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Analysis of the dRET input parameters under varying wind conditions at 20 GHz

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***Abstract*— In this paper, the discrete Radiative Energy Transfer (dRET) theory is addressed as a means to the model dynamic effects through vegetation at millimetre-wave frequencies. The proposed approach, suggests the use of the dRET input parameters time-variant properties, to achieve the modelling of time-variant effects. Analysis of the input parameters time-variability, and its effect on the directional spectra is performed, in order to assess the feasibility of the proposed model approach.**

I. INTRODUCTION

The time-variant effects of vegetation on radiowave propagation have been addressed, and modelled through various techniques. In [1-3] the authors mostly make use of statistical distributions, such as Lognormal, Rayleigh and/or Nakagami-Rice to model the fast fading effects. On the other hand in [4,5], the authors use a more physical based approach. In [4] the authors represent the vegetation volume as an arbitrary shape and density. Furthermore, in [5] the authors consider the swaying tree to be represented by a multiple mass-spring system.

Due to the complex scattering nature of a foliage channel, the use alone of statistical models may not lend themselves to model the physical processes inherent to time-variant scattering channels. Theoretical models may provide insight into the propagation physical phenomena, resulting in increased modelling accuracy. The Radiative Energy Transfer (RET) theory aims to model the vegetation medium and does so by considering it a random homogeneous medium comprised of small discrete scatterers. [6]

The dRET, which has been derived from the RET by [7, 8] will be considered for modelling purposes, in this paper.

II. MODEL RATIONALE

A. The dRET Model

The dRET models the vegetation medium as a set of individual non-overlapping cells. At millimetre-wave frequencies, e.g. 20 GHz, scatter objects in a forest environment, including small branches and leaves, can assume comparable dimension to the propagating signal wavelength. Consequently each cell may be characterised by four parameters: α and β, and σA and σS. Parameters a and b represent the scatter pattern known as the phase function. This function may be represented by a pronounced forward lobe, in the direction of signal propagation, with an isotropic background. The absorption coefficient (σ_A, in *Np/m*), and the scattering cross section per unit volume (σ_S, in m^{-1}) represent the amount of energy absorbed and scattered by the vegetation volume [6]. These parameters are represented as:

$$\sigma_E = \sigma_A + \sigma_S \quad (1)$$

$$P(\psi) = \alpha\left(\frac{2}{\beta}\right)^2 e^{-\left(\frac{\psi}{\beta}\right)^2} + (1-\alpha) \quad (2)$$

where σ_E is the extinction coefficient, and Ψ is the scatter angle subtended by directions of the incoming and outgoing radiations.

The dRET modelling enables and inhomogeneous vegetation volume to be more accurately characterised. The process of splitting the vegetation into discrete elementary volumes allows the assignment of scattering parameters to each cell [7,8].

The dRET estimates the output radiation of each cell as an intensity. The total output intensity of each cell is the sum of incoming diffuse and reduced intensities [8]:

$$I_T^{OUT}(\gamma) = I_{ri}^{OUT}(\gamma_0)\delta(\gamma-\gamma_0) + I_d^{OUT}(\gamma)\,. \quad (3)$$

B. Modelling of Time-variant Effects

The dRET has previously been used to model scattered signals from vegetation [7,8], in time-static scenarios

Since the dRET is only applicable to time-invariant conditions its use to model time-varying scattered radio signals is not straightforward. The proposed framework in this paper uses the dRET to predict time-variant scattered signals from trees by considering the time-variation of its input parameters, which represent the electromagnetic properties for a specific vegetation volume. . The dRET parameters are expected to vary over time with foliage movement, i.e. channel dynamics, as the branches, twigs and leaves move and sway to the wind. Consequently this is expected to result in variation of the dRET output with time.

However, is the time-variation provided by the dRET input parameters significant? And if so, will it result in significant directional spectra signal variation with time? These issues will be addressed in this paper.

C. Extraction of Input Parameters

The extraction of the input parameters, for a single tree, is done through the measurement of the re-radiation pattern of the tree. The re-radiation pattern is the convolution of the tree scatter profile, or phase function, and the receiver antenna effect [6]. Although the measured re-radiation differs from the real phase function because of the receiver antenna distortion effect [8], it is considered a valid approximation of the tree scatter pattern and used to assess the input parameters.

Once the re-radiation of a tree is obtained an optimum Gaussian curve is fitted against it. All of the input parameters may be retrieved from the resulting Gaussian curve [8]. To ensure that the parameters may be retrieved as a function of time, the re-radiation measurement must provide with sufficient signal information through time. Thus allowing for single Gaussian curves to be estimated for individual time instants, resulting in a set of input parameters for all time instants.

III. MEASUREMENT SET-UP

Specific measurements were performed at 20 GHz on a single tree and a 3x3 plant formation inside an anechoic chamber. The single tree measurements were envisaged to enable the extraction of the dRET input parameters for time-invariant and more importantly time-variant conditions. The tree formation measurements will be used to obtain the received signal directional spectrum, at a given position, and further use it to validate the dRET simulated directional spectrum through time.

A. Single Tree Set-up

The single tree measurements consisted of recording the re-radiation pattern of a single tree through time with wind induced effects. Radio measurements were performed on one downscaled tree, of *Ficus* species. The tree was around 1.60 metres high and its canopy diameter around 60 centimetres. The measurement geometry is shown in Fig. 1a. One household fan was placed strategically inside the anechoic chamber to create wind-induced foliage movement. The fan generated wind at a constant speed of 4.7m/s. The receiver was rotated around the vegetation volume, in the azimuth plane, over a range of 240º with an angular resolution of 2º. The receiver antenna is always directed towards the centre of the tree. The received signal was recorded over a period of 10 seconds for each receiver angle with a sampling period of 1000 samples per second. The selected sampling period allowed for a time resolution of 1ms to assess the wind effects on the re-radiated signal from the tree.

B. Tree Formation Set-up

The tree formation measurements consisted of recording the directional spectrum at one specific position (Rx1) inside the forest medium (see Fig. 1b.). The directional spectrum was recorded for both time-static and time-variant conditions. The receiver was rotated around its own axis inside the vegetation volume, in the azimuth plane, over a range of 360º with an angular resolution of 2º. The received signal was recorded over a period of 10 seconds for each receiver angle with a sampling period of 1000 samples per second. As a result dRET input parameters were extracted throughout 10 seconds with a time resolution of 10 ms

IV. THE dRET TIME-VARIANT INPUT PARAMETERS

Analysis of the input parameters will focus on retrieved data from wind incidence A with high wind speeds. The time-variant extracted dRET input parameters are presented against the static case, in Fig. 3 from a) to d). In Fig. 3 e) the measured re-radiation and fitted Gaussian function (approximation to the phase function) are presented as an average over time. Additionally, a tree dimensional perspective of the phase function is presented in Fig. 4. Parameters σ_A, and σ_S are expressed in *Np/m*, and m^{-1}, respectively. Whereas β is expressed in degrees. .

Through the analysis of the time-variant parameters against the static scenario, depicted in Fig. 3, wind induced signal variation is clear. For all cases, the measured σ is far greater in wind induced scenarios in comparison to the static case. The increase of parameter variation with time amounts to 0.6 for α, 34º for β, around 2.8 for σ_A, and around 0.2 for σ_S.

Analysis of the mean values of the parameters, for wind conditions in comparison to the static case, shows how much interference is caused by the dynamic effects. The decrease of forward-to-back ratio and increase of σS indicates the increase of side scatter level, and consequently the increase of signal scattering under dynamic conditions, as a result of movement of the scatterers, i.e. leafs, twigs and branches. Furthermore, the increase of the absorption coefficient indicates the increase of excess attenuation in the main lobe as a result of the movement of scatterers.

Additionally, a close look at Fig. 4, shows the significant effect of a dynamic channel on the phase function of the tree. Both the side scatter and main lobe of the phase function reveal strong variation through time, especially in the main lobe.

V. IMPACT OF INPUT DYNAMICS ON DIRECTIONAL SPECTRA

All of the dRET input parameters show strong correlation between their variation and movement of vegetation caused by wind effects.

The dRET model was executed based on the simulation scenario depicted in Fig. 4, using the time-variant input parameters depicted in Fig. 2.

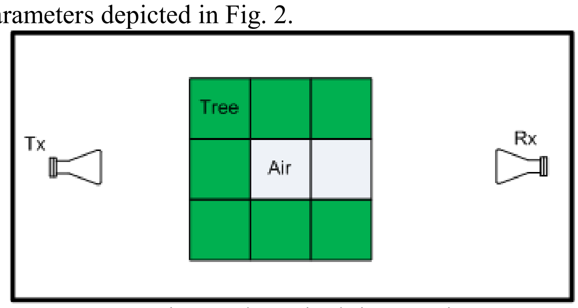

Figure 4: dRET simulation scenario.

VI. CONCLUSIONS

In spite of significant dRET input parameter variation, due to dynamic effects, the input variation to the model seems to underestimate the measured directional spectra variation. This may be caused by the methodology used to extract the parameters by fitting a Gaussian curve to the measured re-radiation pattern, which underestimates the observed signal variation. This issue is currently subject of investigation. The authors aim to improve the extraction methodology, and increase the variation by using a modified Gaussian curve together with additional statistical data, e.g. mathematical distributions such as Lognormal and Rayleigh. T

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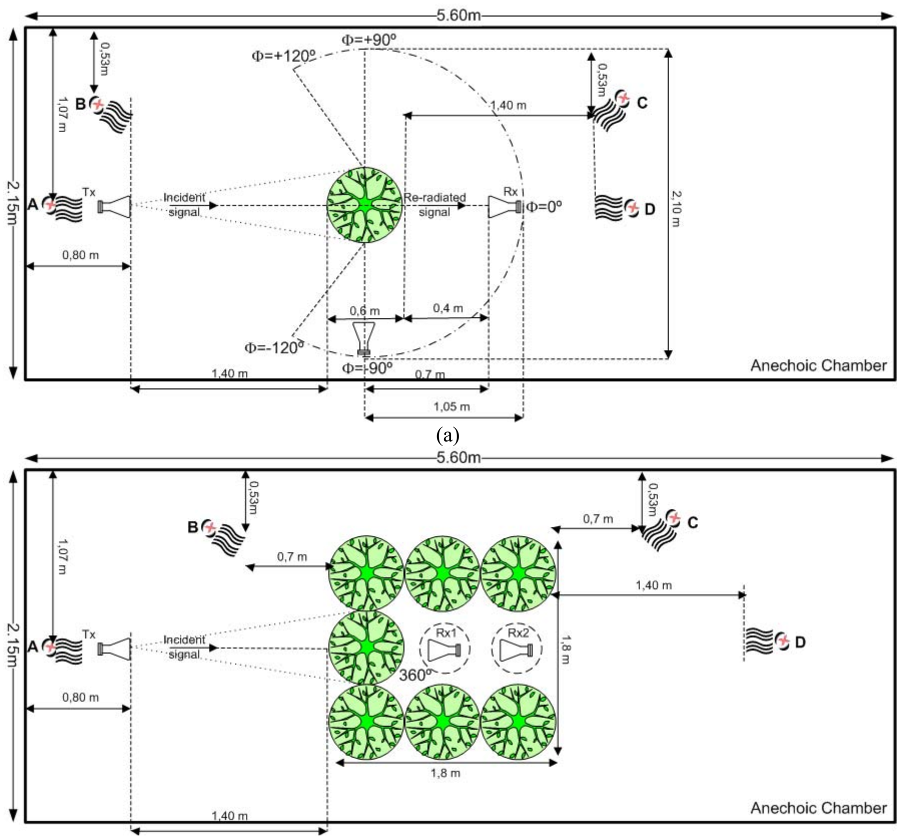

(a)

(b)

Figure 1: Measurement geometry of a) single tree, and b) 3x3 tree formation.

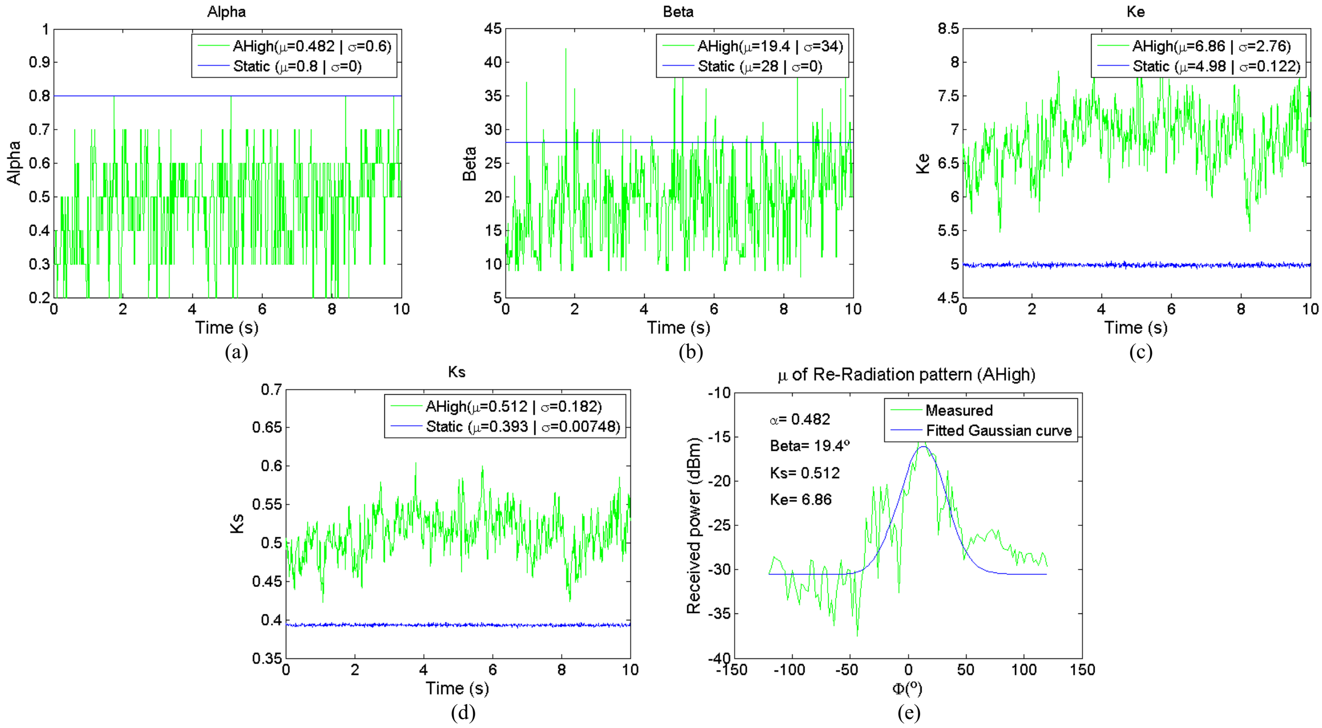

Figure 2: dRET input parameters for wind incidence A, and high wind speed, against the static case.

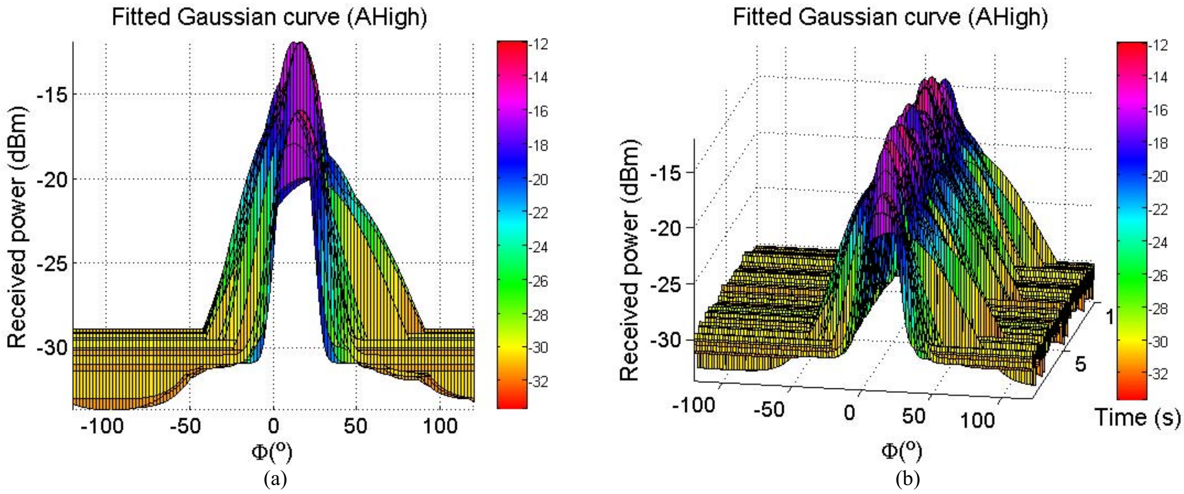

Figure 3: Representation of the phase function: a) front view and b) top-side view.

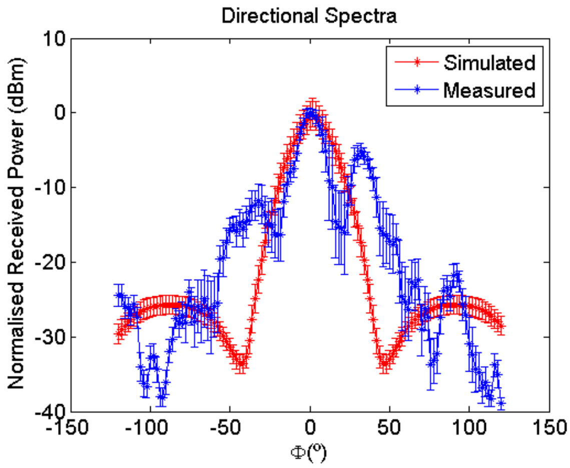

Figure 5: Representation of the phase function: a) front view and b) top-side view.