USING LIDAR DATA IN WIRELESS COMMUNICATION SYSTEM DESIGN

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ABSTRACT

As the telecommunications industry responds to the rapidly growing demand for wireless services in the commercial and residential sectors, data suppliers are trying to tailor their products to competitively meet the needs of this lucrative market. One such service is a high frequency point-to-multipoint system for urban areas called LMDS (local multipoint distribution service). Two requirements of LMDS provide a challenge for system designers: 1) there must be line of sight between transmitter and receiver, and 2) a fairly dense pattern of transmitters is required because these microwave radio waves travel only a short distance before weakening and dispersing. Therefore, high resolution geographic databases that accurately depict potential signal obstructions—terrain, buildings and major foliage—are necessary.

LIDAR technology has emerged as an alternative to the traditional method of using digital orthophotography to derive footprints and elevations of urban features. Its ability to produce high resolution (1-3 meters) databases and sub-meter accuracies has advantages and disadvantages for telecom planning. The detailed picture of the urban landscape can assist engineers as they design high-frequency wireless systems. But the high resolutions may generate an unwieldy amount of data when applied to the entire urban area. In this paper, LIDAR data is used as a basis for signal prediction studies, and suggestions for and issues surrounding its use are discussed.

INTRODUCTION

During the past five years, demand for wireless services in both the commercial and residential sectors has exploded. Wireless telecommunications service providers are responding to this demand by developing several high frequency systems for urban areas, one of which is local multipoint distribution service (LMDS). The goal of LMDS is to enable customers to send and receive voice, video and data at high speeds, while keeping prices low and reliability high.

WHAT IS LMDS?

Computers, telephones, fax machines and cable TV have traditionally been wired services. They connect to the wider world through telephone lines or underground cables. With LMDS, which started as an alternative to wired cable television in New York, these services connect via wireless radio transmissions. In the United States LMDS operates in the microwave 28-31 gigahertz (GHz) range and is part of a service category called fixed broadband wireless. Fixed means that the receiver stays in one location, unlike a cell phone receiver that can travel with the user. Broadband refers to the amount of radio spectrum, or bandwidth, that may be needed to provide all the wireless services that a customer may want. A good analogy for radio spectrum is a pipe. The pipes connecting the kitchen sink or outside sprinklers are narrow. But a water main pipe serving a whole neighborhood has a larger diameter because more water must pass through it. An LMDS service provider may have customers signed up for only data transmission service. For that customer, only a small amount of radio spectrum is needed. But another customer may want voice, video and data service; in this case, broadband or a large amount of radio spectrum is needed.

LMDS directly competes with fiber optic cable to provide high speed services such as data, telephony and digital television to the "last mile". The "last mile" (which may actually be just a few hundred feet) refers to the telecommunications link to each building from a neighborhood hub or base station. It is the main constraint to providing new high speed services because there are no economies of scale—each building requires its own connection. Laying fiber optic cable is expensive and time-consuming; it requires digging up the streets. LMDS is a more cost-effective way of connecting office buildings (and maybe residences later) in the "last mile" of high speed services. It requires placing a small 12" antenna on the building rooftop. Although LMDS is not available nationwide, service providers are continually adding new areas of coverage. Over 100 markets are currently being served around the U.S.

Requirements and Challenges of LMDS

There are two major challenges in LMDS service—radio wave obstruction and short traveling distance. For low frequency AM and FM broadcast radio systems, the signal is not greatly affected by most terrain features. As you move up the frequency spectrum, though, more features on the earth's surface attenuate (weaken) the signal. In the LMDS spectrum, most everything attenuates the signal. Even the position of a tree can determine whether a signal arrives at the intended receiver. For this reason, LMDS requires a line of sight between transmitter and receiver. Besides being easily obstructed, microwave radio waves travel only a short distance. They experience significant path loss after traveling 3-5 kilometers. This means that a fairly dense pattern of transmitters is required to cover the service area.

One way for telecommunication companies to design systems with clear paths and an adequate number of transmitters is to use supporting databases in their planning software that can offer information about natural and man-made obstructions. Communications engineers use software in which they can accurately and efficiently design a system of transmitters and receivers with maximum service coverage and minimum interference before any hardware is even placed in the field. The software uses propagation models, or algorithms, designed to predict the strength of the radio signal. The algorithms account for certain types of geographic parameters. Because knowledge of the land over which a signal passes is critical to the engineer, a variety of geographic data is used in signal prediction studies—terrain elevation, clutter (land use/land cover), building height data for urban areas, raster map imagery (topographic maps, air photos, satellite images), vector data (roads, water, railroads, etc.).

Supporting Data Products That Can Fulfill LMDS Requirements

LMDS system design requires in-depth knowledge of the signal study area. The primary type of data needed for high frequency studies is high resolution building, terrain and foliage databases that describe the footprint and elevation of potential obstructions. There are generally two types of databases for LMDS work. The first is a canopy digital elevation model (DEM) with a resolution in the range of 1, 2 or 5 meters (see Figure 1). A DEM is a regularly gridded matrix of elevation values where the elevation is the maximum aggregate height above mean sea level at that point, giving a shrinkwrap portrayal of the study area. Engineering software utilizes a canopy database just like a terrain elevation database. There is no distinction made between any of the features on the landscape. All features—hills, buildings, foliage—are seen as obstructions. Signal prediction studies such as line-of-sight and shadow studies can be performed using a canopy database. They are suitable when the engineer does not need information about individual buildings.

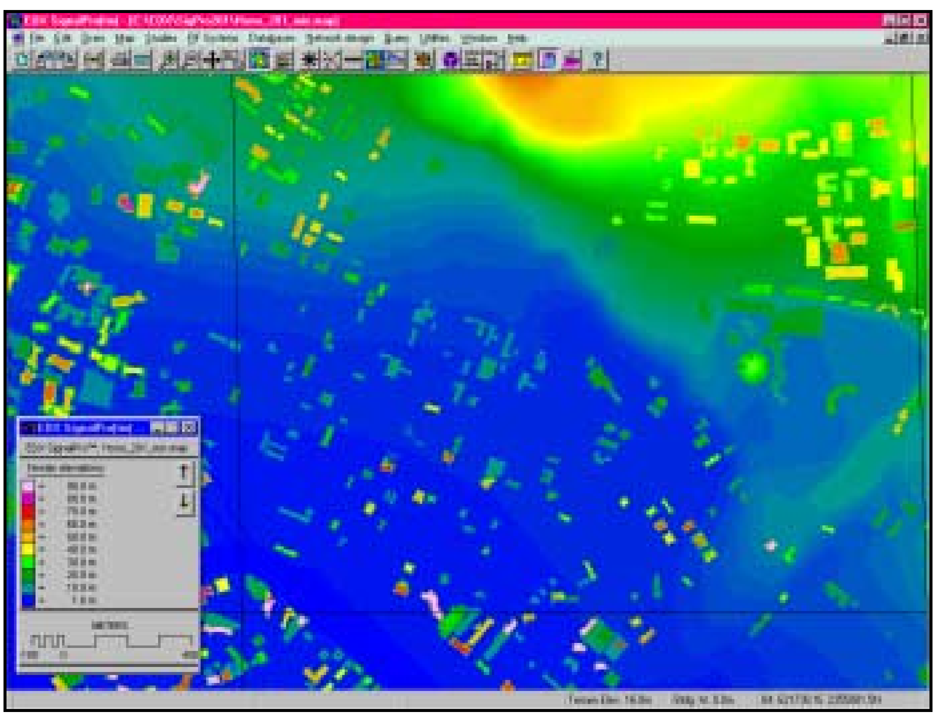

Figure 1. Canopy database

The second is polygon (or vector) data showing the exact footprints of individual buildings with their associated heights (Figure 2). To account for terrain, an accompanying "bald earth" database must also be used in order to adequately describe the geographic area. Bald earth DEMs describe only the surface, with no features on it. Each polygon is assigned a unique ID so that characteristics of the polygons can also be included in the database. Information about building material types (e.g. concrete vs. glass), conductivity and permittivity values can also be described, if needed. However, LMDS providers are most interested in building attributes that can identify tenants of a particular building who would be ready for high speed wireless connections. Is the building already connected by fiber optics? What is the building name and address? Who are the main tenants? What types of businesses are housed in the building? How many fax and phone line connections are present? This type of information can be tied to a particular building polygon and used to map out potential service areas, in addition to performing signal prediction studies.

For both types, one must acquire current and suitable air photos, and large amounts of digital and manual processing are required to derive heights. There are several data suppliers providing these types of databases specifically for the telecom industry.

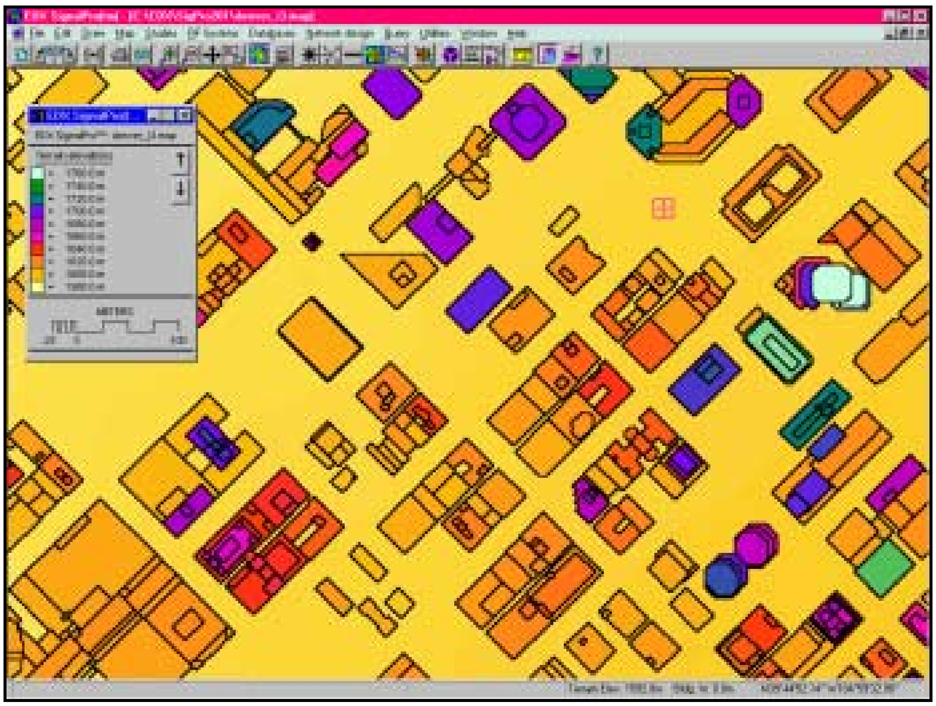

Figure 2. Polygon database (*Data courtesy of i3 : information integration & imaging LLC)*

LIDAR

A technique called LIDAR (Light Detection and Ranging) is emerging as a new method of data acquisition, providing a highly detailed canopy DEM. Laser pulses are directed towards the earth, and since the speed of light is a constant, the time from pulse emission to pulse return can be accurately calculated. The time required to record the "return" allows the distance to the terrain surface to be mathematically determined. From this, the shape and heights of surface features can be described. Figures 3a, b and c show the same area of Addison, TX at various resolutions. The USGS 3-arc-second and 30-meter DEMs, Figures 3a and 3b, respectively, are "bald earth" datasets that are commonly used in wireless system planning. Each database is available for the entire US, is inexpensive and has adequately modeled the terrain for wireless systems at a variety of frequencies. These datasets, though, do not provide the detail needed for LMDS. Figure 3c shows LIDAR data of the same area, providing a detailed description of terrain, buildings, foliage, highway overpasses and other surface features.

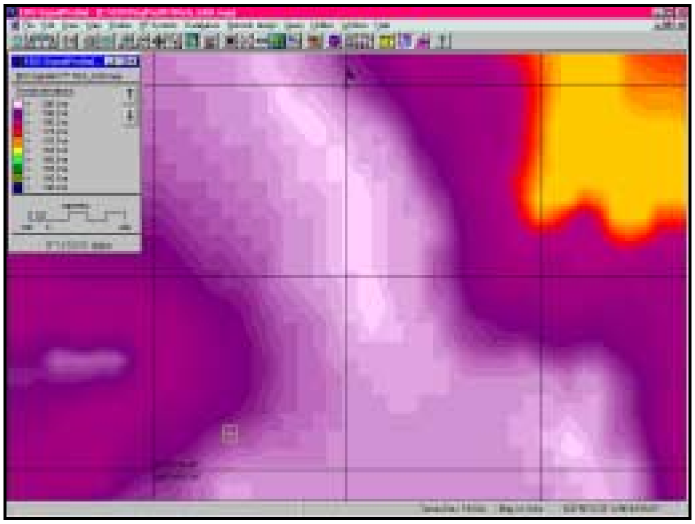

Figure 3a. 3 arc second DEM

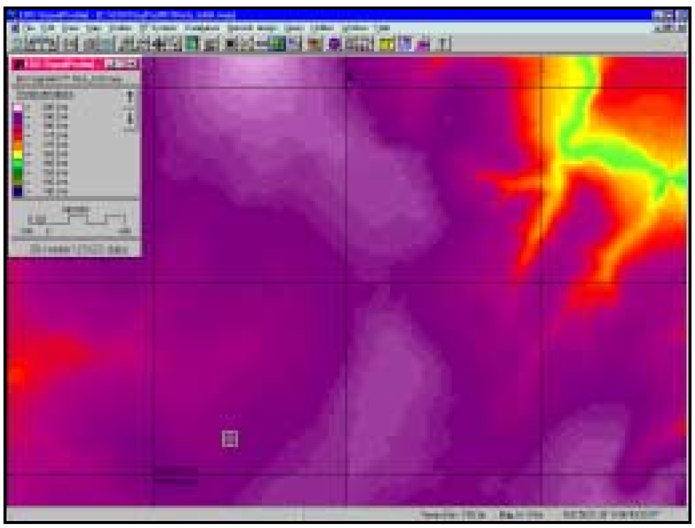

Figure 3b. 30-meter DEM

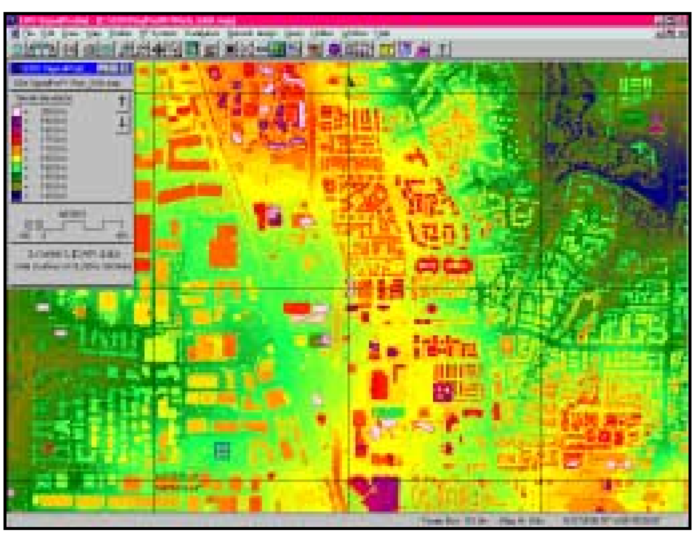

Figure 3c. 3-meter LIDAR canopy DEM *(Lidar data courtesy of Global GeoData)*

LIDAR in a Signal Study

The LIDAR data shown in Figure 3c was used in wireless planning software as the basis for a simplified LMDS study. Two hub sites containing transmitting antennas were placed in the study area (see Figure 4). Six customer terminals (CTs) were placed throughout the area. (In reality there may be dozens of hub sites and hundreds of CTs.) The hub antennas were positioned two meters above the rooftop. The CTs were placed on the roof of each of the six buildings at a height of three meters above the rooftop. The first study that was done was "Percent availability at CT". The purpose is to determine the amount of time that service is available to a customer (over a period of one year). The results are shown in Figure 5. The hub site to the north is the best server for four of the CTs; The southern site is the best server for two of the CTs. In an LMDS system there is two-way communication between the hub and CT, so details about each direction must be analyzed. The two-color link between each hub and CT indicates parameters such as channel assignment of the downlink (from the hub to the CT) and the uplink (from CT to hub).

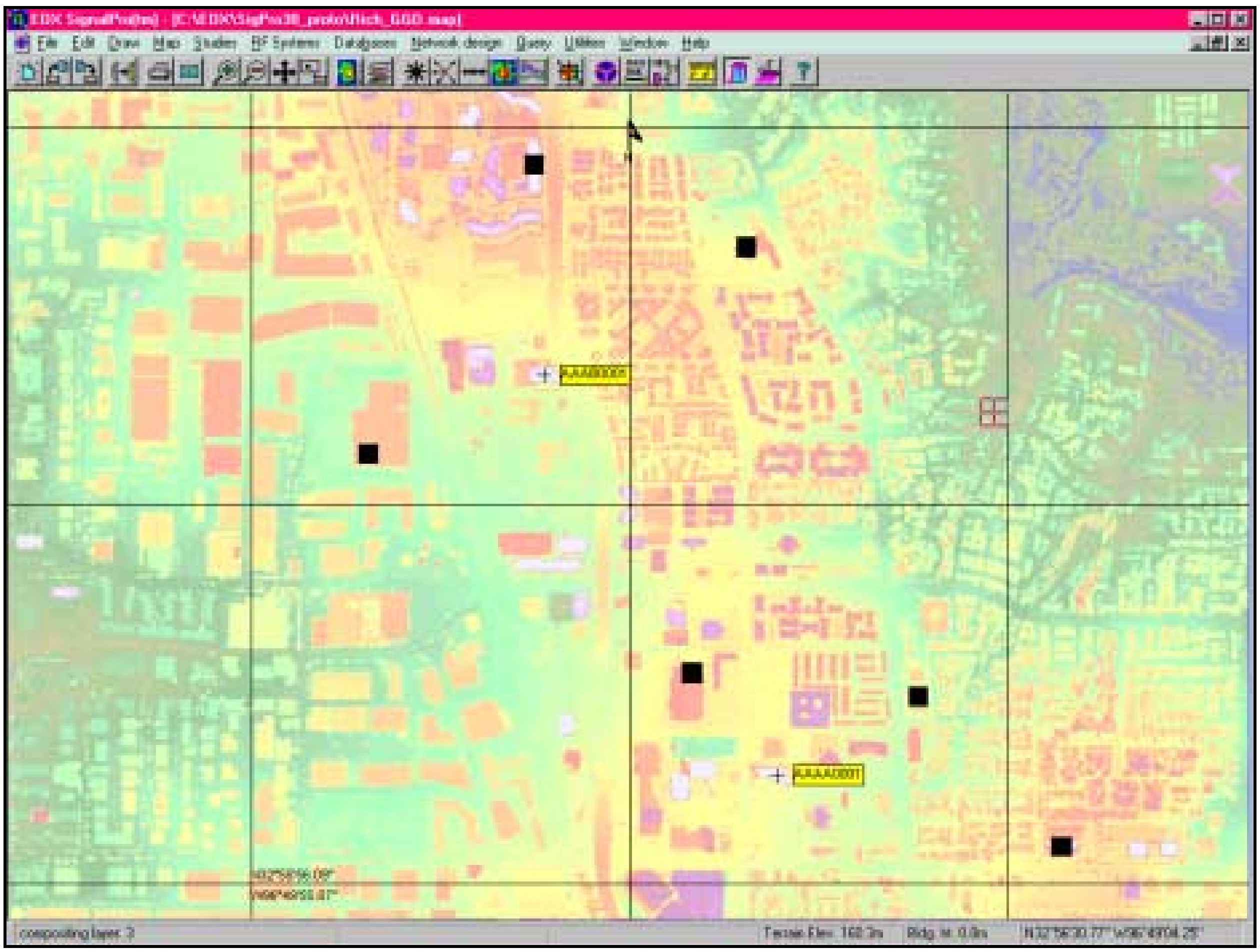

Figure 4. Hub sites and CTs placed throughout the study area

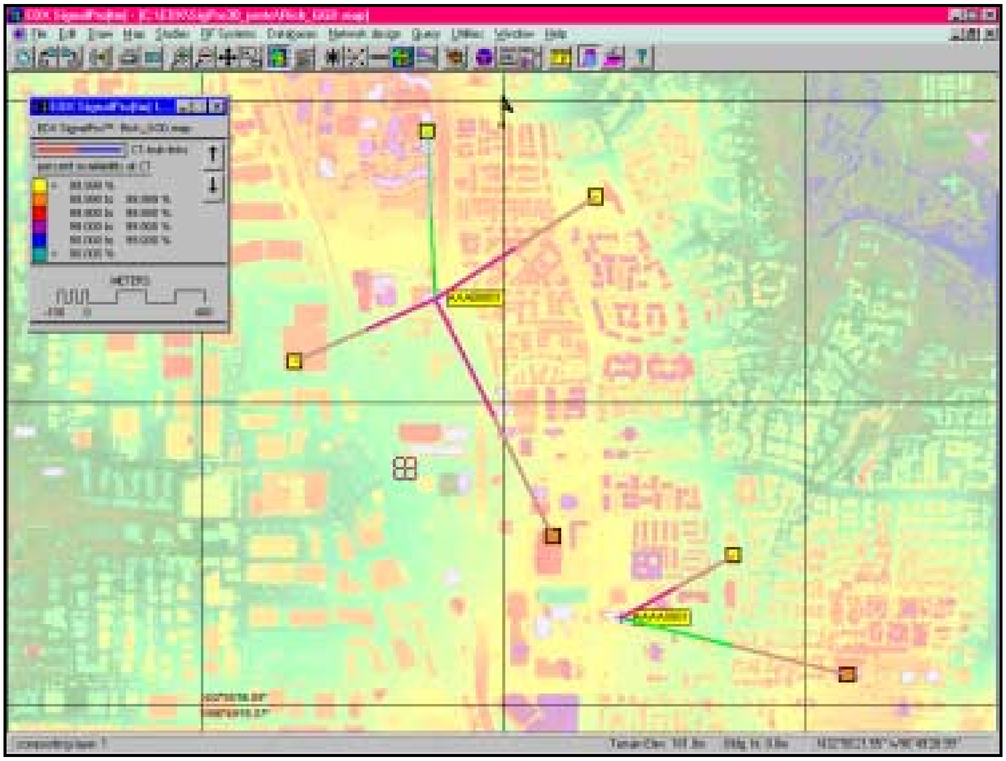

Figure 5. CTs assigned to hub sites

Figure 6 shows the detailed study results for one of the CTs. An engineer can use this to see why a particular hub was assigned to that CT. Signal strength, interference from other links and percent availability can also be viewed.

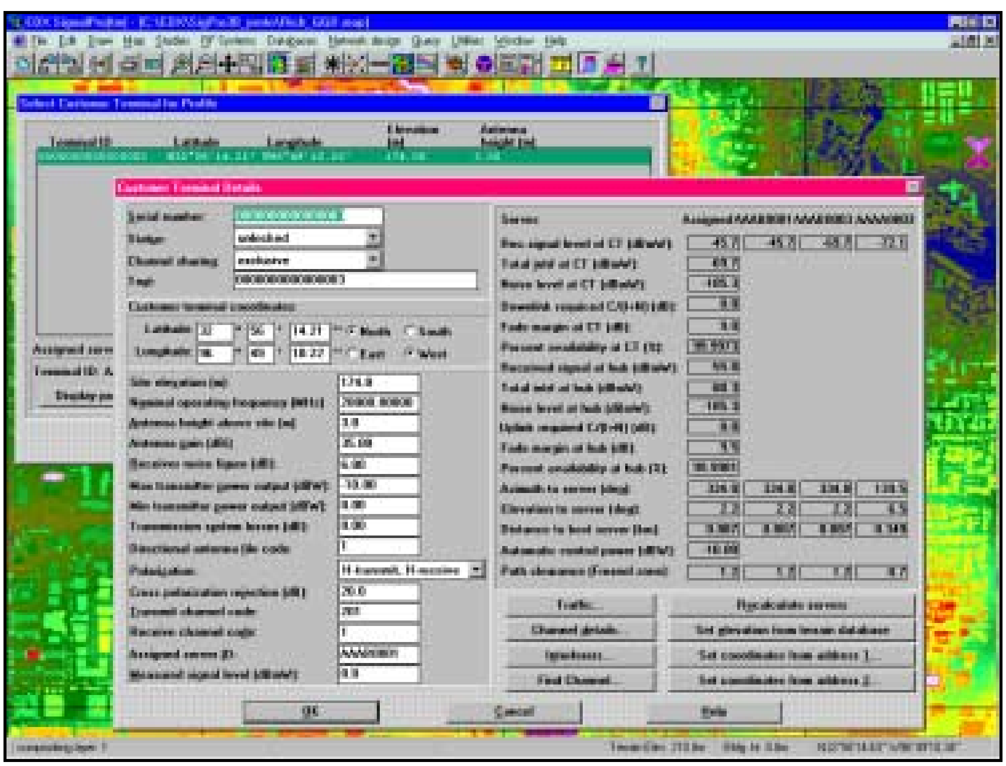

Figure 6. Details for one CT

Figure 7 shows a link analysis, or path profile, between a CT and its assigned hub. Terrain details can be seen along the path, along with some of the same link information shown in Figure 6. The straight line on the plot here indicates the path of the radio signal from the hub to the CT. Note that this particular path is not obstructed by any terrain or building features and therefore could provide reliable communication between the hub and the CT.

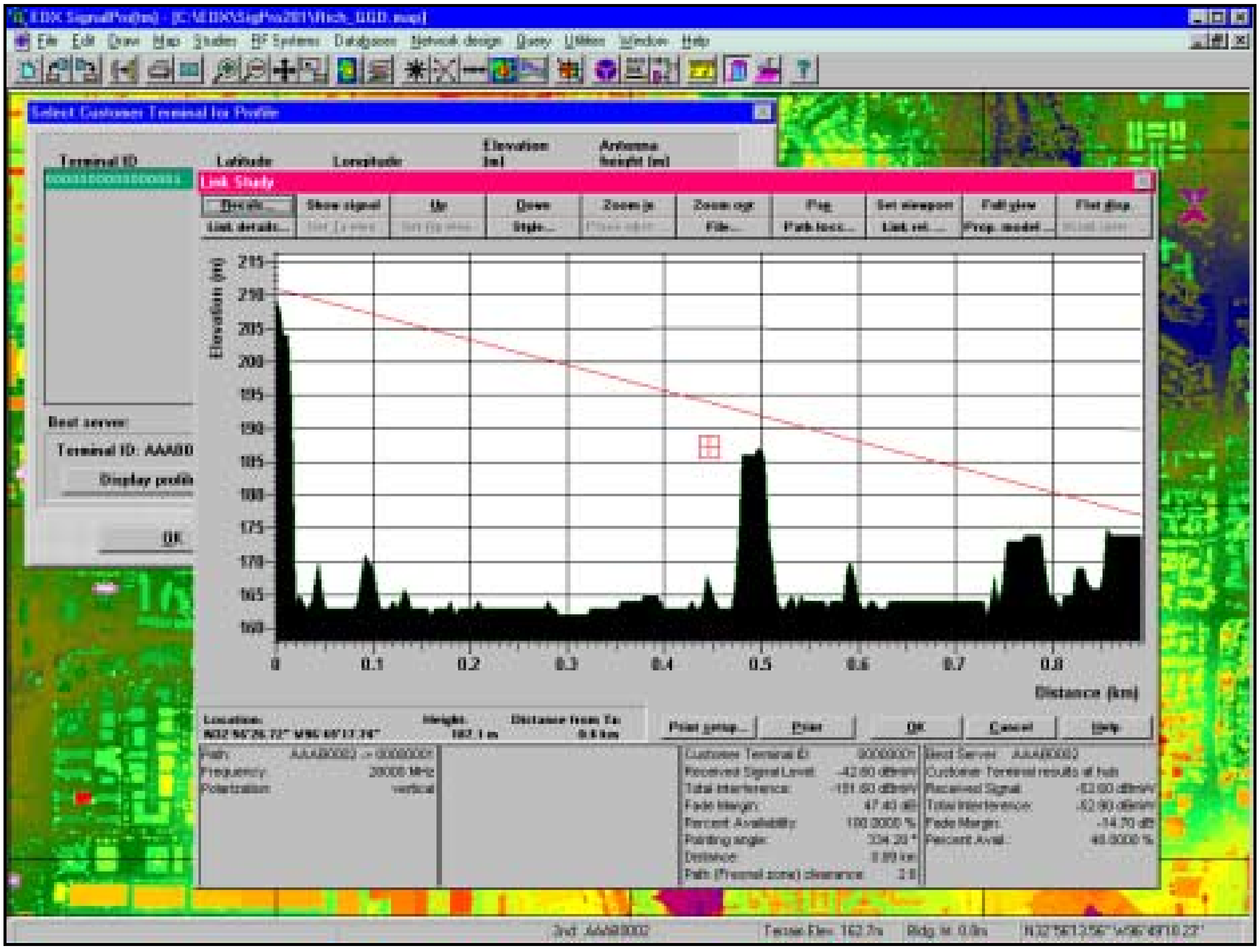

Figure 7. Path profile from a hub to a CT

Figure 8 portrays a shadow study, indicating where there is line of sight (white) and where there is shadowing (obstruction) of the signal (red). Notice that the shadowing patterns closely follow the building outlines and heights. This type of study quickly provides the engineer with an overview of problem areas. To reduce the shadowing, the engineer can modify a variety of parameters, such as number of hub sites, location of hub sites, antenna power, orientation, and height.

CONCLUSIONS

LIDAR has several advantages for wireless telecom planning. It can provide a very realistic representation of a study area—all potential obstructions can be displayed. Since the data gathering process is completely automated, capturing more objects on the landscape costs no more than capturing fewer objects. In addition, the ability to produce a high resolution dataset fits well with the needs of LMDS system planners. Finally, the vertical accuracies quoted by LIDAR producers would give engineers a high level of confidence with which to design and display a system.

There are also disadvantages to LIDAR for telecom planning. The high resolution of a LIDAR dataset may not be necessary over a large urban area. Systems are currently being designed for dense urban areas and clusters of tall buildings throughout the urban area. The remainder of the area does not need to be covered by such high resolutions. It would be worth investigating providing the data in a "mosaic" manner—pockets of high resolution data surrounded by data that has been resampled to a lower resolution.

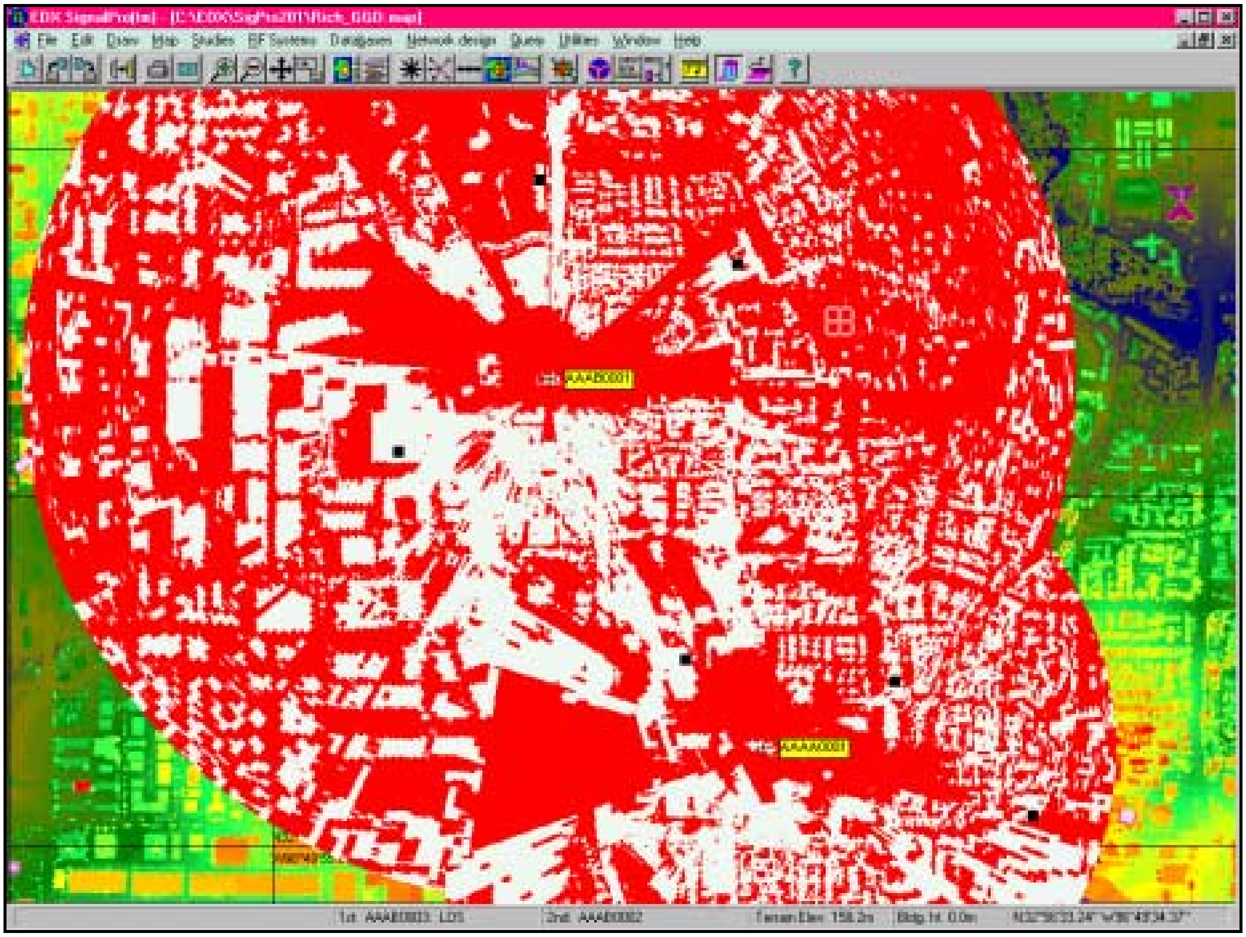

Figure 8. Shadow study

Second, LIDAR data does not include building polygons to which attributes can be attached. This is a problem for some system providers who need this kind of information as they enter new markets or expand existing ones.

Third, can LIDAR be commercially viable for all market sizes? LIDAR seems well suited for capturing data for large geographic areas. However, many engineers need data for smaller areas, where economies of scale may not apply.

This paper has shown that LIDAR can be used to perform signal prediction studies. Its detailed portrayal of an urban area provides a good base on which to design an LMDS system. It is worth addressing the issues mentioned above to see how LIDAR can become a viable data source for telecom planning.

LIDAR data courtesy of Global GeoData and EarthData Int'l.