Investigation of a time-variant dRET model in vegetation
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Abstract

In this paper, the discrete Radiative Energy Transfer is investigated as an effective mean to model wind induced time-variant vegetative radio channels. The investigated model will make use of the input parameters time-variation properties to achieve channel dynamics modeling. Analysis of both the foliated channel statistics and model performance against measured data, at 20 GHz, will be presented.

1. Introduction

Radio propagation through vegetation has been investigated at various frequencies [1]. Models have been proposed to successfully tackle the mitigation effects induced by scattering vegetation. However, many of the work presented in literature focuses and makes use of time-invariant models. This paper proposes a time-variant model for foliated conditions by making use of a physical based approach. The dRET which has been derived from the RET will be investigated for modeling purposes.

2. Model Rationale and Development

The dRET considers the vegetation medium as a set of individual non-overlapping cells. At millimetre-wave frequencies, scatter objects in a forest environment, including small branches and leaves, can assume comparable dimension to the propagating signal wavelength. Consequently, based on the RET theory each cell may be characterised by four parameters: α and β, and Ke and Ks [2].

Parameters α and β represent the scatter pattern known as the phase function. The absorption coefficient (Ke, in Np/m), and the scattering cross section per unit volume (Ks, in m-1) represent the amount of energy absorbed and scattered by the vegetation volume [2]. 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 [3 and 4]. The dRET has previously been used to model scattered signals from vegetation [3 and 4], 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. Therefore the dRET input parameters: α and β, and Ke and Ks, will be estimated as a function of time. The extraction of the input parameters, for a single vegetation volume, is done through the measurement of the re-radiation pattern of the tree. For time-invariant conditions a single set of re-radiation pattern of a tree is obtained, and a optimum Gaussian curve is fitted against it [4]. On the other hand to ensure that parameters may be retrieved as a function of time, the re-radiation measurement must contain sufficient signal information through time. In order to do so multiple re-radiation patterns are recorded, each one corresponding to a specific time instant. Single Gaussian curves are estimated for each time instant, resulting in a set of input parameters for all time instants. The parameters α and Ks are particularly sensitive to any changes in the side scatter level as they are estimated accordingly to the backscattering level [4]. For time-static conditions the α and Ks are extracted based on a averaged backscatter level. However for time-variant conditions using an average will decrease both angular and time variations. Therefore, to solve this issue both parameters are extracted from a backscatter level estimated for an angle of $\Phi=|90°|$, where the side received signal is expected to be mostly scattered from the tree. To do so, analysis of the channel dynamics and angular variation of the re-radiation pattern was

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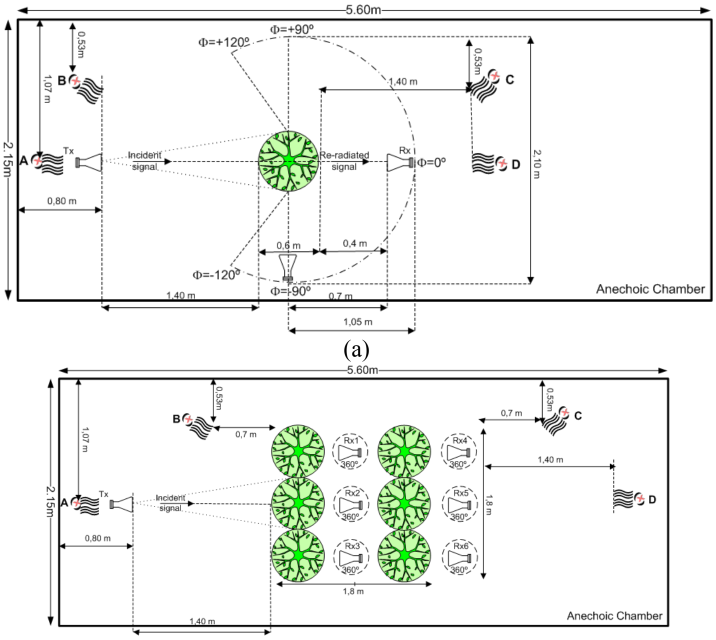
conducted to assess if selecting a single angle as a representation of the backscatter level is satisfactory given the behavior of the surrounding angular received signals. This will further be discussed in section 4.

3. Measurement Geometry and Procedure

Two sets of RF measurements were envisaged to investigate the wind induced effects on vegetation. These were performed at 20 GHz in a controlled environment inside an anechoic chamber. The single tree measurements are used to investigate channel dynamics effects in foliage and to enable the extraction of the proposed modeling approach input parameters. The tree formation measurements are used to validate the presented time-variant model and assess its performance. 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 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.



(a)

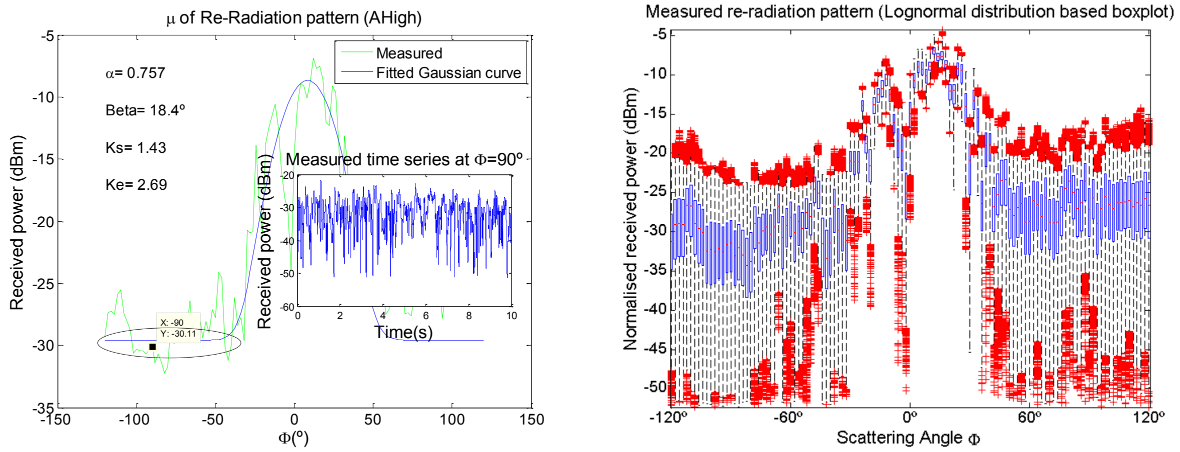
(b)

Figure 1: Indoor measurement geometry of a) single tree and b) tree formation.

The tree formation measurements consisted of recording the directional spectrum at specific positions 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.

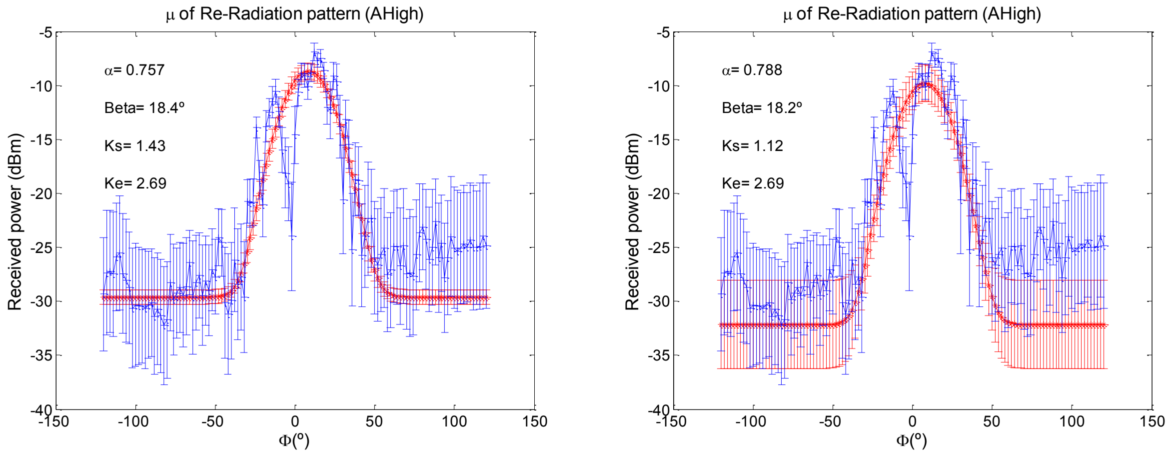
4. Statistical Analysis of the Measured Re-radiation Pattern

The measured and fitted Gaussian function re-radiation patterns of a single tree are presented in Fig. 2, where in Fig. 2b is plotted a skewed box plot based on a Lognormal distribution. On each blue box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers (dotted line) extend to the most extreme data points, and the outliers (red line) are plotted individually. In this particular case a box plot is a tool which enables the analysis of the following information about the data: position, spread, skewness and tails. The measured time series that comprise the re-radiation pattern are skewed and follow a Lognormal distribution [5]. Below in Fig. 3 are depicted the measured and fitted re-radiation patterns, where the corresponding signal dispersion through time, per scatter angle, is shown by means of an error bar. The dRET time-variant input parameters are estimated based on a fitted Gaussian phase function representation of the re-radiation pattern. These parameters are estimated based on the backscatter level of the phase function [4]. Under time-static conditions these parameters are estimated from an angular averaged backscatter level (-120≤Φ≤50º), depicted in Fig. 2a inside the ellipse. However, under time-variant conditions this is not satisfactory as the angular variation along with most of the time variation will be discriminated. Thus, the backscatter level may be defined as the signal level, through time, at around Φ=|90º|. However, further statistical analysis to the received signal at Φ=|90º| is required in order to verify that it follows a similar pattern in comparison to other scatter signals in the side scatter region, and shows no abnormalities in its pattern. Analysis of Fig. 2b shows that the received signal at Φ=|90º| has similar statistics to the scatter signals around Φ=|90º|. Both the median and the upper and lower quartiles are comparable to each other, as are the whiskers length and outliers size. Plots of results using both methods, the averaged backscatter level and the singular (Φ=|90º|) backscatter level are presented in Fig. 3, where the corresponding signal dispersion through time, per scatter angle, is shown by means of an error bar. Significant difference is observable on the resulting time-variant phase function (Gaussian function). By using a single scatter angle signal to obtain the time-variant parameters the resulting phase function shows improved signal dispersion through time against measured data, in comparison to the averaged approach. Under the averaged approach the phase function significantly underestimates the received signal standard deviation.



(a) (b)

Figure 2: Statistics retrieved for high wind speed scenario, and wind incidence from A, where a) measured vs. fitted Gaussian function and b) measured re-radiation boxplot.

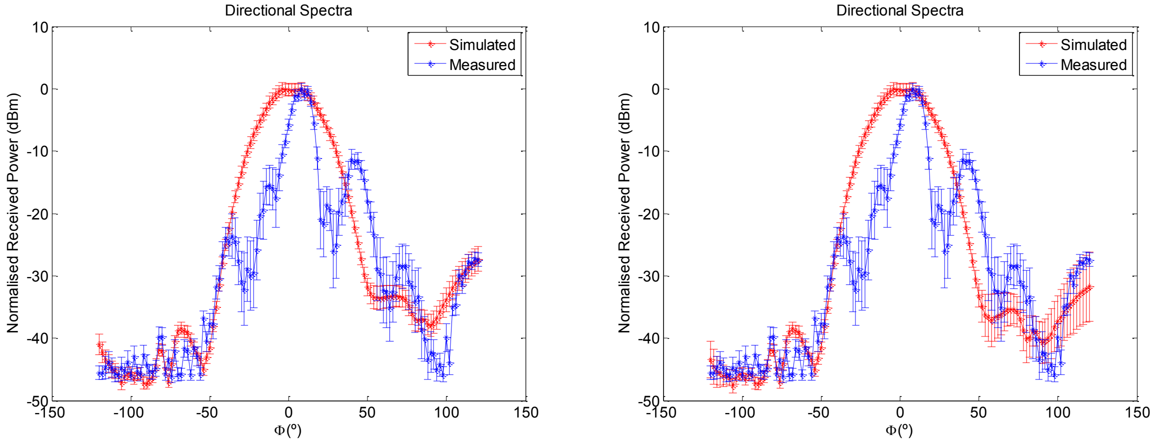


(a) (b)

Figure 3: Comparison between input parameters extraction approaches, a) averaged backscatter level and b) Φ=|90º| backscatter level, where the blue lines represents the measured re-radiation pattern and the red line the fitted Gaussian function.

5. Assessment and Validation of Modelling Results

Below in Fig. 4 are depicted the measured and simulated directional spectra, where the corresponding signal dispersion through time, per scatter angle, is shown by means of an error bar. The dRET results using the 1st method of parameter extraction show that the simulated directional spectra signal variation with time is underestimated against the measured directional spectra (for a 4x4 tree formation). The resulting simulated directional spectra using the 2nd method of parameter extraction shows increased signal variation with time, Fig. 2b. This is especially true for the side scatter region. Because the employed method of extraction was applied to the side scatter only the transition and forward scatter regions show little variation. However, the new method of extraction may only consider the transition region, besides the scatter, since the main lobe shows very little signal variation. Due to the geometry of the tree formation setup, increased signal variation with time is observed in the transition region. The reason the model performs poorly in the side scatter region so far is that the adjustments have been made to increase the simulated variation in the side scatter region. Against the indoor data the model must be modified in order to increase signal variation in the transition region. This is where the measured directional spectra varies the most with time.



(a) (b)

Figure 4: Comparison between dRET directional spectra for a) averaged backscatter level and b) Φ=|90°| backscatter level, where the blue lines represents the measured re-radiation pattern and the red line the dRET simulated data.

6. Conclusions

The dRET has been investigated as a means to model highly time-variant signals scattered from vegetation. Due to its nature as a time-static model, adjustments to comprehend time-variation must be employed to the dRET. A method to extract the dRET time-varying input parameters was presented and discussed. Obtained results, using the proposed method, show that the resulting phase function does not underestimate the signal variation against measured data. Additionally, the directional spectra output of the dRET model is in better agreement with the measured directional spectra. Further investigation is required to improve the model performance. The authors will focus on extending the model to accommodate wind speed decay through vegetation volumes.

7. References

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