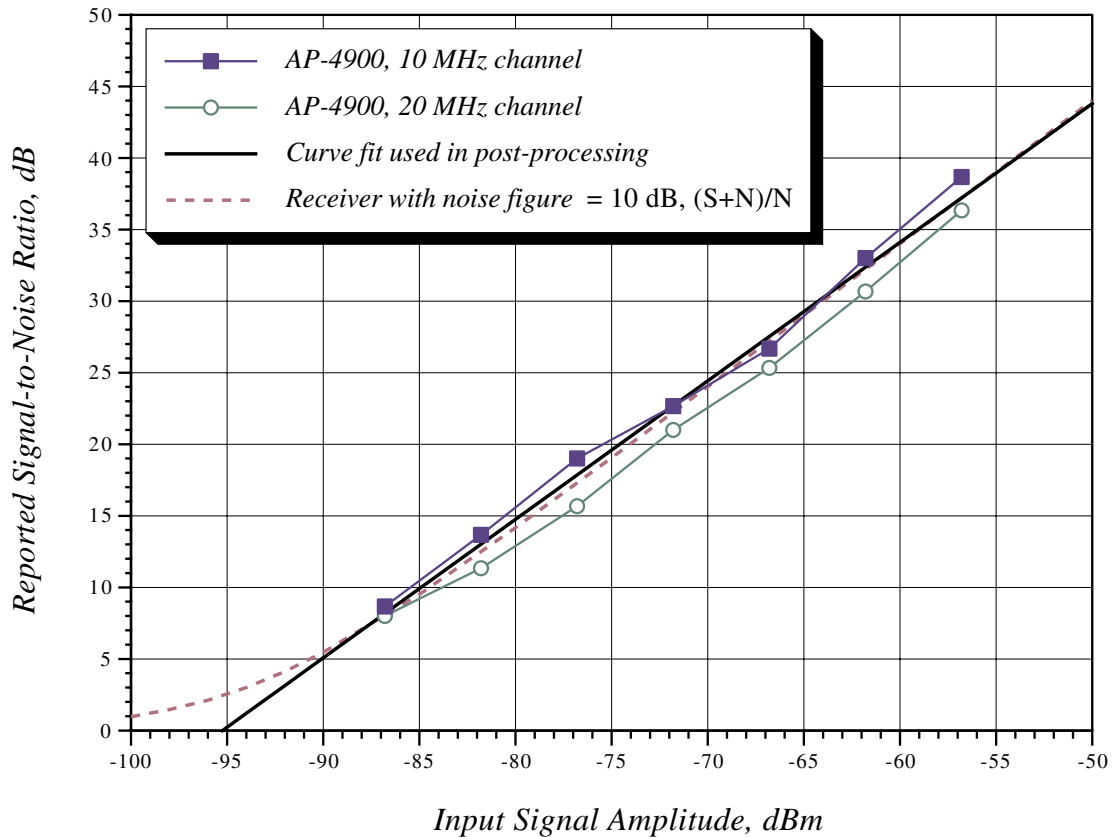


Figure 4 - Signal Level in dBm Versus Reported RSSI from AP-4900 (Static conditions)

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.

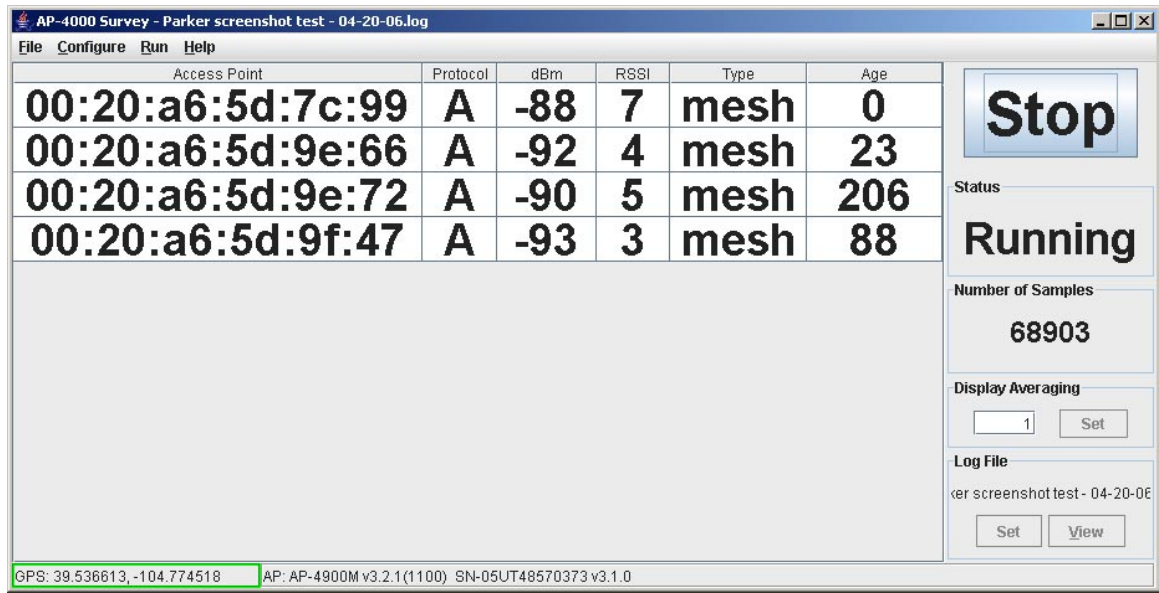


Figure 7 - Screen Shot of Survey Software Window

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 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 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.

<b>Table 6 - EIRP, Sensitivity &amp; Maximum Path Loss (Typical)</b> (Effective Gain of Mobile Omni Antenna = 7.3 dBi, Sector Antenna = 14.9 dBi)					
<b>Forward Link (Fixed to Mobile)</b>	<b>EIRP</b>	<b>10 MHz Channel</b>		<b>20 MHz Channel</b>	
		<b>Sensitivity</b>	<b>Maximum Path Loss</b>	<b>Sensitivity</b>	<b>Maximum Path Loss</b>
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
<b>Reverse Link (Mobile to Fixed)</b>	<b>EIRP</b>	<b>10 MHz Channel</b>		<b>20 MHz Channel</b>	
		<b>Sensitivity</b>	<b>Maximum Path Loss</b>	<b>Sensitivity</b>	<b>Maximum Path Loss</b>
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.

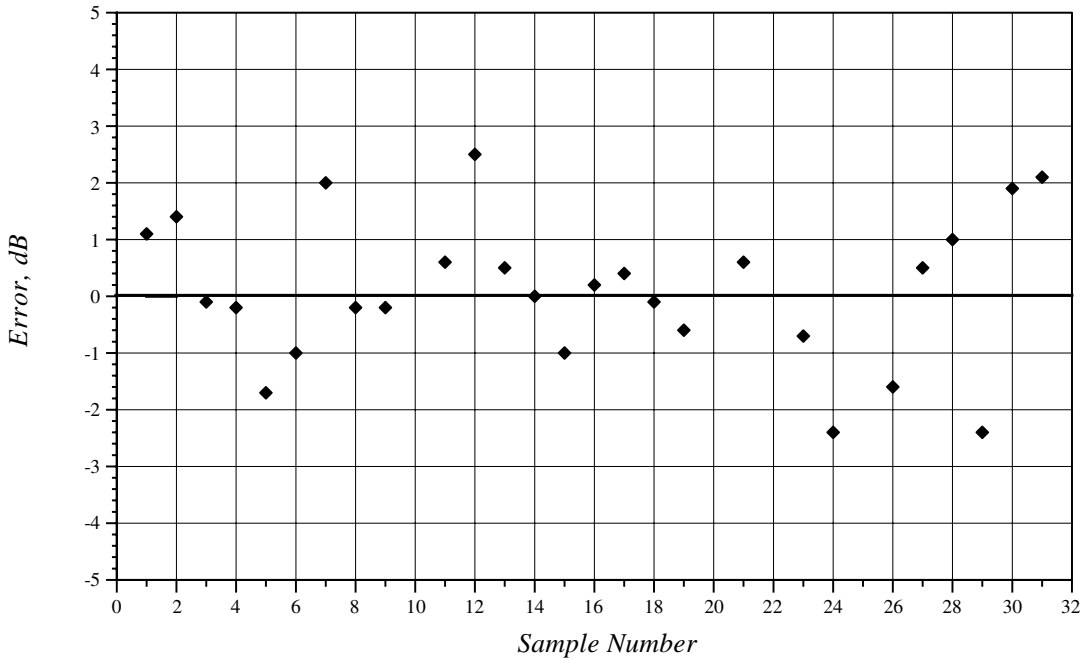


Figure 8 - Antenna Calibration Results (0=mfr. spec.)  
(Mean Error = 0.1 dB, Standard Deviation = 1.3 dB)

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.

<b>Table 7 - Legend for Coverage Maps (10 MHz Channel)</b>			
<b>Color</b>	<b>S/N Range</b>	<b>Nominal Throughput</b>	<b>Comment</b>
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

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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.

<b>Table 8 - Urban Area Drive Tests</b> (O=Fixed AP Omni, P=Fixed AP Panel)						
<b>Test</b>	<b>Date</b>	<b>Fixed AP Antenna</b>	<b>AP Location</b>	<b>BDA?</b>	<b>Latitude</b>	<b>Longitude</b>
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.

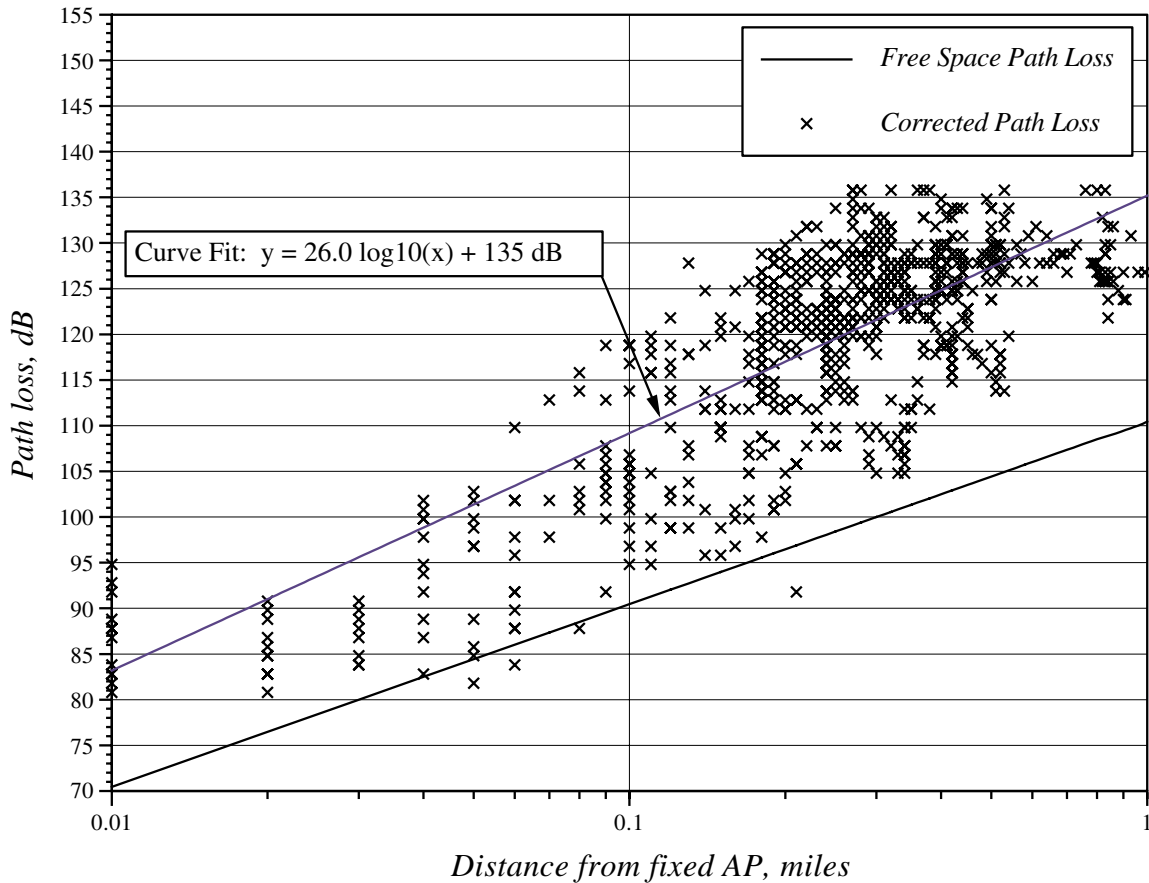


Figure 11- Path Loss Versus Distance for Test 105  
(Downtown Denver, Omni TX & RX Antennas, BDA at Each End)

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.

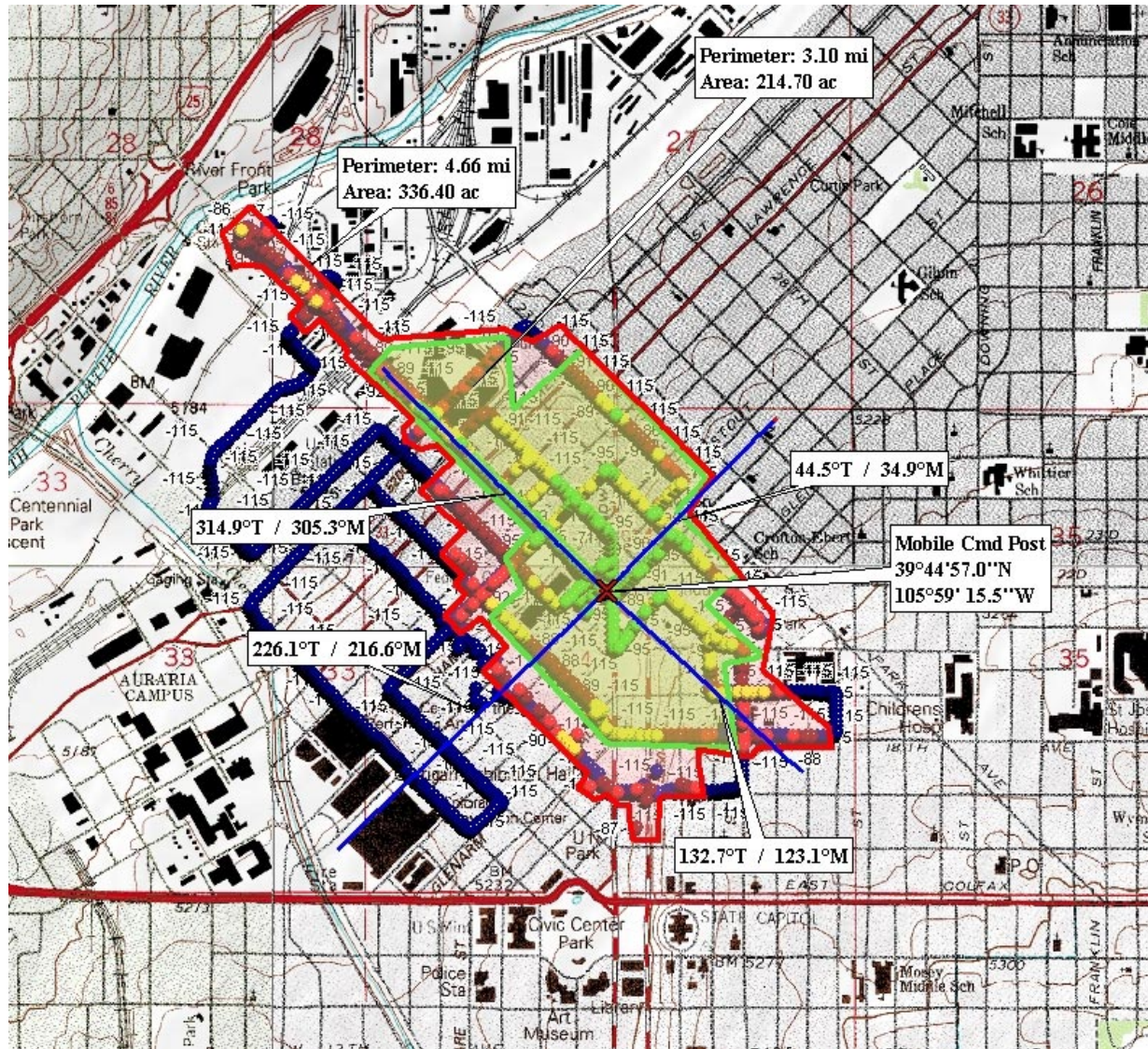


Figure 12 - Downtown Denver Coverage, Test 105 Omnidirectional, Legend in Table 7  
 (Note Difference Between Standard AP (Green Shading) and BDA Coverage)

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](http://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.

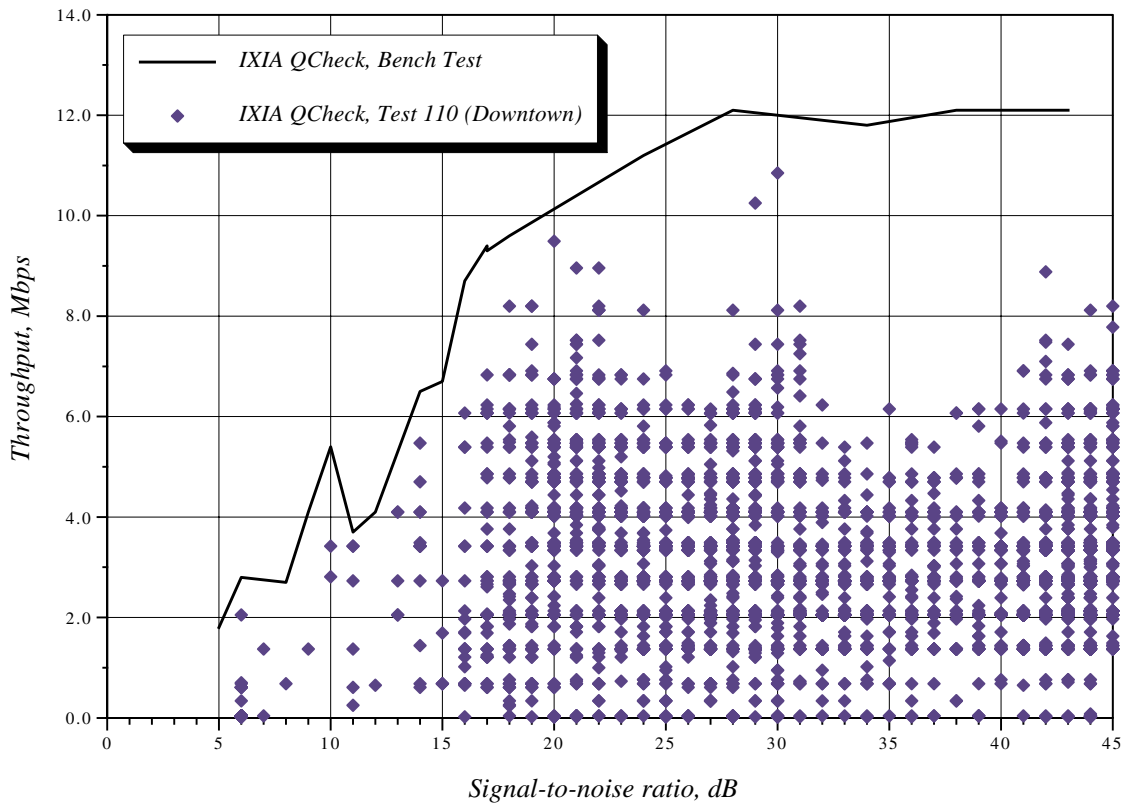


Figure 13 - Transport Layer Throughput, AP-4900, 10 MHz Channel

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.

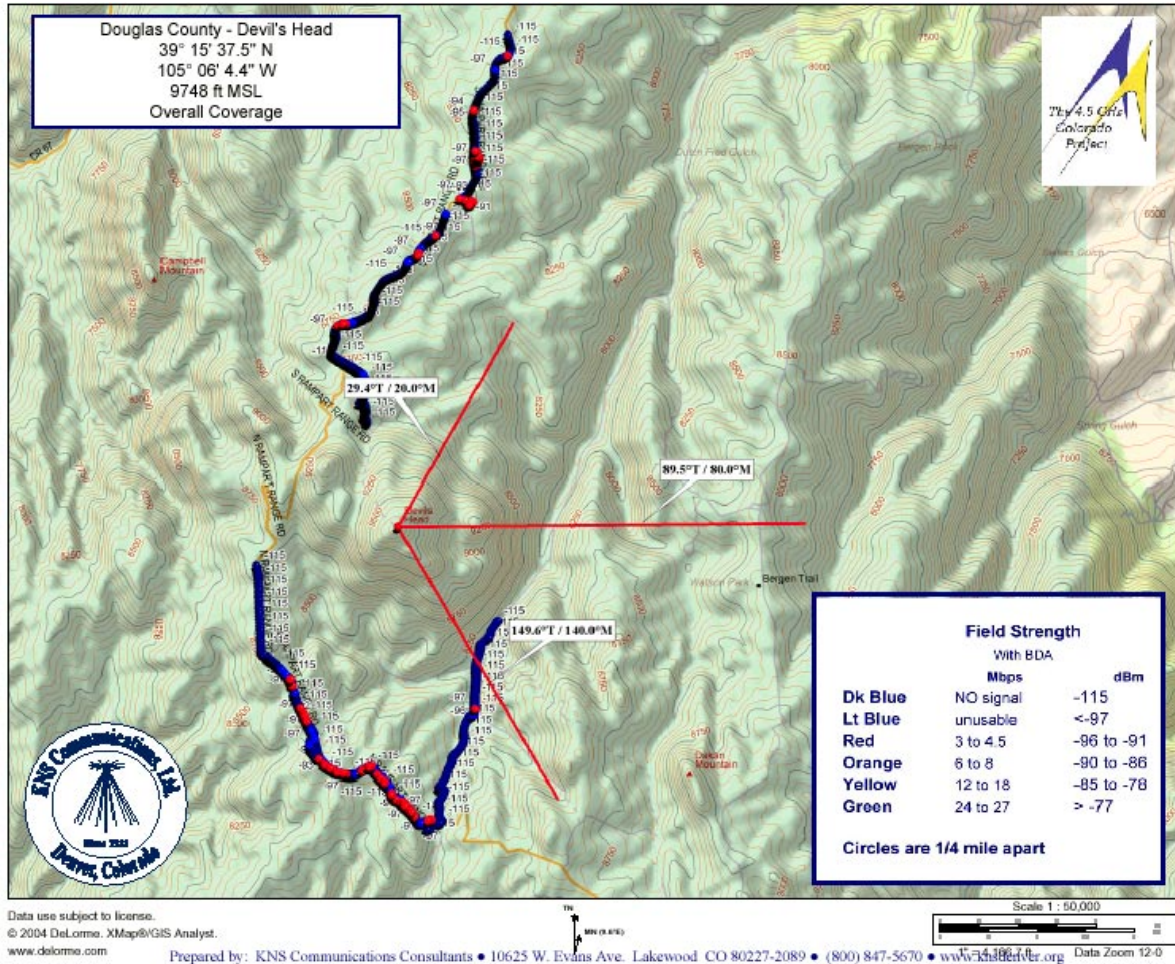


Figure 16 - Devil's Head Coverage (EIRP = 31 dBm)

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.

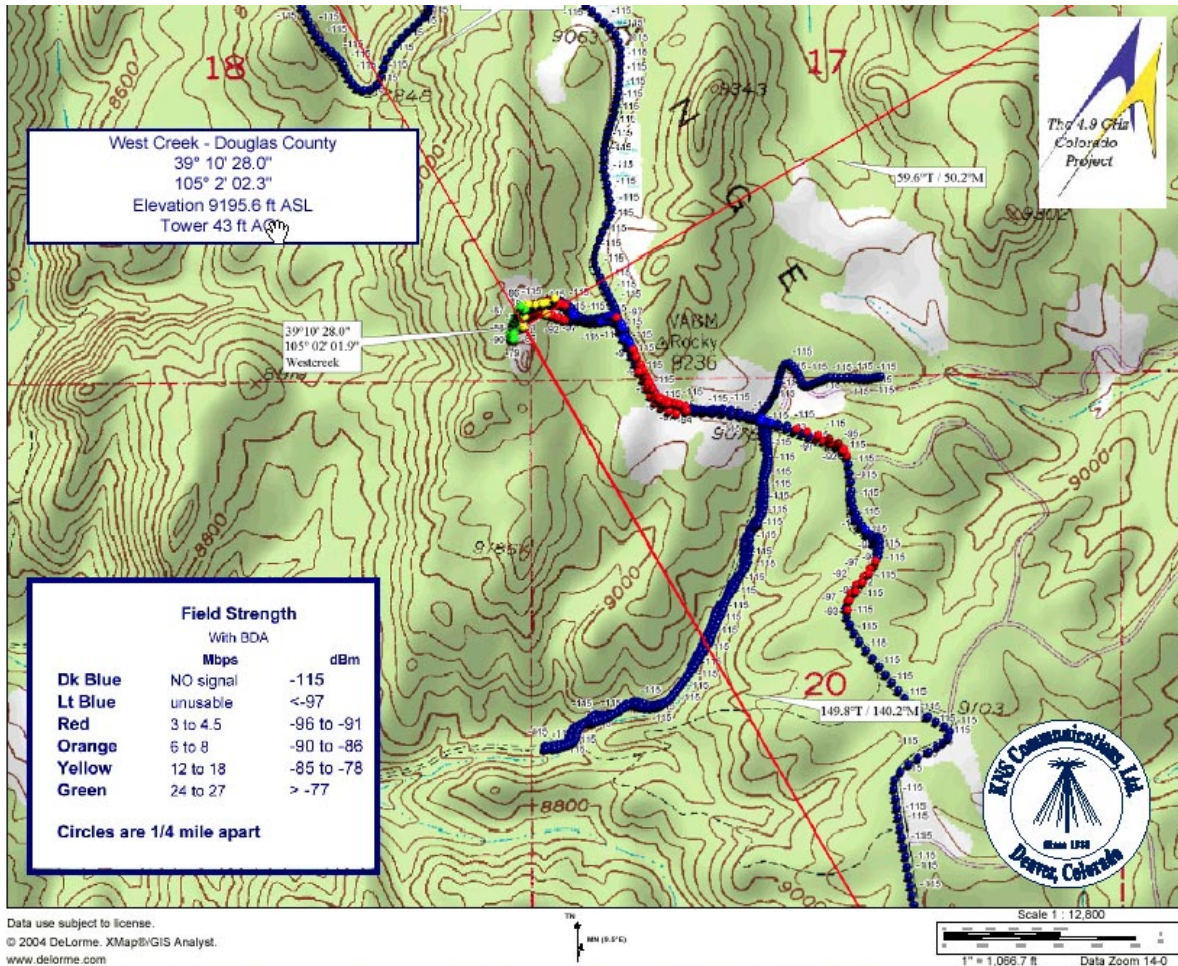


Figure 19 - West Creek Coverage (EIRP = 31 dBm)

**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.

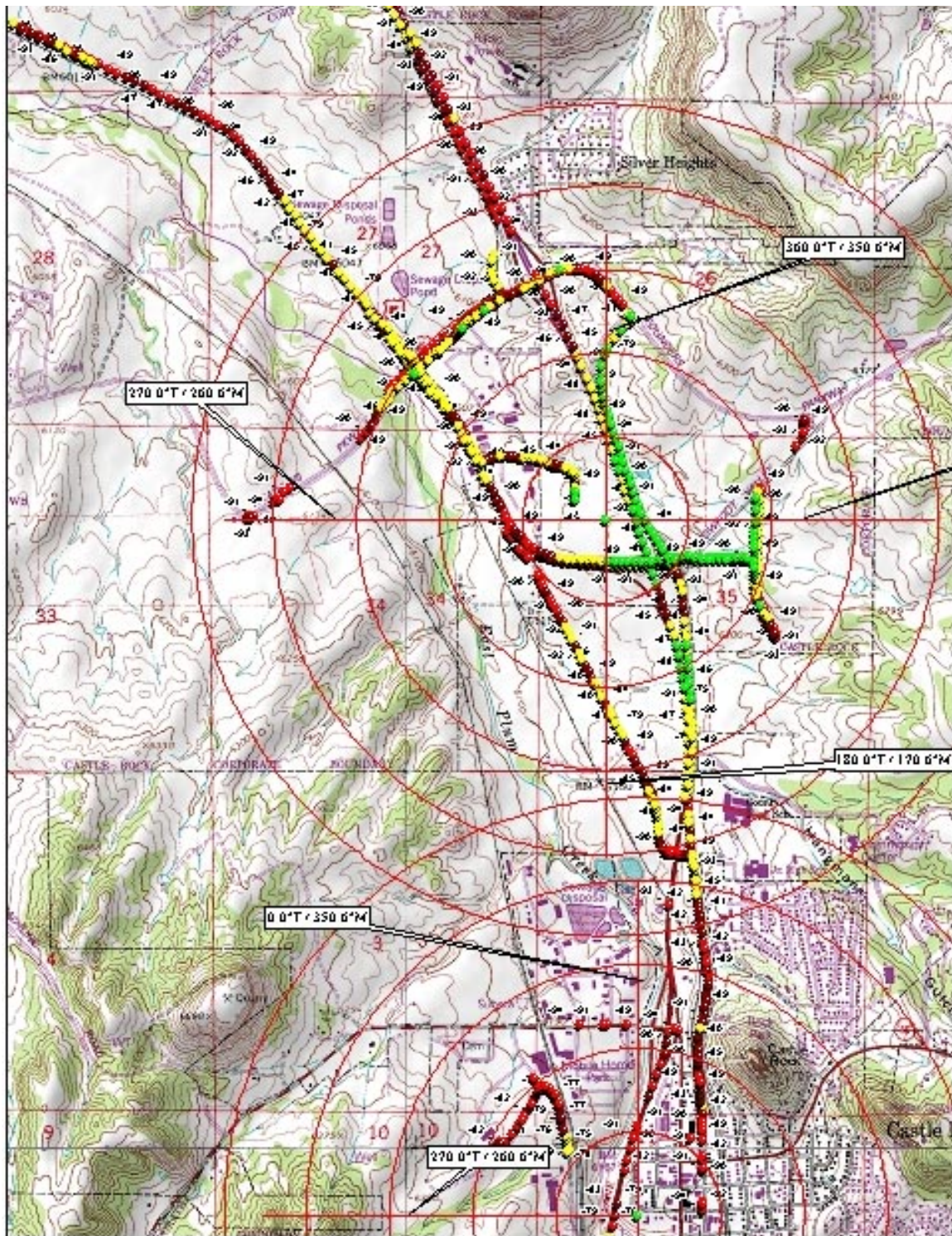


Figure 20 - Castle Rock Composite 2-Site Coverage, Test 039 (10 MHz)  
 (Rate Fixed at 3 Mbps, EIRP = 31 dBm, Concentric Circles are 1/4 Mile Apart)

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.

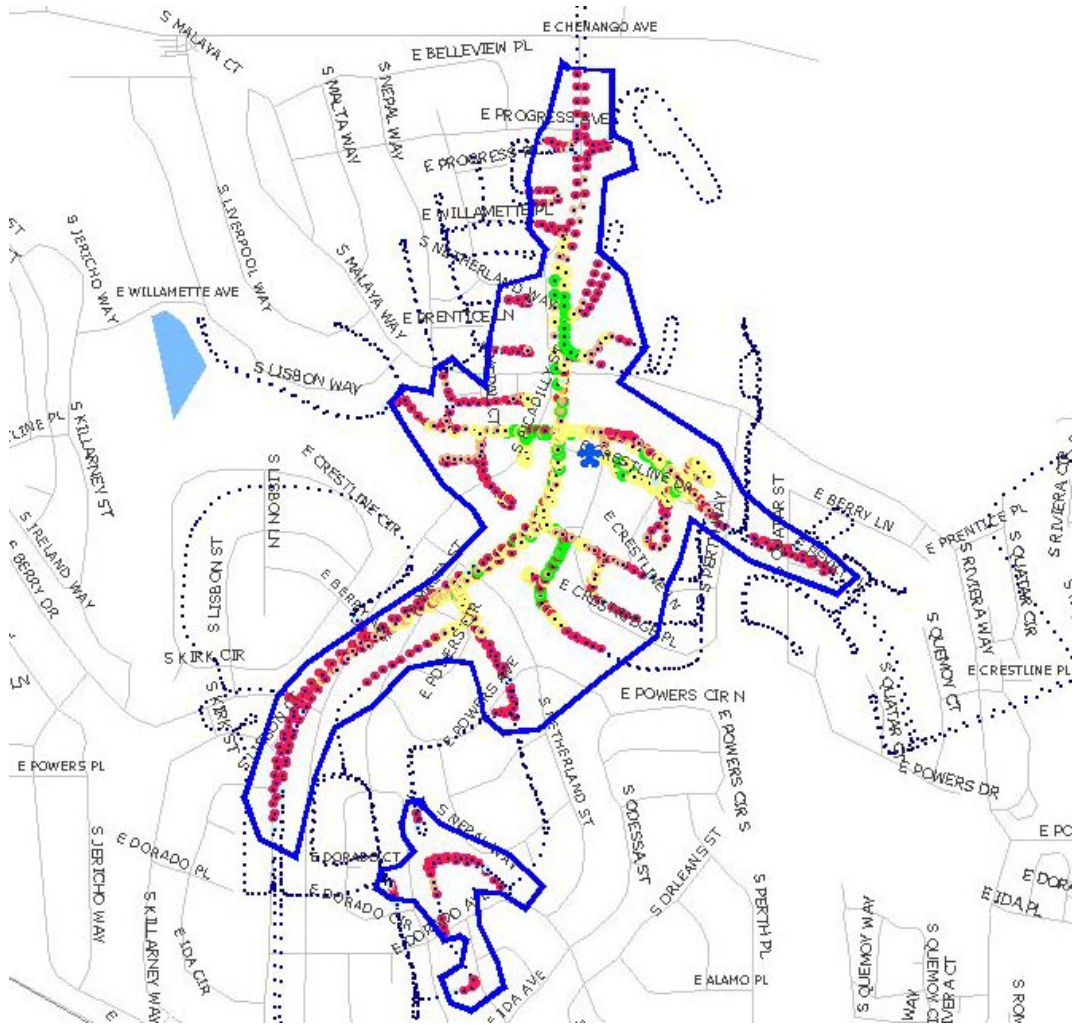


Figure 21 - Cunningham Fire Station 3 Coverage  
(Blue Outline Indicates Limit of Coverage)

**7.5 Suburban - Parker, Colorado.** The most sophisticated network configuration was 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.

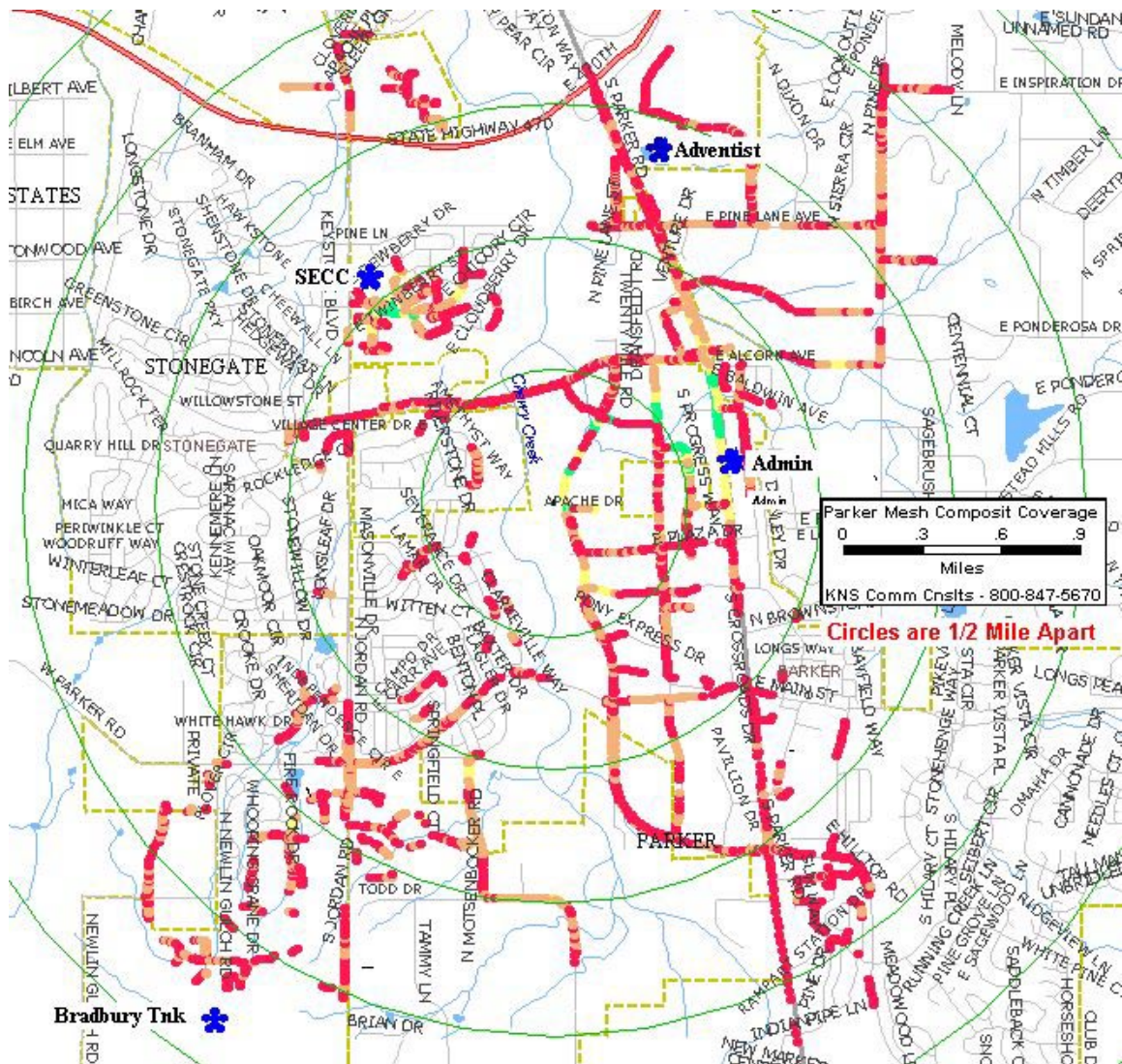


Figure 22 - Parker Fire Network Composite Coverage (4 Sites)  
(See Table 7 for Legend)

## 8.0 Mesh Networks

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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.

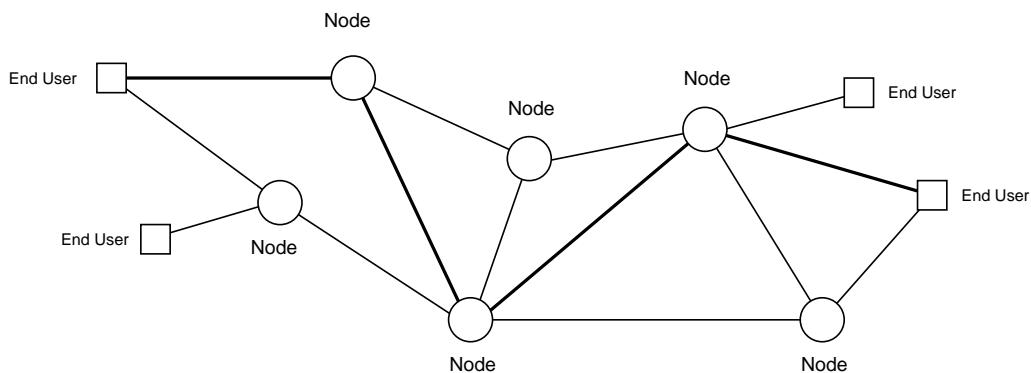


Figure 23 - Typical Network Topology with a Shortest Path Highlighted

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

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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.

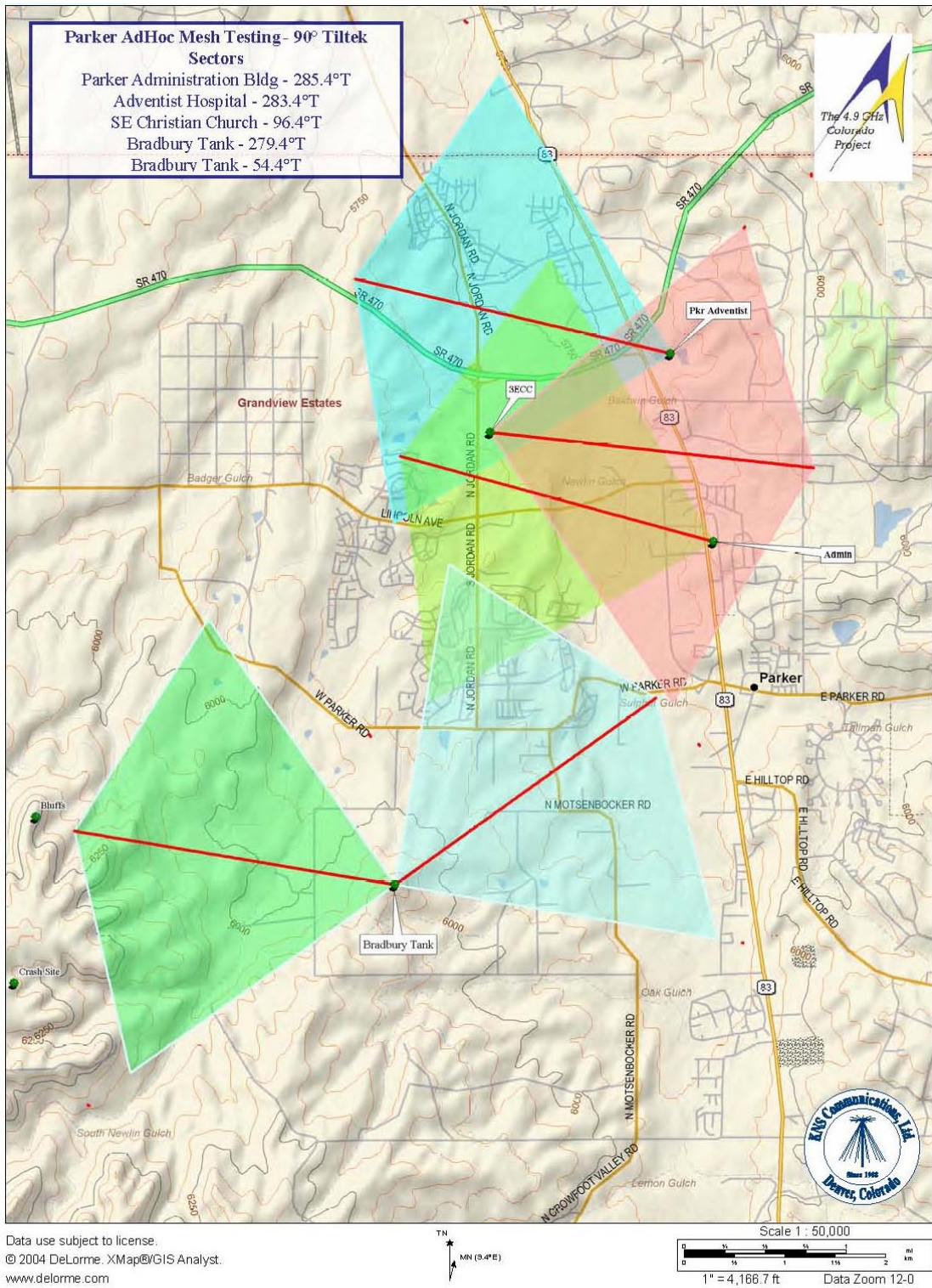


Figure 24 - Network Configuration for Mesh Network Application Testing

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).

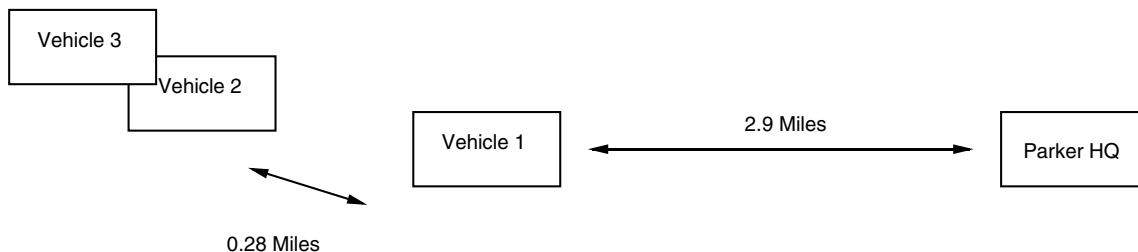


Figure 25 - Application Test #1

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 a 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.

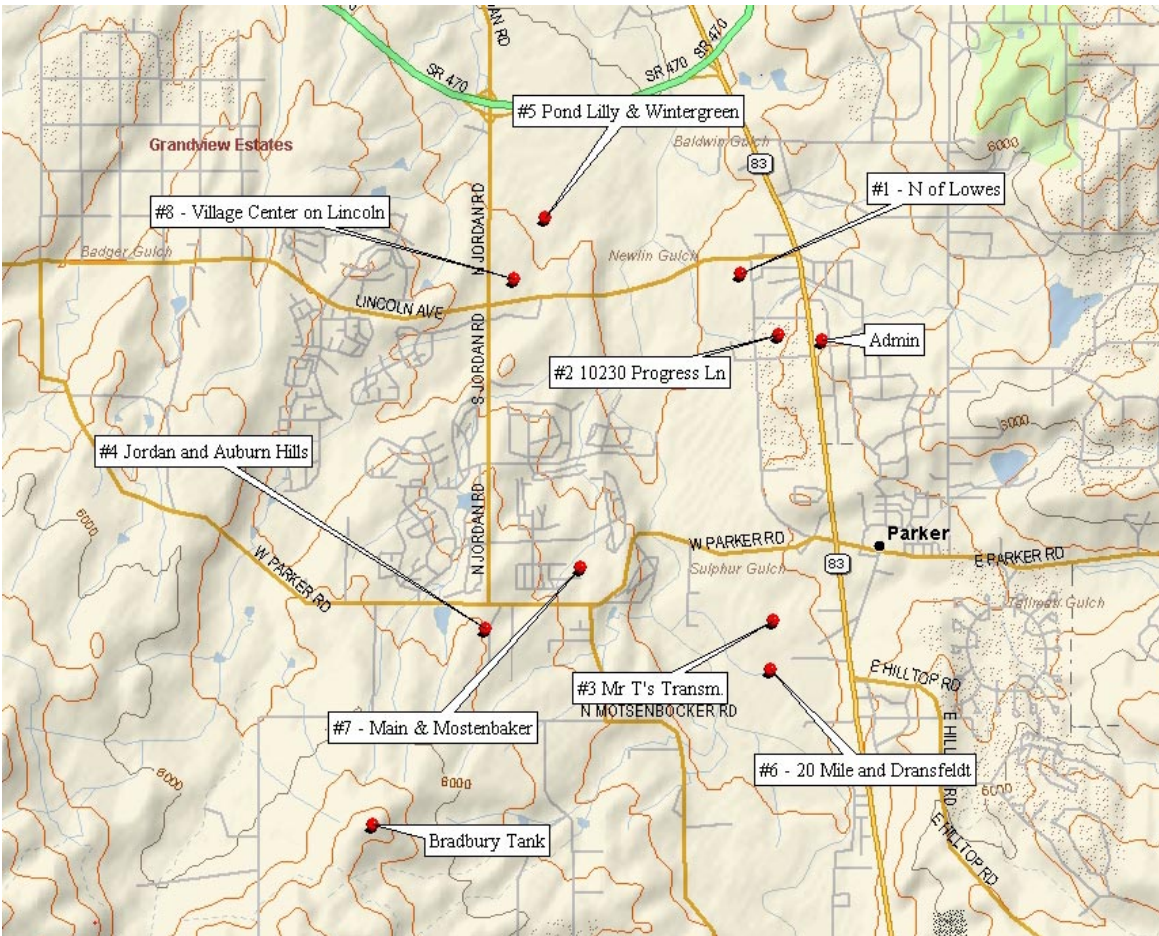


Figure 26 - Locations for Application Test #6

The application testing shows that the system will work for many typical first responder 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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### 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:

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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)

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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

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### Local Government Agencies

#### **Parker Fire Protection District, Lead Agency**

10235 Parkglenn Way

Parker, CO 80138

(303) 841-2608

[www.parkerfire.org](http://www.parkerfire.org)

Daniel Qualman, Chief, [dqualman@parkerfire.org](mailto:dqualman@parkerfire.org)

Cheryl L. Poage, Grant Manager, [cpoage@parkerfire.org](mailto:cpoage@parkerfire.org)

Rob Krause, IT Department, [rkrause@parkerfire.org](mailto:rkrause@parkerfire.org)

Steve Macaulay, IT Department, [sgmacaulay@parkerfire.org](mailto:sgmacaulay@parkerfire.org)

#### **Cunningham Fire Protection District**

2250 South Emporia Street

Denver, CO 80231

(303) 755-9202

[www.cfpd.org](http://www.cfpd.org)

Ira Rhodes, Chief, [irhodes@cfpd.org](mailto:irhodes@cfpd.org)

David Markham, Assistant Chief, [dmarkham@cfpd.org](mailto: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](http://www.denvergov.org/Electronic_Engineering_Bureau/default.asp)  
Myron Kissinger, Supervisor, Electronic Engineering Bureau  
[kissingerm@ci.denver.co.us](mailto:kissingerm@ci.denver.co.us)

**Douglas County**

4000 Justice Way  
Castle Rock, CO 80104  
(303) 660-7536

[www.douglas.co.us/countyadmin/emergencyservices](http://www.douglas.co.us/countyadmin/emergencyservices)

Mike Coleman, Administrative Chief, Communications, [mcoleman@douglas.co.us](mailto:mcoleman@douglas.co.us)

Allison Robenstein, Systems Analyst, [ARobenst@dcsheriff.net](mailto:ARobenst@dcsheriff.net)

Kevin Layton, Network Engineer, Supervisor IT Dept, [klayton@douglas.co.us](mailto:klayton@douglas.co.us)

Tony Gerhardt, Network Engineer, [tgerhard@douglas.co.us](mailto:tgerhard@douglas.co.us)

Jeff Vaughn, Telecommunications Technician, [jvaughn@douglas.co.us](mailto:jvaughn@douglas.co.us)

**Commercial Partners**

**Proxim Wireless**

2115 O'Nel Drive  
San Jose, CA 95131  
(800) 229-1630

[www.proxim.com](http://www.proxim.com)

Michael Johnston, Systems Engineer, (602) 820-8549, [mjohnston@proxim.com](mailto:mjohnston@proxim.com)

Colby Carr, Regional Sales Manager, (303) 285-0021, [CCarr@proxim.com](mailto: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](http://www.knsdenver.org)

L. Sue Scott-Thomas, President, [suethomas@knsdenver.org](mailto:suethomas@knsdenver.org)

**Pericle Communications Company**

1910 Vindicator Drive, Suite 100  
Colorado Springs CO 80919

[www.pericle.com](http://www.pericle.com)

Jay Jacobsmeyer, P.E., President, (719) 548-10404, [jacobsmeyer@pericle.com](mailto:jacobsmeyer@pericle.com)

Frank Pratte, P.E., (303) 594-0094, [fpratte@ieee.org](mailto:fpratte@ieee.org)

Dan Mieszala, Vice President, (720) 344-9556, [mieszala@pericle.com](mailto: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 K0G 1J0, Canada

(613) 258-5928

*www.tiltek.com*

Doug Kerr, Regional Sales Manager, (707) 433-2477, *dkerr@tiltek.com*

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Schiller Park, IL 60176

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*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.mwavelc.com*

Mike Cahill, Vice President, Sales, *mcahill@Mwavelc.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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Parker, CO 80134

(303) 841-9292

**Parker Adventist Hospital**

9895 Crown Crest blvd

Parker CO 80138

(303) 269-4000

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  - 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

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## 13.0 Acronyms

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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 <sup>6</sup> 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

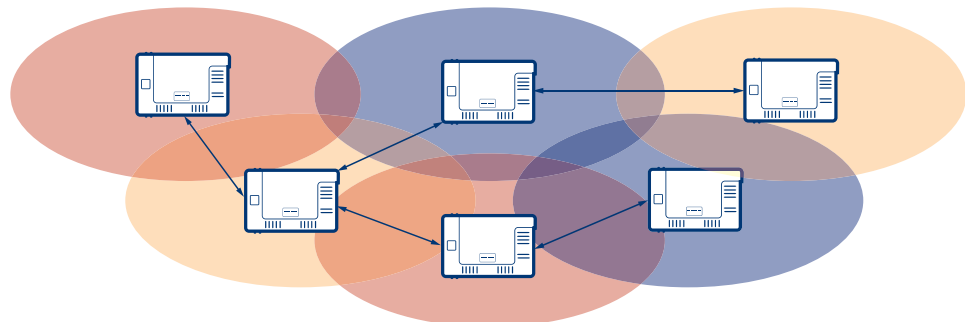
Ease of deployment and integration with the wired network are critical factors in a successful, profitable wireless LAN rollout. ORiNOCO access points excel with key capabilities that simplify WLAN deployment.

- 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 clients in the 2.4, 4.9, and 5 GHz bands <sup>1</sup>
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 <sup>1</sup>
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	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/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

Proxim Wireless Corporation  
2115 O'Nel Drive  
San Jose, CA 95131  
tel: 800.229.1630  
tel: 408.731.2700  
fax: 408.731.3675  
www.proxim.com



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<sup>1</sup> In conjunction with Proxim WaveLink Mobile Manager



# 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.

<b>RADIO</b>	Dual Radio Access Point with integrated radios:802.11a/4.9 GHz Public Safety + 802.11b/g							
<b>DATA RATES SUPPORTED</b>	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						
<b>NETWORK STANDARD</b>	IEEE 802.11a IEEE 802.11b or IEEE 802.11g							
<b>UPLINK</b>	Autosensing 802.3 10/100BASE-T Ethernet							
<b>FREQUENCY BAND</b>	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)						
<b>NETWORK ARCHITECTURE TYPE</b>	Infrastructure mesh							
<b>WIRELESS MEDIUM</b>	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)						
<b>MEDIA ACCESS PROTOCOL</b>	Carrier sense multiple access with collision avoidance (CSMA/CA)							
<b>MODULATION</b>	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						
<b>OPERATING CHANNEL</b>	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						
<b>NON-OVERLAPPING CHANNELS</b>	802.11a: 12; 802.11b/g: 3; 4.9 GHz 10 MHz: 5; 4.9 GHz 20 MHz: 2							
<b>RADIO SPECIFICATIONS RF PERFORMANCE</b>	The following tables show typical RF performance values for FCC-certified products (values may differ for products certified in other regulatory domains)							
	<b>802.11a RF Performance</b>							
	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	<b>802.11b/g RF Performance</b>												
		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)											
	<b>4.9 GHz 20 MHz Channel Public Safety RF Performance</b>												
	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											
	<b>4.9 GHz 10 MHz Channel Public Safety RF Performance</b>												
	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	<b>2.4 GHz</b>											
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											
<b>5 GHz</b>													
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											
<b>2.4, 4.9, and 5GHz</b>													
Tri band (2.4, 4.9, and 5GHz) external Range Extender Antenna for use indoors													
<b>2.4, 4.9, and 5GHz</b>													
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											

# 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.

<sup>1</sup> 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  
tel: 800.229.1630  
tel: 408.731.2700  
fax: 408.731.3675  
www.proxim.com





# 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

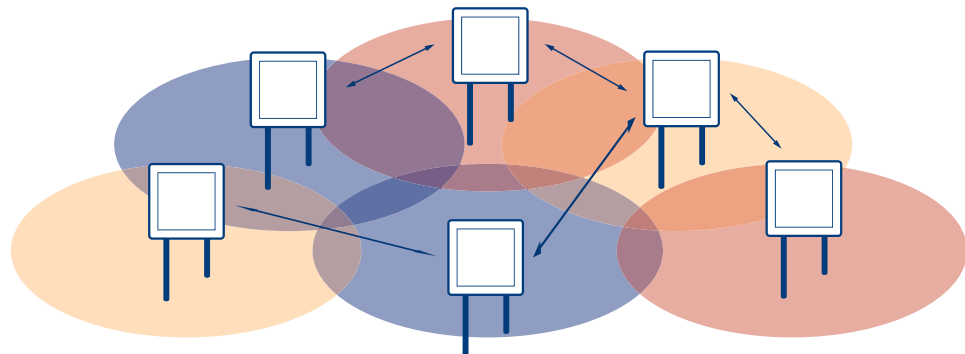
Ease of deployment and integration with the wired network are critical factors in a successful, profitable wireless LAN rollout. ORiNOCO access points excel with key capabilities that simplify WLAN deployment.

- 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.

## 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.

# ORiNOCO AP-4900MR-LR Specifications

## 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 <sup>1</sup>
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° Celcius, 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
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## 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  
www.proxim.com

Wi-Fi is a trademark of the Wireless Ethernet Compatibility Alliance, Inc.

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DSUS\_406\_AP4900MRLR

# ANTENNAFIER™ 4900-5800 S SERIES

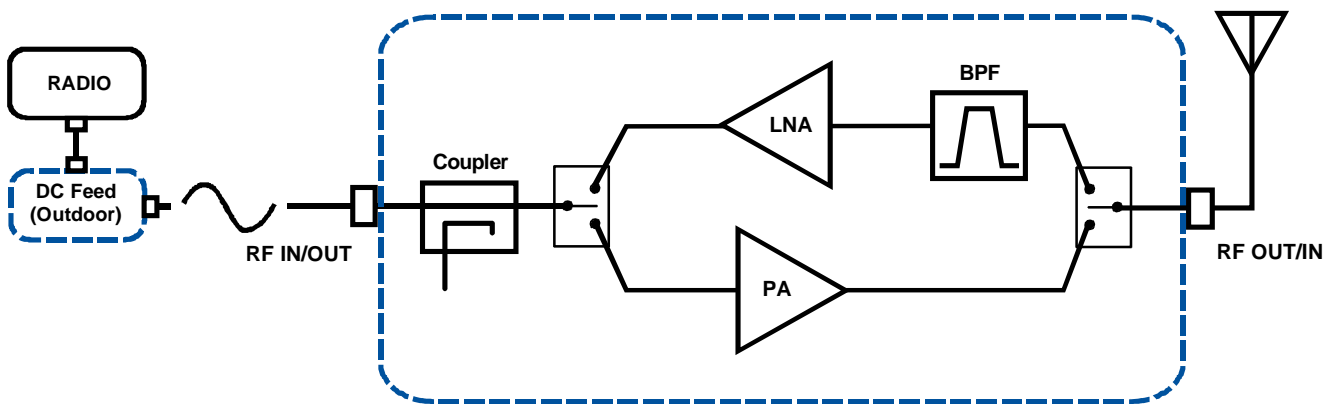


The Antennafier™ 4900-5800 S series Bi-Directional Amplifiers will significantly improve link reliability and operating range by providing Low Noise Amplification during Receive, and Spectrally Clean Power Amplification during Transmit. These fixed gain devices housed in a rugged machined aluminum chassis 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.*

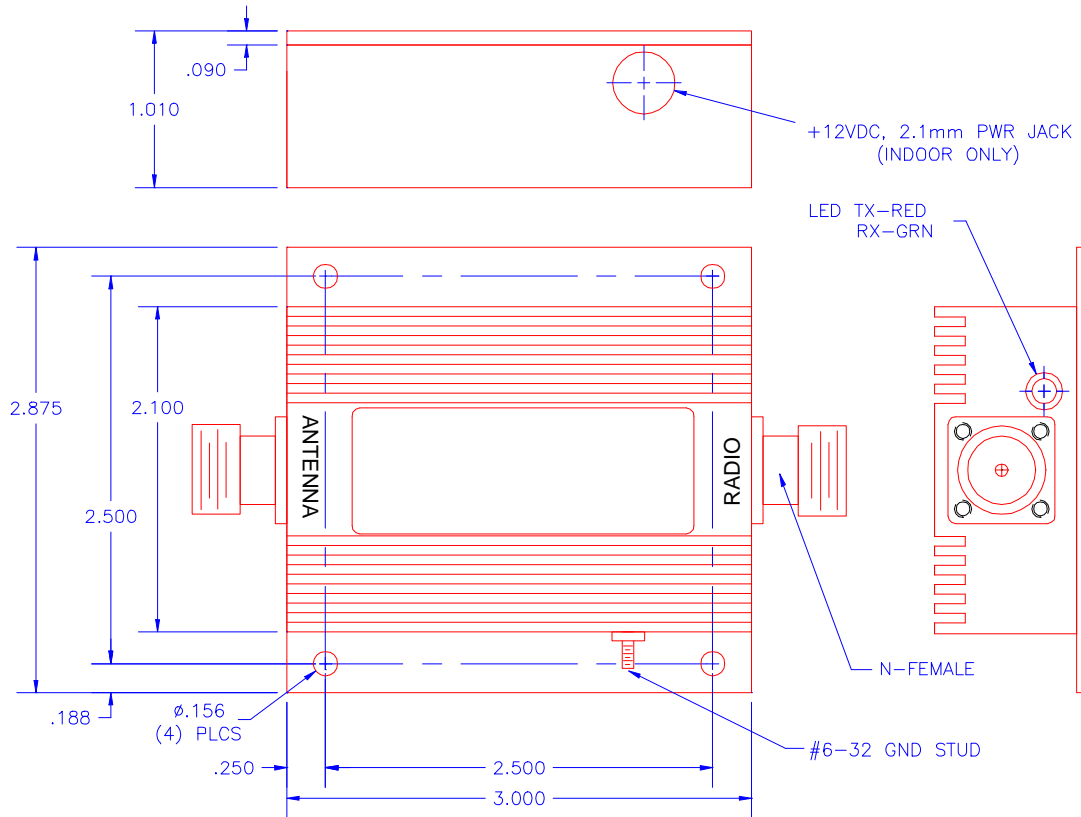
9017 Cincinnati Columbus Rd.  
West Chester, Ohio 45069  
PH: 513-777-2774

## Typical Performance Parameters

<b>Frequency Bands:</b>	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
<b>Supply Voltage:</b>	+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. (-)
<b>Receive:</b>	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
<b>Transmit:</b>	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
<b>Maximum Ratings:</b>	Pin (Radio Port) +30 dBm Pin (Antenna Port) +27 dBm
<b>Size:</b>	2.88" x 3.00"x 1.01"
<b>Weight:</b>	< 12 oz
<b>Chassis:</b>	Machined Aluminum with durable black anodize finish CCA is protected with a conformal coating compound
<b>Indicator LED:</b>	Green LED -Receive Mode, Red LED-Transmit Mode
<b>Lightning Suppression:</b>	1/4 wavelength short

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## Mechanical Envelope:



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## Ordering Guide:

<u>Indoor Series</u>	<u>Freq Band</u>	<u>Description</u>
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	

<u>Outdoor Series</u>	<u>Freq Band</u>	<u>Description</u>
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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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)

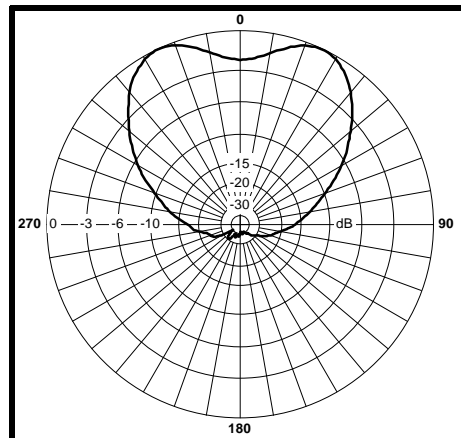
### Mechanical Specifications

**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)

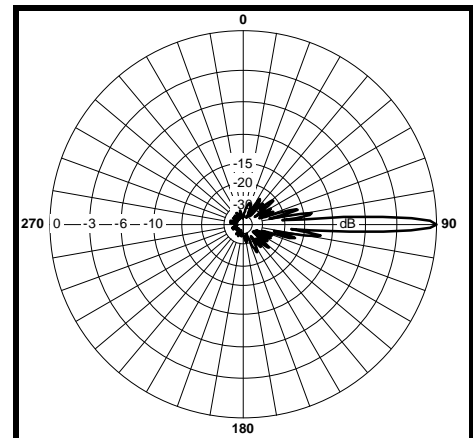
### Materials

**Radiating Elements:** Plated copper on PCB  
**Reflector:** Irridited aluminum  
**Radome:** Gray UV stabilized ASA  
**Clamps:** Aluminum and stainless steel

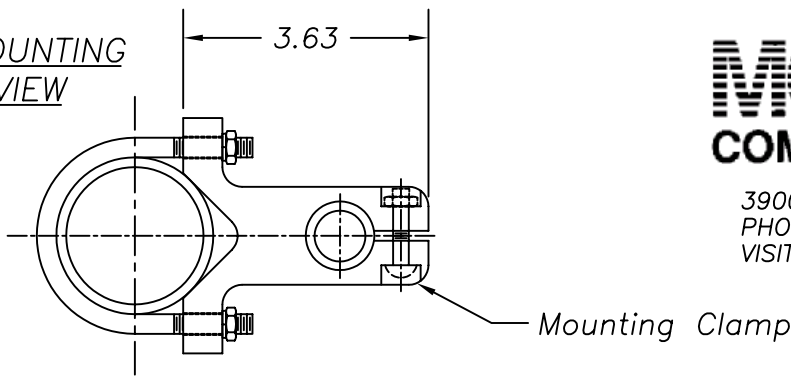
H-Plane



E-Plane



PIPE MOUNTING  
TOP VIEW

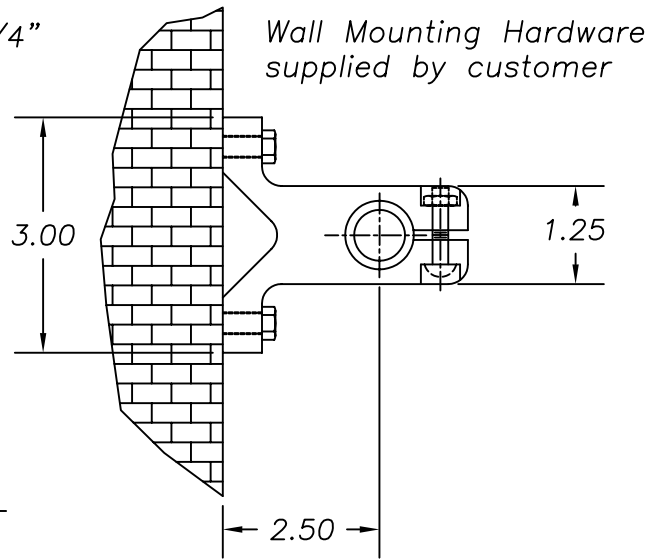
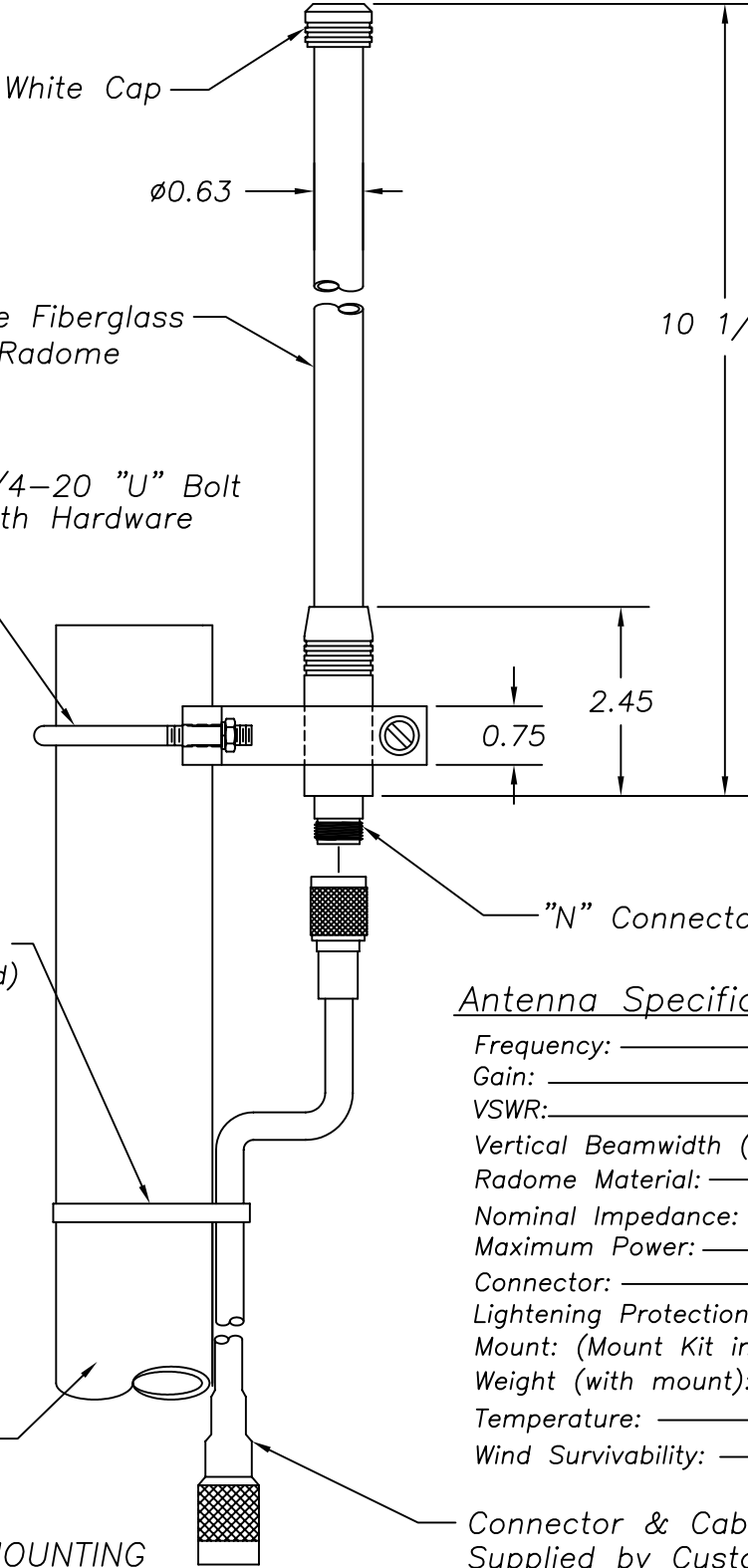


**MOBILE MARK®**  
**COMMUNICATIONS ANTENNAS**

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VISIT OUR WEBSITE AT WWW.MOBILEMARK.COM

**ECO6-4900**

**Omni Directional Antenna**  
**6 dBi with Mounting Kit**  
**4.9 - 5.0 GHz**



WALL MOUNTING  
TOP VIEW

Antenna Specifications:

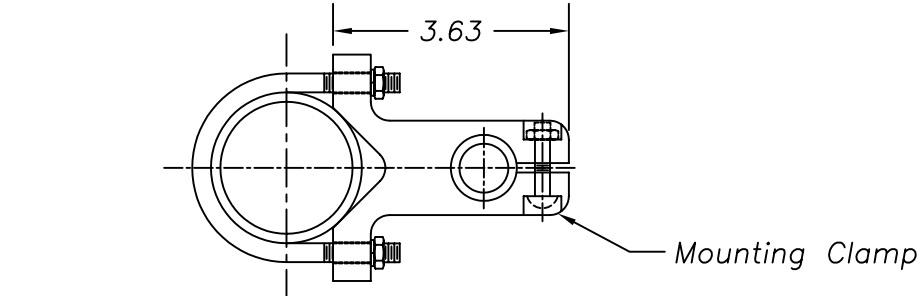
- Frequency: \_\_\_\_\_ 4.9-5.0 GHz
- Gain: \_\_\_\_\_ 6 dBi
- VSWR: \_\_\_\_\_ 2:1 Max
- Vertical Beamwidth (-3 dB) \_\_\_\_\_ 20 degrees
- Radome Material: \_\_\_\_\_ White Fiberglass
- Nominal Impedance: \_\_\_\_\_ 50 OHM Nominal
- Maximum Power: \_\_\_\_\_ 10 Watts
- Connector: \_\_\_\_\_ "N" Female 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

Connector & Cable  
Supplied by Customer

# MOBILE MARK<sup>®</sup>

## COMMUNICATIONS ANTENNAS

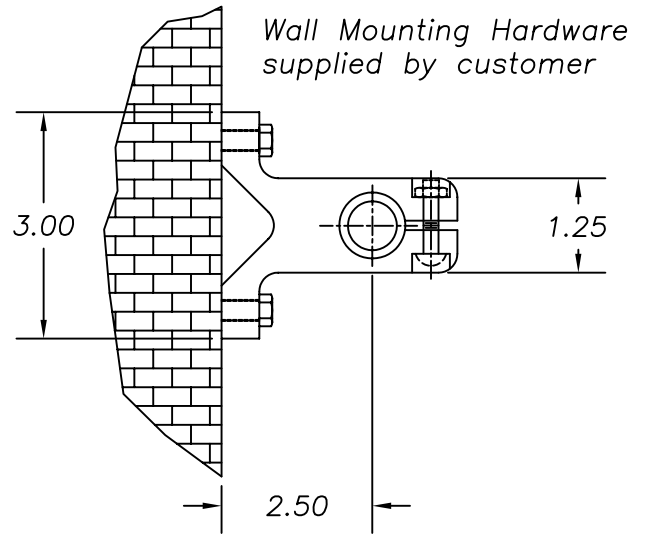
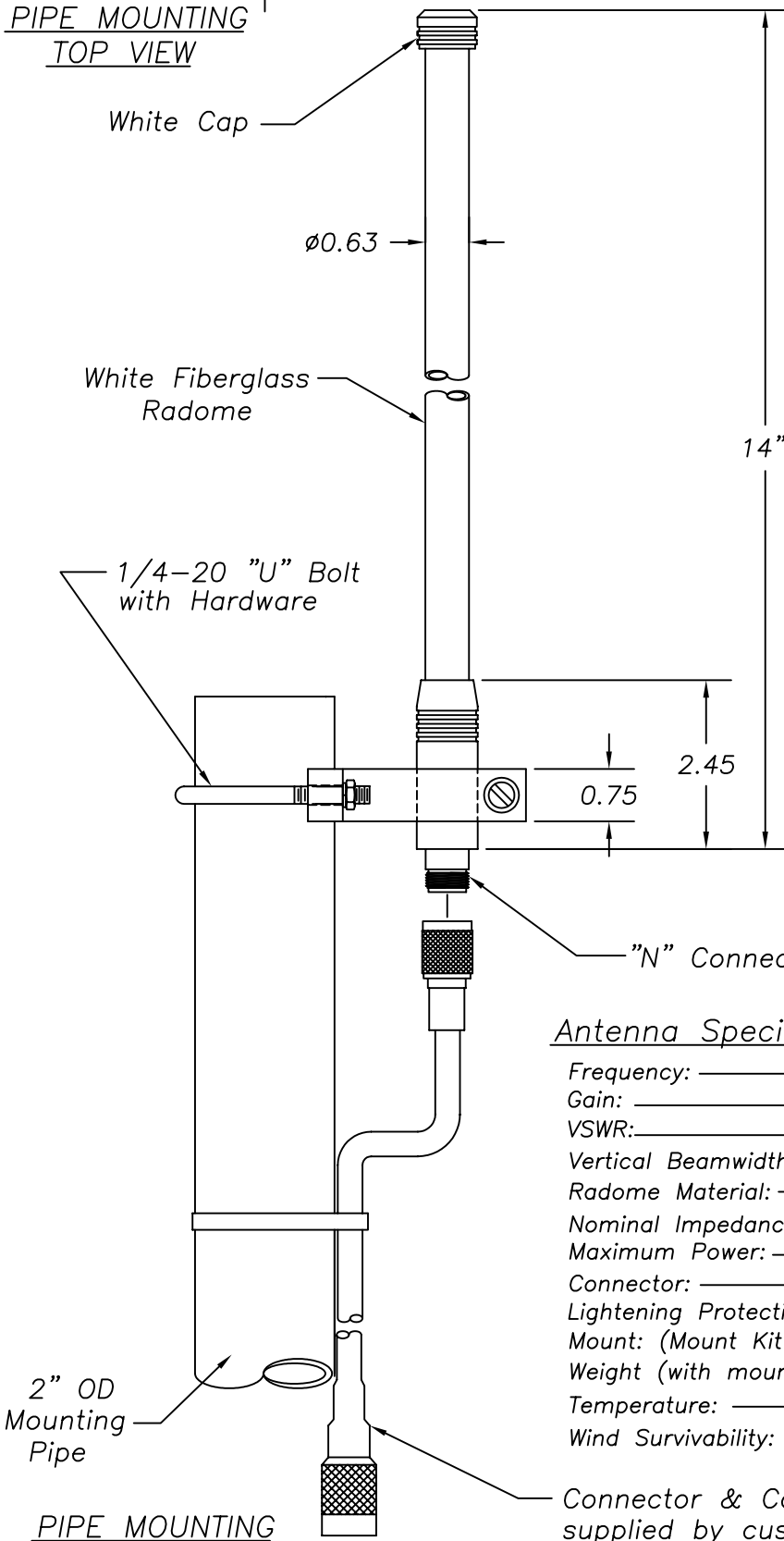
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PIPE MOUNTING  
TOP VIEW

# ECO9-4900

## Omni Directional Antenna 9 dBi with Mounting Kit 4.9 - 5.0 GHz



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
- Lightning 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

## 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		Notes	Gain, nominal dBi	HPBW Deg.	Xpol dB	F/B dB	VSWR max	R.L. dB
			ft.	m							
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



# FibeAir<sup>®</sup> 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.

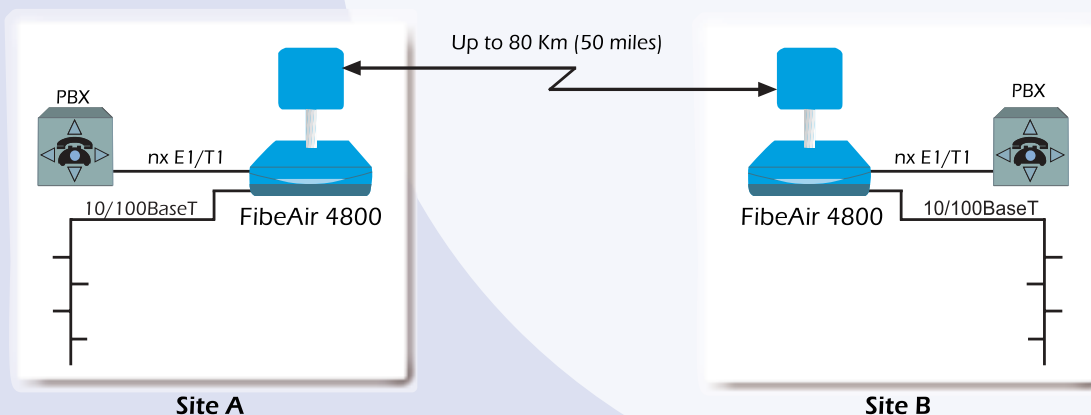
FibeAir® 4800 enables direct connection of existing equipment, such as LANs and PBX systems, thus eliminating the need for additional external equipment. FibeAir® 4800 product family is a split-mount system consisting of an IDU, ODU and antenna on each side of the link.

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 nx E1/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 EN 301 893 V1.2.2	EN300 440 V1.3.1
Dynamic Frequency Selection and Transmission Power Control (DFS/TPC)					
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](http://www.ceragon.com).

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Corporate Headquarters  
Ceragon Networks Ltd.  
24 Raoul Wallenberg St.  
Tel Aviv 69719, Israel  
Tel: +972-3-645-5733  
Fax: +972-3-645-5499  
info@ceragon.com

Ceragon Networks, Inc.  
10 Forest Avenue, Paramus,  
NJ 07652, U.S.A.  
Tel: +1-201-845-6955  
Fax: +1-201-845-5665  
Toll free: 1-877- FIBEAIR  
infous@ceragon.com

Ceragon Networks (UK) Limited  
4 Oak Tree Park, Burnt Meadow Rd.  
North Moons Moat, Redditch,  
Worcestershire B98 9NZ, UK  
Tel: +44-(0)-1527-591900  
Fax: +44-(0)-1527-591903  
infoeuro@ceragon.com

Ceragon Networks (HK) Ltd.  
Singapore RO  
Level 34 Centennial Tower  
3 Temasek Avenue,  
Singapore 039190  
Tel: + 65 65 49 7886  
Fax: + 65 65 49 7011  
infoasia@ceragon.com

[www.ceragon.com](http://www.ceragon.com)



## 1/2" Foam Dielectric, LDF Series – 50-ohm



### LDF4-50A

Description	Type No.
<b>Cable Ordering Information</b>	
<b>Standard Cable</b>	
1/2" Standard Cable, Standard Jacket	LDF4-50A
<b>Fire Retardant Cables</b>	
1/2" Fire Retardant Jacket (CATVX)	LDF4RN-50A
1/2" Fire Retardant Jacket (CATVR)	LDF4RN-50A
<b>Low VSWR and Specialized Cables</b>	
1/2" Low VSWR, specify operating band	LDF4P-50A-(**)
Phase Stabilized and Phase Measured Cable	See page 590
<b>Jumper Cable Assemblies</b> – See page 584	
** Insert suffix number from "Low VSWR Specifications" table, page 498	
<b>Characteristics</b>	
<b>Electrical</b>	
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)
<b>Mechanical</b>	
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.

# TIMES MICROWAVE SYSTEMS

A Smiths Group plc company

## LMR<sup>®</sup>-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<sup>®</sup>** 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<sup>®</sup>-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<sup>®</sup>-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<sup>®</sup>-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<sup>®</sup>-PVC** is designed for low loss general-purpose indoor/outdoor applications and is somewhat more flexible than the standard polyethylene jacketed LMR.
- **LMR<sup>®</sup>-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

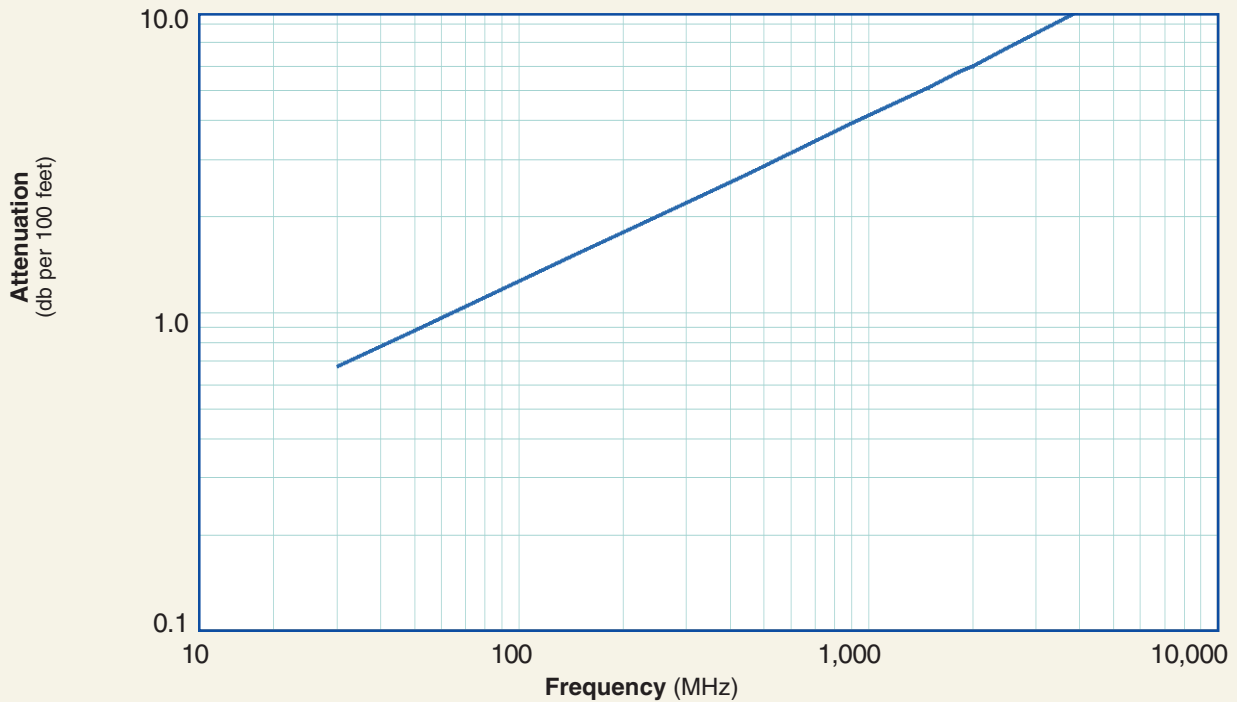
Construction Specifications			
Description	Material	In.	(mm)
Inner Conductor	Solid BCCAI	0.108	(2.74)
Dielectric	Foam PE	0.285	(7.24)
Outer Conductor	Aluminum Tape	0.291	(7.39)
Overall Braid	Tinned Copper	0.320	(8.13)
Jacket	(see table above)	0.405	(10.29)

<b>Mechanical Specifications</b>			
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)

<b>Environmental Specifications</b>		
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

<b>Electrical Specifications</b>			
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
<b>DC Resistance</b>			
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
<b>Attenuation dB/100 ft</b>	0.7	0.9	1.5	1.9	2.7	3.9	5.1	5.7	6.0	6.8	10.8
<b>Attenuation dB/100 m</b>	2.2	2.9	5.0	6.1	8.9	12.8	16.8	18.6	19.6	22.2	35.5
<b>Avg. Power kW</b>	3.33	2.57	1.47	1.20	0.83	0.58	0.44	0.40	0.37	0.33	0.21

**Calculate Attenuation =**  
 $(0.122290) \cdot \sqrt{\text{FMHz}} + (0.000260) \cdot \text{FMHz}$  (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

A Smiths Group plc company

## LMR<sup>®</sup>-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 (mm)	Width in (mm)	Weight lb (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 (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=Alloy \*\*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)

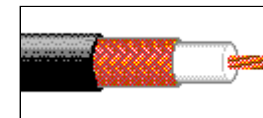


1-800-BELDEN-1

# 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.
<b>8267</b>  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 <b>Inner</b> 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	<b>Inner</b> 3.9 ohms/km			101.0 pF/m

**Description:**

<b>Insulation:</b>	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
<b>Jacket:</b>	PVC-NC	
<b>Plenum Version(s):</b>	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

<b>FCC Registration Number (FRN):</b> 0010555266	
<b>Call Sign:</b> WQAC428	<b>File Number:</b>
<b>Radio Service:</b> PA - Public Safety 4940-4990 MHz Band	
<b>Regulatory Status:</b> PMRS	
<b>Frequency Coordination Number:</b>	

<b>Grant Date</b> 05/04/2004	<b>Effective Date</b> 05/04/2004	<b>Expiration Date</b> 05/04/2014	<b>Print Date</b> 06/20/2005
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**STATION TECHNICAL SPECIFICATIONS**

**Fixed Location Address or Mobile Area of Operation**

**Loc. 1 Area of Operation**  
Countywide

**County**  
DOUGLAS

**State**  
CO

**Location 1 Special Condition:** 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**  
DOUGLAS

**State**  
CO

**Location 2 Special Condition:** 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 <sup>1</sup> .....	A or B	A or C
25-50 .....	B	C
72-76 .....	B	C
150-174 <sup>2</sup> .....	B, D, or E	C, D, or E
150 Paging-only .....	B	C
220-222 .....	F	F
421-512 <sup>2</sup> .....	B, D, or E	C, D, or E
450 Paging-only .....	B	G
806-809/851-854 .....	B	H
809-824/854-869 <sup>3</sup> .....	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.

APPLICABLE EMISSION MASKS—Continued

Frequency band (MHz)	Mask for equipment with Audio low pass filter	Mask for equipment without audio low pass filter
5850-5925 <sup>4</sup> .....		
All other bands .....	B	C

<sup>1</sup> 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.

<sup>2</sup> 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.

<sup>3</sup> Equipment used in this licensed to EA or non-EA systems shall comply with the emission mask provisions of § 90.691.

<sup>4</sup> 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  $7.27(f_d - 2.88 \text{ kHz})$  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  $30 + 16.67(f_d - 3 \text{ kHz})$  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  $f_c$  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  $f_d \geq$ : 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  $43 + 10 \log(P)$  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.

(1) *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:  $219 \log (\% \text{ of } (BW)/45)$  dB.

(3) On any frequency removed from the assigned frequency between 50–55% of the authorized bandwidth:  $10 + 242 \log (\% \text{ of } (BW)/50)$  dB.

(4) On any frequency removed from the assigned frequency between 55–100% of the authorized bandwidth:  $20 + 31 \log (\% \text{ of } (BW)/55)$  dB attenuation.

(5) On any frequency removed from the assigned frequency between 100–150% of the authorized bandwidth:  $28 + 68 \log (\% \text{ of } (BW)/100)$  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 than 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:  $568 \log (\% \text{ of } (BW)/45)$  dB.

(3) On any frequency removed from the assigned frequency between 50–55% of the authorized bandwidth:  $26 + 145 \log (\% \text{ of } (BW)/50)$  dB.

(4) On any frequency removed from the assigned frequency between 55–100% of the authorized bandwidth:  $32 + 31 \log (\% \text{ of } (BW)/55)$  dB.

(5) On any frequency removed from the assigned frequency between 100–150% of the authorized bandwidth:  $40 + 57 \log (\% \text{ of } (BW)/100)$  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 lev-

els 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]

## § 90.1201

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 business, 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

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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

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## § 90.1213

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.

§ 90.1215

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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## § 90.517

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 sta-

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tions 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.