Modelling Radiowave Propagation through Vegetation media: a comparison between RET and dRET models

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Abstract

This paper compares the performance of the Radiative Energy Transfer (RET) model and an enhanced discrete version of the RET, the so called dRET, when predicting the scattered signals emanating from inhomogeneous vegetation volumes. The analysis of each model performance was carried out by comparing the model predictions with the actual scattered signal measured in a selected inhomogeneous tree formation at 11.2 and 62.4 GHz. It is shown that both models perform satisfactorily provided that the vegetation surrounding the receiver remains relatively homogenous. Nevertheless, when the vegetation geometry is more irregular, and therefore consists of differing types of vegetation, only the dRET model was observed to provide reasonable signal level estimates over the entire angular range.

1 Introduction

The overall growth in cellular, fixed and satellite communications markets has exceeded many expectations and there is a widespread anticipation that the demand for wireless telecommunication systems will continue to expand in the foreseeable future [1]. Such systems rely in their planning, design and implementation on the availability of radiowave propagation models. In the particular case of land mobile radio systems and wireless fixed access systems, obstacles in the form of vegetation volumes, which include tree plantations, are likely to influence radio propagation, giving rise to absorption and scattering of radio signals. Here the paper compares two suitable techniques to characterise and model the effects of inhomogeneous vegetation volumes on the propagation modes of radiowaves. The paper analyses a model based on the Radiative Energy Transfer theory (RET) and an enhanced version of this model discretised to accommodate forests consisting of multiple vegetation species with their own distinct propagation characteristics. The discrete model computational structure comprises several element cells, whose propagation parameters can be assigned independently. The discrete RET (dRET) [5], is shown to be capable of gathering the interactive responses between the element cells comprising the computational vegetation structure, leading to the determination of the received signal inside or around the illuminated vegetation computational volume.

2 The RET propagation model

The RET model, described in [2-4], [6], relies on the Energy Transfer equation which describes the variation of the signal specific intensity throughout a statistically homogeneous medium, randomly filled with small scatterers, which are characterised by the following set of input parameters:

- The **Extinction Coefficient** or k_e. This parameter specifies the amount of energy which is lost due to absorption and scattering mechanisms;
- The **Scattering Coefficient**, k_s, which specifies the scattered energy;
- The scatter directional profile $p(\hat{s},\hat{s}')$, also known as **Phase Function** [6], with $\hat{s}$ and $\hat{s}'$ representing the directions of the energy entering and emanating from each scatterer volume respectively.

The phase function may be modelled according to Eq. 1 [4], [6], which represents a Gaussian function superimposed to an isotropic background level:

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

where α is the ratio of the forward lobe scattered power to the total power of the phase function, β represents the half power beamwidth of the forward lobe and γ is the angle subtended by $\hat{s}$ and $\hat{s}'$.

The RET equation, expressed in its differential form is presented in (2).

$$\frac{dI}{ds} = -k_e I + k_s \int_{4\pi} p(\hat{s},\hat{s}') I d\omega, \qquad (2)$$

where the left hand side (LHS) describes the spatial variability (i.e. derivative) of intensity over one scatterer, while the first term on the right hand side (RHS) accounts for the reduction in the signal intensity due to the absorption and scattering. The second term on the RHS represents the increase of intensity resulting from the scattering contributions of surrounding scatterers [4]. In [4], the overall signal intensity I is divided into two different intensities: the reduced intensity, I_{ri} and the diffuse intensity I_d. I_{ri} is the attenuated incident intensity whereas I_d accounts for the contributions from incoherent scattered components inside the vegetation medium.

3 The discrete RET propagation model

The discrete RET (dRET) was originally proposed by [5], as a method to overcome the RET limitations in terms of its applicability to isolated vegetation volumes. In the dRET modelling, the vegetation volume is divided in nonoverlapping square cells and an iterative algorithm is used to gather all the interactions between these primary cells, allowing for the computation of the intensity across the entire tree formation. The approach of splitting the vegetation into discrete elementary volumes, allows the assignment of different scattering parameters to every cell, consequently enabling an inhomogeneous vegetation volume to be more accurately represented at the expense of overall model increased complexity.
The extended dRET approach presented in [7] and used here, comprises 4 major improvements compared to the algorithm given in [5]. These are summarised as follows: (i) the improved dRET version yields results for angles other than those which are integer multiples of $\pm 45^{\circ}$; (ii) it accounts for the effect of the receiving antenna radiation pattern; (iii) the dRET differential equation is more readily solved, which means that piecewise linear approximation is no longer needed, and therefore the algorithm can cover larger cell sizes; and (iv) the cell parameters can be defined individually, thus allowing one to define inhomogeneous scenarios.

4 Experimental procedure

An experimental program was designed to assess the performance of both the RET and the extended dRET models in a real outdoor environment. The simulation of the dRET model was carried out using propagation parameters extracted from the various types of vegetation forming the test vegetation scenario. The RET model simulation, was performed using average forest parameters, consequently reflecting its suitability to the modelling of homogeneous forests. The predictions from each model were subsequently compared with measurement results performed in a selected test forest site.

4.1 Description of the measurement site

The measurement site (Wyevale) is located in the North-East of Cardiff in South Wales, UK. The test forest consist of an isolated group of trees formed by 6 different species. To completely characterise the test forest, precise locations of each tree and the mean canopy diameters were measured using a standard theodolite. Based on this data, a 2D representation from the test forest was produced as presented in Fig. 1. The transmitter location (TX) and the direction where it was pointed during the measurements are both presented. The red dots labelled Mp_x, represent the received signal measurement locations. The tree species forming the test forest as well as the dimensions of the various trees are presented in Table I.

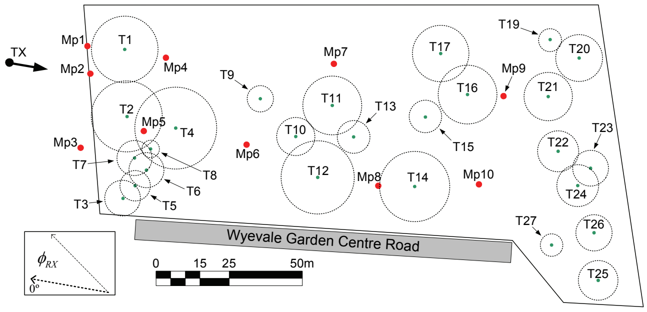

Fig. 1 – Scaled plan of the Wyevale Garden Center test site.

Tree label	Common Name	Canopy diameter (m)	Tree height (m)
T_1	Oak	11.4	10.9
T_2	Oleaster	12.1	16.5
T_3	Ornamental Cherry	6.1	3.5
T_4	Oleaster	14.0	17.7
T_5	Ornamental Cherry	5.2	3.5
T_6	Ornamental Cherry	6.0	3.5
T_7	Ornamental Cherry	6.0	3.5
T_8	Ornamental Cherry	3.0	3.0
T_9	Silver Birch	4.5	8.4
T_{10}	Silver Birch	6.5	6.4
T_{11}	Silver Birch	10.0	10.0
T_{12}	Oleaster	12.5	15.6
T_{13}	Silver Birch	5.6	5.5
T_{14}	Oleaster	12.0	15.0
T_{15}	Oak	6.5	2.5
T_{16}	Oak	10.1	7.2
T_{17}	Gean	9.6	7.3
T_{19}	Pecan	3.9	8.9
T_{20}	Oak	8.0	9.6
T_{21}	Pecan	8.3	5.2
T_{22}	Pecan	7.0	7.0
T_{23}	Oak	6.1	7.8
T_{24}	Oak	7.2	6.8
T_{25}	Pecan	6.8	13.0
T_{26}	Pecan	6.2	14.3
T_{27}	Pecan	3.9	4.3

Table 1 - Tree species of the Wyevale Garden Center site.

4.2 Model parameter extraction

The dRET input parameters were extracted from specific measurement data. This data was obtained from received signal measurements at specific locations around the tree, as explained in Fig. 2. The distances d_1, d_2, and d_3 were chosen so that 100% of the canopy diameter width could be illuminated within the Half Power Beamwidth (HPBW) of the TX antenna. At the same time, the RX antenna was placed as close as possible to the tree canopy, in order to minimise the received signal contamination from the scattering due to the remaining vegetation volumes forming the forest. At each of the 3 measurement locations presented in Fig. 2, *i.e.* M_n, the receiver antenna was rotated around its vertical axes in a ±45° angular range in 1° steps.

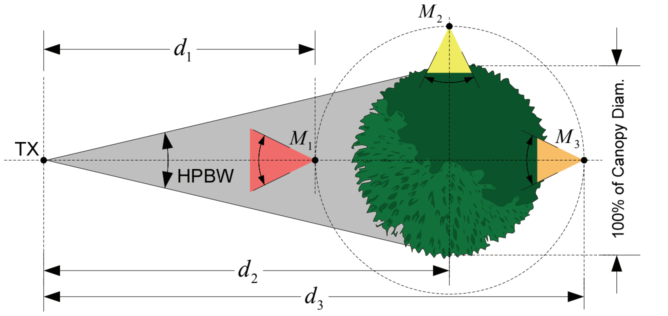

Fig. 2 - Parameter extraction measurement setup.

The extraction of k_e was based on the measurement of the insertion loss caused by the tree, hence relying on measurements M_1 and M_3. The ratio between the maximum received signal power levels at these locations was used to calculate k_e using Eq. 3.

$$\frac{P_{3\max}}{P_{1\max}} = e^{-k_e(d_3-d_1)}\left(\frac{d_1}{d_3}\right)^2, \quad (3)$$

where $P_{1\max}$ and $P_{3\max}$ are the maximum received power levels at positions M_1 and M_3, respectively, and d_n is the distance between the TX and the n^{th} measurement location in meters.

To extract the phase function parameters α and β, a modified version of the re-radiation indoor measurement procedure [7] was employed. This modified measurement method overcomes some inaccuracies reported in [8] and is easier to carry out. The optimisation of parameter k_s, is performed through the evaluation of the side scattered signal evaluated at measurement location M_2 [9].

The parameter extraction, outlined above, was performed for 5 of the 6 species present in the test forest. The trees chosen to carry out the parameter extraction were: T_1, T_3, T_{11}, T_{12} and T_{17}. These were chosen due to their locations at the border of the test site, thus avoiding the possible contamination of measured results caused by interference from other species. The extracted parameters are presented in Table 2. Some parameters were somehow difficult to extract from the measured data due to the high attenuation of the coherent signal component, especially for the larger trees. In such cases, average parameter values were assigned to the corresponding trees.

To limit the stair case error due to the discretisation of the forest while maintaining a reasonable computational time, 2.5 m vegetation cells were used, as depicted in Fig. 3. For the phase function parameters to remain valid, these have to be adapted to the new cell sizes by performing an appropriate scaling. The scaling method used here is explained in [10], which suggests a linear behaviour of the estimated α and β values with the variation of the vegetation volume.

Tree Label	11.2 GHz				62.4 GHz			
	k_e	k_s	α	β(°)	k_e	k_s	α	β(°)
T_1	0.39	0.19	0.05	3.0	0.3	0.13	0.08	2.8
T_3	0.93	0.54	0.37	9.7	1.26	1.02	0.07	15.5
T_{11}	0.84	*0.37*	0.01	13.4	0.81	*0.41*	*0.09*	12.1
T_{12}	0.61	*0.37*	*0.14*	10.2	0.5	0.1	0.15	14.8
T_{17}	0.61	*0.37*	*0.14*	13.4	0.49	0.37	0.04	11.1
Mean	**0.68**	**0.37**	**0.14**	**9.94**	**0.67**	**0.41**	**0.09**	**11.3**

Table 2- Extracted dRET input parameters

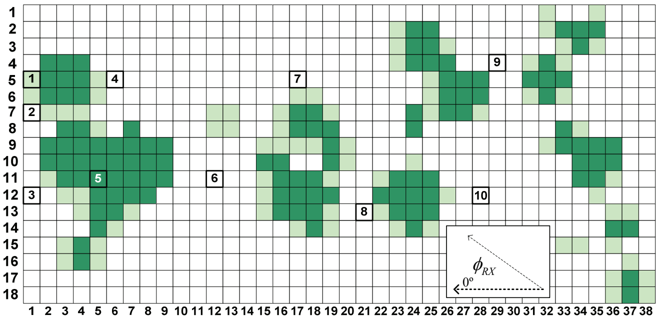

Fig. 3 - 2D cell structure characterising the inhomogeneous test forest.

4.3 RET forest modelling

Recognising that the RET exclusively models homogeneous vegetation volumes, the comparative RET simulations were performed using the mean forest parameters shown in Table 3. The various incidence angles and vegetation depths used in the RET calculations, corresponding to the various measurement locations inside the test forest, are presented in Table 4.

Parameters	Mean RET parameters 11.2 GHz	62.4 GHz
k_e	0.68	0.67
k_s	0.37	0.41
α	0.14	0.09
β(°)	9.9	11.3
Albedo	0.55	0.61
RX HP Beamwidth(°)	3.20	2.8

Table 3 - RET input parameter set.

Pos #	θp	z(m)
1	338°	0
2	359°	0
3	41°	0
4	349°	15
5	18°	12
6	10°	30
7	351°	42.5
8	9°	52.5
9	354°	72.5
10	5°	70

Table 4 - Test forest RET geometry parameters.

4.3 Directional spectrum measurement

The excess attenuation caused by the vegetation, was evaluated by placing the RX antenna at the locations shown in Fig. 1. At each location, the directional profile from the received signal was evaluated. Such evaluation was performed positioning the receiver antenna at 5.5 m high, which represents approximately one half of the mean canopy height of the trees present in the test forest. At each location, the RX antenna was rotated clockwise through $\pm 360^{\circ}$ around its vertical axes (ϕ_{RX}) in 1° incremental steps. The TX antenna was placed outside the forest in the position shown in Fig. 1 at a 13 m distance from the air to vegetation interface. To achieve an almost uniform illumination of the interface, relatively broad $\pm 50^{\circ}$ (10 dBi) half power beamwidth antennas were used at both test frequencies. At the receiver side, high gain directional antennas were used. At 11.2 GHz the RX antenna was a dish with 33 dBi and $\pm 3.2^{\circ}$ of HPBW, while at 62.4 GHz a lens horn antenna with 36 dBi and $\pm 2.8^{\circ}$ of HPBW was used.

5 Measurement and simulation results

In order to evaluate the performances of both the RET and the dRET models, a set of simulations were performed utilising the parameter sets shown in tables 2 to 4. In principle, such parameters should represent the propagation characteristics of the test forest. Subsequently, the predicted received signal directional profiles obtained from both models, were compared with actual measurement results, obtained at 11.2, and 62.4 GHz, consequently leading to an assessment of the models behaviour. This comparison, between measured and predicted results, was carried out using the RMS error criterion.
The RET signal predictions for the positions located at the air to vegetation interface were obtained considering a vegetation depth of zero meters. The results for measurement position #1 at 11.2 and position #3 at 62.4 GHz are shown in Fig. 4 and 5, respectively.

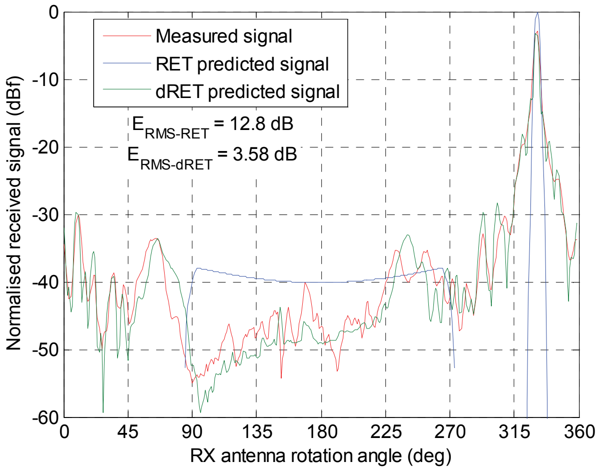

Fig. 4 - Comparison between RET and dRET predictions at 11,2 GHz for measurement location #1.

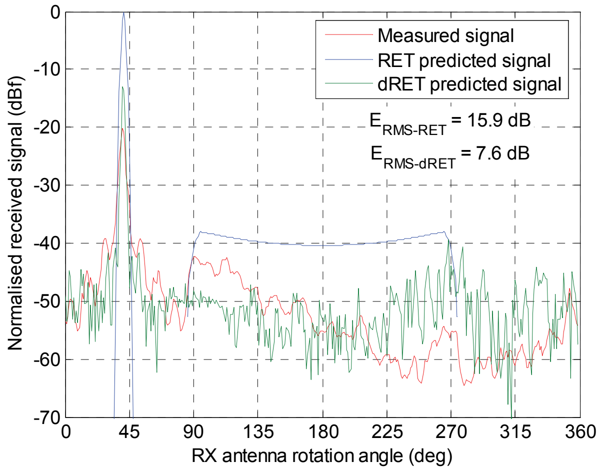

Fig. 5 - Comparison between RET and dRET predictions at 62.4 GHz for measurement location #3.

In these figures, the effect caused by the simplistic assumption of a Gaussian shaped receiver antenna, used in the RET model, is quite evident. At the air-vegetation interface, the RET model is unable to predict the correct received signal for the angular directions where the receiver antenna is pointing away from the test forest or the transmitter *e.g.*: $0^{\circ} \le \theta_{RX} \le 90^{\circ}$, $270^{\circ} \le \theta_{RX} \le 335^{\circ}$ and $335^{\circ} \le \theta_{RX} \le 360^{\circ}$ for position #1. Nevertheless, this effect is only evident at the air-vegetation interface, since the remainder of the test forest is considered semi-infinite by the RET.
Figure 6 shows the predictions and measured results obtained at location #4 using the 62.4 GHz signal frequency. As in other situations, the dRET performs significantly better than the RET. The RET models the forest as a homogeneous semi-infinite medium. Consequently, the predicted received signal profile tends to be symmetric around the maximum received signal direction, independently of the receiver antenna location.

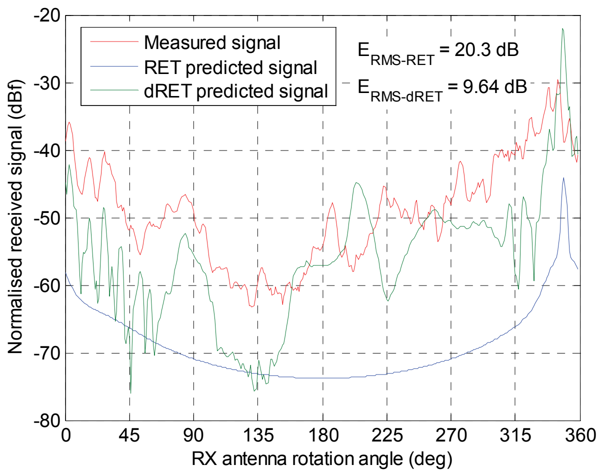

Fig. 6 - Comparison between RET and dRET predictions at 62.4 GHz for measurement location #4.

In contrast, the dRET uses a more accurate geometric representation of the forest, leading to the prediction of higher received signal levels when the antenna is pointing towards significant vegetation volumes.

The complete RMS error results, corresponding to the 10 locations used to measure the received signal profile, are shown in Table 5. The table also shows the comparison between the RET RMS errors and the error obtained from the dRET inhomogeneous forest simulation. The single negative comparison value corresponds to the only situation where the RET appeared to outperform the dRET.

Comparing the RMS errors resulting from the RET and the dRET calculations, one may conclude that, as anticipated, the dRET consistently produces better estimations for the received signal directional profile. The more accurate dRET estimations are expressed by the widespread positive RMS relative improvement values shown in Table 5. The few measurement positions where both model performances were similar, are located in the air-vegetation interface vicinity (position #1 to #3) and at position #5 which is completely surrounded by vegetation.

	dRET-RMS Error		RET-RMS Error		RET/dRET Compar.	
Pos #	11.2 GHz	62.4 GHz	11.2 GHz	62.4 GHz	11.2 GHz	62.4 GHz
1	3.6	8.7	12.8	12.0	9.2	3.3
2	4.5	9.2	13.0	13.2	8.5	4.0
3	9.3	7.6	16.1	15.9	6.8	8.3
4	9.6	7.9	20.3	17.4	10.7	9.5
5	7.4	16.3	13.7	16.0	6.3	-0.3
6	13.0	15.3	43.6	51.7	30.6	36.4
7	8.0	10.2	76.5	94.0	68.5	83.8
8	13.0	20.3	89.7	98.7	76.7	78.4
9	7.5	8.7	143.0	148.0	135.5	139.3
10	14.1	-	131.0	-	116.9	-
Mean	9.0	11.6	56.0	51.9	47.0	40.3

Table 5 – RMS errors between RET/dRET and measured received signal at 11.2 and 62.4 GHz.

Although there are multiple factors contributing to the different RET and dRET results, the more accurate geometric representation of the real vegetation medium, inherent to the dRET, is highly evident and beneficial. The dRET has the capability to predict specific signal variations associated with the inhomogeneous characteristics of the medium.

Although results shown in this paper only relate to two signal frequencies at 11.2 and 62.4 GHz, similar results were obtained at 20 and 40 GHz, confirming the superiority of dRET model predictions.

6 Conclusions

This paper performs a comparison between the RET and the dRET models, when predicting the received directional signal profile which emanating from an inhomogeneous forest. This comparison is performed employing 11.2 and 62.4 GHz signal frequencies. In order to validate and assess the predictions from both models, these predictions were compared with measured received signal results. Such results were derived from an extensive measurement campaign performed in a real test vegetation site, forming a part of a Garden Centre. The measurement campaign was carried out during the summer, hence all the trees were in a foliated state. This site provides the mixed forest geometry suited to test the dRET model. The relatively low RMS errors between the dRET and the measured received signal values, effectively show the good overall performance of the proposed model and the parameter extraction method. The dRET model, despite its increased complexity, is superior and acts as a good replacement for the RET in modelling radiowave propagation due to the presence of vegetation in the radio path.

Further, increased prediction accuracy may be achieved through the use of a more refined parameter extraction method to avoid localised blockages which tend to disturb the parameter measurement procedure. This improvement is currently being addressed in further research studies.

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