Point-to-Point Backhaul Systems at 3.5GHz Predictions vs. Measurements in a Vegetated Residential Area of Washington, DC, USA

Saúl A. Torrico
Comsearch
19700 Janelia Farm Blvd.
Asburn, VA 20147, USA

Roger H. Lang
Department of Electrical and Computer Engineering
The George Washington University
Washington, DC 20052, USA

Abstract—**For point-to-point backhaul systems located in a vegetated residential area, the base-station transmitter is located close to the surrounding rooftops; the propagation takes place over the rooftops and through the canopy of the trees. The receivers, in many cases, are also located close to the surrounding rooftops or well below them. The objective of the present paper is to use the Torrico-Bertoni-Lang model to predict the propagation losses and compare them with measurements made at 3.5 GHz in the Washington, DC area. Results show that by using a physical-base propagation model and GIS data, a close correlation between the measurements and the predictions is obtained. In particular, for all the point-to-point links measured the root-mean-square-error (RMSE) is 5.5 dB.**

I. INTRODUCTION

As new generation of wireless systems are being deployed or studied for the future, it is clear that due to growing congestion levels in the present available spectrum, the new generation wireless systems are only possible at higher frequencies. As we increase, however, to higher carrier frequencies, for example 3.5 GHz or 5.8 GHz, the size of the outdoor environmental objects become much more comparable to the wavelength of the carrier signal. For a point-to-point backhaul system, operating at 3.5 GHz, the wavelength is about 8.6 cm; this is comparable with the size of the leaves and branches of the canopy of a deciduous tree and much smaller than the size of the houses. When the line-of-sight (LOS) between the transmitter and the receiver are blocked either by the rooftop of the houses or by the canopy of trees or by both, the diffraction effects produced by the houses and the absorption and scattering effects of the canopy become significant. The effect in the overall analytical prediction loss needs to be quantified and tested against measurements.

The objective of the presentation is to use the Torrico-Bertoni-Lang model [1] as the basis for including the effects of both vegetation and houses to predict the propagation loss for point-to-point backhaul system at 3.5 GHz. Another objective is also to include the attenuation and the phase delay of the tree canopy to obtain a simplified Torrico-Bertoni-Lang model in a form that looks like the Walfish-Beroni model [2] or the propagation model given by [3]. It is noted that [3] includes vegetation as part of the propagation model but its weakness is that it does not include the canopy phase delay as described in [1], which plays an important role for high frequency wireless systems. The prediction model [1] is verified with the data derived from measurements at 3.5 GHz conducted in the Washington, DC area.

II. PROPAGATION LOSS MODELING AND MEASUREMENTS

The Torrico-Bertoni-Lang model [1] has been used to compute the path attenuation in a vegetated residential area. Here a vegetated residential area is defined as an area outside of the high-rise core of a city, where the heights of the houses are relatively uniform and the tree canopies are located in front of each house to form nearly a continuous row of trees along the street. A propagation test was performed in a residential area in greater Washington DC. In order to compare the theoretical propagation model vs. the measurements, the terrain and the morphology data were obtained for the vegetated residential area where the measurements took place. The terrain data was obtained from the United States Geological Survey (USGS) with 1/9 arc second resolution. The building data was obtained from the Light Detection and Ranging (LiDAR) data, and the vegetation data was obtained from the USGS NLCD 2011.

Following the Torrico-Bertoni-Lang model [1], each row of houses is viewed as diffracting cylinders and a canopy of the trees located adjacent to and above the houses. In this scenario at 3.5 GHz, the diffracting cylinders where modeled as absorbing screens and the adjacent canopy of trees by partially absorbing phase screens. The field at the aperture of the first absorbing screen depends on the mean field going through the first tree due to an incident plane wave. Then, physical optics (PO) is used to evaluate the diffracting field at each of the successive absorbing/phase half-screens configuration up to the mobile receiver by using the multiple Kirchhoff-Huygens integration. In order to find the properties of a partially absorbing phase screen, the attenuation and phase delay of the mean field propagating through the canopy is evaluated using a random media model. The tree canopy is represented as an ensemble of leaves and branches all having prescribed location and orientation statistics. Leaves are modeled as flat, circular, lossy-dielectric discs and branches as finitely long, circular, lossy-dielectric cylinders. The mean field in the canopy is calculated using the discrete scattering theory of Foldy-Lax. By solving the wave equation for the mean scattered field propagating through a tree, it is found that the wave propagation constant has both real and imaginary components. The integral effect of the propagation constant over the tree volume leads to expressions for the attenuation and phase delay of the partially absorbing phase screen. This shows the importance of including the real and the imaginary components of the propagation constant at high frequencies in the overall propagation loss in a vegetated residential environment between a transmitter and a receiver. Backscattering effects from the tree canopy have been neglected.

A point-to-point measurement campaign was performed during the month of November 2015 in the Washington DC area. The landscape was rather flat and consisted of vegetated residential areas. The transmitter, a Berkeley Varitronics Class A Gator, was used to generate a continuous wave (CW) RF signal at 3.5 GHz with a transmitter output of 33.5 dBm. A CRFS RFeye spectrum monitor with a receiver sensitivity of -130 dBm was used to collect the measured data. The transmit and receive antenna were omnidirectional with 2.1 dBi of antenna gain. The transmitter-elevated antenna was located at 47 m above ground and well above the average rooftops. Sixteen receiver sites were selected to provide two types of obstruction scenarios. The first scenario was selected to provide path obstruction due to rooftop of the houses only, and the second scenario to provide path obstruction by the rooftops and the canopy of the trees simultaneously.

III. RESULTS AND CONCLUTIONS

For the first scenario, where the direct path between the transmitter and the receiver is only blocked by houses, results show that the Torrico-Bertoni-Lang model underestimates the propagation loss with a RMSE of 5.2 dB. The loss hasa mean of -2.4 dB and a standard deviation of 4.6 dB. For the second scenario, in order to highlight the effects of the canopy of the trees in the total propagation loss, we further divide it in two sub-cases: the sub-case where the direct path is blocked simultaneously by the trees and houses and the hypothetical sub-case when the trees are not present in the environment. In the sub-case, when the trees and the houses are taken into consideration, the mean error is 6.0 dB, the standard deviation is 3.0 dB and the RMSE error is 6.7dB. In the hypothetical sub-case, when the trees are absent of the environment, we find that the mean error is 13.7 dB, the standard deviation is 7.5 dB and the RMSE error is 15.6 dB. Finally, if we include all the point-to-point links that were measured, the comparative analysis between the Torrico-Bertoni-Lang propagation loss model and the measured propagation loss shows that we obtain a mean error of -0.7 dB with a standard deviation of 5.5 and a RMSE of 5.5 dB. These results indicate a very close correlation between the measured and the predicted propagation losses; they also indicate the importance of using a physical-base propagation model as the Torrico-Bertoni-Lang model in conjunction with GIS data (terrain, houses, and vegetation data) to predict the propagation loss in a vegetated residential area.

ACKNOWLEDGEMENT

The authors would like to thank to the Comsearch team S. Langhnoja, R. Corpuz, and A. Obichere under the direction of the Director K. Oliver for planning and implementing the measurements. Also, an especial thank to C. Hardy Vice President of Comsearch for allowing us to share the measurement results.

REFERENCES

[1] S. A. Torrico, H. L. Bertoni, and R. H. Lang, “Modeling tree effects on path loss in a residential environment,” *IEEE Transactions on Antennas and Propagation*, vol. AP-46, no. 6, pp. 872-880, June 1998.

[2] J. Walfisch and H. L. Bertoni, “Theoretical model of UHF propagation in urban environments,” *IEEE Transactions on Antennas and Propagation*, vol. AP-36, no. 12, pp. 1788-1796, December 1988.

[3] K. L. Chee, S. A. Torrico, and T. Kurner, “Radio wave propagation prediction in residential environments,” *IEEE Transactions on Vehicular Technology*, vol. 62, no. 2, pp. 486-499, February 2013.