Extension of the dRET Model to include Scattering from Tree Trunks in Microcell Urban Mobile Scenarios

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Abstract— **This paper proposes a framework for extending the applicability of the discrete RET (dRET) model to accommodate radiowave scattering from tree trunks, particularly in microcell urban mobile scenarios, at micro- and millimetre wave frequencies. This framework aims to provide accurate modelling of the signal emanated inside and around isolated blocks of tree trunks, for instances, in raised canopy forests or in urban street canyons like scenarios. Model validation against measurement results inside an anechoic chamber for a double line of regularly spaced metallic and dielectric trunks at 18.8 GHz, as well as recommendations for a more encompassing model, are presented.**

Vegetation; Scattering; Trunk; Raised Canopy Forest; dRET; RCS

I. INTRODUCTION

The Radiative Energy Transfer (RET) based models have successfully been used to simulate radiowave propagation and scattering in vegetation environments [1]. However, the existing models, which can be used for ground-to-ground propagation, do not account for the propagation mechanisms in the trunk layer of raised canopy trees, particularly in urban street canyons like scenarios.

The work reported in this paper seeks to build on progress achieved so far in developing a generic model of 1-60 GHz radio propagation through vegetation [1], which formed the basis and the motivation of the recent ITU-R recommendation on propagation through vegetation [2]. Appropriate estimation and establishment of the input parameters required by the discretised version of the RET model [3], in addition to the need to incorporate the effects of multilayer mixed volumes of vegetation in the propagation of radiowaves, including the raised canopy and subsequently trunk region propagation effects, form the main motivation of this paper.

And thus, this paper proposes a framework for extending the applicability of discrete RET (dRET) model to accommodate radiowave scattering from tree trunks in microcell urban mobile propagation channel. This extension represents novel additional analytical and experimental work and it will contribute to the effective establishment of desired relationships between the physical attributes of the tree trunks and their electromagnetic propagation properties.

The proposed model is initially based on the knowledge of the 3D bistatic radar cross section (RCS) of a metallic cylinder [4], which served as an input to the current dRET model [3]. The dRET model will then be used to predict the signal behaviour of a more complex scattering structure such as a double line of metallic and/or dielectric cylinders. Model validation against measurement results inside an anechoic chamber for various trunk geometries and at 18.8 GHz, are presented in the subsequent sections.

II. MODEL DEVELOPMENT

The work reported in this paper aims to make use of both the dRET model presented in [3] and the RCS model of a metallic lamppost proposed in [4], so that combined will provide a model for radio wave scattering from trunks of raised canopies, usually present in urban areas. The discretised computational structure comprises several element cells, whose propagation parameters may be assigned independently [3].

A. dRET Model Overview

The discrete RET (dRET) was originally proposed by [5], as a method to overcome the RET limitations in terms of applicability to isolated vegetation volumes. In the dRET modelling, the vegetation volume is divided in non-overlapping square cells and an iterative algorithm is used to gather all the interactions between these primary cells, allowing for the computation of the signal intensity across the entire tree formation. This approach of splitting the vegetation in discrete elementary volumes, allows one to assign different scattering parameters to every cell, consequently enabling an inhomogeneous vegetation volume to be more accurately represented. This is depicted in Fig. 1.

B. Single trunk/cell model

The model presented in [4] models a lamppost as a finite length conductor cylinder, as depicted in Fig. 2, and formulates the RCS, σ, of such a cylinder as provided by (1).The model gives a more detailed insight and well supported fairly accurate predictions of the scattering processes arising in metallic cylinders interacting with an incident radiowave.

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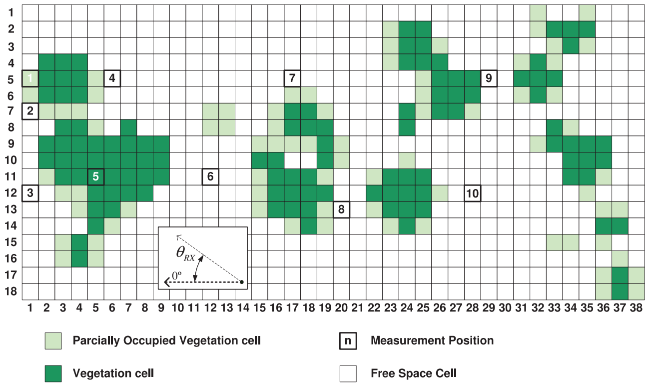


Figure 1. 2D cell structure.

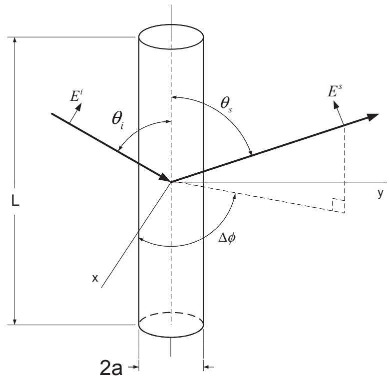


Figure 2. Scattering geometry in a long conductor cylinder.

$$\sigma = \frac{4L^2 \sin^2 \theta_s}{\pi \sin^2 \theta_i} \left\{ \frac{\sin\left[\frac{kL}{2}\left(\cos\theta_s + \cos\theta_i\right)\right]}{\frac{kL}{2}\left(\cos\theta_s + \cos\theta_i\right)} \right\}^2 \cdot \left| \sum_{n=-\infty}^{\infty} (-1)^n e^{jn\Delta\phi} \frac{J_n\left(ka\sin\theta_s\right)}{H_n^{(2)}\left(ka\sin\theta_s\right)} \right|^2 \quad (1)$$

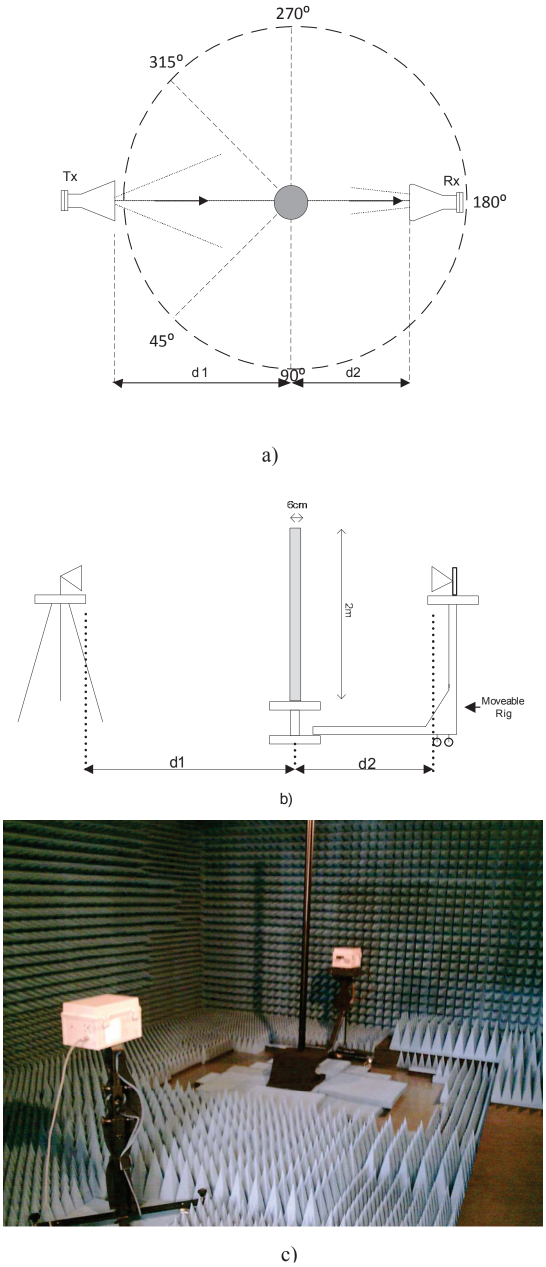


Figure 3. Indoor measurement geometry : (a) top view, (b) side view and (c) photograh

III. Measurement Procedure and Results

A. Single cell model assessment

1) RCS model

The model presented in (1) was validated against appropriate measurements at 18.8 GHz inside an anechoic chamber on realistic individual cylinders, mimicking trunks. The measurement geometry is shown in Fig. 3. Fig. 4 presents the assessment of this model for both metallic and dielectric (wooden) trunks and for various scatter angles $\Delta\phi$ at a constant incident angle, i.e. θ_i=90°. Measurement results were however converted into RCS values by solving the bistatic radar equation. It is observed that the model presented in (1) shows that some agreement between measured and predicted values is achievable, particularly in the forward scattering region. However, in the other angular regions the model seems to over-estimate the RCS, in which errors can be as high as 18 dB. In fact, experimental verification of the model could only be undertaken with measurement data obtained in the near-field region of the trunk, thus justifying some of the discrepancies observed. Additionally, in order to ensure that the data obtained from re-radiation measurements was not affected by contamination from antenna coupling, a free space measurement was performed (without the trunk in the radio path). The result from this measurement is also depicted in Fig. 4. A comparison of received signal levels between free space and re-radiation function measurements can then be made. In the backscatter region ($\Delta\phi \le 60^o \vee \Delta\phi \ge 240^o$) the signal levels in the presence of the trunk are about 10 to

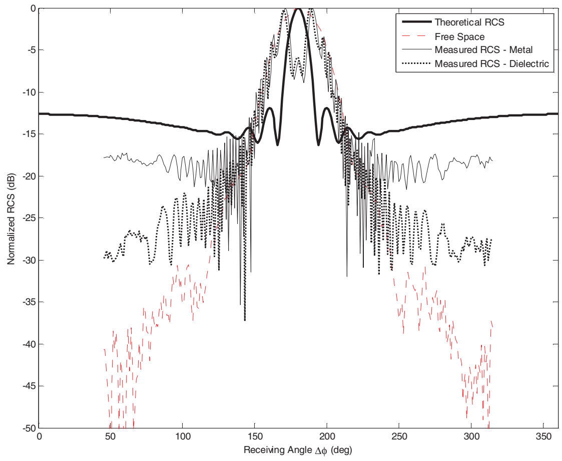


Figure 4. RCS of a metallic cylinder for θi=θs =90º.

23dB above those recorded in the free space measurement. This is sufficient signal level difference to indicate uncontaminated measurements.

Further work is therefore needed to either improve the RCS model or propose an alternative formulation based on the physical (e.g. roughness) and dielectric attributes of trunks. In the mean time and solely the purpose of this paper, a best fit model is used instead, as described in the next subsection.

2) Best-fit model

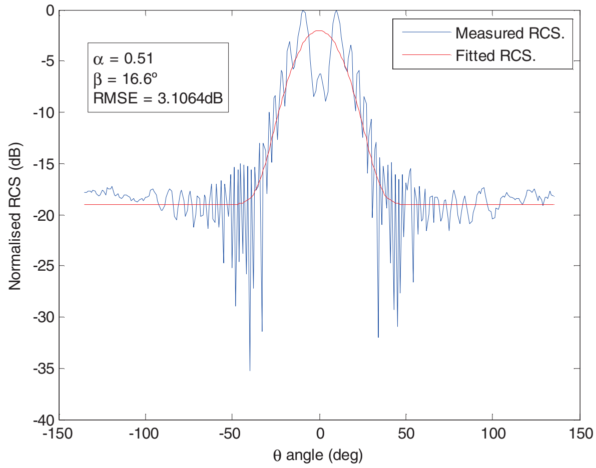
As mentioned previously, a best fit model is used instead of the RCS model given by (1). This model is based on the knowledge of the RET phase function or scattering profile [6], which is normally modelled as a Gaussian function with an isotropic background given by the following equation:

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

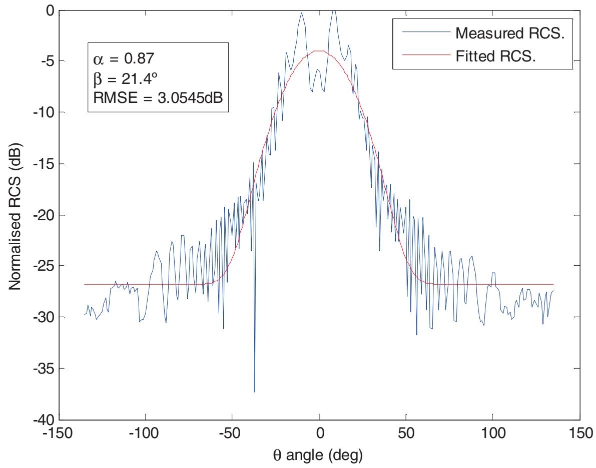
where α is the ratio between the forward lobe power and the total power of the phase function, β represents the half power beamwidth of the forward lobe and γ is the scatter angle. Both β and α were evaluated based on a RMS error (RMSE) criterion between measured and predicted results. Table 1 presents the optimised parameters that minimises the RMS error. Results of the best-fit for both metallic and dielectric (wooden) trunks are presented in Fig. 5. Please note that in these graphs the abscissas are offset, so that $\theta = \Delta\phi - 135^{\circ}$. These are shown to be in good agreement with measurement results, yielding a mean RMS error of 3 dB.

TABLE I. RMS ERROR BETWEEN MEASURED AND BEST-FIT RCS MODEL

Trunk type	Best-fit model parameters		
	β	γ	***RMSE (dB)***
Metallic	16.6	0.51	3.10
Dielectric (wooden)	21.4	0.87	3.05



a)



b)

Figure 5. Measured and best-fit RCS model for: (a) metallic and (b) dielectric trunks, at 18.8 GHz.

B. Trunk formation measurement

In this paper, only the 2D (azimuth) representation of the model will be used due to limitations of the current dRET model implementation [6]. The dRET is used to model the multiple scattering between various trunks. The bistatic RCS of each single (metallic or dielectric) structure will be fed into the dRET as a phase function [3], and thus characterising the pattern of the scattered signal by these cylinder formations, which are intended to mimic single trunks.

In order to simulate a double line of tree trunks, the scenario presented in Fig. 6 was created. In this scenario, the trunk formation was divided into 0.2 m square cells, where grey cells represent the trunks, and white cells represent free space cells. The complete scenario is illuminated by a broad transmitter (TX) antenna with more than 50º of beamwidth. For the purpose of this paper, the locations of the receiver antenna

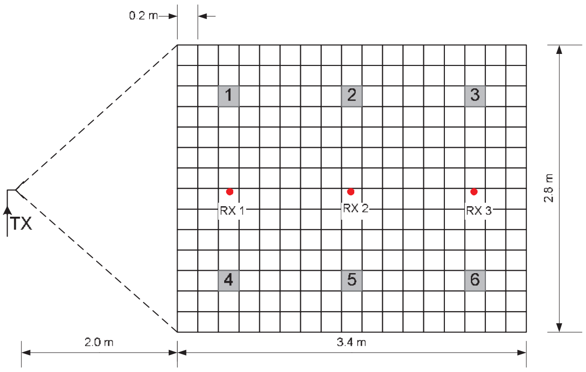


Figure 6. Idealised trunk formation simulated with the dRET.

were chosen to be Rx1 through Rx3. For each measurement location, the receiver antenna is made to rotate clockwise around its vertical axis in increments of 1º, starting at 0º angle - when the antennas are at boresight. The collected power was recorded for each increment angle of the receiver, and thus a directional spectrum of the received signal is obtained.

C. *Measurement system*

The measurement system consisted of a transmitter placed outside the trunk formation and a receiver placed in-between the two lines of trunks. The transmitter consists of a highly stable continuous-wave (CW) phase locked loop oscillator (PLO) rated at 13 dBm. The output of the oscillator was fed to an isolator with an insertion loss of 0.7 dB, which provides a 30 dB isolation, preventing from any signal being reflected back. The output of the isolator was connected to a standard gain horn antenna of 10 dBi and with a beamwidth of 56º. The receiver consisted of a horn antenna similar to that used in the transmitter, but with 20 dBi of gain and 18º of beamwidth, which was fed to a balanced mixer. The mixing between the incoming wave at 18.8 GHz and the 18.2 GHz local PLO resulted in an intermediate frequency (IF) signal of 600 MHz. The IF signal was then connected to a spectrum analyzer (SA) which was used as a radio receiver. A run of 15m low-loss coaxial cable was used to carry the IF signal to the SA. Subsequently, a computer was connected via the GPIB bus to the radio receiver and it was used not only to monitor and store the measurement data, but also to control the rotary tables. Both transmitter and receiver block diagrams are depicted in Fig. 7.

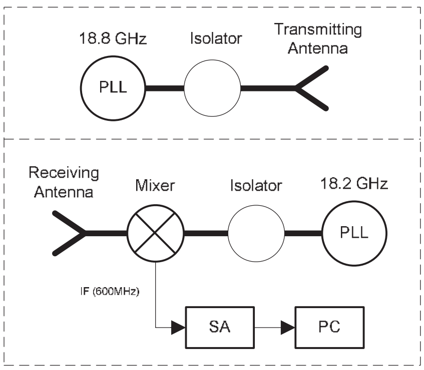


Figure 7. Block diagram of the measurement system.

IV. Model Validation

Simulation results of the dRET were obtained for the scenario given in Fig.6, using dielectric and metallic cylinder formations. Measurement results are then compared with simulations, as depicted in Fig. 8. This figure presents model validation for all measurement positions (#1 to #3) and for the following validation cases when using: (i) the original RCS model for metallic cylinders; (ii) the best-fit model for metallic; and (iii) dielectric (wooden) cylinders or trunks. In this figure, the reflections from the various trunks considered in the idealised scenario are clearly visible. Although such reflections are very narrow, they appear broader due to the effect of the receiver antenna which was considered to have 18º of beamwidth. One should take into account that the receiver and the transmitter antennas are in line of sight, consequently explaining the relatively strong received signal level at approximately 360º, where the antennas are boresight.

Overall good agreement between measurements and both modelled functions can be observed, particularly when the best-fit model is used. However, the model seems to be unable to accurately predict the received signal in the backscattered region. This appears to be due to the trial and error method used to tune the model input parameter, which suggests that further work is needed to fine tune the parameter extraction. The model performance was assessed through a comparative analysis between measurement and simulation results using the RMS error criterion. The complete set of RMSE obtained for the validation cases mentioned above is presented in Table 2. The average RMS error values are consistently below 9 dB which denotes a relatively good performance of the proposed extension of the dRET to the trunk region.

V. Conclusions

Results obtained from specific measurements on a single trunk and on a double line of tree trunks, suggest that the dRET extension to the trunk layer is a practical alternative to the implementation of more complex and theoretical models to estimate the scattering phenomena emanating from the trunk region into the canopy region. The RCS model investigated should be optimized to accommodate dielectric trunks and also the trunk roughness. Further work will address the extension of the 3D dRET model to a 2-layer stratified model, in which the contributions from/to the canopy region into/from the trunk region are taken into account. Finally, the proposed framework, in its present form, presented signal estimates in relatively good agreement with measurement data, thus providing a flexible resource for obtaining data for specific scenarios without having to perform expensive measurements.

TABLE II. RMS error between measured and best-fit RCS models

Position	RMSE (dB)		
	RCS Model	*Best-fit model*	
	Metallic	*Metallic*	*Dielectric*
#1	8.31	6.83	7.27
#2	5.97	6.92	9.42
#3	8.35	8.37	9.34
Average value	**7.54**	**7.37**	**8.67**

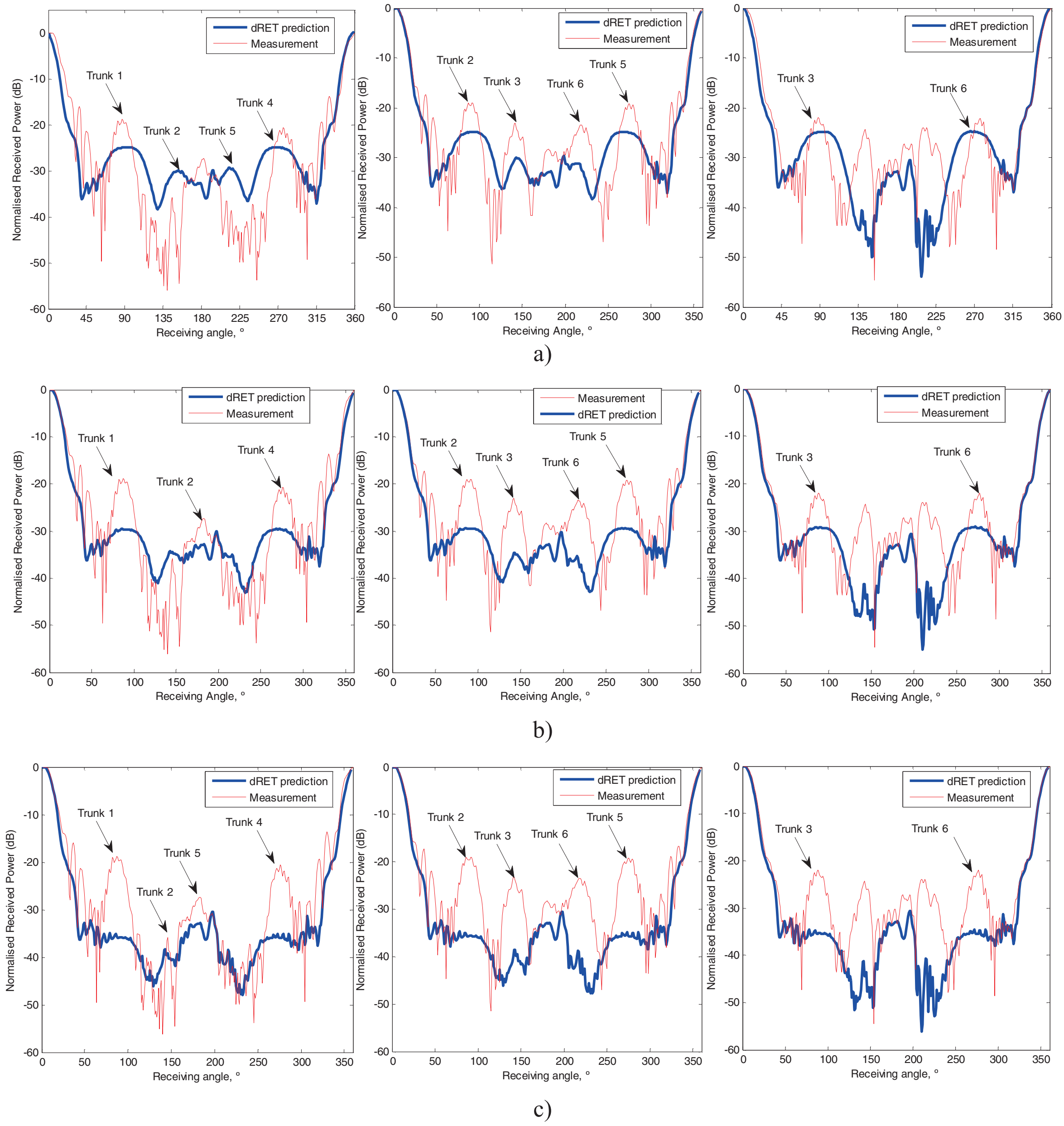


Figure 8. dRET Model validation at positions # 1 (left graph), #2 (middle graph) and "3 (right graph), for: (a) metallic cylinders using the initial RCS model; (b) metallic cylinders with the best-fit model;and (c) dieletric (wooden) cylinders with the best-fit model.

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