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 [1– 4].

The Radiative Energy Transfer (RET) [5,6] 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 1–36
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: 2D proof-of-concept

Ray-tracing algorithm

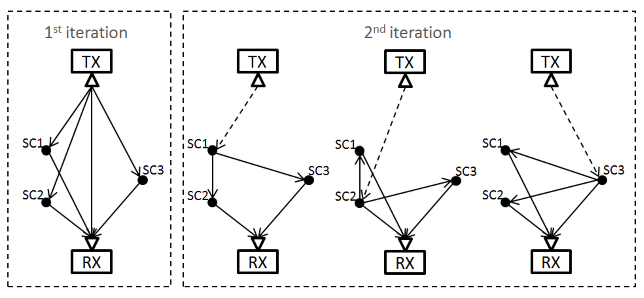

Fig.1 – Iterations of ray-tracing algorithm [7].

$$N_{multipath_{components}} = N_{scatters}^{2} + 1 \quad (1)$$

$$\mathrm{Signal}_{complex_{env}} = \sum_{i=1}^{N_{paths}} \frac{e^{\left(\frac{-i2\pi d_i}{\lambda}\right)^2}}{\left(\frac{4\pi d_i}{\lambda}\right)^2} \times \frac{1}{a_i} \quad (2)$$

$N_{scatters}$ number of point scatterers
d_i travelled distance
λ wavelength
a_i path attenuation

Measurement geometry

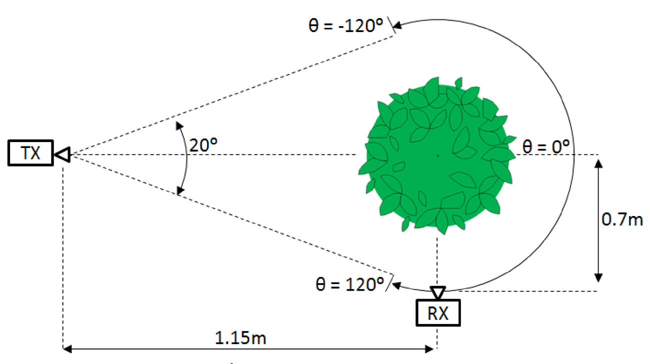

Fig.2 – Tree re-radiation measurement geometry

- 13 *ficus benjamina* trees;
- 16 conifer trees;
- 2 frequencies – 20 and 62.4 GHz.

2D scattering model

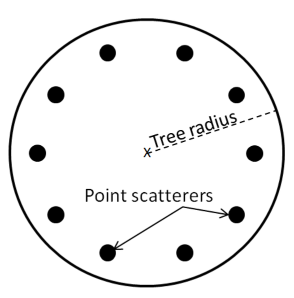

Fig.3 – Scattering model for a single tree.

$$\rho(\gamma) = \frac{\alpha.\left(\frac{2}{\beta}\right)^2 .e^{-\left(\frac{\gamma}{\beta}\right)^2} + (1-\alpha)}{\alpha.\left(\frac{2}{\beta}\right)^2 + (1-\alpha)} \quad (3)$$

$$L_{Ex} = \frac{1}{(d.Att_k + 1)} \quad (4)$$

Input parameter extraction method

β:

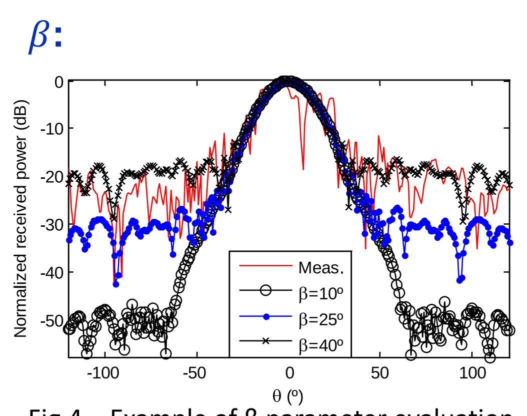

Fig.4 – Example of β parameter evaluation.

Att_k:

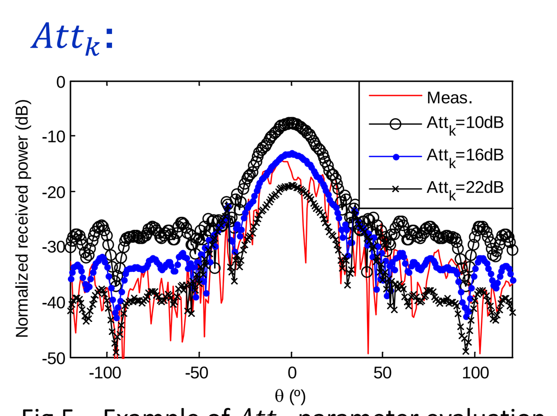

Fig.5 – Example of Att_k parameter evaluation.

➔RMSE minimization process.

Extracted input parameters

Ficus benjamina **trees**

	β		Att_k (dB)		RMSE (dB)	
Freq./ Tree #	20 GHz	62.4 GHz	20 GHz	62.4 GHz	20 GHz	62.4 GHz
1	22,3	16,0	15,2	27,6	5,8	6,1
2	15,4	14,5	9,5	22,0	5,8	6,5
3	16,3	14,0	15,2	23,9	6,6	6,4
4	17,9	23,6	9,5	26,6	5,1	7,0
5	20,7	25,6	14,6	30,1	6,2	6,5
6	17,7	11,1	10,0	22,5	5,6	6,9
7	15,3	25,6	8,5	26,5	6,9	7,7
8	14,9	23,2	12,8	30,7	5,9	6,5
9	25,8	31,8	19,2	39,2	6,5	7,3
10	25,3	19,8	14,8	26,8	5,5	6,4
11	30,0	26,2	17,5	31,4	7,0	7,2
12	15,3	25,5	12,8	29,0	6,1	6,5
13	35,4	26,1	18,8	28,2	6,9	6,8
				Avg.	**6,1**	**6,8**

Conifer trees

	β^0		Att_k (dB)		RMSE (dB)	
Freq. Tree #	20 GHz	62.4 GHz	20 GHz	62.4 GHz	20 GHz	62.4 GHz
1	34,9	30,5	29,9	41,8	7,3	7,4
2	39,7	23,8	22,5	34,5	6,6	8,2
3	44,3	34,3	23,8	40,4	7,2	6,8
4	40,9	52,2	25,5	45,7	7,4	6,5
5	53,9	33,3	26,0	38,0	6,8	8,0
6	74,0	29,0	25,4	35,6	7,5	10,4
7	40,7	38,5	23,9	40,5	6,5	8,7
8	34,3	49,7	22,5	44,7	7,9	6,2
9	34,9	32,7	23,2	38,3	6,2	7,3
10	22,8	25,7	18,4	33,8	6,0	7,3
11	34,0	42,5	20,1	40,7	7,0	7,2
12	34,9	35,7	21,6	37,8	8,2	9,2
13	42,1	38,1	24,7	42,2	8,2	8,4
14	70,3	61,0	26,5	44,4	6,7	7,5
15	39,0	27,1	24,5	35,6	6,3	7,8
16	41,3	33,1	26,7	42,5	9,0	12,1
				Avg.	**7,2**	**8,1**

Results

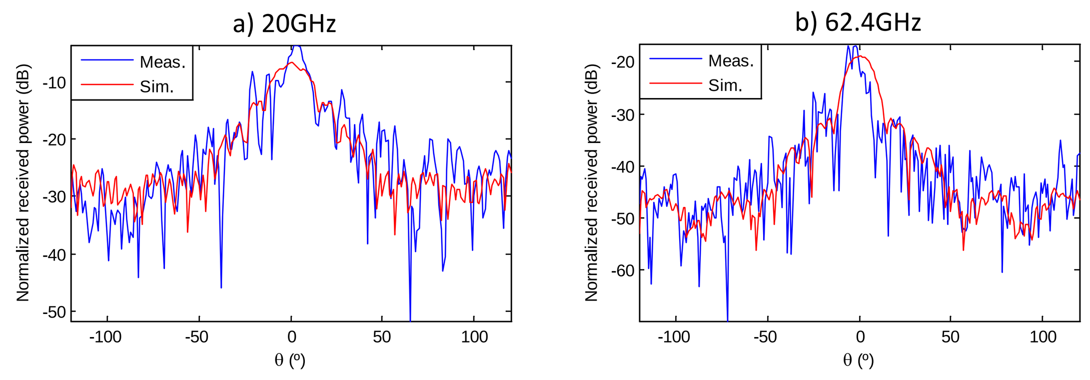

Fig.6 – Measured and predicted re-radiation function of *ficus* tree #2.

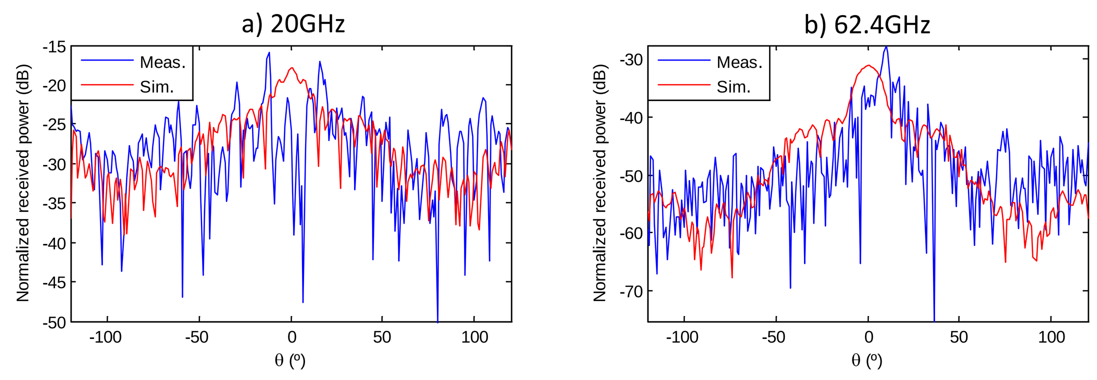

Fig.7 – Measured and predicted re-radiation function of conifer tree #3.

Next year's work plan

To build upon the current 2D static canopy scattering model and formulate its extension 3D scenarios. The tasks at the outset of this milestone are the following:

3D SCM - Measurement geometry

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

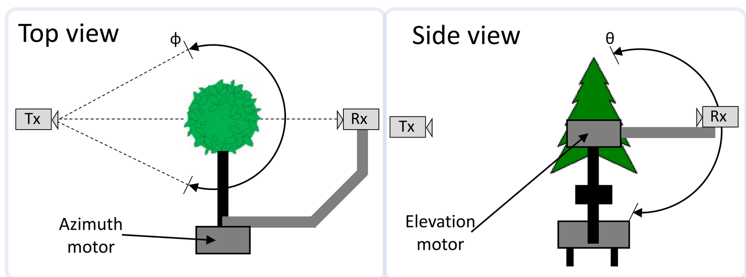

Fig.8 – Diagram of the 3D re-radiation measurement mechanical rig.

3D SCM - Scattering model

According with the 3D measurement results, a study should be performed in order to analyze 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. Some distributions are already being analyzed (see Fig. 9). Furthermore, re-radiation model of point scatterers should also be adapted to include 3D phenomena and signal depolarization.

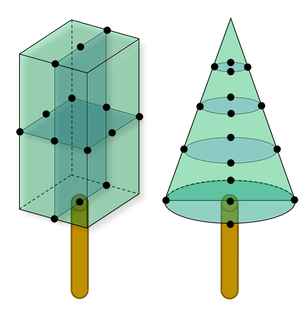

Fig.9 – Tree 3D model possibilities under consideration.

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**.

Outcomes (to date)

- Design, implementation and initial practical validation of the 2D static canopy model;
- Submission of a journal paper to IEEE Transactions on Antennas and Propagation, entitled "A 2D ray-tracing based model for micro- and millimeter-wave propagation through vegetation" (May 2014).

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