MODELING NEAR-EARTH GROUNDWAVE PROPAGATION OVER RANDOM TERRAIN ROUGHNESS WITH AN EFFECTIVE LOW-GRAZING REFLECTION COEFFICIENT

DaHan Liao and Kamal Sarabandi

The Radiation Laboratory
The University of Michigan, Ann Arbor, MI. 48109-2122, USA

ABSTRACT

Accurate characterization of the electromagnetic wave scattering and propagation properties of the terrain surface is essential in optimizing the performance of wireless sensor networks (WSN) deployed for environmental monitoring and geophysical sensing applications. As the WSN nodes are positioned near or at the ground level, the conditions of the ground have a substantial effect on the radio signal; as such, an investigation of the interactions between ground conditions and the radio signal is important for establishing inter-nodal radio communication connectivity as well as for deducing geophysical parameters directly from the nodal signal strength measurements (e.g., wave tilt data).

For propagation over a rough terrain, the physical statistical properties of the surface (height profile probability density function, surface autocorrelation function or roughness spectrum) have a direct impact on the statistics of the propagating signal. In the near field, the LOS (line-of-sight) space wave from the transmitting antenna, when it exists, provides the primary contribution to the total received signal, as coherent reflection is reduced by the random scattering effects. However, over a long distance, as the propagation path approaches the grazing condition, in accordance with the Rayleigh criterion, the surface appears electrically smooth again and coherent cancellation between the direct and ground scattered signals is re-established. These qualitative observations are consistent with numerical simulation results presented in previous works [1,2]; specifically, as it has been shown in [1], for fixed transmitter and receiver locations, the far field propagation loss increases with corrugation *rms* height as expected but also shows considerable dependence on the surface correlation length; furthermore, at grazing propagation, it is no longer proper to calculate coherent signal statistics by a *complete* replacement of the rough surface with a smooth surface positioned at the original surface's physical mean height, for now the *effective* height is a function of both surface *rms* height and correlation length. Although numerical models such as those prescribed in [1,2] have proven to be efficient simulators in dealing with the near-ground channel, it is also convenient to quantitatively capture the aforementioned observations—which have not been sufficiently addressed and explained in existing literature—in analytical formulations.

Owing to the random multi-scattering processes inherent in an undulating terrain environment, a radio signal has both coherent and incoherent components, each contributing to the total channel transfer characteristics. In considering the effects of random roughness, an equivalent coherent reflection coefficient can be produced from the Kirchhoff approach, leading to the Ament approximation [3], which has been incorporated into ray-tracing routines by other workers for predicting reflection loss due to surface roughness. Another commonly-used form of the reflection coefficient has been derived by Miller and Brown [4]. While being simple to implement, both the Ament and Miller-Brown approximations are not valid for grazing angle propagation as they do not include terrain self-shadowing effects. The fraction of the surface that is illuminated by the incident rays can be estimated and the surface PDF can be modified to include a shadowing factor [5]; the subsequent expression for the effective reflection coefficient so derived, however, maybe in a complicated integral form that is contingent upon the choice of an ``optimal'' shadowing PDF [6]. The shadowing PDF approach provides improvement over the traditional Ament and Miller-Brown formulations, although this approach still does not consider the implications of surface wave effects and has not been tested for near-ground propagation scenarios.

In this study, in order to arrive at an analytical representation for the effects of terrain roughness on the near-ground channel, new closed-form expressions for the effective reflection coefficient are presented. The basis of the derivation is founded on the perturbation approach applied to a volumetric integral equation as introduced by Sarabandi and Chiu [7] for remote sensing applications involving the modeling of the general scattering coefficients of rough surfaces with inhomogeneous

dielectric profiles. Here, expressions for the coherent effective reflection coefficient are derived for the 2D problem; the accuracy of these expressions for excitation sources of vertical and horizontal polarizations is validated by comparing the simulation results to those obtained from the numerical solver outlined in [2].

REFERENCES

[1] D.H. Liao and K. Sarabandi, "An approximate numerical model for simulation of long-distance near-ground radiowave propagation over random terrain profiles," *Military Communications Conference (MILCOM 2007)*, 2007.

[2] D.H. Liao and K. Sarabandi, "Simulation of near-ground long-distance radiowave propagation over terrain using Nyström method with phase extraction technique and FMM-acceleration," *IEEE Trans. Antennas and Propagation*, 2008, submitted: under review.

[3] W.S. Ament, "Toward a theory of reflection by a rough surface," *Proc. IRE*, 1953.

[4] A.R. Miller, R.M. Brown, and E. Vegh, "New derivation for the rough-surface reflection coefficient for the distribution of sea wave elevations," *IEE Proc.-H*, vol. 131, Apr. 1984.

[5] D.M. Milder, "Surface shadowing at small grazing angle," *Waves in Random Media*, vol. 13, 2003.

[6] C. Bourlier, N. Pinel, and V. Fabbro, "Illuminated height PDF of a random rough surface and its impact on the forward propagation above oceans at grazing angles," Tech. Rep. ESA SP626 SP, European Space Agency, 2006.

[7] K. Sarabandi and T. Chiu, "Electromagnetic scattering from slightly rough surfaces with inhomogeneous dielectric profiles," *IEEE Trans. Antennas and Propagation*, vol. 45, Sep. 1997.