Comparative Study of Computational Electromagnetics Applied to Radiowave Propagation in Wildfires

Stefânia Faria¹, Mário Vala¹, Pedro Coimbra¹,³, João Felício¹,³,⁴, Nuno Leonor¹,², Carlos Fernandes¹,³, Carlos Salema¹,³ and Rafael Caldeirinha¹,²

¹ Instituto de Telecomunicações, Portugal
² Instituto Politécnico de Leiria, Leiria, Portugal
³ Instituto Superior Técnico, Lisboa, Portugal
⁴ Centro de Investigação Naval, Escola Naval, Almada, Portugal
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Introduction

- Besides fauna and flora damages caused by wildfires, fires may also affect emergency communication systems;

- In 2017, the region of Pedrógão Grande in Portugal was affected by deadly wildfires and the Portuguese rescue communication network failed to assist forest fire victims.

- Since the 60’s decade, fire fighters have testified the radio-wave propagation fragility all around the world;
Modelling of radiowave propagation in fire

- One way to describe signal attenuation in wildfires is considering the Cold Plasma Model (CPM);
Modelling of radiowave propagation in fire

• Estimation of electron density:

\[ N_e = (K_1N_a)^{\frac{1}{2}} \left[ \left( 1 + \frac{K_1}{4N_a} \right)^{\frac{1}{2}} - \left( \frac{K_1}{4N_a} \right)^{\frac{1}{2}} \right] \text{[m}^{-3}] \] (1)

\[ K_1 = 2 \frac{g_i}{g_0} \frac{2\pi mkT^2}{h^3} e^{-\frac{eV_i}{kT}} \] (2)

\[ N_a = n_0 + n_e = 7.335 \times 10^{27} \frac{\xi}{T} \text{[m}^{-3}] \] (3)
Modelling of radiowave propagation in fire

• Estimation of effective collision frequency:

\[
\nu_{\text{eff}} = \frac{8}{3\sqrt{\pi}} N \left( \frac{m_e}{2kT_e} \right)^{\frac{5}{2}} \int_0^\infty \nu^5 Q^{(m)}(\nu) e^{-\left(\frac{m_e \nu^2}{2kT_e}\right)} \, d\nu \quad (4)
\]

\[
\nu_{\text{eff}} = 7.33 \times 10^3 N_m a^2 \sqrt{T} \quad [s^{-1}] \quad (5)
\]
Modelling of radiowave propagation in fire

- Relative permittivity:

\[ \varepsilon_r = \left[ 1 + \frac{\omega_P^2}{\omega(i\nu_{eff} - \omega)} \right] \]  \hspace{1cm} (6)

\[ \omega_P^2 = \frac{N_e e^2}{m\varepsilon_0} \]  \hspace{1cm} (7)

\[ \omega = 2\pi f \]  \hspace{1cm} (8)

- Propagation constant:

\[ \gamma = \alpha + j\beta = j\omega\sqrt{\mu_0\varepsilon_0\varepsilon_r} \]  \hspace{1cm} (9)
Modelling of radiowave propagation in fire

- Fire Dynamics Simulator (FDS) was used to model a fire scenario of a single tree over time.

- Parameters of a 30 s simulation:
  - *Eucalyptus Diversicolor* tree
  - K=0.9%, Ca=0.82% and Mg=0.28%
  - 385 MHz plane wave normally incident
  - Volumetric mesh of 5 cm cells
  - 80 slice divisions
Comparative study of computational electromagnetics

- Results obtained from CPM model are used as input parameters to 4 different approaches:
  - Full-Stack Model (FSM);
  - Transmission Line Model (TLM);
  - Finite-Difference Time-Domain (FDTD);
  - Commercial CST electromagnetic transient solver.
Comparative study of computational electromagnetics

- Full-Stack Model (FSM)
Comparative study of computational electromagnetics

• Transmission Line Model (TLM)
  • TLM is based on impedance matching in multiple dielectric slabs, in which propagation and marching matrices are calculated, so that incident and reflected fields are considered at each unit-cell interface.
  • Total attenuation [in dB] on a per-tube analysis is in very good agreement with FSM.
  • The study of the CDF of the ROI was also performed, yielding a 2.42 dB of peak excess loss for 90% probability of occurrence, with a difference of only 0.05 dB to FSM.

• Full-wave analysis
  • Finite-Difference Time-Domain (FDTD)
  • Commercial CST electromagnetic transient solver
Comparative study of computational electromagnetics

• Comparative analysis
## Comparative study of computational electromagnetics

- **Comparative analysis**

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<th>CST</th>
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Conclusions

• This study clearly indicates that the effect of fire may dictate the reliability of the radio communications in critical mission applications;

• Signal attenuation in wildfires can be estimated by the cold plasma model (CPM), which was used to obtain the complex permittivity across the fire scenario;

• The complex permittivity allowed then to obtain the total attenuation of each tube on a projection plane, for four different methods.
Acknowledgment

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Thank you