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Technology White Paper

The Application of Land Use/ Land Cover (Clutter) Data to Wireless Communication System Design

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The Application of Land Use/Land Cover (Clutter) Data to Wireless Communication System Design

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Introduction

Land use/land cover (LULC) data can play a significant of role in designing wireless communication systems. It can be used to improve predictions of signal attenuation and other radio propagation effects and to assist in finding the optimal location of network base stations and other wireless system transmitters. It can also be utilized when projecting usage (traffic) trends in any type of mobile or nomadic system.

With literally billions of dollars being spent annually on building wireless communication systems, there is significant incentive to use engineering tools that can accurately and efficiently design and plan such systems. There currently are a number of software tools on the market intended for just that purpose. Considering that a wireless network for a single urban area can be comprised of hundreds of base stations, an efficient system design process can easily justify the expense of the design tool and the effort using it. As the wireless system grows to meet increasing and changing demands for service, the design tool is again a valuable asset in planning optimum modifications to the system to accommodate growth.

Of fundamental importance to the wireless system design tool is the ability to accurately predict the strength of radio signals from the various transmitters in the system. The mathematical algorithms used for these predictions are generally known as propagation models. Originally, propagation models relied on terrain elevation data as the sole environment parameter on which to base predictions. Substantial effort has been invested over the last 20-30 years in developing accurate DTEMs (digital terrain elevation models) for all parts of the world. While terrain has a profound effect on the propagation of radio signals (especially at higher frequencies), more localized features of the environment such as trees and structures (buildings, houses, etc.) also have a substantial impact on propagation. An important trend in wireless system architecture is to use smaller cell coverage areas (so-called microcells) and much higher radio frequencies where significantly greater transmission bandwidth is available. For such short-range system architectures where the coverage radius of the transmitter may range from 0.5 to 5 kilometers, the terrain can often be regarded as locally flat. Under such conditions, signal propagation is dominated by local obstructions ("clutter") rather than by terrain, making the description and accurate classification of land use/land cover data of primary importance.

Wireless System Propagation Modeling

Radio wave propagation is a physical phenomenon that can be described using electromagnetic wave equations. Like waves travelling away from the spot where a stone has been tossed into a pond, radio waves travel away from the transmitting antenna in all directions. Theoretically it is possible to exactly predict the strength of the signal from any transmitter at any other location if all the elements of the propagation environment are correctly taken into account. In so-called "free space" (actually a vacuum), there are no elements in the propagation environment and the signal strength at some distance from the transmitter can be exactly calculated. Radio wave transmission through outer space is one region where such a simple formulation applies. For transmitters located on the earth's surface the problem is much more complicated. Every physical entity a radio signal encounters after it leaves the transmitting antenna affects the strength and direction of the signal. The physical entities that affect the signal can be grouped into four broad categories:

1. The atmosphere (or other gaseous media) refracts (bends) and diffracts (scatters) the radio waves; bending changes the direction of the radio wave while scattering generally weakens the wave.
2. Terrain features (hills and mountains) block the radio waves, requiring them to diffract over the top or around the sides, weakening the signal on the other side. Radio waves also reflect and scatter off of terrain surfaces causing a change in the direction of the radio wave.
3. Much like terrain, structures such as buildings, houses, towers, etc. block the radio waves. The waves diffract, reflect, scatter and transmit through structures.
4. The leaves and branches of trees and other types of foliage also weaken radio waves by scattering them, which has a similar effect as that of the blocking them as terrain or buildings can do

As mentioned in the introduction, the atmosphere and terrain have been included for many decades in the propagation models which are designed to predict the strength of radio signals. Figure 1 shows a representation of a radio wave propagating from a transmitter (on the left) to a receiver location in the open (on the right).

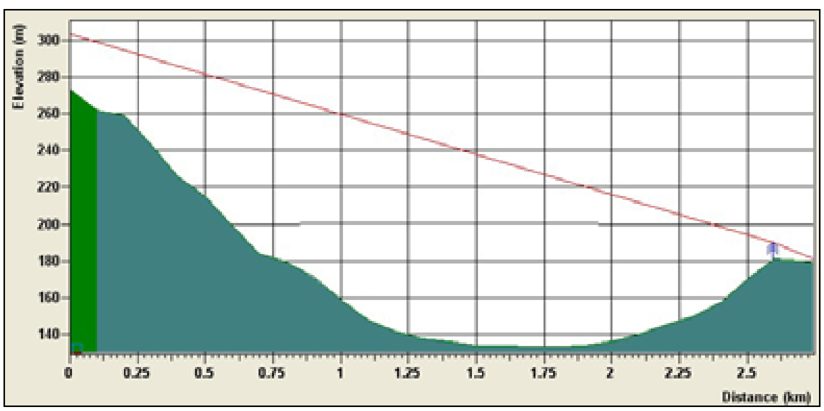

Figure 1 - Radio Path with Tree

Although the signal arriving at the receiver will include some reflections from the terrain, the dominant signal is the one that arrives directly from the transmitter. A tree is located along this path near the receiver. Because of the tree, the signal is some 10-20dB weaker at a frequency of 2.5GHz (a typical WiMAX frequency). This is due to the effects described above in item four and is a simple example of the effect of ground cover on signal propagation. One way to include these effects is to use heuristic propagation models. The Okamura-Hata, COST-231, IEEE-SUI, and "Point-slope" models are examples of these. These designers of these models attempt to integrate the effects of clutter by making many measurements of the signal in typical environments and then creating simple distance vs. path loss formulas that include not only "free space" loss but also the clutter loss found in that environment. For example, the Okamura-Hata model is based on measurements done in and around Tokyo, Japan. Therefore, the model is representative of land use environments similar to that area. These models can be quite useful when one does not have access to good quality digitized ground cover data.

Figure 2 - Received Power using Ray Tracing Propagation Model

However, it is obvious that a simple model cannot fully consider the actual local conditions of every study situation. As an example, Figure 2 shows a typical urban building environment in which a transmitter has been located. In reality, the radio signal from the transmitter will be propagated to the receiver by diffracting and reflecting from the various buildings shown in this figure. Because the signals arrive at the receiver via a number of radio paths, the signal at the receiver is often described as a “multipath signal.” When using a single antenna at the transmitter location and one at the receiver a multipath signal can have a significant impact on the signal quality or integrity of data which is sent because many versions of the same signal are arriving at the receiver at different times. As can be seen, the signal at line-of-sight receiver locations along the streets to the North and the East of the transmitter are considerably different. However, in this study a simple propagation model would show the same signal along both streets because the model would consider all study points in the area has having only one class of clutter rather than seeing the effect each of the individual buildings on the signal. As the environment becomes more complex, a simple propagation model is incapable of accounting completely for how the environment affects the signal.

Classifying Groundcover Data

A ray-tracing propagation model has been used here to show the effect that a building environment has on radio waves. However, for many systems like WiMAX or Cellular/PCS, a detailed analysis of an entire market with ray-tracing may not computationally viable. Moreover, acquiring databases describing the location and characteristics of every tree or building may be time or cost-prohibitive. Therefore, to simplify the problem of accounting for clutter effects in propagation prediction, it is useful to broadly classify the data in some way. For example, instead of considering every tree in a forest, a wider area could be classified as “forest” and any receiver located within that area would experience an additional signal strength loss based on frequency. If signal loss data were also available for different types of forest, e.g. “evergreen” versus “deciduous,” or “tall” trees versus “short” trees, then multiple groundcover classifications for forests would be appropriate.

Many GIS (Geographical Information System) land use classification schemes provide for a large number of categories that may be appropriate for land use planning or zoning. However, for the purpose of wireless system design, unless there are calculations or measurements that demonstrate a statistically significant difference between categories in terms of their relative impact on radio signals, having the additional categories does not necessarily provide more accurate signal predictions. The height, extent, and location of groundcover elements are the factors which primarily govern the impact on radio signals. Different classification types such as “industrial” and “commercial” may be useful in urban planning, but if both indicate relatively low buildings of broad extent, then the distinction is unimportant for wireless engineering – both will affect the signal in similar ways. In the same manner, the grid point spacing resolution of these databases needs to be small enough only to allow the RF planning tool to reasonably locate the boundary between adjacent clutter types. - 30m is typical.

Applying Clutter Data to the Calculation

Clutter data can be used in several ways to enhance the resolution of the signal level calculation to return more accurate point-specific results. The most straightforward approach is to use the method alluded to above where the attenuation at a particular receiver location is a direct function of the clutter type at that location. If for example, a remote unit is located in a suburban area containing single-story houses and mature trees one might apply an additional attenuation of 20dB at 2.5GHz; for relatively open Parklands 10dB might be used. The ongoing challenge in using clutter is determining the appropriate attenuation values for each clutter category. One option is to use the Telecommunications Industry Association resources. This group has typified clutter losses based on ten clutter categories appropriate to RF planning and documented them as part of the TSB-88[1] document. Ultimately the most accurate value will be based on received signal measurements (i.e. drive test) within each market area that take into account the type of vegetation and man-made structures present in that area.

A second approach is to assume that the clutter represents a hard, non-transparent blockage to the radio signal. The clutter data is then used to effectively raise the terrain elevation used by the planning tool so that the propagation calculation will see the clutter as obstacles along the path rather than a "bare earth" condition. Here, the clutter data is categorized as having an above-the-ground height value representing the average height for each type of clutter. This method is most effective at the higher frequencies, especially above 5GHz where almost any clutter type represents a high-loss obstacle to the radio signal. This can be extremely useful in urban areas where buildings represent the primary obstacles to the signal. Rather than investing in a high cost vector database describing each individual building as a 3D-polygon with individually defined wall surfaces, one can create a clutter database using a very fine grid-point spacing (1-5 meters). This allows the transition between building clutter and other types of clutter (such as streets) to be sharply defined. Then, by organizing the buildings into a number of clutter classes based on average building height a reasonable three-dimensional representation of the building environment can be created. Table 1 below contains representative values for typical building heights.

Table 1. Structure Height Classification

Classification	Average block height
Residential	< 2 meters
Low density urban	5 – 10 meters
Moderate density urban	10 –25 meters
High density urban	> 25 meters

Finally, a third method acknowledges that for most clutter, the signal propagation mechanism is of a "pass-through attenuation" type. So, unless the clutter is composed of buildings made of reinforced concrete or some other extremely high loss material, a relationship can be made between signal attenuation and the distance that the signal travels through a clutter area (i.e. dB/m). This is most useful where much if not all of the signal passes horizontally through the clutter environment; an urban WiFi mesh network is a good example. Here, the Mesh Access Points are typically on light poles at about 8 meters above the ground which is usually less than height of the trees and/or buildings in the area. The node-to-node signal paths will pass through the clutter and by determining the length of passage within each type of clutter a good value can be had for the total attenuation effect.

Signal Strength Studies

To illustrate the role of groundcover data in wireless system design, three signal studies are included to show the three methods for using clutter as previously described.

Figure 3 shows the coverage from a four site WiMAX system operating at 2.5GHz in a medium-sized urban area. The base antenna is at 30m above the ground and the remote units are at 1.5m. In this study, no clutter was used; terrain was the only factor in determining signal strength. The area in the top half of the coverage area is relatively flat so not much variation in signal strength is seen - free-space loss is the dominate attenuation factor here. Terrain becomes significant in the bottom half of the area as seen by the sharp reduction of signal along the southern edge of the coverage.

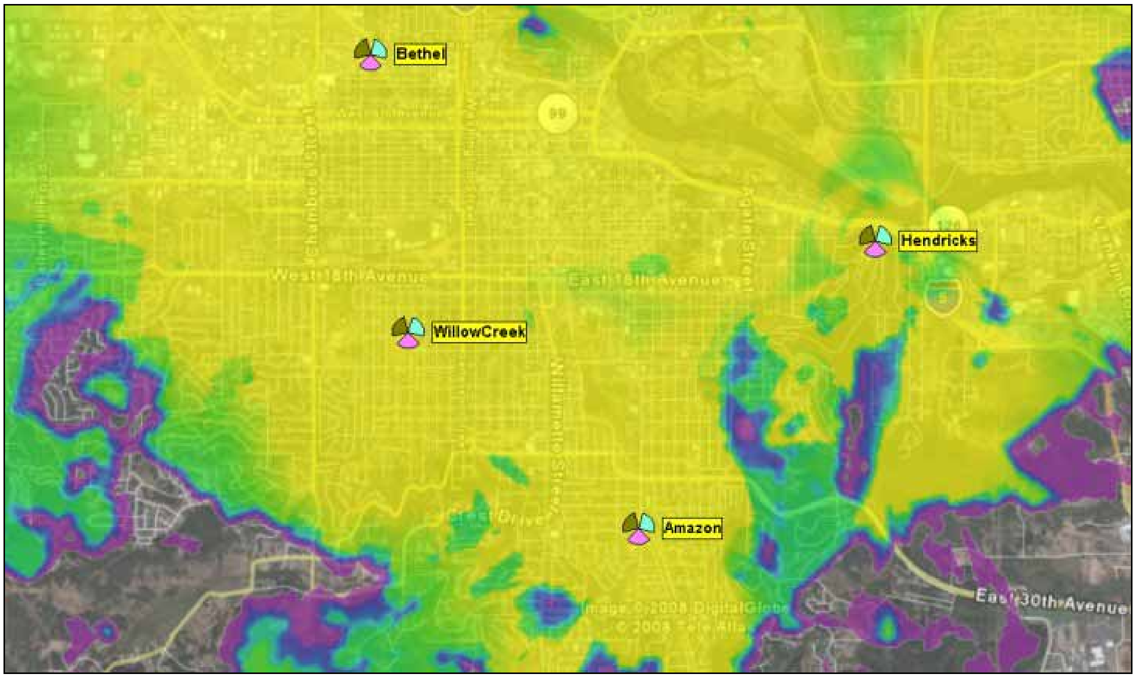

Figure 3 - Received Power (Terrain Data only)

Clutter data was then added to this area and Figure 4 is a map indicating the different types of clutter based on color. The urban and commercial/industrial uses are shown in red and pink respectively; residential is shown in yellow. A signal study was then run using the first method described above where a simple attenuation factor (a margin) was applied to the received signal strength based on the clutter type at the study location. This is shown in Figure 5. The correlation between additional attenuation and clutter type can be clearly seen. Note how the signal strength is now shown as much less in the built-up areas while the coverage along the river (light blue area on the Clutter Category map) has not been affected.

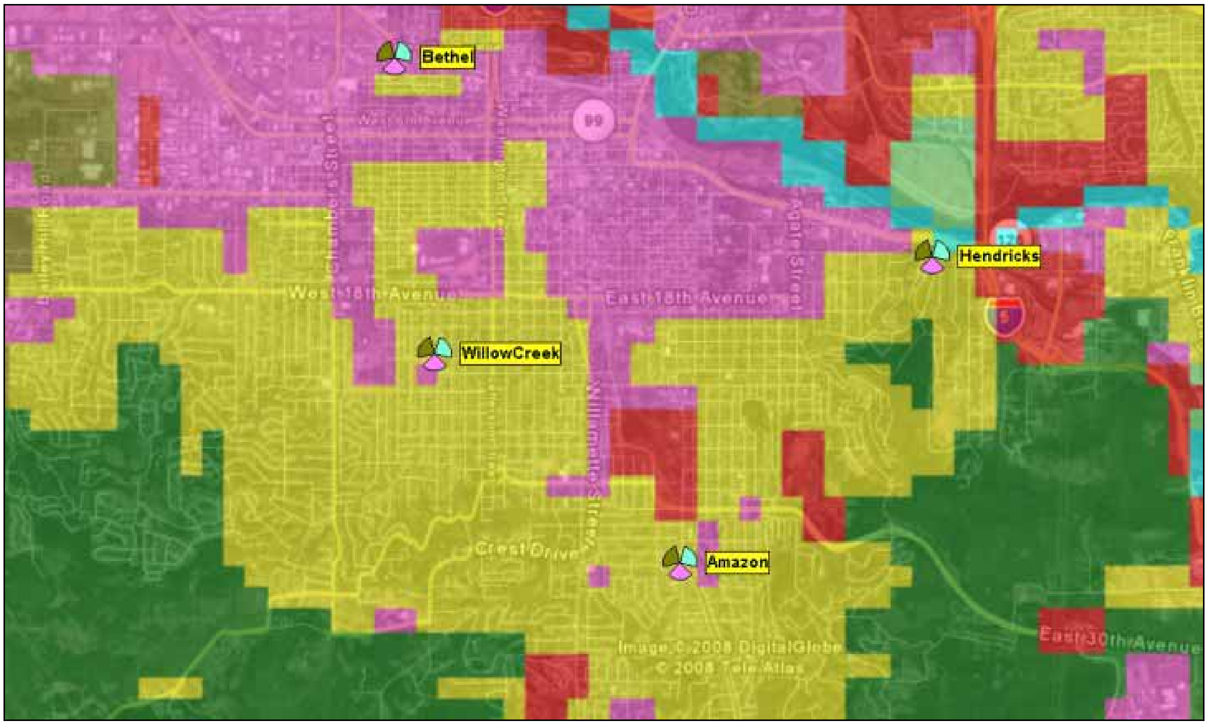

Figure 4 - Clutter Category Areas

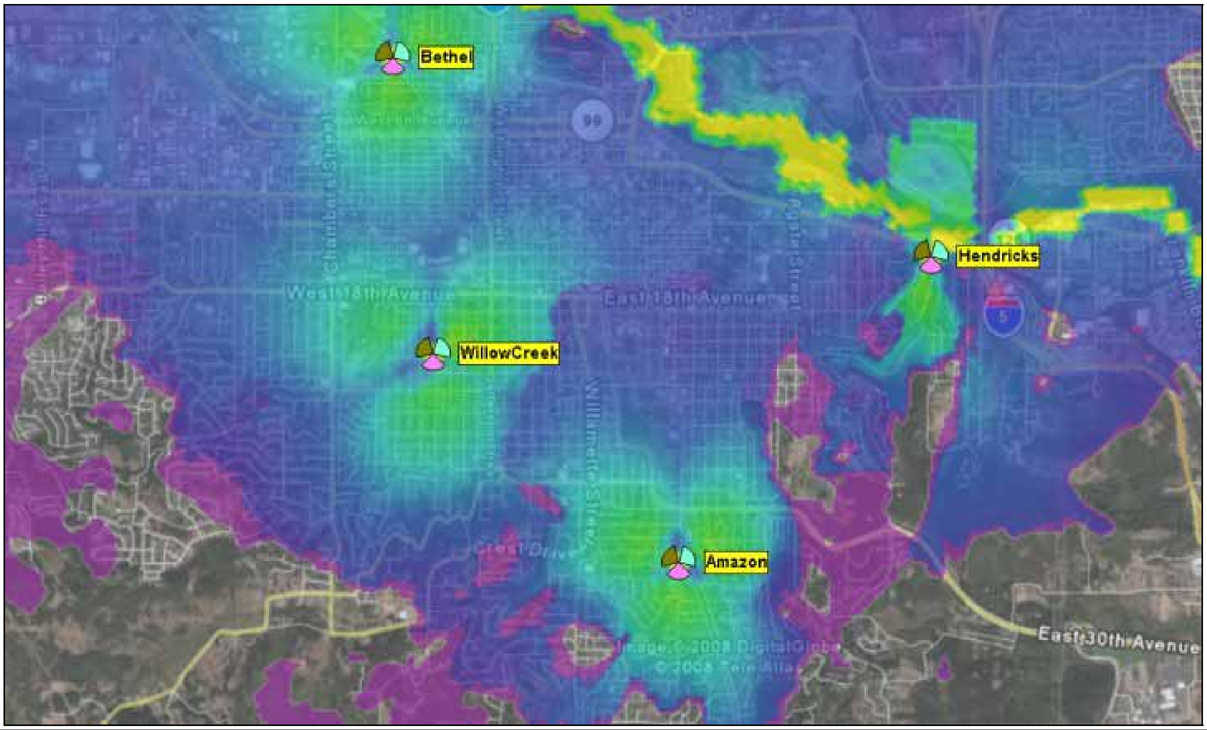

Figure 5 - Received Power - Terrain plus Clutter Category Attenuation

Figure 6 shows the second way to use clutter data where the height of each clutter type is taken into account when establishing the propagation path between transmitter and receiver. Here, instead of applying a fixed attenuation at the receiver location, the signal propagation is instead affected by shadowing from the higher clutter types. In this instance, the commercial/industrial areas (Pink) are set at 20m height and the urban area (Red) is set to 15m. The map shows how the signal is reduced into these areas due to their heights.

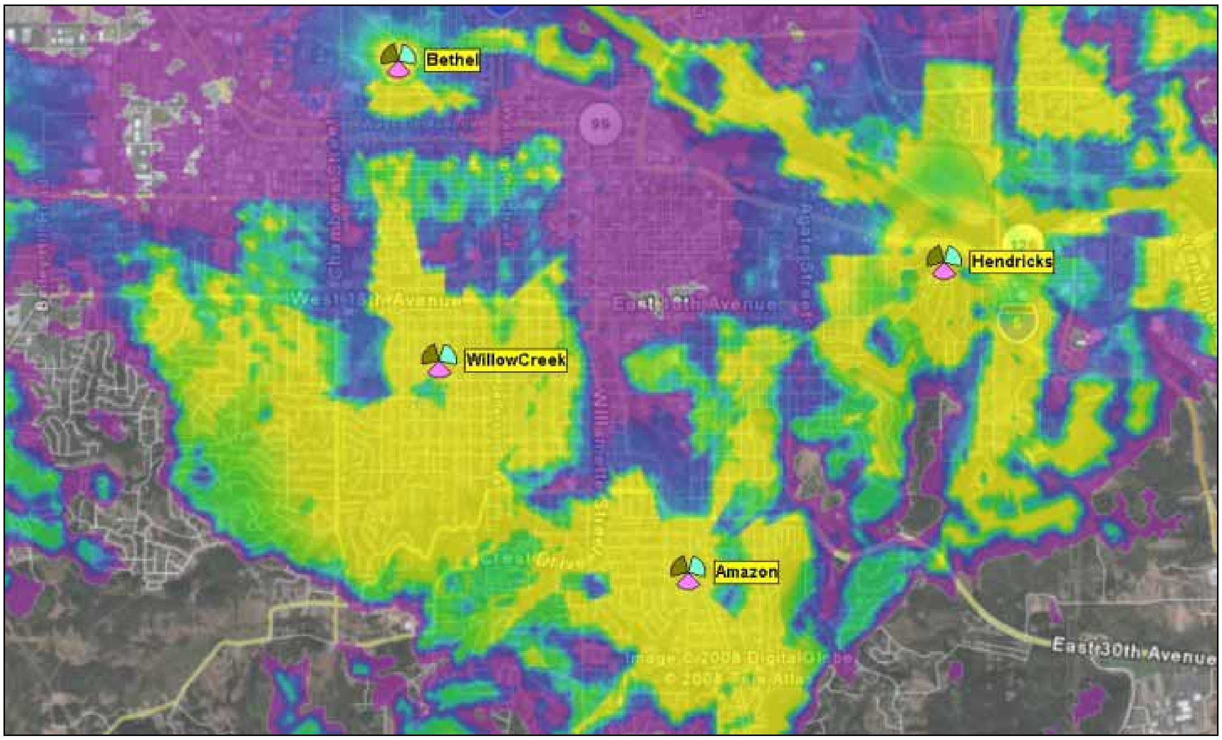

Figure 6 - Received Power with Terrain plus Clutter Height

Finally, Figure 7 is an example of a number of WiFi Mesh nodes located on light poles. A high-resolution clutter database (3m point spacing) was used here to be able to define the streets from other clutter types. Road information is also displayed on this map to show how the signal from the mesh nodes travels further down the street canyons than through the clutter on either side of the streets.

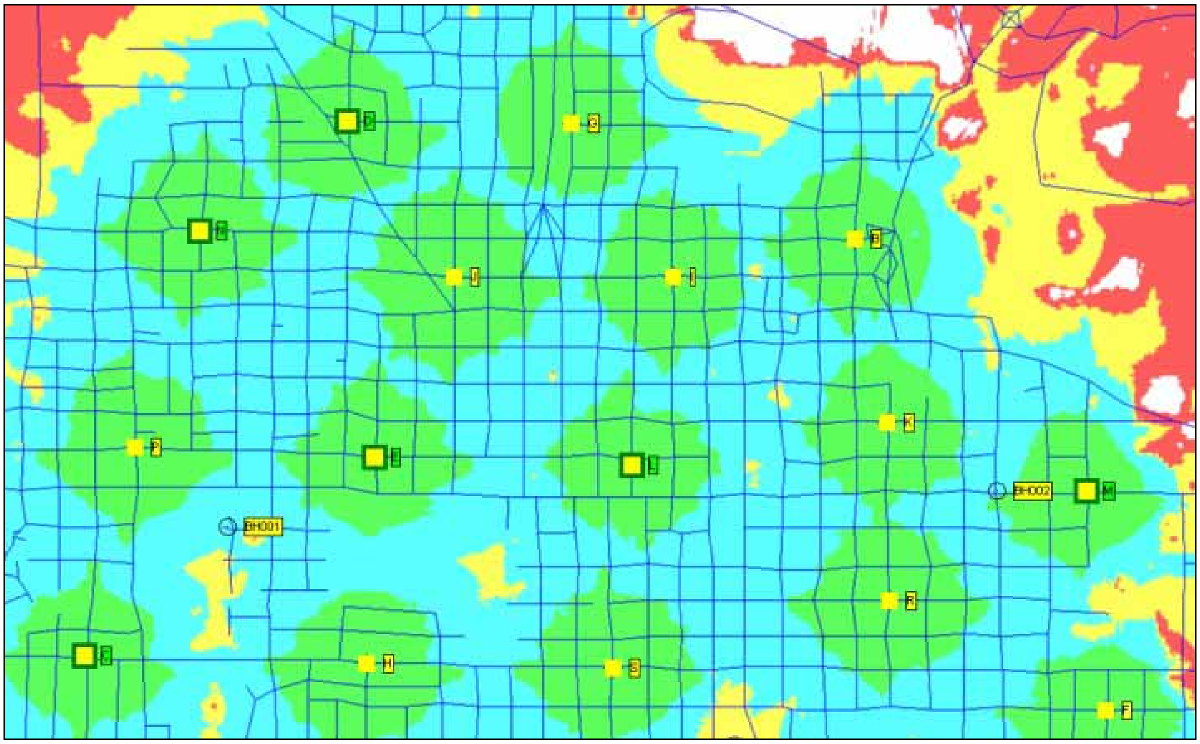

Figure 7 - WiFi Mesh - Clutter Pass-Through Attenuation

From these examples it is clear that clutter data plays an important role in wireless system design. Adding this information provides a critical refinement to a signal study by taking into account a more accurate and realistic characteristic of the service area where the wireless system will be used.

Using Land Use Data to Predict Service Demand (Traffic)

The core of any wireless communication system is the network of towers, transmitters and antennas that convert information to radio signals that can be received and understood by the user. The network must be configured so that enough sectors and channels are allocated to handle the demand. Considerations in system design are: locating transmitters to provide adequate signal levels throughout the service area, judging where system capacity may be insufficient (or under-utilized), and in the case of multi-user systems, gauging how the system may have to evolve to accommodate changing user call and data traffic patterns.

These dynamic traffic patterns refer to time and location. People are using the system at various times throughout the day, and because these users are mobile, they may be located anywhere in the system service area. For example, during morning and evening rush hour, traffic density for cellular/PCS phones is highest along transportation routes. Large, temporary gatherings of users—convention centers, concert halls, sporting events—must also be considered. During work hours traffic is highest in the city centers. To determine the capacity that must be provided by each sector/site in order to handle the traffic, it is necessary to somehow establish a geographical distribution for the demand relative to the base sites. Planners have traditionally accounted for traffic in one of four ways:

1. Assume geographically uniform traffic distribution (in the absence of other data).
2. Use a standard demographic database and assume that more capacity is needed where population density is highest
3. Use a road database as a guide for defining traffic and the geographic location of where calls are originated
4. Use actual customer traffic patterns, which vary by location and time of day. This is the best indicator of traffic demand, but may be difficult to obtain when building into new markets.

A fifth alternative for predicting where usage is highest throughout the day is to use up-to-date land use classifications. By seeing where transportation, urban, dense urban and residential categories are located and correlating this information with user call/data density trends, a picture of traffic will emerge.

Conclusions

Clutter (land use/groundcover) data can have many uses in wireless system design. The most significant applications are in refining signal level predictions to take into account local clutter attenuation effects, and in projecting demands for wireless service. The latter is becoming increasingly important as new types of mobile and nomadic broadband wireless services such as WiMAX and LTE are built out, taking their place alongside existing mobile cellular/3G services. With an increasing trend toward high capacity data wireless services, groundcover/land use data used in conjunction with building height and location data can provide the wireless system designer with a valuable understanding of where service will be required and at what capacity. In this regard, land use data which is as up-to-date as possible is critical. Zoning data that shows a community's plans for future growth can also be effectively applied in the design process.

Finally, some real examples of wireless system coverage prediction were presented with and without groundcover data. Through the use of modern wireless system engineering software, such as found in EDX SignalPro®, the system designer can not only prepare accurate predictions of service and interference areas, but can also rapidly evaluate a wide variety of strategies to arrive at a configuration that best meets the service providers' objectives at the least cost.

[1] Telecommunications Industry Association, "TSB-88.1-C," January 2008