Acceleration Method of Radio Propagation Simulator Based on the Ray Tracing for the Prediction of MIMO Channels in Dynamical Railway Environment.

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***Abstract*—The 3D ray tracing method requires a detailed description of the environment and antenna characteristics. Thus, it allows us to consider all the paths between receivers and transmitters for a fixed number of electromagnetic interactions. However, the computational complexity of this method is directly connected to the number of scatterers and the electromagnetic environment interactions. Thus we proposed an optimization method allowing reducing the computation time of a railway tunnel simulation. It consists in modifying the modeling environment, by eliminating non-significant faces. The aim of our method is, in this case, to provide estimated results close to those obtained with a complete environment modeling, but in fewer computation time.**

***Index Terms*—radio wave propagation simulator, channel modeling, computation time optimization**

I. Introduction

Since some years wireless communications systems found their place in the railway transport. Various solutions have been proposed in order to enhance the safety of railway traffic as the use of the transmission of data to locate trains and transmit the information of speed and stop in real time. However, there remain some obstacles to overcome in confined environments as tunnels and metros-stations. Thus, the propagation channel modeling is essential in a digital railway communication. Indeed, it contributes to the development and the optimization of new techniques which allow achieving train-floor high rate transmission systems, robust and safe in radioelectric resources, for confined propagation environments, which present a high variability due to the circulation of trains. Thus, it is fundamental to take into account the dynamical features of such environments not only for the systems conception but also in the final network deployment step.

In the ANR project PREDIT MOCAMIMODYN, we propose an optimization method allowing reducing the computation time of a railway tunnel simulation. It consists in analyzing the impact of the different faces constituting the environment on the wave propagation. The first step of our study consists in identifying the faces that significantly contribute to the wave propagation. The second step consists in lightly modifying the environment modeling, by eliminating non-significant faces. The aim of our method is, in this case, to provide estimated power close to those obtained with a complete environment modeling, but in a fewer computation time.

This article is composed of several sections. In Section 2, we present our radio propagation simulator. The section 3 is composed of four sub sections. In sub section 3.A we recall our objectives. The sub section 3.B is dedicated to present the considered scenario and the parameters of the simulator. In the sub section 3.C we define the approach used to meet our objectives and finally, in the sub section 3.D we present our results. In the section 4, we show the impact of the modification of the description of the considered environment on the narrow band parameters. Finally, Section 5 is a brief conclusion where we announce the prospects for this work.

II. Propagation channel Simulation

During the propagation between the transmitter and the receiver, the transmitted signal undergoes some perturbations caused by the electromagnetic interactions. These ones have a direct consequence on the received signal as decreasing the total power received, and on the intrinsic parameters of the waves, as phase and the polarization.

In literature, there are several ways to modelize a complex propagation channel as the statistical, the empirical methods and the deterministic one [6]. In our case, the deterministic approach seems very interesting because it uses the complete description of the environment and the antenna characteristics to give a detailed description of the received signal.

In order to predict [7], [8] the wireless radio communication channel performances, the XLIM-SIC laboratory has developed a radio propagation simulator whom the synoptic is presented on figure 1. This simulator is based on a 3D ray tracing associated to the geometrical optics laws (GO) and the Uniform Theory of Diffraction (UTD). Input data are the environment description in 3D, the maximum combination of electromagnetic interactions, in addition with antennas features of transmitters and receivers, carrier frequency etc. The output ones are complex impulse responses, received power and all wide-band characteristic parameters. The 3D ray tracing method allows us to consider all the paths between receivers and the transmitter for a fixed number of electromagnetic interactions. However, the computational complexity of this method directly lies on the number of environment scatterers and electromagnetic interactions. Figure 2 gives a screenshot of the radio propagation simulator. Zone 1 allows configuring the transmitter and receivers antennas features like location,

[1] MOdèles de CAnaux MIMO DYNamique

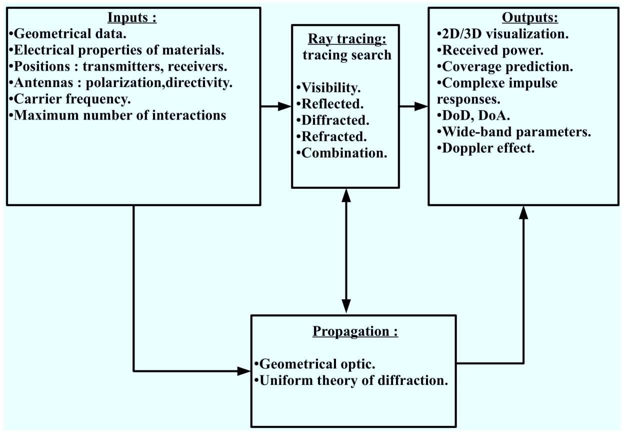


Fig. 1. Synoptic of the radio propagation simulator

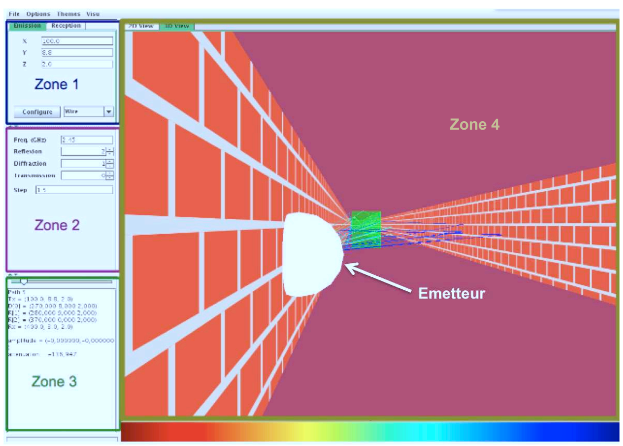
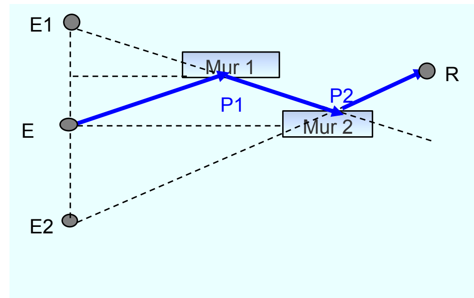


Fig. 2. Radio propagation simulator interface

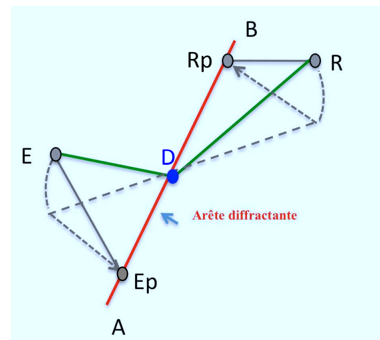
orientation, radiation pattern and so on. In zone 2, we state the frequency and the number of electromagnetic interactions. Zone 3 allows us going through the details of each path (as the coordinates of each interaction point, the nature of the interaction and the power associated to this path). Finally, zone 4 is a 3D view of the environment in which appear all the paths between the transmitter and the receiver.

This tool is based on a research technique using the method of sources / images based on Snell's formalism (see figure 3(a)) to determine the rays reflected on flat surfaces in addition to the method of folding [4] (see figure 3(b)) based on the generalized Fermat's principle and allows to determine the diffracted rays on the edges. This technique is fast and simple to implement.

However, its computation time increases exponentially with the number of obstacles and the number of electromagnetic interactions considered. Thus, the following paragraph provides a method for reducing the computing time by simplifying the geometric modeling environment.



(a) Illustration of the sources / images technic



(b) Illustration of the folding technic

Fig. 3. Research methods of the reflected and the diffracted paths exist between transmitter and receiver

III. Optimization

A. Objective

Recall that the aim of this study is to degrade progressively the geometric description of the environment considered by removing all the faces in the shadows areas and do not contribute enough to the energy balance, without compromising the accuracy of simulation results.

In order to determine the impact of each faces of the environment on the waves propagations, we are interested primarily in the received power. However, other characteristics parameters such as delay spread and Doppler effect will be studied in the near future. In addition, we found more appropriate, initially, just focus on the moving elements (the faces of the moving train) rather than those of fixed elements. Especially, the context of our work considers the study of the waves propagations in dynamic environment. Thus, we set the reference power denoted P_{ref} to the power associated to the packet of paths interact with the moving train (see figure 4). We then compare the reference power to the power associated to the packet of paths interact with one face, denoted P_{face}. If the difference exceeds a threshold we fix in the subsection 3.C, we can consider this face as a non-contributory because the energy provided by the paths that interact with this face is negligible. The difference between P_{ref} and P_{face} is calculated for each position of the train and for each pair of transmitting and receiving antennas in the tunnel. We can then identify all the positions for which the power associated with a face is considered insignificant. In the remainder of this paper, the faces are numbered to facilitate the reading of this document.

B. Scenario and configuration of the simulator

The study was conducted in the case of a dynamic environment associated with a 4x4 MIMO channel. We have modeled a bi-ways concrete tunnel (ϵ = 10 Fm^{-1} and σ = 0.1 Sm^{-1}) that contains two metallics trains (ϵ = 1 Fm^{-1} and σ = 56 000 Sm^{-1}). One is fixed and placed below the network of transmitting antennas (see figure 4) and the other is mobile and placed below the network of receiving antennas (see figure 4). The mobile train moves with a step set at λ/ 3, ie every 1.7 cm with a frequency of 5.8 GHz. We have chosen a small sampling step in order to take into account all the variations of the received power can appear from one position to another. The transmit power is 1 mW, the dimensions of the tunnel are 500 x 4.5 x 4.5 m 3. The two trains have the same size, 120 x 3 x 4 m 3. The emitters antennas are placed at a height of 4.3 m (depending on the z axis) from the floor of the tunnel either at 30 cm from the roof of the train, the four transmitters are spaced by 50 cm. The receivers antennas used here are dipoles that radiate evenly in the azimuthal plan (omnidirectional). The receivers are placed at a height of 4.1 m (depending on the Z axis) of the tunnel floor either at 10 cm from the roof of the moving train and spaced by 50 cm. According to several previous studies carried out in railway environment [9], we have limited the number of reflexions and diffractions to six and one respectively which is sufficient to garanty the power convergence. Obviously no transmission is needed due the width of tunnel walls.

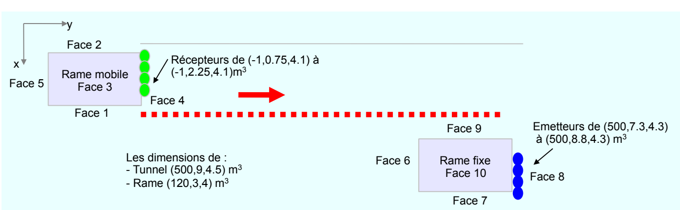


Fig. 4. Studied environment

The sixteen faces of our environment are numbered from 0 to 15 (see Figure 4) as:
- The face 0 corresponds to the floor of the moving train
- The face 11 corresponds to the floor of the fixed train
- The face 12 corresponds to the tunnel floor
- The face 13 corresponds to the tunnel ceiling
- The face 14 corresponds to the tunnel wall side the moving train
- The face 15 corresponds to the side wall of the tunnel the fixed train

C. Method of identifying influential faces

For each position, denoted i, to the train and the receivers antennas (network of mobile antennas) in the tunnel, we calculate the instantaneous gap (1), noted $err_{inst,i}$ (see figure 5) such as:

$$err_{inst,i} = P_{ref,i} - P_{face,i} \quad (1)$$

Where :
$P_{face,i}$: the power only constituted by paths having hit the corresponding facet in i
$P_{ref,i}$: the power only constituted by paths having hit the moving train in i

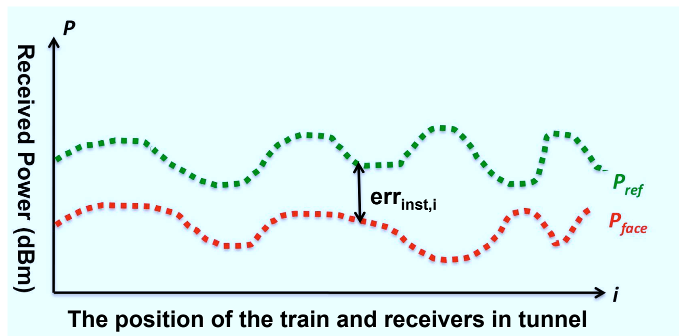


Fig. 5. The computation of the gap between P_{ref} and P_{face}

With a threshold that we arbitrarily fixed, we can identify three categories of faces. Thus:
- If $err_{inst,i}$ is less than or equal to 10 dB, the face belongs to the category of contributory Faces (CF);
- Otherwise, if $err_{inst,i}$ is between 10 dB (excluded) and 20 dB (inclusive), the face belongs to the category of Medium Contributory Faces (MCF);
- Finally, if $err_{inst,i}$ is strictly greater than 20 dB, then the face belongs to the category of Non-Contributory Faces (NCF).

To quantify the impact of each face on the wave propagation in tunnel, we take the maximun of three values obtained by counting the number of positions, where a face is classified as FC, FMC and finally FNC: **max(sum(FC), sum(FMC), sum(FNC))**

We consider a threshold of 10 dB which is very pessimistic because an error of 10 dB is relatively consistent. Thus, we avoid to discriminate faces whose can be important to the waves propagations. Although crude, this arbitrary value can, however, to lay the foundations of our optimization method. Consequently , a further study will be conducted to refine the threshold.

D. Results

In this subsection, we propose to apply the method mentioned in sub section 3.C, taking as reference power, the power

P_{ref}. This will allow us to initially identify the faces of the mobile train were hit by the rays do not contribute sufficiently to P_{ref}. Thus, we can count the number of times a face belongs to the category CF, MCF and NCF. We then classify these faces of the more energetic to the least energy.

TABLE I
THE DISTRIBUTION OF VALUES (POWERS) BY CATEGORY

Liaison E1R1	FC	FMC	FNC
Face 0	0,190%	0,010%	99,80%
Face 1	28,30%	22,86%	48,83%
Face 2	05,97%	15,27%	78,75%
Face 3	66,98%	25,00%	8,021%
Face 4	79,60%	14,15%	06,25%
Face 5	20,64%	08,47%	70,90%

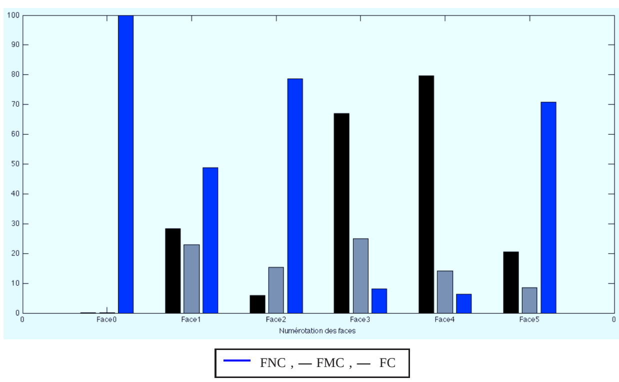


Fig. 6. Identification of contributory faces , medium contributory faces and non-contributory faces for the link E1R1

We first present some results obtained for the link E1R1. Table III-D allows us to classify the six faces of the moving train by category of importance. We observe that the face 4 is the most contributory because 79.60 % of the received powers represent a gap less than 10 dB compared to $P_{ref,i}$. This is followed by the face 3 (66.98%), face 1 (28.30%), face 5 (20.64%), face 2 (5.97%) and finally the face 0 (0.19%) (see figure 6).

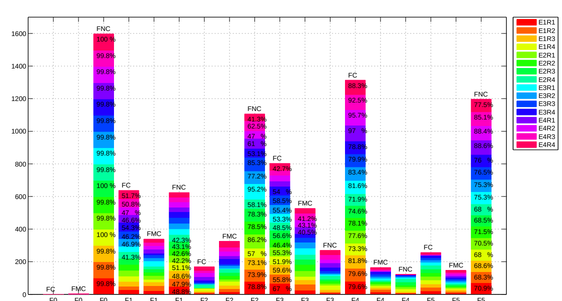


Fig. 7. Identification of contributory faces , medium contributory faces and non-contributory faces

To generalize those observations to the overall results, we have plotted a diagram (see figure 7) which represents all those percentages values for the 16 sub-channels MIMO. For each face we have three bars. Each bar bears a label to refer to the category to which this face belongs, and the number of times a face belongs to a category. We can notice that each bar contains several pads which we have assigned by different colors. Each color represents a link. The height of each pad will increase or decrease according to the percentage of power received by the corresponding face. When the percentage of the received power tends to zero, the higher of the associated pad tends to a thread. With this representation, we found that regardless of the association considered the face 4 is still the highest contribution followed by the face 3, face 1, face 5, face 2 and finally face 0. This conclusion is supported by the geometric description of our environment as carefully watching our scenario (see figure 4), we can see that the body of the moving train is behind the network of receiving antennas except for the face 4 that is in the same plane as the receivers antennas. Knowing that the number of diffractions is limited to one and the number of reflection to six, we can imagine that the number of rays that interact with the face 0, face 1, face 2 and finally the face 5 are very few and non-energitics. This suggests to us that we can start the degradation of the geometry of our environment by removing some faces of the moving train, ie the faces 0, 1, 2 and 5.

IV. VALIDATION RESULTS

The removal of certain faces of the environment aims to save us considerable time. To validate our findings and ensure that the degradation of the geometric description of our environment does not affect the accuracy of our results obtained from a full environment (see figure 4), we will launch a new campaign of simulations where we model only the face 3 and 4 of the moving train. We define the second scenario (see figure 8) where the faces (0, 1, 2 and 5) will not be modeled. This is almost similar to the first scenario.
Figures 9, illustrates the evolution of received power ac-

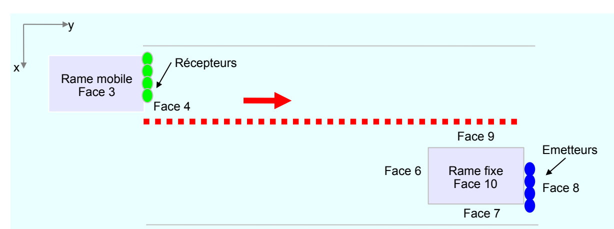


Fig. 8. Modeling a part of the train moving (face 4, face 3)

cording to this new environment representation, in comparison with a complete one (train with 6 faces). Here, we notice that obtained curves are very similar.

TABLE II
THE COMPARISON OF THE SIMULATIONS TIMES

Scenarii	6 faces dynamics	2 faces dynamics	Gain 6f/2f
Simulations times (s)	40 d 12 h 38 min	8 d 1 h 13 min	5

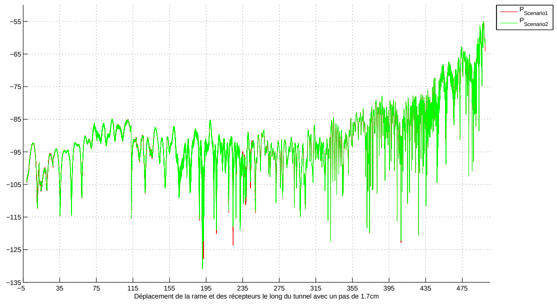


Fig. 9. Evolution of total received power for different environments modeling

V. Conclusion

This investigation allowed us to reduce the simulation time of a dynamic environment associated with a 4x4 MIMO channel at a frequency of 5.8 GHz. The results are potentially interesting. We have shown that it was possible to degrade the geometric description of the environment without compromising the accuracy the total power obtained with the full environment description. However, we would verify this by taking other characteristics parameters as the delay spread and Doppler effect. In addition, we would refine the threshold that we set ourselves in the subsection 3.C by adopting thresholds of 5 dB or 3 dB. With this parametric study related to this thresholding technique we can make a gradual degradation of our environment. We will launch other simulations to validate our results.

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