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3D INDOOR PROPAGATION SIMULATOR USING RAY TRACING FOR 10-20 GHZ FREQUENCY BAND ON GPU WITH NVIDIA-OPTIX UNDER UNITY GRAPHIC ENGINE

Simulador de propagación 3D para Interiores Utilizando Trazado de Rayos para la Banda de Frecuencia de 10-20 GHz sobre GPU con NVIDIA-Optix bajo el motor gráfico Unity

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ABSTRACT

In this research work, a novel Ray Tracing 3D indoor propagation simulator at frequencies of 10-20 GHz using GPU is presented. To carry out the simulation, software tools as Nvidia CUDA 10.0, CMake 3.19.4, Nvidia OPTIX 6.5, Microsoft Visual Studio Community 2017 and Unity 2018.4.21f1 were used. Two indoor line-of-sight (LOS) scenarios were defined in Facultad de Informatica y Electrónica at Escuela Superior Politécnica de Chimborazo (ESPOCH). The first one inside the Microwave Laboratory with minimum and maximum distances between Transmitter and Receiver of 0.34m (far field) and 7m, respectively; and the second one inside the ground floor hall with minimum and maximum distances of 6 and 12m, respectively. In both scenarios, real and simulated measurements were developed with frequency hops of 1GHz. A ray tracing propagation technique under GPU with NVIDIA-Optix was used for the simulation and by comparing simulated and measurement power, it was observed a difference of 10 dB approximately..

Palabras Clave: Indoor Propagation Simulator, Ray Tracing, GPU, Nvidia OPTIX, Unity.

I. Introduction

With the introduction of International Mobile Telecommunications (IMT-2020) also known as 5G NR (New Radio), new transmission bands have been proposed for their development; these bands are defined as FR1 (410 MHz – 7125 MHz), FR2 (24250 MHz – 52600 MHz) [1], Industrial, Scientific, and Medical (ISM) band for 5G NR working in Non-Licensed Spectrum, and even C (3.5 GHz) [2] and millimetric Bands used for satellite communications [3] have been proposed to work in coexistence with 5G. Other satellite bands as Ku (12 GHz – 18 GHz) an K (18 GHz – 36 GHz) bands could be feasible spectrum for 5G deployments. These facts make it necessary to study the propagation conditions and channel models for these bands in different stages. The use of simulation tools for the propagation analysis in communications systems is not new; historically the simulators use CPUs for mathematical calculations. Nowadays, the calculation power of GPUs is exploited to reduce the computing time in complex stages. This is especially useful for outdoor and indoor 3D propagation environments, in which the number of reflections that arrive to the receiver can be very large. In this sense, there

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are some software e.g. OMNET++ and Veneris [4] that use the advantage of GPU computing and realistic physics for propagation simulations. However, these tools are focused on vehicular outdoor communications. Similarly, it is worth to mention the existence of licensed indoor propagation simulators, such as iBwave for indoor wireless network design. However, the price of these licensed software could be restrictive.

Thus, the present work aims the study of: NVIDIA Optix [5] and Unity [6],[7] virtualization technologies and the implementation of Ray Tracing 3D indoor propagation simulator using GPU for the Ku and part of the K satellite band (10 GHz – 20 GHz); Also, the simulated results ware compared with real measurements at different distances and frequencies. The simulation and measurements where deploy for indoor stage with Line Of Sight (LOS).

The rest of the paper is distributed as follows. Section II presents the methodology used for simulations and measurements, Section III presents the results and finally, Section IV concludes the paper.

II. Methodology

In this section, first an introduction of Ray tracing Propagations model is pointed out. Then, the methodology used for the simulator and measurements are detailed.

A. Ray Tracing Model

The ray tracing model is an image-based model, which assumes that all the objects in the propagation environments are potential reflectors. In implementations, the ray tracing model uses the images of the transmitter relative to all reflectors, that is, all objects in the propagation environments to determine the directions of the reflected rays. Ray tracing considers only the paths that exist between the transmitter and the receiver [8].

In this model, the strength of the reflected rays and the refracted rays are calculated according to geometrical optics. The diffracted rays are calculated according to, for example, uniform theory of diffraction (UTD) [9]. The complexity of the propagation environments in Ray Tracing model has a strong impact on their computational load, as more obstacles exists, it leads to more reflections and diffractions. According to this method, each pixel (Rx) receiving power is individually computed. The images of the transmitter are established to determine the reflected rays, that is, the relative image of the Tx to the reflecting plane (Tx' or Tx") as shown in Fig. 1. Since each one of the pixels is calculated independently, the computation time is high, but the results obtained with this method are very accurate, because all the relevant objects in the propagation are considered. In the basic ray tracing models, the prediction is based on "free space" propagation model for ear ray and the reflections on the different walls. Therefore, in this paper the free space model equation (Friis equation) was used for the propagation losses.

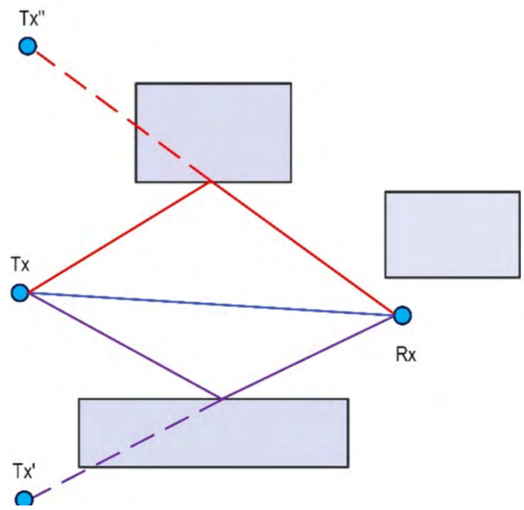

Fig. 1. *Ray Tracing Propagation Model*

B. Simulation

For the development of the simulator, it was necessary to use the following tools.

- NvidiaCUDA 10.0: allows the development of applications with graphics engine.
- Microsoft visual studio community 2017: programming software under which the code was written.
- Nvidia OPTIX 6.5: ray tracing API, allows integration of software with 3D dimensioning.
- CMake 3.19.4: allows the compilation of Optix with Visual Studio 2017 programming software.
- Unity 2018.4.21f1: video game development platform on which the stage (Digital Twin) was mounted.

Is important to highlight that Unity has full integration with Nvidia OPTIX, which allow directly calculate the ray tracing reflection and diffraction within the proposed stages.

1. Simulator parameters

As any simulator, input and output parameters were defined, these are.

Input Parameters:

- *Transmission Power.* - The transmission power at the real and simulated stages was set to 18 dBm.
- *Cable and connector losses.* - These values can vary between 1 to 3 dB, however, for the proposed study this value was set to 2 dB.
- *Distance.* - The distance varies according to the proposed stage (Section II.D), these are:
  - o Stage 1: From 0.34m to 7m
  - o Stage 2: From 6m to 12m
- *Tx – Rx Antenna Gain.* – The antenna Gain for the proposed study between 10 and 20 Ghz.
- *Number of reflections.* - The number of reflections were defined by default at 5, however, this may be modified according to the needs of the study.
- *frequency.* - The frequency is defined between 10 to 20 GHz.

Output Parameters:

- *Propagation losses.* - Value that refers to the amount of power that has been lost during the signal path. For the models studied, it depends on both the distance and the operating frequency.
- *Reception Power.* - It is the power that reach the receptor.
- *Distance-Multipath.* - Travel distance values for each ray of the Multipath components to the receiving antenna.

In the simulator, all the parameters are shown within a "Canvas"; this Canvas is a container within the elements that are part of the results graphical interface are placed, as shown in Fig. 2.

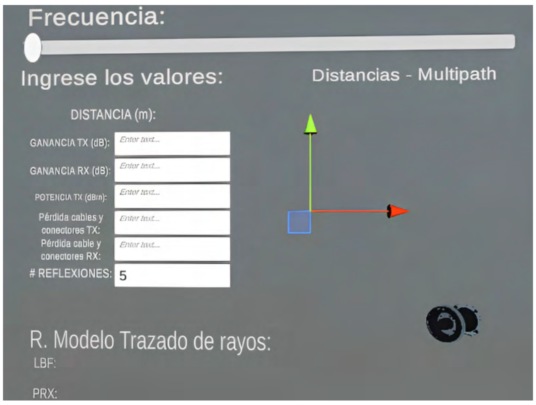

Fig. 2. *Unity "Canvas" utility*

2. Calculation of Rx Powers

First, the losses for each path are calculated using the Free Space Propagation Model [10], as is Shown in the Ec. 1:

$$L_{bf}(dB)=32,45+logf(Mhz)+20logd(Km) \qquad (1)$$

Where, L_{bf} is the Propagation losses in free space, f is the transmitting frequency and d is the distance between Transmitter and receiver. Once the value of the transmission losses has been calculated, the received power of each ray was obtained using the Ec. 2.

$$P_{rxi}=P_{tx}+G_{tx}-L_{cc-tx}-L_{bfi}+G_{rx}-L_{cc-rx}-\sum_{j=1}^{n}L_{ref} \qquad (2)$$

Where the P_{rxi} is the receiver power in dBm of the i-th ray , G_{tx} and G_{rx} are the transmission and reception antenna gain in dBi, L_{bfi} is the Free Space Losses for i-th ray obtain with the Ec.1 in dB, L_{cc-tx} and L_{cc-rx} are the transmission and reception feeder lost in dB, finally $-\sum_{j=1}^{n}L_{ref}$ are the losses in dB due to the *n* reflections of the ray in the obstacles, this value depends on the obstacle material, fin this case, it was used a 3 dB reflection loss in each obstacle. Finally with the Ec. 3 the total receiver power was calculated.

$$P_{rx}=10log\left(\sum_{i=1}^{n}10^{\frac{P_{rxi}}{10}}\right) \qquad (3)$$

Where P_{rx} is the total received power in dBm,P_{rxi} is the received power in dBm of the i-th ray calculate with the Ec.2, and n is number of rays that reach the receiver.

In other hand, to compare the simulate and measured values, the Root Mean squared error (RMSE) was calculated using the Ec. 4.

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{rxi\_s}-P_{rxi\_m})^2} \qquad (4)$$

Where n is the number of values, P_{rxi_s} and P_{rxi_m} are the simulated and measured received power, respectively.

C. Stages

A Digital Twin of FIE's building was used for the stages. The FIE Digital Twin was mounted in UNITY as is Shown in Fig.3. Then, two stages within the Digital Twin with line of sight (LOS) were chosen.

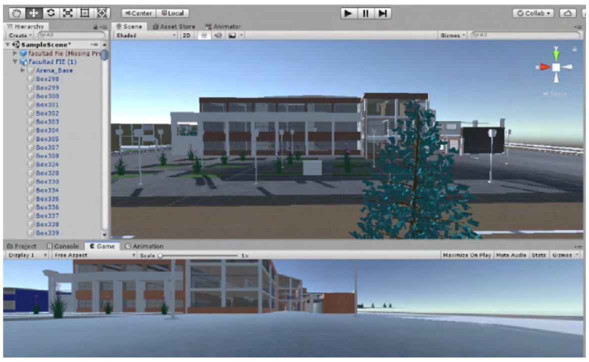

Fig. 3. *Digital Twin of Faculty of Informatics and Electronics in Unity*

Stage 1: For the first stage, it is proposed an analysis of the propagation with LOS, but at short distance. This scenario is performed inside the microwave laboratory, which is located on the third floor of the building, as shown in Fig. 4. The maximum and minimum possible distance between Tx y Rx is 7 m and 0,34 m (Far Field for 20 GHz), respectively.

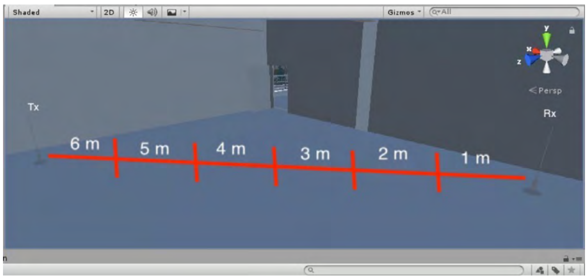

Fig. 4. *Simulation 1, LOS in the Microwave Laboratory*

Stage 2: In this case, other LOS stage was proposed, but with a greater distance. Therefore, a stage in the hallway of the ground floor of the FIE building was chosen. In this case, the maximum and minimum distance are 12 m and 6m, respectively. As is shown in Fig. 5.

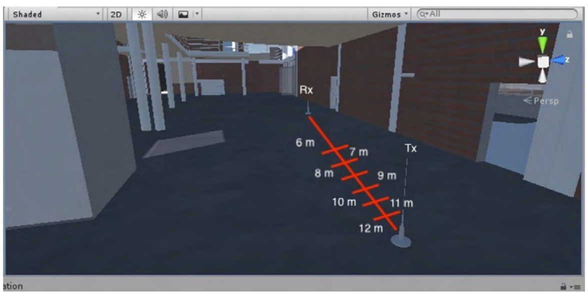

Fig. 5. *Simulation 2, LOS propagation in first floor hall.*

D. Measurements

The real measurements were performed in the real stages (Fig. 6 and Fig. 7). The measurement setup is shown in Fig. 6. A Signal Generator Anritsu MG3692C was used for the transmitter. The receiver power was measured with an Anritsu MS2724C Spectrum analyzer, and for both, Transmitter and Receiver a Horn antenna with same characteristics was used. The measurements were taken with steps of 1 GHz in frequency and 1m in distance.

Fig. 6. *Real Stage 1, Microwave laboratory*

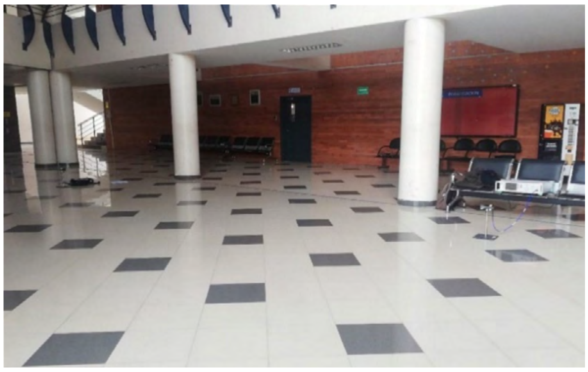

Fig. 7. *Real Stage 2, FIE ground floor*

The gain of the horn antennas for the studied frequencies is shown in the Fig.8.

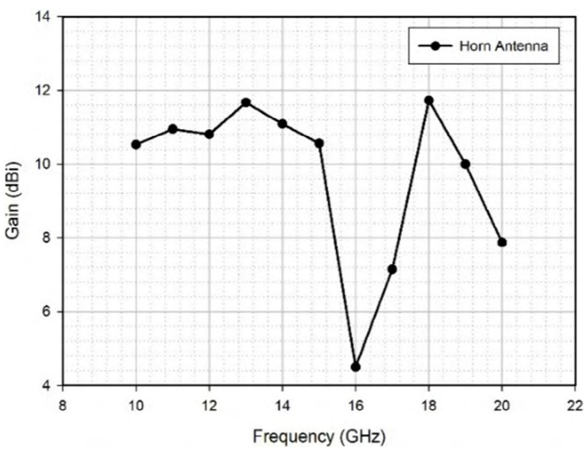

Fig. 8. *Horn Antenna Gain*

III. Results and discussion

In this section the results of simulations and real measurements are presented and compared.

A. Stage 1: Microwave Laboratory

The simulations were carried on over the FIE Digital Twin for the frequencies and distances defined in the Section II and considering all the reflected rays that reach the receiver as shown in Fig. 9.

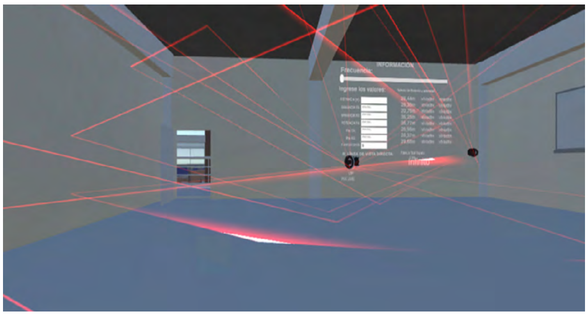

Fig. 9. *Ray Tracing simulated view (Stage 1).*

The simulated reception power for the different frequencies and distances are shown in the Fig. 10. It should be noted that as expected, the receiver power decreases with the distance and the frequency with a difference of 14 dB approximately for 1m compared to 7 m, and 11 dB for 10 GHz, compared with 20 GHz.

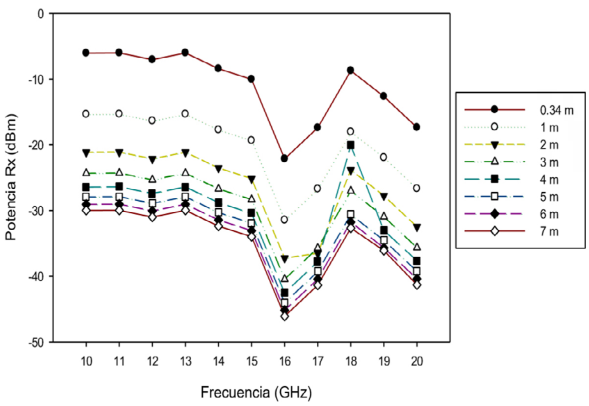

Fig. 10. *Simulated received power using Ray Tracing Model (Stage 1)*

In the other hand, the Fig. 11 shows the measured received power in the same stage. As it is shown in Fig. 11, the measured values have a similar behavior such as the simulated ones. In this case the RMSE is 5.57, this difference is considered acceptable, one of its causes is due to simulation doesn't consider the office furniture present in the real stage.

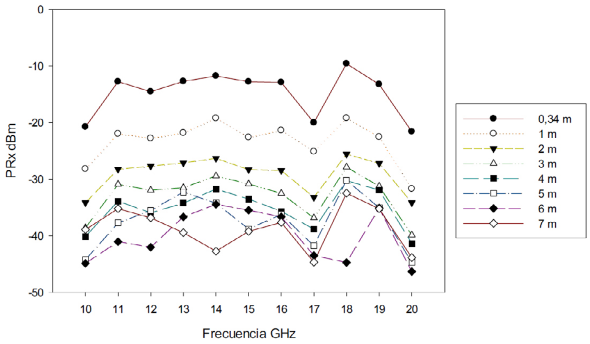

Fig. 11. *Measurement received power (Stage 1)*

Finally, In the Fig. 12 a comparison between simulated receiving power and real measurements for the shortest (0.34 m) and longest distance (7 m) is presented. The RMSE for 0.34 m. distance is 6,72, and for 7 m distance is 6,44.

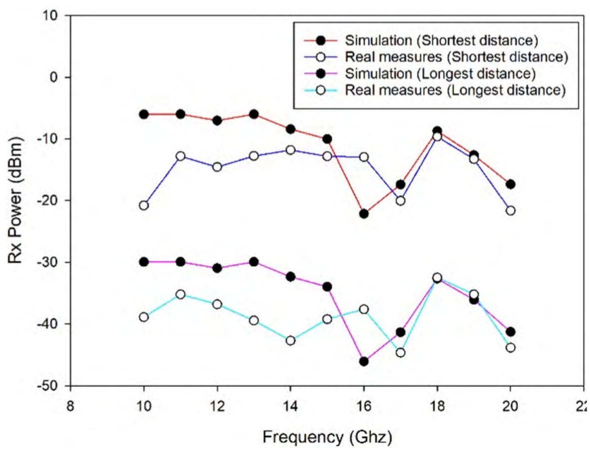

Fig. 12. *Simulate and measurement receive power: Shortest (0.34 m) and Longest distance (7 m) (Stage 1).*

B. Stage 2: FIE Ground floor

As in the previous stage, simulations were carried out on the FIE's Digital Twin considering all the reflected rays that reach the receiver as it is shown in Fig. 13.

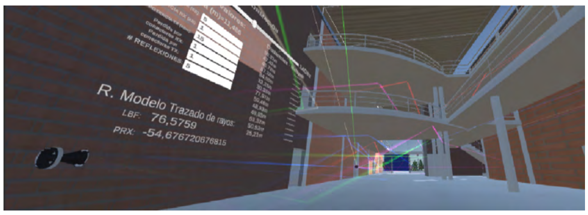

Fig. 13. *SSimulator running (Scenario 2)*

Fig. 14 shows the simulated receiving power using the Ray Tracing model. Also in this case as expected, the receiver power decreases with distance and frequency. The difference between 6m and 12m is 5dB for the same frequency, and 12 dB between 10 GHz to 20 GHz for the same distance.

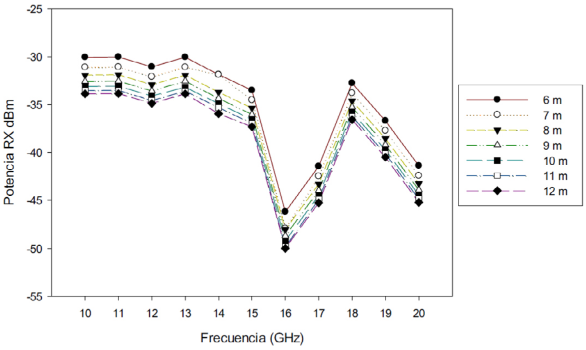

Fig. 14. *Simulated received power using Ray Tracing Model (Stage 2)*

In the other hand, the measurements for this stage are shown in the Fig. 15. In this case the RMSE between real measurments and simulated reception power is 7.

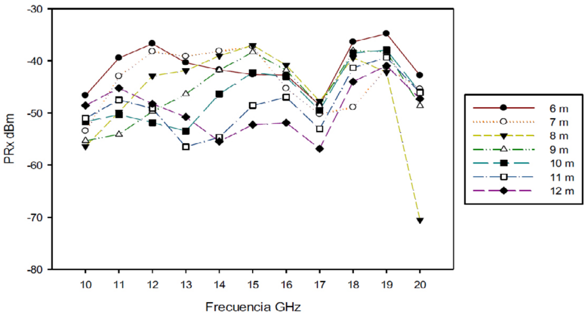

Fig. 15. *Measurement received power (Stage 2)*

As it could be observed in the Fig. 16, the variations in the results are approximated to those obtained in the Microwave Laboratory (Stage 1); the simulated values have a difference of around 10 dB with the real ones. Also it can be noted that the difference tends to decrease when frequency increases.

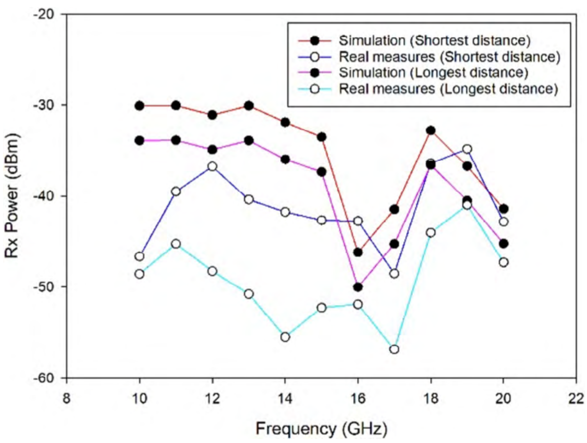

Fig. 16. *Simulate and measurement receive power: Shortest (6 m) and longest distance (12 m) (Stage 2).*

Since it is a more open scenario, a greater power variation is obtained compared with the stage 1, i.e. The RMSE for 6 m. distance is 8.32, and for 12 m distance is 12.10, compared to a RMSE of 6.44 for 7 m distance in stage 1. Also, it can be noted that the difference between the lower frequency (10 GHz) and higher studied frequency (20 GHz.) are 12 dB and 3 dB, approximately. The same behavior can be seen in stage 1, it means that at higher frequencies the simulated values are more accurate; this is because at higher frequencies the Fresnel zone is smaller, i.e. and could be approximated to a ray.

IV. Conclusions

- The difference between simulated and measured values for the first stage in terms of RMSE are 6.72 for the shortest path (0.34 m) and 6.44 for the longest (6 m). In other hand, for the second stage the RMSE are 8.32 and 12.1 for the shortest distance (6 m) and longest Distance (12 m), respectively. These differences are due in the Digital Twin the office furniture was not considered.

- The difference between the lower frequency (10 GHz) and Higher studied frequency (20 GHz) for the same distance are 12 dB and 3 dB, approximately. It could be noted that since the frequency increases, the simulate values are more accurate. This is due that at higher frequencies, the Fresnel zone are smaller, and the wave propagation could be approximated to a ray.

- The use of tool that in a beginning was development for light reflection in high quality graphics, this is the case of Nvidia OPTIX. Could be used to accelerate propagation studies at higher frequencies and complex stages, for example for indoor propagation environments like those presented in this paper.

V. Referencias

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