2.45 GHz Path-Loss Prediction for Wireless Sensor Applications in an Orchard by using UTD method

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Abstracts

This paper presents the path loss prediction for wireless sensor applications in an orchard by using the uniform geometrical theory of diffraction (UTD) method. The tree in the orchard is modeled by using the proposed 3D UTD solution for an impedance cylinder. The wireless sensor network (WSN) is applied to improve the conventional harvesting process in a Thai commercial orchard. A wireless sensor node is attached on a raw fruit for example a durian on the durian tree. Therefore, the durian turns to be a part of the antenna. It is necessary to perform the source modeling. The GB expansion is used for the source modeling and this expansion can be applied to the UTD method effectively. The good comparison between the proposed 3D UTD solution including the effect of the wet good ground and the measurement result are obtained in the paper.

Keywords : Path loss prediction, Propagation, UTD and Wireless sensor network

1. Introduction

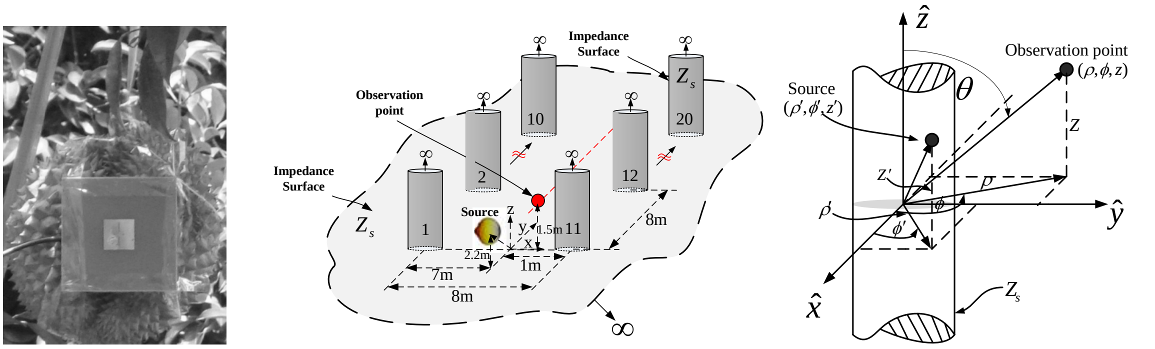
The applications of wireless communication such as WSN require the information of wave propagation channel characteristic of each scenario for the network planning. The empirical models are efficiently used in large area communication for example the case of very high level of the transmitting antenna above from the ground. However, in the small area communication, the transmitting antenna is located above the ground in a few meters. The geometry of the environment such as building, ground, trees and etc., becomes strong effect on the receiving power in the communication area. Therefore, the propagation prediction requires an accurate method to predict the signal strength of the specific scenario. The efficient method that can be used for the propagation prediction is UTD while the other numerical methods become low efficient or cannot treat the propagation problems due to very large computational domain. The UTD method is useful in many path loss predictions such as cellular phone systems in the city [1], the conducting cylinder model for human body presence in indoor propagation channel [2] and the path loss prediction in a durian orchard [3] by simply assuming the durian trees to be a PEC cylinder. However, the PEC surface model is efficiently used for only the case of strong reflection and diffraction from the obstacle such as building, wall and ground usually made from concrete or metal. Therefore, for the tree models, grass ground, soil and ocean surface, the radio wave propagation prediction requires an impedance surface for the UTD solution. The general 2D UTD curved surface solution for a PEC surface was presented in [4]. The 2D UTD solution for the impedance curved surface was presented in [5]. The 3D UTD PEC solution for the smooth convex PEC scattering problems was presented in [6]. However, the 3D UTD solution is not currently available in the case of the impedance surface.

This paper presents path loss prediction in the orchard scenario by using the UTD method. The trees in the orchard are modeled by using a cylindrical impedance surface structure. The grass ground of the orchard will be modeled by using the dielectric ground with the dielectric constants (ε_r, μ_r) and the conductivity (σ). Moreover, the modified UTD solution in 3D curved surface case for compute the electromagnetic (EM) field scattering from the impedance curved surface will be presented. The proposed modified UTD solution is obtained from the solution of 3D UTD PEC scattering problems by modifying the PEC Pekeris' caret integral function to be the impedance Pekeris' caret integral. Finally the 3D UTD solution for the curved impedance surface case is obtained. Here, we apply the numerical integration to compute the Pekeris' caret integral function in case of impedance surface without the tabulate scheme.

2. Problem of Interest

Thailand has exported the fresh Thai fruits such as Durian, Pomelo, Longan, Mangosteen, Rambutan, etc for many decades. Recently, the WSN is used to improve the conventional harvesting process in a Thai commercial orchard. In particular, the WSN can correctly detect an appropriate timing for harvesting of fruits. A sensor node is attached on a raw fruit for example a durian on the durian tree as shown in Fig. 1(a). The sensor devices are used to monitor and detect the maturity of the fruits and sending a radio wave signal to the server via the communication node. Durian is the most valued exported fruit in Thailand. Therefore, in this research the Durian orchard is chosen. The communication nodes are installed in the orchard at a Durian trees in a few height above ground. The efficiency of the WSN system depends strongly on the radio wave propagation in the actual environment or the communication channel. This study will be very useful for designing the WSN in any Thai commercial orchard. It is noted that all the fields in this work are assumed with $e^{j\omega t}$ time dependence and suppressed throughout this work.

3. Orchard and Source Model



(a) (b) (c)

Fig. 1. (a) Actual V-polarized patch antenna on Durian fruit (b) Model of the orchard scenario by using the canonical structure (c) Tree model.

Fig. 1 (b) shows a proposed model of the durian orchard under the assumption of the cylindrical structures (trees, no branch and leaf) with the impedance surface of the cylinder Z_s. Modeling of the ground by using the dielectric ground to representing the actual ground. It is noted that the randomness of the tree is ignored in this work to simplify the problem. The UTD technique is applied to analyze the signal power radiated from the transmitting antenna to the receiving antenna.

4. Theoretical and Measurement

As shown in Fig. 1(a), the patch antenna is attached on a raw durian hanging from the tree. Therefore, the durian turns to be a part of the antenna and it can dramatically change the radiation pattern of the antenna. It is necessary to perform the source modeling. The work in [7] proposes to use the GB expansion for the source modeling and this expansion can be applied to the UTD method effectively.

Fig. 1(c) shows the geometry of a cylinder with an impedance surface. The total field $u_z(P)$ (vertical polarization) at the observation point consists of the incident field $u^i(P)$, the reflected field $u^r(P)$ and the diffracted field $u^d(P)$ from the cylinder. The field at the observations point P in the lit region can be written as

$$u_z(P) = u^i(P) + u^i(P) \cdot R_{s,h} \cdot A_{lit} \cdot e^{-jks^r} \quad (1)$$

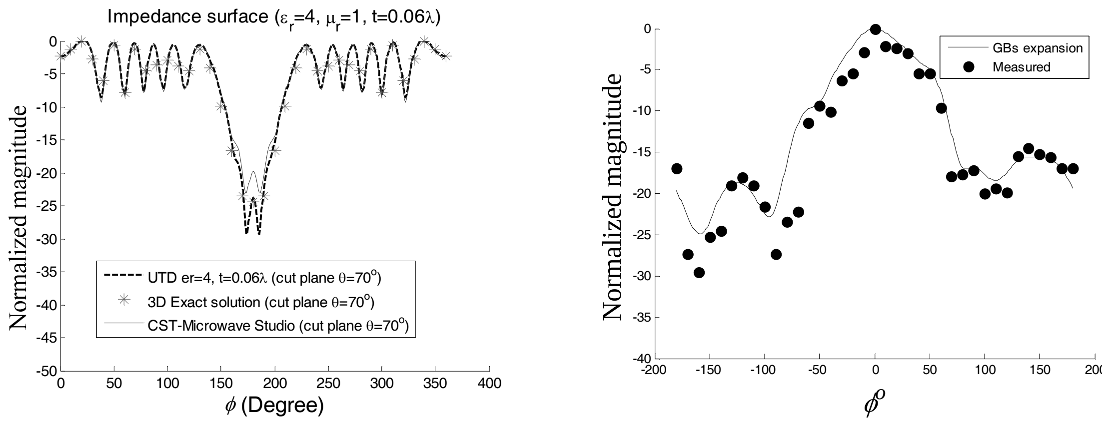
where the $R_{s,h}$ denotes the reflection coefficients of the curve surface. The reflection coefficients $R_{s,h}$ consist of the Fresnel's function $F(kL\tilde{a})$ and the Pekeris' caret function $P_{s,h}(\xi^L)$. The diffracted field can be written as

$$u^d(P) = u^i(Q_1) \cdot T_{s,h} \cdot A_{shadow} \cdot e^{-jks^d} \quad (2)$$

For the impedance cylinder cases the Fock-Type Integral Function [8] can be defined as

$$P_{s,h}(X, q_{s,h}) = \frac{e^{-j\left(\frac{\pi}{4}\right)}}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{V'(t) - q_{s,h}V(t)}{w_2'(t) - q_{s,h}w_2'(t)} e^{-jXt}\, dt \quad (3)$$

The $q_{s,h}$ denotes the surface impedance parameter and depends on the incident wave mode [9]. In this paper, one uses a numerical integration method based on the recursive adaptive Simpson quadrature to compute the Pekeris or Fock-Type integration function, the present method is very efficient and requires less computational time. To verify the accuracy of the Fock-Type Integral Function, the comparison results between the proposed 3D UTD, the 3D exact Eigen solution and the simulation results from the CST Microwave studio program is shown in Fig. 2(a).



(a) $\theta = 70^\circ$ (3D-case) (b) source pattern

Fig. 2. Comparison of the total field (TE^z) between the UTD, CST program and exact solution: $a = 2\lambda$, $\rho' = 5\lambda$, $t = 0.06\lambda$, $\varepsilon_r = 4$, $\mu_r = 1$ and $\rho = 100\lambda$

Fig. 2 (a) shows the total field results of the soft-case wave incident in 3D cases. The comparison result between the 3D UTD and the exact solution are agreed very well and shows some discrepancies when comparing to the CST program in the deep shadow zone. Fig. 2 (b) shows the experiment and the synthesis of the normalized field pattern around the vertical polarized patch antenna on the Durian fruit by using the GB expansion. The sampling field obtained by measuring every 10° around the patch antenna attached on a Durian fruit.

The path loss measurement was performed in an actual Durian orchard at the Horticultural Research Center (HRC), Khlung, Chanthaburi, Thailand in 2010. The spacing between trees is approximately 8 meters of every rows and columns in the orchard. Typically, the height of durian trees is higher than 10 meters and its diameter is around 0.3 meters. A handheld spectrum analyzer is used to record the receiving signal strength. The vertical polarization antennas are chosen to be the source polarization. The source antenna is attached on a Durian fruit with 2.2 meters above the ground and receiving antennas are at 1.5 meters away from the ground. Overall the experimental propagation distance is 80 meters. The sampling distance of receiving signal strength was performed in every 4 meters along the chosen propagation path. The experimental and numerical results will be shown in the next section.

6. Experimental and Numerical Results

The path loss prediction by using the UTD method, proposed in this paper includes the reflection from the actual ground. The actual ground in the simulation is modeled by using the dielectric ground models [10].

Fig. 3 shows the comparisons of the path loss between the numerical and experimental results in case of wet good ground. The impedance cylinder surface for the trees has a loss tangent (tan δ) of 0.1, ϵ_r= 2 and 8. Also, the dielectric coated thickness t=0.1λ and 0.06λ are used. The numerical results are in the color solid lines. The red, blue, green and magenta lines are for the dielectric constant of the cylinder surface equal to 2 and 8 with the coated thickness equal to 0.06λ and 0.1λ, respectively. The UTD path loss predictions show good agreement with the measurement result within the range of 4 to 30 meters. However, for the range of 30 to 60 meters, the discrepancy between the UTD path loss predictions and the measurement one can be observed in very low signal level (under -20 dB) which can be ignored in some applications.

7. Conclusions

This paper demonstrates that the path loss prediction in a Durian orchard can be accurately obtained by using the proposed modified 3D UTD solution for impedance cylinders. The good comparison between the proposed 3D UTD solution including the effect of the wet good ground and the measurement result are shown in the paper. This solution will be very useful for engineering application in WSN planning. Also the 3D UTD model obtained in this work can efficiently applied to any Thai orchard.

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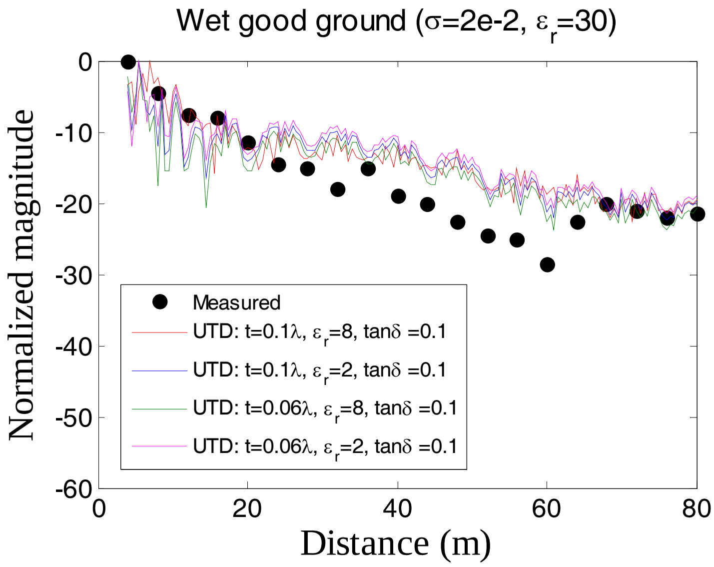

Fig. 3. Comparisons path loss between the numerical and experimental results: wet good ground (σ = 2e-2, ε_r = 30) and impedance cylinder surface (tanδ=0.1, ε_r = 2 and 8, t=0.1λ and 0.06λ)

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