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Communications Coverage-Area Modeling Task

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Task Objectives

A major objective of this task is to develop a reliable and accurate model that can determine the usable communication service area for a given transmitter location. It is expected that this model will be used either to identify uncovered regions for existing communications facilities, or to aid in the siting of new facilities. This work should also shed light on the data rates that can be realized under specific operational conditions.

The most significant mechanisms affecting the wireless transmission of data between terrestrial nodes are listed below, along with a brief description as to how they affect radio propagation.

1. **Terrain:** By blocking, reflecting, and/or diffracting signal energy, the received signal will be enhanced or attenuated by the terrain thus affecting the magnitude of that signal.
2. **Small-Scale Fading:** This effect appears as noise to the receiver, and is caused by motion of the receiver as it moves with respect to nearby objects. It will change with vehicle velocity and the strength of the received signal.
3. **Channel Noise:** This is the background noise that is caused by natural and man-made sources. Because data transmission rates are limited by the ratio of signal to noise, the characterization of background noise is crucial in modeling the radio channel.

An expected deliverable resulting from this task will be a computer model that estimates the effects of the above three mechanisms to quantitatively predict the quality of signal reception for a specified operational condition.

Another objective of this task is to develop the capability to measure and analyze radio signals for the purpose of identifying faulty equipment and noise sources, and for validating propagation models used to estimate coverage areas.

Task Status Overview

As a result of past work on this effort, a terrain-sensitive propagation model has been identified that is capable of estimating received radio signal strength. The model has been modified for this application and has been interfaced to a terrain database, enabling it to produce signal estimates in a format that can be used to create a coverage-area map.

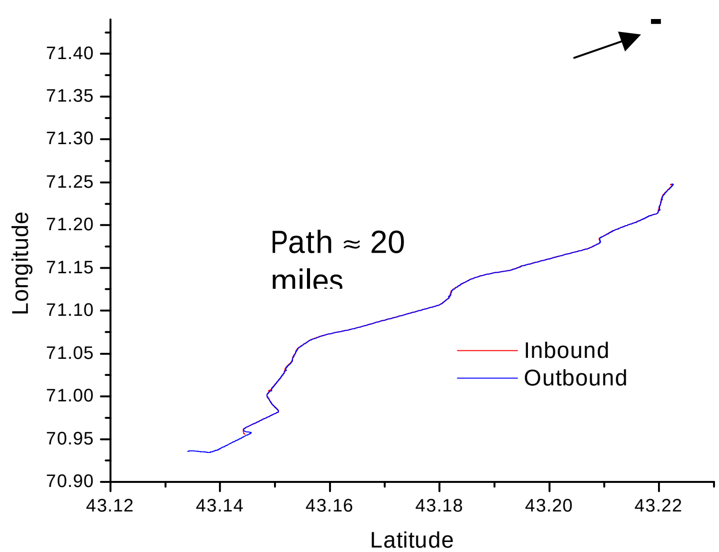
To ensure that the propagation model provides estimates that are sufficiently accurate, a data collection package has been developed (as reported in a previous progress letter) that measures and records signal strength as a function of position. Preliminary work has begun to collect signal strength data in an effort to validate and, if necessary, modify the propagation model.

Work has also begun to use the data collection package to measure small-scale fading and channel noise.

Task Status Specifics

Preliminary Propagation Model Validation Results: As stated, one objective of collecting radio signal strength data is to verify that the propagation model can operate with sufficient accuracy to provide meaningful coverage-area maps. Although the propagation model used for this study has been validated in the past, there have not been enough comparisons made to provide a good statistical understanding of model accuracy. The limiting factor in the past has been the availability of quality measured signal strength data. It is expected that the data collection package developed for this project will enable us to collect enough information to make definitive statements about model accuracy and limitations.

While model validation will continue to take place into the future to evaluate model performance over a range of conditions, some preliminary data have been collected. These measurements were taken along a 20 mile section of highway (Route 4 between Durham and Concord NH) that involves a complex terrain profile between the transmitter and mobile receiver. Because a standard police band transmitter was not available to provide the source signal, a weather radio transmitter, WXJ-40, was used. This source appears to be ideal for this type of measurement since it is continually radiating, widely available, and has operational parameters closely approximating the standard police band transmitter (narrow-band FM at a frequency of 162.4 MHz, radiating power of 330 watts, isotropic radiation pattern, vertical polarization, and antenna height of 180 feet).



A plot of the path taken for the first data collection effort is shown in Figure 1. The latitude and longitude, as measured by GPS, is plotted for both the inbound and outbound legs, and those plots are seen to be nearly overlaid. It is interesting and reassuring to note that an enlargement of this plot has sufficient resolution to reveal that the vehicle was on the right side of the road to for both inbound and outbound legs of the journey, demonstrating the high degree of accuracy afforded by the GPS unit.

Figure 2 shows the terrain profile between the transmitter site and Durham, NH. This is a challenging profile from a propagation perspective because it includes a high degree of irregularity as well as several terrain features that block the line of site path. If the propagation model can accurately predict signal strength on a path of this complexity, it will likely be able to perform satisfactorily on any profile.

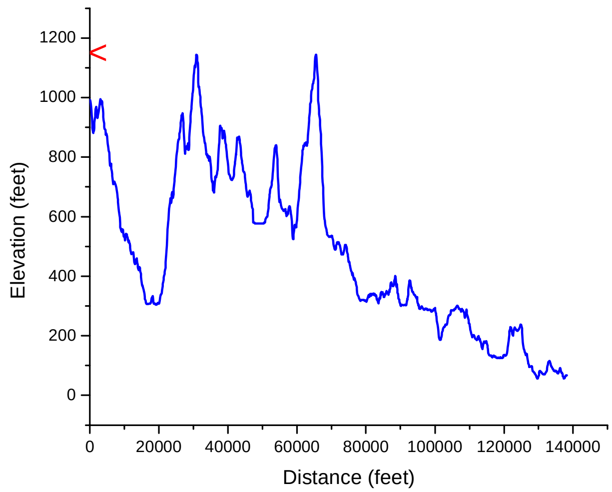
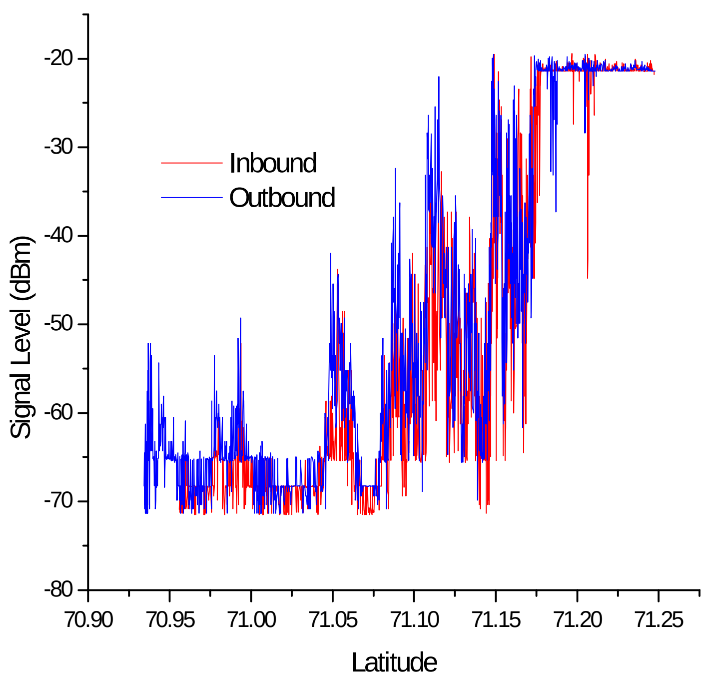


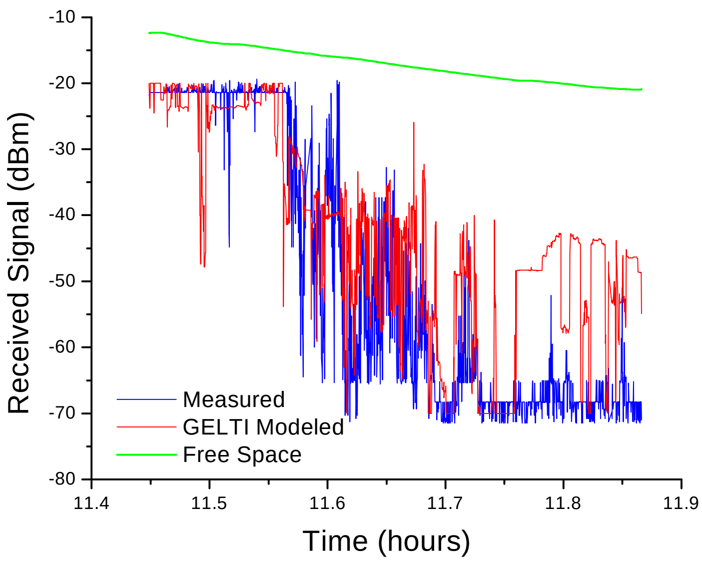
Figure 3 plots the measured signal strength recorded on the 20 mile stretch of highway- both the inbound and outbound signal strengths are plotted in figure. In looking at these data, a large amount of random noise can be seen superimposed upon a more slowly varying underlying trend. The rapidly varying noise is mostly caused by near-object scattering (small-scale fading) which is caused by either the motion of the vehicle in which the measurements were taken, or by the motion of other nearby vehicles. Much of this noise can be compensated for by the radio's automatic gain control (AGC), although it can significantly degrade channel throughput. It is the characterization of this small-scale fading that will be addressed as one component of this task.

The more slowly varying trends in the signal strength plot are caused by the major features in the terrain profile, and result from constructive and destructive interference caused by a terrain reflection and diffraction (large-scale fading). It is expected that the propagation model will account for the large-scale fading, while separate modules will account for the small-scale



fading and ambient noise.

A comparison of measured and modeled data is shown in Figure 4, where the measured data are the same data plotted in Figure 3. The signal level that would be expected in free space is also plotted in order to demonstrate the effects of terrain on the received signal.



As seen in Figure 4, the modeled data appear to follow the trends in the measured data except towards the end of the plot. At present, it is not known whether that error is a result of error in the propagation model, or if it is caused by errors in the terrain database. To resolve this issue, contact has been made with others who are involved with propagation modeling to have them run their models using the same data. Specifically, data have been exchanged with Amalia Barrios[1] and Nick DeMinco[2] , and results of their model comparisons will be reported as they become available.

The model validation effort will continue into the upcoming reporting period, and the next report will provide a statistical validation of model performance.

Preliminary Analysis of Small-Scale Fading As stated above, small-scale fading occurs when there is motion between a receiver and nearby objects. In order to quantify and model this interference source, measurements were collected to explicitly evaluate the effects of small-scale fading and the factors that affect it. In the first set of measurements, high-sample-rate signal strength data were collected in a vehicle traveling on a deserted road. Collecting data on a road with no other vehicles eliminated interference from other vehicles. Data were collected repeatedly over the same section of road when traveling at different speeds, so that the effect of vehicle speed on the received signal could be measured.

Bar graphs of averaged signal strength for three different sections of road, and for three different vehicle speeds (15, 20, and 25 MPH) are presented in Figure 5. Although the degree of variation varies from one section of road to another, a trend evident for the

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[2] Telecom Engineering , Analysis, and Modeling Division of the Institute for Telecommunication Sciences, Dept. of Commerce, NTI/ITS.E, Boulder, CO

three road segments investigated is that the average signal level decreases with increasing vehicle speed. This indicates that channel throughput will decrease with increasing vehicle speed when operating in regions of marginal signal, because of throughput dependence no signal-to-noise ratio.

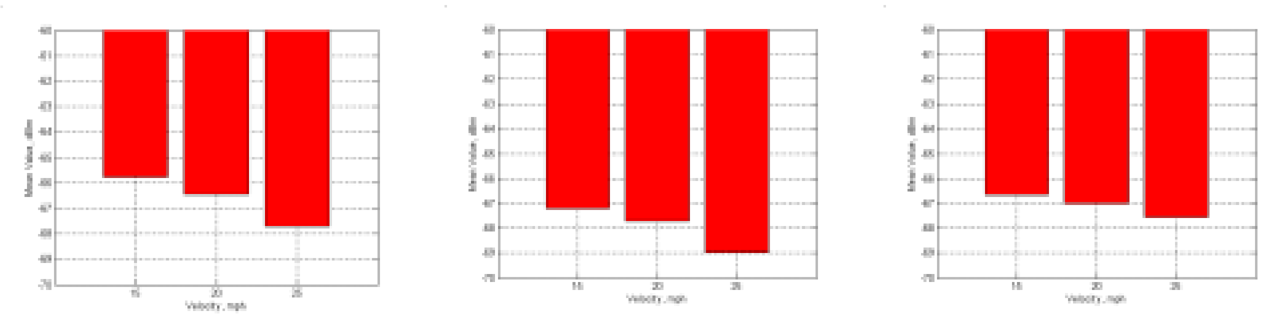
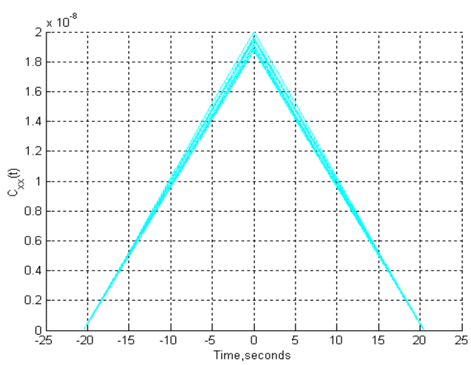


Figure 5. Average signal strength for three sections of road at three different vehicle speeds.

A next step in the investigation into small-scale fading is to gather more data so that the effects on signal can be quantified over a larger range of conditions and vehicle speeds.

<u>Preliminary Analysis of Channel Noise</u> Channel noise is the undesired background noise that is independent of the desired signal. This noise may be natural or man-made, and it acts to mask the desired signal. Because man-made noise is often greater than natural noise, the total channel noise will typically be greater in urban areas, or in areas with industry or hospitals. Channel noise can also be caused by electrical noise sources in a vehicle, such as ignition noise or noise generated by on-board electronics. Consequently, channel noise may vary from vehicle to vehicle.

The signal strength data collection package developed for this task, combined with post-collection data analysis, is an effective means for understanding channel noise sources and their effects on channel throughput. The level of channel noise is documented, and the next step in this task with regards to noise is to compare measured noise values with those reported by others[3,4] . Further, tests will be performed to observe channel noise variation with different vehicles and different measurement locations.



Some preliminary channel noise data have been collected and analyzed with the objective of identifying impulsive noise. The presence of impulsive noise implies man-made sources (such as

[3] "Man-Made Noise Power Measurements at VHF and UHF Frequencies", Robert Achaz and Roger Dalke, National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report 02-390, December, 2001

[4] Man-Made Noise in the 136-138 MHz. VHF Meteorological Satellite Band, Achatz, Lo, Papazian, Dalke, and Hufford, National Telecommunications and Information Administration, U.S. Dept. of Commerce, NTIA Report 98-355, September, 1998

ignition noise), and one study has shown it to degrade channel throughput to a greater degree than Gaussian noise. A simple test for the presence of periodic impulsive noise is the autocorrelation function of noise amplitude as a function of time, and an example of this is shown in Figure 6, which plots the autocorrelation for several measurement sets. The receiver was tuned to a frequency where no signal was present for these particular measurements, so the autocorrelation function was performed only on noise. The triangular shape of the autocorrelation function is typical of band-passed, Gaussian noise. The different data sets plotted were collected both with and without the engine running. Had there been engine-induced noise in these measurements, there would have been spikes on the plot corresponding to the period of the ignition impulses. The lack of such spikes, and the general shape of the autocorrelation function of Figure 6, indicates that the noise is mostly Gaussian. It should be noted that the spark-plug wires in the vehicle in which the measurements were taken had recently been replaced.

Future work with regards to noise measurements will be to collect and analyze noise data for a wider range of conditions (different vehicles in different locations) and compare those data with published values. Of key interest in this work will be to identify cases where in-vehicle electronics is interfering with channel performance.

Capabilities Resulting from this Task that might be of Immediate Use

The equipment developed for this task to probe received signal and noise can be used to identify and resolve a number of existing problems. Specifically, if there are areas where signal coverage is reported to be inadequate, the measurement equipment and analysis techniques can be used to determine whether deficient coverage is caused by insufficient signal or by signal interference. The measurement capability can also be used to answer questions about antenna placement on a vehicle or about radio interference caused by on-board electronics.