A COMPARISON OF MEASURED AND PREDICTED, 800 MHz, LAND-MOBILE-RADIO SIGNALS

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ABSTRACT

The details of a UHF propagation measurement program are presented. A mobile vehicle is equipped with a receiver that is capable of measuring the available power from a roof-mounted vertical monopole antenna. The measurements are performed over rural terrain while the vehicle is in motion. The basic transmission loss for the route traveled is plotted along with a prediction produced by an irregular terrain propagation model. This comparison demonstrates the applicability of the model to the land-mobile environment.

INTRODUCTION

With the expanding use of UHF land-mobile radio systems, reliable propagation prediction methods are needed. Different models have been documented and studies have been performed on the suitability of a model's predictions under a given set of environmental conditions. (1,2) Upon surveying the literature, one is reminded that there does not appear to be a model that is best suited for all environments. The user must exercise some judgment about a particular model's appropriateness, based on personal experience and the documentation provided. To aid in this decision, this paper presents some comparisons of measured data with predictions from the VHF/UHF propagation model developed by the Institute for Telecommunication Sciences (ITS).

Comparisons like this are part of ongoing research at ITS. In 1971, Longley et al. (3) analyzed propagation data from nearly 800 paths located throughout the world. These data, which involved fixed communication links, were compared to model predictions and the results were tabulated. Another comparison, published in 1975 by Longley and Hufford (4), considered data from a sensor system that was placed virtually at ground level. As an extension to the above work, this paper covers yet another communication link. Presently, we are interested in assessing a propagation model's performance for land-mobile systems. Measurements are conducted with a mobile receiver to record the path loss as seen by a moving vehicle. The following is a description of the measurement procedure and some results obtained for a rural environment.

THE PROPAGATION MODEL

The irregular terrain model (also referred to as the Longley-Rice model) is based on well-established electromagnetic theory and includes a statistical analysis of terrain features and radio measurements. The model computes a long-term median reference attenuation (relative to free-space attenuation) for frequencies from 20 MHz to 20 GHz. This attenuation is calculated by classifying the path profile into one of two cases: line-of-sight or transhorizon. For the first case, the calculation of reference attenuation is based on two-ray theory and an extrapolated value of diffraction attenuation. In the second case, the reference value is found by calculating either diffraction attenuation or forward scatter attenuation, whichever is the lesser. Further details on the calculations are presented in the references. (5,6,7)

Two modes are supported by the model. One is called "area prediction" and the other "point-to-point." In the area prediction mode, terrain parameters are determined by generalized terrain statistics. In the point-to-point mode, the actual terrain profile between the defined radio terminals is considered in the computations. This yields a prediction that is more specific to the propagation environment under investigation.

Consider the mobile receiver as it travels upon a road. The road can be represented by a locus of fixed points, spaced at equal intervals, along the ground. The path from the transmitter to one of these points constitutes a fixed link. This is the motivation for choosing the point-to-point mode of the irregular terrain model. This mode is designed to generate a prediction over a fixed communication link. The terrain profile of the link is generated by a computer, using an elevation database. The profile provides the model with information about the terrain roughness and average terrain heights. The model uses this information to determine the effective antenna heights and the locations of the horizons.

The ITS model computes the variability statistics for a given path. These statistics account for the fluctuations in signal level as a function of time and location. In order to produce a prediction of the median signal level, the time variability and prediction confidence
are set to 50 percent. Another source of variability accounted for in the model is defined by the chosen climate. When describing a land-mobile environment that is located in the United States, a continental temperate climate is chosen.

**THE MEASUREMENT SYSTEM**

The measurement system consists of an antenna, receiver, digital computer, and displacement encoder. The equipment is housed in a mobile vehicle as illustrated in Figure 1. A spectrum analyzer serves as the receiver, measuring the available power from the antenna and sending the results to the computer. The interface unit receives displacement information from the speedometer cable. This unit signals the computer when the vehicle has traveled 1.64 meters. The computer is used for storing the data and coordinating the system.

The antenna is a vertical quarter-wave monopole on a ground plane. This antenna is chosen for its ease of construction and omnidirectionality. In order to hide the vehicle structure and prevent reflections from it, a large ground plane is used. A computer program, developed by Fitzgerrell (8), computes the dimensions and provides a prediction of the performance of the monopole. Upon tuning the antenna, a VSWR of less than 1.5:1 is obtained across the operating band. The measured antenna pattern, with the antenna mounted on the vehicle, has some symmetrical rippling; however, it is contained within 1.75 dB of the mean. With this in mind, the horizontal pattern shall be considered omnidirectional.

**MEASUREMENT PROCESS**

The route to be driven is selected by examining United States Geological Survey (USGS) topographic maps. Terrain features that may be difficult for the model are located and included in the route. This includes areas with known ground clutter (i.e., man-made objects, trees) that are not explicitly accounted for by the irregular terrain model. Once a route is selected, it is digitized, that is, representative points are read into a computer and stored for future processing.

The vehicle is driven to the route’s starting point, where the receiver is calibrated. A reference signal is connected to the receiver’s input and an internal routine is then activated. The routine measures correction coefficients, which are used in all subsequent measurements. After calibration, the entire system is activated and measurement data is collected while the vehicle is moving along the route. In this way, the measurements accurately reflect the environment of a land-mobile system. The rate at which data is collected can be expressed as

\[
R = 1.312V\sqrt{T}
\]

where \(R\) is the distance between samples in wavelengths, \(V\) is the vehicle’s velocity in miles per hour, and \(T\) is the time between samples in seconds.

The receiver is set to measure a sample every 20 ms. As indicated by Lee (9), it is desirable to have uncorrelated samples; thus the sample rate is chosen to be one sample per wavelength. Putting these values into (1), we find the vehicle speed to be about 40 mi/h. An effort is made to maintain this velocity when road conditions permit.

The measured data are to be compared to the irregular terrain model, which predicts long-term basic transmission losses. In a mobile application, long-term loss is defined to be the median attenuation of the signal level over the many wavelengths that the vehicle would travel. The raw data contain short-term fading caused by multipath. Multipath occurs when there are objects around the receiver that can reflect the transmitted signal toward the receiver. The signal arrives from more than one direction with different amplitude and phase characteristics than the direct wave. The result is a fading that can have a dynamic range as large as 30 dB. In order to make comparisons with the irregular terrain model, this short-term fading must be smoothed out.

The smoothing is achieved by dividing the data into uniform length blocks. A block is defined as a fixed distance along the route in which data has been recorded. A median power level is computed for each block. This value represents the long-term available power. It is then converted to transmission loss using

\[
BTL = TE - (M + LL - RG)
\]

where \(BTL\) is the basic transmission loss, \(TE\) is the transmitter EIRP, \(M\) is the measured available power, \(LL\) is the line losses, and \(RG\) is the receiving antenna gain.

The measured transmission loss is compared to the model’s prediction which is generated for the same location as the block. A block length of 19.7 m (58 wavelengths) is chosen to smooth the multipath without disturbing the effect of the terrain.

The transmitters used for the measurements are the cellular telephone base stations (Figure 2). At the present, there is one local system with 12 transmitter sites spread throughout the Denver metropolitan area. Three of the sites are monitored in the measurements and are named Boulder, Niwot, and Brighton for their respective locations. They broadcast on separate channels around 880 MHz with a channel
width of 30 kHz. Since it is desirable to have a continuous output, the control channels have been chosen for monitoring. The transmitters have a power output of 60 W (EIRP) in an omnidirectional pattern. The ideal pattern is assumed in these measurements even though there may be some distortion due to the tower and mounting structure. The antenna towers are 45.7 m in height except for the Boulder transmitter which is 28.4 m in height.

RESULTS

The measurements are conducted along routes that exemplify a rural environment. This is defined as land used mostly for agricultural purposes and thus possesses scattered and sparse ground clutter. Although the terrain is rolling plains, it is not uncommon to maintain visual sighting of the transmitter over many kilometers in this environment. Typical clutter consists of trees, small buildings, and automotive vehicles.

The first set of measurements is designed to assess the reproducibility of the measurement system. A series of six measurements are made over a period of 3 days. These measurements are made over the same route and monitor two different transmitters. The results are plotted on a common scale so that they may be overlaid together. An inspection of the results shows that the initial measurement values are reproduced on subsequent plots to within 4 dB. This is within the rated capability of the receiver and thus is the expected accuracy for the system.

Figure 3 is a topographic plot of the area around the Boulder and Niwot transmitters. This plot was generated from a computer database of point elevations stored on a grid with an angular spacing of 30 seconds by 30 seconds. The same database is used by the irregular terrain model in producing a prediction. A rigorous comparison to USGS topographic maps will show some differences in the elevations of various points; however, the major terrain features are accurately located. There exist some small buttes in the actual terrain that are not in the database. These produce extra transmission loss that will not be in the prediction.

Returning to Figure 3, the measurement routes are indicated by relatively straight lines labeled with a number. Along the routes are circles that represent towns. The circles indicate a location within the town, but do not define the physical borders. The letters, which are next to each town, correspond to the descriptions contained in Table 1. The three routes form a "T" intersection. This intersection is where all routes either begin or end, depending upon the direction of travel. For example, route 4 extends from the "T" intersection to the end of the drawn line.

<table>
<thead>
<tr>
<th>Location</th>
<th>Town</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Longmont</td>
<td>42,942</td>
</tr>
<tr>
<td>B</td>
<td>Dacono</td>
<td>2,321</td>
</tr>
<tr>
<td>C</td>
<td>Ft. Lupton</td>
<td>4,251</td>
</tr>
<tr>
<td>D</td>
<td>Lafayette</td>
<td>8,985</td>
</tr>
<tr>
<td>E</td>
<td>Broomfield</td>
<td>20,730</td>
</tr>
<tr>
<td>F</td>
<td>Gilgrest</td>
<td>1,025</td>
</tr>
<tr>
<td>G</td>
<td>Platteville</td>
<td>1,662</td>
</tr>
<tr>
<td>H</td>
<td>Hudson</td>
<td>698</td>
</tr>
<tr>
<td>I</td>
<td>Brighton</td>
<td>12,773</td>
</tr>
</tbody>
</table>

The measurement plots, which correspond to the routes indicated in Figure 3, are presented in Figures 4-9. The ordinate is labeled in decibels which represent basic transmission loss. This is defined as the loss between two loss-free isotropic antennas. The continuous line is the measured data with the aforementioned smoothing process applied. The dashed line indicates the predicted loss as generated by the irregular terrain model. The upper threshold of 170 dB is the maximum basic transmission loss that can be measured by the receiver. A value slightly above this level would be recorded if no signal was present.

In another set of measurements, the Brighton transmitter is monitored. The routes are shown in Figure 10. The plot shows that this transmitter covers an area adjacent to the previous transmitters. Due to the sensitivity of the receiver, measurements can be made outside the 39 dBuV/m contour for which the cellular telephone service is designed. The unwanted transmitter signals in the area are attenuated by more than 60 dB in the receiver’s IF section. The measurements in Figures 11-13 correspond to the routes in Figure 10.

In Figure 11 there is a consistently large difference between the measured and predicted values beyond 10 km. The average difference of about 20 dB is the result of the terrain's topography and the irregular terrain model's calculation of effective antenna heights. The effective antenna height is defined as the height of an antenna above the "effective reflecting plane." This plane is a smooth curve that is fitted by least squares to the terrain elevations that are visible to the antennas. (5,7) The motivation for doing this is best illustrated by an example. Broadcasters of VHF and UHF signals tend to prefer a transmitter site that is elevated from the intended service area. The site may be a hill, a mountain, or a cliff. This extra height, gained by the terrain, is considered, along with the antenna's structural height above the ground, to yield an effective height above the service area.
It is the effective antenna height adjustment that contributes to the difference in Figure 11. The terrain profile between the transmitter and a point along the route is found by using a topographic database. A curve is fitted by least squares to the terrain. Near the transmitter, the curve is 14 meters below the surface. This distance is added to the antenna's structural height to give the effective antenna height. At the receiver, the curve is 16 meters below the surface, thus the receiver antenna height is adjusted to its effective antenna height. This procedure is employed in the prediction in Figure 11. In Figure 14, the effective antenna height adjustment has been removed from the prediction; that is, the effective height is forced to be equal to the structural height. Since the antennas are closer to the effective reflecting surface, more transmission loss is predicted. It is evident that for this particular case, the prediction has improved.

Removal of the added distance in the effective height calculation gives an improved prediction in four of the nine measurement plots. The improvement for each plot is found by computing the average difference over the entire plot. This is done twice for each measurement route, once using the effective height adjustment and once without the adjustment. The two averages are subtracted to give an indication of the amount of improvement. An improvement takes place when the absolute value of the average difference is reduced by the removal of the effective height adjustment. In two of the plots, removal of the effective height adjustment improves the average difference by 10 dB. On the other hand, in two of the nine plots, the average difference is degraded by a similar amount. Table 2 shows the change in the average difference when the effective height adjustment is removed. A negative sign indicates that the absolute value of the average difference is increased. The table shows that an overall improvement in the predictions may be possible if criteria are developed to decide when to apply the effective height adjustment. Further study is needed in this area.

The plots show a direct comparison between the irregular terrain model's predicted loss and the measured loss. The observer is able to see where the differences occur as well as their magnitude. The overall performance can be expressed in a quantitative form by computing a distribution of the difference. Recall that the data are divided into blocks with a prediction generated for each block. The difference is found by subtracting the measured median from the prediction. Thus, the difference term is negative when loss is predicted than exists in the environment and vice versa. A distribution of the difference that includes all of the routes mentioned in this report is shown in Figure 15. This plot uses a probability scale in which a straight line represents a Gaussian distribution. From the plot, the probability that the difference is less than zero is 67 percent. This is also the probability that the model underestimates the loss. Due to the terrain features (i.e., buttes) that are not present in the topographic database, the probability of underestimating the loss is expected to be above 50 percent.

**CONCLUSION**

The data in this paper show the applicability of the ITS irregular terrain model to the prediction of propagation loss in the rural, land-mobile environment. A prediction is overlaid on the measurement to show the ability of the model to account for the perturbations of the signal caused by the environment. In some cases, the prediction can be improved by removing the effective antenna height adjustment from the model. However, further study of measurement data is needed to determine criteria for the removal. A distribution of the difference is presented to give a numerical description of the model's precision. With this report, the user is provided an insight to the use of the ITS irregular terrain model.

**REFERENCES**


Figure 1. Block diagram of the measurement system.

Figure 2. Cellular telephone base station near Niwot, Colorado.

Figure 3. Topographic plot of the terrain around routes 1-3.
Figure 4. Prediction and measurement of the transmission loss for transmission from the Niwot transmitter while traveling south on route 1.

Figure 5. Prediction and measurement of the transmission loss for transmission from the Boulder transmitter while traveling north on route 1.

Figure 6. Prediction and measurement of the transmission loss for transmission from the Niwot transmitter while traveling west on route 2.

Figure 7. Prediction and measurement of the transmission loss for transmission from the Boulder transmitter while traveling east on route 2.
Figure 8. Prediction and measurement of the transmission loss for transmission from the Boulder transmitter while traveling north on route 3.

Figure 10. Topographic plot of the terrain around routes 4-6.

Figure 9. Prediction and measurement of the transmission loss for transmission from the Niwot transmitter while traveling south on route 3.

Figure 11. Prediction and measurement of the transmission loss for transmission from the Brighton transmitter while traveling south on route 4.
Figure 12. Prediction and measurement of the transmission loss for transmission from the Brighton transmitter while traveling west on route 5.

Figure 13. Prediction and measurement of the transmission loss for transmission from the Brighton transmitter while traveling east on route 6.

Figure 14. A replot of Figure 11 with the effective height adjustment removed from the prediction.

Figure 15. Cumulative distribution of predicted loss minus the measured loss for all of the measurements.
Figure 2. Cellular telephone base station near Niwot, Colorado.