# A GENERIC DOUBLY-SELECTIVE 3D VEGETATION MODEL USING POINT SCATTERERS


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## Motivation of the work

**The motivation of this Ph.D programme is to overcome the lack of readily plug-in models of ray-tracing based simulation platforms, when considering propagation through and/or around vegetation volumes.**

The phenomena inherent to radio-wave propagation through vegetation areas have raised particular interest among researchers.

The Radiative Energy Transfer (RET) based models have successfully been used to simulate radio wave propagation in vegetation environments. Its integration with existent commercial simulation platforms appears to be rather difficult.

Ray-tracing based simulation platforms proved to be powerful tools for radio planning, despite their limitation, due to the lack of readily plug-in models, when considering propagation through and/or around vegetation volumes.

To overcome these limitations, this Ph.D programme aims to develop a generic 3D doubly-selective vegetation model based on point scatterers, in which trees are sought to be represented by a number of scatter points, distributed inside a computational volume and each with specific re-radiation characteristics.

## Thesis objectives

**In summary, the main objectives envisaged at the outset for the Ph.D programme are the following:**

**Static Canopy Model (SCM) development:**
Development of static 3D physical model based on ray-tracing approach capable of predicting the behavior of radio waves when propagating in vegetation media;

**Dynamic Canopy Model (DCM) development:**
Extension of the static model to represent doubly-selective phenomena in vegetation media, covering various wind speeds and directions;

**Enhanced Static Trunk and Ground (ESTG) model development:**
Investigate the possibility of extending the point scatterer model framework to a stratified model including both trunk and ground regions;

**Combination of individual models into a generic doubly-selective 3D vegetation model:**
Combination of all individual models (developed in the previous tasks) into a single generic 3D doubly-selective vegetation model using point scatterers. Fine tuning of the proposed generic model through comparison with appropriate measured data;

**Final model validation:**
Extensive experimental validation and measurements including time-varying wideband signal measurements as a function of distance along the radio paths for varying geometries and tree species over the frequency range.

## Research plan

| # | Task name | Duration | Month | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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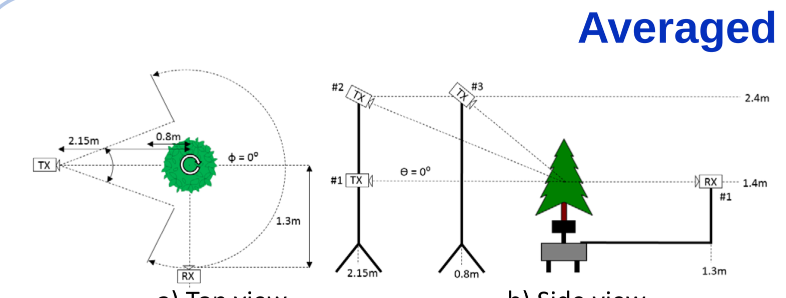
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| 1 | Literature review | 3 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Development of Narrow and Wideband Measurement Systems | 7 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | Definition of Deployment Scenarios | 2 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | Static Canopy Model (SCM) Development | 10 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | Dynamic Canopy Model (DCM) Development | 9 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | Enhanced Static Trunk and Ground Model (ESTG) Development | 6 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | Combination of individual models into a generic doubly-selective 3D vegetation model | 6 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | Documentation | 10 M | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Results: Input parameter extraction simplification

### Averaged re-radiation model



a) Top view b) Side view

Fig. 1 – Measurement geometry.

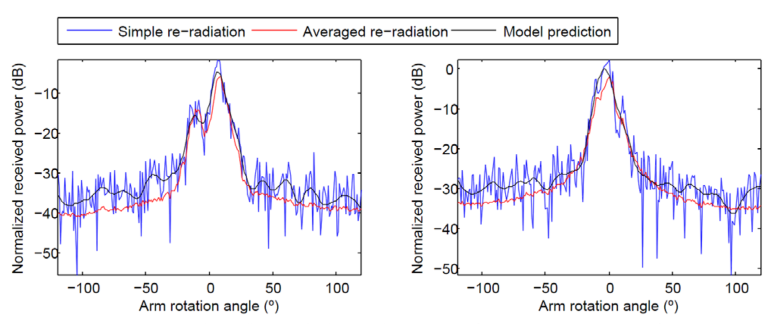


Fig. 2 – Example of model application (tree specimens)

- Tree orientation highly affects the received signal level;
- Signal depolarization as it propagates through the tree, is the most likely process responsible for the signal nulls;
- To obtain reliable re-radiation measurement results, the scattered field around the tree should be recorded for several incidence angles to mitigate the tree orientation dependency, which in turns, can become prohibitive.
- An **empirical method**, using robust weighted local regression, **was developed** to minimize the influence of the effect of the tree inhomogeneity on its re-radiation pattern, allowing the evaluation of averaged re-radiation functions from simple measurements.

### Empirical Input Parameter Extraction Method

#### 2D scattering model

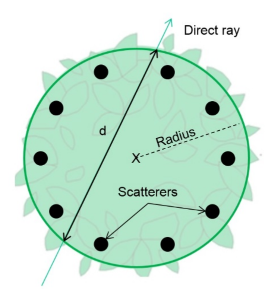


Fig. 3 – Scattering model for a single tree.

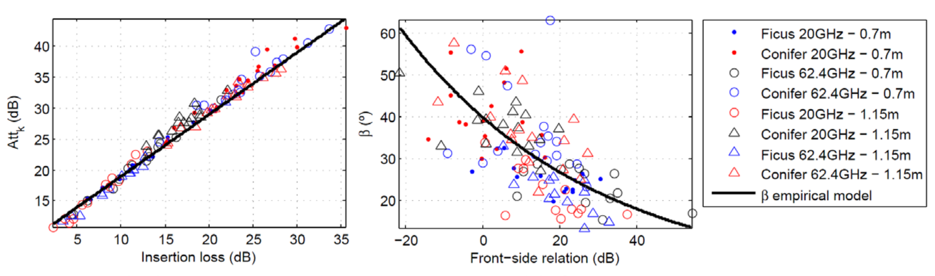
$$\rho(\gamma) = \frac{\alpha\cdot\left(\frac{2}{\beta}\right)^2 \cdot e^{-\left(\frac{\gamma}{\beta}\right)^2} + (1-\alpha)}{\alpha\cdot\left(\frac{2}{\beta}\right)^2 + (1-\alpha)}$$

$$L_{Ex} = \frac{1}{(d.Att_k + 1)}$$

- $\beta$ and $Att_k$ parameters are extracted using a RMSE minimization process, requiring the prior knowledge of the tree re-radiation function.
- As far as real forest scenarios are concerned, such measurement is not always easy, or even possible, to perform.
- **An empirical model** to extract the relevant propagation input parameters from simple measurements, **was proposed.**

#### Input parameter empirical model

- $Att_k$ is evaluated from the tree's insertion loss - $Att_{k(empirical)} = Insertion_{loss} + 9$
- $\beta$ is evaluated from front-side signal level relation - $\beta_{(empirical)} = 40e^{-0.02Gain_{front-side}}$



a) $Att_k$ b) $\beta$

Fig. 4 – Empirical model development.

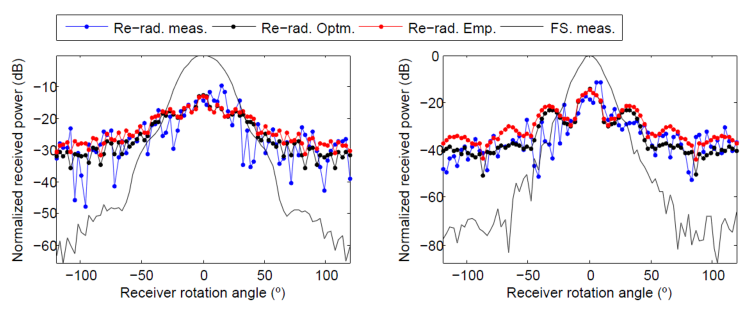
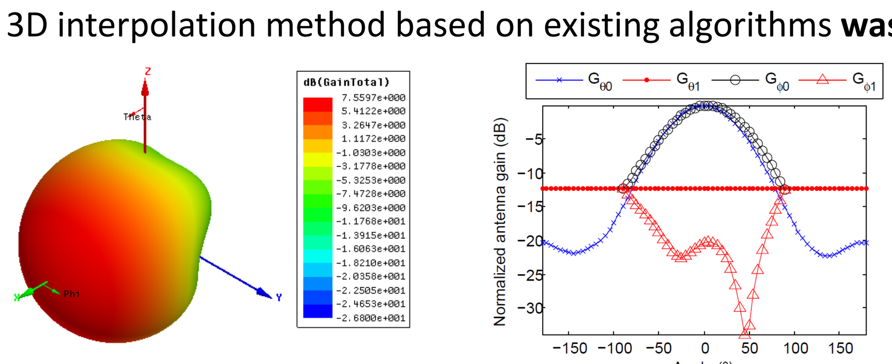


Fig. 5 – Example of model application (tree specimen).

### 3D Antenna Pattern Interpolation Method – Directive antennas

- 3D antenna characterization requires 360x180 = 64800 measurement points.
- A new 3D interpolation method based on existing algorithms **was proposed**.



a) 3D Pattern b) Main planes

Fig. 6 – 3D radiation patterns of a typical patch antenna.

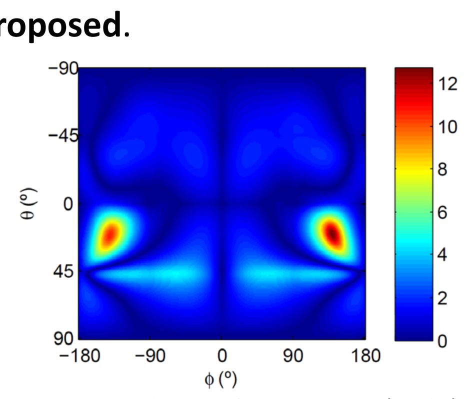


Fig. 7 – 3D interpolation errors (in dB) of a Patch antenna.

## Next year's work plan

### 3D SCM - Measurement geometry

The 3D extension of the SCM model foreseen for the second year of this Ph.D programme, was postponed since consideration was given to the enhancing and simplification of the extraction method of the relevant propagation input parameters.

Nevertheless, an extensive campaign of 3D re-radiation measurements, where several trees are to be included, at various signal frequencies, will be conducted. Fig. 8 depicts the measurement geometry foreseen in this task. Consideration should be given to received signal (de)polarization.

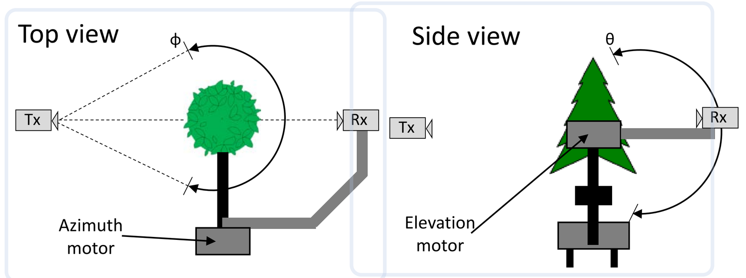


Fig. 8 – Diagram of the 3D re-radiation measurement mechanical rig.

### 3D SCM - Scattering model

The 3D extension of the SCM model will include two different modelling approaches:

- The extension of the 2D scattering model to include the point scatterer distribution inside a 3D volume. This 3D model should be as generic as possible and to be applicable to several tree species. Fig. 9 depicts possible tree physical models currently taken into consideration.

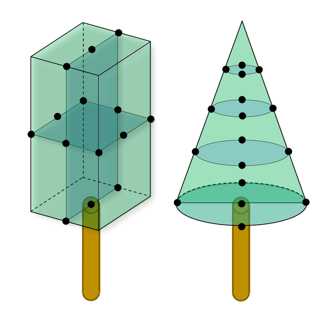


Fig. 9 – Tree 3D model possibilities under consideration.

- Additionally, the development of an interpolation method to re-construct the 3D re-radiation pattern of a single and isolated tree, from its main planes, will be addressed.

### 3D Dynamic Canopy model

Extend the 3D SCM to include wind induced time-varying effects. A stochastic approach will be considered, in addition to the following parameters: **wind speed** and direction, incidence and scattering **angles**, signal **frequency** and **tree species**.

## Dissemination of results (in the last 12 months)


- **Publications in international journals:**

[1] Ferreira, D.; Caldeirinha, R.F.S.; **Leonor, N.**; *"A Real Time High-Resolution RF Channel Sounder Based on the Sliding Correlation Principle"*, IET Microwaves Antennas & Propagation, January, 2015, DOI:10.1049/iet-map.2014.0165, **[Q1, Impact factor = 0.969].**

[2] **Leonor, N.;** Caldeirinha, R.F.S.; Fernandes, T.R.; Ferreira, D.; M. Sanchez ; *"A 2D ray-tracing based model for micro- and millimeter-wave propagation through vegetation"*, IEEE Trans. on Antennas and Propagation, Vol. 62, No. 12, pp. 1 - 11, December, 2014, DOI: 10.1109/TAP.2014.2362124, [Q1, Impact factor = 2.6] , **[Q1, Impact factor = 2.459].**

[3] **Leonor, N.;** Ferreira, D.; Caldeirinha, R.F.S.; Fernandes, T.R.; M. Sanchez; *"Extension of the dRET model to forests of thin cylinders"*, IEEE Trans. on Antennas and Propagation, 2015 **(final revision)**.

[4] **Leonor, N.;** Caldeirinha, R.F.S.; Fernandes, T.R.; M. Sanchez; *"A simple model for average re-radiation patterns of single trees based on weighted regression at 60 GHz"*, IEEE Trans. on Antennas and Propagation, 2015 (under review).

[5] **Leonor, N.;** Caldeirinha, R.F.S.; Fernandes, T.R.; M. Sanchez; *"An Input Parameter Extraction Method for Point Scatterer Formulation in Vegetation Media"*, IEEE Trans. on Antennas and Propagation, 2015 (under review).

[6] **Leonor, N.;** Caldeirinha, R.F.S.; M. Sanchez; Fernandes, T.R.; *"A Three-dimensional Directive Antenna Pattern Interpolation Method"*, IEEE Antennas and Wireless Propagation Letters, 2015 (under review).

[7] **Leonor, N.;** Caldeirinha, R.F.S.; M. Sanchez; Fernandes, T.R.; *"A ray-tracing scattering model for ornamental indoor plants with varying thickness foreseen to 5G radio coverage planning at 60 GHz"*, IEEE Antennas and Wireless Propagation Letters, 2015 (under review).

- **Publications in international conferences:**

[1] **Leonor, N.;** Caldeirinha, R.F.S.; Fernandes, T.R.; M. Sanchez ; *"A feasibility study on the extension of the point scatterer formulation to vegetation media"*, Proc. European Conf. on Antennas & Propagation - EUCAP, Lisbon, Portugal, Vol. 1, pp. 1 - 5, April, 2015.