MEMORANDUM REPORT NO. 187

REGIONAL WIRELESS PLAN IMPLEMENTATION: BROADBAND PUBLIC SAFETY COMMUNICATIONS DEMONSTRATION PROJECT KENOSHA COUNTY WISCONSIN

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Special acknowledgement is due Mr. Jason W. Zehrung, Senior Telecommunications Planner, for his contributions to this report.

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Prepared by the

Southeastern Wisconsin Regional Planning Commission

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Chapter I

INTRODUCTION

This report documents a project in Kenosha County derived from recommendations set forth in the wireless plan element of the regional telecommunications plan for southeastern Wisconsin set forth in SEWRPC Planning Report No. 53, *A Regional Broadband Telecommunications Plan for Southeastern Wisconsin*. The regional wireless plan was selected as the primary vehicle for delivering broadband telecommunications service throughout the Region based on anticipated broadband performance, relatively low implementation cost, and its ability to provide full geographic coverage of the Region.

A key feature of the recommended regional wireless plan is its combined and shared public safety/commercial infrastructure. Such a shared communications infrastructure would significantly reduce the cost of plan implementation and allow for full geographic coverage of the lower population density rural areas of the Region. Without this shared infrastructure, most rural areas represent marginal economic investments. To share a common network infrastructure, the frequency bands must be reasonably adjacent. Otherwise, the radio propagation patterns of the two networks would be incompatible. Fortunately, the recently allocated Federal Communications Commission (FCC) 4.9 GHz public safety frequency band is sufficiently close to the unlicensed 5.8 GHz frequency band to allow for a common network infrastructure.

Prior to this time and since its FCC approval in 2002, the 4.9 GHz frequency band has functioned as a short range, localized "hot-spot" means of public safety communications. To use the network, public safety vehicles are required to move toward an access point for connection and radio transmission much as a laptop computer user would connect with the Internet at a local coffee shop. Such localized communications limitations severely compromises the usefulness of the 4.9 GHz frequency band in public safety communications. For this reason, the practicality of the regional wireless plan with its public safety network foundation depended on new innovation focused on extending the range of 4.9 GHz frequency band communications to provide full coverage on a county-by-county basis.

The recommended broadband wireless technology was first developed at the community level and implemented in the Town of Wayne, Washington County.[1] This experience provided the foundation for the longer range public safety wireless communications needed in a Kenosha County system. The concepts behind the longer range amplified 2.4 GHz frequency band network in Wayne had the potential for extension to the higher frequency 4.9 GHz band. Realization of this potential required the cooperation and financial support of a county government in the Region. Such support was forthcoming from Kenosha County.

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[1] *See SEWRPC Memorandum Report No. 185* Community-Based Wireless Plan Implementation – Town of Wayne, Washington County.

Based on a request from the Kenosha County Executive, a proposal was prepared and submitted in May 2007. This proposal outlined planning, technology development, and field test demonstration projects for broadband public safety communications in the 4.9 GHz frequency band. The following chapters of this report document the plans, developments, and field tests of these projects:

Chapter II	The Proposal
Chapter III	The Infrastructure Technology
Chapter IV	The Plans
Chapter V	The Commercial Business Model
Chapter VI	The Field Tests
Chapter VII	Peer-to-Peer and GeoMessaging Communications
Chapter VIII	The Field Demonstration
Chapter IX	Summary and Conclusions

Chapter II

THE PROPOSAL

INTRODUCTION

The full title of the proposal as submitted to Kenosha County in May 2007 was:

> A Comprehensive Broadband Wireless Communications Plan for Kenosha County Featuring a 4.9 GHz Public Safety Communications Demonstration with a Backup Peer-to-Peer Disaster Emergency Communications Option

The contents of the proposal featured:

1. Preparation of a comprehensive network plan for Kenosha County based on the regional wireless telecommunications plan
2. Development of a supporting infrastructure technology
3. Incorporation of a backup peer-to-peer feature for emergency communications
4. Field testing of the planned 4.9 GHz wireless network
5. In parallel development and testing of the commercial 5.8 GHz commercial network
6. Demonstration of the 4.9 GHz broadband wireless communications network using Kenosha County public safety vehicles

A Comprehensive Network Plan

The aforereferenced SEWRPC Planning Report No. 53 includes a map of the proposed antenna base station sites for the regional wireless plan (see Map 1). As part of a seven-county broadband telecommunications plan, fourteen antenna base station sites were specified for Kenosha County. As a broad system plan, the regional plan did not consider details attendant to property ownerships or the individual heights of existing antenna towers. It was envisioned that a more detailed, engineering-level plan at the county level would take these factors and other site characteristics into account. Such a detailed planning approach would focus on minimizing both initial infrastructure and future operating costs. Plan preparation and wireless network design would be based on radio propagation modeling and more specifically the Anderson 2D model. The Anderson model has been successfully field test verified for many communications network plans in southeastern Wisconsin. The proposal called for a network plan designating future antenna base station sites satisfying the future needs of both a 4.9 GHz public safety network and a 5.8 GHz commercial network. This detailed plan would later be adjusted as necessary based on field test verification.

Map 1

REGIONAL BROADBAND WiFiA WIRELESS SYSTEM PLAN FOR SOUTHEASTERN WISCONSIN

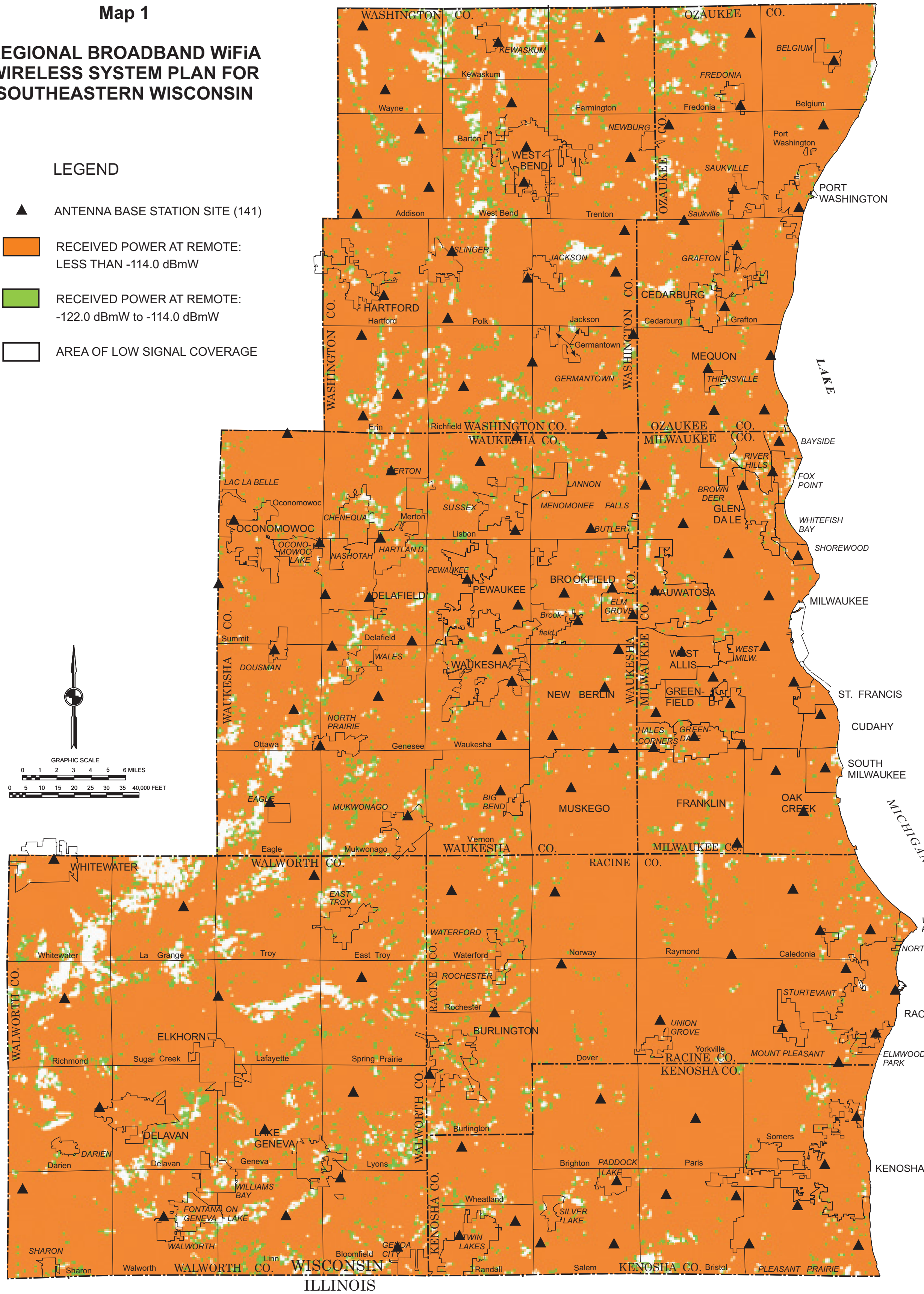
LEGEND

▲ ANTENNA BASE STATION SITE (141)

RECEIVED POWER AT REMOTE: LESS THAN -114.0 dBmW

RECEIVED POWER AT REMOTE: -122.0 dBmW to -114.0 dBmW

AREA OF LOW SIGNAL COVERAGE



Source: SEWRPC.

Technology Development
As noted earlier, the utility of 4.9 GHz public safety communications was severely limited by the short-range nature of the technology. Localized communications confined to specific small area contact points failed to meet the needs for high speed data and communications throughout a county. It also did not provide for the backup public safety communications required in times of major public emergencies. Given these two technical shortcomings, the focus of technology development had to be on increasing the range of the antenna base station and incorporating a peer-to-peer communications feature to function particularly in public safety emergencies when fixed infrastructure based messaging becomes difficult or impossible. These technological developments are discussed in the chapters that follow.

Backup Peer-to-Peer Communications
Most wireless communications networks, including public safety networks in the United States and elsewhere, are based on an access point infrastructure. Communications between users occur only through the deployed access point network. Such a network is very susceptible to breakdowns caused by infrastructure damage. While most access point base stations are supported by backup power generators, they are not immune from other sources of equipment failure or physical damage caused by flooding or other natural or human-caused disasters. The recent record in the nation is not reassuring. Communications networks, including wireless public safety networks, have consistently failed to operate in every one of the major national disasters of the last decade, including 9/11, Katrina, and the hurricane that overwhelmed Galveston, Texas, in 2008. Most of these breakdowns resulted from either infrastructure damage or network saturation. The obvious cure for these broken networks is a communications system not dependent solely on infrastructure access. For this reason, a backup peer-to-peer communications feature (Chapter VII) was incorporated as part of the Kenosha County wireless network plan. This technology also provides redundant paths to minimize the likelihood of network saturation.

Field Testing
Wireless network plans are based on radio propagation modeling using specific models such as the Anderson 2D model. Such models require terrain databases that provide information on the natural terrain including forest cover and building structures. These data are collected from aerial photography and satellite imagery as well as the NASA shuttle. Since these data are limited in resolution and are not always current, radio propagation model-based plans require field test confirmation. In Kenosha County, such field testing was to take the form of equipping one of the plan-selected tower sites with a temporary tower installation and subsequently field testing the anticipated coverage area of that tower. The field testing results are reported in Chapter VI.

The 5.8 GHz Commercial Wireless Network
The rationale of the regional wireless plan is based on a dual public safety/commercial shared base station infrastructure. Such a shared infrastructure significantly improves the economics of a county-wide deployment of a commercial broadband wireless network. For this reason, it was necessary in the Kenosha County project to co-develop and co-test the 5.8 GHz commercial network in parallel with the 4.9 GHz public safety network. Development and testing activities of this commercial network are reported in Chapters V and VI.

System Demonstration
The culmination of the project was a full-scale demonstration of the entire public safety communications system including the peer-to-peer backup communications. Vehicular equipment was to be mounted in two sheriff's vehicles for mobile range, performance, and general utility testing. An existing tower site in the Town of Bristol and its temporary base station was to be integrated into the existing county communications network for a comprehensive evaluation of system function and performance. The results of this demonstration are reported in Chapter VIII.

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Chapter III

THE INFRASTRUCTURE TECHNOLOGY

INTRODUCTION

Previous implementation projects using the new (FCC, 2002) 4.9 GHz public safety communications frequency band have suffered from a lack of range of the antenna base stations. Higher radio frequencies such as the 4.9 GHz are characterized by shorter propagation ranges even in unobstructed line-of-sight transmissions in free space. They are also strongly attenuated over transmission paths featuring either heavy tree or building concentrations. Range extension of radio signals is accomplished primarily either by higher transmit powers or more sensitive receivers. Developing such improved transmit powers and sensitive receivers was the primary focus of the Kenosha County project.

Taking first the area of transmit power, the FCC allows a higher level of wireless transmit power in the 4.9 GHz frequency band than in the unlicensed 2.4 GHz and 5.8 GHz bands employed in commercial networks. While the 4.9 GHz power level for a public safety network does not in any way compare with the power levels employed by wireless cell phone providers, it is nonetheless higher than in unlicensed commercial WiFi networks. Transmitter output levels in the 4.9 GHz band can rise as high as two watts, twice the one watt level of WiFi networks. Cellular wireless networks can transmit at powers as high as 750 watts in their unlicensed frequency bands. The FCC, however, also allows for an additional 4.9 antenna gain of 23 dBi which is equivalent to a total transmitting output of 56 dBm, or 400 watts. This transmit power limit applies to the base station end. The user end restrictions are much more severe. Because the public safety user is a mobile user, that user must employ an omnidirectional rather than a directional antenna on the public safety vehicle. Since omnidirectional antennas radiate in all directions, the FCC restricts their power to an antenna gain of 9 dBi. Using the same transmitter power of two watts (33 dBm), the total antenna output from the remote is restricted to only 42 dBm, or about 15 watts. Since data communication must flow in both directions, the vehicular radio—and particularly its antenna—becomes the limiting factor in antenna base station range.

The first development task, then, was to achieve the maximum transmit power permitted by the FCC on the weakest communications link – the path from the vehicle to the base station.

Transceiver power increases can be achieved in any one of three ways:

1. Increase the power of the basic transceiver
2. Install a high gain power amplifier
3. Increase the gain of the antenna

The most attractive of the above alternatives is the third one since a gain increase in the antenna will increase receiver performance as well as transmit performance. Unfortunately, the FCC limits omnidirectional antenna gains to 9 dBi, only one dBi higher than antennas presently in use. This FCC restriction limits power increases from improved vehicular antenna gain except for technologies that would allow the antenna to become directional. Recent advances in electronic scanning (beam shaping) antennas offer possibilities in this direction. This technology is being pursued for advanced versions of the network, but the time schedule of the Kenosha County project did not allow for a research investigation in this area. It is still possible, however, to increase antenna gain at the access point since the sectoral antennas there are already directional with additional FCC allowances for increased gain. The maximum allowable FCC total transmitted power called effective radiated power (ERP) is 56 dBm. With the current transceiver power of 25 dBM, the antenna gain allowance is 31 dBi. To understand the implications of increased antenna gain on system range, a link budget calculation shows a free space range of 6.1 miles. An ERP of 56 dBm resulting from a 31 dBi antenna gain would increase the free space range to 34.4 miles. While such a new free space range may seem excessive for a network that requires only a 3 mile average range to comply with the original 10 base station tower plan, it is important to remember that Kenosha County has a variable terrain with some areas sufficiently wooded, so that additional transmit power to overcome pathway "clutter" is definitely advisable. The current access point (AP) and vehicular antenna gains of 17 dBi and 8 dBi, respectively, represent the current state of the art at 4.9 GHz. Although it is possible to design an antenna with a gain of 31 dBi and thereby further increase the range of the 4.9 GHz infrastructure, such design do not have sufficient sectoral beam width to support a 90° sector.

The easiest of the three transmit power augmentation alternatives to bring about proved to be increasing the gain of the basic transceiver. The original transceiver used in initial field testing had an output of 18 dBm which in conjunction with the other components of the system produced a link free space range of only 2.7 miles. Since there is a three mile radius requirement to comply with the system plan calling for only 10 base stations for county wide coverage, some means had to be found to extend the free space range to at least five miles. The extra distance is necessary to allow for additional signal attenuation from trees or buildings. The longer the range capability provided, the more likely any given location will comply with the performance specifications. In the first round of field testing, a bi-directional amplifier with automatic gain control was incorporated that provided a combined output of 27 dBm. Such a configuration resulted in a predicted range of 7.7 miles. Unfortunately, this same amplifier magnified the noise to a greater extent than the signal, degrading the overall performance of the system. For this reason, the original transceiver/amplifier combination was replaced with a higher power transceiver board that furnished 25 dBm of power but with an improved signal-to-noise ratio and system performance. This modification provided a free space link range of 6.1 miles which has been field test verified to meet plan specifications. Future enhancements of transmit power up to the FCC – allowed total of 56 dBm are best achieved through antenna gain enhancements at the access point end since the FCC limitations are less restrictive for antenna gain than for transceiver elements.

The second area of technology improvement, receiver sensitivity, can be improved at both ends of the access point/user link by either the integration of more sensitive transceiver units or through the use of low noise amplifiers. Receiver sensitivity is defined as the lowest detection signal level for a specified bit error rate, usually one error in one billion bits transmitted. The current range of 6.1 miles is based on a receiver sensitivity of −90.0 dBm. Since 10.0 dBm represents 10 milliwatts, −90 dBm would represent 100 dBm lower, or 1.0 picowatts (pico represents 10^{-12}).

With antenna gain increases at both the user and access point and limited by either FCC regulations (remote user) or the state-of-the art in (access point) antenna technology, amplifier development is the only practical avenue to receiver sensitivity improvement. The benefit of a low noise amplifier (LNA) in front of the radio receiver lies in its ability to lower receiver sensitivity. For example, if a radio receiver sensitivity of a radio channel could be reduced from −90.0 dBm to −96.0 dBm, the free space range of the antenna base station would be doubled. To lower the sensitivity of the receiver, the amplifier must have a lower noise figure than the receiver itself. Fortunately, such an amplifier was found later in the project schedule that can be incorporated in both the base station and user equipment for lower receiver sensitivity and increased antenna base station range. Receiver sensitivity improvements are most dramatic at extreme distances from the access point where the signal-to-noise ratio, (SNR) is low and throughput rates necessarily lowered. It is, of course, at these distant ranges where improvements in sensitivity are most needed. Extensive field testing has established the capability of low noise amplifiers to achieve significant improvements in receiver sensitivity.

The end result of the project from higher transmit power and lower receiver sensitivity has been a range extension of 4.9 GHz radio communications technology that allows for a future network of 10 antenna base stations in Kenosha County consistent with the regional wireless plan.

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Chapter IV

THE PLANS

INTRODUCTION

Kenosha County
Kenosha County is located in the southeastern corner of the seven-county region adjacent to the Illinois border. The County has a land area of 273 square miles and a year 2000 resident population of 149,577 people located in 56,057 households. With a population density ranging from 41 persons to 3,835 persons square miles, it is a combination rural/urban county. The major population concentration is in the eastern part of the county in the City of Kenosha and its suburbs. The remaining 80 percent of the county west of Interstate Highway 94 is largely rural with a much lower population density. The county's primary economic activities are still manufacturing and agriculture, but it also has become a "bedroom" community for commuters working in northeastern Illinois.

The Regional Wireless Plan
A major objective of the regional wireless plan described in SEWRPC Planning Report No. 53 was universal geographic coverage. Because many parts of the Region are rural with lower population densities, the regional wireless plan called for a combined public safety/commercial wireless communications infrastructure to improve the economics of broadband communications deployment and to justify comprehensive network deployment in the Region. The regional wireless plan is fully described in Planning Report No. 53. The plan designates fourteen antenna base station sites within Kenosha County as part of a 141 base station site regional plan. This network would support both 4.9 GHz public safety and 5.8 GHz frequency band services. This plan was used as the starting point for the more detailed engineering level plan prepared as part of this project.

The Kenosha County Broadband Public Safety Wireless Communications Demonstration Plan
Planning in the context of this project extended beyond the scope of the previous regional telecommunications planning in both the detail and scope of the planning effort. Planning work efforts took place in two primary categories.

1. Network Layout Planning
   - The county-level more detailed equivalent of the regional wireless plan
   - For both the selected base station demonstration area
   - And for a future full-scale county-wide network

2. Technology Planning
   - To define the development, procurement, assembly and test work activities necessary for the combined network demonstration
   - To schedule these work activities in the project time frame

Network Layout Planning
Wireless communications network layout plan preparation was carried out to support two project objectives:

1. Field Test Demonstration
   - To provide geographic radio coverage maps for the two initial base stations BST2 and SAL6, both county-owned antenna sites
   - To guide range and performance testing during the field demonstration
2. Preliminary County-wide Wireless Network
   - A plan detailing the number, location, and performance-level geographic coverage of antenna base stations for county-wide coverage for both public safety (4.9 GHz) and commercial (5.8 GHz) communication services
   - Providing the basis for a preliminary infrastructure budget for the two frequency bands

Wireless network plans (4.9 GHz) for the two demonstration antenna site base stations are shown in Map 2 (using a 12 dB preamplifier) and Map 3 (for a 23 dB preamplifier). The longer range and more complete coverage of the 23 dB preamplifier network is evident from map examination. The differences in performance of the two technical alternatives will be more dramatic when the larger number of antenna sites for the 12 dB preamplifier network is shown. Both radio coverage maps were needed to guide field demonstration testing since the higher performance 23 dB preamplifier was not available for early field testing. Initial field testing was performed using the commercially available 12 dB preamplifier. Radio coverage and throughput performance were to be tested and compared with these radio coverage maps to verify the technology and provide the supporting evidence for the final wireless network plan layouts.

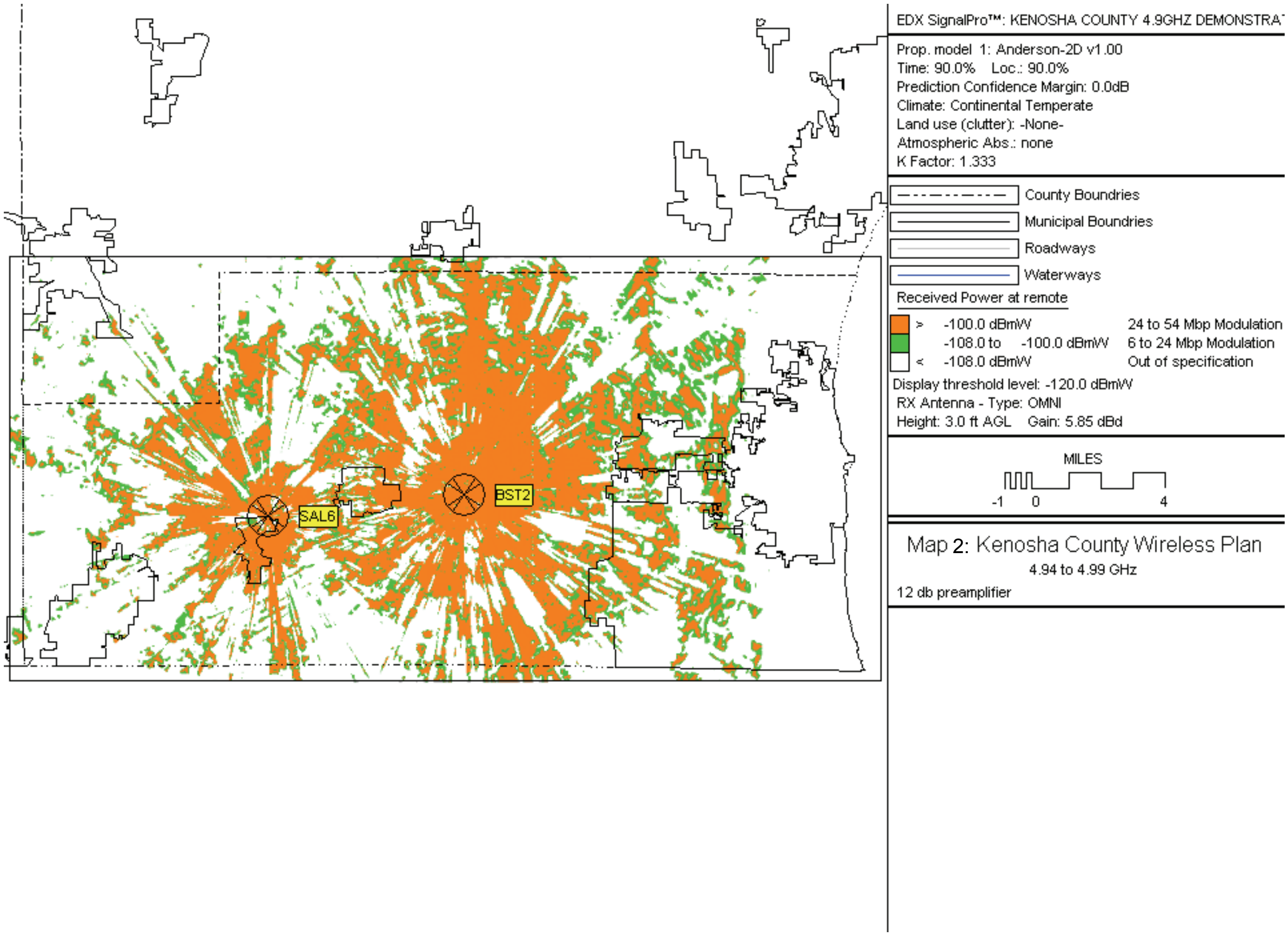
Similar plans for the commercial 5.8 GHz network using the same base stations are shown in Map 4 and Map 5. Radio transmission at the higher 5.8 GHz frequency has higher signal attenuation, but the higher gain fixed user antennas more than compensate for this difference. Higher signal levels at the user end result in more comprehensive coverage than that displayed on the equivalent 4.9 GHz maps. This 5.8 GHz network advantage simplifies the dual frequency network design problem since a network designed for adequate 4.9 GHz public safety communications coverage should readily satisfy the coverage and throughput performance needs of the 5.8 GHz network. These networks characteristics allows for design concentration on the 4.9 GHz public safety communications network.

First attempts at developing a county-wide 4.9 GHz coverage network plan utilized only the 8 county-controlled (owned or leased) antenna sites. Such a network, illustrated in Map 6, still leaves considerable parts of the county without coverage. The same is also true for the 5.8 GHz network shown in Map 7. Uncovered areas are particularly noteworthy in the southwest corner and southern fringes of the county.

The next iteration of network design added 6 new non-county sites to the original 8 county sites to provide essentially complete county-wide coverage with 14 base stations, the same as in the original regional wireless plan. The Gateway Technical College antenna site was then brought to the project staff's attention. By adding this site to the original alternatives, it was possible to eliminate four county-controlled sites, add the Gateway site, and provide complete coverage with only ten sites, four less than the previous plan. This network plan is shown in Map 8. The influence of antenna heights on the plan is illustrated in Map 9, with the relative tower heights indicated by the radii of the circles centered at each site. Heights range from 140 meters at PLP6 to only 9 meters at PLP9. All of these new sites are privately-owned and presumably available for the same lease arrangements as some of the original eight county-controlled sites.

Map 2

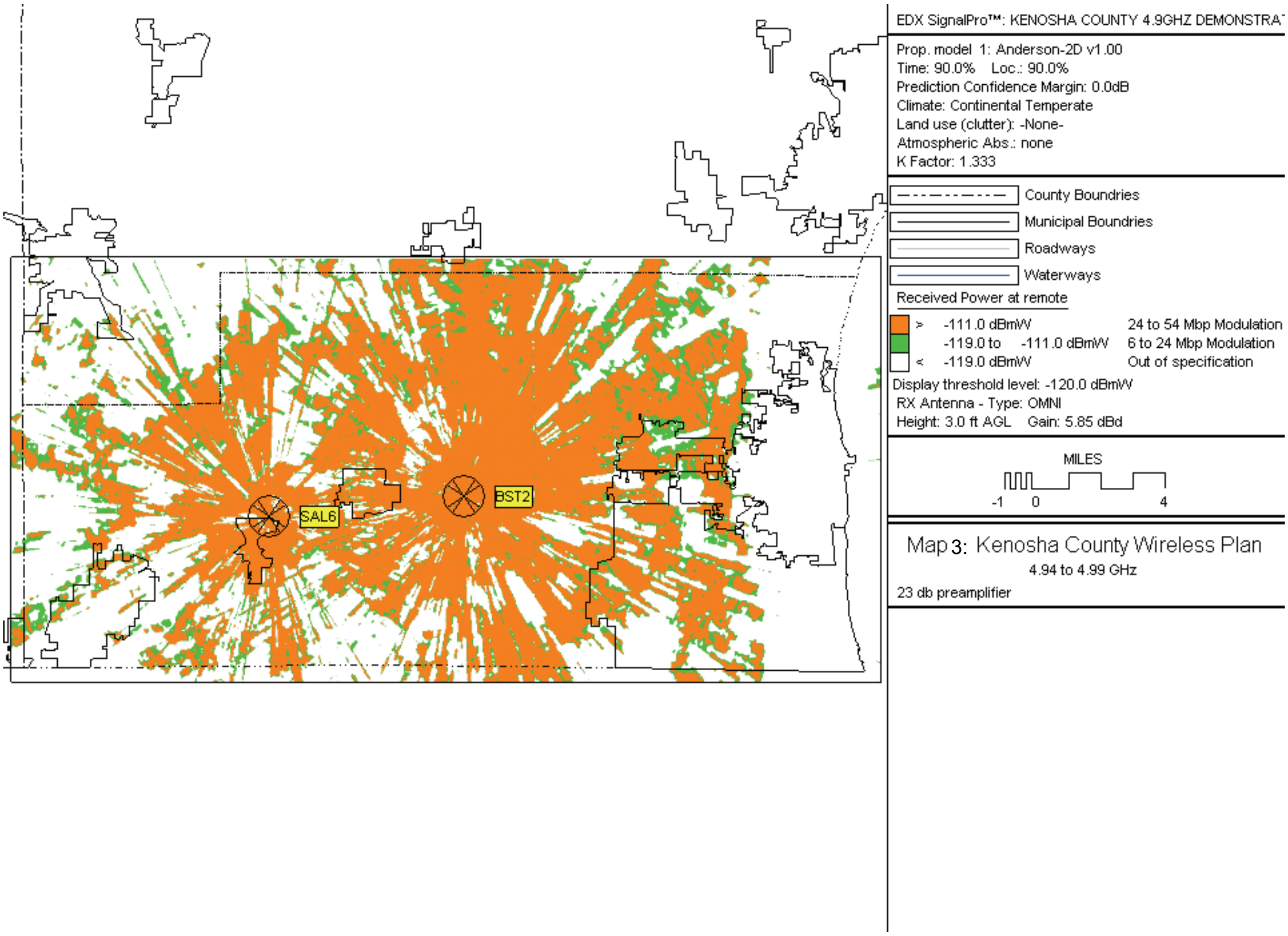
WIRELESS FIELD TEST NETWORK PLAN (4.9 GHz) – 12dB PREAMPLIFIER



Source: SEWRPC.

Map 3

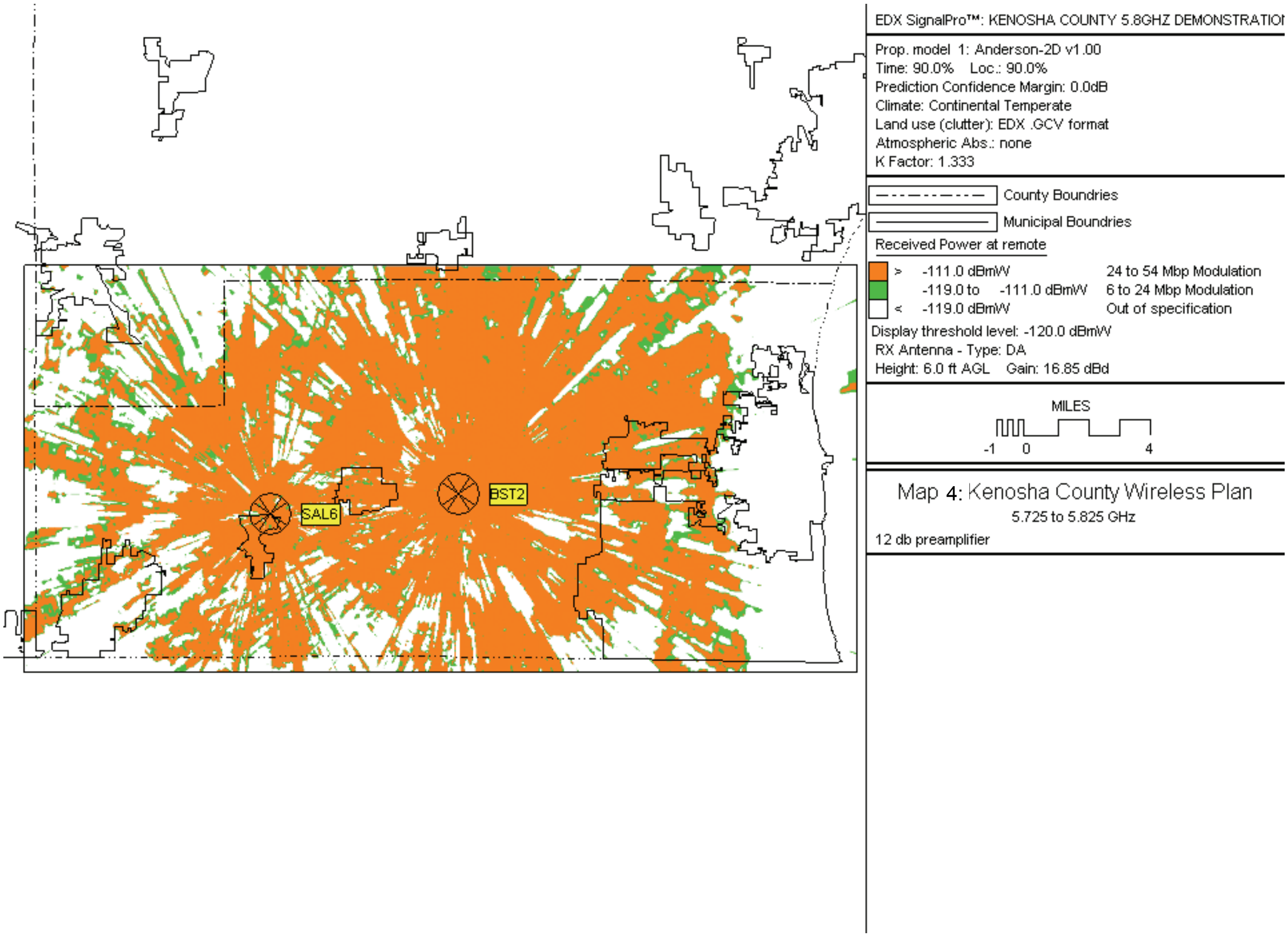
WIRELESS FIELD TEST NETWORK PLAN (4.9 GHz) – 23dB PREAMPLIFIER



Source: SEWRPC.

Map 4

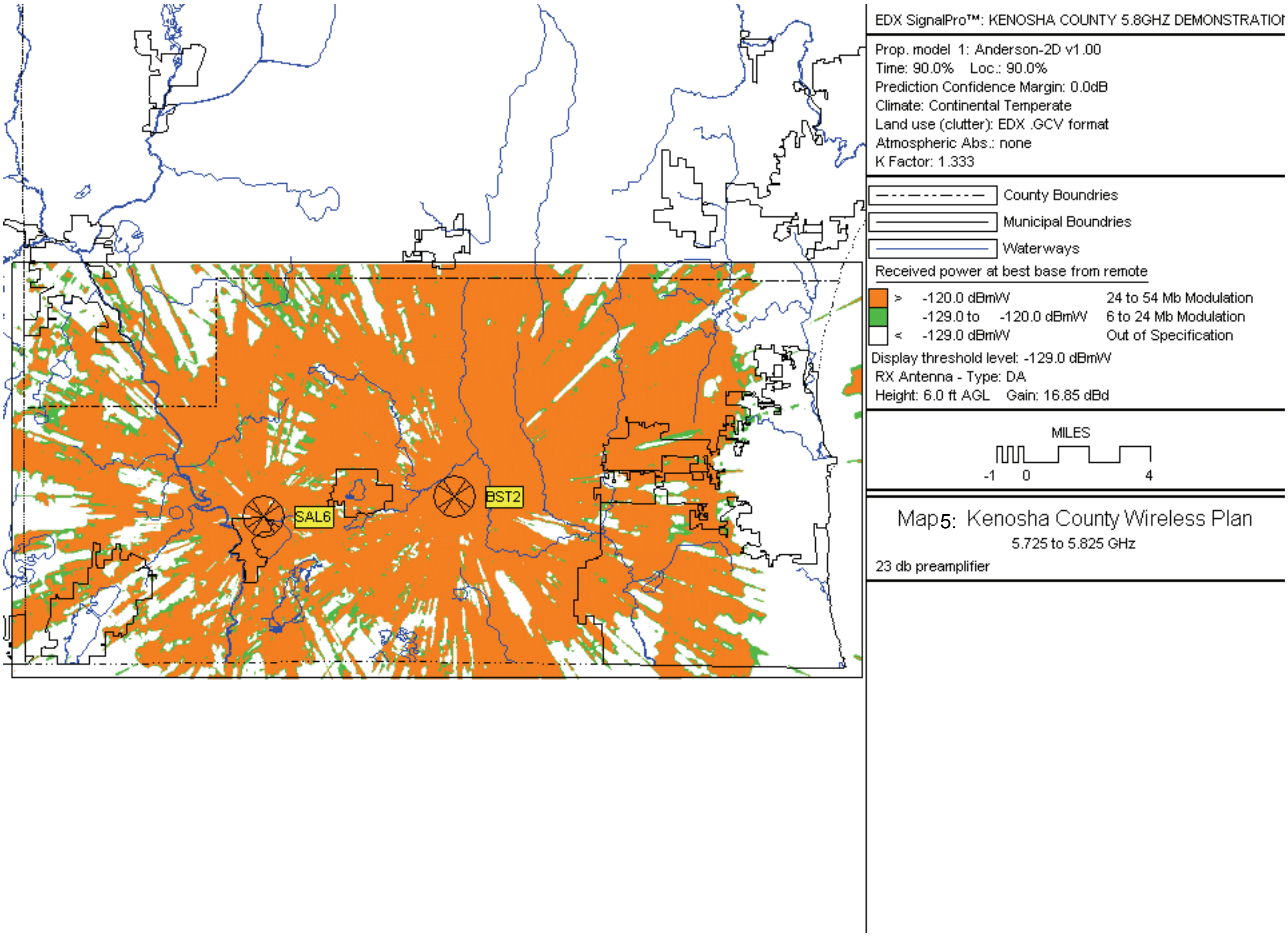
WIRELESS FIELD TEST NETWORK PLAN (5.8 GHz) – 12dB PREAMPLIFIER



Source: SEWRPC.

Map 5

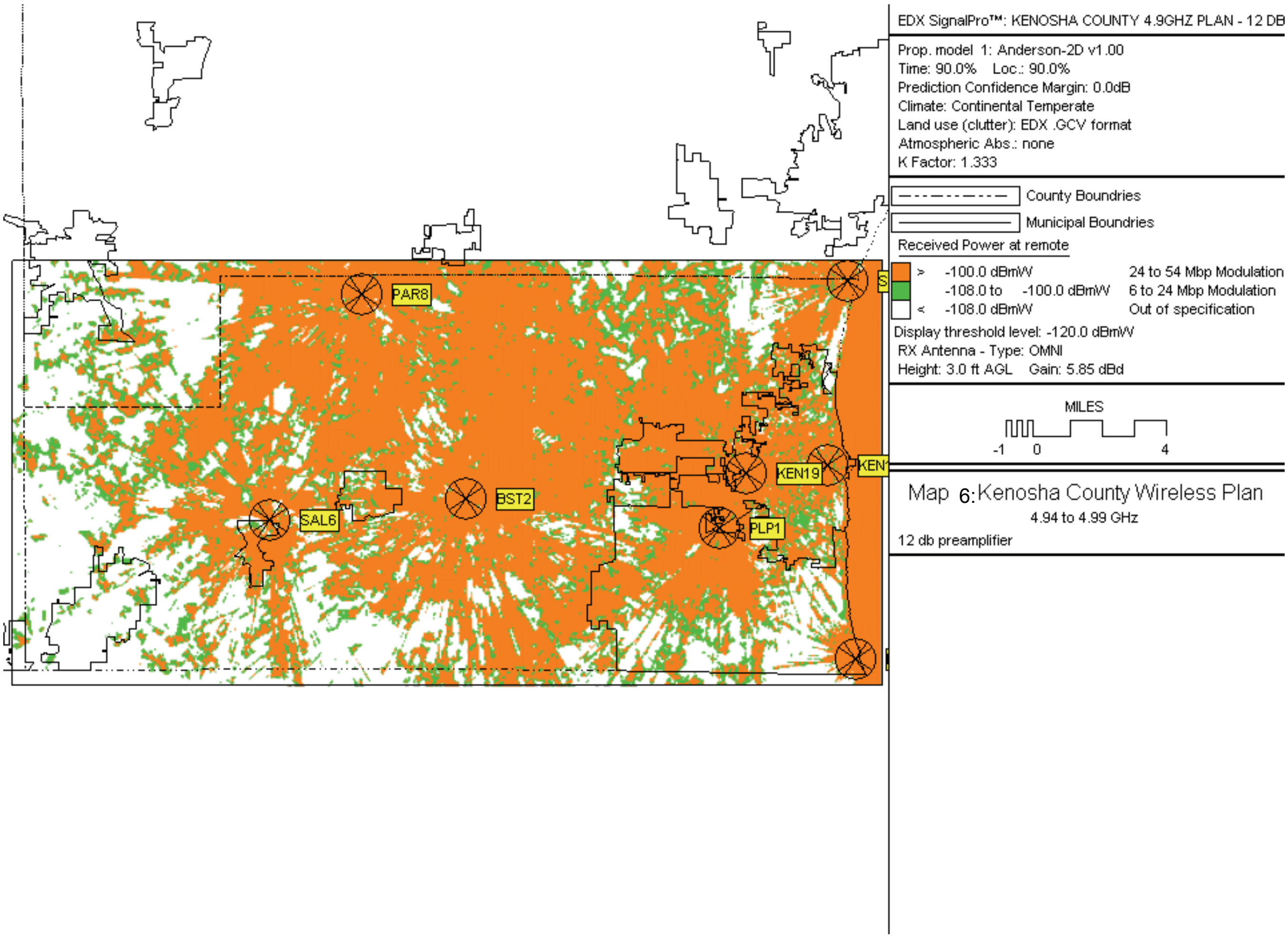
WIRELESS FIELD TEST NETWORK PLAN (5.8 GHz) – 23dB PREAMPLIFIER



Source: SEWRPC.

Map 6

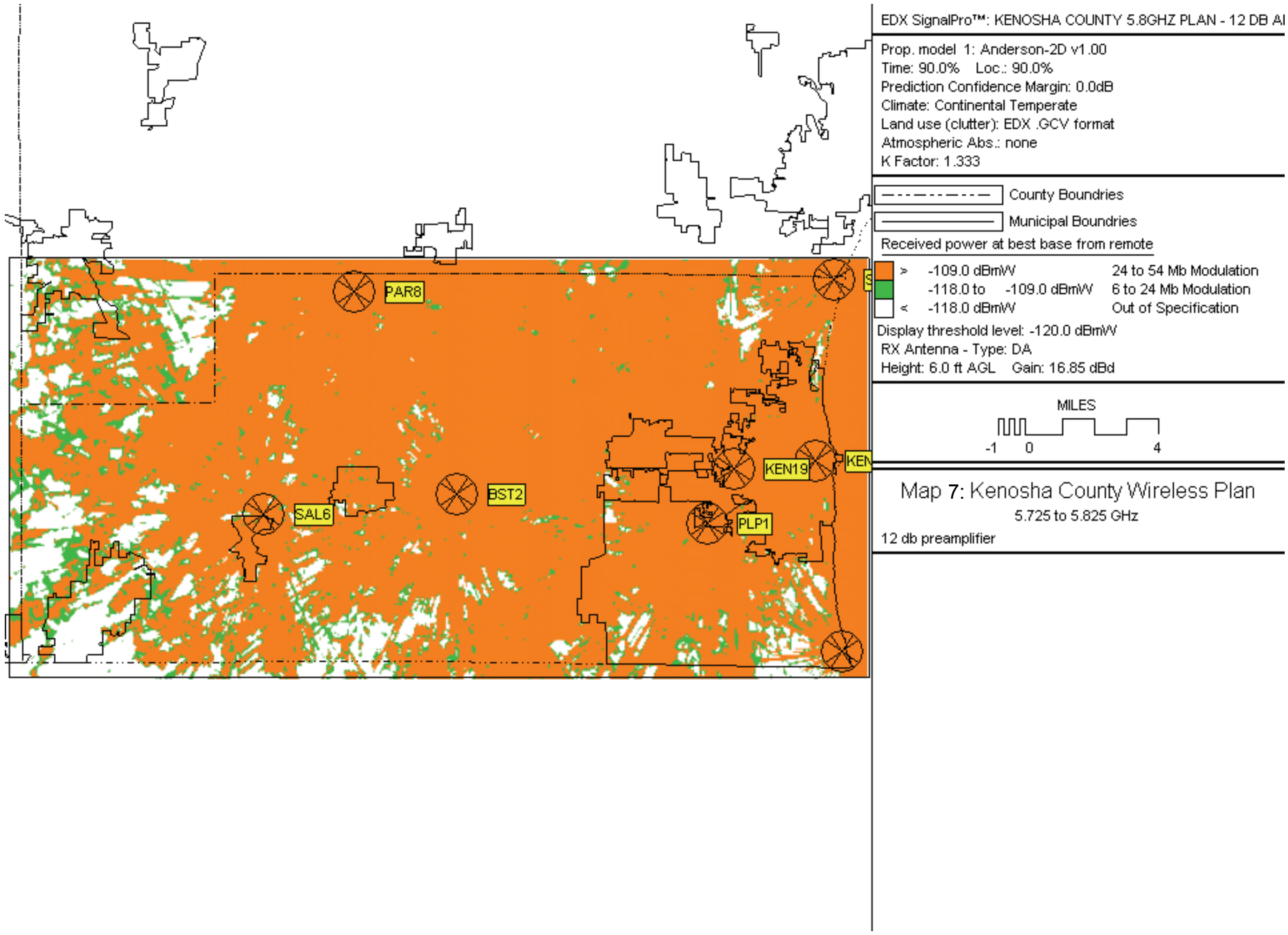
WIRELESS FIELD TEST NETWORK PLAN (4.9 GHz) – COUNTY SITES ONLY



Source: SEWRPC.

Map 7

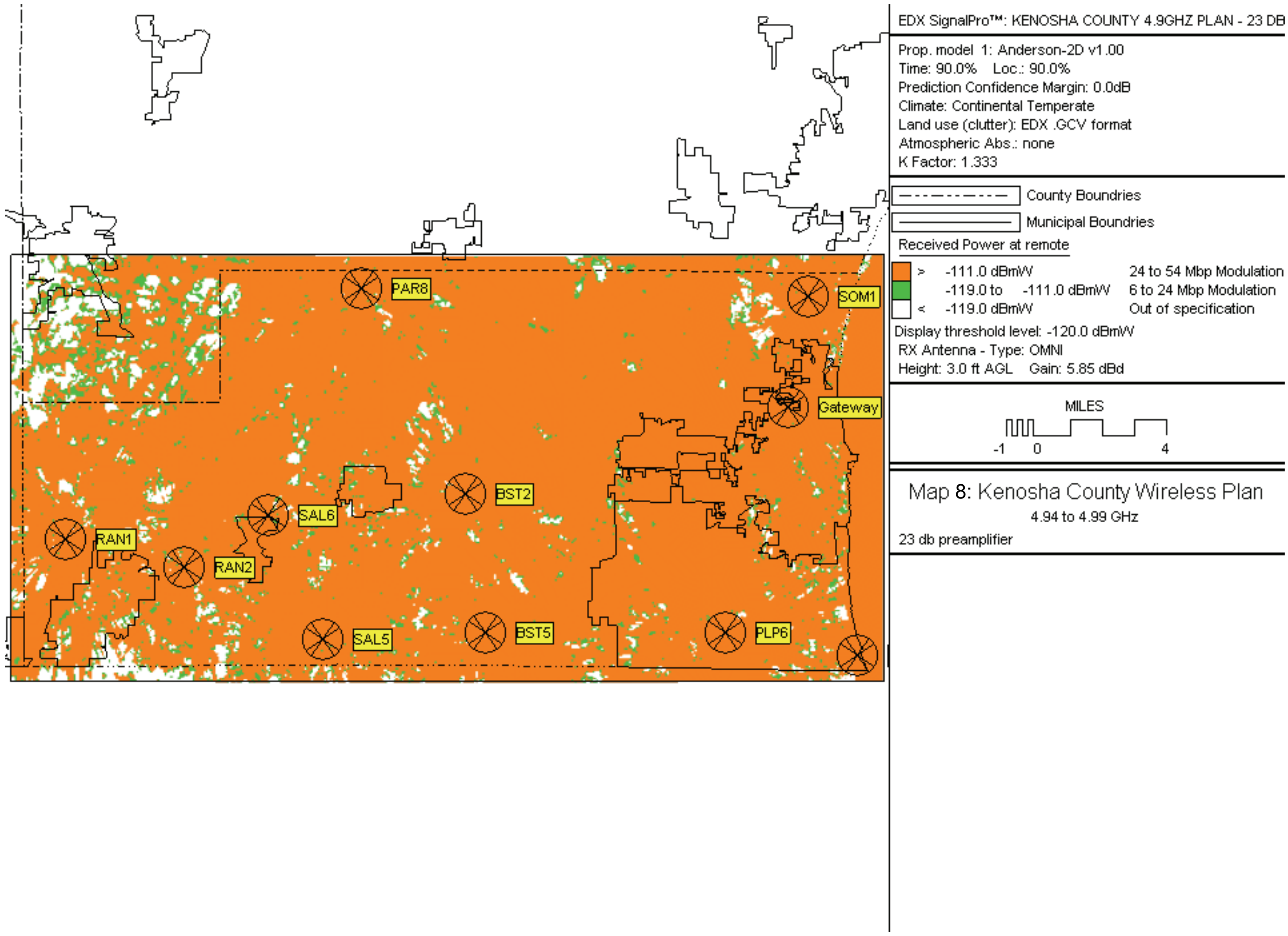
WIRELESS FIELD TEST NETWORK PLAN (5.8 GHz) – COUNTY SITES ONLY



Source: SEWRPC.

Map 8

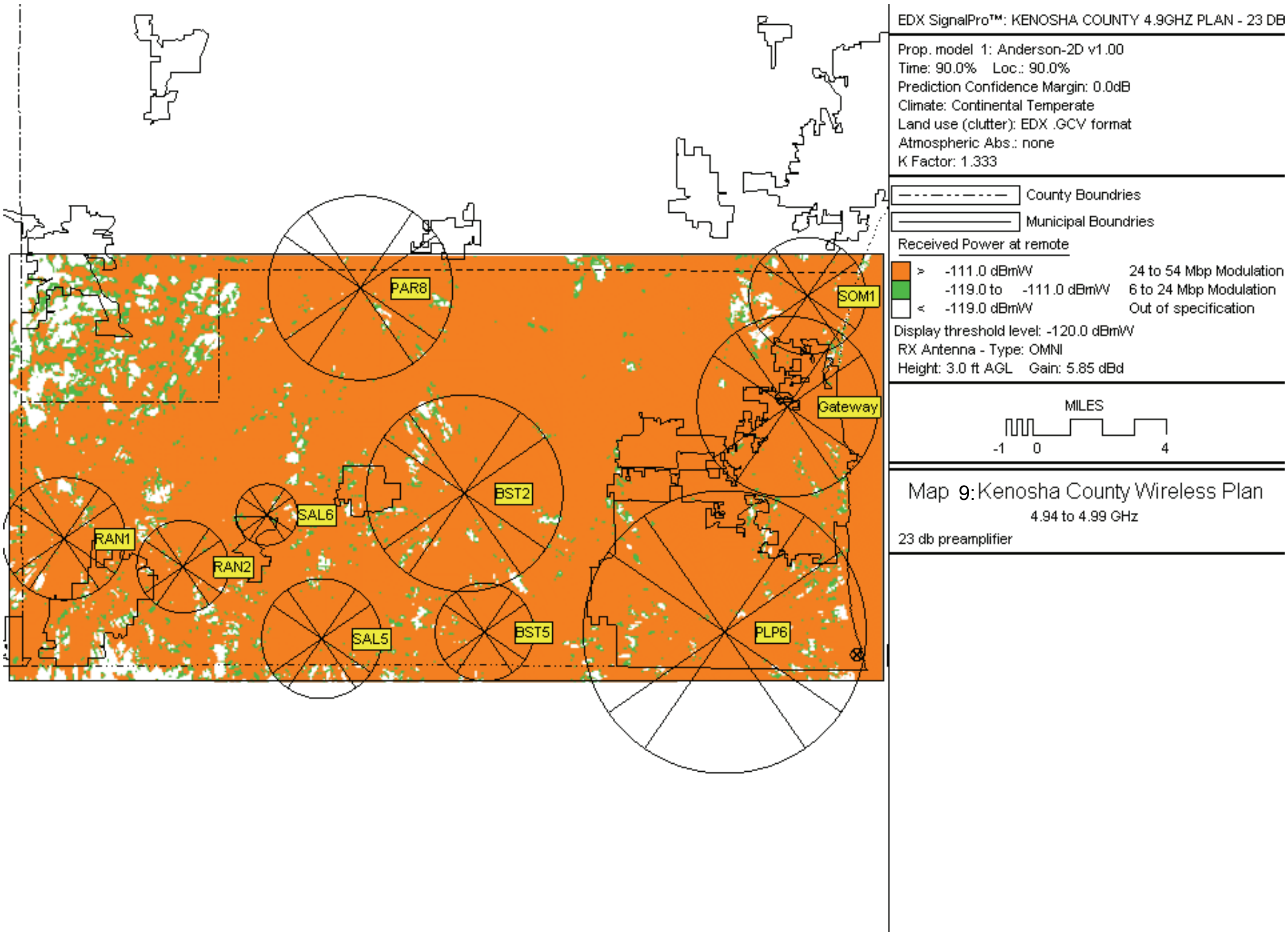
FINAL WIRELESS NETWORK PLAN (4.9 GHz)



Source: SEWRPC.

Map 9

INFLUENCE OF ANTENNA TOWER HEIGHTS ON THE 4.9 GHz PLAN



Source: SEWRPC.

A number of design iterations evaluated the use of repeater sites. These antenna sites would generally be lower in height and could utilize county-owned emergency siren locations and structures. Electric utility poles could also be used for these sites which typically would range from 20 to 50 feet in height. Unfortunately, this approach did not prove to be effective, with an excessive number of repeaters needed to replace one antenna base station site. The 10 antenna base station plan shown on Map 10 previously presented areas to offer the required county-wide coverage at least cost. The height of the antenna is an important parameter in network design. The ability of an antenna to clear the heights of buildings and forestation greatly increases the range of the site and makes for a more cost effective network design. The cost effective nature of the proposed network becomes evident with the formulation of a network infrastructure budget in the section that follows.

In the interest of both historical continuity and current relevance, two system infrastructure budgets were provided. Following an original infrastructure previously budget presented in a January 2008 progress report, and a description of the development process, a revised infrastructure budget reflecting the actual equipment used in the field demonstration was detailed. The basis for the changes in infrastructure equipment are explained in the development process narrative.

Network Infrastructure Budget - Original
Based on a network infrastructure of 10 antenna base station sites, a preliminary infrastructure budget was prepared with appropriate contingencies to allow for uncertainties in some of the cost elements.

Antenna Base Station Costs

1.	Transceiver Modules	
	4.9 GHz (2)	$3,000
	5.8 GHz (2)	3,000
2.	Sectorized Antenna (1)	1,000
3.	Directional Antennas (2)	200
4.	Power Conditioning and Backup	4,000
5.	Amplifiers (6)	3,300
6.	Utility connection	2,000
7.	Installation and Testing	4,000
8.	Miscellaneous	3,000
	(Freight, cabling and travel)	
9.	Fiber Interconnection	2,000
		$25,500

4.9 GHz Network Cost Summary

1.	Antenna Base Stations	
	10 at $25,500	$255,000
2.	Network Monitoring System	50,000
3.	Project Management and Engineering	125,000
4.	Contingency (20%)	85,800
		$515,800

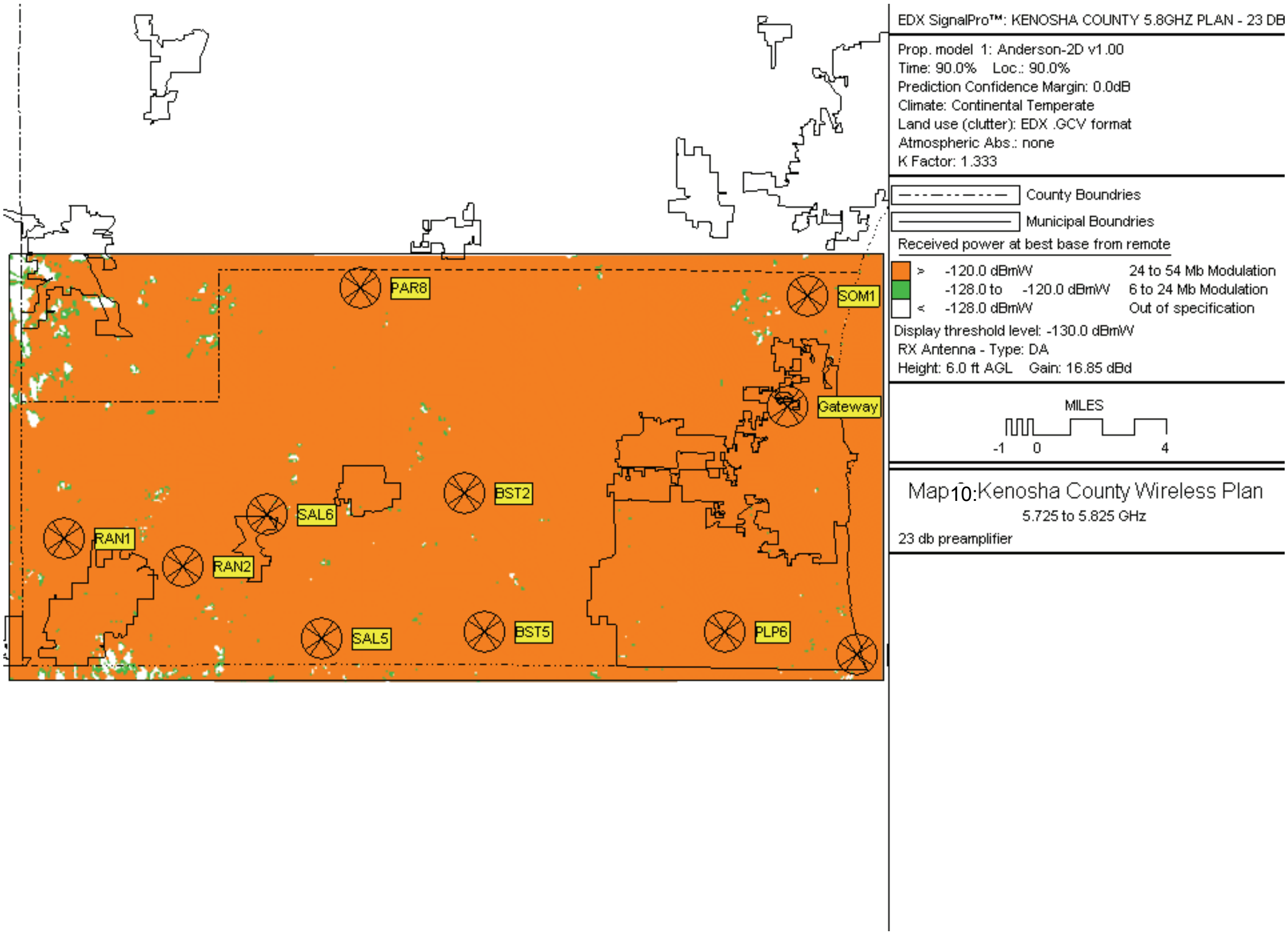
Note 1: The above infrastructure cost budget assumes the eventual availability of optical fiber for Internet gateway interconnection at each base station.

Note 2: The above budget does not include costs for any front-end property fees for co-location at antenna base station sites.

Note 3: The above budget does not include costs for installing communications equipment in public safety vehicles.

Map 10

FINAL WIRELESS NETWORK PLAN (5.8 GHz)



Source: SEWRPC.

Note 4: Costs are included in the above budget for wireless backhaul pending the availability of an optical fiber gateway at each antenna base station site.

Technology Development Planning

From the onset of the project, it was known that the primary objective of the project calling for a county-wide 4.9 GHz public safety network could not be achieved with COTS (commercial-off-the-shelf) technology. Existing 4.9 GHz networks are short range in nature requiring mobile users to be in the close proximity of a designated access point. Achieving county-wide communications coverage in accordance with the network plan would require considerable extension of access point range. Because of the small existing market in the 4.9 GHz frequency band, there is also a lack of readily available components in some categories. For this reason, a detailed development/procurement plan was necessary to assure the timely completion and success of the project. This planning took place in four communications equipment categories:

1. Access Point equipment
2. Vehicular Equipment
3. Fixed User Equipment
4. Peer-to-Peer Feature Equipment

Access Point Equipment

Originally, the basic access point transceiver/router communications equipment plan specified the use of the Waveteq Comunications Shadowmaster unit which embodied two sets of transceiver/routers and a backhaul antenna all in one compact enclosure. Waveteq, a Canadian company from British Columbia, converted an existing commercial 5.8 GHz product into a 4.9 GHz equivalent for public safety. Following some initial equipment purchases and bench testing, the Waveteq alternative was abandoned for the following reasons:

1. Future Production Commitment
   Wateteq at the time was unwilling to make a future commitment to produce the 4.9 GHz transceiver/router equipment in volume. Lacking such a commitment, there was no assurance of equipment availability if Kenosha County were to move ahead with a full-scale deployment.
2. Performance
   Bench testing and early field testing indicated that Waveteq throughput performance may not achieve the 4G (fourth generation wireless) standard of 20 megabits per second. Early test results averaged in the 10-12 megabits per second range.
3. Packaging
   Since additional amplifier equipment was needed to achieve range and performance objectives, extensive cabling requirements led to an equipment package that appeared too experimental in appearance.

Notwithstanding the above decision, Waveteq access point equipment was still used for the 5.8 GHz commercial frequency band since the performance requirements for this band were not as stringent as in the 4.9 GHz public safety band. Because the 5.8 GHz band was designed for fixed users with directional antennas, the network in this band had a significant link gain, range, and performance advantage. Any infrastructure design satisfying the 4.9 GHz network needs would easily comply with the 5.8 GHz network specifications.

Lacking any communications equipment capable of fulfilling plan requirements for designated access points, the development plan called for specifying an access point equipment configuration with the following elements:

1. Routerboard(s)
   - To process and route access point data
2. Transceiver(s)
   - To send and receive data from sectoral users
3. Amplifier(s)

   - To amplify transmitted and received data
   - In accordance with the IEEE 802.11x standard
4. Sectoral Antenna Array
   - To convert received electromagnetic radio signals into electrical values for signal processing
   - To convert electrical signals into transmitted radio waves
   - For each of the four 90 degree access point sectors
5. Weatherproof Enclosures
   - To house all of the above components except the sectoral antenna array

The key specifications defining the performance of each of the above components were determined as follows:

1. Routerboard
   a. Interface capacity
   b. Processor speed (megabits/second)
   c. Channel speed (megabits/second)
   d. Other communications features
2. Transceiver
   a. Transmit power (dBm)
   b. Receive sensitivity (dBm)
   c. Compatibility
   d. Channel speed (megabits/second)
3. Amplifier
   e. Gain (dB)
   f. Insertion loss (dB)
   g. Noise figure (dB)
4. Antenna Array
   a. Gain (dBi)
   b. Beamwidth (degrees)

The technology development plan called for a review of existing technology to identify the best system components and to point out areas where no existing technology met system requirements.

Vehicular Equipment
The router, transceiver, and amplifier equipment previously described for the access point location are also an integral part of the communications equipment in the public safety vehicle. For compatibility reasons, equipment selections for the access point configuration will generally dictate selections at the user end. Router equipment for mobile vehicles is usually simpler than its access point equivalent, but channel compatibility is key, so that access point equipment selections govern vehicular equipment choices.

A notable exception is the vehicular antenna. Because the public safety vehicle is mobile, it must employ an omnidirectional antenna, an antenna configuration very different from the access point. Required was a monopole class of antenna with a gain of at least 8 dBi with performance independent of the mounting surface. Mounting surface needs derive from the need to mount the antenna on a variety of vehicles (law enforcement, fire, and ambulances) while retaining the gain performance characteristics of the device. Such an antenna was designed, fabricated, and tested during the project that met all system requirements.

Fixed User Equipment
Fixed user equipment applied only to commercial users in the 5.8 GHz frequency band. The transceiver/router/amplifier equipment is similar to that used in public safety vehicles except for the frequency band being 5.8 GHz rather than 4.9 GHz. The antenna, however, is directional in nature utilizing a panel antenna design that is housed in a common enclosure with the other subscriber electronic components.

Peer-to-Peer Equipment
By itself, the peer-to-peer communications feature is implemented in software and does not require additional equipment. The addition of the geomessaging function, however, does require a geographic positioning system (GPS) unit to provide continuing user location. Such a GPS unit with its own very small antenna was incorporated in the public safety vehicular equipment package.

Network Infrastructure Budget – Revised
A revised network infrastructure budget was prepared that reflected the costs of the upgraded 4.9 GHz network technology.

Antenna Base Station Costs:

1.	Transceiver/Router Modules (2)	$3,000
2.	Sectorized Antenna	1,500
3.	Amplifiers (4)	1,600
4.	Installation and Testing	5,000
5.	Miscellaneous	3,000
6.	Structural Engineering Study	4,000
		$18,100

4.9 GHz Network Cost Summary:

1.	Antenna Base Stations 10 @ $18,100	181,000
2.	Project Management and Engineering	294,000
		475,000

Note: Power Backup, Power Utility and Fiber Interconnection costs are not included in the above summary.

Vehicular Equipment Costs
A price estimate of future vehicular 4.9 GHz communications equipment for public safety vehicles was required. The estimated price was $2,000 for each vehicle based on the following components comprising the vehicular configuration:

1. Omnidirectional antenna
   - with decoupled antenna mount
2. Amplifier
3. Routerboard
4. Transceiver(s)
   - Set of three to perform basic peer-to-peer and geomessaging functions
5. Power supply
6. Lightning and surge protection
7. Cabling and miscellaneous
8. Global positioning module
9. Hardened enclosure

The $2,000 price estimate was based on a parts and labor cost of $1,100 and a $900 manufacturer's margin. Those estimates are believed to be accurate for budgeting purposes.

Summary

The Kenosha County Broadband Public Safety Wireless Communications Demonstration Plan was prepared in support of the regional wireless plan described in SEWRPC Planning Report No. 53. Planning was carried out in two categories – network layout planning and technology planning. Network layout plans were prepared for both the two-tower demonstration area and for the final fully deployed multi-base station network. Technology planning related to the requirements for either developing or purchasing all of the components of the system required to achieve project objectives.

Chapter V

THE COMMERCIAL BUSINESS MODEL

INTRODUCTION

A major rationale for the regional wireless plan was based on infrastructure cost sharing between broadband wireless public safety and commercial networks. This cost sharing would significantly improve the economics of commercial broadband communications deployment particularly in low density rural areas of the country. Kenosha County is a mixture of urban and rural settings. Although the County has 56,000 households, 41,000 of those households reside in urbanized areas mostly east of the Interstate 94 freeway. The remaining 15,000 households live in 80 percent of the low density land area located west of IH-94. The population density in this rural part of the county averages less than 150 households per square mile. As a potential market opportunity, this rural area compares very favorably with the market situation previously reported for the Town of Wayne in Washington County where the population density was only 23 per square mile. The question here - how does the public safety/commercial infrastructure cost sharing impact the viability of the business model?

A detailed financial analysis was carried out for Kenosha County comparing a stand-alone network deployment with a shared infrastructure approach consistent with the socio-economic and geographic characteristics of Kenosha County. A stand-alone network would be similar to the previous example of the Town of Wayne in Washington County except on a much larger scale. There were only 830 resident households in Wayne while there are 15,000 households in the rural part of Kenosha County. An assumption was made that initial commercial concentration would be on the 15,000 potential rural subscribers. Following the establishment of a profitable business in the rural areas, expansion to the urban/suburban part of the county may represent a worthwhile business opportunity. There are also often underserved areas in the lower income portions of these urban communities.

The infrastructure costs of a broadband wireless network are of three kinds:

1. Cost of the tower or access point structure
2. Cost of the fiber wireline or wireless backhaul
3. Cost of the tower or access point communications equipment

The cost level of the second of the above items far exceeds the cost of the other two categories. Considering structure costs first, the cost of a 100 foot tower for the foundation and structure alone is about $15,000. Additional costs related to land cost, various utility connections, building structures, and security features can readily increase the total cost to over $20,000. A very detailed estimate of the cost of a new base station tower in SEWRPC Planning Report No. 53 indicates a total cost of about $38,000. Since this estimate included communications equipment, subtracting the revised communications budget to obtain the cost for the tower itself with building and accessories would total about $21,000.

The major cost, however, lies with category number two – the backhaul. An early decision in Kenosha County was made to deploy a fiber wireline backhaul in which all of the 10 base station towers are connected in a fiber ring. Although considerably more expensive than an alternative wireless backhaul network, a fiber backhaul ring has considerably greater capacity both immediately and in the long term. As network usage grows, wireless backhaul links frequently become the bottleneck in the system. The very large capacity of fiber networks insures that a fiber backhaul ring will never become a system bottleneck. The cost of such a fiber ring, however, is estimated about $3.0 million, far more than the cost of the other two categories.

In accordance with the regional wireless plan, the primary investment of the commercial ISP operator would relate to the third of the above cost categories - the cost of the access point communications equipment. The ISP would be responsible for all of the items listed previously on page 25 for the unlicensed 5.8 GHz band. Since the equipment except for the frequency band is virtually identical at both frequencies, the revised budget in Chapter IV of $500,000 may be used as the best estimate here for ISP investment in 5.8 GHz access point communications equipment and installation.

Investment and Economic Summary
Summarizing the comparative investments for a standalone versus a combined public safety/commercial broadband wireless network, each of the alternatives for the prospective Internet Service Provider is tabulated below:

Stand Alone 5.8 GHz Network

1. Tower Structures and Utilities	
10 x $21,000	$ 210,000
2. Fiber Ring Backhaul	
- For 10 station ring	3,000,000
3. Communications Equipment	500,000
Total	$3,710,000

Combined 4.9/5.8 GHz Network

Communications Equipment (5.8 GHz only)	$500,000

On an initial capital investment basis, there is little question that the combined network has a decisive economic advantage. In a time of capital shortages and tight credit conditions, this 5 to 1 capital advantage can provide great incentive for the deployment of broadband wireless networks.

A true and complete economic analysis, however, must consider the present value of future rental and Internet connection costs based on a fair return for the public investment in the tower structures and the fiber ring network. Tabulating the tower rental and Internet connection costs:

1. Tower Rental – 150 foot tower	
$4/foot/month =	$ 600/month
2. Internet Connection	
$70/Mbps/month rate	
100 Mbps/month =	7,000/month
For 10 towers - $76,000/month	$7,600/month
Annual Total	912,000/year

Present Value Determination	
Period	5 years
Interest rate	5%
Present Value =	$ 3,948,500

The above present value allows for the determination of the breakeven rental/connection for the network alternatives as:

(3.00/3.95) (7,600) = $5,702/month)

Any rental/connection rate lower than $5,700/month would establish the economic advantage of the combined public safety/commercial broadband wireless network.

With the breakeven rental/connection cost at $5,700/month with a connection portion at $5,100, it is possible to obtain connection rates on a wholesale basis as low as $45/Mbps/month which indicates an annual savings of $72,000 beyond breakeven which has a present 5 year value at 5% of $311,000. This savings in conjunction with the much lower front end investment clearly established the economic advantage of the combined broadband public safety/commercial wireless network in low density rural or mixed urban/rural counties such as Kenosha County.

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Chapter VI

THE FIELD TESTS

INTRODUCTION

Field testing was scheduled in a three stage sequence.

1. Initial Stage 1 local (Waukesha County) field testing to establish the functionality of the communications equipment.
2. Public Safety Stage 2 (4.9 GHz) field testing in Kenosha County to establish the range, geographic coverage, and performance of the system for mobile vehicular users.
3. Commercial Stage 2 (5.8 GHz) field testing to establish the range, geographic coverage, and performance of the system for fixed users.

Stage I Field Testing in Waukesha County

A SEWRPC truck-mounted 20 feet mast test rig was used for 4.9 GHz field testing in the Towns of Merton and Oconomowoc in Waukesha County. The access point (AP) was located along Peterson Road between West Shore Drive and Stone Bank Road in the Town of Merton, as shown in Map 11. With the truck-mounted AP at this location, signal-level measurements were carried out with a second roving vehicle equipped with a suitable 4.9 GHz interface card and the Air Magnet Survey software program. Signal measurements were recorded along Peterson Road, Stone Bank Road, Town Line Road, West Shore Road and in various local subdivisions. Except for the measurements along Peterson Road, radio paths traversed areas with both tree and building "clutter". All field measurements were performed without an amplifier in the remote receiver unit. An amplified unit would have extended the 10 dB SNR range much farther. Consistent with public safety vehicular communications, a lower gain (8 dBi) omnidirectional antenna was used in the vehicle for all measurements.

Observing Map 11, signals were measured at the 10 dB or greater amplitude level at points 1, 2, 3 and 4 at distances as follows:

Point #1 – 1.46 miles

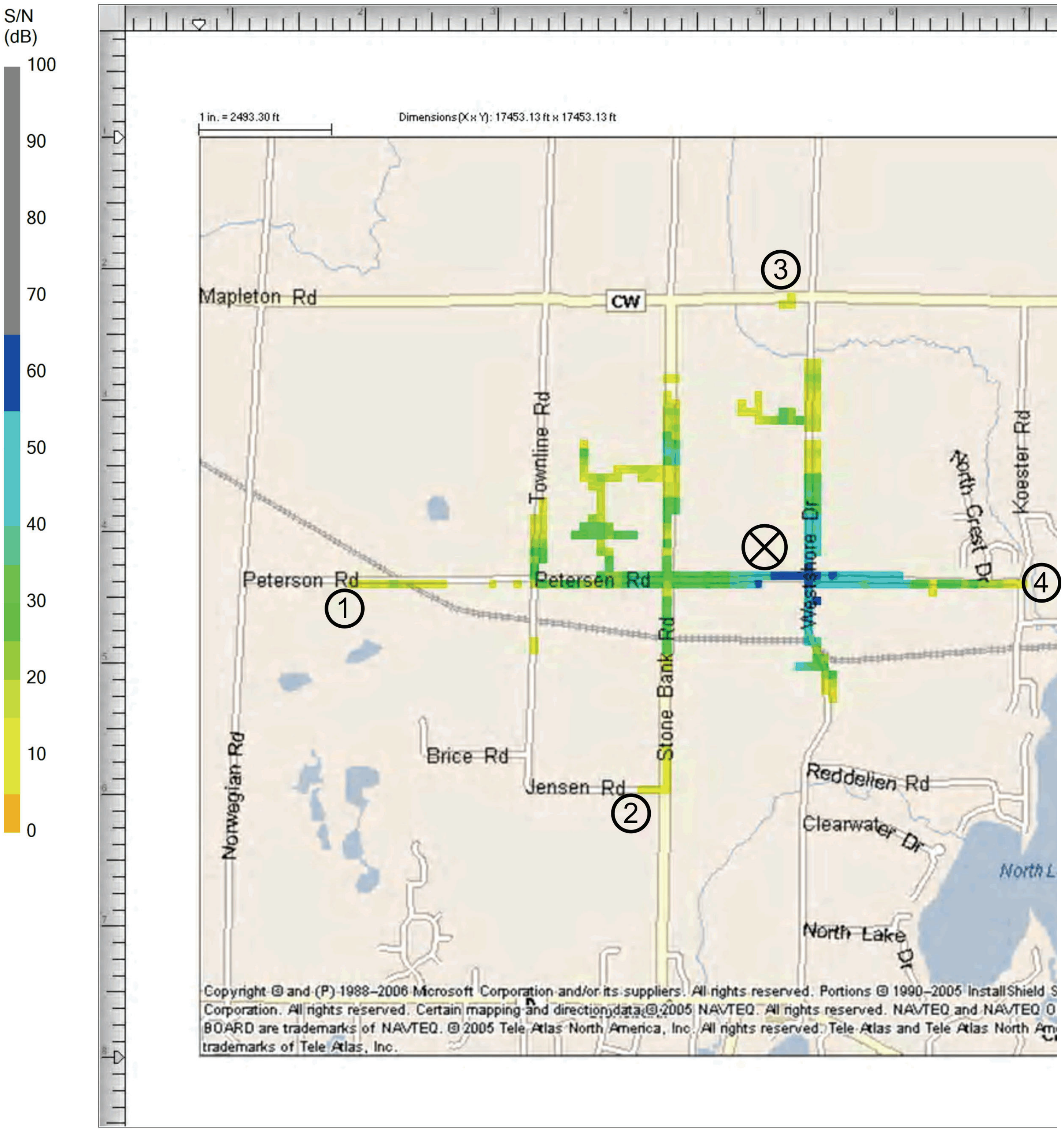
Point #2 - 0.90 miles

Point #3 - 1.09 miles

Point #4 - 0.94 miles

Map 11

INITIAL FIELD TEST RESULTS – WAUKESHA COUNTY – TOWNS OF MERTON AND OCONOMOWOC



Source: SEWRPC.

Comparing these measurements with the same locations in Map 12, the Anderson radio propagation model run, the similarities are rather remarkable. As in the field measurements, best coverage is to the West and Northwest. Comparing similar points, the model distances for equivalent signal-to-noise ratios are:

Point #1 - 0.82

Point #4 - 0.52 miles

These are easy points to check since they are both along Peterson Road. The model proves to be conservative indicating only 55% of the distances actually measured in the field. An attenuation factor set in the database can be adjusted for a less conservative "clutter" attenuation. The important point here is that the model and field test are in mutual confirmation. With such confirmation, it is possible to change the height of the AP in model to determine the potential coverage of the BST2 and SAL6 towers in Kenosha County. The model-based results of this simulation are shown in Map 13. Even with only a 10 dB amplifier (A 23 dB amplifier was tested later), coverage ranging as far as 4 miles is indicated.

Field testing combined with radio propagation modeling has verified the original regional wireless plan coverage estimates for 4.9 GHz broadband wireless technology. While it is still necessary to move on to Stage 2 and Stage 3 for final project confirmation, early field tests at lower AP elevations drastically reduced the risks of the Kenosha County Broadband Wireless Network project.

Public Safety (4.9 GHz) Testing in Kenosha County

The objective of stage 2 testing in Kenosha County using the Bristol (BST2) as the base station tower was to establish the range, geographic coverage, and performance (channel speed) of both the 4.9 GHz and 5.8 GHz networks. The range of communications determined working with BST2 would verify the original base station plan to the extent that the terrain surrounding BST2 is typical of the rest of the county. A base station range objective of 3.0 miles is consistent with the ten base tower network of the revised regional wireless plan.

Public Safety Broadband (4.9 GHz) Field Testing

Forty-one test locations in the area surrounding the BST2 tower site were evaluated in three days of testing during the week of July 21, 2008. The network target range for each base station is a radius of three (3) miles based on 10 base stations covering a Kenosha County area of 278 square miles. The 41 point test set here indicates network coverage has been extended to 4.4 miles. The longest range test location had a signal-to-noise ratio of 18 dB and download/upload throughputs of 11.2 Mbps and 9.9 Mbps respectively. The average download throughput for the test set was 12.45 megabits per second with the upload only slightly slower at 10.44 megabits per second. The average range distance of all test locations was 2.58 miles, so that the other performance measures such as signal-to-noise ratio and throughput data rates, do have meaning for typical network operation. All of these performance measures would undoubtedly be higher if the average range of all test points were 1.5 miles – the mean radius for specified base station coverage. For this reason, the performance results are considered a conservative estimate of future network performance. All test results are tabulated in Table 1 and illustrated with their locations and distances in Map 14. Coverage and throughput (data rate) performance are summarized below:

1. Coverage (Range)

   Minimum – 0.51 miles

   Maximum – 4.41 miles

   Average – 2.58 miles

2. Throughput (download)

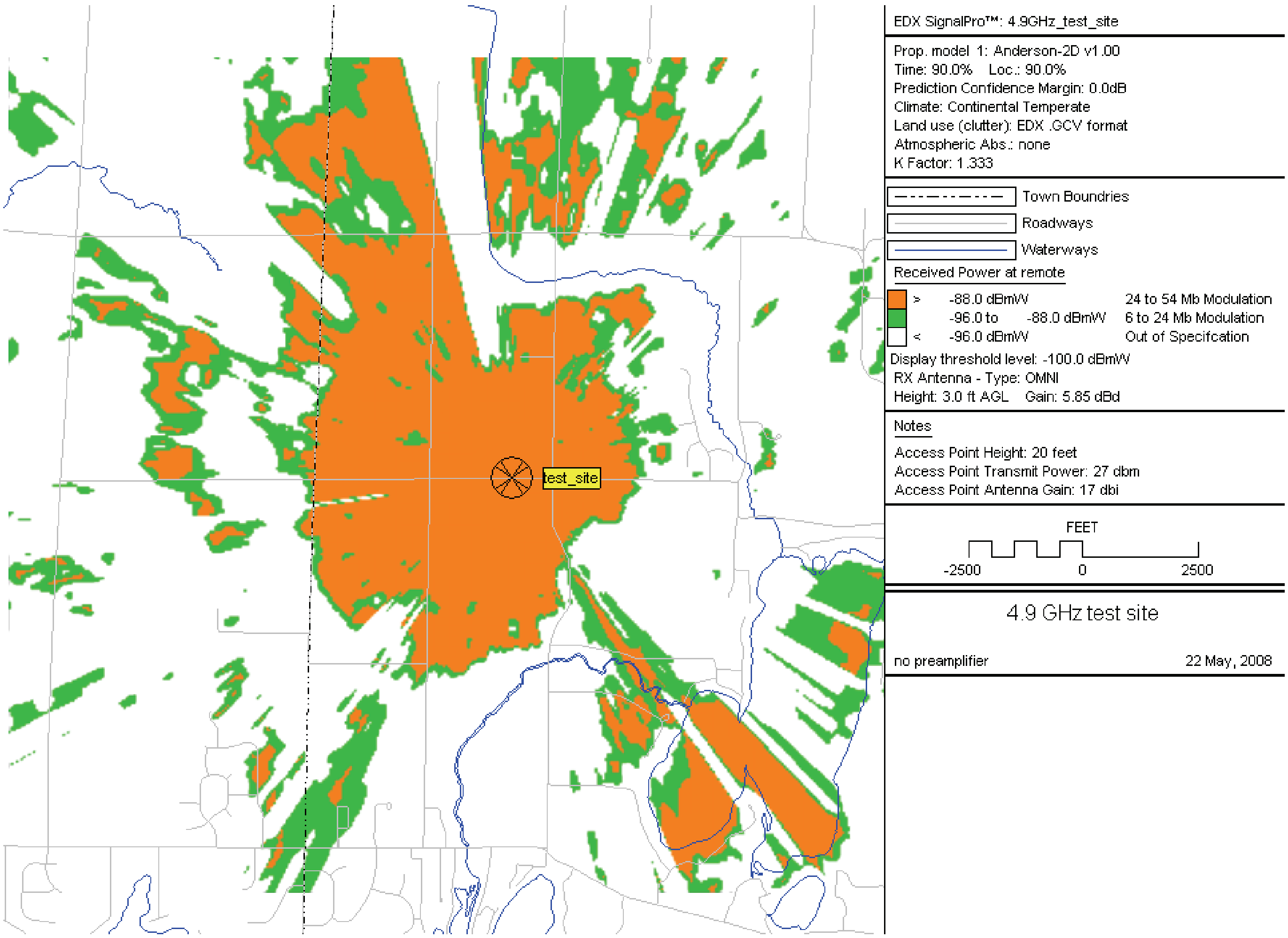
   Minimum – 4.40 megabits/second

   Maximum 22.9 megabits/second

   Average – 12.45 megabits/second

Map 12

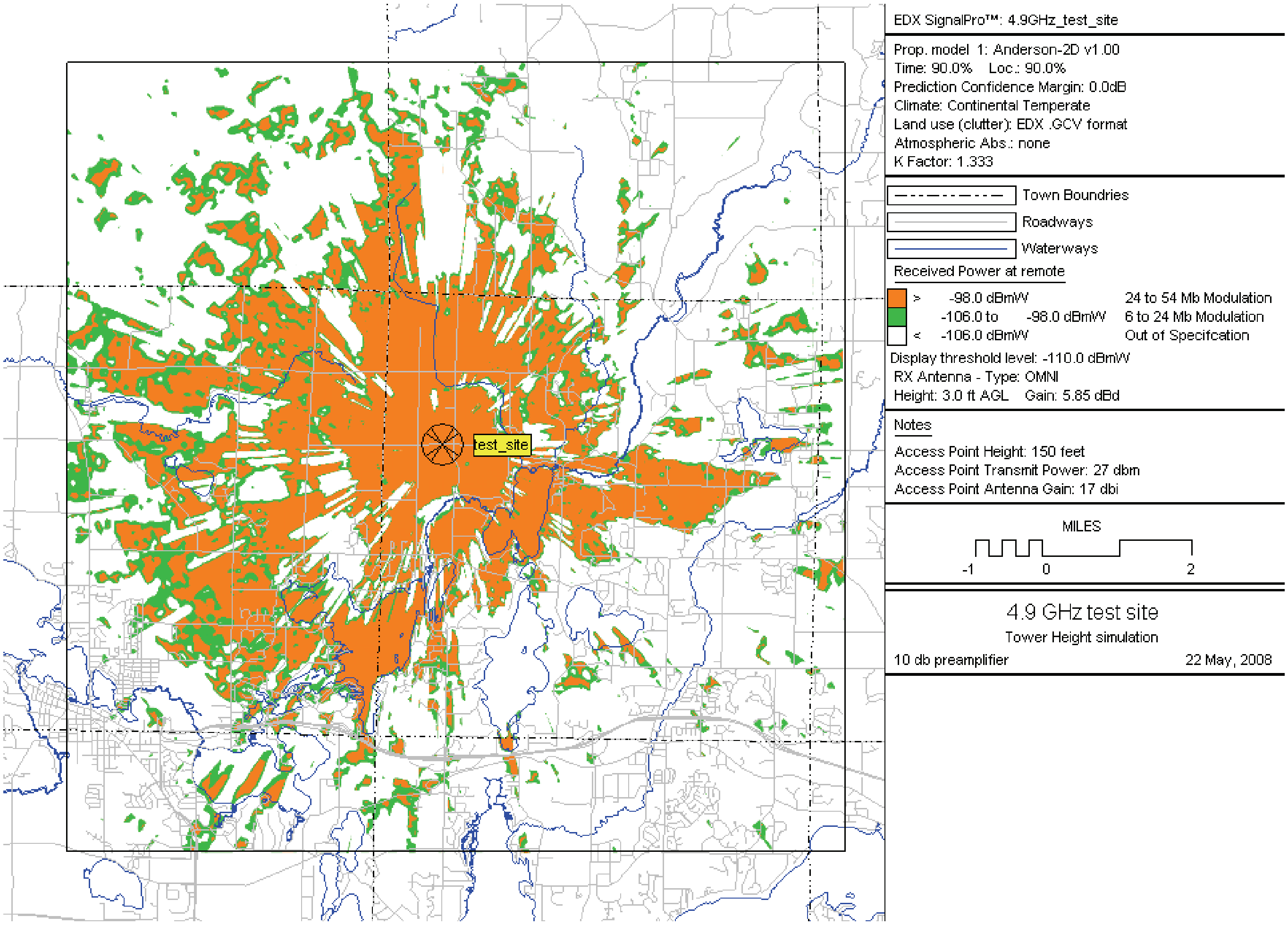
MODEL SIMULATION OF WAUKESHA FIELD TEST RESULTS



Source: SEWRPC.

Map 13

MODEL SIMULATION OF WAUKESHA FIELD TEST RESULTS WITH ANTENNA HEIGHT EXTENSION TO 150 FEET



Source: SEWRPC.

Table 1

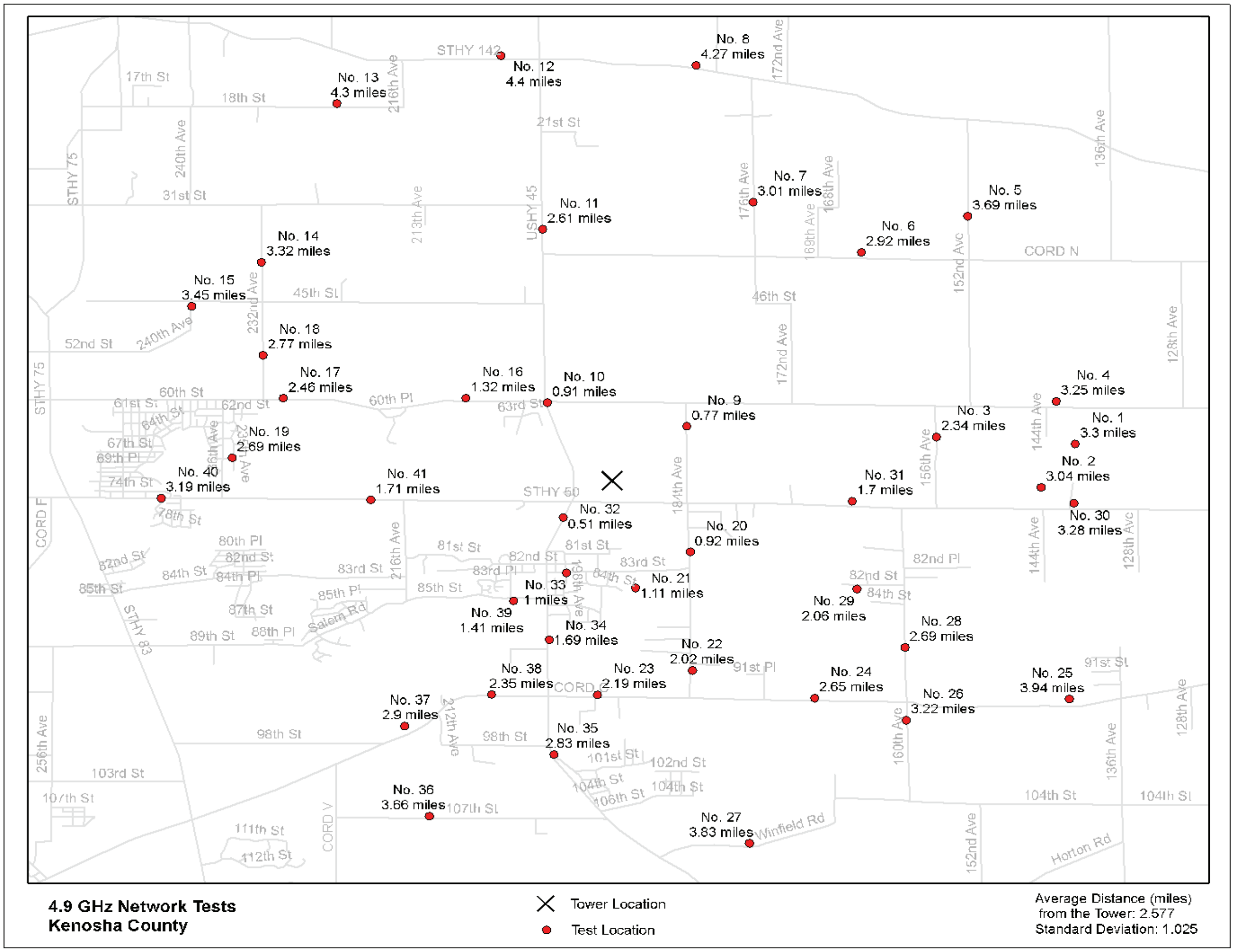
4.9 GHz FIELD TEST RESULTS – KENOSHA COUNTY – BST2 TOWER

Point No.	Latitude Degrees	Latitude Minutes	Longitude Degrees	Longitude Minutes	Distance (miles)	Signal	Noise	SNR	Download Throughput (TCP Mbps)	Upload Throughput (TCP Mbps)
1	42	34.573	87	58.645	3.30	-74	-95	21	12.1	12.7
2	42	34.187	87	58.927	3.04	-86	-94	8	4.4	4.0
3	42	34.636	87	59.796	2.34	-71	-94	23	12.2	12.0
4	42	34.952	87	58.803	3.25	-87	-94	7	4.4	4.1
5	42	36.593	87	59.537	3.69	-79	-94	15	10.7	11.0
6	42	36.272	88	0.423	2.92	-77	-94	17	10.4	11.7
7	42	36.717	88	1.322	3.01	-74	-94	20	11.7	12.5
8	42	37.931	88	1.796	4.27	-77	-94	17	11.3	12.0
9	42	34.729	88	1.871	0.77	-63	-94	31	12.2	12.6
10	42	34.940	88	3.031	0.91	-62	-92	30	11.0	11.9
11	42	36.477	88	3.072	2.61	-76	-92	16	11.8	10.9
12	42	38.018	88	3.418	4.41	-75	-93	18	11.2	9.9
13	42	37.592	88	4.780	4.31	-82	-93	11	8.2	8.0
14	42	36.185	88	5.408	3.33	-71	-93	22	12.2	11.9
15	42	35.795	88	5.988	3.46	-74	-93	19	12.1	12.6
16	42	34.979	88	3.708	1.32	-63	-93	30	12.0	11.8
17	42	34.978	88	5.225	2.46	-72	-94	22	10.9	11.1
18	42	35.360	88	5.394	2.77	-76	-93	16	11.9	11.9
19	42	34.450	88	5.652	2.69	-78	-92	14	11.9	11.0
20	42	33.614	88	1.845	0.92	-64	-90	26	22.8	13.0
21	42	33.297	88	2.300	1.11	-67	-91	24	22.9	12.8
22	42	32.565	88	1.825	2.02	-87	-92	5	11.6	8.1
23	42	32.347	88	2.615	2.20	-79	-92	13	18.6	11.0
24	42	32.319	88	0.810	2.65	-88	-92	4	8.4	7.9
25	42	32.310	87	58.693	3.93	-81	-93	12	15.8	11.0
26	42	32.123	88	0.049	3.22	-85	-93	8	12.3	8.3
27	42	31.031	88	1.352	3.84	-85	-92	7	12.5	8.9
28	42	32.768	88	0.060	2.68	-78	-92	14	21.3	12.2
29	42	33.284	88	0.459	2.06	-83	-94	11	12.4	8.1
30	42	34.046	87	58.656	3.27	-82	-92	10	15.9	9.9
31	42	34.064	88	0.500	1.71	-73	-93	20	21.3	12.6
32	42	33.920	88	2.899	0.51	-60	-93	33	15.9	12.1
33	42	33.428	88	2.873	1.00	-89	-94	5	3.8	3.7
34	42	32.837	88	3.016	1.69	-80	-94	14	11.3	10.4
35	42	31.818	88	2.975	2.83	-84	-94	10	11.0	7.8
36	42	31.272	88	4.015	3.67	-80	-93	13	13.0	11.5
37	42	32.070	88	4.216	2.91	-72	-94	22	16.1	12.7
38	42	32.350	88	3.494	2.35	-80	-94	14	11.9	11.1
39	42	33.180	88	3.313	1.41	-65	-94	29	16.7	11.3
40	42	34.092	88	6.242	3.19	-80	-92	12	12.5	11.0
41	42	34.077	88	4.499	1.71	-82	-93	11	12.2	9.0

Source: SEWRPC.

Map 14

4.9 GHz FIELD TEST RESULTS – KENOSHA COUNTY – BST2 TOWER



Source: SEWRPC.

3. Throughput (upload)
   Minimum – 3.7 megabits/second
   Maximum – 12.8 megabits/second
   Average – 10.44 megabits/second
4. Signal-to-Noise Ratio (SNR)
   Minimum – 4.0 dB
   Maximum – 33.0 dB
   Average – 16.2 dB

A week of 4.9 GHz wireless network field testing clearly demonstrated compliance with both the geographic coverage and throughput performance specifications of the project – 3 mile radius base station coverage and download/upload data rates exceeding 10 megabits per second. A similar set of tests were conducted in the 5.8 GHz frequency band during the week of July 28^{th}. The conclusion of these tests was then followed by a 4.9 GHz system demonstration on the Kenosha County communications network with equipment installed in county public safety vehicles.

On the positive side, it should be noted that data rates over 20 megabits per second are expected in most areas when the amplifier limitations previously mentioned are removed. The sectors with amplifiers meeting all specifications already are showing data rates over 20 megabits per second. Also, all of the above throughput rates were measured with the Internet TCP protocol. This protocol is used for data traffic. Video traffic on this network will use UDP, a faster protocol discussed in the first test report, so that image traffic will experience even faster rates than those reported here.

On the cautionary side, it is important to emphasize that the test results reported here do not insure that every location in the test area will perform at the same level. In a base station network, some "dead spots" are an inevitable result of building and tree obstacles. Uniform coverage of all areas will require the peer-to peer networking feature outlined in the original proposal. As the number of network users increases, uniformity of coverage and performance will develop throughout the network.

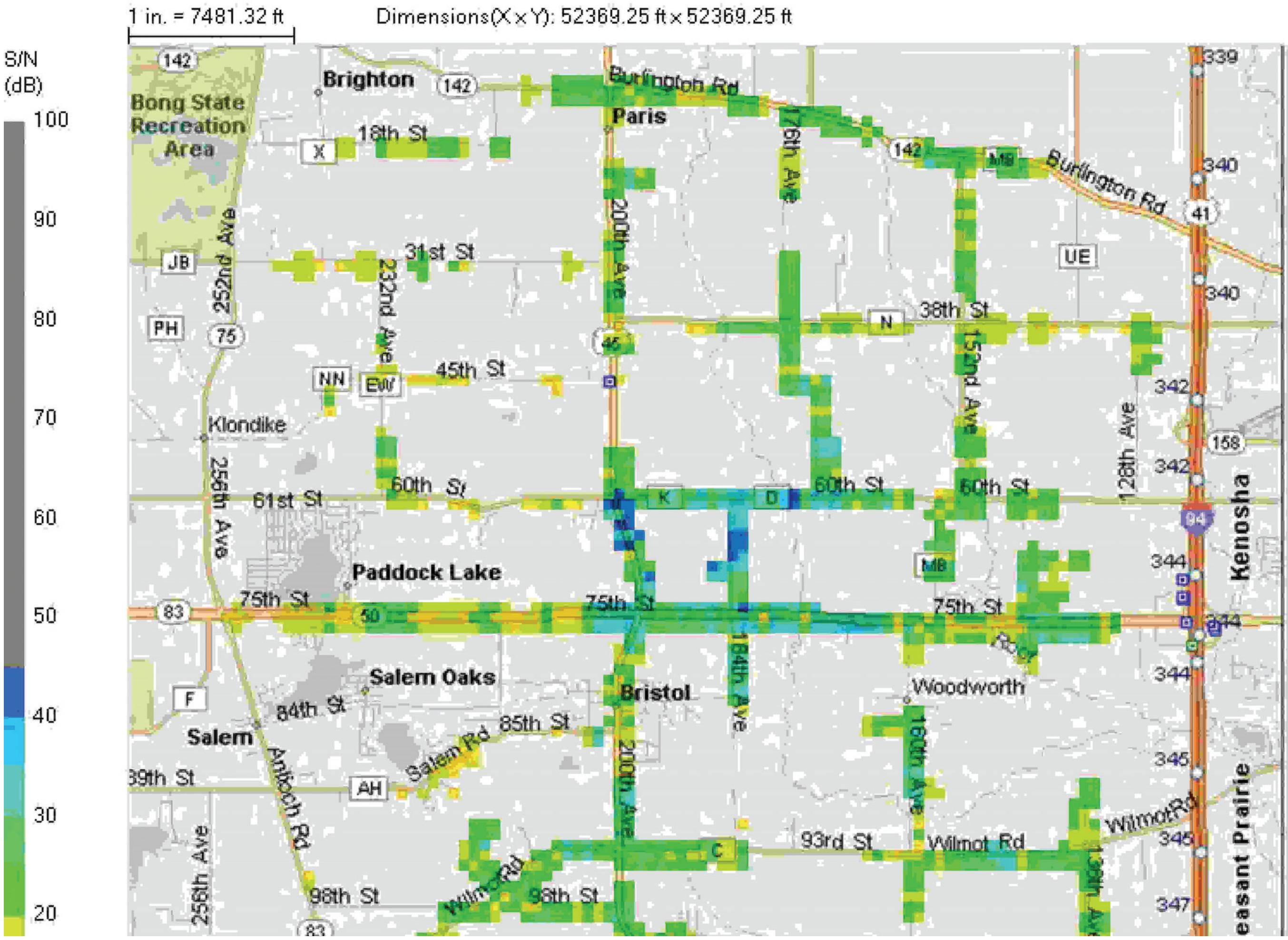
Commercial (5.8 GHz) Field Testing
Field testing of the 5.8 GHz network was significantly expedited through the use of the Air Magnet Surveyor software. Installed in a portable laptop computer in a motor vehicle and connected with a Geographic Positioning System (GPS) unit, Surveyor provides for automated data acquisition of signal and noise recordings. Such data allow for the automated mapping of the signal-to-noise ratio (SNR) as shown in Map 14. The predominant green color represents SNR values between 20 dB and 30 dB a signal that allows for data rates exceeding 20 Mbps. The intermingled yellow colors indicate an SNR in the 10 dB to 20 dB range which will support data rates between 10 and 20 Mbps.

Range performance in clear areas exceeded the specified 3 mile radius requirement. Note particularly SNR values along STH 142 at the top of the Map 15. All of the points along this road are more than four miles from the tower and yet SNR readings over 20 dB predominate in this area. Many other parts of the coverage area indicate similarly high SNR values.

There are, however, the inevitable dead zones of weak or no coverage. Such a zone is indicated along highway STH 45 between 45^{th} and 60^{th} streets. This area is heavily wooded, blocking transmission from the tower even though it is only a little over 1 mile from the tower site. There are a few other similar scattered dead zones throughout the coverage area.

Map 15

5.8 GHz FIELD TEST RESULTS – KENOSHA COUNTY – BST2 TOWER



Source: SEWRPC.

In most sectoral cellular networks, such dead zones would remain unless a new tower site was erected. A recent new passive component known as the passive signal repeater, however, allows the elimination of such dead zones in a very cost effective manner. The PSR is basically a set of metal plates that redirects the direction of the incoming radio wave. Employing such a device it is possible to capture a signal in a clear zone and redirect it along a roadway into a former dead zone. Such a redirected radio wave will allow for customers in a former dead zone to receive the signal and process it in the same manner that a tower-based signal is processed in the remainder of the radio network. Everything considered, the field tests in Kenosha County demonstrated the range and geographic coverage of 5.8 GHz network. While throughput was not directly measured in the field tests, it can be accurately inferred from the signal-to-noise ratio and confirming field measurements. During the middle months of the project it was decided to defer other field testing or the final demonstration until the peer-to-peer communications capability became available.

Chapter VII

PEER-TO-PEER AND GEOMESSAGING COMMUNICATIONS

INTRODUCTION

Peer-to-Peer Communications

Peer-to-Peer Communications allows a 4.9 GHz network user to communicate through another user, the primary antenna base station infrastructure, or any mobile or fixed access point equipped with the appropriate communications equipment and the peer-to-peer software. Peer-to-peer communications is particularly important in public safety networks in times of major emergencies. Such public safety communications systems have almost always failed in major events such as 9/11 or Hurricane Katrina. Power outages and other infrastructure failures along with extreme network congestion have rendered such networks virtually useless in the time of greatest need. Peer-to-peer communications provides significant independence from infrastructure failure by providing alternate transmission paths through other network users or users in combination with surviving parts of the infrastructure. The system at each pathway node will always select the best next link to reach the message destination.

Peer-to-Peer Configuration

In Kenosha County, plans call for a county-wide fiber optic ring backhaul network interconnecting all of the ten antenna base stations. A dynamic peer-to-peer configuration will extend the range of the base station infrastructure and provide for multiple network pathways to message destinations. Observing Figure 1 below, fire truck (D) is out of range of both base station towers (B and F), so police vehicle (C) positions itself to extend the network so that fire truck (D) can connect to tower (B). It is also possible to have a fixed stand-alone peer node (E) on a building or other tall structure in an area that can relay traffic to a base station access point, such as (F). What is not apparent from the drawing is the ability of the moving vehicles to communicate with each other. Any public safety vehicle in range of another public safety vehicle can utilize that vehicle as a dynamic mesh node to relay messages on to their final destination.

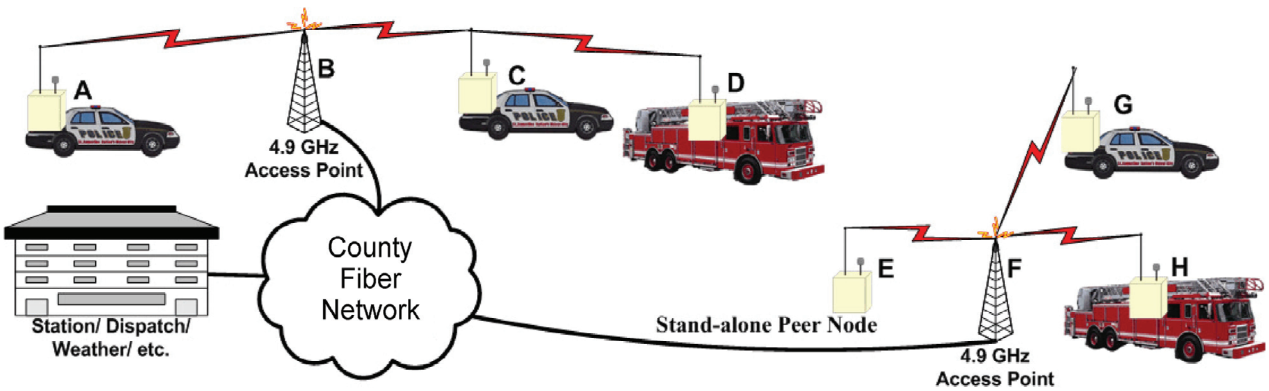
GeoMessaging Communications

As an adjunct and extension of peer-to-peer communications, a major geoMessaging capability has been added to the 4.9 GHz public safety network. GeoMessaging as referenced here is a software package integrated along with peer-to-peer software in the user's router unit or laptop computer. It is also interfaced to a global positioning system (GPS) unit in each vehicle. The three basic GeoMessaging functions are:

1. To provide a continuous dynamic map indicating the geographic position of all network users.
2. 2. To direct messages to users using geographic position addresses.
3. 3. To setup banner messages that are sent to all network users in a defined geographic area.

Figure 1

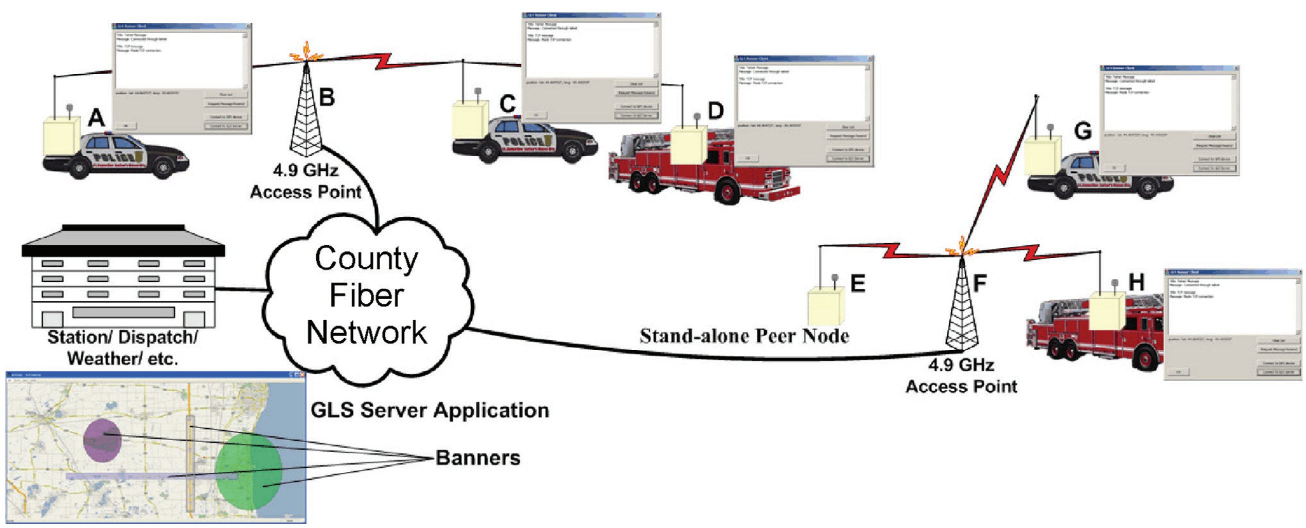
PEER-TO-PEER COMMUNICATIONS NETWORK FOR KENOSHA COUNTY



Source: Architecture Technology Corp. and SEWRPC.

Figure 2

GEOMESSAGING OVERLAY FOR PUBLIC SAFETY NETWORK



Source: Architecture Technology Corp. and SEWRPC.

GeoMessaging software resides at two locations: at the mobile client (user) and at a central server. The client application software relays position data and receives messages. The server application displays the user location map and establishes all setup banners as well as sending messages.

Figure 2 shows the vehicle users application which would run on a laptop computer or an m-dash PC. Each user connects to its local GPS device and the GeoMessaging server. Once connected the user receives messages from the server designated for its location. The Geographic Location Service (GLS) Server Application in Figures 2 shows 4 banners (2 circles and 2 rectangles). As equipped vehicles move around the county they will receive the banner messages when they drive into a banner area.

Map Overlays
One of the major features of the GeoMessaging software package is its map overlay capability. Various types of maps, and images may be used in GeoMessaging. Google Earth resources may also be used in the map overlay process. Map overlays may also be modified to reflect existing conditions during emergency situations such as floods, fires, accidents or other incidents.

Other Applications of Peer-to-Peer and GeoMessaging Communications
Peer-to-peer communications and its related extension, GeoMessaging, are relatively new to the field of wireless communications. Wireless communications network architecture has generally featured the sectoral cellular network architecture since the early days of mobile wireless communications. The primary incentive for this architecture was the efficient allocation of radio bandwidth. In an urban environment with a large number of cellular subscribers, the problem of radio interference becomes a major consideration. Sectoral cellular networks allowed for an efficient allocation of frequency bands for interference avoidance

Communication needs in public safety, particularly in low density rural areas, are quite different. Geographic coverage and network availability replace congestion as the central focus in network design. Network availability is particularly important in times of major public emergencies. Peer-to-peer communications provides at least a partial answer to this problem. Peer-to-peer structures also have the potential of extending the range of the network on both a temporary and a permanent basis. The technology can also help to fill in the inevitable "dead-spot" areas with permanent peer-to-peer links at very low cost to achieve the objective of universal coverage in a cost effective way. Peer-to-peer communications at the same time can also relieve congestion problems by providing extensive redundancy providing multiple alternate paths through the network.

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Chapter VIII

THE FIELD DEMONSTRATION

The field demonstration of the 4.9 GHz Public Safety Communications System took place at the Kenosha County Center in Bristol, Wisconsin, on April 29, 2009, starting at 1:30 PM. The following people were in attendance:

Kenosha County Executive Jim Kreuser

Kenosha County Sheriff David G. Beth
Chief Deputy Charles R. Smith
Lieutenant Paul J. Falduto, Jr.
Sergeant Horace J. Staples

George E. Melcher, Director, Department of Planning and Development, Kenosha County

Gina Turner, Acting Director, Information Services Division, Kenosha County
Craig Kennedy, Network/Server Systems Engineer
Jeff Magno, Network Engineer
Ken Baldwin, Networking Consultant

Lieutenant Ronald Bartholomew, City of Kenosha Police Department

Phil Evenson, Special Projects Advisor, SEWRPC
Ken Schlager, Chief Telecommunications Engineer, SEWRPC
Jason Zehrung, Telecommunications Planner, SEWRPC

Bruce McFadden, HierComm, Inc.

Earlene Frederick, Freelance reporter/photographer, representing *The Report*

The meeting was called to order by Ken Schlager, Chief Telecommunications Engineer of SEWRPC. He delivered a PowerPoint presentation on the history and background of the project and the previous field studies conducted to verify geographic coverage and throughput performance of the 4.9 GHz communications system. These field tests confirmed the original range target of a three mile radius and the original network plan that provided county-wide coverage with 10 antenna base stations. The remainder of the presentation dealt with the role of regional telecommunications planning as a forerunner of the Kenosha County broadband public safety communications project. The presentation in its entirety is attached to this report as Appendix A.

Upon completion of the initial presentation, direction of the demonstration was turned over to Jason Zehrung, telecommunications planner from SEWRPC.

Demonstration Description
The demonstration was performed in two stages.

1. Demonstrations of geomessaging and streaming video at the County Center
2. In-vehicle demonstrations of streaming video, geomessaging and peer-to-peer communications.

County Center Demonstration
In the County Center portion of the demonstration, a definition of geomessaging was followed by application examples such as

1. Amber alerts
2. Pursuit of a suspect
3. Hazardous material spills

A dynamic map display showing the geographic positions of all network users was also presented as a major capability of the server side of geomessaging.

A geomessage was sent to one of the 4.9 GHz-equipped sheriff's vehicles: "Suspect approaching your location from NE". This transaction illustrates a second major feature of the geomessaging function – sending messages to users based on geographic position addresses.

A third feature of geomesaging, the ability to post "banners" or billboards" to all network users in a defined geographic area, was demonstrated by creating banner message for both rectangular and oval areas with following messages:

Rectangular Banner:
"Hazardous material spill on Highway 50, 2 miles west of I-94"

Oval Banner:
"Amber Alert: 5 year old Caucasian girl taken from Woodman's Grocery Store, brown hair, blue eyes, wearing green top and jeans. Last seen heading west in white SUV."

The streaming video communication between the center station and the vehicle camera was then demonstrated showing the panoramic and zoom features.

In-Vehicle Demonstration
The in-vehicle demonstration took place in sequence as follows:

1. The sedan squad car remained in the vicinity of the Center while the Tahoe SUV squad car headed east on STH 50.
2. The Tahoe received a specific message as it entered one of the banner zones.
3. An incident camera demonstration showed video transfer from the incident to a squad car. A bank, school, or other location equipped with a CCT system could effect such a video transfer.
4. The Tahoe SUV squad car moves on but stays connected to the incident and receives a second geomessage.
5. The Tahoe SUV squad car moves temporarily out of range losing the video image. The sedan squad car moves east on STH 50 to serve as a peer-to-peer link bringing the Tahoe SUV back into range and restoring the camera image.

The demonstration then came to an end with all primary functions having been demonstrated.

Demonstration Summary

The demonstration was extremely well received. Participants having witnessed the demonstration all seemed to realize the great potential of broadband public safety communications for improving the scope and efficiency of law enforcement in Kenosha County.

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Chapter IX

SUMMARY AND CONCLUSIONS

The Kenosha County Broadband Public Safety Communications Demonstration Project investigated the feasibility of a cost effective county-wide broadband wireless communications network in the 4.9 GHz frequency band. Such a county-wide network would require a considerable range extension of 4.9 GHz wireless communications technology. The end result of field testing was a base station range extending out beyond four miles. This range extension validated the original regional wireless plan that estimated the need for 15 antenna base stations for county-wide coverage. Antenna range improvements surpassed original projections such that county-wide 4.9/5.8 GHz coverage was possible with only 10 antenna base station—all existing towers suitable for co-location.

Perhaps more important than the broadband public safety network itself was the verification and validation of the SEWRPC Regional Wireless Plan which called for a public/partnership to provide broadband communications services to the rural as well as the urban parts of Kenosha County. The cost-effectiveness of the 4.9 GHz public safety system and its infrastructure support of a commercial 5.8 GHz network validates the public/private partnership concept of the Regional Wireless Plan. A rural broadband wireless network can now be deployed at 5.8 GHz in a cost effective way.

The addition of the peer-to-peer and geomessaging features greatly expanded the capabilities and performance of the 4.9 GHz public safety network. Originally conceived as an emergency backup feature, peer-to-peer networking now promises to not only extend system range and fill in “dead spot” holes in the network but also will expand the capacity and redundancy of the network. The geomessaging feature even in its present basic form engendered strong interest and promised a wide range of future applications.

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APPENDIX

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Appendix A

PRESENTATION TO KENOSHA COUNTY OFFICIALS

COUNTY-WIDE BROADBAND (4.9 GHz) WIRELESS PUBLIC SAFETY COMMUNICATIONS

FOR KENOSHA COUNTY

A FIELD DEMONSTRATION

APRIL 23, 2009

TELECOMMUNICATIONS DIVISION
SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION
WAUKESHA, WISCONSIN

#144257

Agenda

General Outline

- Project and Technology Background and Narrative
- Field Demonstration

Project/Technology Background and Narrative

- Regional Telecommunications Planning Program at SEWRPC
- USDA Broadband Wireless Grant Program
- Regional Wireless Plan
  - 4.9 GHz/5.8 GHz Combination
- Community-Based Wireless Plan Implementation
  - Town of Wayne, Washington County
- Kenosha County Broadband Public Safety Communications Project
  - Previous Range, Coverage and Throughput Testing

Field Demonstration

- GeoMessaging Software Demonstration
- Vehicle to Dispatch Center Streaming Video Demonstration
- GeoMessaging Demonstration in Vehicles
- Incident to Vehicle Streaming Video Demonstration
- Peer to Peer Demonstration

FIRST COUNTY-WIDE 4.9 GHz BROADBAND WIRELESS PUBLIC SAFETY NETWORK IN THE NATION

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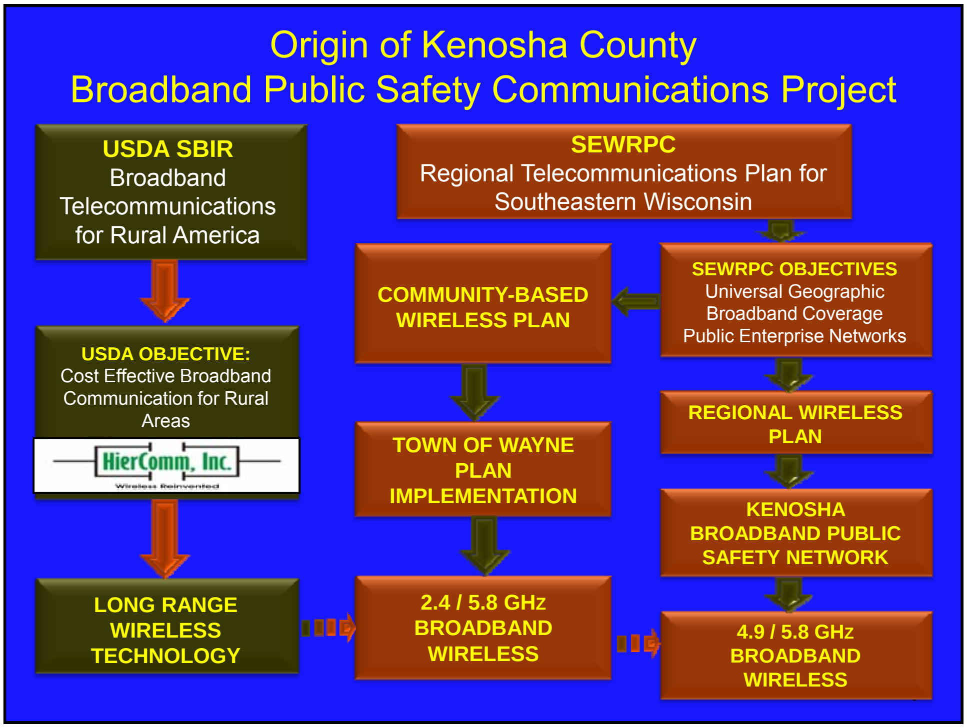

Regional Telecommunications Planning Program at SEWRPC

Planning Process

- Objectives and Standards
- Inventories
  - Service Coverage
  - Performance
  - Reliability
  - Infrastructure
- Plan Design Alternatives
- Plan Selection
- Plan Implementation

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Basic Objectives/Standards of Regional Broadband Planning Program

1. Performance
   - Fourth generation (4G) Throughput – 20 megabits per second
   - Carrier – grade reliability (99.9%)
2. Universal Geographic Coverage
   - Broadband coverage to all geographic areas of the Region
3. Infrastructure Cost
   - Minimal infrastructure costs for cost effective deployment even in low density rural areas

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Basic Objectives/Standards of Regional Broadband Planning Program—continued

4. Redundancy
   - Providing for alternative transmission paths in both public safety and commercial communications networks, particularly in major public emergencies
5. Public Safety
   - Provide major emphasis on joint public safety and commercial communications infrastructure
6. Video Capabilities
   - Provide for all forms of video communications from broadcast television to videoconferencing

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Planning Inventories

- Broadband Service Coverage
  - DSL
  - Cable
  - Mobile Wireless
  - Fixed Wireless
- Performance and Reliability
  - Mobile Wireless
  - Measured
    - Percent Availability
    - Throughput
    - Response
  - Five Wireless Carriers
    - 26 sites
    - 127,680 measurements
- Infrastructure
  - 1,010 cellular/PCS antenna sites

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Regional Telecommunications Plans

- Four Alternative Plans
  - Regional Wireless Plan
  - Community-Based Wireless Plan
  - Fiber-to-the-Node (FTTN)
    - AT&T in Region
  - Fiber to the Premises
    - Scattered subdivisions in Region
- Selected Plans
  - Regional Wireless Plan
    - 4.9/5.8 GHz Public Safety Commercial
    - County-level initiative
    - Least cost
    - Public Safety
      - In leadership role
    - Covers entire Region
  - Community-Based Wireless Plan
    - Community-level initiatives
    - Low cost
    - Non-interfering frequency band (2.4 GHz)
    - Taps community support

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The Kenosha County 4.9/5.8 GHz Public Safety Wireless Communications Project I

- Primary Objective
  - Implementation of SEW Regional Wireless Plan
  - Real broadband performance with universal geographic coverage
- Operational Objective
  - Full geographic coverage with 10 existing base station sites
  - 20 megabits per second throughput performance
- Ad Hoc peer-to-peer network communications alternative
  - For universal geographic coverage
  - For major public safety emergencies

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The Kenosha County 4.9/5.8 GHz Public Safety Wireless Communications *Project II*

- Network Architecture
  - Sectoral Cellular
  - Peer-to-Peer Dynamic Mesh
- Network Plans – Radio Propagation Modeling
  - Public Safety (4.9 GHz)
  - Commercial (5.8 GHz)

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Development and Demonstration Program Kenosha County Broadband Public Safety Communications Network

1. Radio Propagation Modeling
2. The County-Wide 4.9/5.8 GHz Network Plan
3. Equipment Development, Assembly and Checkout
4. Stage I Field Test – Vehicular AP
5. Stage II Field Test – Tower AP – 4.9 GHz and 5.8 GHz

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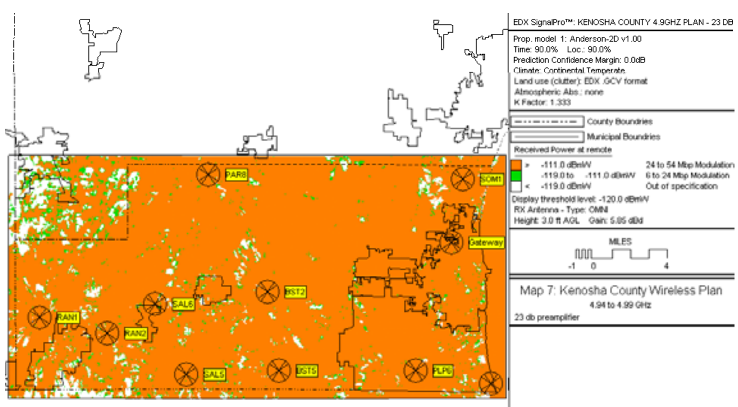
Broadband Wireless (4.9 GHz) Public Safety Communications Plan



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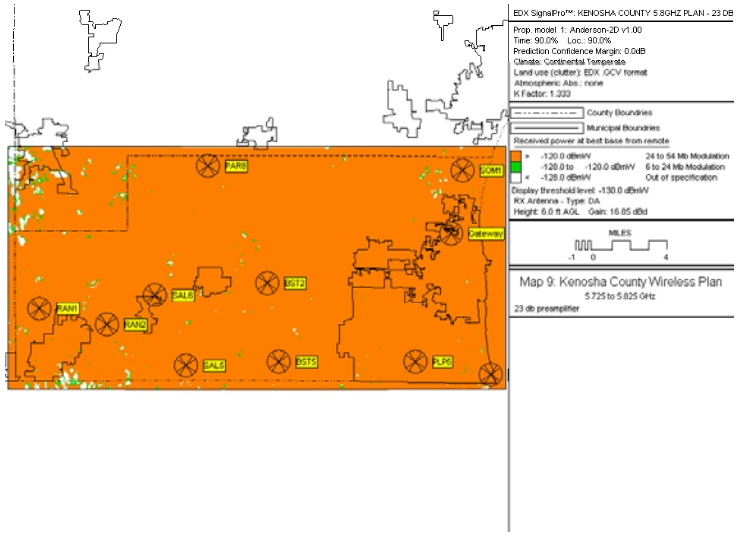
Broadband Wireless (5.8 GHz) Commercial Communications Plan



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Stage I Field Test
Vehicular Access Point – Waukesha County

Goals:

1. Equipment operation verification in a field environment
   – Laboratory checkout alone is not sufficient.
2. Experimental simulation of 4.9 GHz
   – Testing with lower height (20 ft.) antenna
3. Adjustments for optimal operation in high tower environment

Operation:

1. Park vehicular AP truck at test location.
2. Roam surrounding area with test truck recording signal and interference/noise levels.

Test Results:

- Coverage of SNR=10 or greater
- Out to 1.5 miles
- Radio prop-modeling at AP-150 feet
- 3 miles and beyond

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Stage II Field Test
160 foot high Antenna Base Station

Goals:

1. Verify 4.9/5.8 GHz geographic coverage in county field environment with single base station.
2. Verify 4.9/5.8 GHz throughput performance in coverage area.

Operation:

1. Mount AP equipment on BST2 Tower.
2. Simulate 4.9 GHz public safety vehicle.
3. Simulate 5.8 GHz fixed user.
4. Measure Base Station range and throughput performance.

Test Results:

1. Coverage (Range)
   Minimum – 0.51 miles
   Maximum – 4.41 miles
   Average – 2.58 miles
2. Throughput (download)
   Minimum – 4.40 megabits/second
   Maximum – 22.9 megabits/second
   Average – 12.45 megabits/second
3. Throughput (upload)
   Minimum – 3.7 megabits/second
   Maximum – 12.8 megabits/second
   Average – 10.44 megabits/second
4. Signal-to-Noise Ration (SNR)
   Minimum – 4.0 dB
   Maximum – 33.0 dB
   Average – 16.2 dB

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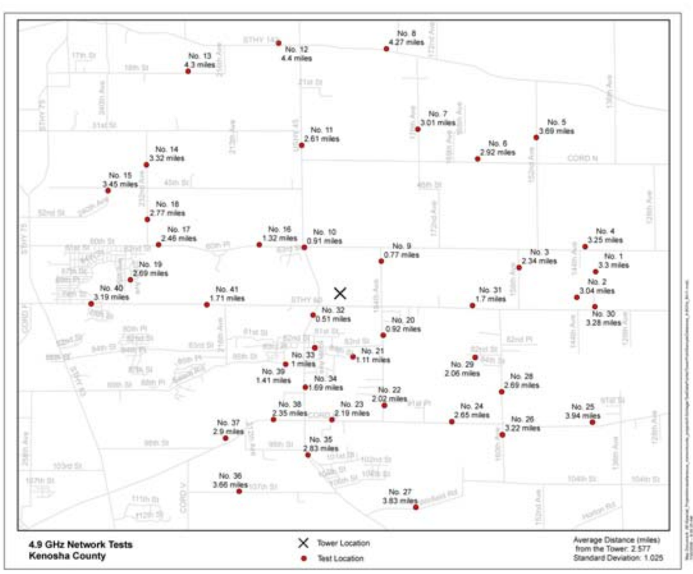
4.9 GHz Geographic Coverage Map



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4.9 GHz Geographic Coverage Table

No.	Latitude Degrees	Latitude Minutes	Decimal Latitude	Longitude Degrees	Longitude Minutes	Decimal Longitude	Distance (miles)	Signal	Noise	SNR	Download Throughput (TCP Mbps)	Upload Throughput (TCP Mbps)
1	42	34.573	42.5762167	87	58.645	-87.9774167	3.3	-74	-95	21	12.1	12.7
2	42	34.187	42.5697833	87	58.927	-87.9821167	3.04	-86	-94	8	4.4	4
3	42	34.636	42.5772667	87	59.796	-87.9966	2.34	-71	-94	23	12.2	12
4	42	34.952	42.5825333	87	58.803	-87.98005	3.25	-87	-94	7	4.4	4.1
5	42	36.593	42.6098833	87	59.537	-87.9922833	3.69	-79	-94	15	10.7	11
6	42	36.272	42.6045333	88	0.423	-88.00705	2.92	-77	-94	17	10.4	11.7
7	42	36.717	42.61195	88	1.322	-88.0220333	3.01	-74	-94	20	11.7	12.5
8	42	37.931	42.6321833	88	1.796	-88.0299333	4.27	-77	-94	17	11.3	12
9	42	34.729	42.5788167	88	1.871	-88.0311833	0.77	-63	-94	31	12.2	12.6
10	42	34.94	42.5823333	88	3.031	-88.0505167	0.91	-62	-92	30	11	11.9
11	42	36.477	42.60795	88	3.072	-88.0512	2.61	-76	-92	16	11.8	10.9
12	42	38.018	42.6336333	88	3.418	-88.0569667	4.41	-75	-93	18	11.2	9.9
13	42	37.592	42.6265333	88	4.78	-88.0796667	4.31	-82	-93	11	8.2	8
14	42	36.185	42.6030833	88	5.408	-88.0901333	3.33	-71	-93	22	12.2	11.9
15	42	35.795	42.5965833	88	5.988	-88.0998	3.46	-74	-93	19	12.1	12.6
16	42	34.979	42.5829833	88	3.708	-88.0618	1.32	-63	-93	30	12	11.8
17	42	34.978	42.5829667	88	5.225	-88.0870833	2.46	-72	-94	22	10.9	11.1
18	42	35.36	42.5893333	88	5.394	-88.0899	2.77	-76	-93	16	11.9	11.9
19	42	34.45	42.5741667	88	5.652	-88.0942	2.69	-78	-92	14	11.9	11
20	42	33.614	42.5602333	88	1.845	-88.03075	0.92	-64	-90	26	22.8	13
21	42	33.297	42.55495	88	2.3	-88.0383333	1.11	-67	-91	24	22.9	12.8
22	42	32.565	42.54275	88	1.825	-88.0304167	2.02	-87	-92	5	11.6	8.1
23	42	32.347	42.5391167	88	2.615	-88.0435833	2.2	-79	-92	13	18.6	11
24	42	32.319	42.53865	88	0.81	-88.0135	2.65	-88	-92	4	8.4	7.9
25	42	32.31	42.5385	87	58.693	-87.9782167	3.93	-81	-93	12	15.8	11
26	42	32.123	42.5353833	88	0.049	-88.0008167	3.22	-85	-93	8	12.3	8.3
27	42	31.031	42.5171833	88	1.352	-88.0225333	3.84	-85	-92	7	12.5	8.9
28	42	32.768	42.5461333	88	0.06	-88.001	2.68	-78	-92	14	21.3	12.2
29	42	33.284	42.5547333	88	0.459	-88.00765	2.06	-83	-94	11	12.4	8.1
30	42	34.046	42.5674333	87	58.656	-87.9776	3.27	-82	-92	10	15.9	9.9
31	42	34.064	42.5677333	88	0.5	-88.0083333	1.71	-73	-93	20	21.3	12.6
32	42	33.92	42.5653333	88	2.899	-88.0483167	0.51	-60	-93	33	15.9	12.1
33	42	33.428	42.5571333	88	2.873	-88.0478833	1	-89	-94	5	3.8	3.7
34	42	32.837	42.5472833	88	3.016	-88.0502667	1.69	-80	-94	14	11.3	10.4
35	42	31.818	42.5303	88	2.975	-88.0495833	2.83	-84	-94	10	11	7.8
36	42	31.272	42.5212	88	4.015	-88.0669167	3.67	-80	-93	13	13	11.5
37	42	32.07	42.5345	88	4.216	-88.0702667	2.91	-72	-94	22	16.1	12.7
38	42	32.35	42.5391667	88	3.494	-88.0582333	2.35	-80	-94	14	11.9	11.1
39	42	33.18	42.553	88	3.313	-88.0552167	1.41	-65	-94	29	16.7	11.3
40	42	34.092	42.5682	88	6.242	-88.1040333	3.19	-80	-92	12	12.5	11
41	42	34.077	42.56795	88	4.499	-88.0749833	1.71	-82	-93	11	12.2	9

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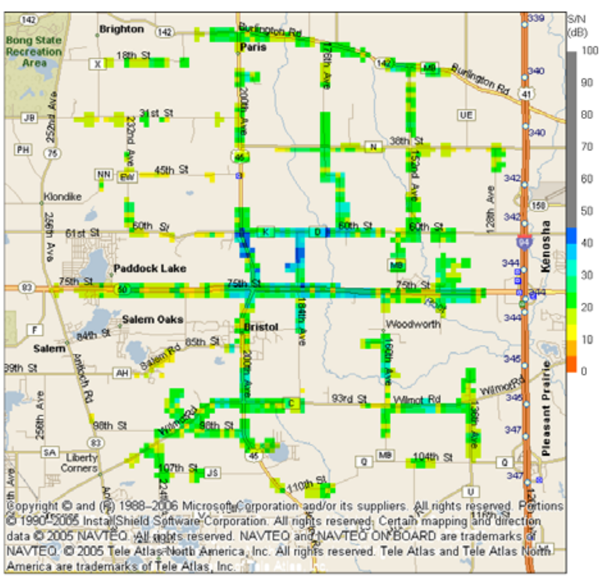
5.8 GHz Geographic Coverage Map



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Project Requirements and Capabilities

Requirements

1. County – Wide 4.9/5.8 GHz Wireless Network Plan – Done
2. Proof of Concept – Demonstrate Network Range, Coverage and Throughput Performance – Done
3. Proof of Concept – Peer to Peer Communications – Today’s Demonstration
4. Additional System Feature – GeoMessaging – not part of original project requirements – major uses in public safety

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Project Requirements and Capabilities—continued

Capabilities

1. High speed, long range 4.9/5.8 GHZ Wireless Public Safety Communications System
2. Peer – to – Peer Communications
3. Basic GeoMessaging Function

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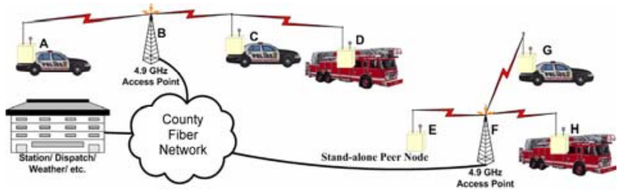
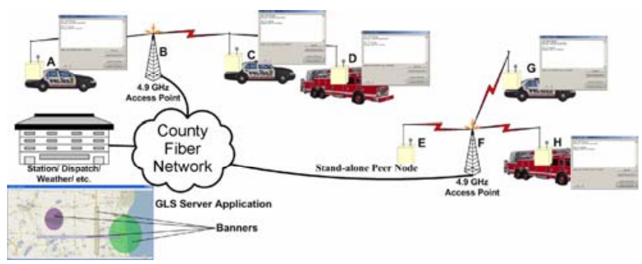
Peer to Peer Communications Network for Kenosha County



GeoMessaging Overlay for Public Safety Network



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Field Demonstration

- GeoMessaging Software Demonstration
- Vehicle to Dispatch Center Streaming Video Demonstration
- GeoMessaging Demonstration in Vehicles
- Incident to Vehicle Streaming Video Demonstration
- Peer to Peer Demonstration

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