ABSTRACT - For development of wireless systems for vegetation regions, the detailed knowledge of the involved propagation mechanisms is essential. The physical and geometric parameters of the vegetation are random. Calculating the mean signal amplitude decay, both absorbing and multiple scattering effects must be taken into account. Statistical parameters of rough terrain and vegetation are important but they are not always available. In our investigations, we use a deterministic model for calculation of the losses of point-to-point paths in order to estimate the influence of some of the medium forest parameters on transmission losses.

Palavras-chaves — FDTD, random media.

I. ASPECTS OF THE WAVE PROPAGATION IN FOREST

From the point of view of electromagnetic wave propagation in forest, the Amazon region has some specific features. First of all, it is high humidity. The vegetation and terrain possess dynamic morphology that change in particular, in accordance with periodic annual climatic variations, modifying some physical properties. For calculation of electromagnetic waves that propagate in this environment, the vegetation itself should be characterized by some parameters [1], such which, (1) type of vegetation: average height, shape and distribution of the elements (trunks, branches and leaves); (2) space density (number of trees per unit of area) (3) vegetation water content: volume of water deposited in the surface of the elements and the interior of the trunks and branches. Another parameter important to consider is the variation of the electric characteristics of the soil with the moisture and salinity [2]. The losses associated with the electromagnetic scattering and absorption in the trunks and branches can be separately calculated considering each element as cylindrical scatterer (absorber) with circular cross-sections of different diameters. The distribution functions of the diameters of the elements in the analysis can be taken into account [3]-[6]. The foliage can be considered as a uniform media with losses [7]-[8]. For the frequency range where the scatterers are small compared with the wavelength, the scattering can be estimated using effective parameters of the media. The dielectric constant can be obtained by theoretical models or by semi-empirical formulas. However, such formulas in many cases possess little versatility, being appropriate for the specific cases (type of vegetation, climatic conditions and range of frequency) for which they have been implemented. The variation of the complex electric permittivity of the vegetation with parameters as frequency, moisture and salinity can be calculated using dielectric mixture models [9]-[10]. An example is the approach for dielectric constant proposed by Peake [11]:

\[ \varepsilon = m_1\varepsilon_w + (1 - m_1)2.5 \approx m_1\varepsilon_w \]  

(1)

where \( \varepsilon_w = \varepsilon'_w + j\varepsilon''_w \) is the relative complex dielectric constant of water. The dielectric constant of saline water is calculated by the Debye relaxation formulas [9]:

\[ \varepsilon'_w = \varepsilon'_w^{\infty} + \frac{\varepsilon_w^{\infty} - \varepsilon'_w^{\infty}}{1 + \left( \frac{f}{f_0} \right)^2} \]  

(2)

\[ \varepsilon''_w = \left( \frac{f}{f_0} \right) \left( \varepsilon_w^{\infty} - \varepsilon'_w^{\infty} \right) + \frac{\sigma}{2\pi\varepsilon_0f} \]  

(3)

where

- \( \varepsilon_w^{\infty} \) - static limit of \( \varepsilon'_w \)
- \( \varepsilon'_w^{\infty} \) - high-frequency limit of \( \varepsilon'_w \)
- \( \sigma \) - ionic conductivity of the aqueous solution (S/m), determined by the salinity of the solution.
- \( f \) - frequency (Hz).

II. PROPAGATION MODEL FOR FOREST ENVIRONMENT

The Amazon rain forest presents a characteristic distribution of vegetation with the peculiarities that can be taken into account to develop a model of electromagnetic propagation in this environment. The model using four dielectric layers, considered by Cavalcante[12], has been adopted in various works [13]-[16]. However, we shall consider a three layers model [17]-[19], that is, the forest represented only by one dielectric layer. This is because the Amazon rain forest, in contrast to the Europe and USA forests, is typically dense with the foliage interwining with the trunks, composing only one layer in which the electric characteristics of each constituent (trunks, branches and leaves) should be considered. Thus, our stratified model consists of three horizontal dielectric layers. The first layer is the semi-infinite free space, the second region represents the forest and the last region is the soil.
The mathematical model, in accordance with Fig. 1, can be implemented using the method of dyadic Green's functions. The following expressions for the electric field in the far zone of the dipole antennas are valid:

\[ E_z(R) = j \omega \mu_0 \int \int \int G_e(R, R') J(R') dV' \]

for \( H \geq z \geq 0 \) \( (3) \)

\[ G_e(R, R') = \frac{i}{4\pi} \sum_{n=0}^{\infty} (2 - \delta_0) x \left[ \frac{2h_1}{h_1 + h_2} D^n(-h_2) + \frac{2h_2}{h_1 + h_2} R'^n e^{/2h_2} D^n M(h_2) \right] M(h_2) \]

\[ + \left( \frac{2k_2 k_1 h_1}{k_2^2 h_1 + k_1^2 h_2} \right) \frac{1}{D^n} N(-h_2) + \left( \frac{2k_2 k_1 h_1}{k_2^2 h_1 + k_1^2 h_2} \right) \frac{R'^n e^{/2h_2}}{D^n} N(h_1) N(h_2) \] \( (4) \)

\[ R_1^V = \frac{k_2^2 h_2 - k_1^2 h_3}{k_2^2 h_3 + k_1^2 h_2} \quad e \quad R_2^H = \frac{h_2 - h_3}{h_3 + h_2} e \]

\[ D^{V, H} = 1 + R_1^V R_2^V e^{/2h_2} \] \( (5) \)

The vector wave eigenfunctions \( M e N \) are given in [20]. To obtain a compact solution and to reduce the computational efforts, some approximate formula can be deduced from the above expressions. The integral in (3) for example, can be substituted by asymptotical expressions using the method of saddle point and branch cuts integration. In this case, the electromagnetic fields are presented in the form of series of reflections in the dielectric interfaces of the layers. The direct and multireflected waves are obtained by application of the method of saddle point, while the lateral waves are as the results of the integration on branch cuts. Details on the asymptotic methods and procedure of field calculations can be found in references [20]-[22].
For frequency range of 0.2-2 GHz, and the distance between transmitter and receiver in 6 Km, the curves of losses are presented in Fig. 4. The parameters of the forest are the same used in Fig. 2.

V. FUTURE WORKS

The model can be improved using the following methods:

1. Taking into account the anisotropy of the forest layer (trunks).

2. Calculating the effective parameters of the forest layer using the methods of the diffraction theory.

3. To introduce the tensor of permittivity in the model for study of the depolarization.

4. To consider random irregularity in the surfaces of the soil and top of the trees.

5. Use Monte Carlo method for modeling of distribution of the vegetation.

6. To improve the model using techniques of generation of trees as Honda Tree and L-systems.

VI. REFERENCES


