Using Geographical Information Systems to Predict Coverage in Broadband Wireless Systems

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ABSTRACT
This paper discusses using Geographical Information Systems to predict broadband wireless coverage and channel characteristics in the bands between 2.4 and 30 GHz. It presents system layout software that integrates demographic, marketing, and land-use data with digital elevation models (DEM) and Light Detection and Ranging (LIDAR) measurements and compares predicted coverage with measurements at 902 MHz (useful for comparison with cellular data), 2.4 GHz, 24.1 GHz, and 27.5 GHz. It discusses the influence of DEM resolution, accurate building and vegetation data, etc. Quantitative results include link margins required to ensure that predicted coverage really exists. It describes an ongoing 28-30 GHz impulse sounding program.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Geographical Information Systems have been used in many spatial analysis tasks for the past 20 years. Although applications of GIS to wireless are relatively new, commercial software producers like MapInfo and Environmental Systems Research Institute (ESRI) have developed commercial system layout products, primarily for the cellular industry. While these tools are extremely sophisticated and useful, they are inherently proprietary, and public information is generally lacking about the accuracy of their algorithms, the tradeoffs made, and the applicability of their predictions to systems operating at higher frequencies.

There are two primary areas in which GIS is pertinent to wireless system layout: demographic analysis of markets and radio path characterization. Demographic analysis is used to locate markets for wireless services and place the services so as to maximize profitability. For example, if a company wishes to offer wireless internet service in a license area, an initial GIS study could indicate those parts of the license area that have enough households with proper income levels to be potential customers. By finding these markets (as could be done with a table of census data) and locating them on maps, GIS provides a quick assessment of whether or not the market is clustered or dispersed.

Radio path characterization begins with a determination of *intervisibility*: ascertaining which potential transmitter sites can see which potential receiver locations. This is a key element of GIS analysis as GIS models provide ready line of sight computations across surfaces. These allow users to model potential tower and antenna sites in a region to determine the degree to which competing locations provide signals to the target markets.

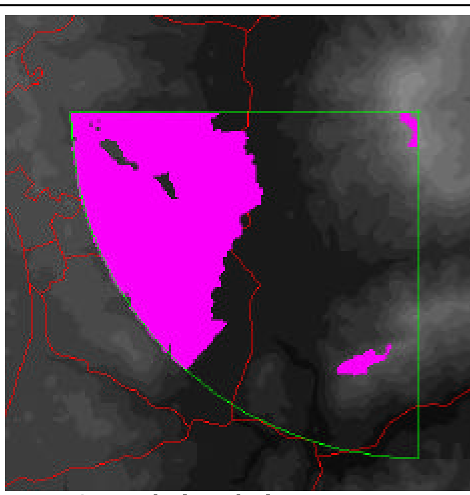


Fig. 1: A viewshed in which magenta represents visible locations computed over a DEM (gray image) with census block groups (red polygons).

GIS Data

Wireless applications require two or more GIS data sets. Demographic analysis requires census maps and data to locate the residences of potential home-base customers. In the USA, the Topologically Integrated Geographic Encoding and Referencing (TIGER) database is of major import. TIGER maps provide complete access to population and housing data at scales ranging from the smallest blocks to the entire nation. Typically data at the block group level are of greatest interest.

A block group is a spatial aggregation generally containing between 600 and 3,000 people, with an optimum size of 1,500 people. This is the most detailed census unit for which attribute coverage is available across the entire USA. Intervisibility analyses also require a digital surface model. The most commonly used surface model is called a Digital Elevation Model (DEM). A DEM is a regular tessellation of cells each of which contains a single elevation value representing either the average elevation of the land within that cell, or the elevation at the central point of that cell. Elevation data have been generated most commonly from aerial photographs in stereo pairs, or from interpolated Triangulated Irregular Networks formed from irregularly spaced surface sample locations taken from topographic maps. Gridded DEM data in the USA are available on-line at resolutions from 30-meters to 3 arc seconds (approximately 92-meters). Typically, for study regions at the scale of US counties, the highest resolution 30-meter data are preferred. These data can be combined through overlay techniques to provide very useful statistics on visibility of customers (Fig. 1). Other data, if available, can be included in wireless analysis. For example, if the target audience for a service is businesses rather than home users, knowledge of the locations of businesses in the community is most useful. Map points representing customers can be added to the GIS data layers.

SYSTEM LAYOUT SOFTWARE

With our colleagues in the Center for Wireless Telecommunications (CWT), we have developed [1] a software package called "GETWEBS" for wireless system design. GETWEBS is written in Visual Basic using ESRI MapObjects components (Fig. 2), combined with a financial modelling package for Microsoft Excel. GETWEBS allows the designer to analyse quickly an area for potential customers, and, once found, to locate equipment to reach them. It provides tools to assist in optimizing equipment positioning, for "what-if" scenarios, for phased deployment and for three service architectures: hub based point-to-point, hub based point-to-multipoint, and hub-less mesh.

Point-to-Point Analysis

In the GETWEBS software, a point-to-point analysis is run in those cases in which the designer knows the locations of both the hub equipment and the customers. While ideally, after analysis, the engineering design is able to serve multiple customers from a single hub (point-to-multipoint), initially the analysis is run by loading appropriate data and proceeding through the analytical steps for wireless design between specific known points.

Point-to-Multipoint Analysis

GETWEBS uses point-to-multipoint analysis for cases in which the hub sites are known but the customer locations are precise only to their being within a specified census enumeration unit. This case occurs for residential markets in which a target market is evident by geographic/demographic analysis, but the exact locations of the customers are not known.

Mesh Analysis

The mesh analysis technique creates mesh geometry among the users themselves rather than using hubs. There is no hub and each user is a node with the ability to receive traffic, originate traffic, or relay traffic bound for other nodes. In this way, the system develops redundancy, and does not require that all the customers be able to see a hub, only that they be able to see at least two other customers. In some types of terrain or in linear arrangements, this architecture may prove more cost effective than the traditional hub approaches.

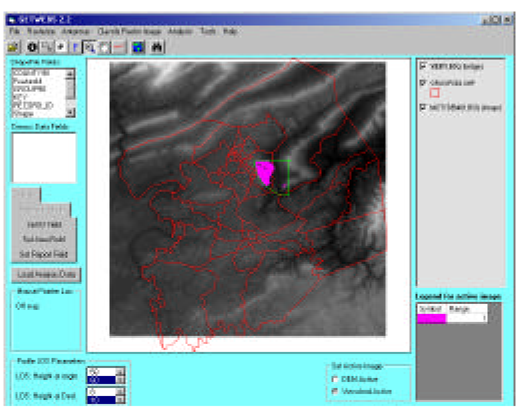


Figure 2. GETWEBS software display

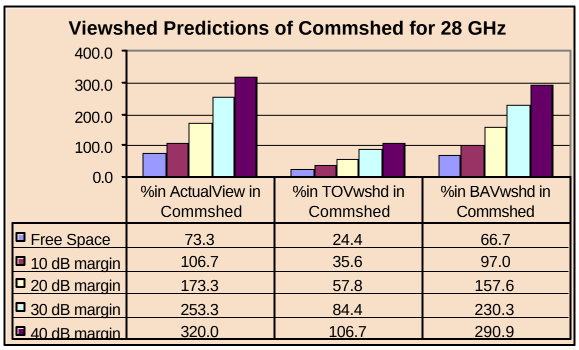
A study area can be modeled for both hub and mesh deployments, or for a combination. The designer can then consult the resulting financial model to determine which is the best choice.

MEASUREMENT RESULTS

Our group has conducted a number of measurement campaigns at frequencies between 900 MHz and 28 GHz to compare predicted and observed path characteristics. Our overall goal is to assess the accuracy of path loss predictions and to understand how it depends on the characteristics of the GIS data used. The data include 257 signal strength measurements and intervisibility determinations at 902 MHz and 2.4, 24.1, and 27.5 GHz made for 63 locations on our campus. (In an intervisibility determination, the observer simply determines by eye whether the transmitting and receiving antennas can see each other. Of course optical visibility does not guarantee sufficient Fresnel clearance of obstacles.) While we would anticipate that the resolution of the DEM would be a major factor in the accuracy of path loss predictions, our experiments have not shown this to be true. Resolutions between 30 meters and 1 meter have little effect on the aggregate accuracy of a predicted viewshed. [2]

Because many of the existing GIS-based propagation prediction tools were created to serve the cellular telephone industry, we compared predictions versus measurements for co-located 900 MHz and 28 GHz transmitters. [3] At each frequency we computed the predicted commsheds (communication viewsheds) based on a terrain-only (TO) digital map and a terrain-with-buildings-added (BA) map. Each field point was classified as being in or out of the viewshed based on whether the transmitter antenna was visible from it. Each field point was classified as in or out of the commshed based on whether or not the received signal strength was less than 10 dB below free space. We selected this value by reasoning that 10 dB was a reasonable fade margin in a 28 GHz system layout if heavy rain is disregarded. Each predicted commshed contained a known number of points, N_V. Field measurements yielded the number of points that are actually in the viewshed, N_M. The fraction of points predicted to be in the commshed that are observed to be in the viewshed is then N_M/N_V, expressed as a percentage. If this fraction exceeds one, it simply means that useful radio paths exist to a set of points that are not predicted to be in the commshed. If the margin is increased to 20,30,or 40 dB above free space, the number of "in" points N_M and the percentage will increase. See Fig. 3.

Fig. 3 indicates that, if we allow a 10 dB fade margin and include buildings in the digital map, the predicted and measured commsheds agree almost exactly (97%). But at 900 MHz, an additional 10 dB of margin is required for the same level of agreement. This is what we would expect. At 900 MHz, the Fresnel zones are much larger than at 28 GHz, and, for the same signal strength, 900 MHz paths must clear obstacles by greater absolute distances than 28 GHz paths. For this reason, we find 28 GHz coverage to be more predictable than 900 MHz coverage.



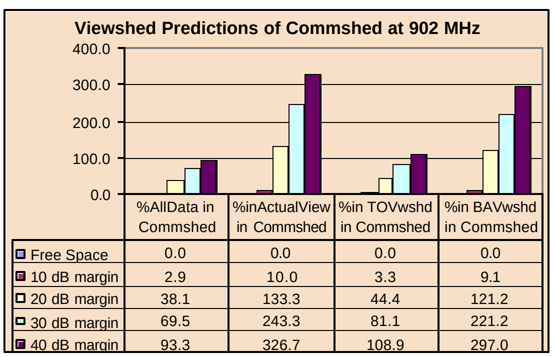


Fig. 3. Percentage of field points in commshed as a function of link margin for co-located 28 GHz and 900

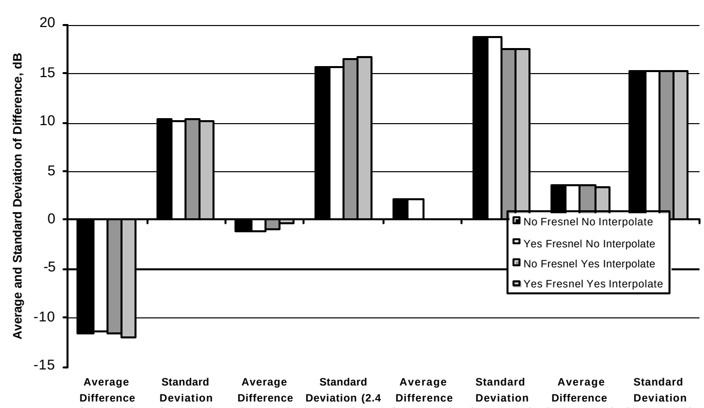
Another set of interesting results appears in Fig. 4 [4] and is discussed in more detail in [5]. Here we compare predicted and measured path loss for several prediction algorithms. A negative error means the measured loss exceeds the predicted value, and a positive error means that the measured path loss is less than the predicted value. Note first that the average error depends on frequency in a reasonable way. At 902 MHz, multipath is important. At 2.4 GHz path loss is more predictable because (with more directional antennas) multipath has declined. At 27 GHz diffraction and vegetative loss become important. In all cases, the sophistication of the prediction method makes little difference.

In Table 1 [5] we show the results of regressing path loss on X, which is 10 times the log of normalized path length. Its coefficient is the path loss exponent *n*. Quoting further from the reference, for ideal LOS paths we would expect $n= 2$; our regression values range from 1.88 at 902 MHz to 4.06 at 24.12 GHz. At the other frequencies, the coefficient approaches 2 as frequency increases indicating a preponderance of LOS paths and a decreasing sensitivity to multipath and diffraction effects. The 24.12 GHz data set is not unusual or incorrect. The field notes of this data set indicated that all of the 24.12 GHz paths were obstructed, even though our DEM calculations predicted that over 65% of the paths were LOS. Obstructed paths incur greater path loss and exhibit steeper slopes than LOS paths.

Table 1. Linear regression equations for actual path loss.

Data Set (by Frequency)	Equation of Regression Line for LOS Path Loss
902 MHz	Y = 1.88X + 90.90
2.4 GHz	Y = 2.72X + 89.84
24.12 GHz	Y = 4.06X + 110.77
27.525 GHz	Y = 2.17X + 105.68

As our previous research has all indicated the strong need for a more detailed terrain surface, we are exploring using surfaces based on LIght Detection And Ranging imagery (LIDAR). LIDAR data provide several bounces off of the surface when flown across an area. The "first bounce" comes from the very top layer of the surface on which it strikes, providing an



excellent and complete propagation surface for LOS and near LOS analysis. LIDAR data are dense enough to provide up to a one meter DEM surface. Research issues include the optimal resolution of the DEM, the improvements possible when using total surface data versus bare earth DEM data alone, and the cost trade offs between different sources of surface data.

IMPULSE SOUNDING PROGRAM

Our results indicate that, given reasonable amounts of margin, shadowed paths may provide viable signal levels at 28 GHz whether the propagation mechanism is diffraction or scattering. Shadowed paths are thought to have rather dispersive characteristics, but most of the evidence is anecdotal. To explore the potential bandwidth of shadowed paths, we are building a wideband channel sounder. It employs ultra wideband (UWB) or short pulse techniques. Implementation difficulties tend to limit the bandwidth of conventional spread spectrum (PN sequence) channel sounders. With the proper choice of filters, UWB is adaptable to a wide range of bandwidths and frequencies.

The transmitter (Fig. 5) generates a fast rise time pulse that is subsequently band limited. The resulting spectrum in up converted to 28 GHz. The receiver takes the 28 GHz spectrum after it transits the channel, down converts it, and applies it to a high-speed sampler. The sampler operates as a sliding correlator in the time domain. Its output is stored and then displayed. The result is the impulse response of the channel.

The impulse response is a profile of the multipath components. This profile can be used to calculate the maximum data rate that the channel can support without equalization. Our current system is designed to measure bandwidths up to 250 MHz. It can easily be adapted to accommodate the entire 850 MHz bandwidth of the US 28 GHz LMDS allocation.

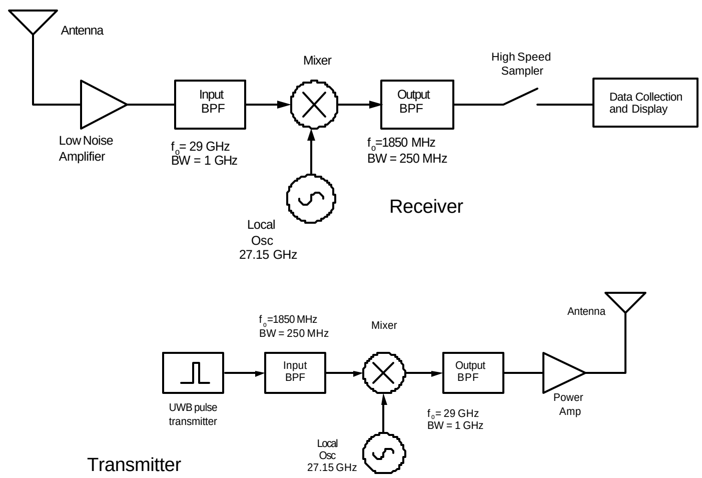


Figure 5. Block diagram of sounder

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