Theory and Measurement of Millimeter-Wave Propagation Through Foliage

Feinian Wang, Il-Suek Koh, and Kamal Sarabandi,
Radiation Laboratory
Department of Electrical Engineering and Computer Science
The University of Michigan, Ann Arbor, MI 48109-2122

Abstract

The military demand for high data rate communication is on the rise. For this purpose wide-band communication at millimeter-wave frequencies is proposed. Urban and forested environments pose a significant challenge for the operation of such systems. In order to assess the performance of communication device operating at millimeter-wave frequencies, characteristics of the channel such as path-loss, coherent bandwidth, fading statistics etc. must be determined. In this paper we investigate the characteristics of a forest channel at millimeter-wave frequencies. This problem is approached both theoretically and experimentally, and a comparison between measurement and theory will be presented at 35GHz.

An outdoor measurement was conducted for a pine tree stand. This stand included 13 pine trees occupying a 15m × 25m area with average distance of 5m between two adjacent trees. In this experiment path-loss due to the tree stand was measured at Ka-band (35GHz). Two identical high-gain horn antennas with a half-power beamwidth of 10° were used for the transmitter and receiver. The transmitter was located in a clear area, 20m away from the tree stand, illuminating it from the side. The antenna foot print at 20m is about 3m × 3m which is substantially smaller than the tree crown dimensions, ensuring a distributed target-type measurement. The receiver was first set up in front of the tree line for calibrating the systems, and then moved behind trees for path-loss measurements. After excluding the free space path loss between the reference point and the measured power beyond the stand, the path loss due to the tree cluster is obtained. To acquire the desired path-loss statistics, 84 independent spatial samples of transmitted signal through the pine stand were collected.

A coherent wave propagation model based on Monte Carlo simulation and realistic looking fractal trees is used to simulate propagation through the tree stand. The trees were generated with physical and structured parameters, such as tree density, height, mean trunk diameter, etc., similar to the experimental tree stand. The model uses Foldys approximation based on single scattering theory to calculate the coherent attenuation rate. It is known that single scattering is not sufficient for the accurate estimation of attenuation rate of a dense and highly scattering medium. Foldy's approximation in conjunction with single scattering overestimates the attenuation effect. Hence to improve the accuracy of the coherent model partial multiple scattering occurred among the needles of highly dense leaf clusters is included for the estimation of the coherent attenuation. Incoherent scattering from the branches, leaf clusters, and tree trunks are calculated and added to the mean field for accurate estimation of the overall path-loss and field fluctuation statistics.