Adjusting the Level of Detail in 3D Models for Wireless Channel Generation using Ray-Tracing

Lucas Mozart, João Borges, Ilan Correa and Aldebaro Klautau

***Abstract*— The usage of ray-tracing techniques alongside 3D models of the real-world environment offer one of the most accurate forms of communication channel modeling. However, as a downside, the complexity of the 3D environment can significantly impact the time consumption of channel modeling simulations. We investigate the trade-off between 3D simplification versus channel accuracy and time consumption by comparing the data obtained in experiments with three different simplificated versions of the 3D scenario. This work uses the open-source software NVIDIA Sionna and the Normalized Mean Square Error (NMSE) for the channel modeling and the channel comparison, respectively.**

***Keywords*— 3D simplification, channel modeling, ray-tracing, simulation complexity.**

I. Introduction

Ray-tracing techniques are one of main candidates to realistically model the propagation environment, given its increased accuracy in comparison with using stochastic models [1].

However, one of the main problems involving simulations that use ray-tracing is the fact that it is computationally intensive. To address this complexity versus accuracy trade-off, the literature most proposes simplification methods such as in [2] and [3], in which the authors evaluate the simplification of the ray-tracing channel modeling based on changes in simulation parameters, e.g. the number of Multi Path Components (MPCs) or the number of reflections allowed.

In [4] the authors simplify the simulation through a less common approach, namely the simplification of the 3D model, as the large number of faces it has cause a great impact on the simulations. However, they focus on a specific environment: natural caves, and the conditions that are created for the simulation due to this fact. This paper follows these same idea of simplifying the 3D environment, but targeting urban environments instead of the internal parts of a cavern.

II. Experiment Description

The simplification was done using the open-source software Blender, which provides tools for modeling and editing the 3D model used in the simulation, as shown in Fig. 1, as well as preparing the file in Mitsuba format, which will be used to create the channel. Regarding channel generation, there are various initiatives to address this area, such as the one developed by the company NVIDIA, which integrated a ray-tracing module in their open-source simulator for the physical and link level layers of wireless and optical communication system, named Sionna [5], which was used in this paper.

Fig. 1. Original scenario used to generate the simplified versions.

A. Adopted Methodology

The methodology adopted in this paper is described in Fig. 2. First, the 3D original model is loaded into the software that has the necessary simplification tools, then we subject this scenario to a simplification process and generate three models, each with a different level of complexity. Next, the channels are generated for each one and the Normalized Mean Squared Error (NMSE) and the ray-tracing duration are calculated. Finally, the results are compared and with this, we can analyze the trade-off between accuracy, with the NMSE, and efficiency, with the ray-tracing duration.

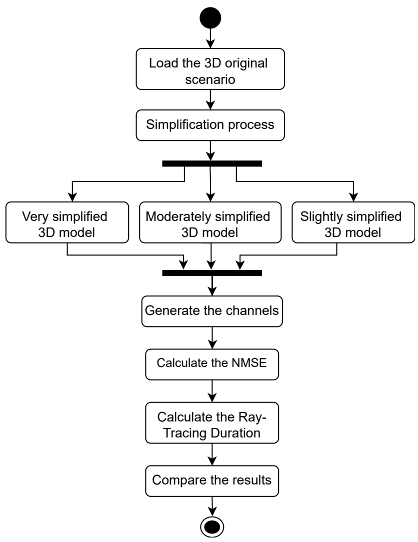

Fig. 2. Diagram illustrating the methodology outlined in the paper.

Lucas Mozart, João Borges, Ilan Correa and Aldebaro Klautau are with LASSE - 5G and IoT Research Group, Federal University of Pará (UFPA), Belém 66075-110, Brazil (email: {lucas.souza.carvalho, joao.tavares.borges}@itec.ufpa.br; {ilan, aldebaro}@ufpa.br). This work was partially financed by the Innovation Center, Ericsson Telecomunicações S.A., Brazil; Universal (CNPq grant 405111/2021-5); Project Smart 5G Core And MUltiRAn Integration (SAMURAI) (MC-TIC/CGI.br/FAPESP under Grant 2020/05127-2) and ISACI.

B. Blender Decimation Method Usage

To simplify the 3D models we adopted the approach of varying the decimation ratio of the *decimation object modifier* in Blender. This modifier uses a variation of the quadric edge collapse method [6] and defines the level of simplification will be done on the 3D model, which varies from 1 to 0, with 1 being without simplification.

In the three simplified models, the decimation rate value was used on almost all objects in the scene in a uniform way according to the level of complexity of that scene. The rates used are, from the least to the most simplified: 0.3, 0.6 and 0.8, and the main objective is to maintain the best possible shape. Certain objects with few faces, more specifically with less than 100 faces, were not subject to decimation, because any simplification led to significant loss or complete destruction of their format.

C. Experiments Parameters

All simulations here were performed with the transmitter (Tx) on top of a tower in the middle of the city, 12 meters above the ground, while the receiver (Rx) was on the ground and with both, Tx and Rx, looking in random directions. For the ray-tracing duration simulation the Rx was fixed without line of sight, but for the simulation involving the NMSE calculation it was moved through 100 different positions in the city, and the average was calculated for each simplified scenario. Regarding the electromagnetic materials, all scenarios have the same ones, with their properties being shown in Table I, in terms of the real part of the relative permittivity (ε_r) and the conductivity (σ).

TABLE I
MATERIALS SPECIFICATIONS

Materials	ε_r	σ[S/m]	Occurences in the scenario
ITU_chipboard	2.58	0.38	79
ITU_metal	1	10^7	364
ITU_wood	1.99	0.24	2948
ITU_concrete	5.24	0.82	8786
Asphalt	5.72	0.0005	1479

III. RESULTS

In Table II, the duration of ray-tracing in each scenario is compared, including the original scenario without simplification. Each value in the mean duration column represents an average of 50 ray-tracing runs. Additionaly, Fig. 3 shows how different the scenarios are from each other using the NMSE metric with the original scenario as ground-truth along with the ray-tracing duration shown previously. Each bar represents the average already mentioned and the red mark represents the standard deviation indicated in the "STD" column of Table II.

These results suggest that the duration of ray-tracing, and consequently, the cost of this process, decreases as we reduce the total number of faces in the 3D scene while maintaining a certain accuracy, with a difference between the most and the least simplified scenarios being less than 2 dB. However, in the number of faces there is a reduction of around 70% and a gain of around 8 seconds per run as shown in the NMSE graph.

TABLE II
RAY-TRACING DURATION PER SCENARIO

Simplif. level	**# of faces (M)**	**Mean dur. (s)**	**STD**
Very	1.86	185.62	1.53
Moderately	3.59	190.02	2.22
Slightly	4.74	193.86	35.3
None	5.92	206.60	7.15

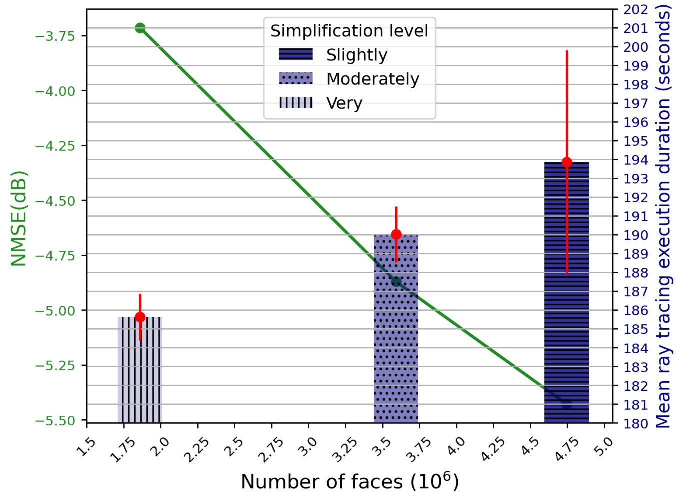

Fig. 3. Comparison between the three simplified scenarios regarding the NMSE and the ray-tracing duration with the standard deviation.

IV. CONCLUSIONS

In this paper, the effects on the channel generated by ray-tracing were analyzed as the model is simplified, with this simplification being divided into 3 scenarios, each with a certain level of simplification, concluding that it is possible to simplify complex 3D scenarios and maintain good channel accuracy even in very simplified models. Future works could explore using new 3D simplification algorithms, as well as increasing the complexity of simulations by modifying parameters such as the maximum number of reflections, diffractions, scattering, etc.

REFERENCES

[1] S. Bastos, A. Oliveira, D. Suzuki, L. Gonçalves, I. Sousa, and A. Klautau, “Generation of 5G/6G Wireless Channels Using Raymobtime with Sionna’s Ray-Tracing,” in *XLI Simpósio Brasileiro de Telecomunicações e Processamento de Sinais*, 2023.

[2] M. Lecci, P. Testolina, M. Giordani, M. Polese, T. Ropitault, C. Gentile, N. Varshney, A. Bodi, and M. Zorzi, “Simplified Ray Tracing for the Millimeter Wave Channel: A Performance Evaluation,” in *2020 Information Theory and Applications Workshop (ITA)*. IEEE, 2020, pp. 1–6.

[3] M. Lecci, P. Testolina, M. Polese, M. Giordani, and M. Zorzi, “Accuracy Versus Complexity for mmWave Ray-Tracing: A Full Stack Perspective,” *IEEE Transactions on Wireless Communications*, vol. 20, no. 12, pp. 7826–7841, 2021.

[4] R. Novak, A. Hrovat, M. D. Bedford, and T. Javornik, “Geometric Simplifications of Natural Caves in Ray-Tracing-Based Propagation Modelling,” *Electronics*, vol. 10, no. 23, 2021. [Online]. Available: https://www.mdpi.com/2079-9292/10/23/2914

[5] J. Hoydis, F. A. Aoudia, S. Cammerer, M. Nimier-David, N. Binder, G. Marcus, and A. Keller, “Sionna RT: Differentiable Ray Tracing for Radio Propagation Modeling,” *arXiv preprint arXiv:2303.11103*, 2023.

[6] M. Garland and P. S. Heckbert, “Surface Simplification Using Quadric Error Metrics,” in *Proceedings of the 24th annual conference on Computer graphics and interactive techniques*, 1997, pp. 209–216.