Test reports - Confrontation between experimental and numerical results: Analysis of the attenuation of the WIFI signals inside and outside a railway vehicle

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2. Terminology

2.1. Definitions

For the purpose of this document, the definitions given in IEC 60050(161), International Electrotechnical Vocabulary (IEV), chapter 161, apply.
Some definitions are recalled in this section.

Electromagnetic compatibility: The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Electromagnetic interference (EMI): Degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance

Immunity (to a disturbance): the ability of a device, equipment or system to perform without degradation in the presence of electromagnetic disturbance.

Interfering signal: a signal that impairs the reception of a wanted signal

(electromagnetic) Susceptibility: The inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

2.2. Abbreviations

a.c.	Alternating current
AP	Access point
BS	Base Station
BTS	Base Transceiver Station
CENELEC	Comité Européen de Normalisation Electrotechnique
CEPT	Conférence Européenne des Postes et Télécommunications
CW	Continuous wave
d.c.	Direct current
E	Electric field magnitude
ECC	Electronic Communications Committee
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ETSI	European Telecommunications Standards Institute
FM	Frequency Modulation
FRBW	Frequency Bandwidth
H	Magnetic field magnitude
MS	Mobile Station
QoS	Quality of Service
RF	Radio Frequency
TGV	Train à Grande Vitesse
UHF	Ultra High Frequency (300 MHz-3000 MHz)
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network

3. Scope

The scope of the WP3 of the Railcom project aims to propose methods of immunity testing and definition of the associated immunity levels for the telecommunication systems, measurement methods of the EM field at the location of the on board telecommunication system and methods of verification of the performances of the telecommunication systems in situ.

The deliverable D3.7 is especially focused on the WLAN employed in the trains in order to offer services to customers. Effectively, different railway operators try to equip their train with WIFI networks in order to permit to their customers' access to multimedia services (internet, video, information, games…). However, different difficulties actually affect the capability of the WLAN deployed inside the trains. In particular, two local wireless networks equipping two different trains can interfere each other when the trains are in each others proximity.

In this report we will give a general presentation of the configuration of a Wifi network inside a train. Then we will present the solution which was employed to model the power distribution of the signal inside and outside the train. Finally, we will compare results of modelling and experimentation and we will discuss the main observations.

4. Context and issues

In order to improve the services to the customers, different European railway operators equip their trains with Wifi wireless network in order to permit the customers to access to internet services. However, the services are regularly interrupted due to electromagnetic interferences. The interferences come mainly from the other Wifi networks which are in proximity of the train. In particular, in a train station a wifi connection inside a train can be disturbed by the urban wifi pollution or by the wifi networks which are present in the other trains. In particular, SNCF noticed that in a train station, up to 150 Wifi networks can be activated at the same time. Moreover, interruption of services can also appear during a journey when two trains cross each other.

Consequently, a first solution consists in reducing the overflow Wifi signal outside the carriage in order to avoid that an on-board Wifi network disturbs the Wifi connection inside other trains. In the work presented in this report, we propose to model the distribution of the signal level inside and outside a carriage.

The purpose is to characterize the electromagnetic pollution caused by the presence of infrastructure and terminals using the 802.11 technology in frequencies 2.4 GHz and 5GHz in an environment corresponding with a "train". Goal is evaluate the levels of signals emitted by such equipment both inside and outside the train or inside neighboring trains in train station.

A second objective is to compare the signal levels of the local wireless network inside a carriage with the signal level which can be induced inside the same carriage by an other local wireless network which is present outside train. Finally, after validation of the results of the model, this study will permit us to optimize the configuration of the local network in order to optimize the distribution inside the coach and to minimize the signal level outside the coach.

5. Example of WIFI solution

The solution presented in this report is based on the configuration presently employed by SNCF.

The customers can access to the different multimedia services by “access points” located inside the carriages and based on the technology 802.11g. Each carriage is equipped with 2 access points represented on figure 1.

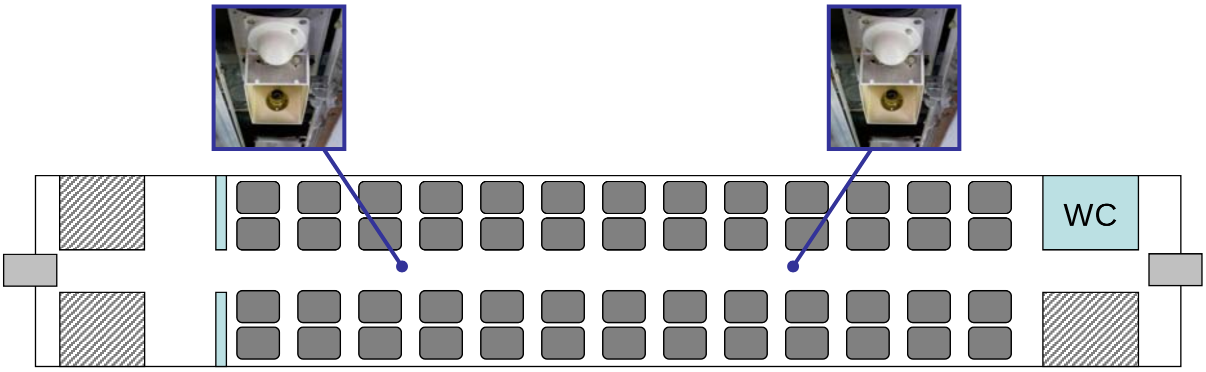


Figure 1: Illustration of the acess points – top view of a coach

The transmission of the data along the train is provided by inter-carriage WIFI system using the technology 802.11a. Data are transmitted from one car to another thanks to the bridge antennas located at each end of cars (Figure 2).

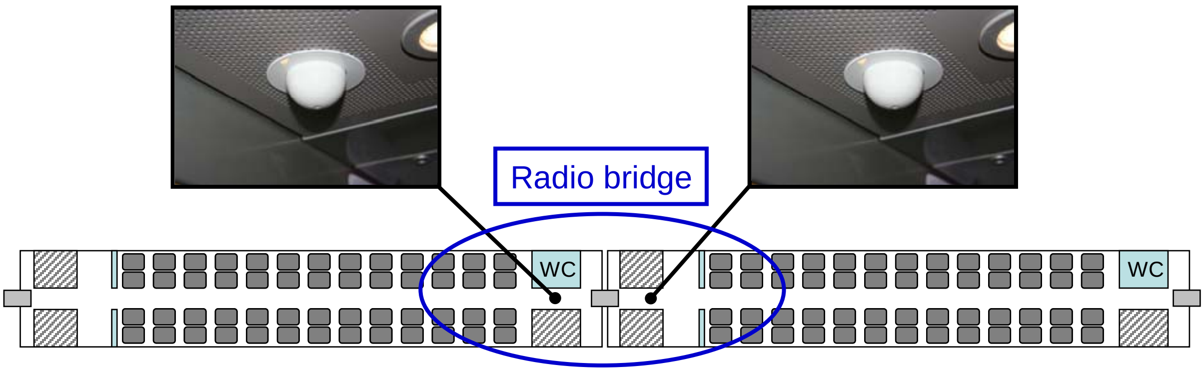


Figure 2: Illustration of the inter-carriage WIFI system

Data acquisition on board the train is provided by a satellite link. The train is equipped with a single satellite antenna placed on the roof of one of the carriages (figure 3). Data are transmitted from one car to another through the bridge antennas placed at the ends of cars.

In areas where the satellite link is not available, such as in tunnels, a terrestrial wireless infrastructure is used.

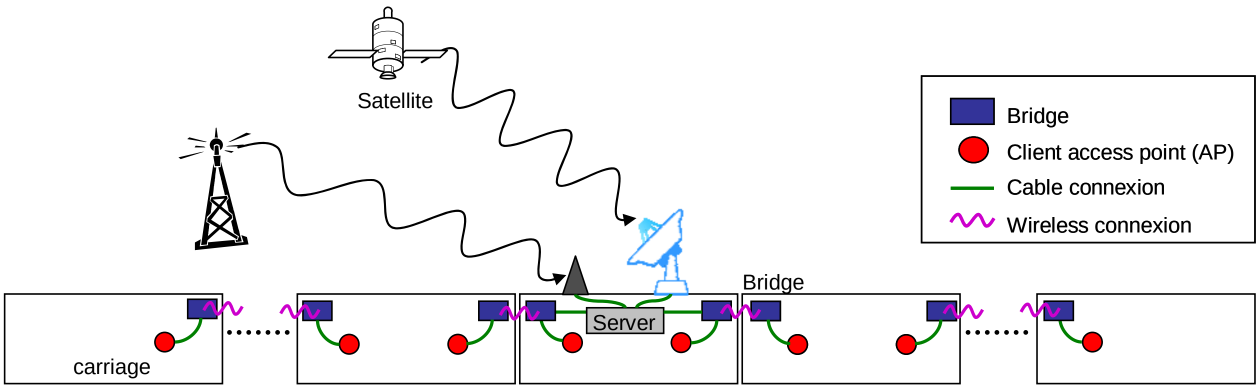


Figure 3: Illustration of the train-ground Wifi system

6. Solution for modelling the distribution of the Wifi signals inside and outside trains

6.1. Simulations with a 3D numerical tool : SimuEM 3D

The simulations were performed by the subcontractor GIGACOM. The simulation tool used by GIGACOMM is based on the theory of rays of geometrical optics.
This tool is adapted to any type of treatment of interactions between VHF-UHF waves and objects three-dimensional shape and nature whatsoever. The geometry of these objects is modeled by plane facets of varying thickness and whose material is characterized by its dielectric permittivity, magnetic permeability and conductivity. The advantage of this modelling technique is that it enables the access both to the amplitude of the electromagnetic field as well as to its phase. Thus, it is possible to apply processing algorithms for signal analysis of the behaviour of the wave both in the frequency domain and as well as in the time domain.

The calculating method of SimuEM 3D can be calibrated using experimental results obtained either by measures pure CW (narrowband) or digital measurements (modulation broadband) on given routes of movement. The comparison between theory and experiment allows calculating the average error and the standard deviation of this error. Changing the settings of the physical walls can reduce this standard deviation, and a value used to offset numerical results focus on actions (average error close to zero). The residual standard deviation provides a clear indication of the accuracy of simulations.

An example of TGV model created with the numerical tool is presented figure 4. This model is employed in section 9 of this report.

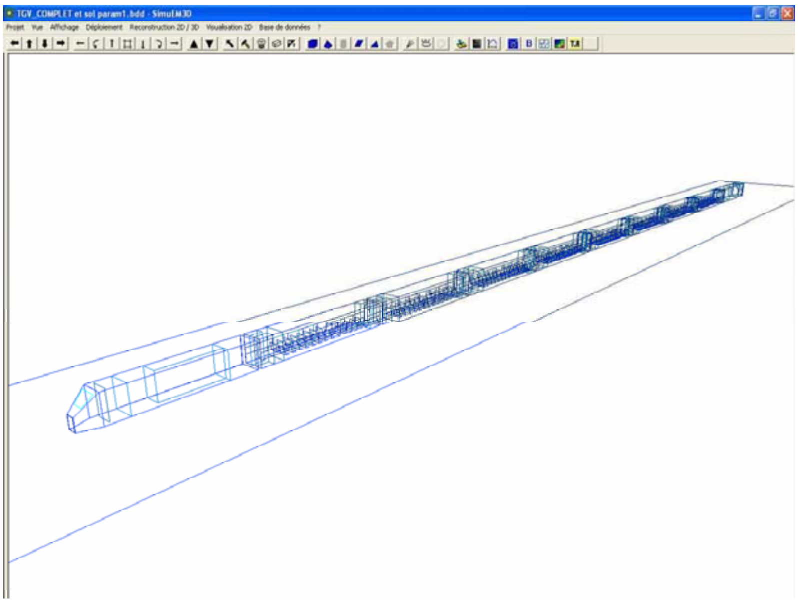


Figure 4: Representation of a 3D train model.

6.2. Preliminary numerical analyses

Firstly, it is necessary to study the influence of the number of reflections which need to be considered for the simulations to obtain a sufficient convergence of simulation results.

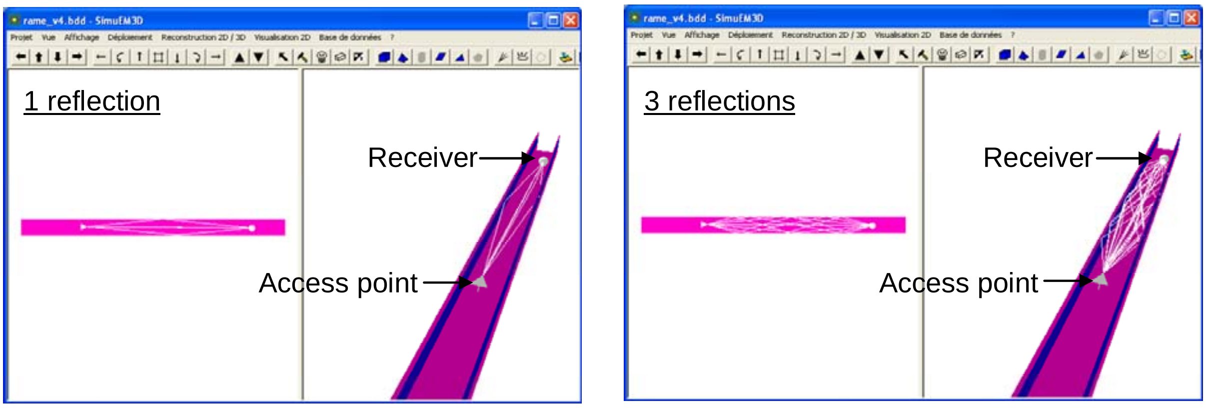
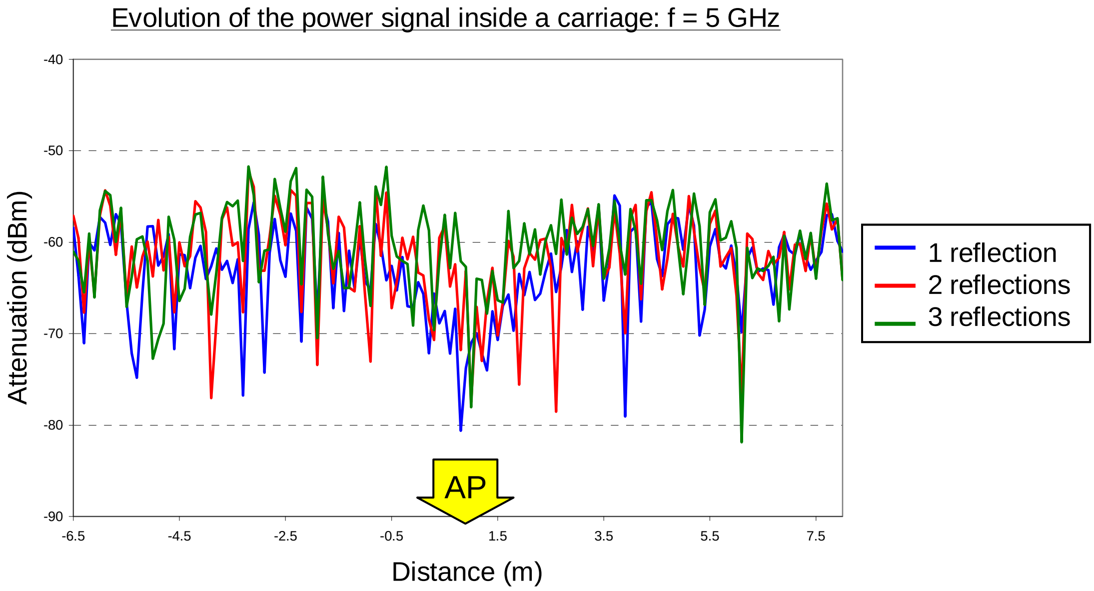


Figure 5: Illustration of the reflections.

Simulations were therefore performed with different numbers of reflections. Results are presented in the following figure 6 for the frequencies 2.4 GHz and 5 GHz

In the illustration cases represented figure 5, the access point is located at the centre of the car and the receiver is located in the corridor, at 1m from the floor and at approximately 10 m from the access point.

Figure 6 represents the attenuation of the signal along the vehicle when the access point is at the centre. The receiver is at 1 m from the floor, centred on the longitudinal axe of the vehicle. The position of the receiver varies along the longitudinal axe in order to obtain the signal attenuation at different distances from the access point.



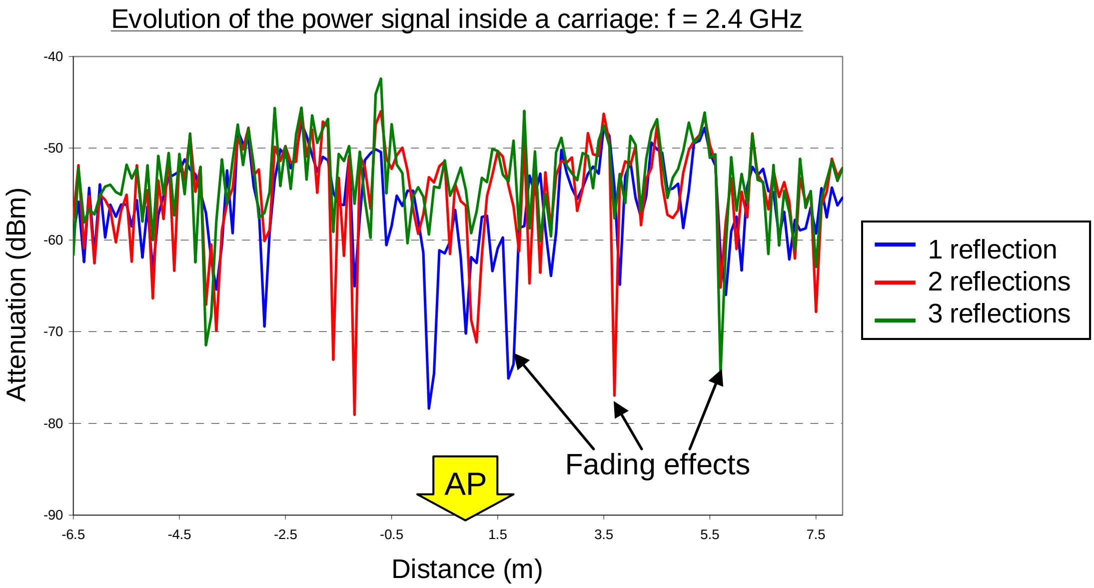


Figure 6: Impact of the number of reflections on the simulated attenuation level of the signal.

Apparently, the inclusion of 2 or 3 reflections do not significantly alter the value of the radio field compared to the inclusion of a reflection. Nevertheless, we noticed clear difference on the position on which the fading effects occur according to the number of reflections. We noticed that with only one reflection, the fading effect is only visible at proximity of the access point. Consequently, to obtain realistic results over large distances (such as the length of the coach) it will be necessary to apply a superior number of reflections to observe the fading effects. Moreover, the number of reflection to apply is not necessary the same according to the vehicle is empty or the vehicle includes seat, interior walls…In the following results presented in this report, 9 reflections were applied.

7. Measurements and simulation performed inside the train

7.1. Measurements configurations

In order to have some reference experimental results to evaluate the validity of the simulation results, measurements were performed in a railway vehicle put at our disposal by Alstom. These measurements were performed in a metro at the railway centre of Valenciennes in France. The train was stationary during the measurements. Measurements were performed at 2.4 GHz and 5 GHz [1]. However, this report present a preliminary work which only analyses the results obtained at 2.4 GHz. Effectively, it can be necessary to modify the EM properties of the material to obtain a simulation model adapted to the frequency of 5 GHz.

The measurements were performed inside an empty vehicle in order to simplify the analysis of the results and to facilitate the comparison with the simulation results. Figure 7 gives a photograph of the interior of the metro.

Figure 7: Photograph of the interior of the vehicle on which were performed the measurements.

Two types of measurements were performed.
The first measurements were carried out using a signal generator at 2.4 GHz and two quarter-wave monopole antennas fixed on a ground plane (Annexe 1). For the emission a monopole antenna was fixed to the ceiling of the carriage (figure 8) and a reception monopole antenna was set up on a mobile trolley (figure 9). The reception level was

measured in CW for different distance from the emission antenna. At the start, the reception antenna was moved inside the vehicle and afterwards outside the vehicle.

Figure 8: Photograph of the emission monopole antenna fixed to the ceiling.

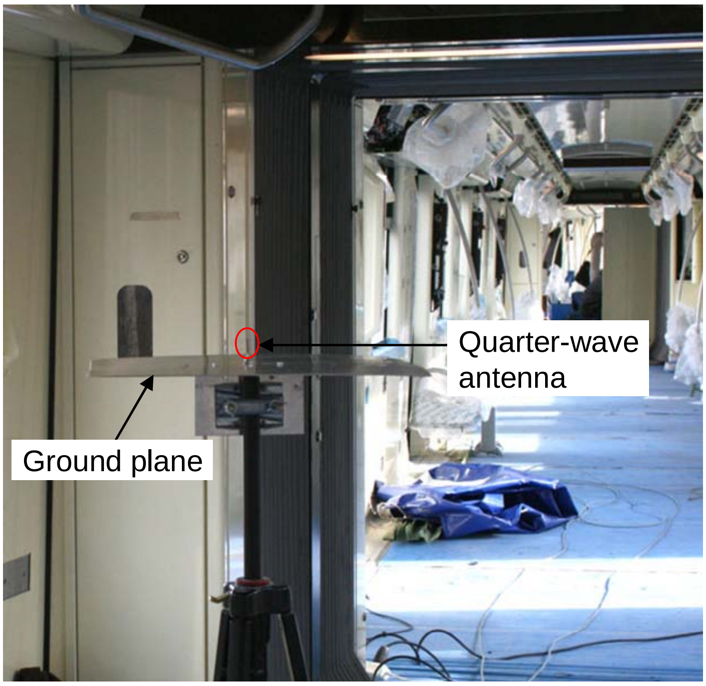


Figure 9: Photograph of the reception monopole antenna on a mobile trolley.

The second series of measurement was carried out using a transmitter (Cisco 1240 equipped with two omni-directional antennas) as an access point. It was set up close to the ceiling inside the train (figure 10). The tests were performed with 802.g signals which the output power was 17 dBm. Channel 11 was employed, corresponding to the frequency of 2462 MHz.

Figure 10: Photograph of the access point.

The measurement of the reception signal is carried using a laptop equipped with an Intel Pro / Wireless 2915 abg and the software package Airmagnet Site Surveyor Pro. Moving the reception antenna at a 1 m/s speed at a height of 1 m above the floor of the carriage, one signal acquisition is performed per second.

7.2. Measurements results inside the vehicle

The first measurements were performed inside the train in moving the reception antenna along the central axe of the vehicle. The results obtained with the two systems presented in section 7.1 are given figures 11 and 12.

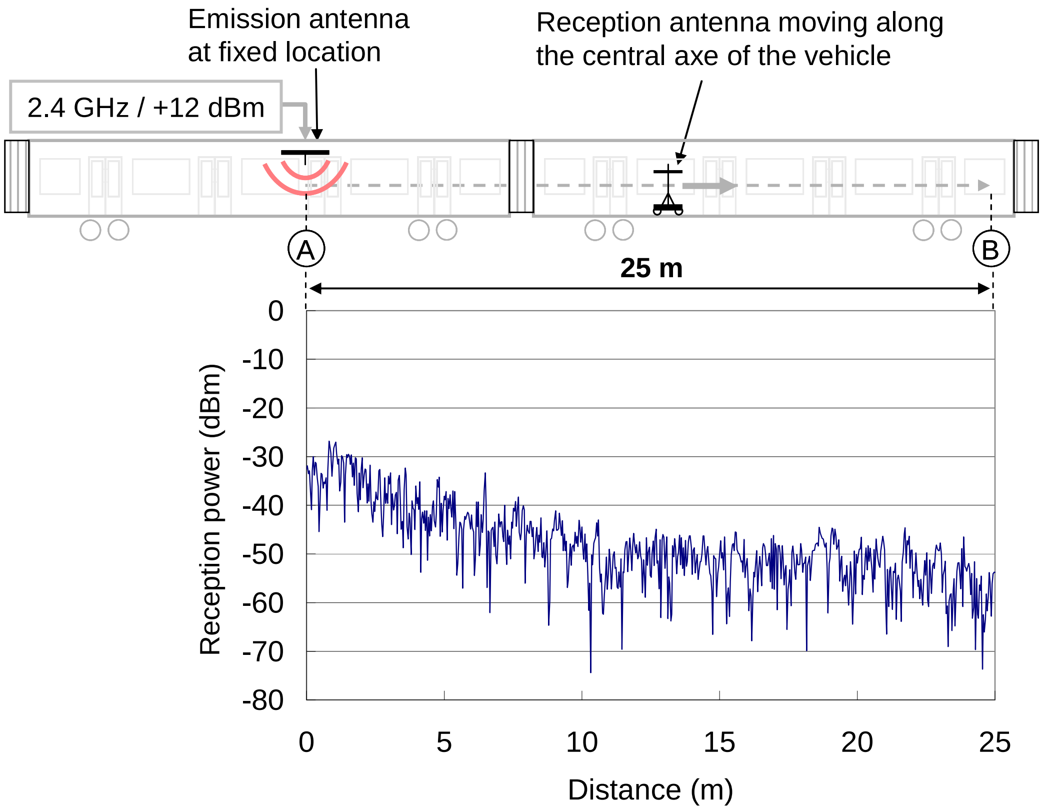


Figure 11: Representation of the measurements configuration inside the train and measured reception levels using two the monopole antennas in reception and emission.

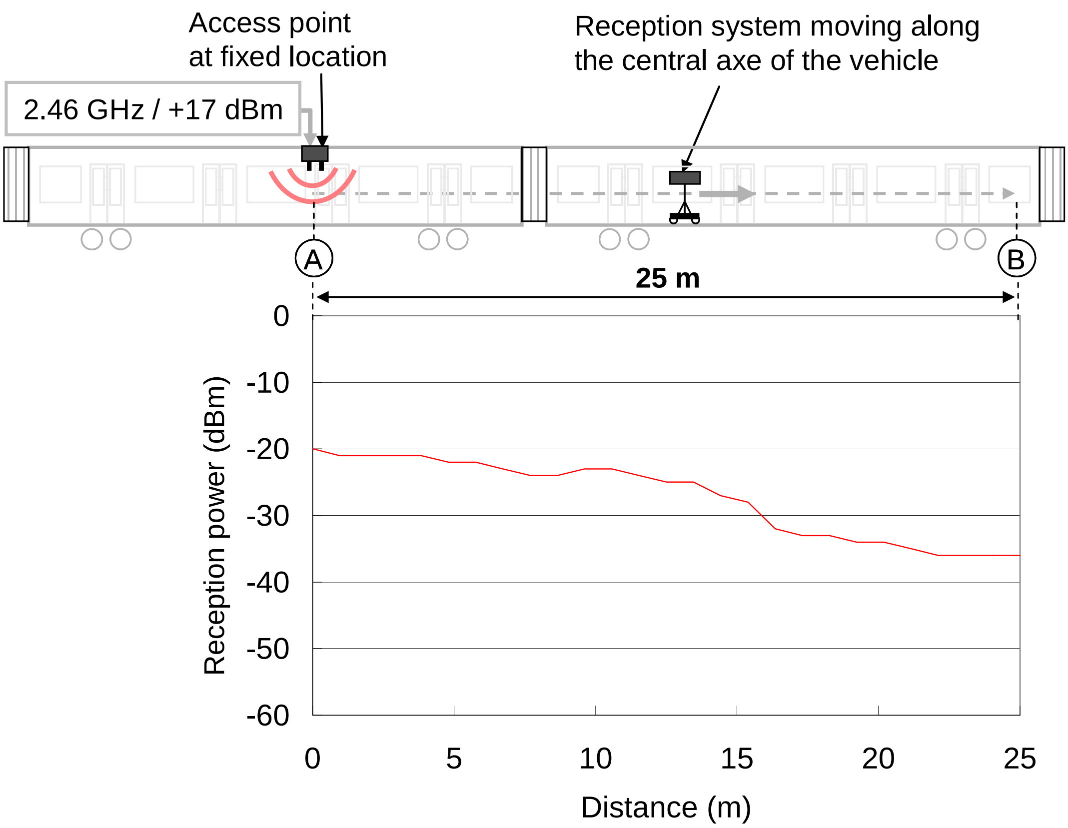


Figure 12: Representation of the measurements configuration inside the train and measured reception levels using the access point in emission.

We notice that the measured reception levels are different between the results obtained with the two series of measurements. This can be explained by the difference between the emission powers and by the efficiency of the emission and reception antennas. Moreover, in both cases, the attenuation over the 25 m distance is hardly different. The attenuation is between -20dB and -25 dB in using two monopole antennas (figure 11) and -17 dBm in using the Wifi access point (figure 12).

7.3. Simulation of the attenuation inside the train

To simulate the attenuation inside the vehicle, a very simplified model of the train was defined. The windows are considered as opened surfaces and the properties of the walls are homogenous. The permittivity and the resistivity of the walls were adjusted to obtained results similar to the measurements results. Practically, the walls are not constituted by a unique material, but are constituted of several plies of materials. Consequently, the permittivity and the resistivity applied in the model do not correspond to the EM properties of a well known material. The values obtained are 0.1 Ωm for the resistivity and 1 for the relative permittivity. The definition of the EM properties of complex surfaces remains an issue to study more precisely. The model of the train is presented figure 13.

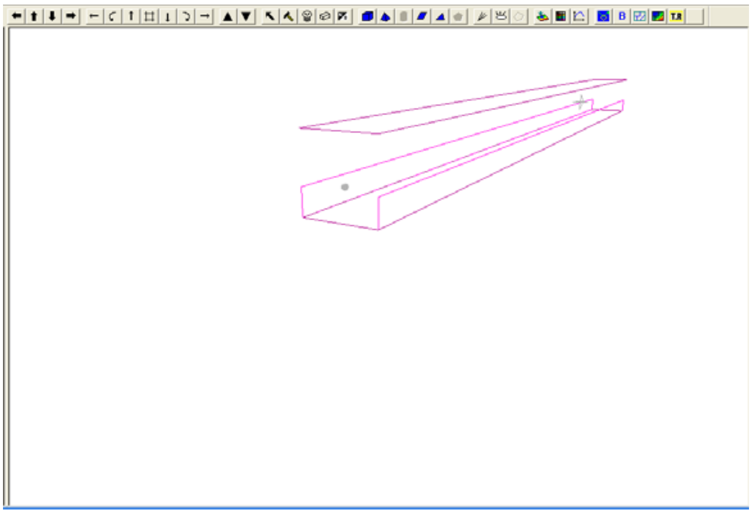


Figure 13: Representation of the simulation model of the train employed to simulate the attenuation inside the vehicle.

The relative permeability of the material modelling the wall is equal to 1.

The following figure 14 compares the simulation results with the measurement results obtained with the monopole antennas. The simulation result is obtained for a 12 dBm emission power, identical the power emission applied during the measurement. These simulation results were obtained in applying 9 reflections.

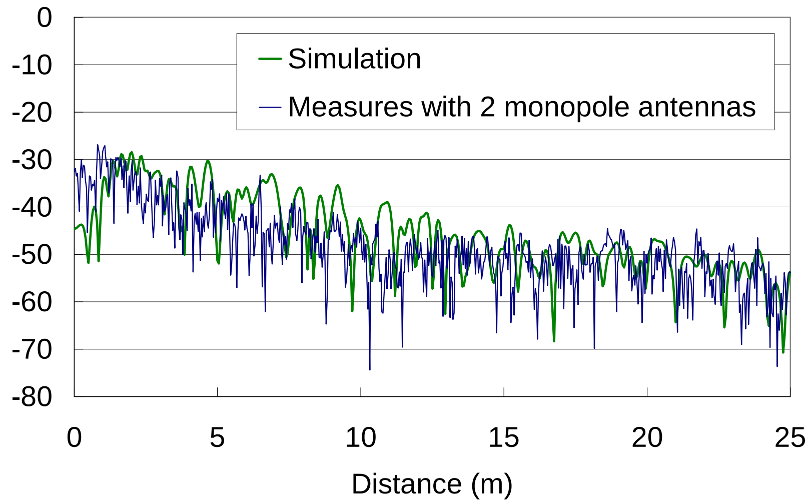


Figure 14: Comparison between simulation and measurement results inside train

We notice a satisfying agreement between the simulation and the measurement performed with the two monopole antennas. However, we did not performing comparisons with the results obtained with the access point. Effectively, we do not have (at this step) sufficient information concerning the gain of the antennas to simulate comparable situation.

8. Measurements and simulation performed outside the train

8.1. Measurements configurations and results

For the measurements carried out outside the train, the reception levels were measured along the train at approximately 3 m from the train, as represented figure 15.

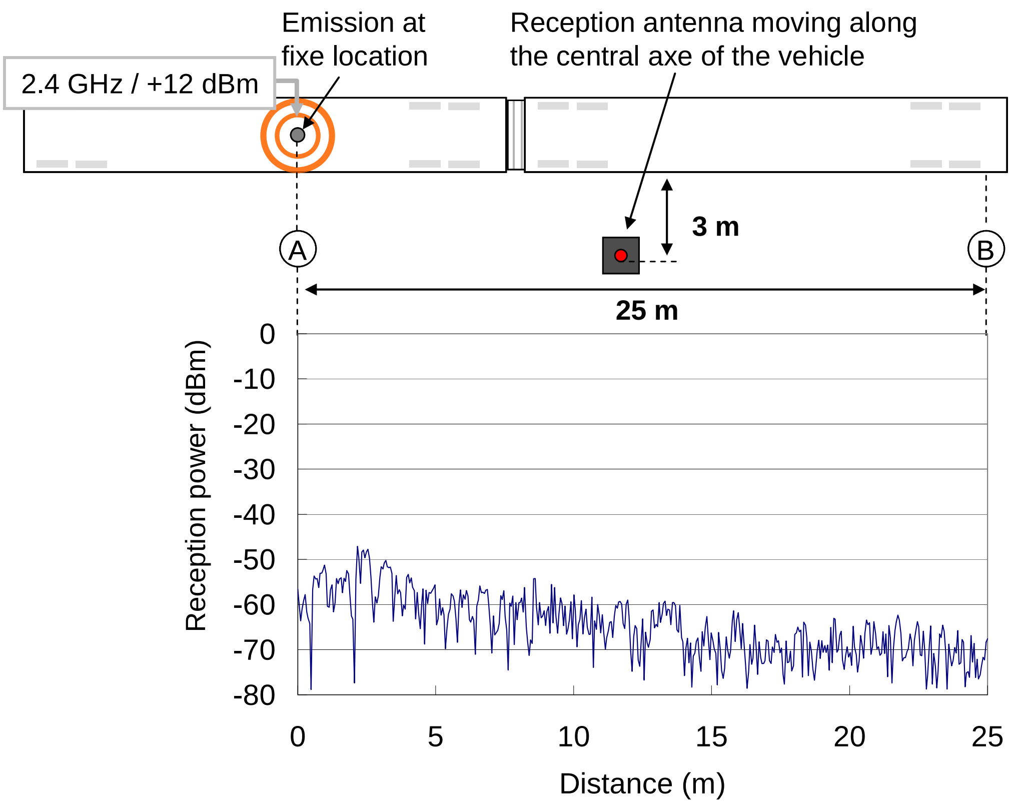


Figure 15: Representation of the measurements configuration outside the train (Top view) and measured reception levels using two the monopole antennas in reception and emission.

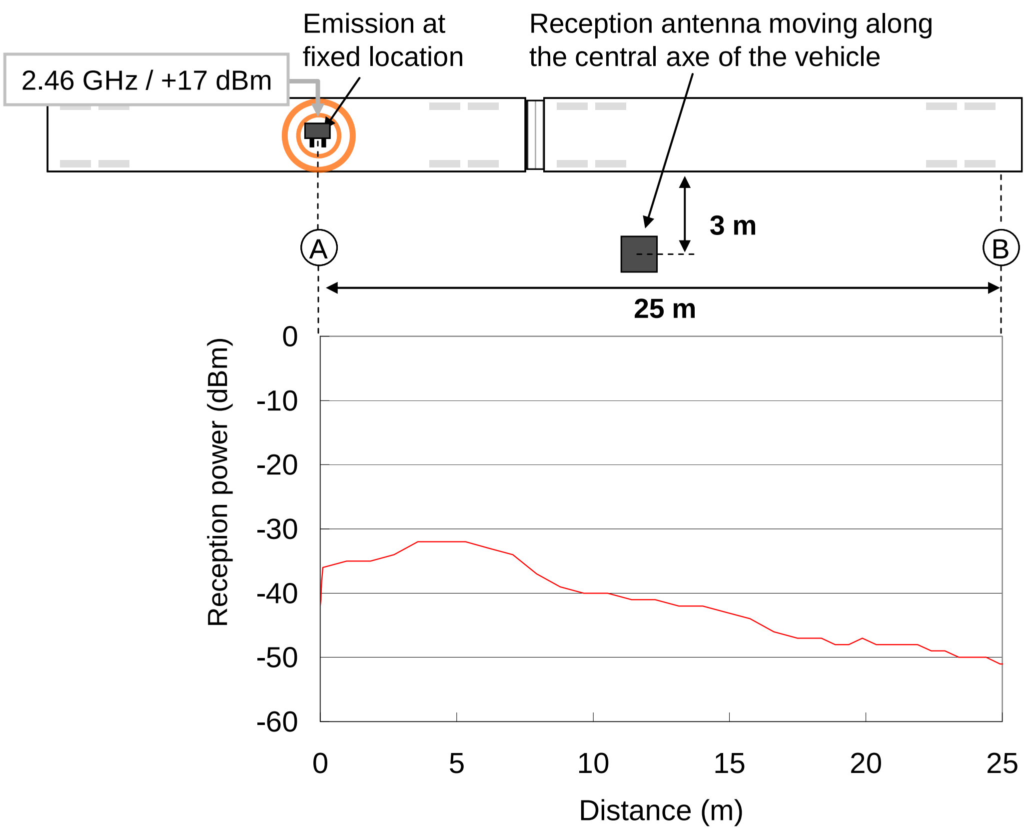


Figure 16: Representation of the measurements configuration outside the train and measured reception levels using the access point in emission.

We again notice that the measured reception levels are different between the results obtained with the two configurations of measurements. This can be explained by the difference between the emission powers and by the efficiency of the emission and reception antennas.

8.2. Simulation of the attenuation outside the train

The simulation model of the vehicle needed to extract the power levels outside the vehicle requires the definition of different materials corresponding with the ground outside the vehicle, the walls of the vehicle and the windows. The EM properties of the different elements are grouped in table 1. At this state, we do not have a lot of references to precisely define the EM properties of the materials at 2.4 GHz. For the walls, we then keep the properties applied for the modelling of the field inside the carriage. Moreover, the material of the windows can be as complex as the material of the wall. Effectively, sometime the windows are constituted of multiply material partially composed of metal. In the deliverable D3.4 [2], transmissions measurement performed trough the windows of a train showed a strong attenuation of the signal. For the window, we then adjusted the EM properties in the model to obtain results similar to the measurements results. The relative permittivity applied for the ground outside the vehicle corresponds to the permittivity of a dry ground.

Table 1: EM properties applied to model the materials

	Relative permittivity	Resistivity
Ground (1 m under the train)	5	100 Ωm
Wall of the train	1	0.1 Ωm
Windows of the train	1	1 Ωm

The relative permeability is equal to 1 for all the materials.

Nevertheless, the method which consists in adjusting the EM properties of the materials can not be applied for a more complex vehicle including seats, people, interior walls… In that case, a preliminary work has to be carried out to define the EM properties of the different materials which composed the vehicle.

The model of the train is presented figure 17.

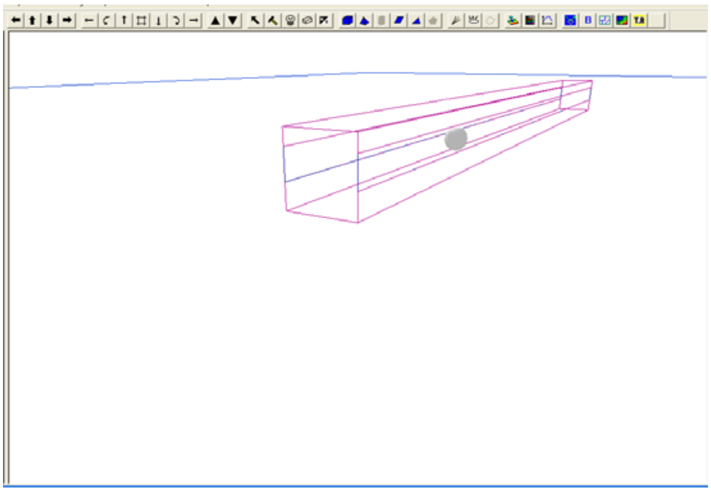


Figure 17: Overview of the simulation model of the train used to simulate the attenuation outside the vehicle.

Figure 18 compares the simulation results with the measurement results obtained with the monopole antennas. These simulation results were obtained using 9 reflections.

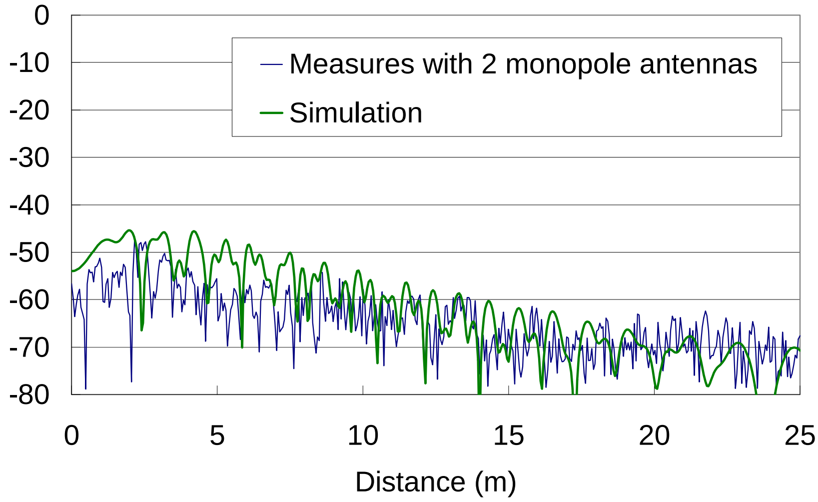


Figure 18: Comparison between simulation and measurement results outside the vehicle.

We notice a good agreement between the simulation and the experimental results. However, we have to keep in mind that the EM properties were adjusted according to the experimental results. We could adjust the values of the properties due to the simplicity of the vehicle to model. Nevertheless, to model a more complex vehicle including seats, interior walls… we can not envisage defining the EM properties of the different materials by the same approach. It is then necessary to preliminary characterize the materials.

9. Simulation with a TGV model

Finally, simulations were performed using a more elaborated model representing a TGV [3], given in figure 19.

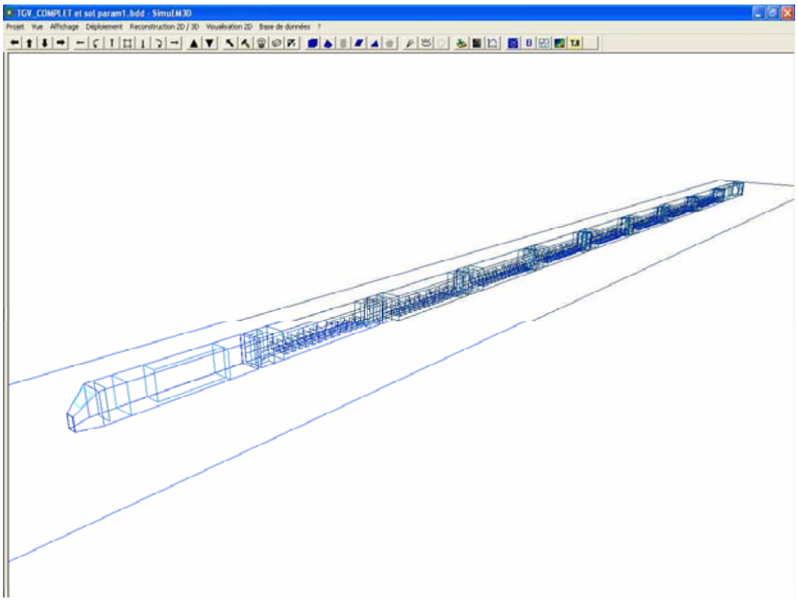


Figure 19: Representation of the 3D TGV model.

The results obtained at 2.4 GHz are given in figure 20. These results show the power level of the signal inside and outside the vehicle for 0 dBm used as emission power.

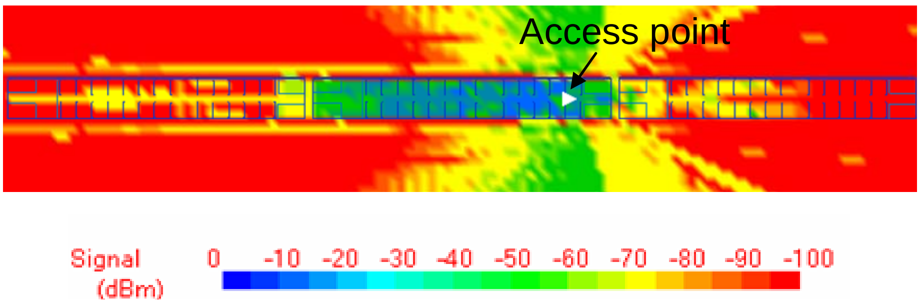


Figure 20: Signal power inside and outside the train at 2.4 GHz

These results show that, at certain locations outside the train, the signal level is comparable to the one existing inside the train. Please, note the signal levels corresponding to the green areas outside and inside the vehicle. This means that there is a significant transmission outside the walls of the carriage. However, these results should still be verified by measurements performed on TGV.
Similar simulations were the carried out in order to evaluate the penetration inside a coach of the signal emitted by an access point located outside the coach. The results are given figure 21.

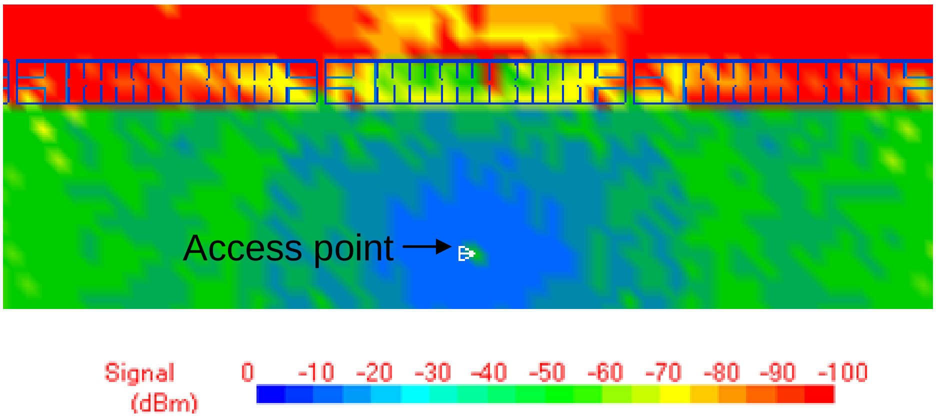


Figure 21: Signal power coming from an access point located outside the train and penetrating inside the train at 2.4 GHz

These simulation results show also a significant penetration of the signal inside the coach.

10. Conclusions

In this report, we proposed an approach to model a train in order to optimize the configuration of the Wifi network inside train by simulation. We can envisage that a realistic model can be used to optimise the antennas and their positions in order to reduce the transmission to the outside of railway carriage. From an EMC point of view, this optimisation can be used to reduce the risk of interference between on board networks and exterior networks.

Measurements were performed on a relatively simple vehicle in order to evaluate the first modelling. Then, we have been able to adjust the EM properties of the materials in the model and we obtained a satisfying agreement between the experimental and numerical results. However, this approach is “global” and it is difficult to establish a link between the values of the EM parameters of the materials used in the simulation model and the physical situation.

Consequently, whereas the simulation results and the measurement results are similar, we can not conclude that the model is good because we are not able to explain the values of the EM properties of the materials. We now have to envisage methodologies to characterize or to take into account the real EM properties of the complex material which constitute the walls and the windows of vehicle. Then, this approach should be extended, modelling a more complex vehicle.

11. References

[1] Jean Rioult, Stephen Dudoyer, “Measurement reports - Study of the signal attenuation inside and outside trains at 2.4 GHz and 5 GHz”, Railcom Project, may 2009

[2] H. Ouaddi, V. Deniau et M. Ben slimen, “deliverable D3.4: Methodology for characterisation of the EM environment inside trains- Measurements of the transmission and reflection of electromagnetic waves through the walls and the windows of a railway vehicle: preliminary work to the study on the WIFI system”, Railcom project, December 2007.

[3] Analyse de la pollution électromagnétique engendrée par l'utilisation de réseaux IEEE 802.11x à bord de TGV, study report, company GIGACOM, September 2008.

12. Annexe 1: Characteristics of the monopole antenna