802.11b Wireless Network Visualization and Radiowave Propagation Modeling

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ABSTRACT

This paper outlines the methods of creating detailed coverage maps of 802.11b networks, with an emphasis on minimizing the expenses and time involved. The goal of this work is to develop and present a streamlined, reproducible approach to wireless visualization as well as techniques for predicting coverage area before conducting network installations.

After evaluating these coverage maps, a repeated series of field measurements will be checked against interpolated values in order to improve techniques for extrapolation of data for unsampled regions. If successful, these extrapolation techniques will provide additional guidelines for, and assist modeling of, new wireless network installations. However, this paper demonstrates that due to the microcellular structure of indoor/outdoor 802.11b networks, accurate interpolation and propagation prediction techniques do not exist independent of highly specific location models. In lieu of the creation of extensive simulation environments, best practice guidelines for municipal wireless network planning and deployment are presented.

1. INTRODUCTION

During the summer of 2002, I have been engaged in deploying an 802.11b wireless network to cover the student housing in the town of Hanover, New Hampshire. One of the major stumbling blocks in this endeavor has been the absence of accurate maps detailing current network coverage areas. The Hanover network uses a meshed topology, so future installation sites must be carefully chosen to be within the current coverage area, but not significantly overlap the coverages of other nodes.[1] Overlapping in this case causes network throughput degradation due to channel saturation. In order to visualize the installed network, and assist in planning future expansion, I intend to develop interpolation and radio propagation prediction techniques to quickly deploy in new areas, and grasp the exact extent of the currently installed network.

The spatial modeling of wireless networks allows valuable analysis. Visualizing the exact extent of the network can help one understand its performance. A recent article in the *Communications of the ACM* [BK03] identified numerous purposes of WiFi mapping, including coverage assessment, security hazard detection, rogue access point location, hotspot access location compilation, and AP configuration habits determination. This paper focuses on the benefits of precise, detailed spatial visualization to the network administrator; Aside from coverage area delineation, visualization enables the network operator to identify issues such as areas of channel saturation, or competing network coverage.

[1] Cisco Aironet 350 Bridges (same as Access Points for our purposes) were installed without a wired backbone; Packets are forwarded from bridge to bridge until a root bridge is reached. Cisco defines a root bridge as a bridge with a wired connection that serves as the center of a meshed or point to multipoint bridge network. Note that this requires that all bridges connected to a specific root node operate on the same radio frequency channel.

These benefits are examined in more detail in the data analysis section.
In radio propagation studies, the importance of GIS techniques is emphasized; Field measurements are essential means of correcting and constructing theoretical models. The radio guru Andy Kukar, believes that extensive work needs to be done to connect the theory of radio propagation with application in the significantly more complex real world [K93]. [LDAT94] details field measurement techniques remarkably similar to those employed in this report, and encourages use of GIS visualization to check correctness of propagation models. Currently, there are no standardized, efficient, modeling techniques available to those deploying wireless local area networks. By analyzing the local networks in Hanover, this report aims to produce reasonably accurate propagation prediction guidelines as are available for other frequencies and radio applications.

2. DEFINITIONS

AP — Access Point. The connection point between the wired and wireless networks. Access Points send out beacons to indicate their presence, usually 100 per second. These beacons enable communication with wireless clients, and are utilized by surveying software to determine signal strength at the user's location.

GIS — Geographic Information System. A software interface for displaying spatial data.

LAN — Local Area Network. A wireless LAN can consist of a single AP, or a collection of APs that are linked together through a wired or wireless network.

SSID — Service Set Identifier. Commonly referred to as the name of a wireless network. In order to associate with an AP, a client needs to know the network SSID. Access Points can broadcast SSIDs to make them public; In broadcast mode, clients are informed of available networks; The user does not need to know the network name in advance.

Wardrive — Term for vehicular-based wireless network discovery. Also called WiLDing for Wireless LAN Discovery. See www.wardriving.com

WiFi — Wireless Fidelity; The nickname given to 802.11b networks.

3. RELATED VISUALIZATION WORK

This section describes currently employed methods of projecting field measurements of wireless LANs. Related work in the field of theoretical radio propagation modeling is discussed in Section 5.2.

Figure 1: Point AP location map from WiFiMaps.com http://www.wifimaps.com

3.1 Wireless Network Maps

There are a great number of wireless mapping projects online, but most fail to address network coverage visualization in any meaningful or organized way. The most primitive method disseminated is warchalking, where mappers inscribe a

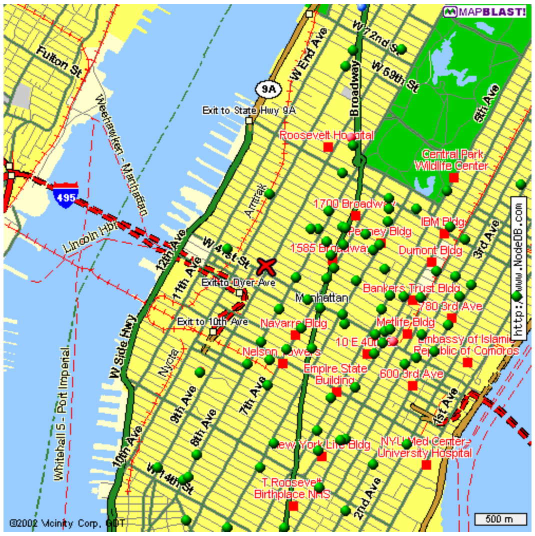


Figure 2: Simple point AP representation
http://www.nodedb.com

symbolic markup on the physical premises to indicate the presence of a wireless network in the area. The legality and effectiveness of this method is questionable. In order to acquire users, most public access wireless networks already advertise configuration information in the physical space. One could argue that distributing maps or access information about other networks without the operator's permission is illegal. On the other hand one might reasonably consider all wireless networks public due to the nature of the wireless medium; These waves are passing through the air and our bodies, and anybody should have a right to analyze them as they see fit. Providing an answer to this debate is outside the scope of this report, but privacy and security considerations observed during this study are discussed in the data collection techniques section.**[2]**

There are numerous digital map repositories, Most wireless community connectivity groups maintain some form of mapping database; A listing of such grassroots groups can be found at Wireless Communities.[3] The maps maintained by these groups are usually limited to pinpoint approximations of Access Point locations plotted on road maps. In addition to these sources, there are several inter-community map repositories including WiFiMaps and The Wireless Node Database Project (Figures 1, 2).[4] Both of these projects also store simple approximated pinpoint AP location data. This type of data is only useful for visualizing the number and general layout of networks and Access Points in a broad area; Exact coverage cannot be determined from the recorded data. The Netstumbler map site and the Wireless Geographic Logging Engine store more detailed wardrive trace data, yet do not offer any visualization format that is particularly useful or informative.[5] Kansas City Wireless has detailed coverage data incorporated into specific node information pages (Figure 3).[6] For some nodes there exists informative coverage maps created using Microsoft Terraserver or Acme Mapper terrain data combined with interpolated NetStumbler measurements or

Figure 3: Acme Mapper data and interpolated field strength overlay
http://www.kcwireless.net

[2] Current legal status at the federal level is of the first mindset; Unauthorized access and use of wireless networks is considered theft of service; The Federal Bureau of Investigation has expressed significant concern over coordinated mapping/chalking efforts [M03]. However, this initial conservative interpretation of existing laws with regards to wireless networks is being rethought due to the proliferation of publicly available wireless access. [W03] details a state law under consideration in New Hampshire that places responsibility for securing wireless networks on the network operator; If unauthorized access is accidentally gained, which is not uncommon since many wireless computers will aggressively attempt to gain access automatically [BK03], the wireless network user is not at fault. New Hampshire is the first state to attempt to legislate this otherwise gray area, and this author hopes that the NH model is adopted on a nationwide level.

[3] www.personaltelco.net/index.cgi/WirelessCommunities

[4] www.wifimaps.com; www.nodedb.com

[5] maps.netstumbler.com; www.wigle.net

[6] www.kcwireless.net

Radio Mobile propagation models.[7] It appears that Kansas City Wireless uses the most advanced mapping techniques of those employed by wireless network operators. Unfortunately, users decide on an individual basis what visualization techniques to use, making comparison of coverage areas meaningless. Though the majority of wireless communities attempt to offer coverage maps, the lack of useful, detailed visualization indicates a need for research in this area.

The most useful wireless network visualization work is being conducted by graduate students at the Information and Telecommunication Technology center at Kansas University.[8] The Wireless Network Visualization project focuses on techniques of data presentation. The procedures and techniques for visualization and data collection are similar to the ones utilized in this report; An unspecified GIS application is used to visualize data output from a Netstumbler & GPS data collection system. An upcoming wireless network analysis of Lawrence, KY will probably parallel this report, and should be an informative read.[9] The researchers at KU coined the term wireless visualization; this report owes much to their efforts. The forums available on the project's website are a great resource to anyone interested in participating in this field.[10]

3.2. Wireless Network Mapping Software

There are several software programs and scripts for wireless data visualization available. A member of Kansas City Wireless contributed code to the carte.pl mapping script, which is distributed by DMZ Services. Carte.pl is a perl script that, using NetStumbler data as its input, creates circular coverage fields using inverse distance weighted interpolation methods to approximate the AP's central location (figure 5). A convenient feature of Carte.pl

Figure 2: Hull map created by GPSMap
http://www.eyecannon.com/wardrive.html

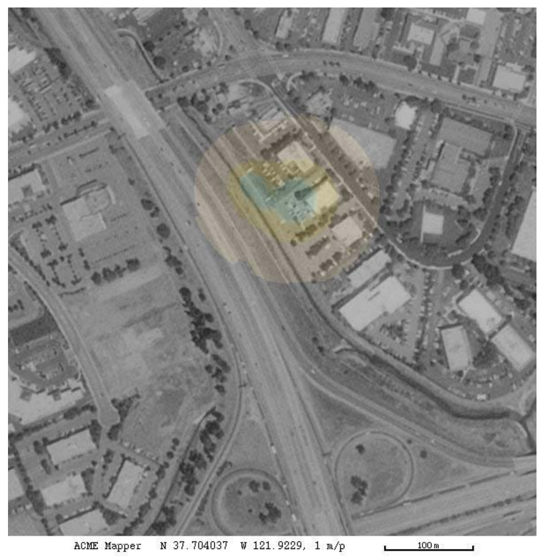


Figure 3: Circular IDW coverage approximation generated by Carte.pl
http://www.dmzs.com/tools/files/wireless.phtml

Figure 4: Generic circular coverage map generated by TrackNS
http://www.eyecannon.com/wardrive.html

[7] terraserver.homeadvisor.msn.com; www.acme.com/mapper
[8] www.ittc.ku.edu
[9] www.ittc.ku.edu/wlan/diststudy.html
[10] www.ittc.ku.edu/wlan

is that it automatically downloads background aerial images from Microsoft's Terraserver. TrackNS and Stumbverter are similar scripts written to convert Netstumbler output into an overlay format readable by Microsoft MapPoint 2002 software. Stumbverter converts data into the simple pinpoint AP location point approximation used by most wireless community mapping resources; Many of these sites accept uploads of Stumbverter output. TrackNS creates coverage fields by approximating the AP location, and draw a circle around this point, using the farthest distance the AP was seen from this point as the radius (figure 5). GPSmap is a utility included with Kismet, which produces circular maps identical to those created by TrackNS. GPSmap can also create hull maps, which are slightly more realistic approximations of wireless coverage areas (figure 4). See the software section for more details on the Kismet/GPSmap program. All of the currently available mapping software is of little use to this project in that the maps produced have insufficient detail, or are highly inaccurate. As outlined in [KNE03], Contiguous, Circular coverage areas are highly unlikely. These mapping programs fail to provide requisite detail or accuracy because they only take the farthest extent measurements into consideration for coverage mapping.

4. WIRELESS NETWORK VISUALIZATION

This section details the entire process of data collection through visualization. Exact visualization formats are analyzed and discussed in section 5; The purpose of this section is to outline the exact techniques of creating a GIS dataset for reproducibility at other locations.

4.1. Data Collection Techniques

Wireless network data was collected using NetStumbler and MiniStumbler. These programs were selected because of their ease of use and installation; both programs run on the Windows platform. These programs observe reasonable privacy guidelines in that:

1. Access Points are detected only if they are publicly broadcasting their SSID, or the client card is configured to look for that specific SSID.
2. No attempt is made by the software to gain access to the network.
3. Other traffic on the network is not intercepted or analyzed in any way.

In addition to observing these guidelines, the software used was chosen because it conformed to spirit of legislation currently under consideration in New Hampshire [W03], and does not broach the concerns outlined in an FBI memo [M02]. Furthermore, all detailed mapping would be conducted on the Dartmouth College and Greenwave Wireless networks, and the approval of both network operators was obtained in advance.

For the driving scans, a Dell Inspiron 7000 Pentium II processor laptop running the Microsoft Windows 98 operating system and NetStumbler 0.3.30 software for data collection was utilized. Wireless signal strength data was collected with a Dell Truemobile 1150 PCMCIA card connected to a 40 cm pigtail, coupled via N-type connectors to 10 feet of LMR-240 cabling which fed directly into a 5 dBi gain omnidirectional antenna mounted on the roof of the car (Picture 1 shows a close up of the antenna). A Garmin eTrex Vista GPS mounted on the dashboard was connected to the serial port of the laptop for location data input.

For walking scans, an iPAQ 3870 with a single PCMCIA card expansion pack running Microsoft PocketPC 2002 operating system and MiniStumbler 0.3.23 (beta) software for data collection was utilized. Wireless signal strength data was collected with a Lucent Orinoco Gold PCMCIA card connected to the same antenna assembly as described above; In this case the antenna was mounted on a pole attached to a backpack, so that the antenna would be at the same height as before for data collection, and the user's body would not obstruct wireless signals. The Garmin eTrex Vista GPS was connected via a serial gender changer and null modem adapter to a mobile serial synchronization cable connected to the iPAQ (Picture 2 shows the entire system).

Note that though the wireless cards appear to be different (Orinoco Gold and Dell) they are both from the same manufacturer (Lucent). It was posted in the Netstumbler Forums that the Dell card was functionally the same as the Orinoco Gold model. Using the Lucent/Orinoco driver hardware identification tool confirmed that a Dell Truemobile 1150 is a repackaged Orinoco Gold card, as they are identical on a hardware level . Also note that the antenna used in the study provides a certain amount of gain; but this was necessary for vehicular data collection. Wireless signals would have been received poorly inside the car's metal and glass frame. The same antenna was used for the walking scans to ensure uniformity in the data.

4.2. Data Manipulation

The data collected by Netstumbler is geocoded in Decimal Degrees of the World Lat/Long coordinate system. ARCMap was selected as the GIS software to be used for mapping, as it is a robust vector and raster capable GIS application; Being an Earth Science minor; It was also a program I was suitably familiar with. Unfortunately it is a fairly expensive program as well. For reproduction of these results, however, any GIS solution should work.

4.2.1 Netstumbler Data

The Netstumbler and Ministumbler data files were exported from Netstumbler as tab-delimited text files and imported into Microsoft Excel. In Excel, the sign was changed to negative for the longitude, to represent the proper value, and the data fields were given appropriate labels. The file was then saved in DBASE-3 format for import into ARCMap. Before being imported into ARCMap, the data needed to be projected in a common coordinate system. For this report, the 1983 Universal Transverse Mercator projection, Zone 18 North, which includes the Hanover and Upper Valley area, was chosen. First, the file was opened using ARCToolbox, and identified as using the World Geographic Lat/Long Degrees coordinate system. Then ARCToolbox was used to reproject the data in the UTM Zone 18N coordinate system. The reprojected data was then added to the ARCMap GIS.

In some cases, to reduce noise in the GPS data, the tab-delimited text files were run through shell scripts that rounded the location to the nearest 1/8000th of a degree; The data in the files was originally recorded to 1/1000000th of a degree, though the error of the GPS was significantly greater than this precision implies. This rounding served to grid the data, and values for each grid point were determined to be the average of all the locations that had been rounded to a specific grid point. The gridded data provided more precise and accurate visualizations.

4.2.2 Background Images

For the upper valley mapping, high resolution Digital Ortho Quadrangles (DOQs) provided by the USGS were utilized. These images were downloaded from GRANIT in SID format, which includes geocoded information.[11] The metadata files accompanying each DOQ specify the appropriate coordinate system. Using ARCToolbox, these images were reprojected in the UTM Zone 18N coordinate system, and added to the ARCMap GIS. For various visualizations, Digital Elevation Data (DEM) was utilized. These datasets were downloaded from

[11] www.granit.sr.unh.edu

GRANIT and reprojected to the UTM coordinate system using the same techniques as for the DOQs.

A high resolution aerial photo was used for the detailed maps of the Hanover networks; This image has spatial resolution down to 30cm/pixel, and was purchased by Dartmouth College in the fall of 2001. The aerial photo had no associated coordinate data. Using a GPS, location data was collected at 15 locations in the photo's scene. Over 200 readings were taken at each location and averaged. This location data was then corrected using Differential GPS techniques (DGPS), and the exact location data was assigned to the correlating points on the photo. Using these ground control points the photo was then registered to the UTM Zone 18N coordinate system using the ENVI software package, and imported into the ARCMap GIS as a GeoTIFF.

Finally, an AutoCAD 2002 file containing Access Point locations as well as outlines and floorplans of buildings on the Dartmouth College Campus was imported into ARCMap, and scaled using the building footprints as reference points to overlay the registered aerial photo.

4.3. Data Visualization

With the images and network data in the GIS, various visualizations were created. These involve altering the symbology of the network data display and were specific to the GIS program used, in this case ARCMap. Once the data is available within a GIS program such as ARCMap, it can be viewed in almost any way imaginable, if supported by the GIS. The Various visualizations are discussed in section 5.1.

5. RESULTS

Results are presented and discussed on the following pages. Below are examples of how the data is combined (as detailed in section 4).

Data Manipulation Techniques Example

Figure 5: Netstumbler output is projected in the UTM Zone 18N coordinate system. ARCGis reads in the text or dbf file, and spatially projects the data with the desired symbology. The dots represent points where netstumbler recorded wireless activity; Here a red dot means poor signal strength, and green is strong signal. The dots provide a breadcrumb trail showing where the scanner was driving/walking.

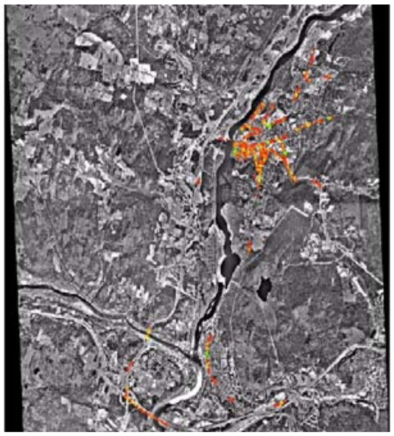
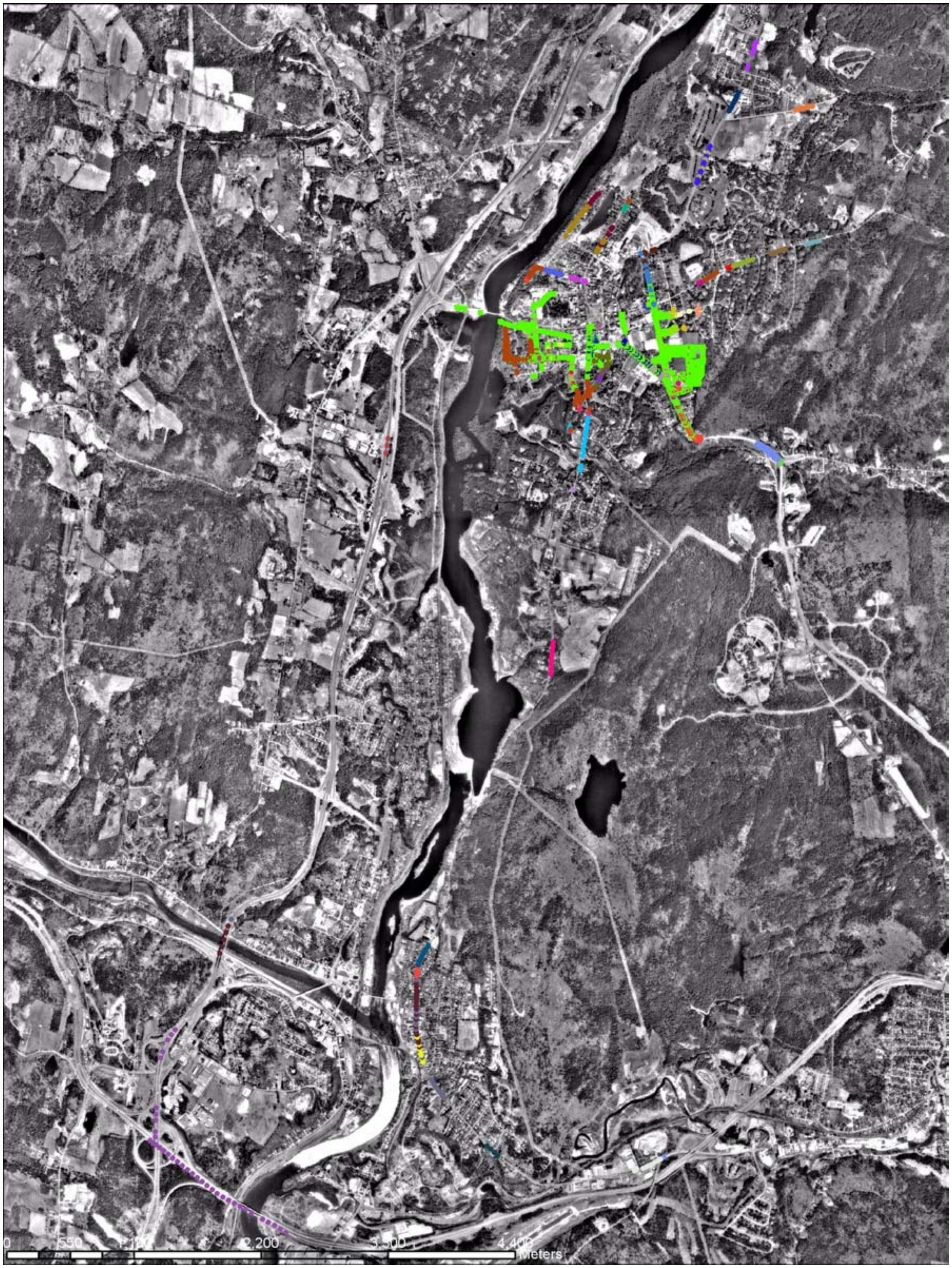
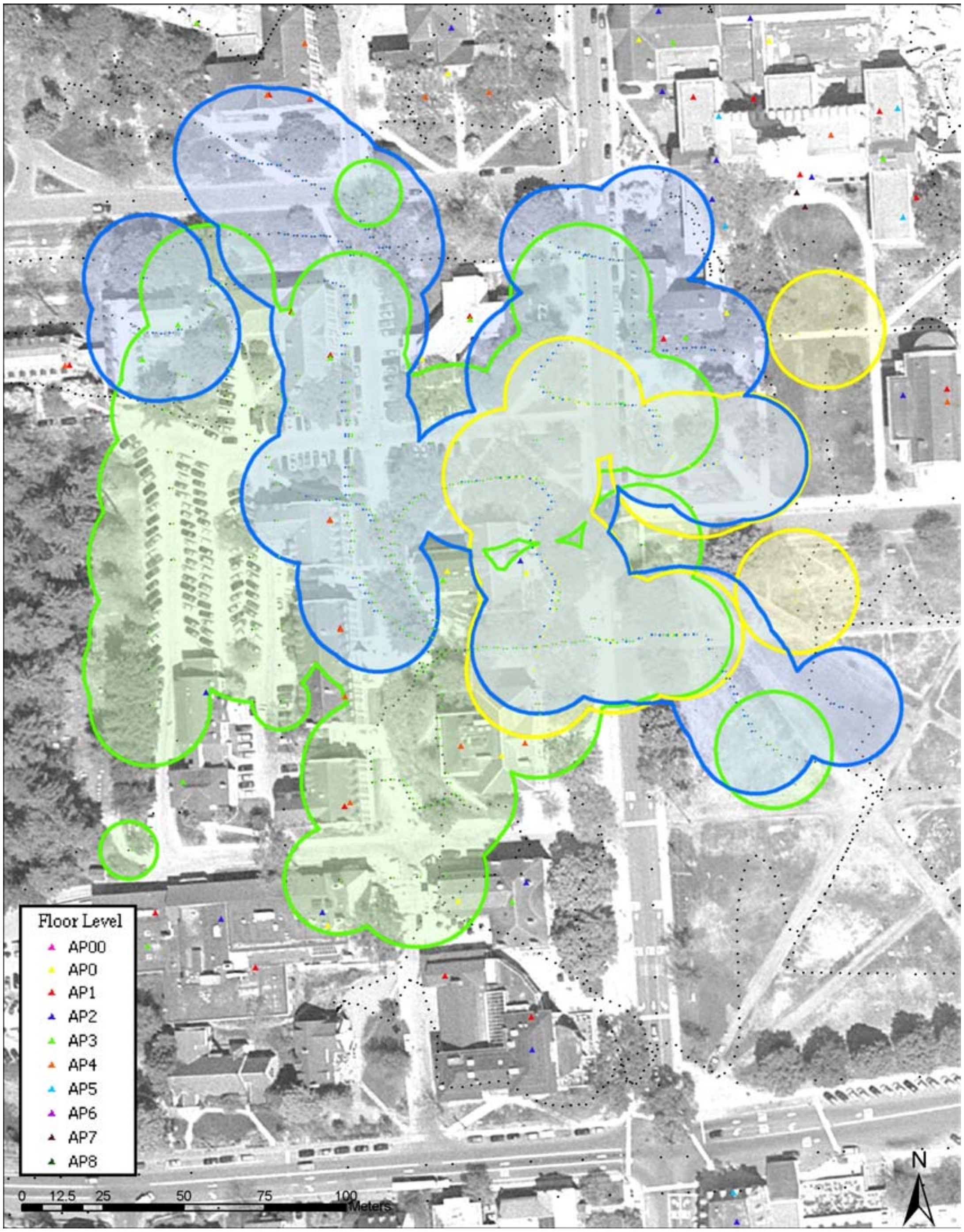


Figure 6: Netstumbler data projected against a backdrop. Here point signal strength data is plotted over the DOQ that has been converted to the UTM coordinate system. The Netstumbler data is automatically projected without user alignment since both the picture and the wireless datapoints are projected in the same coordinate system. SomeGIS lingo: The Netstumbler data is an example of vector data as it is not a grid; There are point values for various locations. The aerial photo is raster data, as there is a value (represented by a shade of grey) for every point in its grid.

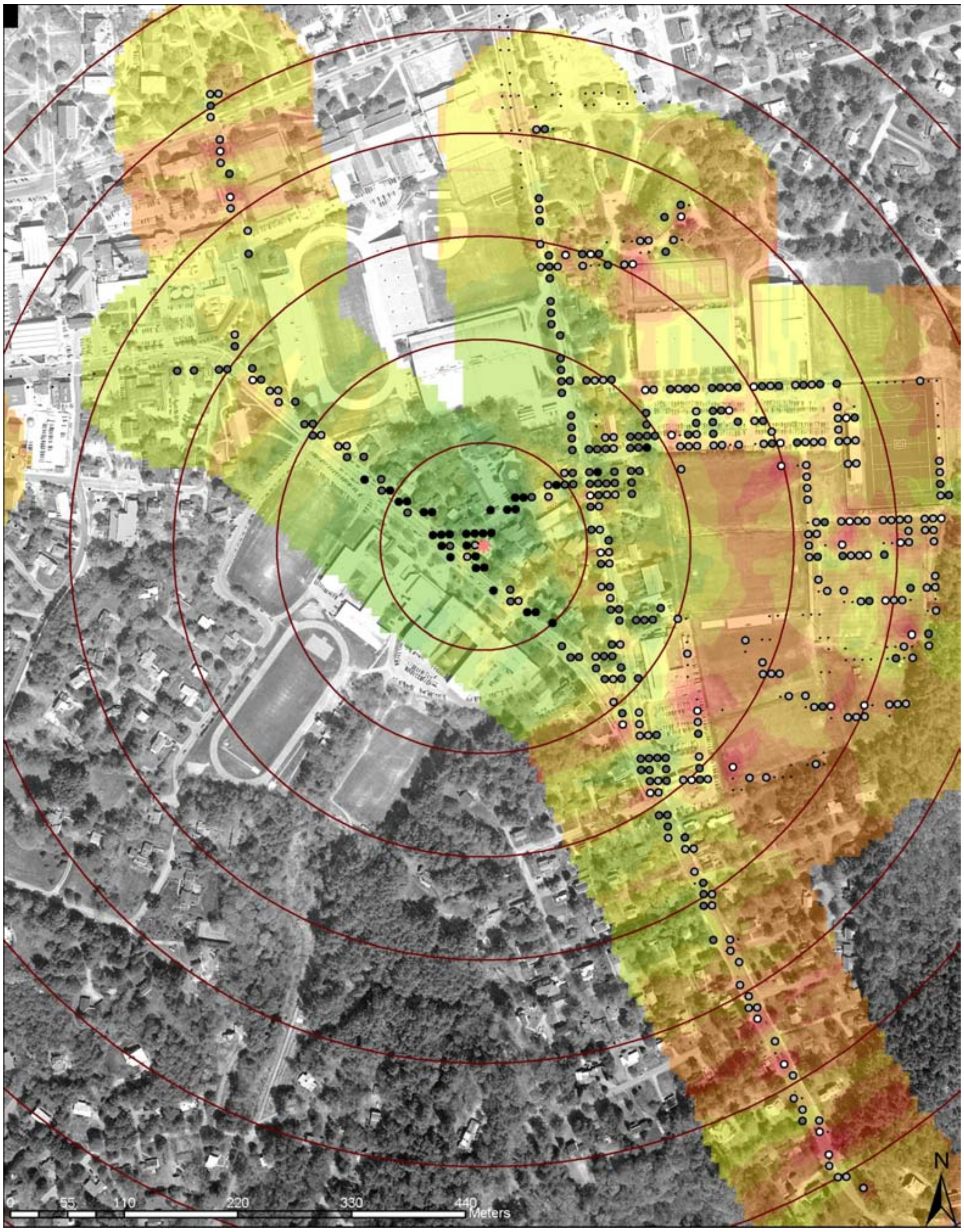
Map 1: Driving Tour of the wireless networks in Hanover NH. This is a map of every network in Hanover that broadcasts its SSID. Each dot represents a Signal to Noise Ratio reading > 5 dB. Different SSIDs are drawn in different colors; The green squares are readings from the Greenwave Wireless network, the off-campus network I am deploying.



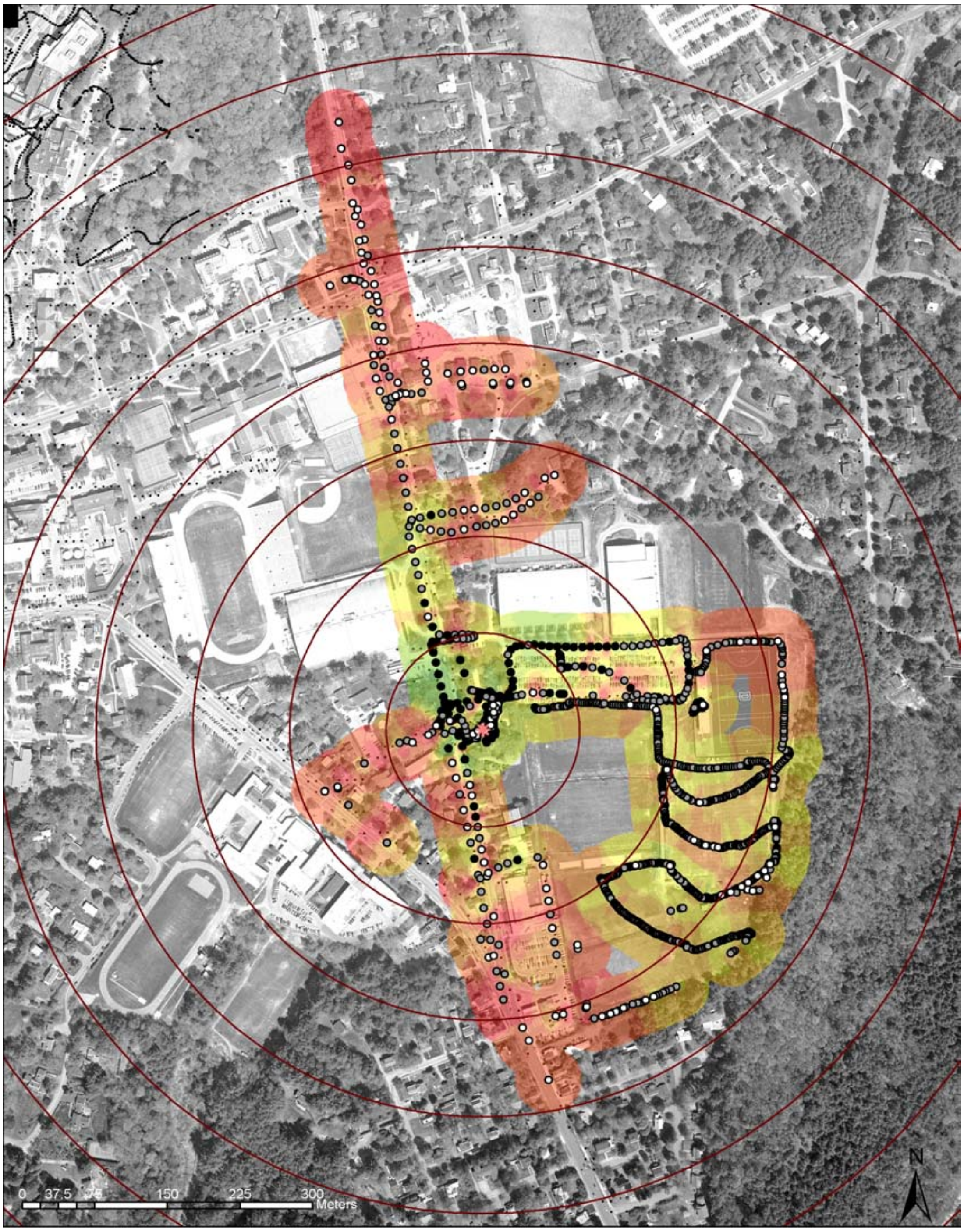
Map 2: Driving Tour of the Upper valley. This is the same style of visualization as the previous map, just zoomed out to a wider scene. On a loop from Hanover through Norwich, down Interstate 91, and back up Route 10, 63 individual networks were discovered. Keep in mind that there may be more; Netstumbler only detects poorly configured access points that are broadcasting their wireless signal.



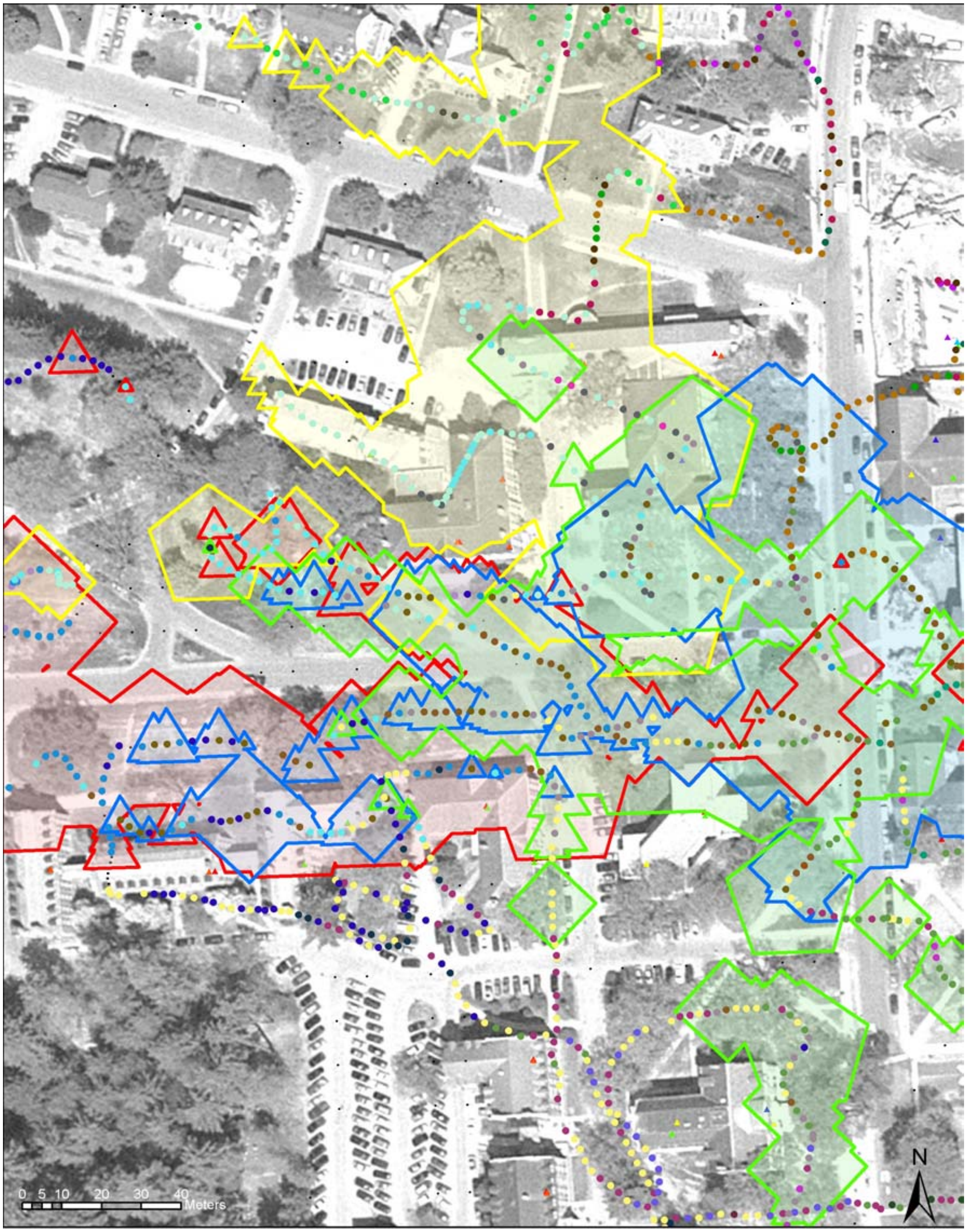
Map 3: This map serves as a prime example of the difficulties of predicting radio coverage area; In this map the triangles are APs located inside buildings; their color indicates what floor they are on. The central building, Parkhurst for the Dartmouth folk, has three active APs in it; The shaded fields and outlines represent the coverage area of the three APs, as approximated by the signal to noise ratio at measurement points. Here we use a crude interpolation method of drawing circular buffers around measurement points with radii in direct relationship to the measured value. It is probably a little generous in terms of coverage, but we can visualize an important concept; that AP height can almost double coverage area. Thus it makes sense that the APs on higher floors have a larger coverage area outside the building. What is perplexing is that the coverage itself does not follow a simple or predictable pattern. Clearly there are complex factors at work here which cannot be adequately simulated by generalized models.



Map 4: Coverage of a Greenwave Wireless Access Point. The Circles and dots are where actual readings were taken; The colored field is interpolated values, with green being strong coverage and red representing little to no coverage. Inverse Distance Weighted Interpolation was used, with a minimum of 3 neighbor points in a variable radius with a ceiling of 100 meters. This ceiling is why the interpolation stops 100m away from the data points; At this point there is little accuracy to the interpolated value, if any. One improvement to this interpolation would be a fade in the interpolation, as the variable radius approached its maximum. White circles indicate Signal Strength from 0 to 25 dB, light gray circles indicate Signal Strength from 26 to 50 dB, dark gray circles indicate Signal Strength from 51 to 75 dB, and black circles indicate Signal Strength over 75 dB. Black dots are where we could not hear the node, but these were not included in the interpolation; Notice that the interpolation function incorrectly interpolates higher values for the areas with no signal strength values; it is weighted towards providing a higher signal value; The pockets of weak signal that form around the white circles are indicative of this issue. The maroon rings are spaced 100 meters apart for reference.

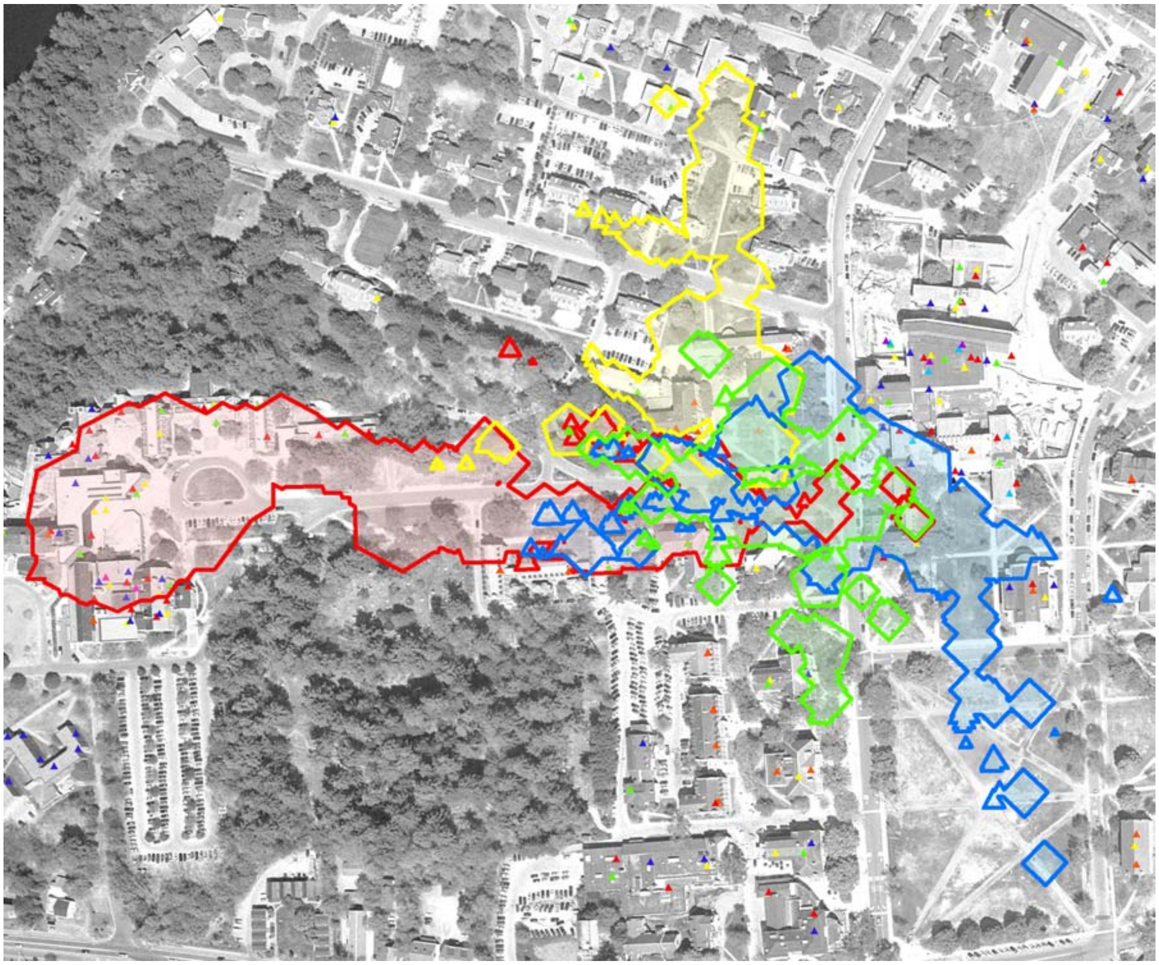


Map 5: Another Greenwave Node. This map follows the same symbology of the above map, but instead of graphing Signal Strength, the Signal to Noise ratio is plotted and interpolated. The Signal to Noise ratio is a more useful measurement than signal strength alone; Wireless clients can only connect if there is a positive SNR, no matter how strong the Signal. Note that the lack of circular coverage is exaggerated in this map; The signal disappears 200 meters West of the broadcast point, but is still strong 500 meters North. There's a reason: Look back at Map four, and remember the Greenwave Network Toplology. Excessive noise is generated to the west from the adjacent installation operating in the same frequency. The Interpolation used in this visualization is still inverse distance weighted, but requires 8 points, and has a maximum radius of 40 meters. Numerous methods of interpolation were tested, but none yielded particularly accurate results. Interpolation is best applied as a stopgap method for small holes in survey data.



Map 6: Can Someone turn down the volume? This map illuminates a severe channel saturation problem. On this map, we plotted our path through the network with the little black dots; Wherever we encountered a radio broadcasting on Channel 11, we plot a uniquely colored dot for the Unique MAC of the AP. Four APs were chosen at random, and our crude buffering coverage visualization method was implemented. Here the buffers were derived from Signal Strength alone, not the SNR. From this map it is painfully clear that Dartmouth needs to turn down the power on some of the campus APs. Having more than 4 APs in range of each other on the same channel causes significant network degradation. Here, apart from the four we have highlighted, there are regions where up to 8 different APs on the same channel can be heard. Drawing our

scope back a bit, we see the extent of the propagation of these nodes. Granted, these measurements are enhanced by the 5 dBi antenna we are using, but this is clearly poor network design.



A closer examination at the Netstumbler Data for one of these overgrown nodes shows the negative effect on network performance; A strong signal is being received, but a very mediocre SNR is involved.

SNR	Signal	Noise
0	60	60
5	64	59
3	59	56
11	65	54
11	70	59
7	64	57
6	61	55
6	65	59
7	65	58
9	67	58

5.1. Visualization Summary

Once the data is compiled into a GIS format, visualization is remarkably simple; With decent GIS software, most of the visualization work is done by the computer. The images provided in this section are sample formats found to be particularly informative.

5.2. Radio Propagation Modeling

The stated goal of this paper is to streamline the mapping process, so that less data needs to be collected, and develop new propagation and coverage prediction techniques for expansion modeling. Though the visualizations in section 4 were useful, it was clear from the results that coverages were hardly predictable. Since we were unable to determine any interpolation techniques through the actual visualization process, we will examine existing radio propagation modeling techniques.

One useful technique for modeling coverage has been a distance-based approach. While this has enjoyed widespread success with lower frequency and high power radio applications, the line of sight requirements of the 2.4Ghz frequency band, coupled with the relatively low power output (< 20dbm or <100mW) of standard 802.11b equipment, make distance-based signal strength calculations inaccurate; This can be inferred simply from the non-circular coverage areas illustrated in the maps we have produced. Specific research with 802.11b coverage and location, covered in [GBB02] and [SK02], indicates that purely distance-based coverage approximations are highly inaccurate, especially in indoor, or mixed indoor/outdoor installations.

There are numerous complex propagation models for accurately modeling radio performance; The author examined Broadcast, Carey, COST231, Bullington, Okumura (Hata), Longley-Rice, and Egli; Prior research outlined in [MK00] and [SLB96] indicates that the Okumura-Hata model would probably be the most appropriate given the omnidirectional application and high frequencies involved. It should be noted that the suburban model considered by Okumura is more applicable to an urban area in the United States; Okumura's equations were derived in substantially more dense environments than their parallels in the United States. This is the reason that Okumura's equations are not considered accurate for rural applications. [MK00] demonstrates means of tailoring the Okumura-Hata propagation equations for rural areas. However, these modifications are too generalized for the smaller coverage areas of 802.11b LANs. The rural propagation model presented assumes relatively homogenous attenuation throughout the coverage area; The small cell size and reduced power of the radios in this study places a sensitivity on the coverage area, and the heterogeneous attenuation of its features cannot be suitably generalized in this manner. [SLB96] addresses these issues by providing several different levels of morphological classification for coverage areas. However, the error present in their model, 4dB, is too large for detailed mapping purposes, since the output of a typical Access Point is 15dBm.

These conclusions are supported by [ARY95] which indicates that one set of equations, such as the Okumura-Hata model, is insufficient for modeling microcell propagation. [ARY95] suggests that Nakagami-Rice distribution models should be used for line of sight propagation calculations and Rayleigh distribution models utilized for and non line of sight calculations. For our application this would involve building a substantially detailed three dimensional model of the coverage area to determine line of sight and non line of sight locations. The topographic data used in this report would not be sufficient; buildings and trees would need to be measured and incorporated into a simulation environment. Modeling outdoor propagation from indoor antennas, as is the case for most of the radio sources studied in this report, would be especially challenging; Floor plan models, and indoor propagation simulation would be required.

The goal of this report is to streamline the mapping procedure through generalized interpolation guidelines based on those used for propagation modeling. However, it is apparent that the complexity of microcell modeling is significant, and that the time involved in building such detailed models might be better spent doing field surveys. However, for the Dartmouth Campus, we already have the floor plans in the GIS database, so simulation may not be out of the question. [IYZ01] specifically addressed the issue of Indoor/Outdoor modeling, and suggests that with a refinement of the ray tracing method, and well tested diffraction and transmission coefficients, effective modeling is possible, as suitable coefficients can be determined, even for non homogeneous wall constructions.

Unfortunately several studies show that obtaining reasonably accurate coefficients given the weak (<20dBm) broadcast strength involved will be relatively impossible, and certainly more time consuming than a field-based approach. Furthermore, the coefficients provided in these studies are for frequencies surrounding the desired 2.4Ghz spectrum; There are means provided for scaling these values for the desired frequency, but this will increase the error of the coefficients. To give an idea of the detail involved in this modeling process, a short list of the applicable coefficient sources available is provided here. [JMCF03] provides sample coefficients for radio propagation through concrete and brick walls; Data is provided for attenuation characteristics of walls based on cement and brick composition, water content, and thickness. [CDE94] provides attenuation coefficients for radio propagation through trees. The coefficients listed are distributed over a significant (in terms of 802.11b cell power) range of values depending on the type of tree involved; classification and identification of specific tree types will be necessary for reliable models. [DRX98] details a comprehensive study of residential radio propagation; It is particularly suited to the purposes of this report, as the study is conducted in a suburban area comparable to Hanover. [DRX98] provides useful coefficients for home penetration attenuation, with values for multiple floors, and room depth with regard to transmitter location. Values are derived from over 276,000 signal strength measurements. However, three separate houses are studied, and there is significant fluctuation in coefficient values for each household. These discrepancies were attributed to exterior and interior wall construction, floor height, and other factors.

6. CONCLUSIONS

The reduced output power of 802.11b Access Points makes application of traditional modeling techniques dependent on creation of modeling environments that incorporate an inconceivable level of detail. [ARY95] states that “widely encompassing and reasonably compact” methods of classifying environments are needed for advanced modeling and wireless ubiquity. However, the papers cited above demonstrate that in the case of suburban microcells, simple classification generalizes the propagation models to such a degree that they fail to yield useful results. Collecting and compiling exact composition and spatial data for every home on a street, and every tree in between, requires a prohibitive amount of time if the final goal is rapid broadband deployment. The requisite composition information may not be available; and invasive characterizations and modeling of residential homes will undoubtedly be difficult on a social and technical level. Given the low costs of 802.11b access points, a more suitable approach might be to first install Access Points based on conservative propagation estimates, and use the techniques detailed in this report to take field readings and visualize the network. Cisco Access Points, and radios of other enterprise class hardware manufacturers, can be configured to broadcast at variable power levels [D02]. After a field analysis, the transmission power of specific access points can be increased or decreased to achieve the desired

coverage area. [HL99] demonstrates a conservative means for predicting urban and suburban coverage of 802.11b access points using the Okumura model. The report arrives at the conservative estimate of a cell radius of 27 meters for a suburban environment, given a transmitter height of 30 meters and radiated power of 15dBm.
This conservative estimation technique, followed by field measurements is the best practice for Wireless LAN deployment offered by this report. Extensive modeling is prohibitively time consuming, and the accuracy of the final result is not guaranteed; the margin of error involved in most calculations exceeds 1/7 of the initial transmitter power. Furthermore, data for creating an accurate simulation environment may not be available. Perhaps with extensive experience in a given region, such as rural and suburban New Hampshire townships, the conservative estimation method can be fine tuned using the methods presented in [MK00] or purely empirical observation of coverage patterns.

7. FUTURE WORK

The author of this report is investigating better data collection techniques such as incorporating zero values into the data sets for more accurate map interpolation; Currently Netstumbler does not record location points when it is not receiving a wireless signal; These zero points cannot be added based on the GPS path data, since not all GPS recorded points are utilized by Netstumbler when it is under heavy load, and GPS wander (inaccuracy) would result in false zero values throughout the data. Hopfully, an 802.11b environment categorization scheme for reasonably conservative coverage estimation will also be developed as the author continues deployment work; Antenna height, and tree density are the two factors believed to have the most significant impact on the coverage area.

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9. SOFTWARE & RESOURCES

The software used in this project is listed here for those interested in reproducing the results, or conducting wireless network visualization at their own site. Except for MiniStumbler, the software below runs on the Microsoft Windows (98, 2000) operating system.

ArcGIS

http://www.esri.com/software/arcgis/

ArcGIS is a collection of commercially available programs including ArcView, ArcMap, and ArcToolbox made by ESRI for visualization and manipulation of GIS data. ArcView was used to design the maps created through this project; ArcToolbox was invaluable in converting coordinate systems of the various data inputs.

ENVI 3.6
http://www.rsinc.com/envi/index.cfm
ENVI, the Environment for Visualizing Images, is a commercial software program used primarily for manipulation of raster image data. ENVI was used sparingly to format DOQs, DEMs and Radio Mobile output.

GRANIT
http://www.granit.sr.unh.edu/
GRANIT is the New Hampshire repository of free GIS data. GRANIT provided the DOQ images used for the map backgrounds. A high-resolution aerial photo of Hanover purchased by Dartmouth College was used in some map images.

Kismet
http://www.kismetwireless.com/
Kismet is a freely available 802.11b wireless network sniffer with many advanced features that runs under Linux and BSD. It can be coupled with a GPS daemon (such as GPSd) for mapping purposes, and supports such features as runtime WEP detection and IP block identification. Kismet comes bundled with GPSmap for creating primitive coverage maps. While scanning, Kismet detects hidden or 'cloaked' networks, and thus is significantly more invasive than Netstumbler; It enables the user to monitor and record all traffic on any wireless network.

NetStumbler & MiniStumbler
http://www.stumbler.net/
NetStumbler and MiniStumbler are freeware programs used to simultaneously collect location information (via GPS) and wireless network signal strength data. MiniStumbler runs under the WindowsCE/PocketPC operating system, and was used on an iPAQ 3870 for data collection.

Radio Mobile
http://www.cplus.org/rmw/english1.html
Radio Mobile is a freeware application for designing radio links and modeling coverage areas of antennae. It uses DEM data and the Longley-Rice ITS Irregular Terrain Model for calculations.

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