Proceedings of ISAP'04, Sendai, JAPAN

A DISCRETE RET MODEL FOR MILLIMETER-WAVE PROPAGATION IN ISOLATED TREE FORMATIONS

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1. Introduction

Mobile and fixed radio communications have experienced increasing growth over the past few years. The global explosion of radio users has demanded more services and applications, which indeed has resulted in the need of better planning and coverage tools, as well as more available bandwidth for higher data transmission rates. Such a huge increase has led to the appropriate development of radio planning techniques, which allow network operators to provide good grade of service to users at an acceptable cost [1]. Indeed, radio planning plays a major role in the deployment of mobile and fixed radio communication networks. Radio propagation is influenced by obstacles present in the radio path such as buildings, terrain profile and vegetation etc. Vegetation in general is likely to be present in the radio path representing a significant obstruction, especially in urban and sub urban environments [2]. To this extent, specification of the scattering of trees is important to achieve more accurate predictions when using planning tools. For instance, the proposed method can provide good estimates of the relative amplitudes and directions of propagation of radio signals inside an inhomogeneous volume of vegetation.

An extensive measurement campaign was conducted in an anechoic chamber to obtain the re-radiation functions of 12 *Ficus Benjamina* trees at 2 different frequencies e.g. 20 GHz and 62.4 GHz. Subsequently, the measured functions were used as inputs to the Discrete Radiative Energy Transfer (dRET) model presented in [3], in two different ways: (i) the complete re-radiation functions as measured were used; (ii) the re-radiation function for each tree was approximated to a Gaussian main lobe with isotropic backscattering and the extracted parameters of this effective phase function were subsequently used in the model. Using these models, estimates for the received signal at selected positions inside a tree formation (simulating a forest) were produced. The underlying theory, i.e. the RET, has been extensively shown in the literature to provide fairly accurate estimates of the signal behaviour in homogeneous infinite forests [2]. Applicability of the RET is compromised by the presence of inhomogeneity in the vegetation volume. Furthermore, the difficulty in accurately estimating the phase function which provides 2 of the 4 parameters of the RET leads to consideration of an alternative approach utilising the dRET. Presented here is a scatter model (Section 2) in which the re-radiation function (as distinct from the phase function) for each single tree is measured and subsequently used in a dRET algorithm to predict the received signal inside the forest. As a result, the performance of the model is assessed in terms of the RMS error values between measured values on the one hand and predictions yielded by either method on the other (Section 4).

2. The Scattering Propagation Model

The RET models the vegetation as a homogeneous medium randomly filled with similar scatterers ds, which are characterised by a set of parameters: k_a, known as the absorption coefficient ($Np \cdot m^{-1}$); k_s which is the scattering cross section per unit of volume (m^2/m^3) and the scatter directional profile, also known as Phase Function [4], $p(s,s')$, with s and s' representing the directions of the energy entering and emanating from each scatterer, respectively. The phase function is normally modelled as a Gaussian function [5] with an isotropic background (here referred to as the effective phase function)

ISBN: 4-88552-207-2 C3055©IEICE

given by equation (1).

$$p(\gamma)=\alpha\left(\frac{2}{\beta}\right)^{2}e^{-\left(\frac{\gamma}{\beta}\right)^{2}}+(1-\alpha), \qquad (1)$$

where α is the ratio between the forward lobe power and the total power of the phase function, β represents the half power beamwidth of the forward lobe and γ is the angle subtended by s and s'. The RET model uses specific intensity rather than power and these two quantities are related by equation (2).

$$I(s)=\frac{dP}{dadw}, \qquad (2)$$

where dP is the power emerging from area da through a solid angle dw [4].
The RET equation is normally expressed in its differential form

$$\frac{dI}{ds}=-(k_a+k_s)I+k_s\int_{4\pi}p(s,s')Idw \qquad (3)$$

The LHS describes the spatial variability (derivative) of intensity over one cell. The first term on the RHS accounts for the reduction in intensity due to the absorption and scattering. The second term of the RHS represents the increase of intensity resulting from the scattering contributions of surrounding scatterers. [3][6].
To overcome the limitations of the RET, an improved version of the Discrete RET originally proposed by Didascalou *et. al.* in [3] is presented in this paper. This version of the dRET has 4 major improvements when related to the algorithm given in [3]. These are summarised as follows: (i) the dRET version yields results for angles other than those which are integer multiples of 45º; (ii) it accounts for the effect of the radiation pattern of the receiving antenna; (iii) the differential equation (3) is more readily solved, which means that piecewise linear approximation is no longer needed, so that the algorithm can cover larger cell sizes; and iv) the cell parameters can be defined individually thus allowing one to define non homogeneous scenarios.
Each of the cell in the structure is characterised by its k_e, k_s and by the re-radiation function which represents the directional spectrum of the incoming radiation occurring within each cell. The algorithm uses the measured re-radiation function for each tree, instead of the phase function as explained above. A more detailed description of the measurements will be given in section 3.

3. Measurement Setup

Re-radiation function measurements were conducted individually for all of the 12 trees available, as this constitutes one essential input parameter of the model. The measurement setup used is depicted in Fig. 1 and Fig. 2. The 1.15m distance between transmitter and the tree was chosen to allow illumination of at least 2/3 of the canopy when using the 20dBi standard horn antenna.

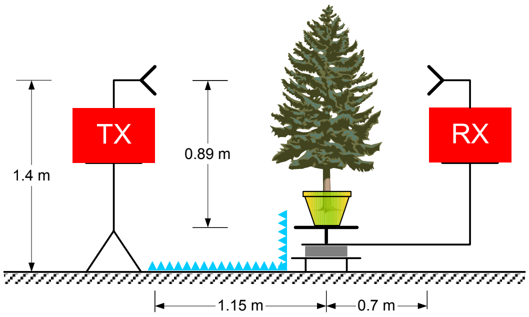

Fig. 1 – Re-radiation measurement setup (side view)

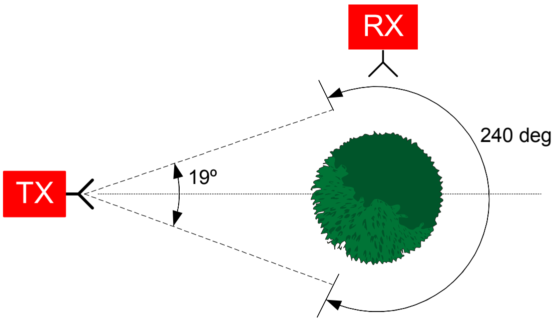

Fig. 2 – Re-radiation measurement setup(top view)

A non-homogeneous tree formation was placed inside the anechoic chamber to simulate a real outdoor forest. A matrix of four by three trees was used. The trees were equally spaced along each column, as shown in Fig. 3. The non homogeneity in the volume arises from the existing air gaps between canopies. In Fig. 4 we can see the model of the test forest, with the receiver positions used to measure the signal inside the vegetation volume.

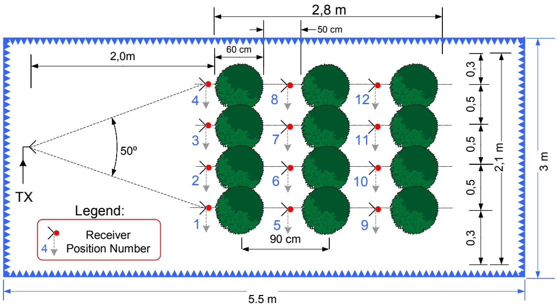

Fig. 3 – Non homogeneous vegetation volume (Tree Formation)

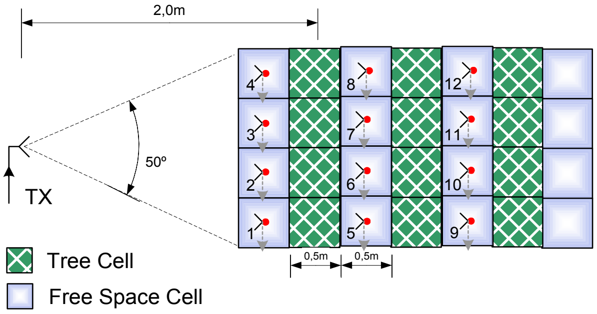

Fig. 4 – Model of the vegetation volume

4. Measurement Results and Validation

To model the re-radiation function as a Gaussian lobe superimposed to an isotropic back scattering, α and β were optimised so that equation (1) could fit the measured results. This was accomplished by using the *Matlab R13 Curve Fitting Tool*. The measured re-radiation function for ficus #4 and its corresponding fitted curve are plotted in Fig. 5. The fitted α and β values for all the 12 measured trees are indicated in Table 1.

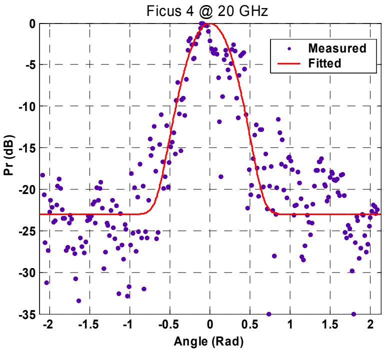

Fig. 5 – Measured re-radiation function

	20GHz			62.4GHz		
Tree #	Alfa	Beta (rad)	Beta (deg)	Alfa	Beta (rad)	Beta (deg)
1	0.64	0.29	16.44	0.82	0.19	10.65
2	0.82	0.26	14.79	0.84	0.17	9.92
3	0.87	0.30	17.28	0.94	0.22	12.39
4	0.79	0.28	15.88	0.77	0.20	11.71
5	0.79	0.32	18.39	0.80	0.27	15.35
6	0.84	0.31	17.80	0.90	0.14	8.14
7	0.85	0.27	15.28	0.68	0.20	11.23
8	0.92	0.30	17.34	0.58	0.14	8.19
9	0.53	0.27	15.46	0.04	0.06	3.38
10	0.68	0.32	18.40	0.84	0.21	12.23
11	0.60	0.32	18.54	0.53	0.16	9.44
12	0.80	0.25	14.15	0.64	0.19	11.14

Table 1 – Fitted α and β values

Although an appropriate method to extract k_e and k_s from the tree formation is under development, in this paper both parameters had to be adjusted so that the predicted received signal could fit the measurements. The extinction coefficient k_e was adjusted so that the predicted forward scattering lobe fitted the measurements. Similar approach was employed to adjust k_s, but this time with the back scattering signal levels. The parameters used in the model are given in Table 2.

Cell Parameters

	20GHz		62.4GHz	
Cell	ke	ks	ke	ks
1	4	0.4	4	0.8
2	4	0.8	4	0.8
3	4	2	4	3.2
4	4	2	4	2
5	4	0.8	4	2
6	4	0.8	6	3
7	4	0.8	5	2.5
8	4	0.8	4	2
9	4	3.6	5	2.5
10	4	3.6	6	3
11	4	3.2	5	2.5
12	4	2	5	2.5

Table 2 – Cell Parameters

RMS Error (dB)

	20 GHz		62.4 GHz	
Position	Re-Rad	Fitted	Re-Rad	Fitted
1	8.3	8.0	8.0	9.0
2	7.0	8.1	8.6	8.0
3	8.1	9.7	11.4	10.8
4	7.2	8.5	9.4	8.2
5	7.5	7.6	8.1	7.8
6	6.6	7.2	9.0	7.1
7	6.7	7.7	10.7	7.1
8	6.0	6.5	9.8	6.6
9	11.0	12.0	9.3	9.7
10	14.0	15.8	11.2	9.7
11	14.7	14.8	12.3	8.9
12	12.0	11.2	9.9	8.0
Mean	**9.1**	**9.8**	**9.8**	**8.4**

Table 3 – Prediction/Measurement RMS Error

In Fig. 6 and Fig. 7 is shown the directional spectrum of the received signal related to the maximum received power at the interface for positions 4 and 8 at 20 GHz. One notes the overall good agreement between the measurements and the model using both functions, i.e. the complete re-radiation function and the effective phase function, which lead to RMS error values of 7.2 and 8.5 dB, respectively. Similar performance is obtained for results at the higher 62.4 GHz frequency (Fig. 8 and Fig. 9), where the model using fitted α and β provides a better fit to measurements when compared with the case where the complete re-radiation function was used.

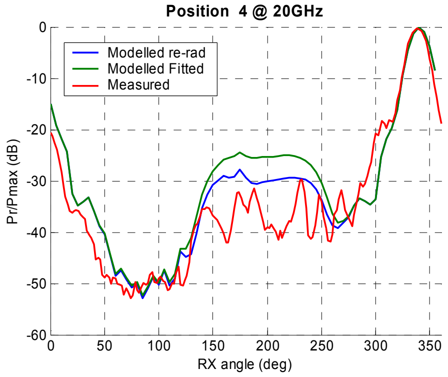

Fig. 6 – RX signal in position 4 at 20 GHz

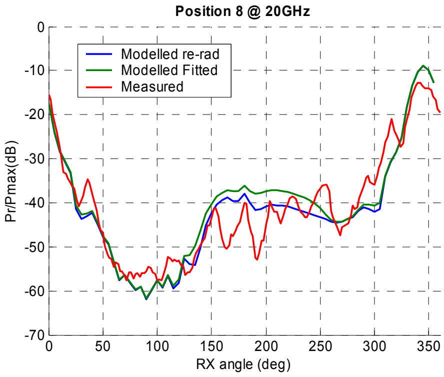

Fig. 7 – RX signal in position 8 at 20 GHz

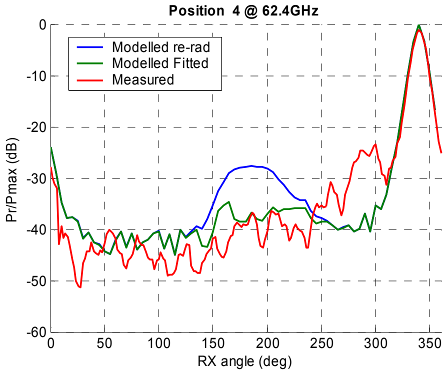

Fig. 8 – RX signal in position 4 at 62.4 GHz

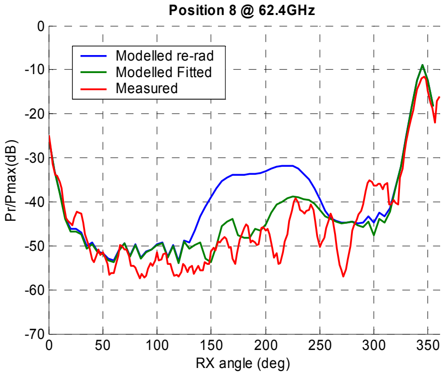

Fig. 9 – RX signal in position 8 at 62.4 GHz

Finally, an RSM error assessment was performed between predictions provided by the model and measurements performed at each receiver location, as presented in Table 3. One can conclude that the generalisation of the re-radiation function by an effective phase function with fitted α and β parameters, does not significantly affect the overall RMS error of the received signal prediction. The replacing of the re-radiation function by such an effective phase function makes the model more suitable for real applications. This is because the re-radiation function is somewhat difficult to obtain in the field as it requires to be evaluated from measurements. Secondly the effective phase function specified completely by two parameters α and β is far more suited to a planning model than the more complex re-radiation function.

5. Conclusions

This paper presents a propagation model for non-homogeneous vegetation media that uses the re-radiation function of individual trees as an input parameter instead of the real phase function. Two solutions for the implementation of the algorithm with the re-radiation function were presented, one based on the completely specified re-radiation function and other using an effective phase function. Measurements and predictions were compared in terms of the resulting RMS error. The results show that the effective phase function specified completely by two parameters, acts as a good substitute for the re-radiation function without compromising the overall accuracy of the model.

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