2-D Radiative Transport Theory: Propagation Loss Predictions in a Trunk Dominated Forest

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With the emergence of new applications for wireless sensor networks (WSN) in outdoor environments, such as, WSN measuring environmental parameters in forested areas, there needs to be more precise analysis of the propagation loss between transmitters and receivers. The objective of this presentation is to demonstrate the importance of including the incoherent field as part of the total field to predict the propagation loss in a trunk dominated forest. A typical WSN in a forested environment involves an undetermined number of independent nodes where each independent node has many sensors that measure different environmental variables, such as, solar radiation, pressure, and humidity. To link all these nodes to a central node therefore, they need to meet the link reliability between each node and the central node. An accurate propagation loss prediction also needs to be obtained. As it will be shown in the present paper, the propagation loss changes with frequency, with the location of the transmitter and receiver between nodes, and with the biophysical parameters of the forest. In this context, the radiative transport (RT) theory is used to demonstrate the importance of the coherent and the incoherent fields on propagation loss. To check the soundness of the RT theory, a Monte-Carlo (MC) simulation will be employed.

In this study, we will solve the two-dimensional RT equation for a plane wave incident on a trunk-dominated forest. The exact RT equation is solved numerically by the discrete ordinate analysis technique. It is assumed that the transmitter and receiver are at the same height and that the effects of the ground can be neglected. Under these assumptions, waves that travel between the transmitter and the receiver propagate in a plane parallel to the ground, essentially rendering the problem two-dimensional. The forest can now be considered to be a slab of randomly distributed parallel cylinders. The phase function appearing in the RTE is obtained from the differential scattering cross section of a dielectric cylinder for both low and high frequencies. A practical application of this configuration is low height WSN peer-to-peer communications. Numerical results are obtained for vertical polarization at frequencies of 2.4, 3.5 and 5.8 GHz. The solutions are used to compute both the coherent and the incoherent attenuation constants in a trunk-dominated forest and the propagation loss between a WSN transmitter and receiver. It is noted that at low frequencies, the incoherent intensity is relatively small; only the coherent intensity needs to be considered. As the frequency increases, however, multiple scattering effects must be taken into account making the incoherent intensity as important as the coherent intensity. As expected, this approach shows that as the distance increases, the coherent intensity decreases, while an increase is observed in the incoherent intensity

To validate the RT results, a MC simulation is performed. The MC simulation consists of an array of infinite parallel dielectric cylinders distributed in a slab region. The slab has a finite width that is extended until the solution converges. Many slab realizations are computed and averaged to obtain estimates of the coherent and incoherent intensity. The results show that as we enter deeper into the forest, the total intensities obtained by the RT theory and the MC theory agree, however, for small penetration depths into the forest, the MC simulation underestimates the RT results by few dBs. The reason for this small discrepancy is still under investigation.

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