Mapping the Invisible World

Modeling Wireless Communications with GIS

—by Anna F. Tapp and Rick L. Bunch

Wireless communications technology is making traditional landline telephones obsolete. This is not an exaggeration; it's a fact. In 2005, for instance, there were, according to the Federal Communications Commission (FCC), 213 million U.S. wireless telephone subscribers. This surprisingly large figure equates to a nationwide market penetration of approximately 71 percent, with nearly everyone in the U.S. between the ages of 20 and 49 using wireless telephone services. Although many U.S. citizens have yet to fully "cut the cord" and cancel their land line services, the preference for wireless is strong and upwardly trending. The growing number of cell phone adopters in the past decade can directly be attributed to the reliability, multi-functionality, and increased affordability of the technology. Personal safety, security, and general economic competitiveness are also cited as significant reasons for going wireless.

Enhancements of the wireless communications infrastructure were enshrined in the Wireless Communications and Public Safety Act of 1999 (911 Act); the first major beneficiary of the use of the technology were emergency services. The Enhanced 911 (or E911) program, which calls for upgrades to the local 911 communication systems and the coordination of wireless telephone carriers, technology companies, and public safety agencies, has had an impact on the type and quantity of data carried by the infrastructure. Wireless telephone carriers are now required to provide the telephone number, the wireless 911 call, and the location of the cell tower that handled the call. Increasingly also, the location of the caller is being reported to within 50 and 300 meters using latitude and longitude data.

Our national wireless infrastructure and E911 underwent a rigorous test on September 11, 2001. Cellular telephones were successful in many instances in helping rescue workers to locate trapped victims. However, the sudden spike in calls stressed the system to the extreme, and it became obvious that


Source: www.ece.queensu.ca/

the band frequencies set aside for public communication were too close to the frequency bands used by law enforcement.

Deeply concerned that public safety not be compromised, FCC mandated that the wireless telecommunications industry expedite its transition to higher digital bands and, importantly, continue to enhance the E911 program with positioning technology. Not only cell phones, but many other popular, pocket-sized, integrated gadgets now have GPS (Global Positioning System). In urban areas in particular, cell phones have become commonplace, and the ability to use them as accurate positioning devices has been amply demonstrated on TV in such programs as NCIS and Law and Order. Yet, many victims who have cell phones cannot call for help because the signal is too weak, intermittent, or completely out of range.

The increasing reliance in the U.S. on wireless communication will continue to create demand for dependable networks in both rural and urban areas. Research has focused on determining the effect structures have on the strength of wireless signals in urban areas. In rural communities, distance, topography, and low population density all create challenges that wireless carriers can be reluctant to tackle head on.

The antennas in cell phone towers, for instance, can each handle only a few dozen calls simultaneously. When capacity becomes a problem, a quick-fix solution may be to insert another tower with another antenna to pick up the slack and reduce the number of dropped calls. Existing antennas may be adjusted to prevent some interference but, that's often the extent of the improvement.

Critical improvements such as the development of wireless networks in rural areas are hampered by lack of data on topography and vegetation and can thus be expensive. Yet, these areas experience the same need for speedy and accurate location of people in times of emergency as do urban areas. This is particularly true in recreation areas.

The need to extend efficient wireless coverage to North Carolina's rural areas is urgent. This urgency is particularly felt at University of North Carolina Greensboro's Center for Geographic Information Science and Health which recently undertook to investigate some of the common problems encountered in expanding the "invisible world" of wireless communication.

Mapping wireless coverage

Much research has been done on how cellular radio waves penetrate building materials. Unfortunately, we don't know nearly as much about the behavior of radio waves when they pass through dense vegetation. Generally accepted values associated with signal losses in needle forests vs deciduous forests exist, but the data are far from complete. Even given more specific values for tree species and their density there is the additional variable of time, contributing to measurable seasonal variations between leaf-on and leaf-off situations. The problem of mapping wireless coverage in a rural setting is thus not only three-dimensional but also temporal.

The variables involved in mapping radio waves have been investigated by the Center for Geographic Information Science and Health at a pilot research area in the Great Smoky Mountains National Park in North Carolina. The park is eminently suitable for such research given its rugged terrain and an incredible diversity of vegetation. It is also one of the most visited national parks which has a less notable record of nearly 130 serious injuries per year. Because the park's vegetation has already been mapped, conducting research there makes it possible to extend the findings to areas with similar vegetation canopy.

The research at the park involved collecting topographic and vegetation data using mostly LIDAR [Light Detection And Ranging] and building 3D GIS models. LIDAR, also dubbed airborne laser swath mapping, yields thousands of laser points per second. The raw LIDAR data include ground elevation points, buildings, tree crowns, and even cars and birds. A great deal of LIDAR is flown leaf-off to maximize the number of ground points collected.

The raw data obtained in the Great Smoky Mountains National Park by high-definition surveying were filtered and then two 3D visualizations were produced—a highly accurate representation of the ground surface, i.e., the terrain model, and a representation of the tree canopy. Superimposing on these two models the location and height of a cell phone tower should then provide information about the extent of wireless coverage in an area.

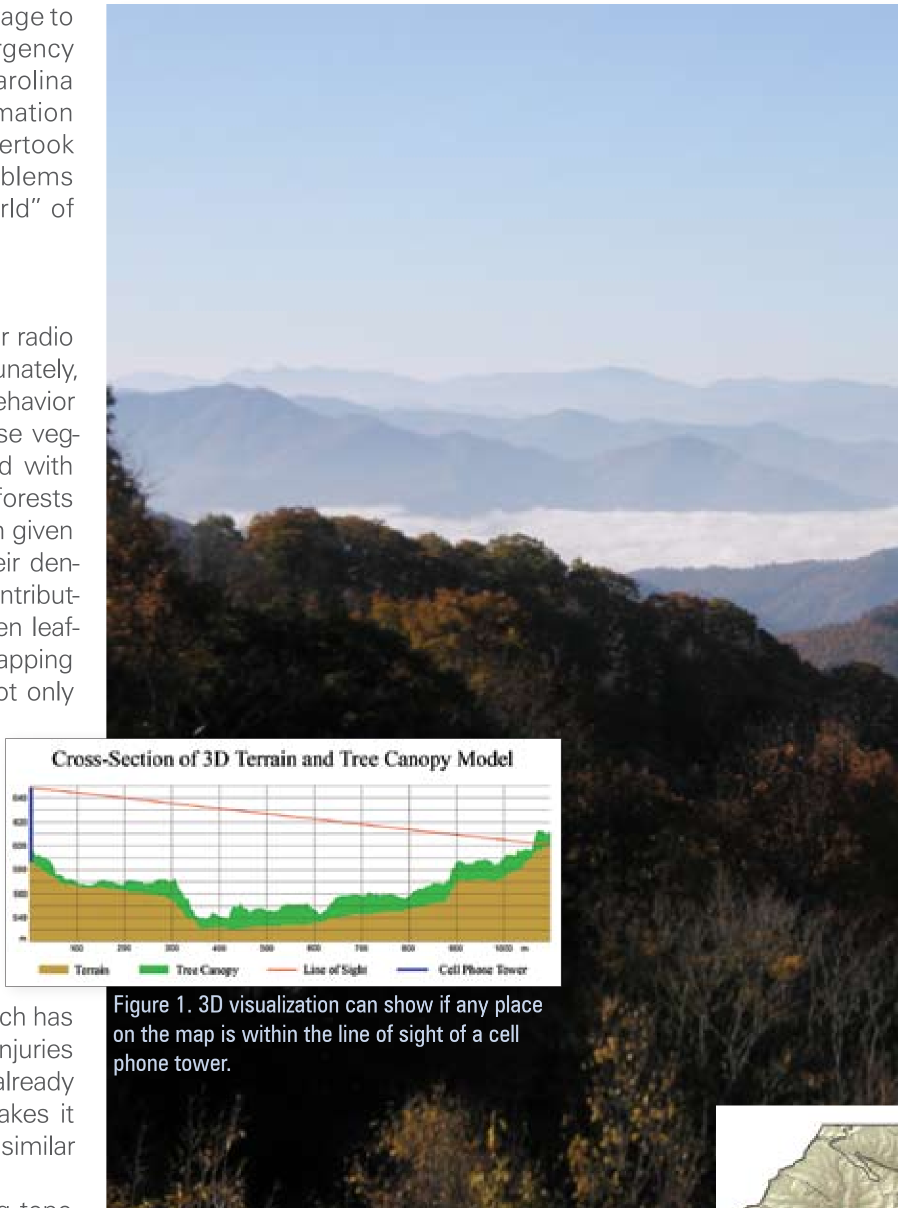
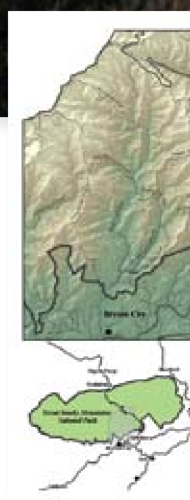


Figure 1. 3D visualization can show if any place on the map is within the line of sight of a cell phone tower.

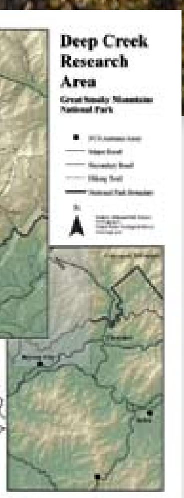


Problem #1—Signal losses

Suppose there is a particular area where accidents are prone to happen or where hikers or tourists tend to congregate. Using 3D visualization, one can discover if a theoretical cell phone user at this location is in the line of sight of a tower. One can also estimate from the canopy

Photo credits: Kirsten Hunt for background photo—An overlook of the North Carolina side of the Great Smoky Mountain National Park. Andrew Tapp—Leaf-on data collection with a spectrum analyzer during summer [first right]. Kay Miles—Re-measuring winter cellular signals at the same GPS locations where the summer measurements were made [second right].

Figure 2. Multiple data layers make up the puzzle of signal strength in rural areas.



model how many meters of trees would be between the theoretical phone and the tower. Will the cell phone user be able to make a call?

The first variable to consider is the distance between the cell phone user and the nearest tower. Radio waves systematically degrade as they pass through the atmosphere. Higher frequencies will dissipate much faster than lower frequencies during a process called path loss or attenuation. If there are no obstructions between the antenna and the caller, the loss is called "free space." In real-life situations, attenuation will often be more severe than free space, because ground is covered by various interference factors, including buildings and trees.

Field data were collected in the park throughout the year to determine which kinds of trees pose problems all year round and which interfere more significantly in the summer than in the winter, and vice versa. Then, by combining antenna data with those on vegetation classes and terrain, and applying radio wave propagation principles, the Center created a GIS model of wireless coverage throughout the park area.

A single antenna array in Bryson City, North Caroline, was used to obtain the data layers input into the GIS model (see Figure 2). An example of a cellular coverage area calculated from the data in the GIS model is given in Figure 3.

Problem #2—Visual impact

Once the existing coverage has been established, the same models can be used to identify ideal locations of additional sites. An excellent model gives site planners the tools they need to mitigate public safety concerns while keeping the number of towers and their heights to a minimum. New solutions are continuing to be invented, from systems of small, disguised antennas, to tall, slender towers which look like trees or flag poles.

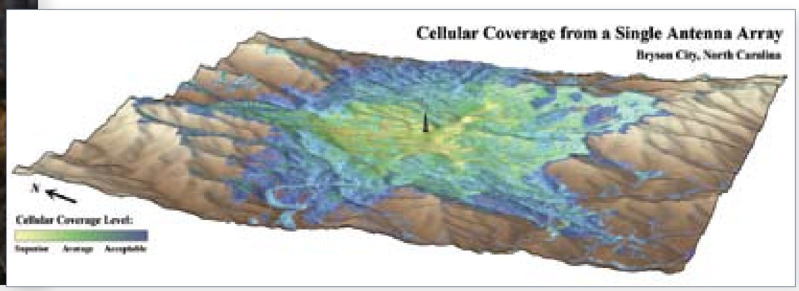


Figure 3. Cellular coverage from a single antenna array.

The goal

Wireless positioning technology presents new opportunities for improving public safety in rural areas so that more and more people can enjoy the beauty and splendor of our national parks and other scenic environments. The research conducted by the Center for Geographic Information Science and Health in North Carolina is at the forefront of efforts to achieve widespread wireless communication that would enhance both public and private lives.