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
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

Month: 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

Results: Extensive assessment of the SCM model

2D Outdoor forest scenario

Fig. 1 – Forest environment

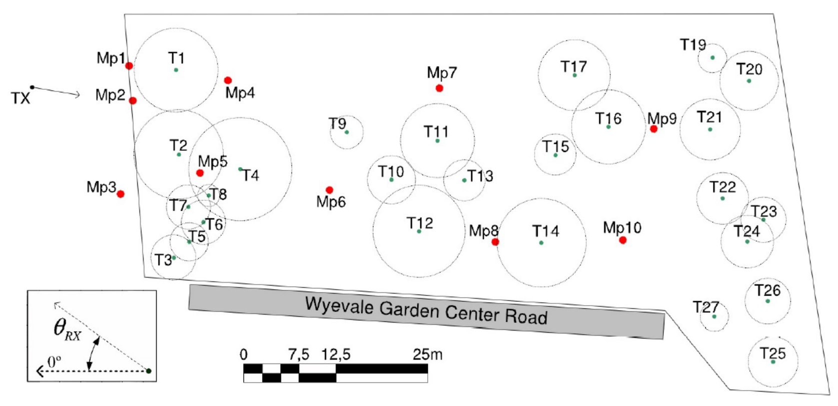


Fig. 2 – Scaled diagram of the measurement scenario

- An inhomogenous outdoor forest scenario composed by trees of various species was considered for assessment purposes;
- Directional spectra was recorded at 10 different within the forest environment at 11.2, 40 and 62.4 GHz;
- Additional measurements were conducted for tree input parameter extraction.

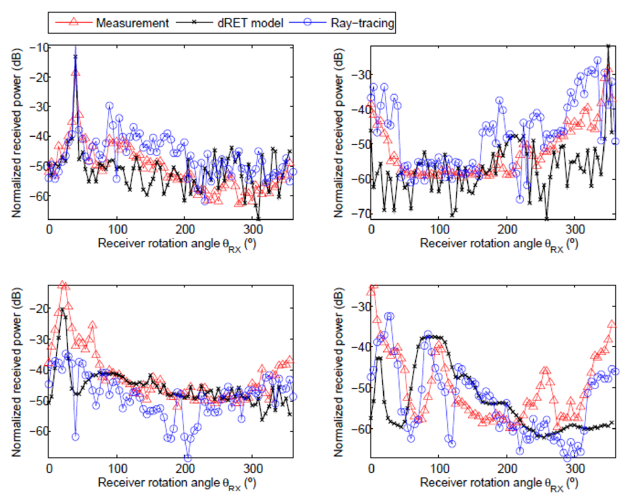


Fig. 2 – Directional spectra results obtained at position: a) MP3 and b) MP4 at 62.4 GHz; c) MP5 and d) MP6 at 40 GHz;

	Ray-tracing Frequency [GHz]			dRET Frequency [GHz]		
Pos.	11.2	40	62.4	11.2	40	62.4
MP1	7.6	10.1	9.7	4.9	8.0	7.9
MP2	8.7	8.7	9.4	3.7	8.4	8.3
MP3	8.9	6.2	7.3	7.5	8.0	7.5
MP4	8.5	5.4	8.5	11.6	9.4	8.6
MP5	7.4	9.6	11.2	9.2	7.6	17.6
MP6	10.3	8.6	10.6	13.8	11.7	16.1
MP7	9.4	5.3	5.8	6.6	7.4	11.3
MP8	9.8	7.3	11.4	15.2	17.8	21.6
MP9	9.5	11.7	10.3	6.8	6.5	7.9
MP10	9.3	7.1	N/A	16.3	7.3	N/A
Mean	8.9	8.0	9.4	9.6	9.2	11.9

3D Re-radiation assessment

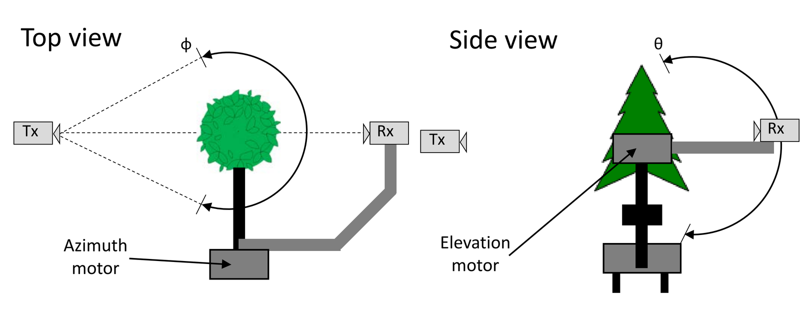


Fig. 3 – 3D Re-radiation measurement geometry.

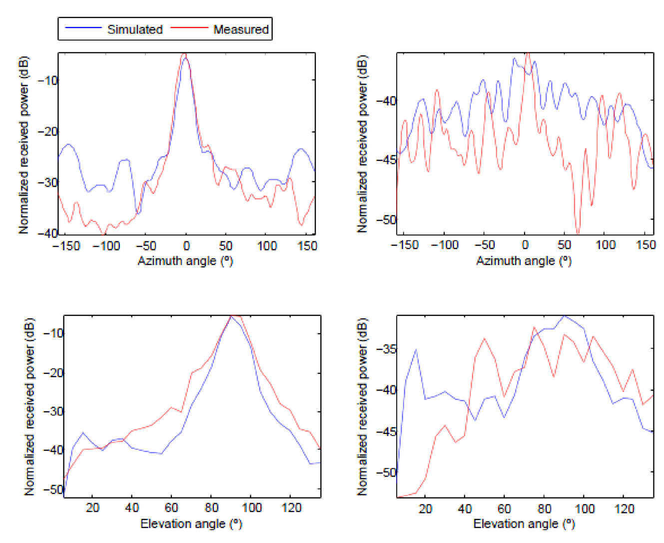
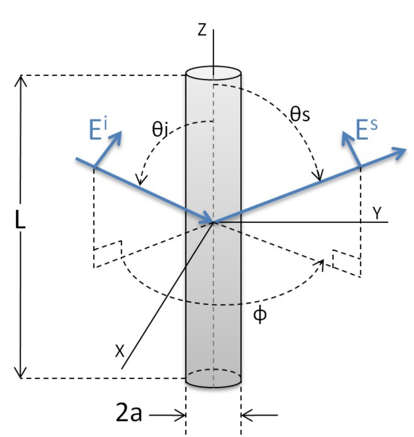


Fig. 4 – Directional spectra results obtained at position: a) MP3 and b) MP4 at 62.4 GHz; c) MP5 and d) MP6 at 40 GHz;

- Measurements intending to record the 3D re-radiation function of single trees were performed in a controlled environment;
- The measurement geometry depicted in Fig. 3 was used to record the 3D re-radiation pattern of 4 *Ficus benjamina* specimens and 3 groups of trees, mimicking trees with varying thickness, at 60.6 GHz
- The proposed propagation model was assessed against the experimental data.

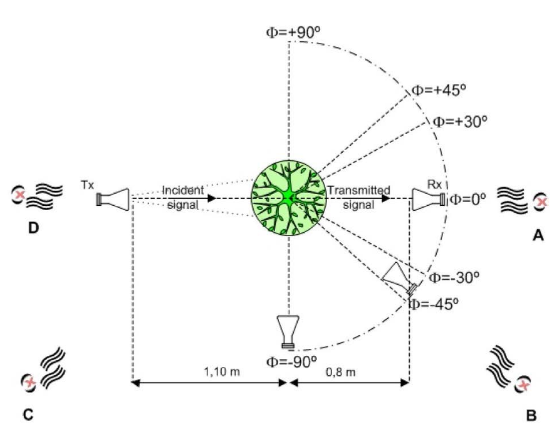
RMSE [dB]						
Tree label	Physical model A	B	C	D	E	F
F1	8.1	7.9	8.3	7.5	6.7	6.2
F2	7.2	7.1	8.6	7.1	7.3	6.7
F3	7.7	7.7	10.0	7.7	8.5	7.6
F4	8.0	7.9	8.8	7.9	7.4	7.0
GF1	8.9	8.3	8.2	8.5	6.5	6.1
GF2	8.5	7.9	8.7	7.8	7.0	6.5
GF3	9.1	8.9	8.8	8.8	6.9	6.4
Mean	8.2	8.0	8.8	7.9	7.2	6.6

Next year's work plan



Trunk and ground model

- Conduct appropriate measurements on realistic scenarios to characterize the radiowave propagation in the trunk and ground regions. More specifically, 3D re-radiation profile emanating from the trunk and ground layers will be investigated on a scaled model inside an anechoic chamber for various trunk shapes and forms, diameter, roughness (including the ground), height and spacing (regularly or arbitrarily distributed) and later on a real forest, typically on high raised canopy pine forests.



Dynamic propagation model

- Investigate the wind effect on the narrow and wideband channel characteristics in vegetation media for varying geometries and wind speeds and directions;
- Develop a dynamic canopy model to represent the doubly selective phenomena in vegetation media;
- Development of a reliable method to extract the effective parameters characterising the time-variability of the channel for the DCM modelling approach. The model should also account for variations in attenuation for wet and dry conditions.

Dissemination of results:

- **Publications in international journals:**

[1] **N. Leonor**, R. F. S. Caldeirinha, T. Fernandes, D. Ferreira, 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. 6443 - 6453, October, 2014, DOI:10.1109/TAP.2014.2362124, **[Q1, Impact factor = 2.181].**

[2] D. Ferreira, R. F. S. Caldeirinha, **N. Leonor**, "A Real Time High-Resolution RF Channel Sounder Based on the Sliding Correlation Principle", IET Microwaves Antennas & Propagation, Vol. 9, No. 8, pp. 837 - 846, June, 2015, DOI:10.1049/iet-map.2014.0165, **[Q1, Impact factor = 0.969].**

[3] **N. Leonor**, R. F. S. Caldeirinha, T. Fernandes, 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, Vol. 63, No. 11, pp. 5113 - 5118, August, 2015, DOI:10.1109/TAP.2015.2474126, **[Q1, Impact factor = 2.181].**

[4] **N. Leonor**, D. Ferreira, R. F. S. Caldeirinha, M. Sanchez, Extension of the dRET model to forests of thin cylinders , IEEE Trans. on Antennas and Propagation, Vol. 63, No. 9, pp. 4049 - 4056, September, 2015, DOI:10.1109/TAP.2015.2448752, **[Q1, Impact factor = 2.181].**

[5] **N. Leonor**, R. F. S. Caldeirinha, M. Sanchez, T. Fernandes, "A Three-dimensional Directive Antenna Pattern Interpolation Method", IEEE Antennas and Wireless Propagation Letters, Vol. 15, No. 1, pp. 881 - 884, March, 2016, DOI:10.1109/AWPL.2015.2478962, **[Q1, Impact factor = 1.579].**

[6] N. Leonor, R. F. S. Caldeirinha, T. Fernandes, M. Sanchez; "An Input Parameter Extraction Method for Point Scatterer Formulation in Vegetation Media", IET Microwaves Antennas & Propagation, 2016 **(under review).**

[7] **N. Leonor**; R.F.S. Caldeirinha; M. Sanchez; T.R. Fernandes; "A practical assessment of the 2D Ray-tracing based model for propagation through vegetation using ornamental plants with varying thickness at 60 GHz", IEEE Antennas and Propagation Magazine, 2016 **(under review).**

[8] **N. Leonor**, R. F. S. Caldeirinha, M. Sanchez, T. Fernandes, " A 2D Ray-Tracing Based Model for Wave Propagation Through Forests at Micro- and Millimeter Wave Frequencies", IEEE Trans. on Antennas and Propagation, 2016 **(under review).**

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