ETSI TR 103 704 V1.1.1 (2022-05)

TECHNICAL REPORT

Urban Rail ITS and Road ITS applications in the 5,9 GHz band; Measurement campaign to confirm simulation parameters to define Urban Rail ITS protected zones in 5 915 MHz to 5 925 MHz

Reference

DTR/RT-JTFIR-4

Keywords

ITS, simulation, spectrum

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° w061004871

Contents

Intellectual Property Rights

Essential patents

IPRs essential or potentially essential to normative deliverables may have been declared to ETSI. The declarations pertaining to these essential IPRs, if any, are publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (https://ipr.etsi.org/).

Pursuant to the ETSI Directives including the ETSI IPR Policy, no investigation regarding the essentiality of IPRs, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Trademarks

The present document may include trademarks and/or tradenames which are asserted and/or registered by their owners. ETSI claims no ownership of these except for any which are indicated as being the property of ETSI, and conveys no right to use or reproduce any trademark and/or tradename. Mention of those trademarks in the present document does not constitute an endorsement by ETSI of products, services or organizations associated with those trademarks.

DECT™, **PLUGTESTS™**, **UMTS™** and the ETSI logo are trademarks of ETSI registered for the benefit of its Members. **3GPP™** and **LTE™** are trademarks of ETSI registered for the benefit of its Members and of the 3GPP Organizational Partners. **oneM2M™** logo is a trademark of ETSI registered for the benefit of its Members and of the oneM2M Partners. **GSM**® and the GSM logo are trademarks registered and owned by the GSM Association.

Copyright acknowledgment

Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Railway Telecommunications (RT).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

Executive summary

ETSI TR 103 580 [i.2] described possible sharing and interference mitigation techniques between Road ITS and Urban Rail ITS. These techniques would allow the technical implementation of the regulatory priority regime afforded to Urban Rail ITS in the spectrum band 5 915 MHz to 5 925 MHz.

ETSI TR 103 580 [i.2] concluded that a measurement campaign would be needed to validate the results and the simulations parameters applicable for the definition of the protected zones, where mitigation techniques would be required.

The present document describes the work undertaken to perform the required measurements and analyses the resulting data. The following items are covered:

- Identification of relevant test cases representative of typical coexistence situations.

- Identification of relevant areas to conduct the measurements.
- Description of test procedures and test tools.
- Detailed plan of the measurements.
- Analysis of the measurements campaign.
- Conclusion on the results.

The analysis confirms that the levels received by urban rail ITS, from vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP and driving in the surrounding of a metro Line, are above the defined protection levels of the CBTC communications.

Although the received levels in the present document are displayed for vehicles transmitting at maximum output power (23 dBm/MHz, i.e. 33 dBm per a 10 MHz channel as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]), the results could be scaled down for different transmit powers (e.g. 10 dB decrease for vehicles transmitting 23 dBm/10 MHz).

The aggregated power from multiple vehicles interfering has not been investigated in the present document, however this could be investigated later with the measurement data available.

The assessment of interference on CBTC systems is outside the scope of the present document. Following the measurement campaign presented in the present document, a revision of ETSI TR 103 580 [i.2] will be required. The revision will focus on identifying the most appropriate mitigation technique. This will be the basis of future normative work allowing sharing of the spectrum band 5 915 MHz to 5 925 MHz between Urban Rail and Road ITS.

Introduction

Commission Implementing Decision (EU) 2020/1426 [i.8] designates the band 5 875-5 935 MHz for intelligent transport systems and limits it to urban rail ITS in 5 925 to 5 935MHz. [i.8] also states that "*Road ITS applications shall have priority below 5 915 MHz and urban rail ITS applications shall have priority above 5 915 MHz, so that protection is afforded to the application having priority" and further instructs that "Access by road ITS to the frequency range 5 915-5 925 MHz shall be limited to applications involving infrastructure-to-vehicle (I2V) connectivity only, coordinated, where appropriate, with urban rail ITS*"

The sharing and interference mitigation techniques would enable the technical implementation of the priority regime afforded to Urban Rail ITS.

One key concept introduced in ETSI TR 103 580 [i.2] is the "Urban rail protected zones" which should be used to define the mitigation areas to protect Urban Rail communications. ETSI TR 103 580 [i.2] concluded that a measurement campaign would be needed to validate the results and the simulation parameters applicable for the definition of the protected zones.

In the present document, a set of measurement scenarios are defined together with a set of relevant areas, on two metro Lines, where measurements have been performed. The measurement setup, procedures and planning are also introduced. After completion of the measurement campaign, the measurements have been analysed and the results of these analysis are presented.

The measurements performed on the three sections of RATP Line 6 and on the 3 sections of RATP Line 8, both in Paris, with trains and base stations, confirm the levels received by trains and base stations from vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP and driving on parallel roads, on bridge above or below the tracks and in different areas in the surrounding of a metro Line are above the defined protection levels of the CBTC communications. This result could be hypothesized already from the simulations of propagation performed previously and aiming at identifying the relevant areas.

1 Scope

The present document describes the work undertaken to perform the required measurements, and analyses the resulting data. The following items are covered:

- Identification of relevant test cases representative of typical coexistence situations.
- Identification of relevant areas to conduct the measurements.
- Description of test procedures and test tools.
- Detailed plan of the measurements.
- Analysis of the measurements campaign.
- Conclusion on the results.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long-term validity.

The following referenced documents are not necessary for the application of the present document, but they assist the user regarding a particular subject area.

[i.1] Commission Decision 2008/671/EC on the harmonised use of radio spectrum in the 5875 - 5905 MHz frequency band for safety related applications of Intelligent Transport Systems (ITS).

[i.2] ETSI TR 103 580 (V1.1.1) (2019-08): "Urban Rail ITS and Road ITS applications in the 5,9 GHz band; Investigations for the shared use of spectrum".

[i.3] ETSI EN 302 571 (V2.1.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.4] ECC Report 101: "Compatibility studies in the band 5855 - 5 925 MHz between Intelligent Transports Systems (ITS) and other systems".

[i.5] ECC Report 68:"Compatibility studies in the band 5725-5875 MHz between Fixed Wireless Access (FWA) systems and other systems", Riga, June 2005.

[i.6] CEPT Report 71: "Report from CEPT to the European Commission in response to the Mandate to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz".

[i.7] Recommendation ITU-R P.1411-6: "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz".

[i.8] Commission Implementing Decision (EU) 2020/1426 of 7 October 2020 on the harmonised use of radio spectrum in the 5 875-5 935 MHz frequency band for safety-related applications of intelligent transport systems (ITS) and repealing Decision 2008/671/EC.

[i.9] Z. Živković, D. Senić, C. Bodendorf, J. Skrzypczynski and A. Šarolić: "Radiation pattern and impedance of a quarter wavelength monopole antenna above a finite ground plane", SoftCOM 2012, 20th International Conference on Software, Telecommunications and Computer Networks, 2012, pp. 1-5.

[i.10] A. Kwoczek, Z. Raida, J. Láčík, M. Pokorny, J. Puskelý and P. Vágner: "Influence of car panorama glass roofs on Car2Car communication (poster)", 2011 IEEE Vehicular Networking Conference (VNC), 2011, pp. 246-251, doi: 10.1109/VNC.2011.6117107.

[i.11] IEEE 802.11p™: "IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments".

[i.12] Ublox receiver ZED F9R Product sheet.

[i.13] Recommendation ITU-R F.1336:"Reference radiation patterns of omni-directional, sector and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz".

[i.14] HTZ Communications - brochure.

NOTE: Available at https://atdi.com/products-and-solutions/htz-communications.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADR	Automotive Dead Reckoning
BS	Base Station
C/I	Carrier to Interference ratio
CBTC	Communications-Based Train Control systems
CEPT	European Conference of Postal and Telecommunications Administrations
dB	Decibel
dBi	Decibel isotropic
dBm	decibel-milliwatts
DCC	Decentralized Congestion Control
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Server
DSRC	Dedicated Short-Range Communications
EC	European Commission
ECC	Electronic Communications Committee
EIRP	Equivalent Isotopically Radiated Power
EMSL	European Microwave Signature Laboratory
ETSI	European Telecommunications Standards Institute

EU	European Union
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HTTP	HyperText Transfer Protocol
I2V	Infrastructure to-Vehicle
IMU	Inertial Measurement Unit
IP	Internet Protocol
ITS	Intelligent Transport Systems
ITS-G5	Intelligent Transport Systems operating in the 5 GHz frequency band
JRC	DG Joint Research Centre of EC
LoS	Line-of-Sight
LTE	Long Term Evolution
NA	Non Applicable
NLoS	Non-Line of Sight
NRTK	Network Real Time Kinematic
NTRIP	Network Transport of RTCM via Internet Protocol
OBU	Onboard Unit
OCC	Operation Control Centre
OEM	Original Equipment Manufacturer

NOTE: A term in the automotive industry used for the vehicle manufacturers.

OSR	Observation Space Representation
QPSK	Quadrature Phase-Shift Keying
QZSS	Quasi-Zenith Satellite System
RATP	Régie Autonome des Transports Parisiens

NOTE: State-owned public transport operator and maintainer Metro of Paris.

RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RTCM	Radio Technical Commission for Maritime
RTK	Real Time Kinematic
Rx	Receiver
SBAS	Satellite-Based Augmentation System
SUV	Sports Utility Vehicle
TR	Technical Report
Tx	Transmitter
V2V	Vehicle to Vehicle
V2X	Vehicle to anything communication
VPN	Virtual Private Network
WGS 84	World Geodetic System 1984

4 Measurement campaign context and organization

4.1 General

In October 2017, the European Commission mandated CEPT/ECC to provide the Commission with the necessary information to consider the amendment of Commission Decision 2008/671/EC [i.1] of 5 August 2008, on the harmonised use of radio spectrum in the 5 875 MHz to 5 905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS).

In particular, the purpose of the EC ITS mandate to the CEPT was to study the possibility of:

- Extending the upper edge of the EC harmonised safety related ITS band (5 875 MHz to 5 905 MHz) by 20 MHz up to 5 925 MHz.
- In addition to road transport, allowing other means of transport such as Urban Rail (using Communication Based Train Control (CBTC)) in the EC harmonised safety related ITS band.

CEPT/ECC concluded in CEPT Report 71 [i.6] and invited ETSI to develop sharing and interference mitigation techniques with a reasonable timeframe (no more than 3 years), to ensure co-channel coexistence in the frequency range 5 875 MHz to 5 925 MHz between Road ITS and Urban Rail applications, and between Road ITS radio technologies, by considering the following (see also Figure 1):

"*Minimum technical requirements (without any change for Road ITS in 5875-5905 MHz):*

- *the frequency band 5875-5 925 MHz is designated for all safety related ITS applications (Road ITS and Urban Rail ITS).*
- *the frequency band 5 925-5935 MHz is designated for safety-related Urban Rail ITS applications.*
- *define priority to Road ITS applications below 5 915 MHz and to Urban Rail ITS applications above 5 915 MHz, so that protection is afforded to the application having priority;"*

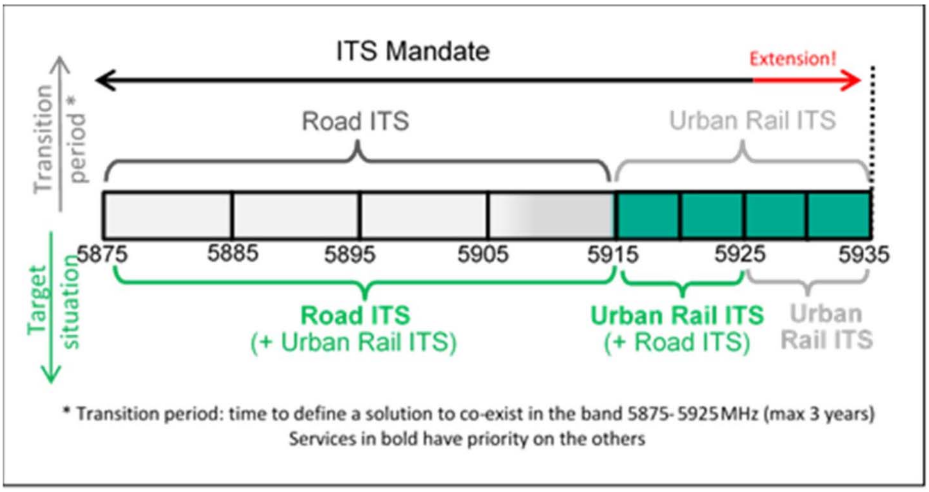

Figure 1: Road ITS and Urban Rail ITS bands

4.2 Available results and studies

ETSI has been conducting studies since 2017 and the outcome was summarized in ETSI TR 103 580 [i.2]. ETSI TR 103 580 [i.2] focused on the 5 915 MHz to 5 925 MHz band where Urban Rail ITS would have priority and proposed the following:

- Identify methods to define protected zones.
- Define Protected Zone detection methods.
- Define mitigation techniques to apply in protected zones.

Regarding the definition of protected zones, several methods have been identified. ETSI TR 103 580 [i.2] concluded the need to conduct a measurement campaign to validate these results and to confirm the simulation parameters which should be used to define the proper mitigation area to protect Urban Rail communications systems.

ETSI TR 103 580 [i.2] also concluded that further studies are needed on:

- The protected zone detection methods, in particular:
    - Read-only database combined with alert beacons.
    - Updatable database combined with optional permissive beacons.
- The mitigation techniques to apply in protected zones.

5 Critical interference scenarios

5.1 Description of critical interference scenarios

5.1.1 Introduction

A metro Line can leave a tunnel for different reasons:

- At the end of the Line, the last station may be in open air followed by a transfer track where several switches will distribute the trains to entrances in the depot.
- In suburban area, long section of Line can be in open air because there is more place than in a dense urban area and in this case an expensive tunnel is not justified.
- In a dense urban area, a metro Line can leave a tunnel because the underground does not allow to drill a tunnel at an acceptable cost. In this case the metro Line may run on a viaduct.

A metro Line in open air can have:

- One road parallel on one side of the track.
- Two roads parallel to the track with one parallel to each side.
- The tracks and the road can be at different levels:
    - tracks and road at the same level;
    - tracks on a viaduct or road on a viaduct.

A metro Line in open air can be on a viaduct or a bridge and cross a road. A road on a bridge can also cross a metro Line in open air.

It is also important to consider that a CBTC base station antenna can receive transmission from different areas in a city. Several vehicles present in each area can exchange messages. In each area these ones can receive each other and limit the use of the channel capacity at 62 % with the DCC; but vehicles in the different areas are not able to listen each other.

Because a CBTC base station has two high gain antennas pointing in two opposite directions, it can receive interference from several areas and "see" a channel occupancy much higher than 62 %.

5.1.2 Road parallel to Urban Rail tracks

Road parallel to urban rail tracks is a common situation that can be encountered in European cities as shown in Figure 2, Figure 3 and Figure 4.

Figure 2: Parallel road, Metro of Bruxelles (image source: http://transporturbain.canalblog.com/pages/bruxelles---du-tramway-souterrain-au-metro-automatique/34966419.html

Figure 2 shows a metro Line in open air surrounded with two parallel roads, one with two lanes on the right and one with one lane on the left.

Figure 3: Parallel road, Metro of Malaga (Map Source Google Earth: © Google)

Figure 3 shows a metro Line in open air that has a two lanes parallel road, while in Figure 4 the metro Line in open air is surrounded by two parallel roads having two lanes.

Figure 4: Parallel road Metro Line 8 of Paris (Map Source Google Earth: © Google)

In Figure 4 the distance between the axis of a track and the axis of the closest lane of the road varies between 7 m and 12 m. The tracks and the roads are at the same level or with a difference of level of maximum 1 m due to the ballast.

In some Lines, inside a city, the metro Line can leave the tunnel and continue on a viaduct. The viaduct can be surrounded by two roads as shown in Figure 5.

Figure 5: Metro Line 6 of Paris on a viaduct with parallel road and crossing road (Map Source Google Earth: © Google)

During peak business hours, traffic jam can be expected meaning a significant number of vehicles on the roads. On a section of metro Line of 1 km, one train can run every minute.

5.1.3 Road crossing Rail tracks

In suburban area a road can cross metro Line on a bridge as shown in Figure 6.

Figure 6: Metro Line 8 of Paris on a bridge crossing a road (Map Source Google Earth: © Google)

In a suburban area, a metro Line in open air can also cross a road being on a viaduct or a bridge as shown in Figure 7.

Figure 7: Road on a bridge crossing metro Line 8 of Paris (Map Source Google Earth: © Google)

The typical height of the track or the road above the ground is between 5 m to 6 m.

A CBTC base station antenna may be installed on or under a bridge for situation shown in Figure 6 and Figure 7.

5.1.4 Isles (group of vehicles) in a city or multiple RF sources

Figure 8 illustrates the scenario where the transmissions from multiple groups of vehicles are received by a CBTC base station or a train.

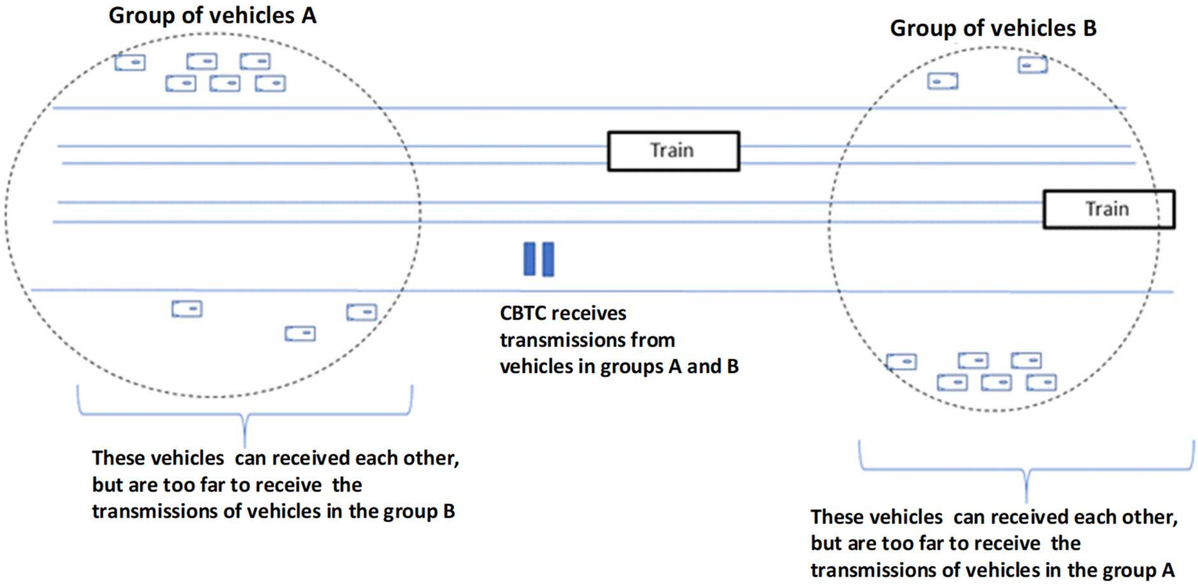

Figure 8: Isles in a city

Each group of vehicles can reach the channel occupancy limits of 62 % but the vehicles of the different groups are not able to listen each other. The CBTC base station has two high antennas pointing to two opposite directions to cover the track and the height of the CBTC base station above the ground is 5 m to 6 m. It means that a CBTC base station can receive transmissions of vehicles from different groups.

5.2 Summary

Table 1 below lists all the scenarios that have been considered.

Table 1: List of scenarios with definition

Scenario number	Definition
1	Parallel Tracks and Road at the same level
2	Parallel Tracks and Road with tracks on a viaduct
3	Parallel Tracks and Road with Road on a viaduct
4	Parallel Tracks and Road with Tracks entering in a tunnel
5	Crossing Tracks and Road with road on a bridge
6	Crossing Tracks and Road with tracks on a bridge
7	Isle (Group of vehicles) in a city or multiple RF sources

6 Identification of the relevant areas to conduct the measurements

6.1 Overview

In the following clauses the measurement areas are defined. These areas cover as much as possible the critical interference scenarios described in clause 5.

The purpose is to:

- List the different types of areas where the measurement campaign needs to be conducted, describe their characteristics, and link the areas with the different cases based on the critical interference scenarios identified in clause 5.
- Identify specific requirements to conduct the measurements (authorization from public transport operator or from city, etc.).
- Evaluate the time needed to prepare the measurements.

6.2 List of Identified relevant areas to conduct measurements

The relevant areas have been selected to allow performing the measurements for the seven scenarios defined in clause 5 in two types of environment: urban and suburban.

In addition, several criteria have been considered such as:

- Test scenarios covered
- Propagation environment
- Presence of singularities
- GNSS coverage
- Proximity with the depot
- Road traffic conditions
- Presence of a parking
- Metro operator constraints

Based on these criteria, six relevant areas have been identified on two Lines of the Metro of Paris (RATP).

Three relevant areas have been identified and selected on RATP Line 6 running inside the city in an urban environment that can be encountered in other European Cities.

Three relevant areas have been identified and selected on RATP Line 8 running inside an environment that can be considered as a typical suburban environment that can be encountered in European cities.

In the following, a "section" of a metro Line is a coherent area where measurements have been performed.

6.3 Description of each selected relevant areas

6.3.1 Selected relevant areas of RATP Line 6

6.3.1.0 Description of the sections of RATP Line 6

Three relevant areas have been selected for Line 6:

- Section 1: From station Duplex and station Bir-Hakeim
- Section 2: From station Sèvres-Lecourbe and entrance of tunnel direction station Pasteur
- Section 3: From station Quai de la gare and entrance of tunnel direction station Bercy

Line 6 offers a dense urban environment.

6.3.1.1 Description of the section 1 of RATP Line 6

The first section of Line 6 is between the Duplex and station Bi-Hakeim. The RATP Line 6 is running on a viaduct in this section as shown in Figure 9.

Figure 9: Section 1 of Line 6
(Map Source Google Earth: © Google)

Figure 10 shows a detailed description of the section 1 and how the measurement campaign was performed.

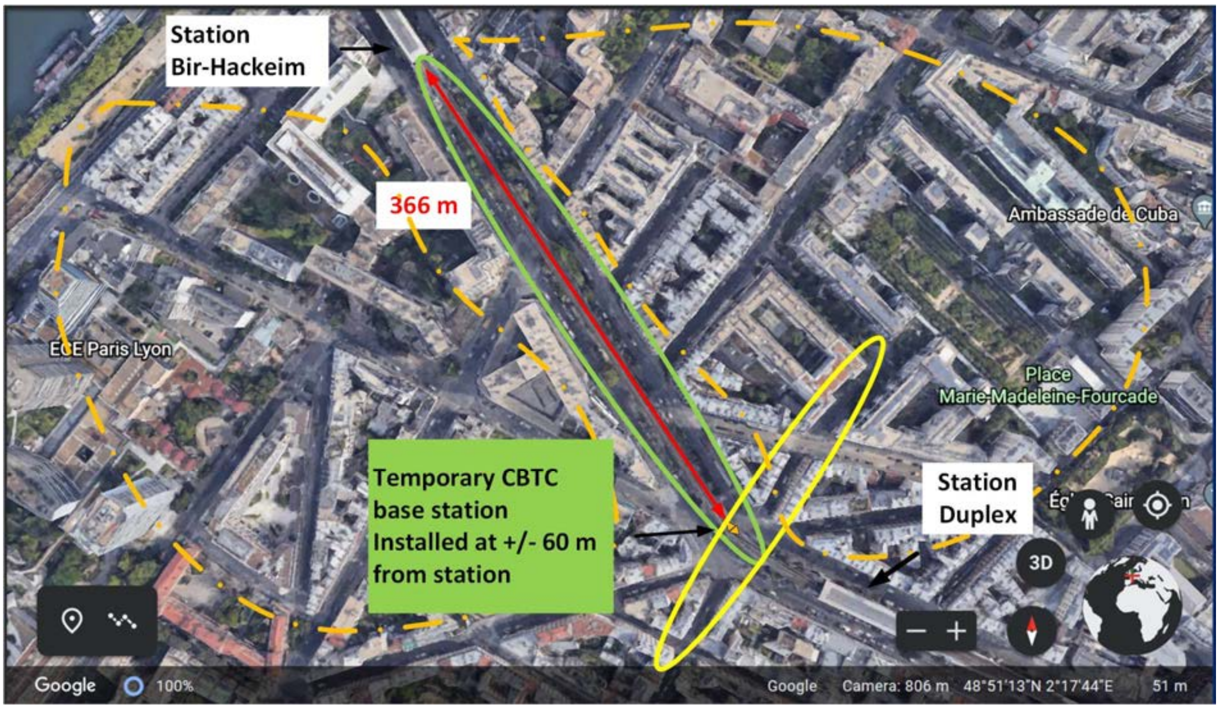

Figure 10: Section 1 of RATP Line 6 configuration for measurements (Map Source Google Earth: © Google)

A temporary CBTC base station was installed in the curve at a distance of around 80 m from the Duplex station extremity. It covered northward a section having a length of 350 m up to the extremity of the station Bir-Hakeim.

The ellipse in green identifies the tracks running on a viaduct, where two receivers modelling trains have been installed, on the south-east and over the crossing street.

The green ellipse encompasses also the two parallel roads, each one parallel to a side of the tracks on the viaduct.

The ellipse in yellow encompasses a road that crosses the tracks. The transmission of the vehicles running on these roads may be received by a CBTC base station installed on a curve and a train leaving the station duplex. These areas are therefore of primary interest.

The measurement vehicles drive in the area of the city surrounded by a Line composed of a dot followed by a dash, to measure the field-strength received from streets in the vicinity of the tracks which are not necessarily in Line-of-sight.

In the section 1 of RATP Line 6, measurements can be performed for scenarios 2, 6 and 7.

6.3.1.2 Description of the section 2 of RATP Line 6

The second section of RATP Line 6 is from Station Sèvres-Lecourbe and entrance of tunnel direction station Pasteur. The tracks are on a viaduct when they leave the Station Sèvres-Lecourbe, after 150 m they are at the same level as the roads. After 350 m from the extremity of the station, the tracks enter in a tunnel

The length of the section was 360 m with 200 m inside the tunnel as shown in Figure 11.

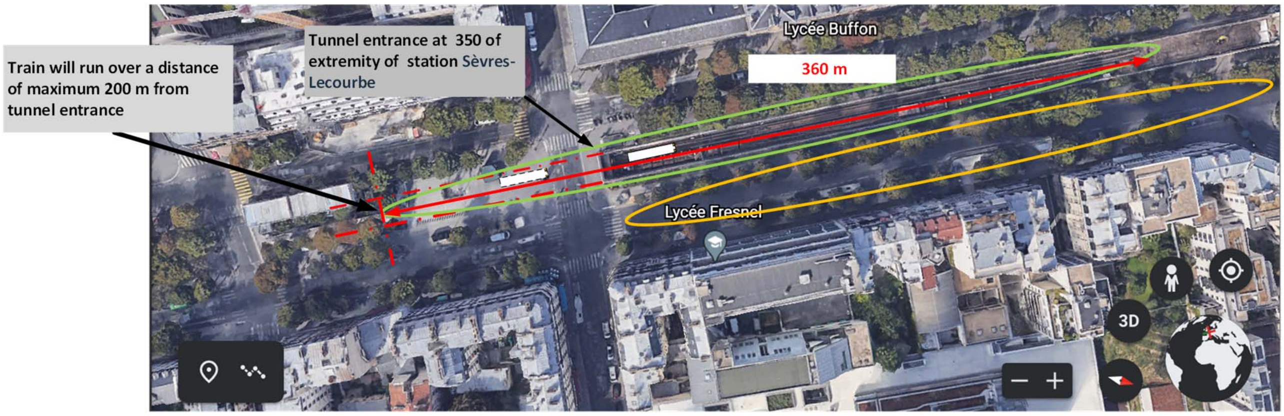

Figure 11: Section 2 of RATP Line 6 configuration for measurements (Map Source Google Earth: © Google)

Two types of measurements were performed:

1) When the train runs in the tunnel, the objective of the measurement is to evaluate how far the vehicle transmissions penetrate inside the tunnel. This corresponds to the scenario 4.

2) For the second type of measurements, the train was positioned at the defined location outside the tunnel and the vehicles were driving on the neighbouring roads, this corresponds to the scenarios 1 and 7 in an urban environment.

6.3.1.3 Description of the section 3 of RATP Line 6

The third section of the Line 6 was between station Quai de la Gare and entrance of tunnel direction station Bercy. After the station Quai de la Gare the tracks are on a viaduct. The viaduct crosses the Seine river on a bridge ("Pont de Bercy") with two parallel roads, one at each side as shown in Figure 12.

Figure 12: Section 3 of Line 6 environment (Map Source Google Earth: © Google)

The viaduct is a at a height of 6 m above the roads.

Figure 13 shows a detailed description of the section 3 of Line 6.

Figure 13: Section 3 of RATP Line 6 configuration for measurements (Map Source Google Earth: © Google)

The section 3 of Line 6 started at the extremity of the Station Quai de la Gare and ends at the tunnel entrance direction station Bercy. The length of the section was 560 m.

The ellipse in green identifies the tracks over the viaduct.

The ellipse in yellow highlight identifies crossing roads below the viaduct.

Measurements were performed with the two vehicles driving routes including the adjacent bridges as shown in Figure 14.

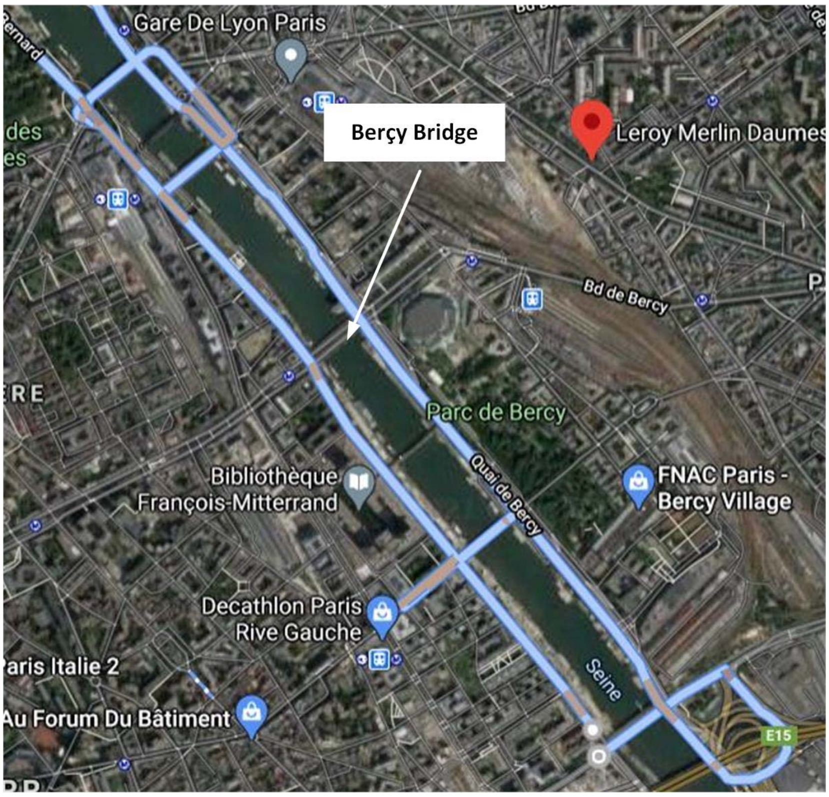

Figure 14: Circuit followed by vehicles for evaluation of interference from adjacent bridges (Map Source Google Earth: © Google)

6.3.2 Selected relevant areas of RATP Line 8

6.3.2.1 Description of the sections of RATP Line 8

Three relevant areas were selected for Line 8:

- Section 1: between depot of Line 8 and the station Pointe du Lac.
- Section 2: between station Créteil-Préfecture and Station Créteil-université.
  The section started at the extremity of station Créteil and ended at around 500 m from this one.
- Section 3: between Station Créteil-Préfecture and Station Créteil-Université.
  The section started at around 616 m from the extremity of station Créteil and ended at a distance of around 1 062 m from this one.

On section 3 of RATP Line 8, measurements were performed for scenarios 2, 5 and 7.

Line 8 offers a suburban environment.

6.3.2.2 Description of the section 1 of RATP Line 8

The first section of Line 8 was between the depot of the Line and the station Pointe du Lac. The section started at a distance around 320 m from the depot and ended at a distance around 600 m from this one as shown in Figure 15.

Figure 15: Section 1 of RATP Line 8
(Map Source Google Earth: © Google)

The distance between the axis of the track and the axis of the closest lane of the road was between 8 m and 9 m. Due to the presence of ballast the track was around 1 m above the road.

A temporary CBTC Base station was installed at the second curve of the depot with one antenna pointing to the station pointe du lac and the other one pointing to the track going to the direction of the depot.

The length of the section was 250 m, between the temporary base station and the station Pointe du Lac.

The measurement train was positioned on section of the tracks surrounded by the green ellipse. This one also encompasses the parallel road on which the two vehicles for measurements drove.

The two vehicles for the measurements drove on the parallel road to the track but not only. They followed a circuit that includes the parallel road to the tracks and roads and streets around the metro Line.

On section 1 of RATP Line 8, measurements were performed for scenarios 1 and 7.

6.3.2.3 Description of the section 2 of RATP Line 8

The section 2 started at the extremity of the station Créteil-Préfecture in the direction of the station Créteil-Université and ended at 500 m from the station Créteil-Préfecture as shown in Figure 16.

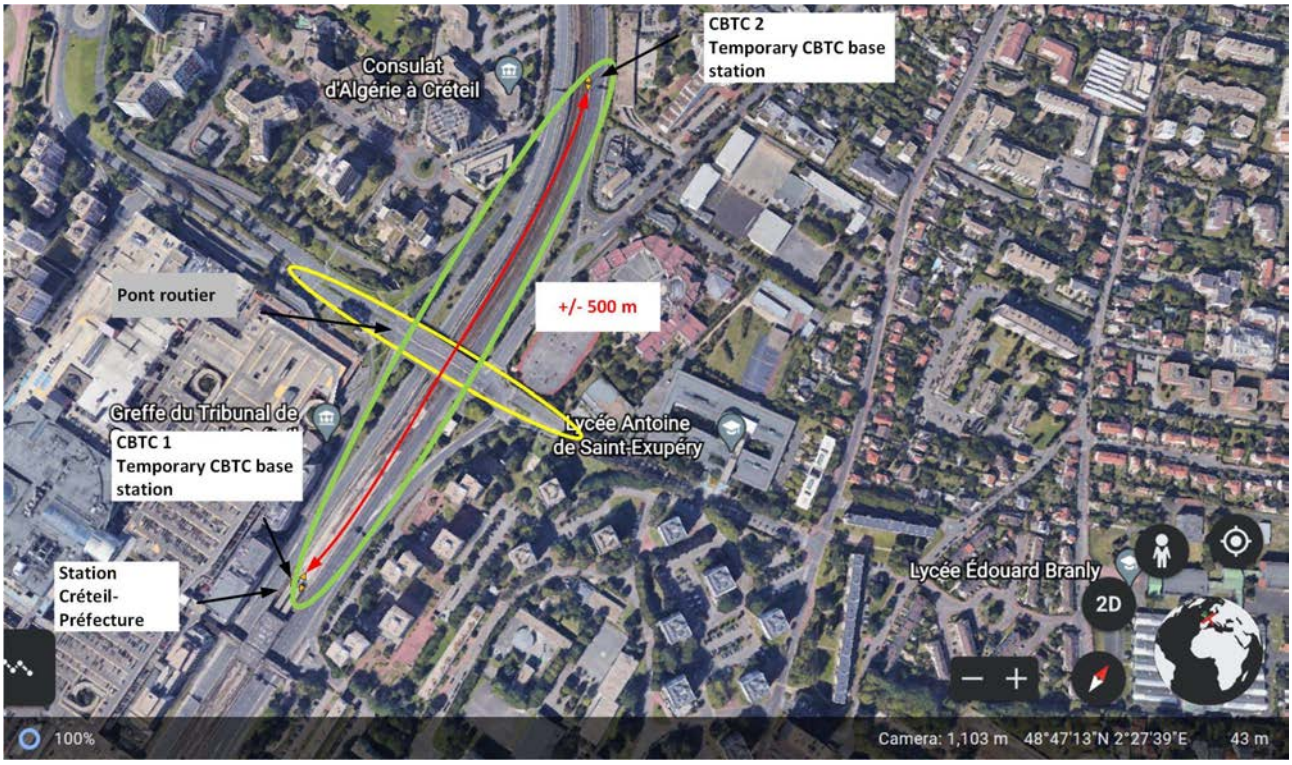

Figure 16: Section 2 of RATP Line 8
(Map Source Google Earth: © Google)

The distance between the axis of the tracks and the axis of the first lane of the road was between 7 m and 8 m. Due to the ballast the tracks area are around 1 m above the level of the road.

Measurements were performed with one temporary CBTC base station installed at the extremity of the station Créteil-Préfecture (CBTC1) and another base station (CBTC2) installed at ±500 m from the extremity of station Créteil-Préfecture.

For the measurements, the train was positioned at different locations on the section of the tracks surrounded by the green ellipse. This one also encompasses the parallel roads on which the two vehicles for measurements drove.

The yellow ellipse encompasses the bridge and the access to this one on which the vehicles drove.

The two vehicles for measurements drove on the parallel road to the track but not only. They followed a circuit that includes the parallel road to the tracks, the bridge and roads and streets around the metro Line.

On section 2 of RATP Line 8, measurements were performed for scenarios 1, 5 and 7.

6.3.2.4 Description of the section 3 of RATP Line 8

The section 3 started at around 616 m from the extremity of station Créteil-Préfecture and ended at 1 062 m from this one. The length of the section 3 was 446 m as shown in Figure 17.

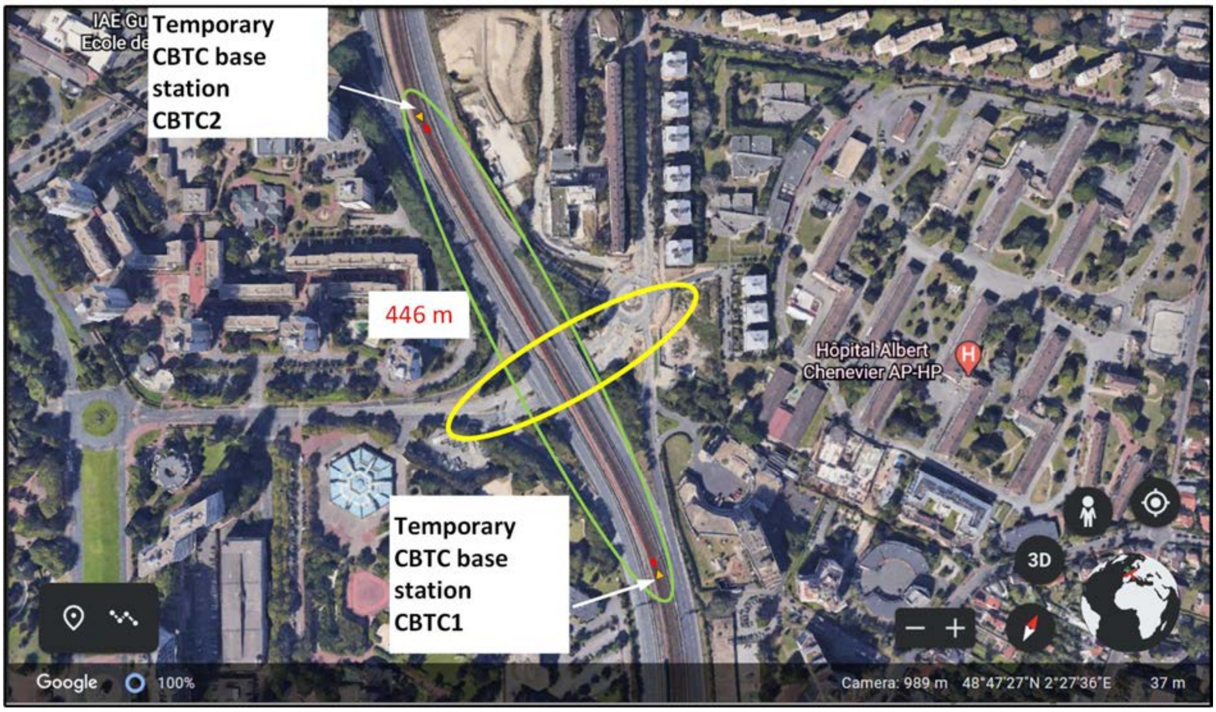

Figure 17: Section 3 of RATP Line 8
(Map Source Google Earth: © Google)

The section 3 of RATP Line 8 is surrounded by two parallel roads. Each road has two lanes. The distance between the axis of the track and the axis of the closest lane of each road is between 7 m and 8 m.

Due to the ballast, the tracks are around 1 m above the level of the roads.

The measurements were performed with one CBTC base station installed along the track where the road crosses the tracks below a bridge.

The measurements train was positioned at different locations on the section of the tracks surrounded by the green ellipse. The two vehicles for the measurement drove on the two parallel roads surrounded by the green ellipse but not only.

The yellow ellipse in Figure 17 surrounds a road that crosses the tracks where these ones are on the bridge. This is an area of interest.

The two vehicles for measurements drove on circuits that included the two parallel roads, a passage below the bridge and the road and neighbouring streets.

On section 3 of RATP Line 8, measurements will be performed for scenarios 1, 6 and 7.

6.4 Specific requirements to conduct the measurements

Scheduling of overnight measurements is a complex process because concurrent maintenance activities have to be considered. In addition, critical operations may be given top priority, causing the measurements to be postponed at a very late stage.

The exact schedule for the measurement campaign needs to be requested with at least two months anticipation at a monthly conference and needs to be confirmed two weeks before the measurement day. Cancellation of the measurements may be imposed up to the very last moment to allow critical operations.

A detailed description of the measurement procedure needs to be issued, emphasizing on hazard identification and mitigation. The measurement plans are approved by Line managers.

Staffs are requested to undergo a risk management information session, mandatory to access the infrastructure overnight, including platforms and trains.

Ultimately, the train operators have the full authority to deny a train movement on their own initiative.

7 Description of measurement procedures and measurement tools for each case

7.1 Overview

There are three objectives:

- High level description of test set-up and identification of requirements for RF measurement tool
- Description of test set-up and RF measurement tool for all the measurements and installation consideration
- Description of measurement procedure

7.2 General test set-up

7.2.1 High level description of the test set-up

The purpose of the test set-up was to measure the received level (RF power) by CBTC base stations and trains when Road-ITS equipped vehicles are driving in the vicinity of the tracks, including on parallel and perpendicular roads, bridges, etc.

Two vehicles were equipped with an RF measurement tool connected to roof-top antennas. The RF measurement tools installed inside the vehicle were configured to transmit small packets on a periodic basis.

The RF measurement tools installed at the CBTC base stations were connected to two high gain antennas and were configured to receive the packets generated by the RF measurement tools installed in the vehicles.

Inside the Train, the RF measurement tools were connected to two high gain antennas fitted on the windshield and were configured to receive the packets generated by the RF measurement tools installed in the vehicles.

The antenna installed in the train for the temporary base station was a type of patch antenna. This type of antenna is small for their gain and can be easily fitted on a mast or on a windshield. This type of antenna cannot be installed on the train roof.

Figure 18 gives an overview of the test setup.

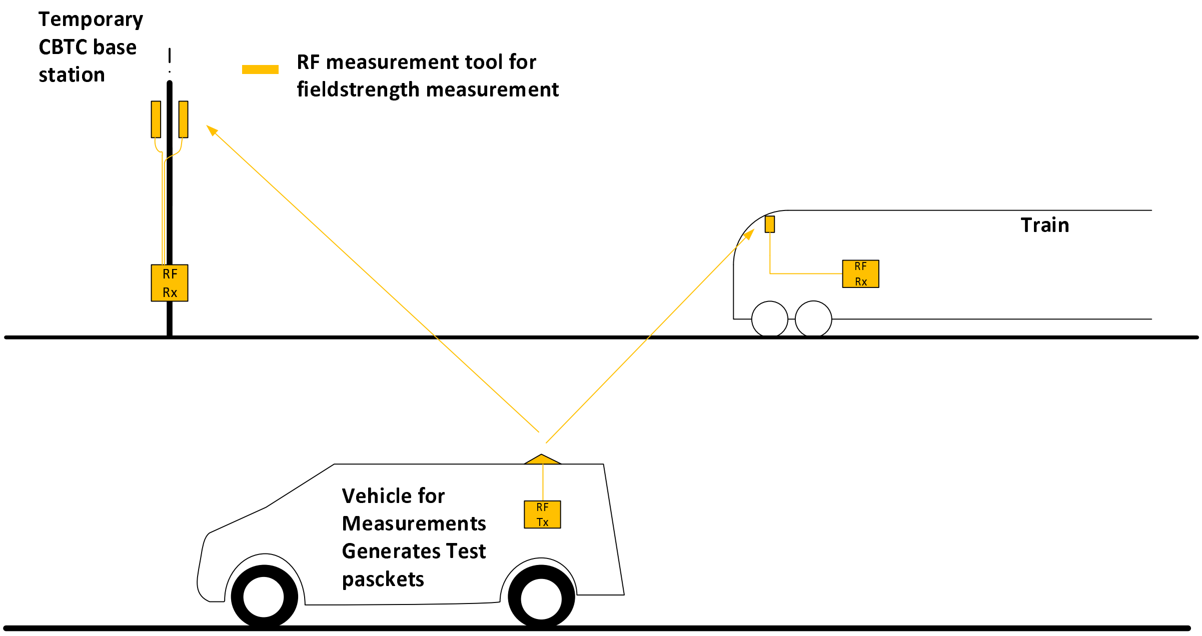

Figure 18: Test-setup for measurement campaign overview

For most measurements, the train was positioned at fixed location. For one set of measurements, the train runs in a tunnel.

The objective of the measurements was to record the received power from two vehicles.

It has to be noted that received power level versus distance is technology agnostic, but dependent upon the EIRP of the vehicles. Although the received levels in the present document are displayed for vehicles transmitting at maximum output power (33 dBm/10 MHz), the results could be scaled down for different transmit powers (e.g. 10 dB decrease for vehicles transmitting 23 dBm/10 MHz).

7.2.2 Requirements for the RF measurement tool

To define the requirements for the optimal RF measurement tool, it was necessary to start from the CBTC system requirement.

A CBTC system operates on channel having a channel bandwidth of 5 MHz. The maximum interference level accepted by a CBTC radio modem is given in Table 2.

Table 2: CBTC System requirements

CBTC System requirements			
Item	**Value**	**Unit**	**Comments**
Rx sensitivity	-85	dBm/5 MHz	For a Transfer rate of 3 Mbits/s
Protection ratio	9	dB	C/I minimum for QPSK
Interference max in 5 MHz channel	-94	dBm/5 MHz	This assumes a noise free receiver, which is not achievable in practise. Hence interference may arise at lower power levels. However, this provides a reasonable target for the measurement setup. The level at which interference may arise is out of the scope of the present document
Interference max per MHz	-101	dBm/1 MHz	At input of RF connector

The typical antennas used for CBTC base station have a high gain of 15 dB at 5 915 MHz.

Two CBTC antennas were used, fitted on the mast back-to-back and both connected to a coupler. The coupler was connected to an Access point. Each antenna was pointed to the tracks but in opposite direction as shown in Figure 19.

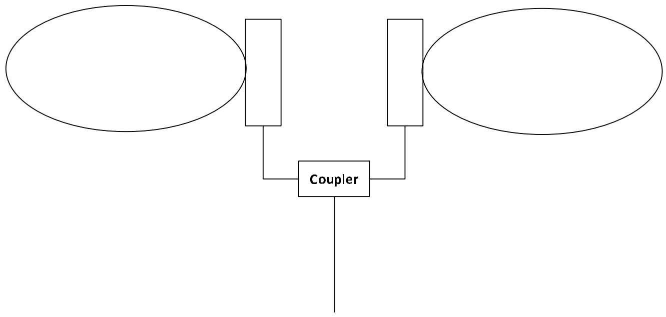

Figure 19: CBTC antennas

For the coverage of metro Lines, various types of antennae are used but the most current one is antenna based on patch technology having a gain of 15 dB at 5 915 MHz. Some CBTC systems use different types of antennae for the Train and the base station and others use the same type of antenna for CBTC base station and inside the train. The approach based on the same type of antennas for train and base station has been considered for the measurement campaign. The description of the antenna is available in clause A.2.

Based on CBTC system requirements, it was possible to define the RF measurement tool specification.

The RF measurement tool installed inside the train and the temporary CBTC base station will have a minimum sensitivity of -101 dBm/MHz if the EIRP of the vehicles corresponds to the maximum EIRP used by Road-ITS. Matching the maximum allowed EIRP would require that the RF measurement tool installed in the vehicles be able to generate packets with an EIRP of 33 dBm/10 MHz.

When installed along the track, the temporary CBTC base station cannot be accessed. It means that the RF measurement tool of the Temporary CBTC base station will be remotely controlled.

The antenna installed on the roof of the vehicle needs to be omnidirectional. Because there are different types of vehicle and different types of roof-top antennas for vehicle, there are different types of radiating pattern of roof-top antennas installed on vehicles.

For the measurement campaign, it was not possible to perform measurements with a wide variety of vehicles and different types of roof-top antennas. About the choice vehicle roof-top antenna for measurements, a detailed analysis of the problem is given in clause A.3.

The antenna that has been chosen was a 3 dB omnidirectional antenna that has been installed at 50 cm above the vehicle roof. The radiating pattern of this antenna has been measured by the European Microwave Signature Laboratory (EMSL) of the Joint Research Centre (JRC) of the European Commission in Ispra, Italy.

A description of the measurements performed by the Joint Research Centre (JRC) of the European Commission in Ispra, Italy is given in clause A.4.

The RF measurement tool installed in a vehicle will generate packets or messages at a frequency that allows a correct sampling of slow fading.

The definition of frequency of packets or message generation takes into consideration the allowed speed range of the vehicles used for the measurements.

The measurements were performed in the centre of a city and in a suburban area. For relevant test areas of RATP Line 6 that is in the centre of the city, the speed limits range is between 30 km/h and 50 km/h. For the relevant test areas of RATP Line 8 that is in a suburban area, the speed limits range is between 50 km/h and 90 km/h.

A vehicle driving at 50 km/h or14 m/s, with a message generation frequency of 100 Hz, a field-strength value is obtained every 14 cm which is equivalent to three wavelengths with the power received averaged on the packet duration. This sampling rate allows a correct evaluation of the slow fading.

A vehicle driving at 90 km/h or 25 m/s with a message generation frequency of 100 Hz, a field-strength value is obtained every 25 cm which is equivalent to five wavelengths with the power received averaged on the packet duration. This sampling rate allows a correct evaluation of the slow fading.

Because the objective of the measurements was to obtain received level by CBTC base stations antennas and train antennas versus distance and location of vehicles, an accurate location of these ones was recorded and associated with received field-strength.

It means that the RF measurement tool installed inside each vehicle needs to include a high accuracy GNSS receiver.

Because the measurements will take place with base stations and trains at defined position, the accuracy of GNSS receiver can be lower than the GNSS receiver inside the vehicle. The accuracy of position of base stations and trains can be increased with post processing.

To allow precise analysis, it was also important that all the RF measurements tool be synchronized so that timestamps of received packets and transmitted packets are very closed.

Concerning the localization accuracy, it was decided to target the highest possible accuracy for the two vehicles. To achieve this goal, a GNSS receiver able to receive correction data from a RTK network has been installed in each vehicle.

Table 3 summarizes the requirements of the RF measurement tools that were installed in CBTC base station, Train, and vehicles.

Table 3: Summary of the requirements for the RF measurement tool

Item	Values or feature	Applicability
Minimum sensitivity	-101 dBm/MHz	For RF measurement tool that was installed inside the CBTC station and the train
Minimum obtained EIRP obtained with a generic roof-top antenna of 3,5 dB between 0° to 1° elevation	23 dBm/MHz	For RF measurement tool that was installed inside the Vehicles
Packets or message generation frequency	Minimum 100 Hz	For RF measurement tool that was installed inside the Vehicles
Synchronization	Mandatory Via GNSS receiver with an accuracy of 60 ns for 95 % of the time	For all RF measurement tools
Localization	Via GNSS receiver Accuracy < 1 m	For RF measurement tool installed inside train and vehicle
Control	Remote	RF measurement tool of the temporary CBTC base station

7.3 Description of test set-up and RF measurement tool

To perform the field-strength measurements, the RF measurement tool will have to meet the requirements defined in clause 7.2.2, but additional constraints will be considered.

For the temporary CBTC base station, there was no power supply available along the track, it means that the power was be provided by a battery. This was also the case inside the train.

The GNSS receiver which is included in an ITS platform can be used for precise time stamp generation but its accuracy for localization is not high enough. A better accuracy for position was obtained with the combination of a GNSS receiver, dedicated GNSS antennas and post processing.

For this reason, the ITS platforms complemented with dedicated GNSS receiver have been selected as RF measurement tool for temporary CBTC base station, the train, and the vehicle.

The selected ITS platform meets the requirement for the minimum sensitivity. Typical sensitivity of an ITS platform is between -92 dBm/10 MHz and -94 dBm/10 MHz. It means a sensitivity between -102 dBm/MHz and -104 dBm/MHz.

The selected ITS platform did not meet the requirement for an EIRP of 23 dBm/MHz. The maximum of output power at antenna connector of the ITS platform is 23 dBm/10 MHz, meaning 13 dBm/MHz. To meet the target a power amplifier has been inserted between the ITS platform and the rooftop antenna.

The ITS platform can generate short messages of packets (100 bytes to 200 bytes) at a frequency between 100 Hz and 300 Hz.

It is also important to consider the link budget and evaluate the maximum achievable pathloss corresponding to the maximum interference level: -101 dBm/MHz.

Table 4 gives the link budget for the CBTC base station assuming an EIRP for the vehicle of 33 dBm/10 MHz at elevation angle between 0° and 0,5° above the roof.

The link budget takes into account the coupler and feeder loss.

Table 4: Link budget with maximum achievable pathloss CBTC base station

CBTC base station		
EIRP at 0,5° elevation	33	dBm/10 MHz
EIRP dBm/MHz at 0,5° elevation	23	dBm/MHz
Path loss maximum	-134	dB
CBTC antenna gain measured	15	dB
Coupler plus feeder Loss	-5	dB
Received level by CBTC base station at input of ITS platform corresponding to maximum Interference level for CBTC	-101	dBm/MHz
Level in a channel of 10 MHz	-91	dBm/10 MHz
Minimum sensitivity level of ITS platform for 1/2 BPSK	-92	dBm/MHz
Margin	1	dB

Table 5 gives the same link budget for the train.

Table 5: Link budget with maximum achievable pathloss for Train RF tool

Train		
EIRP at 0,5° elevation	33	dBm/10 MHz
EIRP dBm/MHz at 0,5° elevation	23	dBm/MHz
Path loss maximum	-135	dB
Wind screen Material loss	-3	dB
Train antenna gain measured	15	dB
Coupler plus Feeder loss	-1	dB
Received level by ITS platform in the train corresponding to maximum Interference level for CBTC	-101	dBm/MHz
Level in a channel of 10 MHz	-91	dBm/10 MHz
Minimum Sensitivity of ITS wireless platform for 1/2 BPSK	-92	dBm/MHz
Margin	1	dB

It has to be noted that the sensitivity of the ITS platform is close to the maximum interference level for CBTC system. The margin is 1 dB which is too small to obtain reliable measurements at low interfering power levels. This margin is too short in Non-Light of Sight condition.

For this reason, a request was sent to the regulator to be allowed to increase the EIRP at 36 dBm/10 MHz for the test duration. If the EIRP is increased by 3 dB, margin will be 4 dB for the same pathloss. Measurement with a higher pathloss can also be considered.

Table 6 gives the link budget for interfering link between the CBTC receivers and a road ITS vehicles, assuming an EIRP for the vehicle of 33 dBm/10 MHz (regulatory maximum limit), 30 dBm/10 MHz and 26 dBm/10 MHz.

Table 6: Link budget for interfering link between the CBTC receivers and a road ITS vehicles for different EIRP

Interference				
Vehicle EIRP	**Train windshield attenuation**	**Coupler and cable losses**	**Min interference level likely to cause interference (e.g. Receiver noise -3 dB)**	**Max pathloss that may cause interference**
dBm/10MHz	**dB**	**dB**	**dBm/10 MHz**	**dB**
Train receiver				
33	3	1,93	-94	122,07
30	3	1,93	-94	119,07
26	3	1,93	-94	115,07
BS receiver				
33	0	5	-94	122
30	0	5	-94	119
26	0	5	-94	115

Table 7 gives the actual link budget for the measurement performed. The maximum path loss measurable between the transmitting vehicles and the receivers on the metro Line is derived. It has to be noted that four EIRP values are present because the two vehicles have slightly different EIRP, and this changed slightly during the measurement due to the swapping of the power supplies. This is duly considered in the measurement results.

Table 7: Link budget for interfering link between the CBTC receivers and a road ITS with EIRP used during measurements

Measurements				
Vehicle EIRP	Train windshield attenuation	Coupler and cable losses	Sensitivity (to be assessed from measurements).	Maximum path observed loss
dBm/10 MHz	dB	dB	dBm/10 MHz	dB
Train receiver				
37	3	1,93	-97	129,07
35,7	3	1,93	-97	127,77
37,1	3	1,93	-98	130,17
36,3	3	1,93	-98	129,37
BS receiver modelling a train				
37	0	4,66	-96	128,34
35,7	0	4,66	-96	127,04
37,1	0	4,66	-97	129,44
36,3	0	4,66	-97	128,64
BS receiver				
37	0	4,66	-96	128,34
35,7	0	4,66	-96	127,04
37,1	0	4,66	-97	129,44
36,3	0	4,66	-97	128,64

Based on all constraints, the completed test set-up depicted in Figure 20 has been defined.

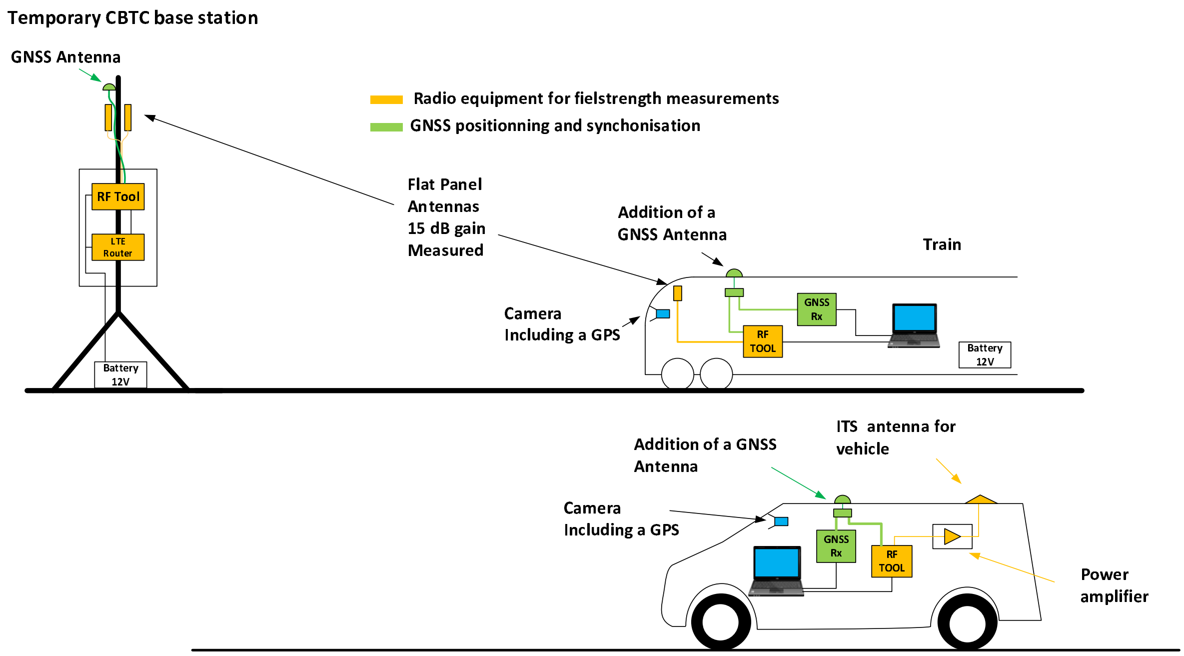

Figure 20: Test-setup for measurement campaign

The test setup for measurement equipment was composed of:

- One or two temporary base stations that were installed along the tracks composed of:
    - An RF measurement tool that was an ITS platform

  - Two CBTC high gain antennas connected to the RF measurement tool via a coupler
  - An LTE/Ethernet router connected to the RF measurement tool for its remote control
  - A 12V battery that provides power to the RF measurement tool and the LTE/Ethernet router
  - A telescopic mast supporting the antennas, the RF measurement tool and the LTE/Ethernet router

- A train with the RF measurements equipment composed of:
  - Two high gain antennas fixed on the windshield of the train and connected to the RF measurement tool
  - An RF measurement tool connected to a laptop PC
  - A GNSS antenna fitted on the train roof via a magnetic support and connected to a GNSS coupler
  - A GNSS coupler connected to the RF measurement tool and the GNSS receiver
  - A high accuracy GNSS receiver connected to a laptop PC
  - A 12V battery to provide power to all the components, camera excepted

- Two vehicles with an RF measurement equipment composed of:
  - An ITS roof-top antenna connected to the RF measurement tool acting as a packet generator
  - An RF measurement tool connected to a laptop PC
  - A power amplifier connected to the ITS roof-top antenna and the RF measurement tool
  - A GNSS antenna fitted on the vehicle roof via a magnetic support and connected to a GNSS coupler
  - A GNSS coupler connected to the RF measurement tool and the GNSS receiver
  - A high accuracy GNSS receiver connected to a laptop PC
  - A camera that includes a GNSS receiver

The heights of the two vehicles were respectively 2 m and 3 m to assess the impact of the Road ITS antenna height. The corresponding antenna heights, including the poles, were then 2,5 m and 3,2 m. During the measurement, both vehicles transmitted continuously short messages at a frequency of 300 Hz. The messages issued by the GNSS receiver were recorded by the laptop.

The RF measurement tool inside the vehicles recorded each transmitted message associated with a time stamp. The time stamp was generated by an internal clock synchronized with the internal GNSS receiver. The vehicles also recorded the positions delivered by the high accuracy GNSS receiver.

The RF measurement tools inside the train and the CBTC base stations were configured to receive the messages generated by both vehicles. Each RF tool stored the received messages and its originating timestamp associated with received level.

The camera with intergraded GPS installed in two vehicles recorded continuously the images associated with GNSS coordinates and its time stamp.

The images recorded by the camera provided the detailed information about environment when the recorded data was analysed.

7.4 Measurement procedures

These procedures were applied after the installation of the RF measurement tool.

Before starting the relevant procedure, all the RF measurement tools are supposed to have been tested and operating correctly.

One generic procedure is defined for all areas. It is applicable when trains are standing at a defined location and vehicle driving on a circuit. Another specific procedure applies when the vehicle is at defined location and the train is running.

The generic procedure is composed of the following steps:

1) The train is positioned at the first defined location.

2) Transmissions and logging at the two vehicles are activated.

3) Measurement recording is launched at the temporary CBTC base stations (via remote control) and/or at the train.

4) The two vehicles start driving on a pre-defined circuit for the current section.

5) When both vehicles terminate their circuit, the recording of measurements are stopped and saved for each RF measurement tool and for the laptops PCs that record messages issued from GNSS receiver. Files are saved with a name that clearly identifies the measurements with date and an Identification Code related to the device.

6) When all routes are completed, if applicable the Train is positioned at the next defined location and the process is repeated from step 2.

Figure 21 shows an example.

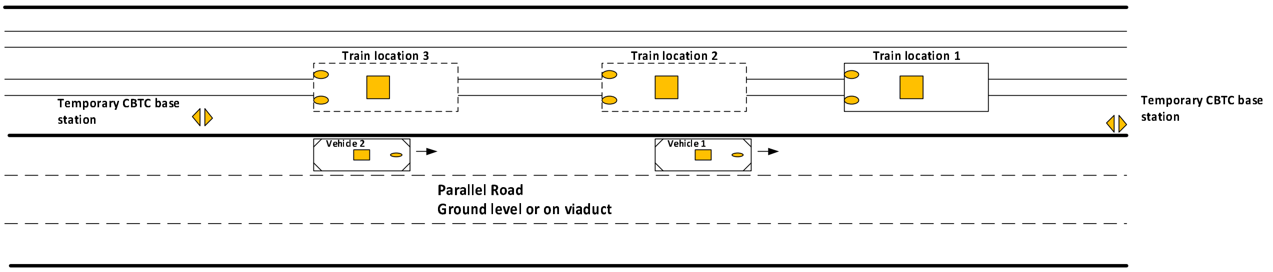

Figure 21: Measurement procedure illustration for majority of relevant areas

The second type of procedure was similar. The only difference is that the vehicles were standing at defined location and the train was driving inside the tunnel as shown in Figure 22.

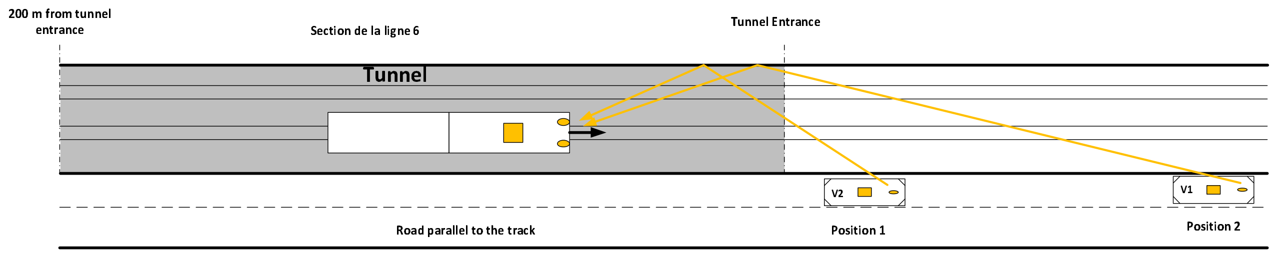

Figure 22: Measurement procedure illustration for measurement in tunnel

During the measurements, a logbook is also written on the fly to record all noticeable events that can help the analysis of the data and include the following data:

- Date
- Line (6 or 8)
- Section of the Line (1, 2 or 3)
- Train position or vehicle position:
  - Position number
  - Coordinate
- Circuit followed: circuit number referring to a circuit description
- Time of beginning for measurement: hours, minutes, seconds

- Time of end of the measurements: hours, minutes, seconds

A camera was also installed in each vehicle to provide some help to understand what happens during the circuit.

7.5 Implementation of the Measurements campaign

7.5.1 Implementation process

The implementation process was composed of three tasks:

- Preparation and optimization of the planning for measurements on Line 6 and Line 8
- Preparation and test of the RF Measurement tool in laboratory
- Conduct the measurements campaign

The two first tasks were executed in parallel.

7.5.2 Definition of Planning for measurements

The first task deals with the preparation and optimization of planning of measurements on Line 6 and Line 8. It was an iterative process with the objective to maximize the number of measurements to be performed for one night considering the specific constraints imposed by the metro Line operator:

- End of revenue service: 01H15.
- Section of the Line consigned and dedicated for the measurements.
- Authorization to access to track (high voltage switched off).
- Time at which the Line needs to be given back to the operator: 04H30, maximum 04H35.

The typical time available to perform measurements was 2H with a maximum of 2H30. The definition of the planning of measurements has considered this short period of time.

To maximize the number of measurements during a night, it was necessary to use up to three base stations installed along the tracks, and performing measurements with a train fitted with one RF measurement tool per cab instead of only one cab.

It was initially foreseen to perform the measurements with two temporary base stations remotely controlled via the public 4G network. It has been decided to add a temporary base station remotely controlled via a long ethernet cable.

For one night of Line 8 and three nights of Line 6, the train has been replaced by a temporary base station. To simulate the train the telescopic mast has been adjusted so that the antennas were at a height of 3,5 m above the ground, as it is the case for a train. The reason of this decision was to reduce the total time taken to switch off and switch on the high voltage and obtain the authorization of the OCC to access to the tracks. The analysis of planning has shown that the combination of measurements using train and base station was not optimal. The total time taken to switch off high voltage, install base station, to switch on high voltage, perform measurements, switch off high voltage, remove base station from the track and switch on High voltage again would not have make it possible to perform all the expected measurements for all the nights.

For Line 6, the decision was also driven by the operator who had maintenance works to perform on the tracks and in the stations. Replacing the train by temporary base stations allowed to share activities with the maintenance operations and, consequently, to find suitable dates for the measurements within a six months' timeframe.

7.5.3 Preparation of the RF measurements tools

7.5.3.1 Preparation of the RF measurements tool for vehicles

As explained in clause 7.3, the RF measurement tool was installed inside both vehicles and transmitted packets with a frequency of 300 Hz at a minimum EIRP of about 36-37 dBm/10 MHz, however the results are post processed and scaled down to 33 dBm/10 MHz.

The maximum output power of the RF measurement tool installed inside the vehicles was 23 dBm, to obtain an EIRP with a vehicle antenna gain, a power amplifier is inserted between the RF measurement tool and the vehicle antenna.

Several measurements have been performed in laboratory to search for the maximum amplifier transmit power that allows reception of transmitted packets with very low Packet failure rate. The amplifier was operating close to the 1 dB compression point.

This maximum transmit power measured in laboratory at vehicle antenna input was 34 dBm EIRP for IEEE 802.11p [i.11] packets transmitted with Rate ID11 meaning 3 Mbits/s, BPSK rate ½ in the channel 176 with 5 880 MHz as centre frequency.

The antenna installed on the roof of the vehicles was measured at JRC-Ispra European facilities located in Italy. In this laboratory, the gain of the radiating pattern of the antenna has been measured at different heights above a metallic plate.

The objective was to identify the optimal height that provides a smooth radiating pattern between 0° and 50° of elevation above the horizon and allows a stable and robust installation above the roof of the vehicle. A description of the process followed for the radiating pattern measurement can be found in clause A.4.

7.5.3.2 Preparation of the RF measurements tool for train

The initial installation foresaw that a geodesic GNSS antenna be installed on the train Roof and be connected to a coupler to be shared by the GNSS receiver of the RF measurement tool and a High accuracy GNSS receiver.

A train site survey has shown that for the train of Line 8, the roof is in aluminium and the roof above the train cab is in composite material. After the survey, the conclusion was that the geodesic GNSS antenna cannot be used, but a smaller GNSS antenna can be fitted on the roof with tape.

The change of type of GNSS antenna has an impact on the accuracy of the localization but are limited because measurements were performed when the train was standing, and post processing can contribute to increase the localization accuracy.

A decision has been taken to install a high accuracy GNSS receiver in one cab only. For the other cab, a GNSS antenna will be installed and connected to the RF measurement tool that includes a GPS receiver.

Because measurements are performed with train at defined location, decision has been taken to not install a camera inside the train but take pictures.

7.5.3.3 Preparation of the RF measurements tool for the base stations

The preparation of the RF measurements tool for the base station has focused on the remote control via the public LTE 4G network.

The LTE/Ethernet router has been configured to set-up automatically after initialization an OpenVPN tunnel with a server in the cloud. Inside each base station the LTE/ethernet router is connected to the RF measurement tool.

The remote control of the temporary base station is done via a PC connected to an LTE/Ethernet router. This one is set-up automatically after initialization of an OpenVPN tunnel with the OpenVPN tunnel server in the cloud.

The role of the OpenVPN server is to accept the OpenVPN request from identified client and routes IP packets between these ones.

The configuration of the LTE/Ethernet required to configure several parameters in the security system.

When properly configured, a LTE/Ethernet routers, set-up each time after its initialization an OpenVPN tunnel with the OpenVPN server running in the cloud and allows reliable connexion with the RF measurements tool.

An issue occurred on site and in lab due to DHCP client or Server and solved by defining static IP address.

7.5.4 Measurement set-up as implemented and onsite parameters

The measurement set-up has been implemented as shown on Figure 20 but with some adaptations due to the results of planning optimization.

Figure 23 shows the measurements set-up when a train was used to perform the measurements.

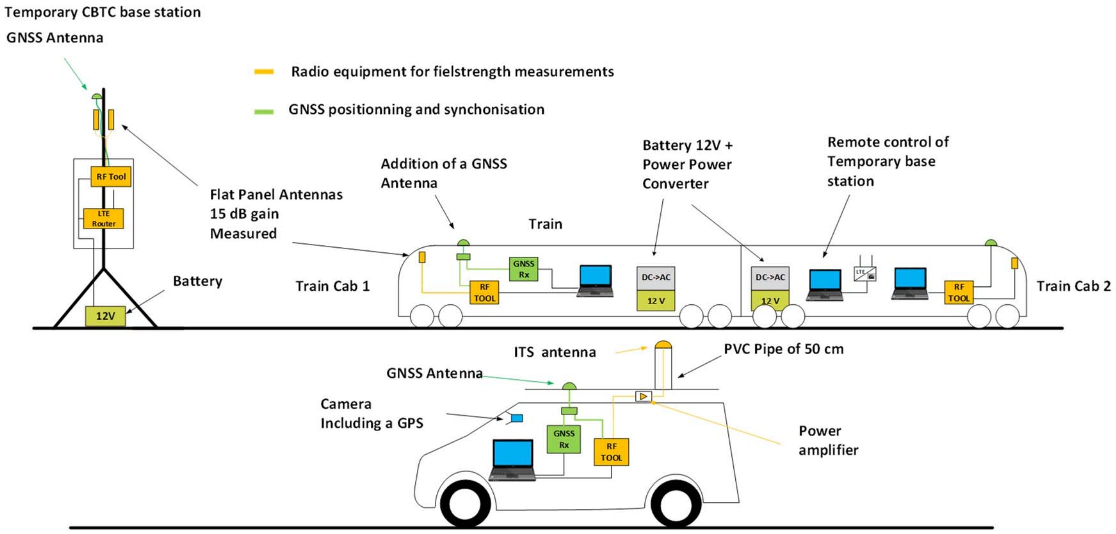

Figure 23: Measurements set-up with a Train

Figure 24 shows the measurements set-up when the train was simulated by a temporary base station.

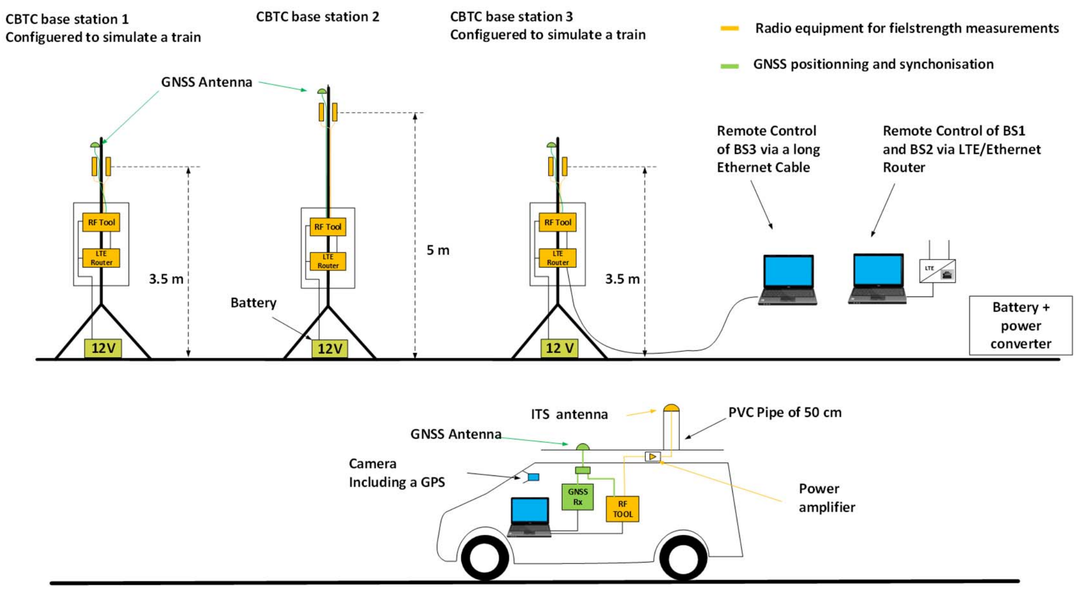

Figure 24: Measurements set-up with base stations simulating trains

Figure 25 shows the train installation.

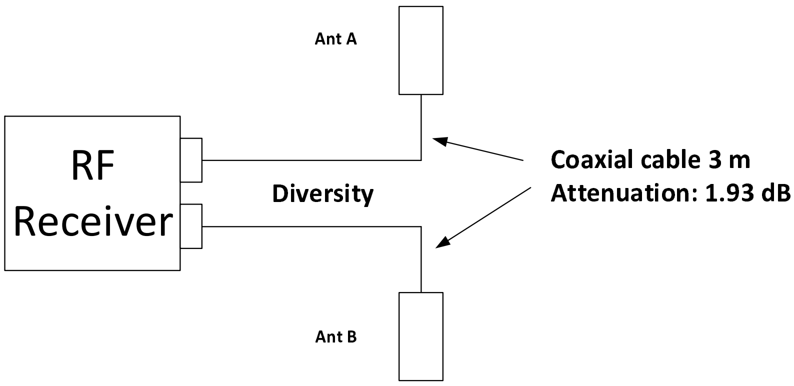

Figure 25: Train installation of the RF measurement tool

Figure 26 shows the installation of the RF measurement tool for a base station.

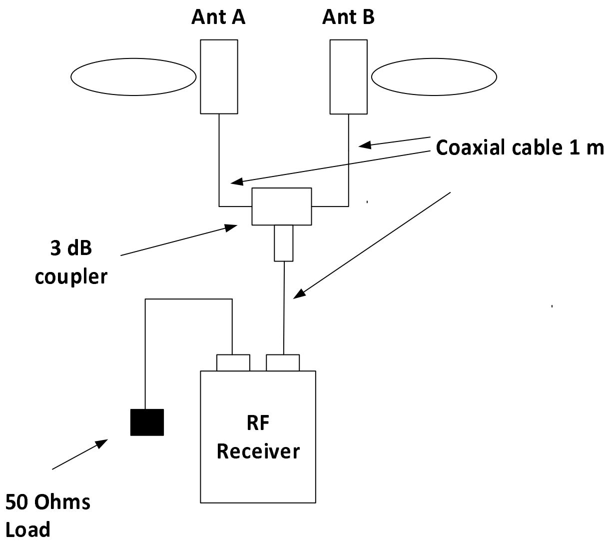

Figure 26: Installation of RF measurement tool on temporary base station

Table 8 gives the attenuation between antennas and the RF receiver for a base station.

Table 8: Base Station Total attenuation

Base station Total attenuation between Antenna and RF Receiver		
Item	**Attenuation**	**Unit**
Coaxial section 1 of 1 m between 5.4 and 6 GHz including connectors	0.73	dB
Coupleur 3 dB	3.2	dB
Coaxial section 2 of 1 m between 5.4 and 6 GHz including connectors	0.73	dB
Total attenuation	**4.66**	**dB**

The measurement was performed on channel 176 that has 5 880 MHz as centre frequency.

The EIRP to be considered for each vehicle is given below:

- Measurement between the 6th and the 12th of September:
  - Vehicle 1: EIRP of 37 dBm/10 MHz
  - Vehicle 2: EIRP of 35,7 dBm/10 MHz
- Measurements between the 13th and the 16th of September:
  - Vehicle 1: EIRP of 37,1 dBm/10 MHz
  - Vehicle 2: EIRP of 36,3 dBm/10 MHz

Each vehicle has generated packets at the frequency of 300 Hz with the length of the packet depending on the vehicle:

- Packet length for Vehicle 1: 66 bytes
- Packet length for Vehicle 2: 56 bytes

8 Measurement results analysis

8.1 Method of analysis

8.1.1 General approach

The analysis of the data captured on site begins with the processing of the data captured on site and then the analysis itself.

The processing of the measurements is done in three main steps:

- Interpolation/up-sampling of location.
  The first step deals with the interpolation of latitudes and longitudes. The GNSS receiver inside a vehicle generates between 5 and 10 new positions per second while 300 packets are generated per second. It means that between 30 and 60 packets are associated with the same location. It is for this reason that the interpolation and location up-sampling is required.
- Application of a correction factor.
  The second step consists in applying a correction factor to the measured power, so that the values displayed and analysed corresponds to power levels expected at a real CBTC antenna connector for a vehicle transmitting at the maximum allowed EIRP of 33 dBm/10 MHz, specified in the ITS regulation.
- Compute distances and angles between vehicles and receivers.
  The third step consists in computing for a part of the measurements the distances between the receiver (Train or Temporary base station) and the vehicle and also the angles between the receiver antenna axis and the RF source.

The analysis itself will be composed of four steps:

- Clause 8.2 provides an overview of the received levels for each receiver (train or temporary base station) and identifies the list of scenarios covered by the measurements. General information is also included.
- Clause 8.3 is a detailed analysis for some scenarios. This analysis will be done with the up-sampled locations. The distance between antennas (train or base station and vehicles) and angles will be used with identification of propagation (Line-of-sight or non-Line-of-sight).
- Clause 8.4 compares the measurements performed with some base stations and trains with simulations.
- Clause 8.5 gives a statistical analysis of the measurement results.

Annex C also introduces desensitization maps.

8.1.2 Reference interfaces

Attenuation will be computed based on the EIRP of the vehicles at a reference interface. For the train, the reference interface is the antenna input as shown in Figure 27.

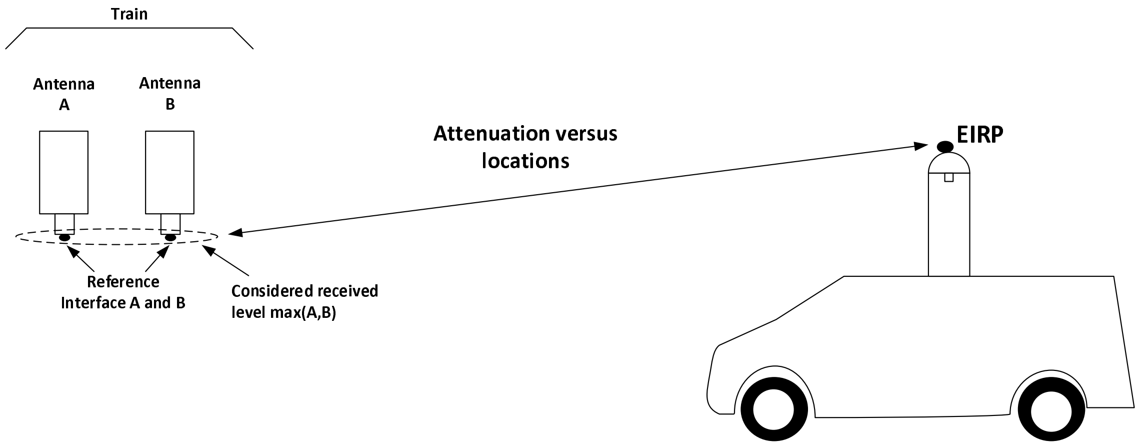

Figure 27: Reference interface for Train

The RF measurement tool inside the train have been done with two antennas connected to this one. The RF measurement tool has provided for each received packet the level received for each antenna. The Maximum received level between Antennas A and B has been considered.

For the temporary base station, the reference interface is the input RF interface of a 3 dB coupler as shown in Figure 28.

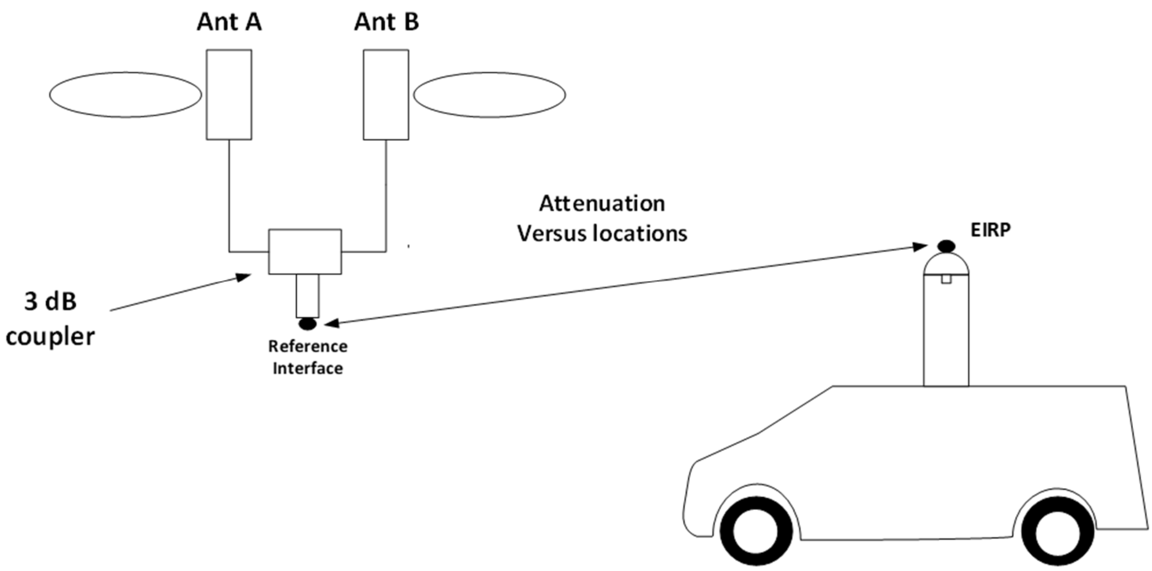

Figure 28: Reference interface for Base station

8.2 Presentation of results per relevant area

8.2.1 Mode of presentation

The results will be presented under the form of a satellite photo of the section on which the circuit followed by the vehicles is represented by a white colour Line and the received levels are represented with colour according to the colour palette shown in Figure 29.

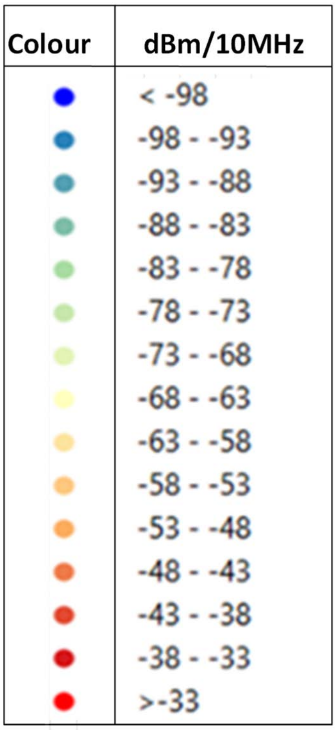

Figure 29: Colour Palette for received level

The received level is represented with colour at the location of the vehicles.

The colour palette will be included also in all the figures.

8.2.2 Analysis of measurements for Line 6

8.2.2.1 Analysis of measurements for the section 1 of Line 6

8.2.2.1.1 Localization of the receivers for section 1 of Line 6

The measurements on section 1 of Line 6 have been performed with base stations (one modelling an access point and two modelling trains). The base stations were installed on a viaduct between station Dupleix and station Bir-Hakeim.

Figure 30 shows the localization of the base stations and the orientation of their antennas.

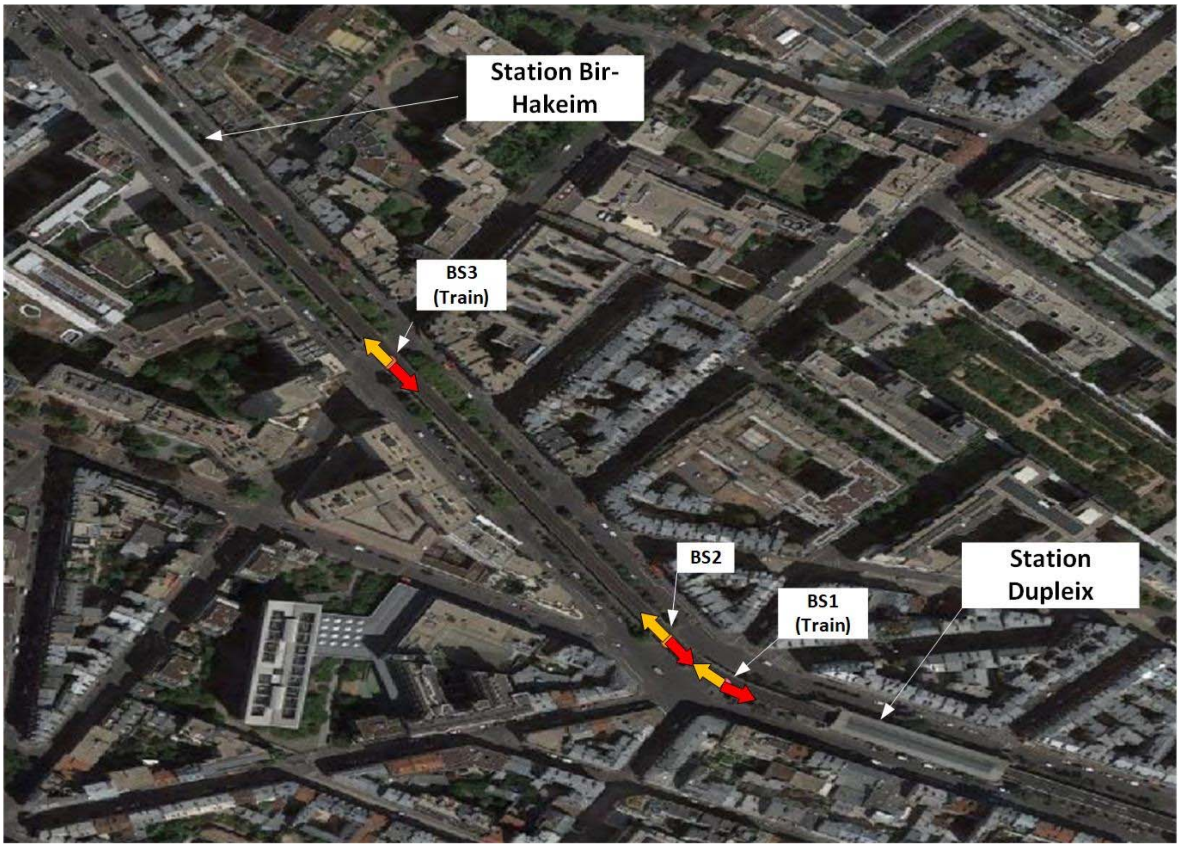

Figure 30: Localization of base stations for the section 1 of Line 6 (Map Source Google Earth: © Google)

Table 9 gives the coordinates and information for each base station.

Table 9: Section 1 of Line 6 position of Base stations

Base station number	Coordinates and antennas height above the ground	Comments
BS1	Latitude (WGS 84 Decimal): 48.850766044199105 Longitude (WGS 84 Decimal): 2.292571930181244 Antennas height: 3,5 m	The BS1 is configured as a train. It has been installed at 52 m from the end of station Dupleix.
BS2	Latitude (WGS 84 Decimal): 48.851010082269916 Longitude (WGS 84 Decimal): 2.292253741036301 Antennas height: 5 m	The BS2 is configured as a Base station and it has been installed at 87 m from the station Dupleix, just after a curve.
BS3	Latitude (WGS 84 Decimal): 48.85255484 Longitude (WGS 84 Decimal): 2.29070431 Antennas height: 3,5 m	The BS3 is configured as a train and has been installed at 142 m from the end of the station Bir-Hakeim.

8.2.2.1.2 Analysis of measurements for each receiver of section 1

8.2.2.1.2.1 Received level from vehicles for base station at position 1 and at position 2

The base station installed at position 1 was configured as a train with its antennas heigh at 3,5 m above the ground. The position 1 is at 51 m from the end of the platform of the station Dupleix.

The base station installed at position 2 was configured as a base station. The height of its antennas was 5 m above the ground. The position 2 is at 85 m from the station Dupleix and at 35 m from position 1.

Because the two base stations were close with the first one configured as train and the second one configured as base station, they were analysed in parallel with the same number of points of interest.

Figure 31 shows the level received by the base station at position 1 (train).

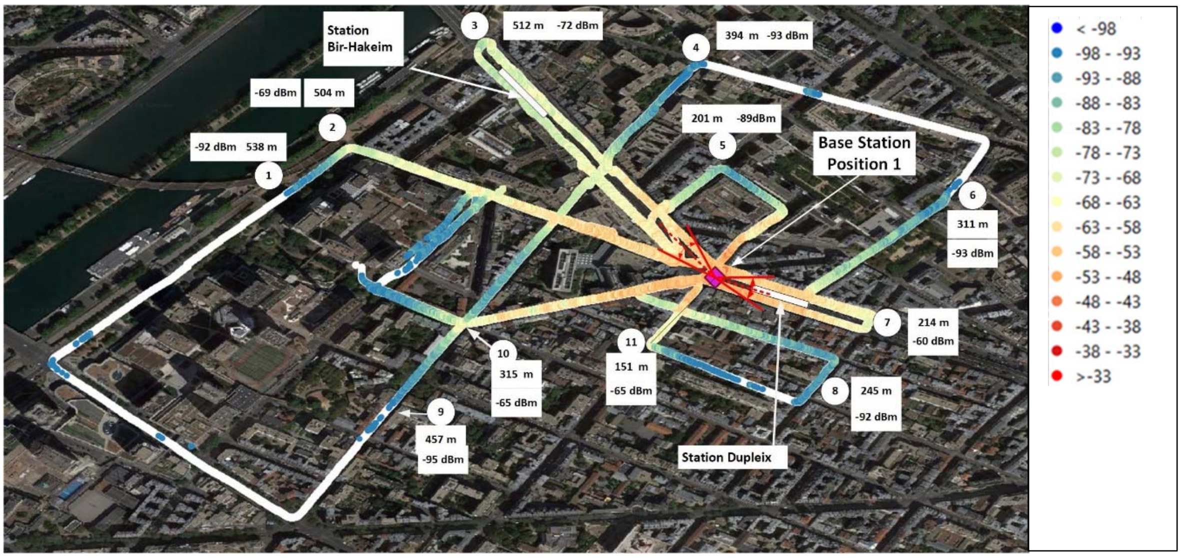

Figure 31: Line 6 Section 1 Base station at position 1 (Train) level received from Vehicles (Map Source Google Earth: © Google)

Figure 32 shows the level received by the base station at position 2.

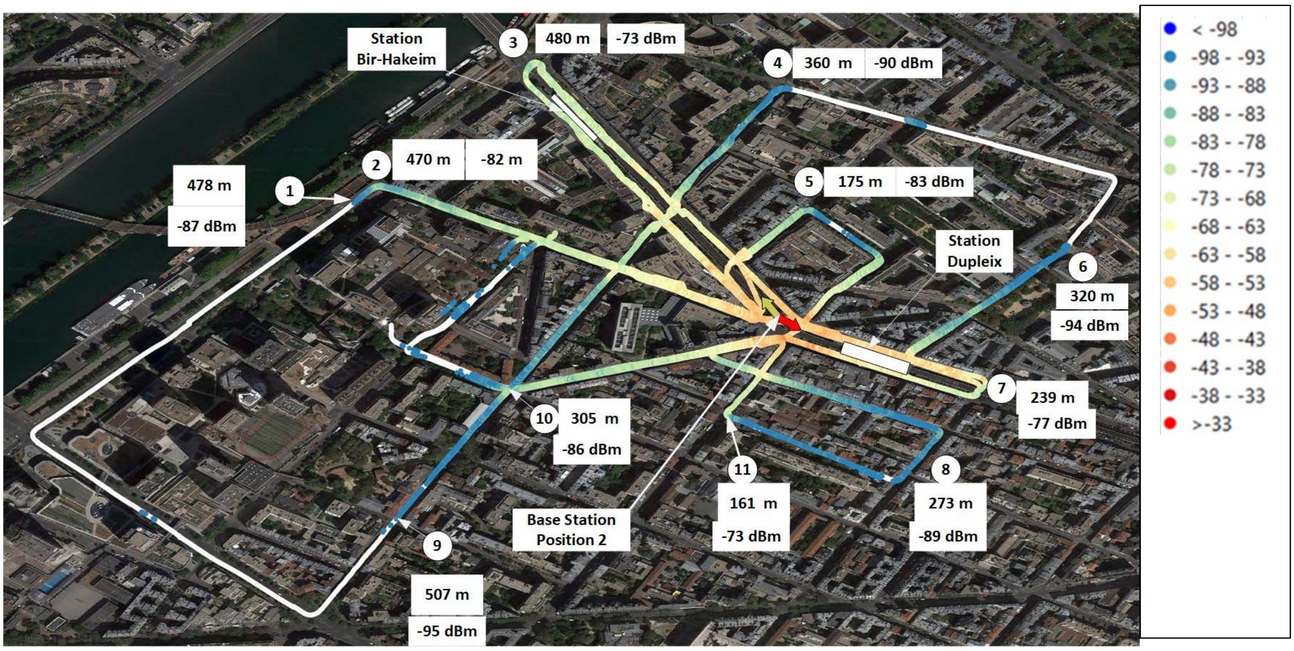

Figure 32: Line 6 Section 1 Base station at position 2 level received from Vehicles (Map Source Google Earth: © Google)

For both base stations, one antenna was pointing to the station Bir-Hackeim and one antenna was pointing to station Dupleix.

The observations of Figure 31 and Figure 32 show that they are very similar. There are small differences in the limit of radio coverage.

The same number of points of interest have been identified, will be analysed and compared. Table 10, Table 11 and Table 12 give information about each point of interest and comparison between both base stations.

Table 10: Section 1 of Line 6 Point of interest analysis 1 to 4

Point of interest number	Base station at position 1 (Train) Figure 31	Base station at position 2 Figure 32	Comments
1 (edge of coverage for the receivers)	Located at 538 m from the base station antenna Received level: -92 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim. The antenna 3 dB Beamwidth is 35° it means ±17,5° from its axis The angle for point of interest 2 is 33° Type of propagation: non-Line of Sight	Located at 478 m from the base station antenna Received level -87 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim. The antenna 3 dB beamwidth is 35° it means ±17,5° from its axis The angle with point of interest 2 is 30° Type of propagation: non-Line of Sight	No simple propagation model urban or suburban (see annex B) provides a value close to the measurements The angle of arrival is around 33° and the antenna gain is around 0 dB
2	Located at 504 m Received level: -69 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim The angle for point of interest 2 is 27°	Located at 470 m Received level -82 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim The angle for point of interest 2 is 24°	Even with a longer distance the received level is significantly higher No simple propagation model urban or suburban (see annex B) provides a value close to measurements
3	Located at 512 m Received level: -72 dBm/10 MHz Vehicles are received in the main lobe of the base station antenna The propagation is non-Line of Sight The vehicles are received in the main lobe of the base station antenna	Located at 480 m Received level: - 73 dBm/10 MHz Vehicles are received in the main lobe of the base station antenna The propagation is non-Line of Sight The vehicles are received in the main lobe of the base station antenna	At point of interest 3, both vehicles were driving above the station Bir Hackeim on the map and were driving below the viaduct during their U-turns The sub-urban propagation model (see annex B) gives a value of -70 dBm/10 MHz
4 (edge of coverage for the receivers)	Located at: 394 m Received level: -93 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Located at: 360 m Received level: -90 dBm/10 MHz Vehicles are not in the main lobe of the Base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Both received levels can be considered as similar No simple propagation model (see annex B) provides a value close to the measurement

Table 11: Section 1 of Line 6 Point of interest analysis 5 to 9

Point of interest number	Base station at position 1 (train)	Base station at position 2	Comments
5	Located at: 201 m from the base station at the corner of a street Received level: -89 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Located at: 175 m from the base station Received level: -83 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Both received levels can be considered as similar No simple propagation model (see annex B) provides a value close to the measurement
6 (edge of coverage for the receivers)	Located at: 311 m Received level: -93 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Dupleix The propagation is non-Line of Sight	Located at: 320 m Received level: -94 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Dupleix The propagation is non-Line of Sight	Both received levels can be considered as similar No simple propagation model (see annex B) provides a value close to the measurement
7	Located at: 214 m Received level: - 60 dBm/10 MHz Vehicles are in the main lobe of the antenna pointing to the Dupleix station The propagation is non-Line of Sight	Located at: 299 m Received level: -77 dBm/10 MHz Vehicles are in the main lobe of the antenna pointing to the Dupleix station The propagation is non-Line of Sight	There is a significant difference. The point of interest 7 is located below the viaduct when the vehicles are making their U-turns for BS1 The simple urban propagation model (see annex B) gives a value of -60 dBm/10 MHz
8	Located at: 245 m Received level: -92 dBm/10 MHz Vehicles are not in the main lobe of the antenna pointing to the Dupleix station The propagation is non-Line of Sight	Located at: 273 m Received level: -89 dBm/10 MHz Vehicles are not in the main lobe of the antenna pointing to the Dupleix station The propagation is non-Line of Sight	Both received levels can be considered as similar No simple propagation model (see annex B) provides a value close to the measurement
9 (edge of coverage for the receivers)	Located at: 457 m Received level: -95 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Located at: 507 m Received level: -95 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Similar received level No simple propagation model (see annex B) provides a value close to the measurement

Table 12: Section 1 of Line 6 Point of interest analysis 10 and 11

Point of interest number	Base station at position 1 (Train)	Base station at position 2	Comments
10	Located at: 315 m Received level: -65 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Located at: 305 m Received level: -86 dBm/10 MHz Vehicles are not in the main lobe of the base station antenna pointing to station Bir-Hackeim The propagation is non-Line of Sight	Significant difference of received levels Even if for base station 1, the RF signal arrives under an angle of 55° from the axis of the antenna, this one is in the front of the street This is not the case for the base station No simple propagation model (see annex B) provides a value close to the measurement
11	Located at: 151 m Received level: - 65 dBm/10 MHz Vehicles are not in the main lobe The path is perpendicular to both antennas of the base station The propagation is non-Line of Sight	Located at: 161 m Received level: -73 dBm/10 MHz Vehicles are not in the main lobe The path is perpendicular to both antennas of the base station The propagation is non-Line of Sight	Significant difference of received levels The reason can be due to the fact that the base station 1 (train) is at the extremity of the street No simple propagation model (see annex B) provides a value close to the measurement

8.2.2.1.2.2 Received level from vehicles for base station at position 3

The base station at position 3 is configured as a train; its antenna height above the ground was 3,5 m.

The position 3 was located at 141 m from the station Bir-Hackeim and 295 m from station Dupleix.

Figure 33 shows the level received by the base station at position 3.

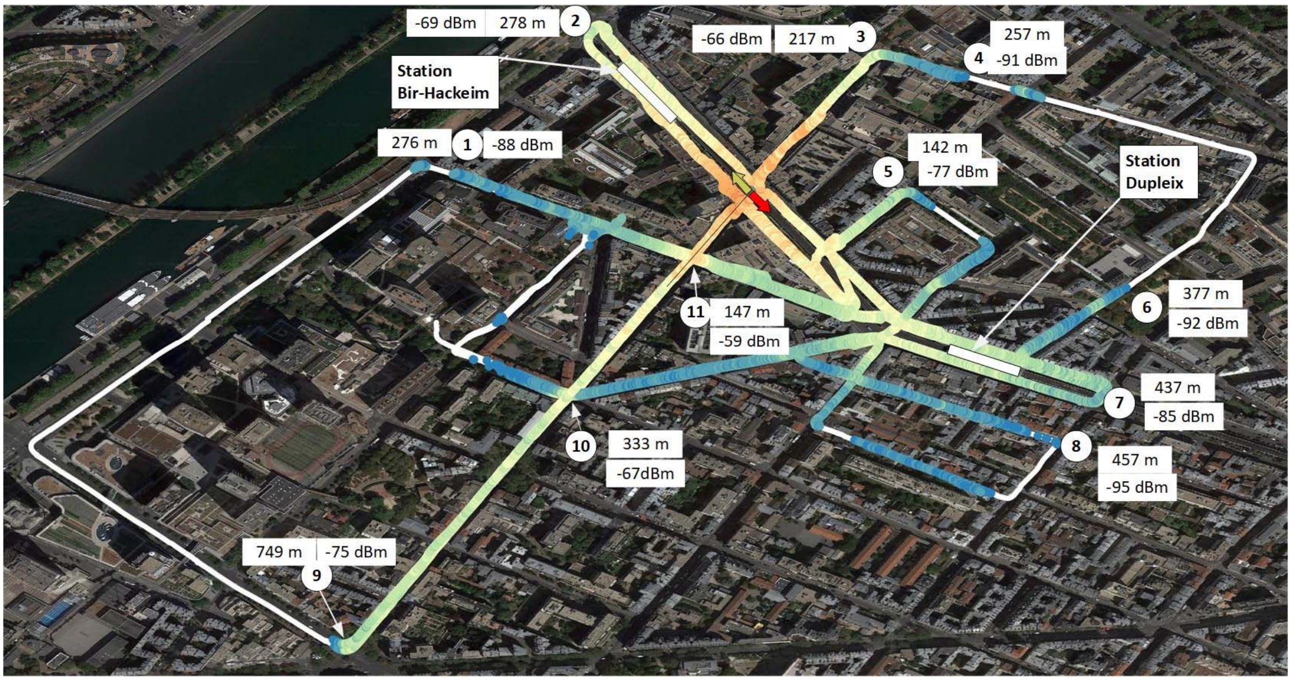

Figure 33: Line 6 Section 1 Base station at position 3 (Train) level received from Vehicles (Map Source Google Earth: © Google)

The base station at position 3 had an antenna pointing to station Bir-Hackeim and another one pointing to the Dupleix station.

The same points of interest have been considered as for Base stations at position 1 and 2 (train), point of interest 11 excepted.

Points of interest 3, 9, 10 and 11 excepted, non-Line of Sight propagation can be considered.

The angle arrival for points of interest 3, 9 10 and 11 is close to 90°. The base station antenna system (antenna coupler coax and coupler) has a gain of - 5 dB at the reference RF interface.

The level computed with the simple urban and suburban propagation model (see annex B) will give the following levels:

Table 13: Section 1 of Line 6 Point of interest analysis simple propagation model comparison

Point of interest and distance and received level	Simple Urban propagation mode	Simple suburban propagation model (see annex B)
3, 217 m, -66 dBm/10 MHz	-76 dBm/10 MHz	-74 dBm/10 MHz
9, 749 m, -75 dBm/10 MHz	-95 dBm/10 MHz	-80 dBm/10 MHz
10, 333 m, -67 dBm/10 MHz	-73 dBm/10 MHz	-60 dBm/10 MHz
11, 147 m, -59 dBm/10 MHz	-50 dBm/10 MHz	-50 dBm /10 MHz

Table 13 shows that simple urban and suburban propagation model (see annex B) cannot provide a correct estimation of the received level (range of ±3 dB).

8.2.2.1.3 Summary of observation for the section 1 of Line 6

The measurements performed on section 1 have covered the scenarios 2, 6 and 7.

The measurements performed on the section 1 of Line 6 at three locations confirm what has been discovered with the simulation. Even if the track is on a viaduct, the level received from vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]) is above the defined protection levels of the CBTC communications.

It has been observed that levels up to -66 dBm/10 MHz are received from vehicles driving on roads nearly perpendicular to the tracks or making an angle of around 45° even if the antennas are not located at the crossroads.

It is interesting to compare points of interest 3, 4 and 9 between base stations. These two ones are in some way the west and east limits of the coverage from the tracks.

Table 14: Section 1 of Line 6 points of interest comparison of received levels between base stations

Point of Interest	Base station	Distance from base station	Received level	Comments
4 for BS1&2 and 3 for BS3	BS1 BS2 BS3	394 m 360 m 217 m	-93 dBm/10 MHz -90 dBm/10 MHz -66 dBm/10 MHz	For BS1 and BS2 it is a non-Line of Sight propagation. BS3 is at the crossroad. This is a Line-of-sight propagation. The street is nearly perpendicular to the track. Simple Urban and suburban propagation mode do not provide correct estimation. At this point the simple Friis formula gives -66 dBm/10 MHz. Based on this formula at 1 000 m, the received level can be -80 dBm/10 MHz.
9	BS1 BS2 BS3	457 m 507 m 749 m	-95 dBm/10 MHz -95 dBm/10 MHz -75 dBm/10 MHz	BS1 and BS2 are not at the crossroad. BS3 is at the crossroad. The level remains high and drop sharply because at the end of the street the vehicle has turned.

When a base station or a train was at a crossroad with perpendicular or nearly perpendicular road received level can be above -90 dBm/10 MHz for distance above 1 000 m.

8.2.2.2 Analysis of measurements for the section 2 of Line 6

8.2.2.2.1 Localization of the receivers for section 2 of Line 6

The measurements on section 2 of Line 6 was performed with temporary base stations. The base stations were deployed on an incLined track between the station Sèvres-Lecourbe and the tunnel entrance in the direction of metro station Pasteur.

Figure 34 shows the localization of the base stations and the orientation of their antennas.

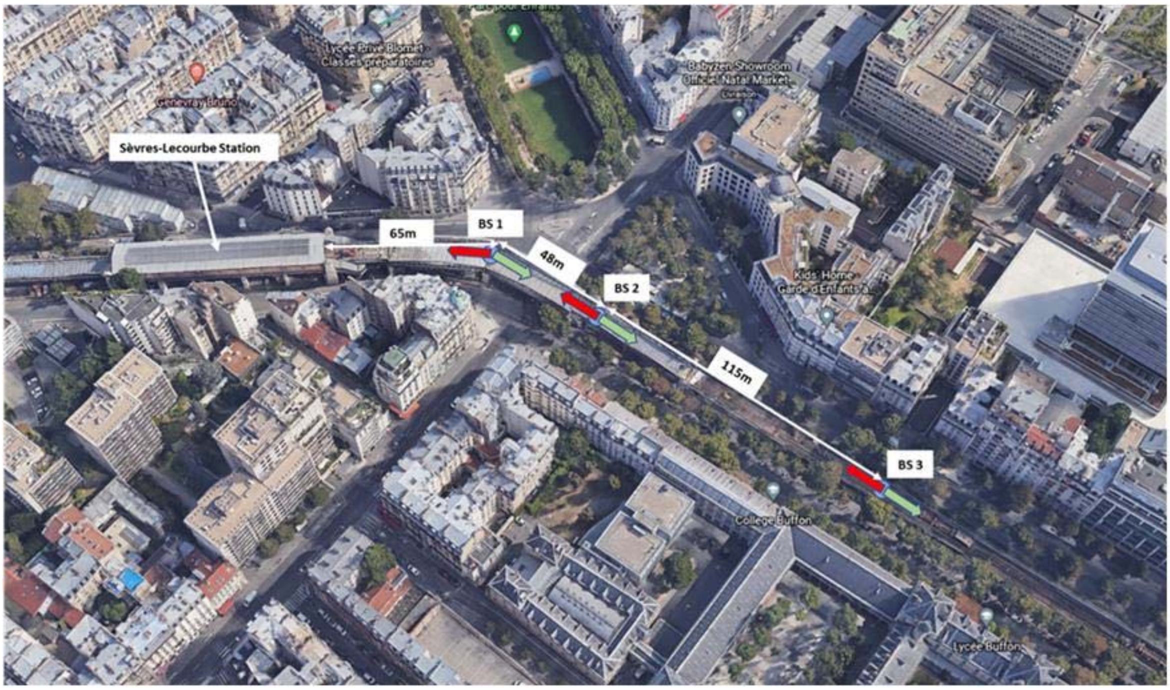

Figure 34: Localization of base stations for the section 2 of Line 6 (Map Source Google Earth: © Google)

One base station was configured with its antennas at a height of 5 m above the ground and two with a height of 3,5 m above the ground to simulate a train.

Between the station Sèvres-Lecourbe the tracks are on a viaduct that is slowly descending to reach the same level of the road, after the tracks continue to descend to reach the entrance of a tunnel.

Table 15 gives for each temporary base station its latitude and longitude and height of its antenna above the ground.

Table 15: Section 2 of Line 6 positions of base stations

Base station number	Coordinates and antennas height above the ground	Comments
BS1	Latitude (WGS 84 Decimal): 48.845272021163176 Longitude (WGS 84 Decimal): 2.3107311814740394 Antennas height: 5 m	The base station 1 is located at 65 m from the end of the station Sèvres-Lecourbe in the middle of a curve. The base station 1 is configured as a base station. The tracks are on a viaduct. This one is descending slowly. At the location of BS1, the viaduct is still at its maximum height above the ground. Around 6 m.
BS2	Latitude (WGS 84 Decimal): 48.84491219303031 Longitude (WGS 84 Decimal): 2.311060884960381 Antennas height: 3,5 m	The base station 2 is located at 48 m from base station 1 and configured to simulate a train and at 106 m from the station Sèvres-Lecourbe. The tracks are descending but at a level that is still higher than the road.
BS3	Latitude (WGS 84 Decimal): 48.843980390251104 Longitude (WGS 84 Decimal): 2.3117726340534506 Antennas height: 3,5 m	The base station 3 is located at 115 m from the previous one, 163 m from the station Sèvres-Lecourbe and configured to simulate a train. The track where base station is deployed is nearly at the same level of the roads.

8.2.2.2.2 Analysis of measurements for each receiver of section 2

8.2.2.2.2.1 Received level from vehicles for base station at position 1

The antennas of the base station 1 were at 5 m above the ground. The base station was located in the middle of a curve at around 65 m from the station Sèvres-Lecourbe. One antenna was pointing to the station and the other one was pointing to the tunnel entrance.

Figure 35 shows the level received by the base station at position 1.

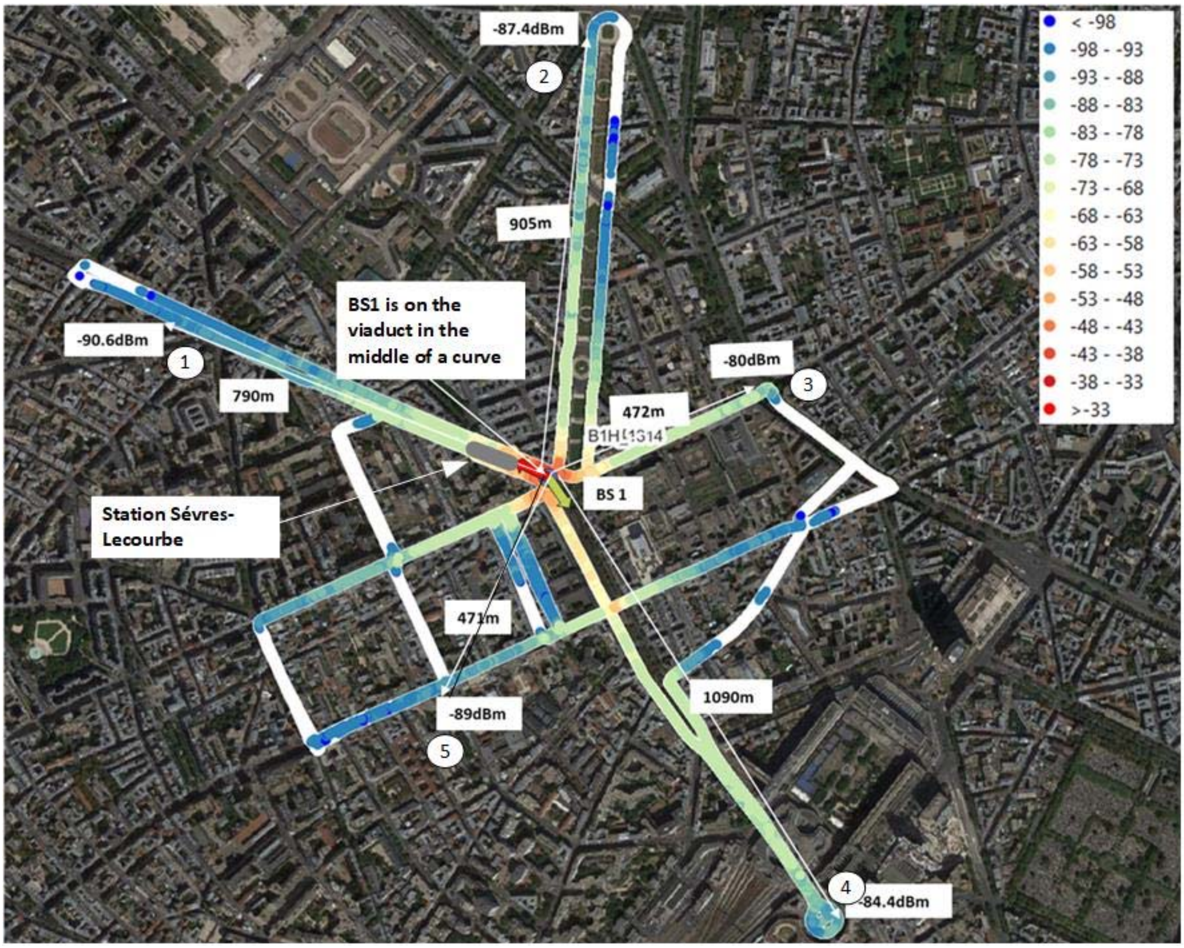

Figure 35: Line 6 Section 2 base station at position 1 level received from Vehicles (Map Source Google Earth: © Google)

The point of interest 1 is located at 790 m from the base station 1. The received level from vehicles at this location is -90,6 dBm/10 MHz. It has to be noted that the base station antenna is pointing to the station Sèvres-Lecourbe. It means that received RF signals are travelling via the station that is on the viaduct.

The propagation is not Line-of-sight. The vehicles are driving on the road that is below the viaduct at point of interest 1. The use of simple propagation model (urban or suburban) does not provide value close enough to the measured level.

The point of interest 2 is located at 905 m. The level received from the vehicle is -87 dBm/10 MHz. The angle of arrival is 72°. The gain of the base station antenna system (two directive antennas, coupler and coax) is around -5 dB. The propagation can be considered as Line-of-sight.

The received level from vehicles at point of interest 2 is higher, taking into account the distance and the antenna gain, than assuming the simple propagation model (urban or suburban).

The point of interest 3 is located at 472 m and the received level is -80 dBm/10 MHz. The antenna gain in the direction of this point of interest is around -5 dB. The level computed with the simple suburban propagation model (see annex B) gives a value of -83 dBm/10 MHz but the site is in an urban environment.

The point of interest 4 is located at 1 090 m and the received level is -84,4 dBm/10 MHz. The vehicles are received in the main lobe of the base station antenna. This is a Line-of-sight propagation. No simple propagation model (see annex B) provides a value close to the measured one.

The point of interest 5 is located at 471 m from the base station with a received level of -89 dBm/10 MHz. This is a non-Line-of-sight propagation. There are buildings on the path. The angle of arrival with the axis of the antenna pointing to the tunnel is around 60°. The antenna gain is around -5 dB. No simple propagation model (see annex B) provides a level close to the measured level.

No simple urban or suburban propagation model (see annex B) can provide a correct estimation of the received level (range of ±3 dB).

8.2.2.2.2.2 Received level from vehicles for base station at position 2

The base station 2 was installed at 163 m from the base station 1. Its antennas height was adjusted at 3,5 m above the ground to simulate a train. One antenna was pointing to the station Sèvres-Lecourbe and the other antenna was pointing to the tunnel entrance.

Figure 36 shows the level received by the base station at position 2.

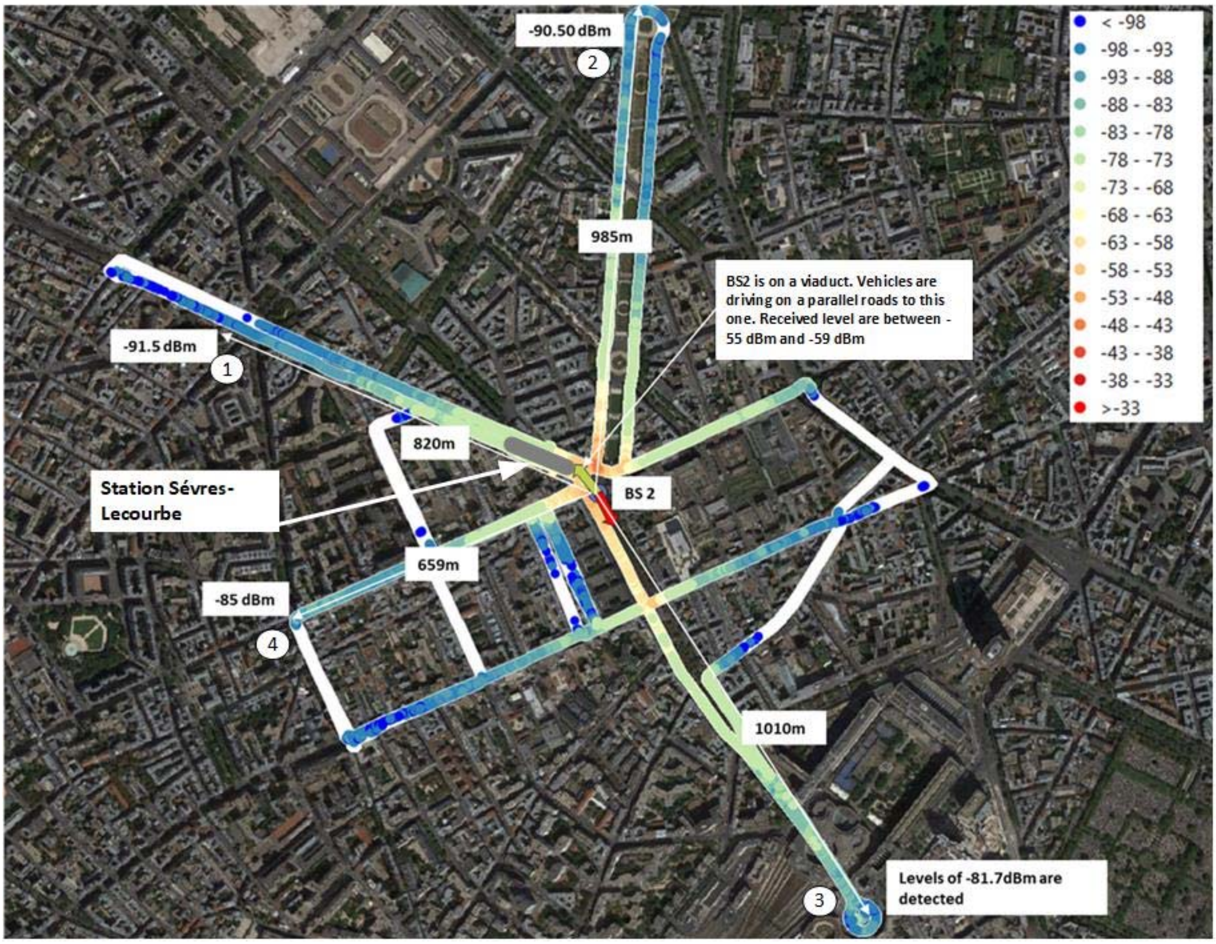

Figure 36: Line 6 Section 2 base station at position 2 level received from Vehicles (Map Source Google Earth: © Google)

For point of interests 1, 2 and 3 the results of the analysis are like the ones of the analysis done for the base station 1.

The point of interest 4 is located at 659 m. The received level is -85 dBm/10 MHz. The angle of arrival is perpendicular to the antenna axis that point to the tunnel entrance and nearly perpendicular to the other antenna. The gain of the antenna system is around -5 dB. This is Line-of-sight propagation.

Computation of level with simple propagation model (see annex B) does not provide a result close enough to the measured level.

It is important to highlight the level received by the base station at position 2 when vehicles were driven on the parallel roads to the viaduct and below this one. Levels received from vehicles at this location are between -55 dBm/10 MHz and -59 dBm/10 MHz. There is non-Line of Sight propagation.

8.2.2.2.2.3 Received level from vehicles for base station at position 3

The base station at position 3 has been installed at 163 m from the station Sèvres-Lecourbe. One antenna is pointing to the tunnel entrance and the other one is pointing to the opposite direction.

Figure 37 shows the level received by the base station at position 3.

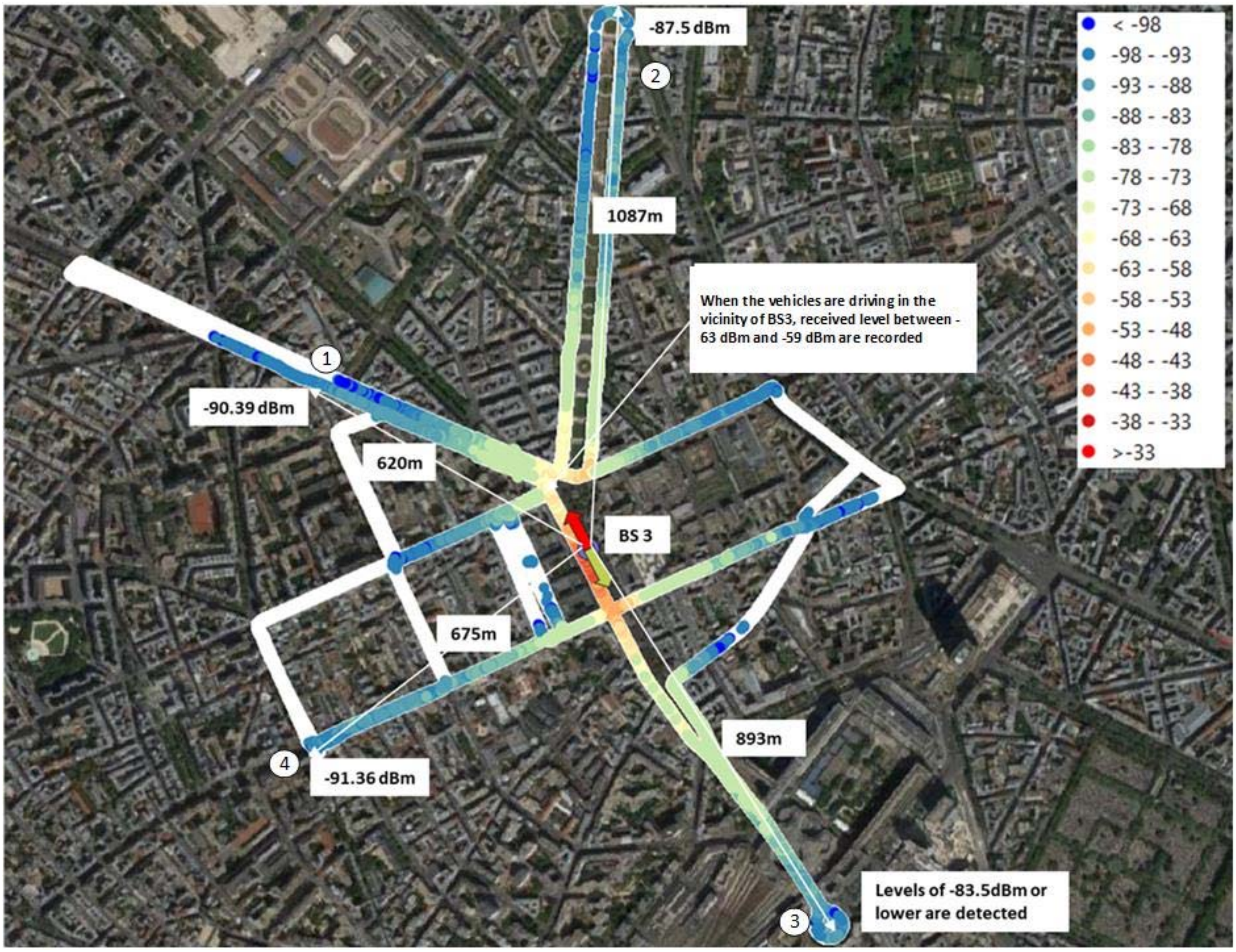

Figure 37: Line 6 Section 2 base station at position 3 level received from Vehicles (Map Source Google Earth: © Google)

For point of interests 1, 2 the results of the analysis are similar to the ones of the analysis done for the base stations 1 and 2.

The point of interest 3 is located at 893 m. The received level is -83 dBm/10 MHz. The vehicles are received in the main lobe of the antenna pointing to the tunnel. The simple suburban propagation model (see annex B) gives a level of -84 dBm/10 MHz.

The point of interest 4 is located at 675 m from the base station. The received level is -91 dBm/10 MHz. The angle of arrival at the base station antenna is nearly perpendicular to the axis of both antennas. The gain of the antenna system is around -5 dB. This is a non-Line of Sight propagation. There are several buildings on the path.

The simple suburban propagation model (see annex B) provides a level of -92 dBm/10 MHz.

The simple sub-urban propagation model (see annex B) provides two levels close to the measurement, but this will be taken with caution.

The level received by the base station when the vehicles were driven on the roads parallel to the viaduct in the vicinity of the base station is between -63 dBm/10 MHz and -59 dBm/10 MHz.

8.2.2.2.3 Measurements with train in the tunnel

The section 2 of Line 6 has been extended from tunnel entrance to station Montparnasse. The objective was to perform measurements with train inside the tunnel to evaluate how far inside the tunnel the transmissions of the vehicles are received.

The train has been positioned has follows:

- Rear cab at tunnel entrance
- Rear cab at 40 m from the tunnel entrance
- Rear cab at 80 m from the tunnel entrance
- Rear cab et 120 m from the tunnel entrance

The vehicles were driving on a circuit that included the roads parallel to the tracks.

Figure 38 shows the level received by the rear cab for the train positioned at the tunnel entrance.

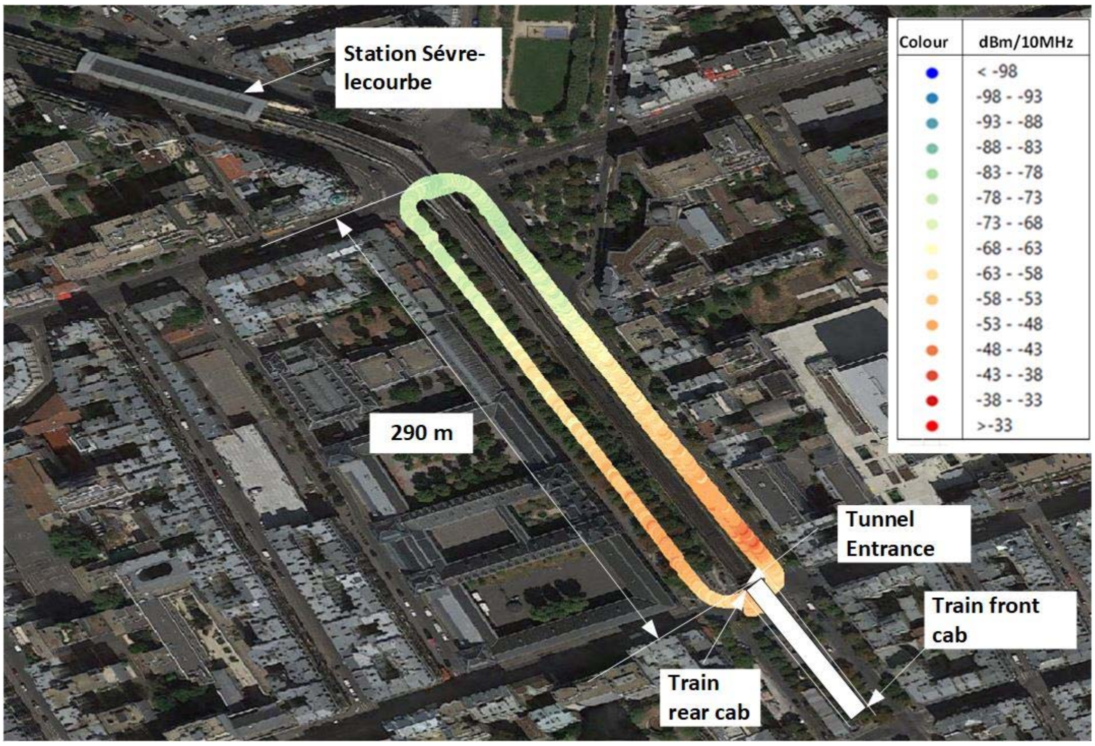

Figure 38: Measurements in tunnel with train rear cab at tunnel entrance (Map Source Google Earth: © Google)

The analysis of the measurements for each vehicle gives the following values:

- Vehicle 1:
  - Median Rx level: -58 dBm/10 MHz
  - Maximum Rx level: -39 dBm/10 MHz
  - Total received packets: 153 314
- Vehicle 2:
  - Median Rx level: -58 dBm/10 MHz

- Maximum Rx level: -40 dBm/10 MHz
- Total received packets: 156 725

Figure 39 shows the levels received by the rear cab for the train positioned at 40 m from the tunnel entrance inside the tunnel.

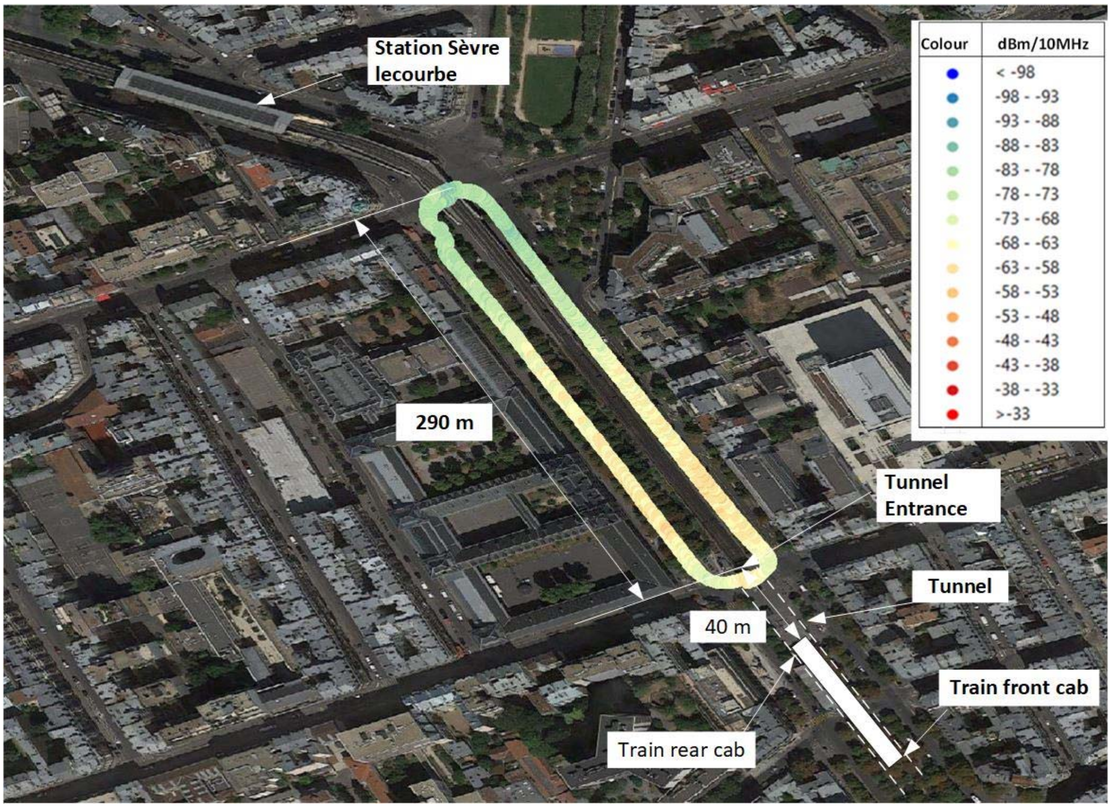

Figure 39: Measurements in tunnel with train rear cab at 40 m from tunnel entrance (Map Source Google Earth: © Google)

The analysis of the measurements for each vehicle gives the following values:

- Vehicle 1:
  - Median Rx level: -78 dBm/10 MHz
  - Maximum Rx level: -51 dBm/10 MHz
  - Number of received packets: 65 530
- Vehicle 2:
  - Median Rx level: -58 dBm/10 MHz
  - Maximum Rx level: -40 dBm/10 MHz
  - Number of packets: 64 670

Figure 40 shows the levels received by the rear cab for the train positioned at 80 m from the tunnel entrance inside the tunnel.

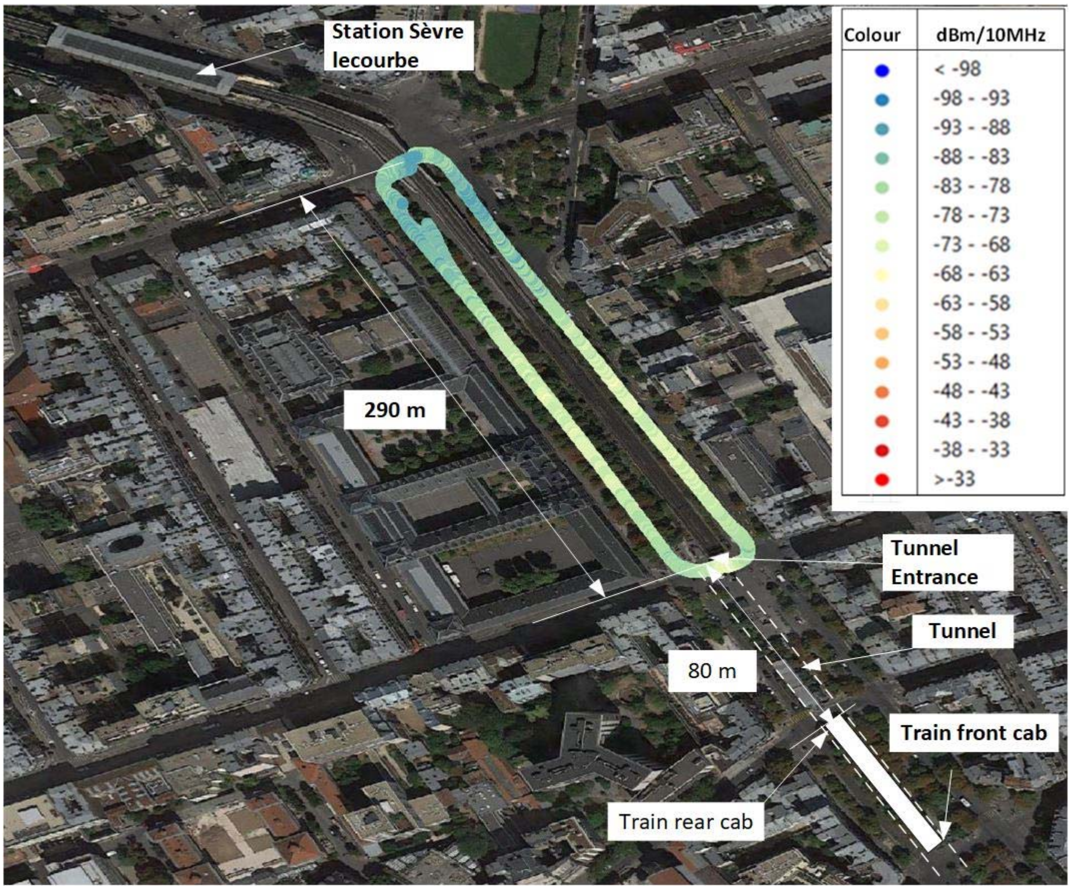

Figure 40: Measurements in tunnel with train rear cab at 80 m from tunnel entrance (Map Source Google Earth: © Google)

The analysis of the measurements for each vehicle gives the following values:

- Vehicle 1:
  - Median Rx level: -82 dBm/10 MHz
  - Maximum Rx level: -63 dBm/10 MHz
  - Number of packets: 58 905
- Vehicle 2:
  - Median Rx level: -85 dBm/10 MHz
  - Maximum Rx level: -64 dBm/10 MHz
  - Number of packets: 62 063

Measurements have been performed with the train located at 120 m from the tunnel entrance and no packet has been received. It can be concluded that he maximum distance for penetration of signal received by train rear cab in the tunnel is between 80 m and 120 m.

Measurements were also performed with the train front cab.

Figure 41 shows the levels received by the train front cab when the train rear cab is at the tunnel entrance.

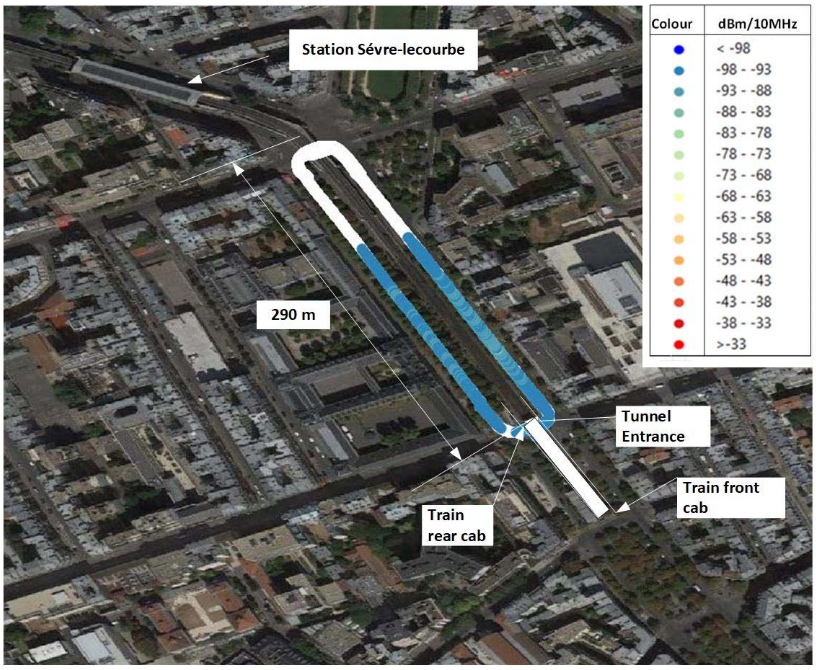

Figure 41: Measurements in tunnel with train front cab when rear cab is at entrance (Map Source Google Earth: © Google)

The analysis of the measurements for each vehicle gives the following values:

- Vehicle 1:
  - Median Rx level: -94 dBm/10 MHz
  - Maximum Rx level: -84 dBm/10 MHz
  - Total received packets: 63 572
- Vehicle 2:
  - Median Rx level: -94 dBm/10 MHz
  - Maximum Rx level: -84 dBm/10 MHz
  - Total received packets: 59 030

Figure 42 shows the levels received by the train front cab when the train front cab is located at 40 m from the tunnel entrance.

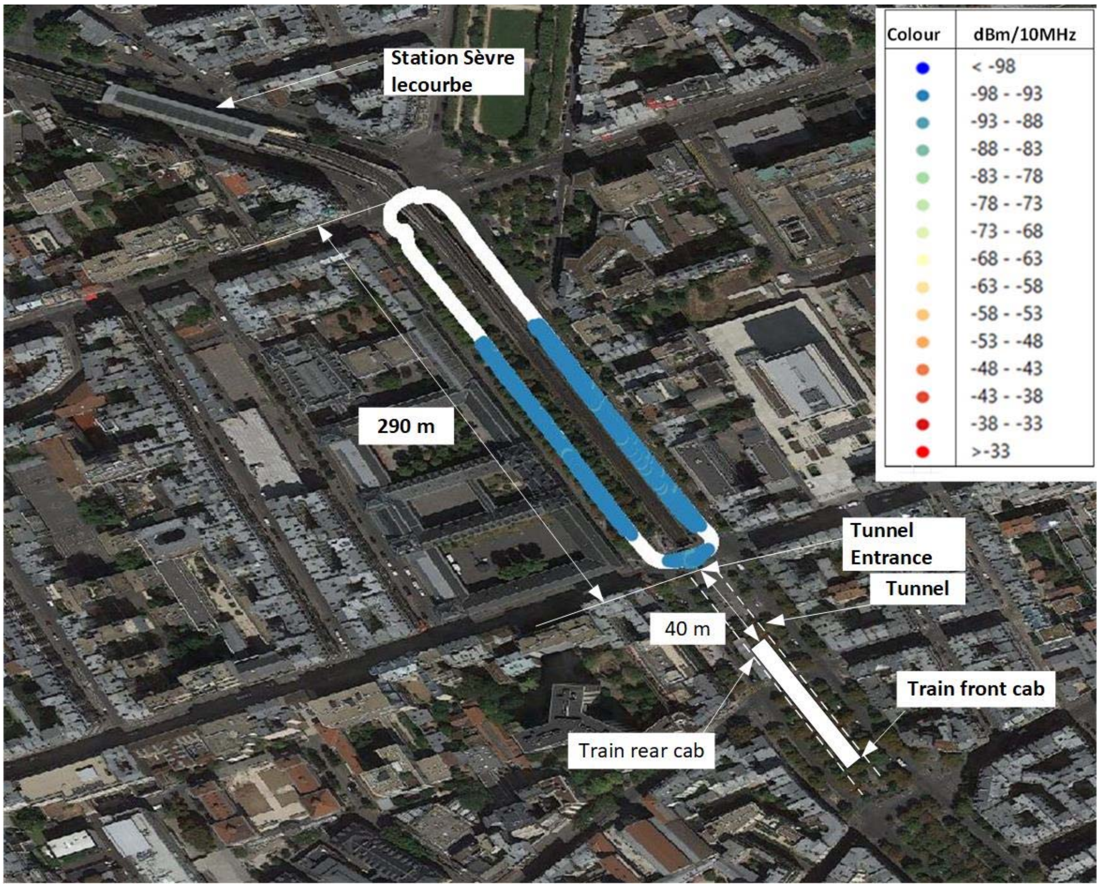

Figure 42: Measurements in tunnel with train front cab for rear cab at 40 m from tunnel entrance (Map Source Google Earth: © Google)

The analysis of the measurements for each vehicle gives the following values:

- Vehicle 1:
  - Median Rx level: -95 dBm/10 MHz
  - Maximum Rx level: -84 dBm/10 MHz
  - Total received packets: 5 967
- Vehicle 2:
  - Median Rx level: -92 dBm/10 MHz
  - Maximum Rx level: -87 dBm/10 MHz
  - Total received packets: 11 005

Measurements were performed with front cab when the rear cab was located at 80 m from the tunnel entrance.

Each vehicle received 6 packets with a level of -96 dBm/10 MHz. It can be concluded that he maximum distance for penetration of signal received by train rear cab in the tunnel is between 40 m and 80 m.

8.2.2.2.4 Summary of observation for the section 2 of Line 6

The measurements performed on section 2 have covered the scenarios 2, 6 and 7.

The measurements performed on the section 2 of Line 6 at three locations confirm what has been discovered with the simulation. Even if a part of the tracks is on a viaduct and another part is below the level of the street descending to the tunnel entrance, the levels received from vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]) above the defined protection levels of the CBTC communications.

For the three Base stations, the level received at point interest 1 from the vehicles remain above the protection levels defined in Table 2 over a distance up to 820 m from the base station. One of the base station antennas was pointing to the station Sèvres-Lecourbe that can be considered as a tunnel with a length of 80 m.

On the street going to the northeast (point of interest 2) the received level reaches a value of around between -87 dBm/10 MHz and -90 dBm/10 MHz over around 1 000 m from the Line as foreseen by the simulation.

On streets going to eat and west, it is after a distance from the Line of around 450 m that the received level from vehicles is below -80 dBm/10 MHz.

On the street going south-east, the level is still above -85 dBm/10 MHz at 1 000 m.

8.2.2.3 Analysis of measurements for the section 3 of Line 6

8.2.2.3.1 Localization of the receivers for section 3 of Line 6

The measurements on section 2 of Line 6 have been performed with temporary base stations. Three base stations have been installed on a viaduct on the Bercy after the Station Quai de la Gare as shown on Figure 43.

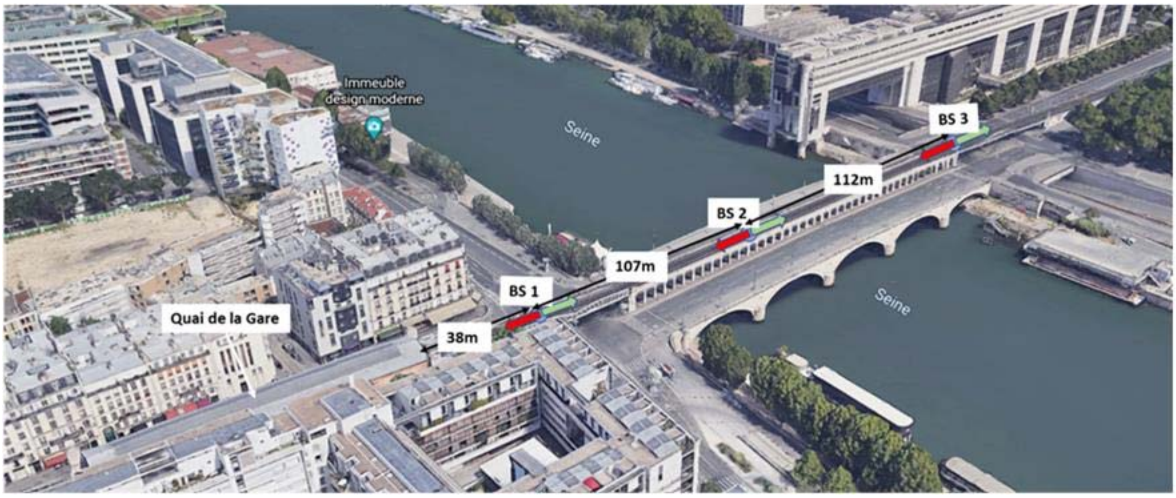

Figure 43: Localization of base stations for the section 3 of Line 6 (Map Source Google Earth: © Google)

Two base stations were configured as train (antenna height 3,5 m above the tracks) and one base station was configured as base station (antenna height 5 m above the tracks).

Table 16 gives for each temporary base station its latitude and longitude and height of its antenna above the ground.

Table 16: Section 3 of Line 6 positions of base stations

Base station number	Coordinates and antennas height above the ground	Comments
BS1	Latitude (WGS 84 Decimal): 48.83742014102563 Longitude (WGS 84 Decimal): 2.3736912323717996 Antennas height: 3,5 m	BS1 has been installed at 38 m from the station Quai de la Gare. One antenna was pointing to the station and the other in the opposite direction.
BS2	Latitude (WGS 84 Decimal): 48.83804501242249 Longitude (WGS 84 Decimal): 2.3747908364389274 Antennas height config 1: 5 m Antennas height config 2: 3,5 m	BS2 has been installed at 145 m from the station Quai de la Gare with one antenna pointing to this one and the other to the opposite direction. BS2 has been installed nearly at the middle of the bridge. Measurements have been performed with Antenna height of 5 m and after 3,5 m.
BS3	Latitude (WGS 84 Decimal): 48.83867799752163 Longitude (WGS 84 Decimal): 2.3760267286245487 Antennas height: 5 m	BS3 has been installed at 257 m from the station Quai de la Gare with one antenna pointing to this one and the other in the opposite direction. BS3 is located at the other bank of the river.

8.2.2.3.2 Analysis of measurements for each receiver of section 3

8.2.2.3.2.1 Received level from vehicles for base station at position 1 and position 2

The base station 1 was installed on the viaduct at 38 m from the metro station Quai de la Gare. The base station was configured to simulate a train meaning that its antennas was installed at 3,5 m above the level of the tracks.

One of the antennas was pointing to the station Quai de la Gare and the other one was pointing to the opposite direction.

The base station 2 was installed at 145 m from the station Quai de la Gare. This location was installed at the middle of the bridge.

For base station 2, measurements were performed with antenna height at 5 m and at 3,5 m.

The circuits followed by both vehicles were the same for BS1 (Train) and BS2 with antenna height at 3,5 m, this allows comparison between the levels received by both base stations.

Figure 44 shows the level received by the base station at position 1.

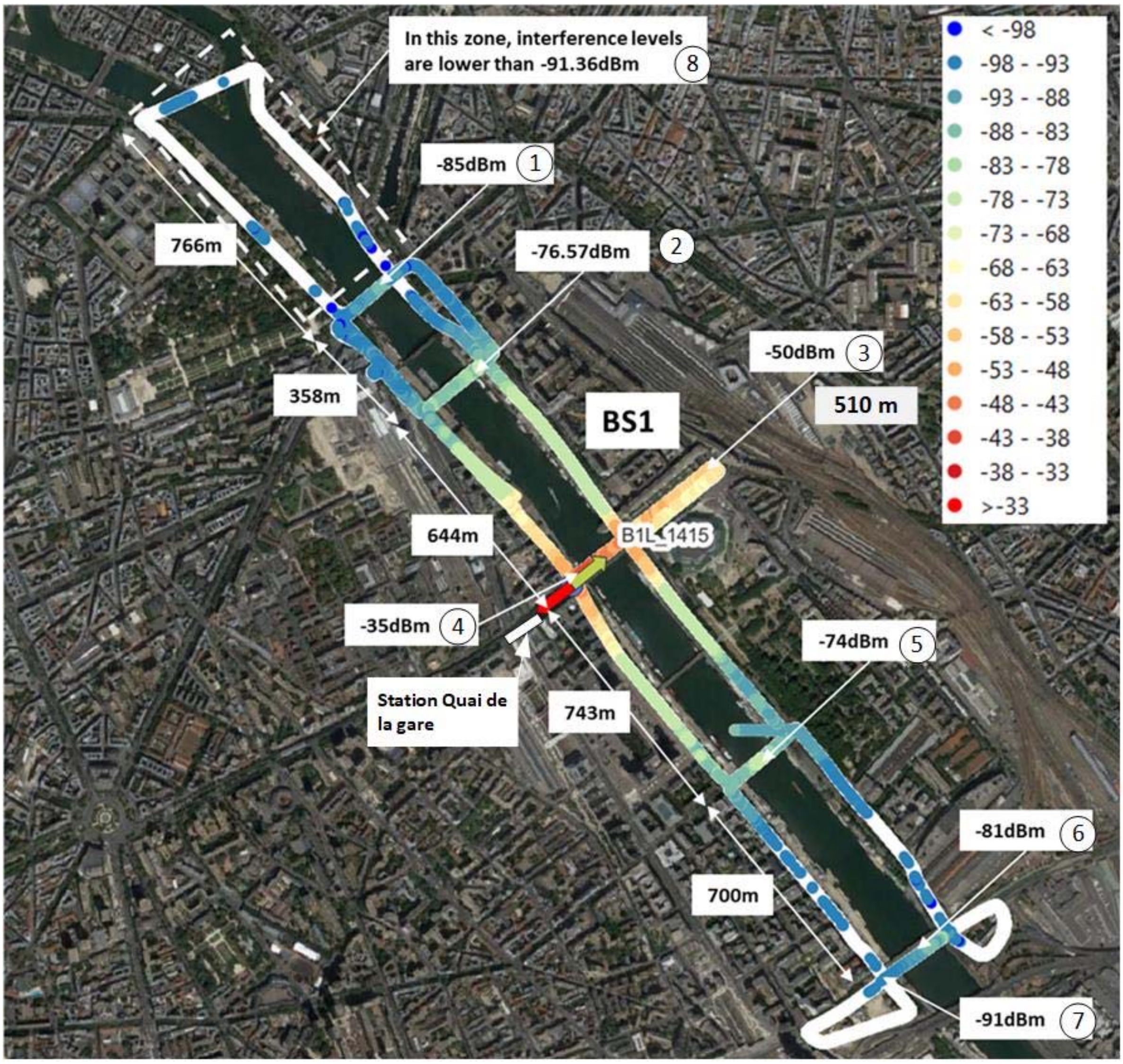

Figure 44: Line 6 Section 3 Base station at position 1 level received from Vehicles (Map Source Google Earth: © Google)

Figure 45 shows the level received by the base station at position 2 with the antennas at 5 m above the tracks.

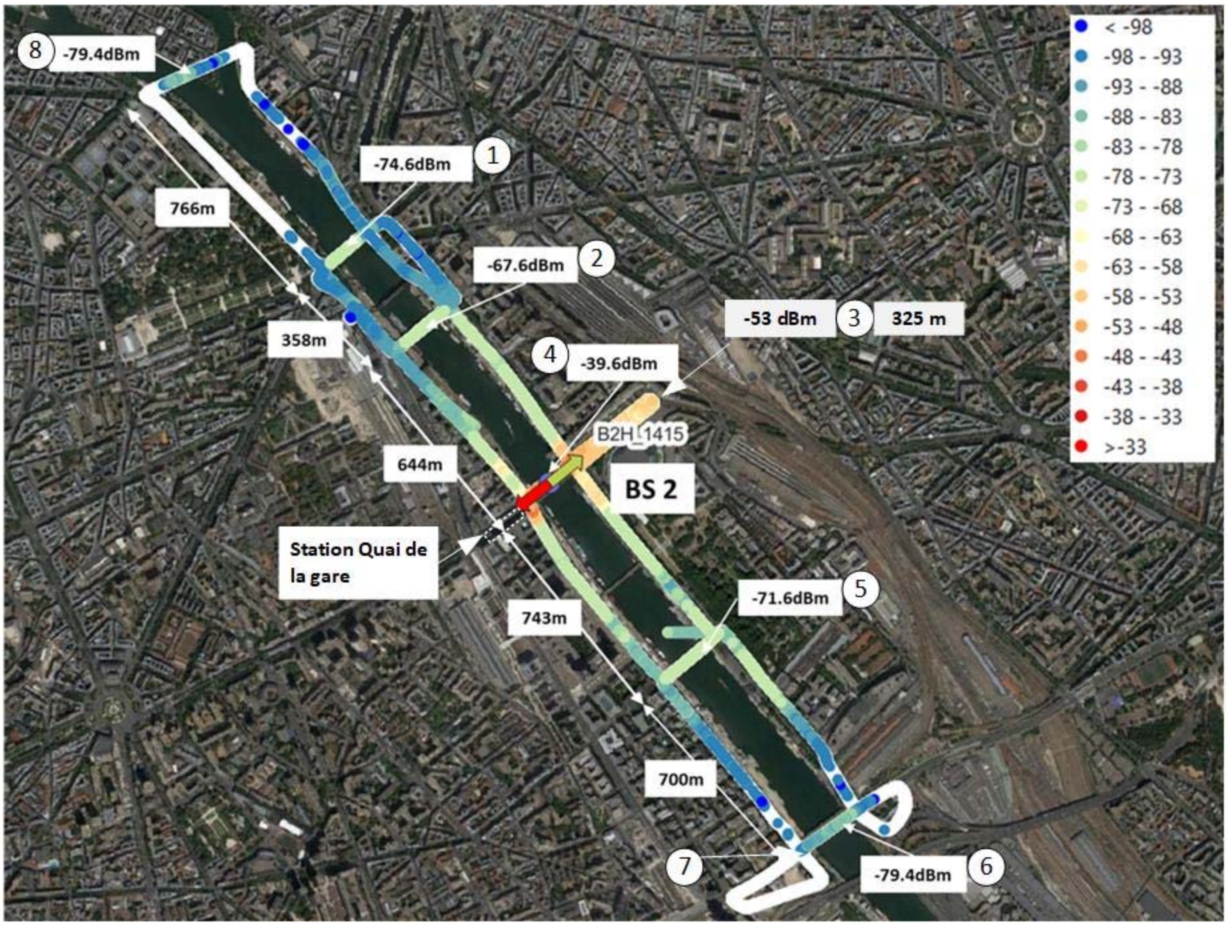

Figure 45: Line 6 Section 3 Base station at position 2 with antenna height 5 m level received from Vehicles (Map Source Google Earth: © Google)

Table 17 and Table 18 provide an analysis for each point of interest.

Table 17: Section 3 of Line 6 Point of interest analysis 1 to 4

Point of interest number	Base station at position 1 (Train)	Base station at position 2 with antenna height 5 m above tracks	Comments
1	Distance from base station 992 m Middle of the second bridge direction northwest Level: -85 dBm/10 MHz	Distance from base station 992 m Middle of the second bridge direction northwest Level: -75 dBm/10 MHz	There are 10 dB of difference. The BS1 is on the viaduct above the street parallel to the river. The BS2 is in the middle of the bridge. It is located on the viaduct that is 6 m above the bridge. Antenna height are 11 m above the roads. For BS1 and BS2, the RF signal are received under an angle of 90° with the axis of the antennas. The gain is around -5 dB. For BS1 and BS2 the propagation is Line-of-sight. No simple propagation model (see annex B) provides a value close to the measurement.
2	Distance from base station 644 m Middle of the second first direction northwest Level: -77 dBm/10 MHz	Distance from base station 644 m Middle of the second first direction northwest Level: -67 dBm/10 MHz	Same difference as for previous point of interest. Same reason.
3	Distance from base station 520 m Location on street parallel to the tracks close to tunnel entrance Level: -50 dBm/10 MHz	Distance from base station 325 m Location on street parallel to the tracks close to tunnel entrance. Level: -53 dBm/10 MHz	The propagation is Line-of-sight. The vehicles are in the main lobe of the Base station antenna. No simple propagation model (see annex B) provides a value close to the measurement. The simple Friis formula gives an approximation of -59 dBm/10 MHz for BS1 and -55 dBm/10 MHz for BS2.
4	Located street crossing the Bercy bridge. The vehicles are driving below the station Level: -35 dBm/10 MHz	Vehicle driving below the base station that is installed on a viaduct Level: -39 dBm/10 MHz	The figure is 52 dB above the level defined in Table 2. The propagation is non-Line of Sight.

Table 18: Section 3 of Line 6 point of interest analysis 5 to 8

Point of interest number	Base station at position 1 (Train)	Base station at position 2 with antenna height 5 m above tracks	Comments
5	Located at 743 m from the base station 1 on the first bridge in the south-east direction Level: -74 dBm/10 MHz	Located at 743 m from the base station 1 on the first bridge in the south-east direction Level: -72 dBm/10 MHz	Propagation is Line-of-sight. Similar level received. No simple propagation model (see annex B) provides a value close to the measurement.
6	Located on the second bridge in the direction of south-east at 1 443 m from the base station Level: -81 dBm/10 MHz	located on the second bridge in the direction of south-east at 1 443 m from the base station Level: -79 dBm/10 MHz	Similar level. It is the limit of coverage for both Base stations. No simple propagation model (see annex B) provides a value close to the measurement.
7	1 443 m from the base station on the road parallel to the tracks. Level: -91 dBm/10 MHz	1 443 m from the base station on the road parallel to the tracks. Level: -90 dBm/10 MHz	Same conclusion as for previous point of interest.
8	Area including the third bridge direction northwest Level: -91 dBm/10 MHz	Third bridge direction northwest Level: -79 dBm/10 MHz	For the BS2 located in the middle of the bridge, the propagation is Line-of-sight. It is the case for the BS1.

A measurement was performed with Base station 2 at the same location with the antenna height adjusted at 3,5 m to simulate a Train.

The circuit followed by both vehicles was shorter due to the time available to perform the measurements. The target was to compare level received by a train or a base station. Even if a shorter circuit, it is possible to evaluate the impact of the difference of antenna height.

Figure 46 shows the level received by the base station at position 2 with the antennas at 3,5 m above the tracks.

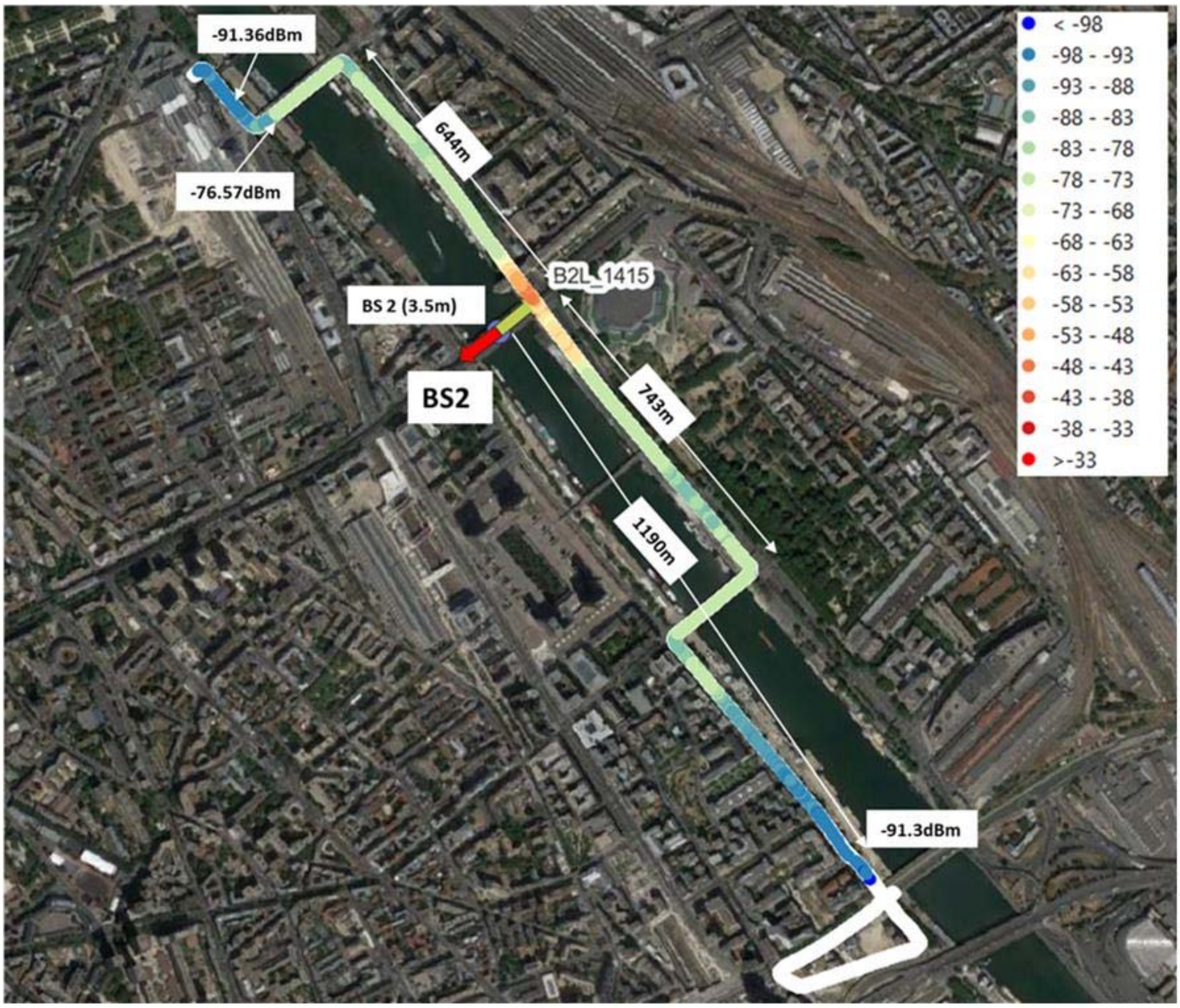

Figure 46: Line 6 Section 3 Base station at position 2 with antenna height 3,5 m level received from Vehicles (Map Source Google Earth: © Google)

It can be observed that on the first bridge in the direction north-west and in the direction south-west, the received levels are like the levels received with antenna at 5 m above the tracks. According to the colour palette, the level is between -73 dBm/10 MHz and -68 dBm/10 MHz.

8.2.2.3.2.2 Received level from vehicles for base station at position 3

The base station 3 was installed at 257 m from the station Quai de la Gare on the opposite bank of the river. The Antennas height above the tracks was 3,5 m.

The distribution of levels on the bridge in the direction of northwest is like the distribution of levels for Base station 1. The levels are lower on the bridge in the south-east direction as shown on Figure 47.

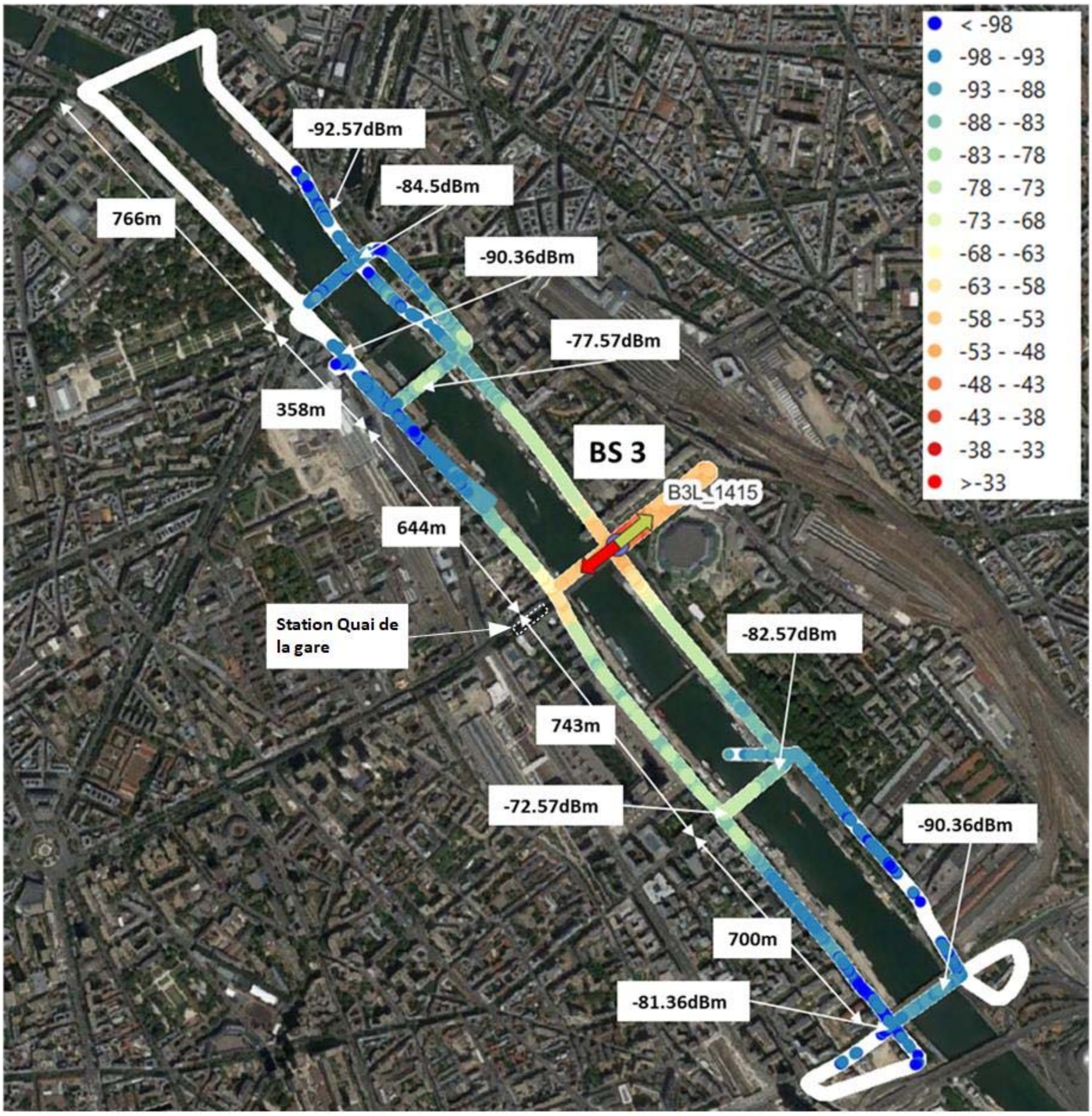

Figure 47: Line 6 Section 3 Base station at position 3 with antenna height 3,5 m level received from Vehicles (Map Source Google Earth: © Google)

8.2.2.3.3 Summary of observation for the section 2 of Line 6

The measurements performed on section 2 have covered the scenarios 2, 6 and 7.

The measurements performed on the section 2 of Line 6 at three locations confirm what has been discovered with the simulation: levels received from vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]) on parallel roads and parallel bridges are above the defined protection levels of the CBTC communications.

The worst-case situation is for the base station at position 2, in the middle of the Bercy bridge. The vehicles driving on the 4 adjacent bridges (two for the north-west direction and two for the north-east direction) are received with level above -75 dBm/10 MHz for three bridges and for the last bridge direction south-east, above -80 dBm/10 MHz.

The level received from vehicles on the road below the viaduct and below the base station can be above -40 dBm/10 MHz.

8.2.3 Analysis of measurements for Line 8

8.2.3.1 Analysis of the Measurements for the section 1 of Line 8

8.2.3.1.1 Localization of the receivers for section 1 of Line 8

The measurements have been performed with a temporary base station and a train at two positions as initially foreseen.

The temporary base station has been installed at the position:

- Latitude (WGS 84 Decimal): 48.76602607
- Longitude (WGS 84 Decimal): 2.465840084

The Train has been moved to two positions:

- Position 1:
  - Latitude (WGS 84 Decimal): 48.76644162681275
  - Longitude (WGS 84 Decimal): 2.4657625773469802
- Position 2:
  - Latitude (WGS 84 Decimal): 48.767503765606456
  - Longitude (WGS 84 Decimal): 2.4653130896939346

Figure 48 shows the location of base station and train positions.

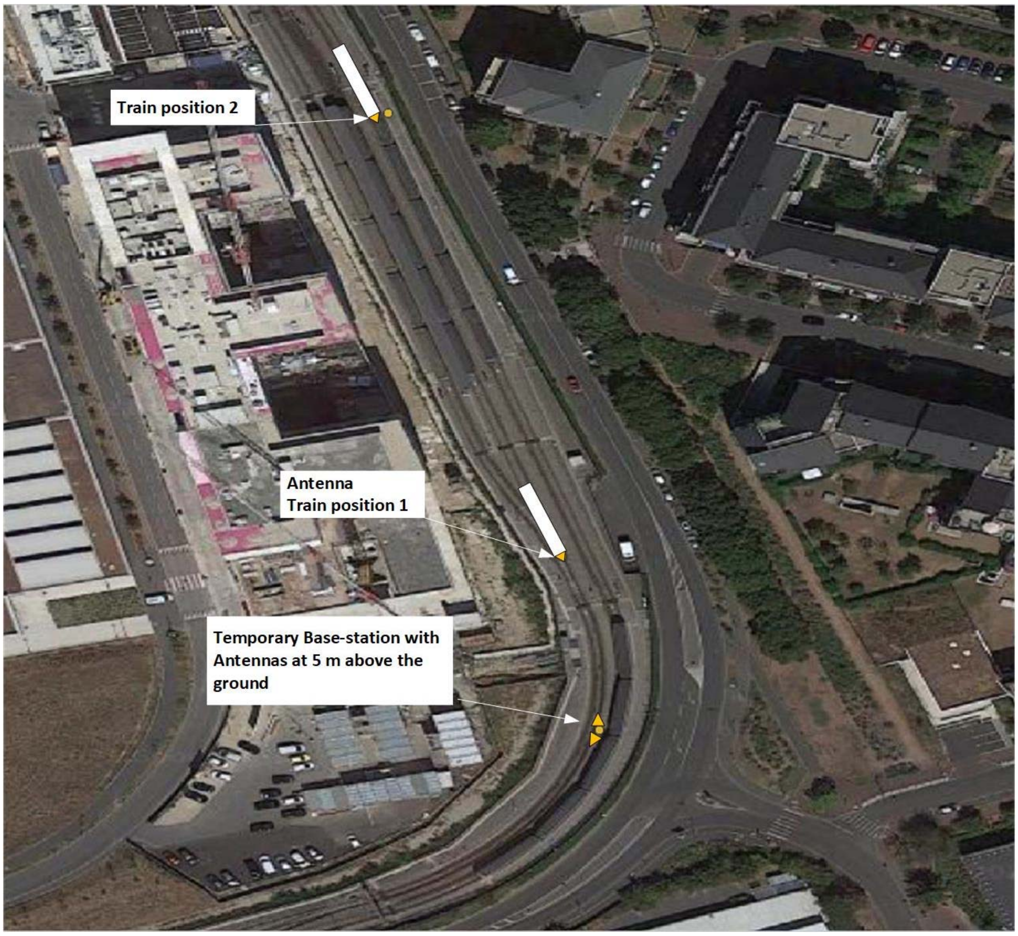

Figure 48: Line 8 section 1 localization of train and the base-station (Map Source Google Earth: © Google)

8.2.3.1.2 Analysis of measurements for each receiver of section 1

8.2.3.1.2.1 Received level from vehicles for train at position 1

Figure 49 shows the level received by the train antennas when the train is at position 1 from two vehicles transmitting packets at 33 dBm/10 MHz.

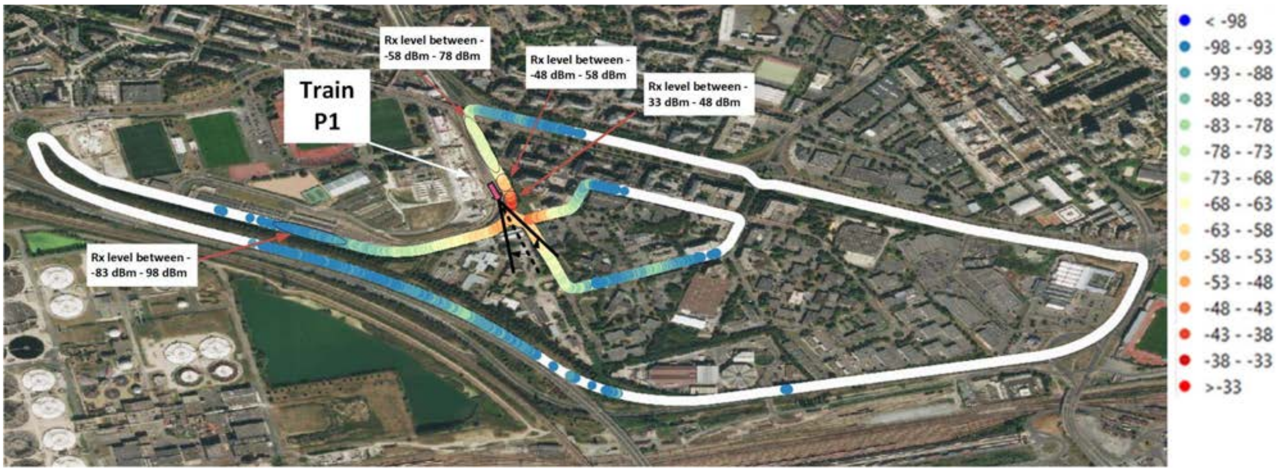

Figure 49: Line 8 section 1 train position 1 level received from vehicles for EIRP 33 dBm/10 MHz (Map Source Google Earth: © Google)

The scenarios covered in section 1 for both train positions and temporary base station were scenario 1 (Track and road parallel road at the same level) and scenario 7 Isle (Group of vehicles) in a city or multiple RF sources.

The white curve shows the circuit followed by the vehicles and coloured circles indicate the range of level received from the vehicles according to the colour palette.

Figure 50 shows the type of propagation between the train and the vehicle and distance to limit of coverage.

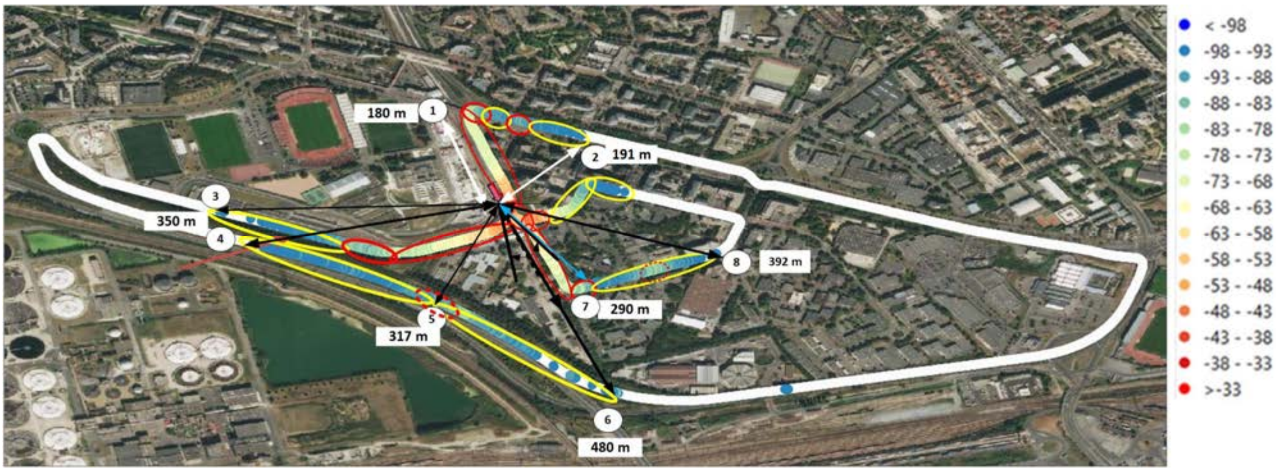

Figure 50: Line 8 section 1 Train position 1 types of propagation and points of interest (Map Source Google Earth: © Google)

The red ellipses identify area with Line-of-sight propagation and the yellow ellipses identify the area with non-Line of Sight propagation.

The locations identified with a number in a white circle indicate the limit of radio coverage. Table 19 gives information about each location.

Table 19 and Table 20 give for each point of interest an analysis.

Table 19: Section 1 of Line 8 Point Train P1 of interest analysis 1 to 4

Point of interest number	Description
1	This location is at 180 m from the train antenna. This a limit of the Line-of-sight propagation with the back-lobe of the train antenna because the vehicles turned right. The level received from a vehicle is between -58 dBm/10 MHz and -78 dBm/10 MHz and the measured value at 180 m from the train antenna is -70 dBm/10 MHz close to a bridge. Considering a back-lobe train antenna gain of -6 dB, the simple suburban propagation model (see annex B) gives a level of -70 dBm/10 MHz and the simple urban propagation model gives a value of -72 dBm/10 MHz. If the vehicles had continued to travel on the road parallel to the track, the vehicle transmissions would have been received over a distance greater than 180 m.
2 (edge of coverage for the receivers)	This location is at the limit of radio coverage with non-Line of Sight propagation. There are buildings on the path. This limit is on a parallel road. The RF signals from location 2 area received with angle of 94° from the axis of the train antenna. The gain of the train antenna is around -5 dB in this case.
3 (edge of coverage for the receivers)	The location 3 is at the end of radio coverage of a non-Line of Sight area. This area is located behind the depot of Line 8 where several trains were parked. The distance from the train antenna is around 350 m. The RF signals of this area arrives with an angle between 114° and 125° from the train antenna axis, meaning in the antenna back-lobe with a gain of -6 dB.
4 (edge of coverage for the receivers)	This location is as the previous one at the end of a non-Line of Sight area and at the same distance from the train antenna. This area covers another road at a lower altitude.

Table 20: Section 1 of Line 8 Train P1 Point of interest analysis 5 to 8

Point of interest number	Description
5	The location 5 is at a centre of a mixed area with Line of Sight and non-sight propagation at around 317 m from the train antenna.
6 (edge of coverage for the receivers)	Location 6 at 480 m from the train antenna is the end of an area with no-Line of Sight in the main lobe of the train antennas.
7	Location 7 is at 290 m from the train antennas, in the main lobe of this one. It is the end of Line-of-sight propagation in the main lobe of the train.
8 (edge of coverage for the receivers)	Location 8 at 392 m from the train antennas with an angle of 46° from the axis of the train antennas, it means outside the main lobe. The area between location 7 and location 8 is with non-Line of Sight propagation but a small part is with Line-of-sight propagation.

8.2.3.1.2.2 Received level from vehicles by base station

Figure 51 shows the level received by the base station antennas from the two vehicles transmitting packets at 33 dBm/10 MHz.

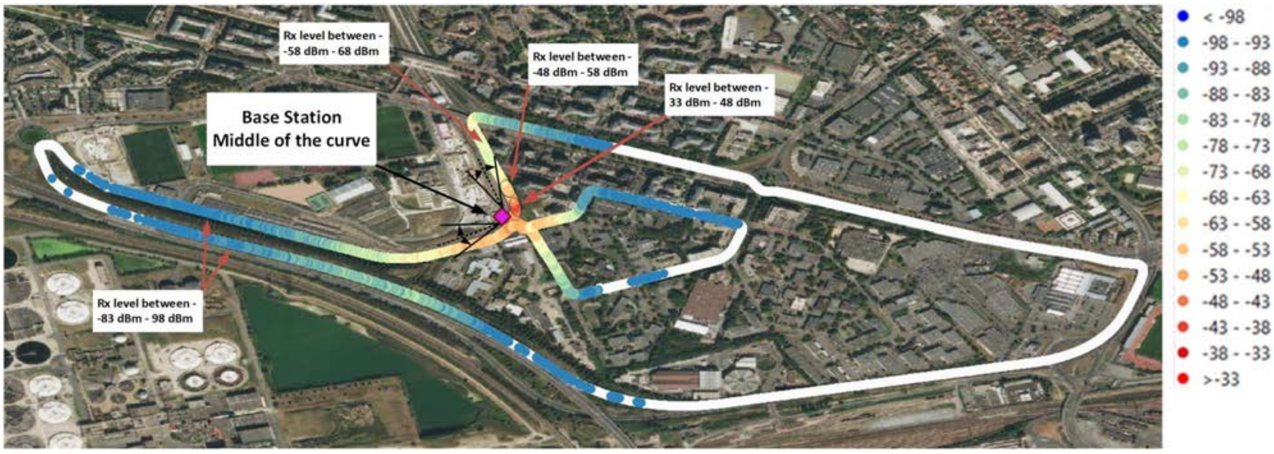

Figure 51: Line 8 section 1 level received from vehicles for EIRP 33 dBm/10 MHz by base station (Map Source Google Earth: © Google)

The base station was installed in the middle of the curve with an antenna pointing to the direction of station "Pointe du lac" and the bridge and the other antenna pointing to a direction perpendicular to the previous one.

The height of the base station antenna was 5 m above the ground.

Figure 52 shows the type of propagation between the train and the vehicle and distance to limit of coverage.

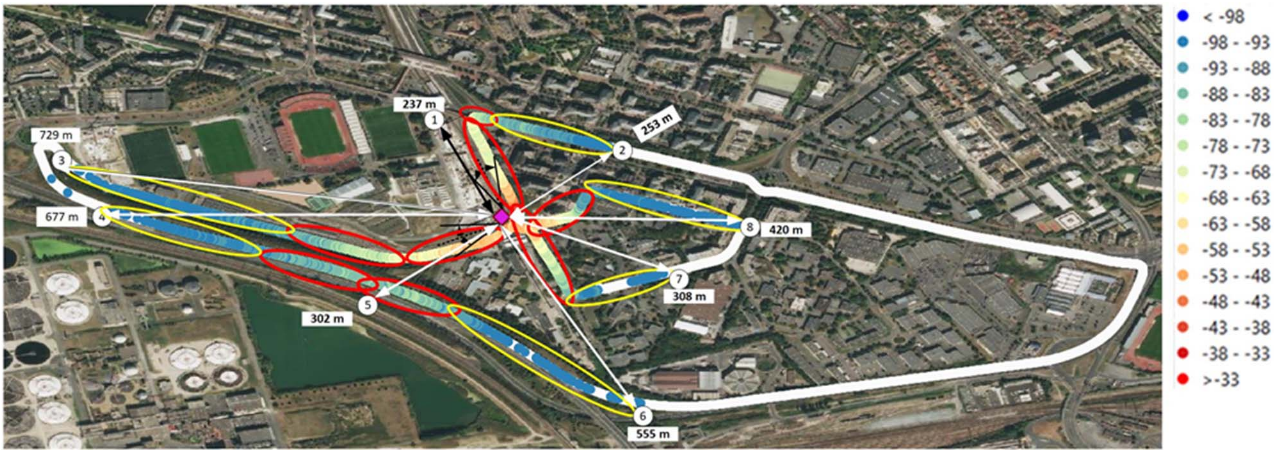

Figure 52: Line 8 section 1 base station with type of propagation and points of interest (Map Source Google Earth: © Google)

The red ellipses identify areas with Line-of-sight propagation and the yellow ellipses identify the area with non-Line of Sight propagation.

A comparison with the train position 1 shows that the base station receiver receives more RF packets from the vehicles over a longer distance than the train receiver. This is due to the fact that a base station has always two antennas pointing in two different directions and the height of Base station antenna is 5 m above the ground instead of 3,5 m for the train.

It can be observed that there are more areas with Line-of-sight propagation than for the train position 1.

On Figure 52, the locations identified with a number in a white circle are point of interest that indicate the limits of radio coverage. Table 21 and Table 22 give information about each point of interest.

Table 21: Section 1 of Line 8 Base station Point of interest analysis 1 and 2

Point of interest number	Description
1	This location is at 237 m from the base station antenna. This a limit of the Line-of-sight propagation with the base station because the vehicles turned right. The level received from a vehicle is between -58 dBm/10 MHz and -68 dBm/10 MHz and the measured value at 237 m from the train antenna is -62 dBm/10 MHz close to the bridge. This is 7 dB above the level received by a train antenna from a vehicle at the same location. The level obtained with a simple urban propagation model (see annex B) is -64 dBm/10 MHz and with a simple suburban propagation model is -61 dBm/10 MHz. The simple urban and suburban propagation model give values close to the measured one.
2 (edge of coverage for the receivers)	This location is at the limit of radio coverage with non-Line of Sight propagation. The RF signals from location 2 area received with angle of 90° from the axis of the train antenna. The gain of the train antenna is around -5 dB in this case. The point of interest 2 is at 253 m from the base station. The distance between point 1 and 2 is 60 m longer than the same distance for the train at position 1. This is because base station is in the middle of the curve at a height of 5 m above the ground.

Table 22: Section 1 of Line 8 Base station Point of interest analysis 3 to 8

Point of interest number	Description
3 (edge of coverage for the receiver)	The location 3 is at the end of radio coverage of a non-Line of Sight area. This area is located behind the depot of Line 8 where several trains are parked. It can be observed that the limit of coverage is at 729 m from the base station antenna while for the train it was 350 m. The base station antennas receive higher level than the train antennas. The RF signals of this area arrive with an angle between 88° and 95° from base station antenna axis, for these angles the base station antenna has a gain of -5 dB.
4 (edge of coverage for the receiver)	This location is as the previous one at the end of a non-Line of Sight area and at distance of 677 m, instead of a distance of around 350 m for the train. This area covers another road at a lower altitude.
5	The location 5 is at a centre of a large mixed area with a majority of Line-of-sight propagation. The location 5 is at around 302 m from the base station.
6 (edge of coverage for the receiver)	Location 6 at 555 m from the Base station antenna is the end of an area with no-Line of Sight area of the base station. Compared to the train position 1, it is similar
7 (edge of coverage for the receiver)	Location 7 is at 308 m from the base station antennas. The area ended by the location 7 is shorter that the same one for train position 1. This is due to the fact this area is "seen" by the back-lobe of the two antennas of the base station while for the train it was in the main lobe.
8 (edge of coverage for the receiver)	The location 8 at 420 m is at the end of an area with non-Line of Sight propagation. This area is seen by both antenna via their back-lobes. This area is 60 m bigger than the same one for train position 1. This is due to the location of the base station, and the heights of base station antennas.

8.2.3.1.2.3 Received level from vehicles for train at position 2

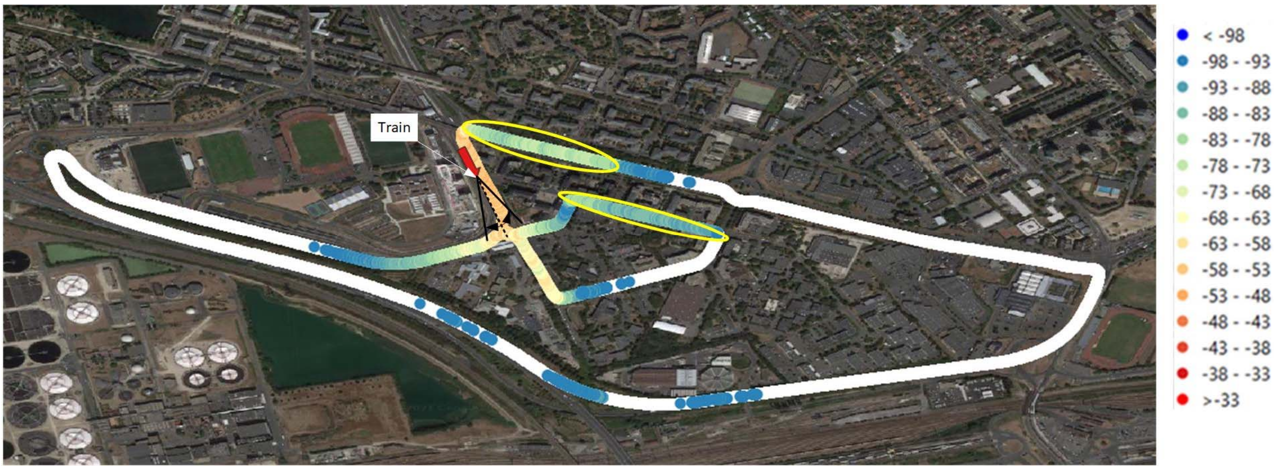

Figure 53: Line 8 section 1 Train position 2 level received from vehicles for EIRP 33 dBm/10 MHz (Map Source Google Earth: © Google)

On Figure 53, the received radio levels for the train at position 2 is comparable to the levels for position 1.

The two yellows ellipses indicate two areas with majority of non-Line of Sight propagation where the level received from the vehicles at train antennas output are high.

8.2.3.1.3 Summary L8 section 1

The measurements performed on section 1 have covered the scenarios 1 and 7.

The measurements performed on the section 1 of Line 8 with a train at two positions and one base station confirm what has been discovered with the simulation: levels received from vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]) on parallel roads and in different areas in the surrounding of the Line are above the defined protection levels of the CBTC communications.

The base station receives higher levels than a train due to two reasons: two antennas pointing in two different directions and the height of the antennas above the ground.

At the point of interest 1 located just be before the vehicles turn left, the levels received by train at position 1 and base station respectively -70 dBm/10 MHz and -62 dBm/10 MHz. If the vehicles had continued to travel on the road parallel to the track, the vehicle transmissions would have been received over a distance greater than 180 m.

It is also remarkably interesting to compare point of interest 3 and 4 for train at position 1 and at the Base station. The distance is 350 m for the train and 729 m for the Base station. The difference is due to location but also orientation of the antenna. A train at the same location will have its antennas pointing in the same direction and in this case a distance a significantly higher distance than 350 m can be expected but probably less than 729 m due to difference of antenna height.

8.2.3.2 Analysis of measurements for the section 2 of Line 8

8.2.3.2.1 Localization of the receivers for section 2 of Line 8

This section 2-3 is between station Créteil-Préfecture and Créteil-Université.

One of the conclusions of the optimization of the planning was that the section 2 and 3 should be combined in one section to maximize the number of measurements for the following reasons:

- For two nights measurements with a train that has two cabs equipped with RF measurements tools. The advantage is no loss of time due to high voltage switching and off.
- On nights with measurements with three base stations. The advantage is on High voltage switching off after revenue service and one switching on at the end of the session.

- Combinations of some circuits to be followed by vehicle.

Table 23 gives the location of each train cab.

Table 23: Section 2-3 of Line 8 Train positions

Train Position	Train Cab1 Latitude and Longitude in decimal format	Train Cab 2 Latitude and longitude in decimal format	Comments
Position 1	Latitude (WGS 84 Decimal): 48.78278788876709 Longitude: 2.4591734624086303	Latitude (WGS 84 Decimal): 48.78209518319527 Longitude (WGS 84 Decimal): 2.4592334448134463	Middle of the train is under a bridge
Position 2	Latitude: Longitude:	Latitude (WGS 84 Decimal): 48.78598328583781 Longitude (WGS 84 Decimal): 2.4571560164504835	Train Cab 2 at end of curve Measurements have been performed only with Cab 2 (Rear cab) for position 2
Position 3	Latitude (WGS 84 Decimal): 48.78693094773145 Longitude (WGS 84 Decimal): 2.454966811077735	Latitude (WGS 84 Decimal): 48.78658977931738 Longitude (WGS 84 Decimal): 2.4558548640089506	Rear Cab of the train is on a bridge
Position 4	Latitude (WGS 84 Decimal): 48.78932453368078 Longitude (WGS 84 Decimal) 2.4510828681139896	Latitude (WGS 84 Decimal): 48.7887314210915 Longitude (WGS 84 Decimal): 2.451672329475059	Rear cab of the train is on a bridge

Figure 54 shows the positions of the train and its cabs on the section 2-3 and the three circuits followed by the vehicles.

Figure 54: Positions of the train cab on section 2-3 of Line 8 with circuits followed by the vehicles (Map Source Google Earth: © Google)

The Lines with colour white, magenta, and green show the circuit followed by the vehicles.

For train position P1 P2 and P3, measurements have been performed with circuit white and magenta, for position 2, 3 and 4, measurements have been performed with circuits magenta and green.

Table 24 gives the location of each base station of section 2-3 of Line 8.

Table 24: Section 2-3 of Line 8 train positions

Base Station Position	Latitude and Longitude in decimal format	Comments
Position 1	Latitude (WGS 84 Decimal): 48.79137264863115 Longitude (WGS 84 Decimal): 2.4491098630556376	The base station 1 is located at 146 m of the north end of the Station Créteil Université on a bridge above the high-speed road 1.
Position 2	Latitude (WGS 84 Decimal): 48.7848755801646 Longitude (WGS 84 Decimal): 2.458548968000339	The base station 2 is in the middle of a curve between station Créteil-Préfecture and station Créteil Université. The track is between the lanes of the high-speed road D1.
Position 3	Latitude (WGS 84 Decimal): 48.78075197292567 Longitude (WGS 84 Decimal): 2.4593930330000977	The base station 3 is located at 41 m of the north end of station Créteil-Préfecture.

Figure 55 shows the positions of the three base stations on the section 2-3.

Figure 55: Position base stations on section 2-3 of Line 8 (Map Source Google Earth: © Google)

8.2.3.2.2 Analysis of measurements for each receiver of section 2

8.2.3.2.2.1 Received level from vehicles by Train at position 1 rear cab

Figure 56 shows the levels received by the Train RF at position 1 rear from the two vehicles transmitting packets at 33 dBm/10 MHz.

Figure 56: Line 8 section 2-3 level received from two vehicles by the Train rear cab at position 1 (Map Source Google Earth: © Google)

The measurements performed with the train at position 1 covers the scenarios 1, 5, 6 and 7 but an emphasis has been given to scenario 5: Crossing Tracks and Road with road on a bridge because the train was positioned in such a way that its middle was below the bridge.

The train antenna was pointing to the station Créteil-Préfecture.

The point of interest 1 is located at 500 m from the train antenna and the received level is -83 dBm/10 MHz. The propagation is at the limit of Line-of-sight propagation. The vehicles are received by the back lobe of the train rear cab antenna. The antenna gain is around -6 dB.

The level computed with the simple propagation models, Free space loss, Urban and suburban gives the following values: -75 dBm/10 MHz, -100 dBm/10 MHz and -85 dBm/10 MHz. The estimation given by the simple suburban propagation model (see annex B) provides the best estimation.

At point of interest 2, located at 600 m from the train antenna, the received level is -81 dBm/10 MHz. The vehicles are received in the main lobe of the train antenna that has a gain of 15 dB.

The train antenna was installed on the wind shield. This one had an estimated attenuation of 3 dB. The propagation is Line-of-sight. The level obtained with simple propagation models, Free space loss, Urban and suburban gives the following values -58 dBm/10 MHz, -87 dBm/10 MHz and -72 dBm/10 MHz.

The best estimation is obtained with the simple urban propagation model (see annex B). But the error is above ±3 dB.

The point of interest 3 is located at 547 m from the train antenna and the received level is -88 dBm/10 MHz. This is a non-Line of Sight propagation. There are building on the path. The arrival angle of RF signals is at 20° from the axis of the train antenna. The antenna gain is around 12 dB. Taking into account the windscreen attenuation, the simple urban propagation model (see annex B) gives -88 dBm/10 MHz.

The point of interest 4 is located at 633 m from the train antenna. The received level is -90 dBm/10 MHz. The arrival angles of RF signals around 36° from the axis of the train antenna. The antenna gain is around 2 dB. There are buildings on the path. This is a non-Line of Sight propagation.

No simple propagation model (see annex B) provides a close estimation for point of interest 4.

The received level from the vehicles on the bridge is around -47 dBm/10 MHz. This is above the level defined in Table 2.

To estimate the limits of interference area, the simple urban and suburban propagation models cannot be considered for the train at position 1.

8.2.3.2.2.2 Received level from vehicles by Train at position 2 rear cab

Figure 57 shows the level received by the train at position 2 rear cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

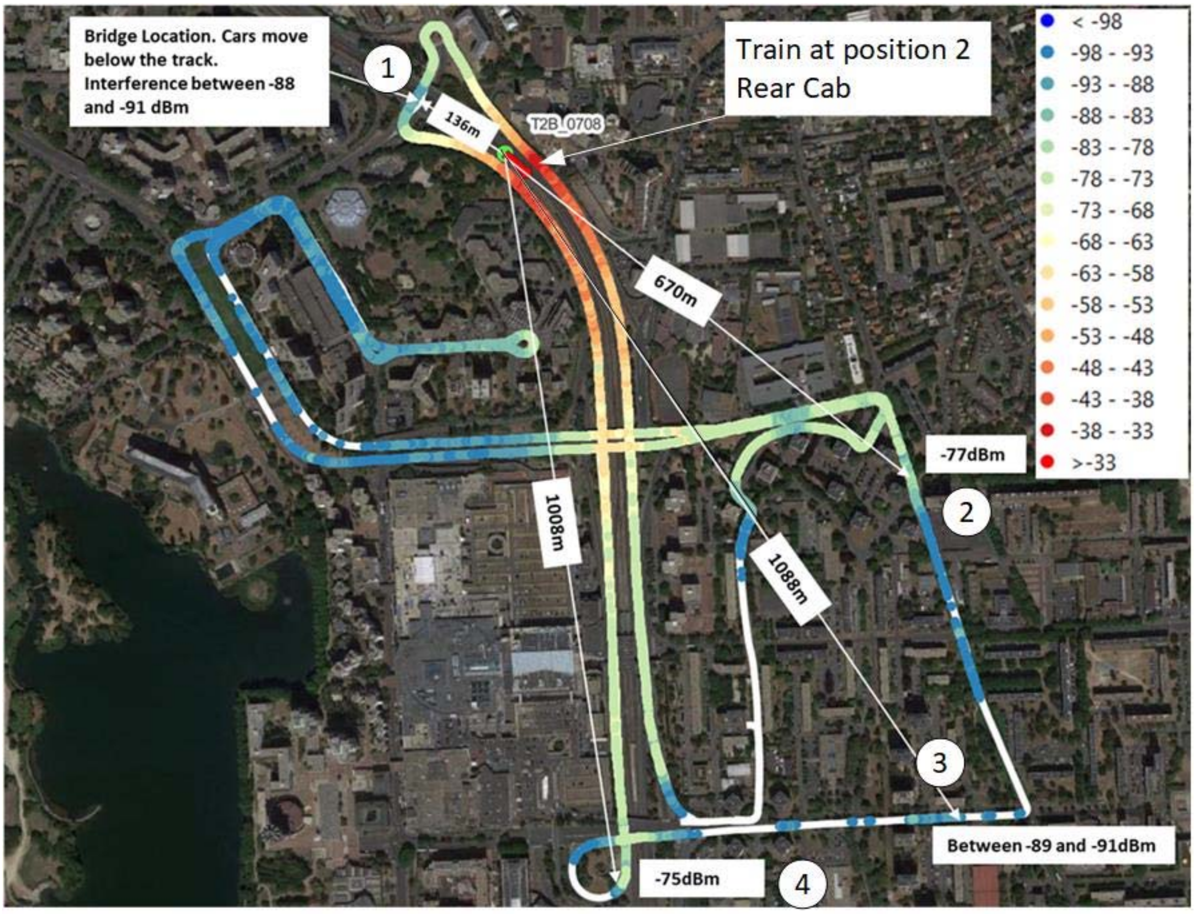

Figure 57: Line 8 section 2-3 level received from two vehicles by the Train rear cab at position 2 (Map Source Google Earth: © Google)

The measurement performed with the train at position 2 covers the scenarios 1, 5, 6 and 7 but an emphasis has been given to scenario 5: Crossing Tracks and Road with road below the tracks.

The train was in the middle of a curve close to a bridge.

At point of interest 1 located at 136 m from the train antenna, the vehicles were driving below the bridge.

From vehicles that were driving below the bridge transmitted packets have been received with levels between: -88 dBm/10 MHz and -91 dBm/10 MHz via the back lobe of the train antenna. These interference levels are just above or at the limit of the defined protection levels of the CBTC communications.

At point of interest 2 located at 670 m from the train antenna, the received level is -77 dBm/10 MHz. Due to the curve, the Train antenna is pointing to the point of interest 2. The Vehicles are in the main lobe of the train antennas. The train antennas gain in this case is 15 dB. There are buildings on the path. This is not a Line-of-sight propagation. Considering the loss due to the windscreen, the level obtained with the simple suburban modem is -75 dBm/10 MHz.

At point of interest 3 located at 1 008 m from the train antenna, the received level is -75 dBm/10 MHz. The vehicles are not in the main lobe of the train antenna. The RF signals are received under an angle between 40 and 42° with the axis of the train antenna. The train antenna gains are around -6 dB. This is a non-Line of Sight propagation. There are buildings on the path.

The point of interest 4 is located at 1 088 m from the train and the received level is between -89 dBm/10 MHz and -91dBm/10 MHz. The vehicles are not in the main lobe of the train antennas. The angle of arrival is around 20° from the train antenna axis. The gain of the antennas is around 9 dB instead of 15 dB. This is a non-Line of Sight propagation. There are several buildings in the path.

At point of interest 3 and 4 both located at a distance higher than 1 000 m, received level it can be observed that interference levels between -75 dBm/10 MHz and -91 dBm/10 MHz are received at higher than 1 000 m. Even at an angle of 40° from the boresight of the antenna, interference levels of -75 dBm/10 MHz are detected at 1 008 m.

For level received at point of interest 3 and 4, no simple propagation model (see annex B) can provide an estimation.

8.2.3.2.2.3 Received level from vehicles by Train at position 2 front cab

Figure 58 shows the level received by the Train RF at position 2 front cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

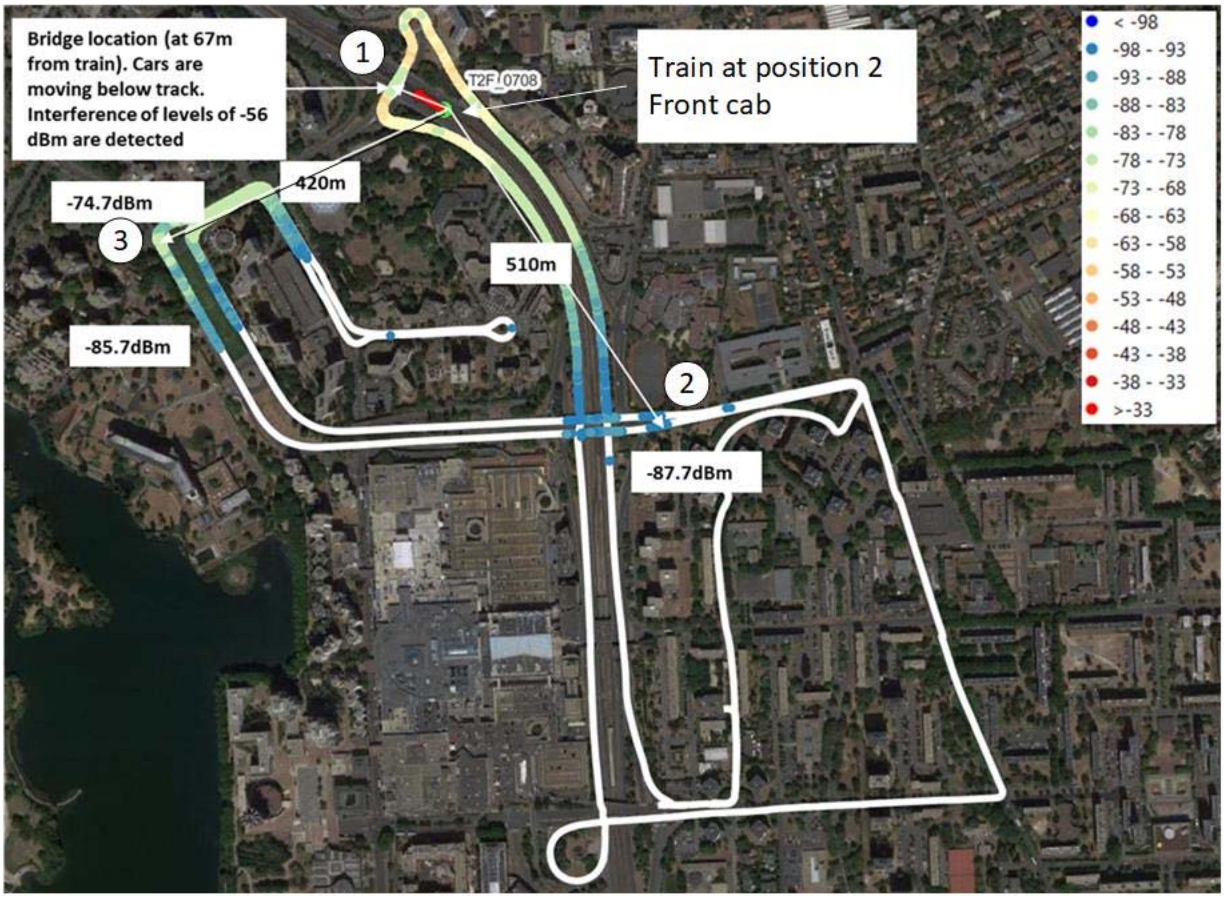

Figure 58: Line 8 section 2-3 level received from two vehicles by the Train Front cab at position 2 (Map Source Google Earth: © Google)

The front cab of the train at position 2 was at 67 m from the bridge. The tracks are on the bridge and the vehicles were driving below this one.

At point interest 1, the vehicles driving below the bridge are received with a level of -56 dBm/10 MHz. The vehicles are in the main lobe of the train antennas but in non-Line of Sight. Without mitigation measure this could possibly lead to interference with CBTC communication.

Point of interest 2 located at 510 m from the train antenna. Vehicles are received via the back-lobe of the Train antennas. The gain of the antennas is around -6 dB. The received level is around -88 dBm/10 MHz. A computed level of -86 dBm/10 MHz is obtained with the simple Urban propagation model (see annex B).

At point of interest 3 located at 420 m from the train cab, the received levels are between -75 dBm/MHz and -86 dBm/10 MHz at the limit of coverage after the corner. The packets are received with an angle of 60° with the train antenna axis. The gain of the train antenna is around 5 dB. No value can be estimated with a simple propagation model.

8.2.3.2.2.4 Received level from vehicles by Train at position 3 rear cab

Figure 59 shows the level received by the Train RF at position 3 rear cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

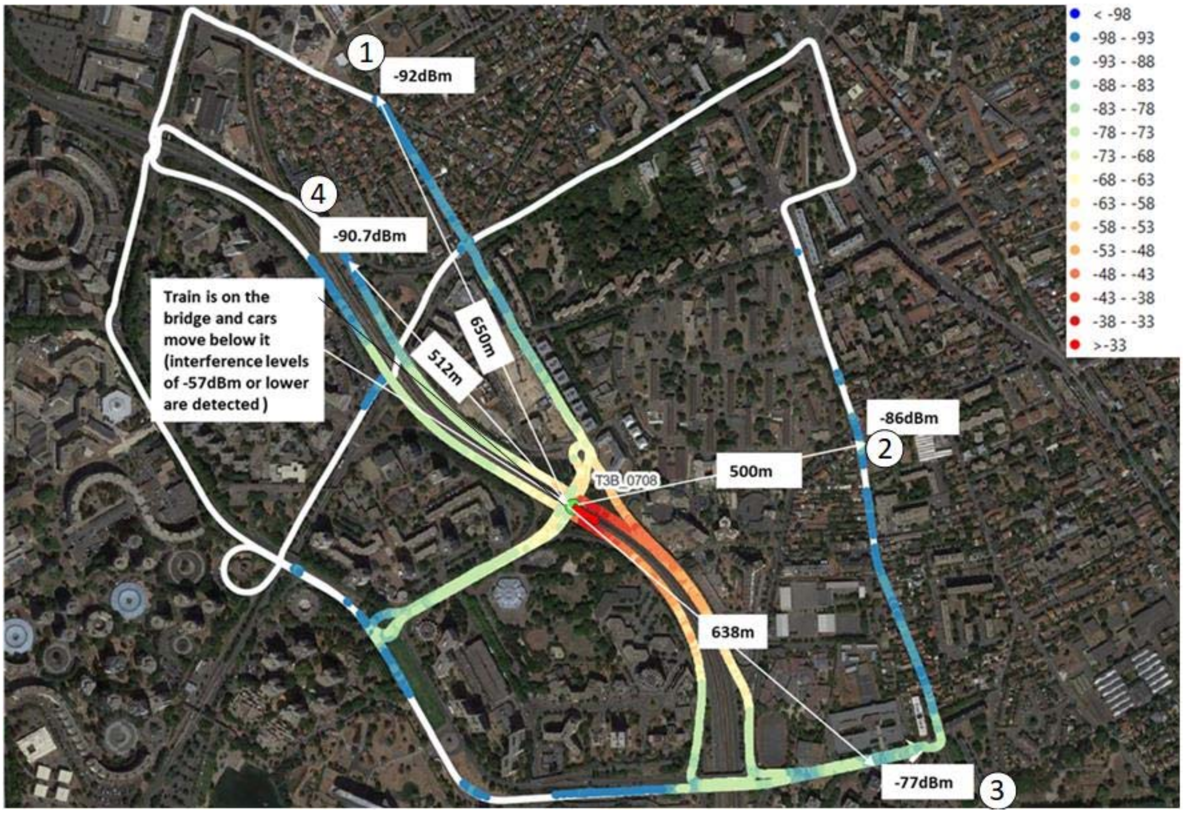

Figure 59: Line 8 section 2-3 level received from two vehicles by the Train rear cab at position 3 (Map Source Google Earth: © Google)

The measurements performed with the train at position 3 cover the scenarios 1, 5, 6 and 7 but an emphasis has been given to scenario 6: Crossing Tracks and Road with tracks on a bridge.

The rear cab of the train was located on the bridge with the vehicles driving below this one.

The analysis of the measurements shows that the level received by the train rear cab from vehicles driving below the bridge is -57 dBm/10 MHz. The vehicles are received via the back-lobe antenna. This is a non-Line of Sight propagation.

At the point of interest 1 located at 650 m, the received level is -92 dBm/10 MHz. The packets are received via the back-lobe of the train antennas with a gain of -6 dB. This a non-Line of Sight propagation. There are building on the path.

Level computed with the simple suburban propagation model (see annex B) gives -92 dBm/10 MHz.

The point of interest 2 is located at 500 m from the train antenna. The received level is -86 dBm/10 MHz. The packets are received with an angle of 51° with the axis of the antenna. The gain of the train antenna is around -5 dB. The level computed with the simple urban propagation model (see annex B) gives -85 dBm/10 MHz.

The point of interest 3 is located at 638 m from the train antenna. The received level is -77 dBm/10 MHz. The vehicles are in the main lobe of the train antennas, but this is a non-Line of Sight propagation there are buildings on the path. The level computed with the simple suburban propagation model (see annex B) gives -74 dBm/10 MHz.

The point of interest 4 is located at 512 m from the train antenna and the received level is -91 dBm/10 MHz. The vehicles are in the back-lobe of the train antennas. The train antennas gain is -6 dB. This is a non-Line of Sight propagation. There are buildings on the path. The level computed with the simple urban model (see annex B) is between -89 dBm when a window loss (lateral windows of the train) if 3 dB is considered.

It seems that for the train at position 3 and rear cab, it is possible to estimate the limit of coverage with the simple suburban model (see annex B), but this will be considered with caution. Measurements will be compared with simulations of propagation taking into account the environment.

8.2.3.2.2.5 Received level from vehicles by Train at position 3 front cab

Figure 60 shows the level received by the Train RF at position 3 by the front cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

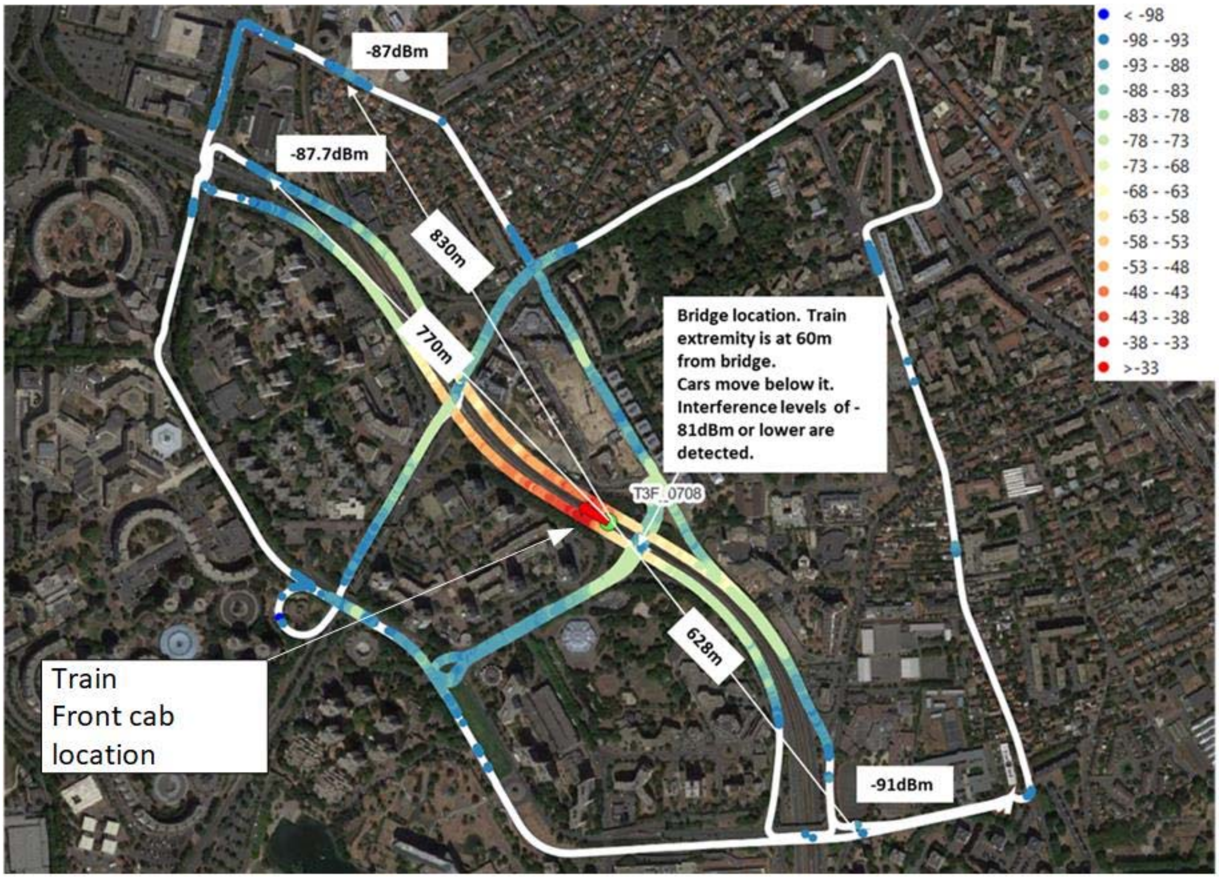

Figure 60: Line 8 section 2-3 level received from two vehicles by the Train front cab at position 3 (Map Source Google Earth: © Google)

The train was located on the bridge with the tracks above the roads. The train front cab was located at 60 m from the bridge.

What is important is to observe that the level received by the RF tool installed in the train front cab from the vehicles driving below the bridge is around -81 dBm/10 MHz. The transmission of the vehicles driving below the bridge are received via the back-lobe of the train antenna.

8.2.3.2.2.6 Received level from vehicles by Train at position 4 rear cab

The rear cab of the train was located on the bridge with the vehicles driving below this one.

The measurements performed with the train at position 4 covers the scenarios 1, 5, 6 and 7.

Figure 61 shows the level received by the Train RF at position 4 rear cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

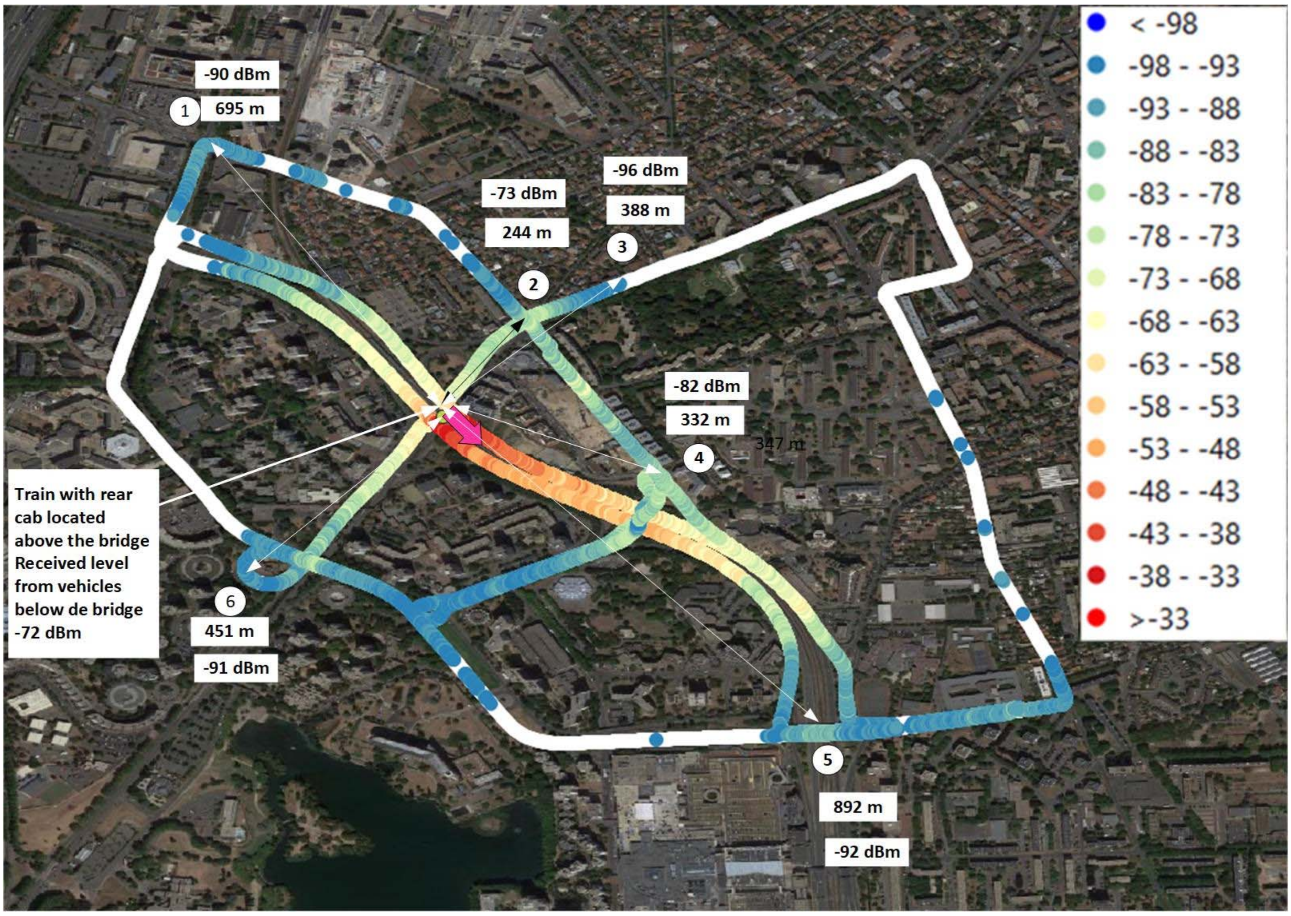

Figure 61: Line 8 section 2-3 level received from two vehicles by the Train rear cab at position 4 (Map Source Google Earth: © Google)

For all the points of interest (1 to 6), point of interest 2 excepted, the propagation is non-Line of Sight. Point of interest 1 is in the back-lode of the train antenna and the point of interest 5 is in the main-lobe of the train antenna.

The point of interest 2 is located at 244 m from the train antenna on crossing road. This is a Line-of-sight propagation, the path is perpendicular to the train antenna. The received level is -73 dBm/10 MHz.

The level received by the RF tool installed inside the train by the vehicles driving under the bridge is -72 dBm/10 MHz. This is a significant level despite that signal is received with the back-lobe of the train antenna.

8.2.3.2.2.7 Received level from vehicles by Train at position 4 front cab

The train was located with its rear cab on the bridge. The measurements performed with the train at position 4 covers the scenarios 1, 5, 6 and 7.

The measurements performed with the train at position 4 covers the scenarios 1, 5, 6 and 7.

Figure 62 shows the level received by the Train RF at position 4 front cab from the two vehicles transmitting packets at an EIRP: 33 dBm/10 MHz.

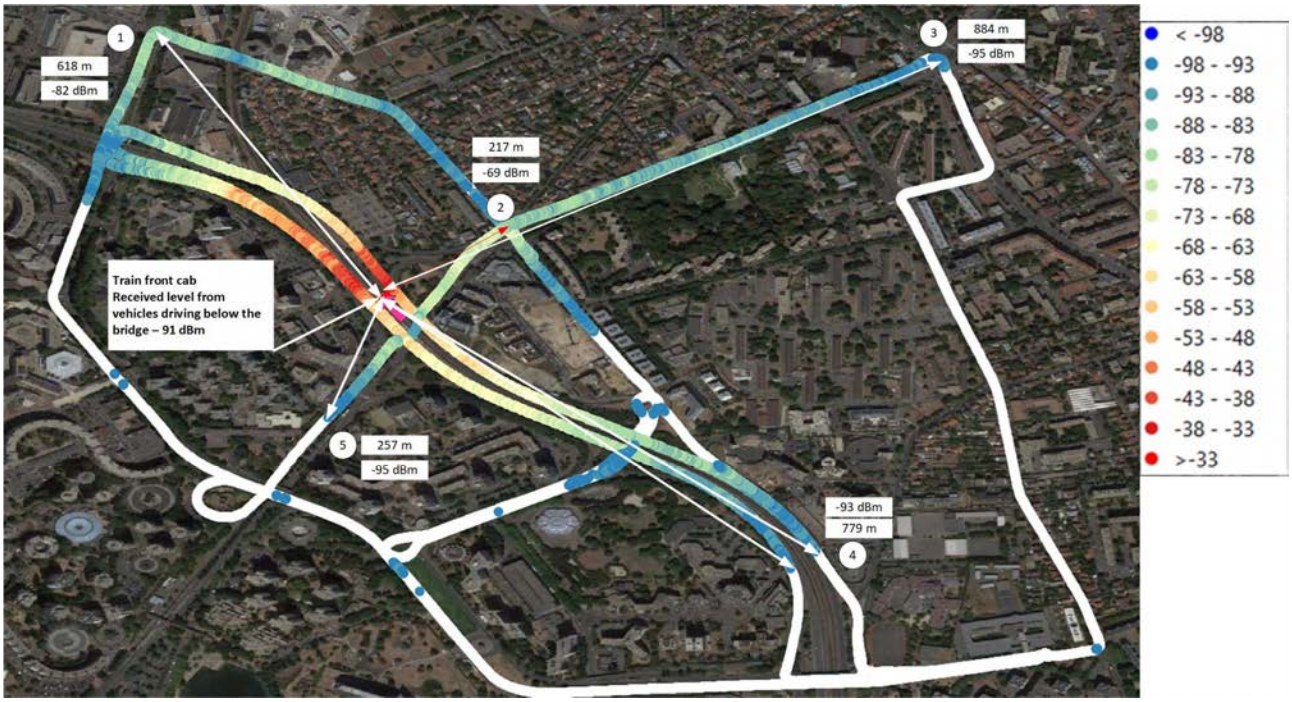

Figure 62: Line 8 section 2-3 level received from two vehicles by the Train front cab at position 4 (Map Source Google Earth: © Google)

The train front cab received a level of -92 dBm/10 MHz via its back-lobe from the vehicles driving below the bridge.

For all the points of interest, 2 and 3 excepted, the propagation is non-Line of Sight.

At the point of interest 1 the received located at 618 m from the train antenna, in the main lobe of this one, the received level is -82 dBm/10 MHz.

The point of interest 2 is located at 217 m from the train antenna in its side lobe, the path is nearly perpendicular. The received level is -69 dBm/10 MHz. This is a Line-of-sight propagation.

The point of interest 3 is located at 884 m from the train antenna and is also in the side lobe in Line-of-Sight condition of propagation. The received level is -95 dBm/10 MHz to be compared with point of interest 5 where the received level is also -95 dBm/10 MHz but at a distance of 257 m.

The point of interest 4 located at 779 m, the received level is -93 dBm/10 MHz in non-Line of Sight condition of propagation via the train antenna back-lobe.

8.2.3.2.2.8 Received level from vehicles by Base station at position 1

Figure 63 shows the level received by the Base station at position 1 from the two vehicles transmitting packets at 33 dBm/10 MHz.

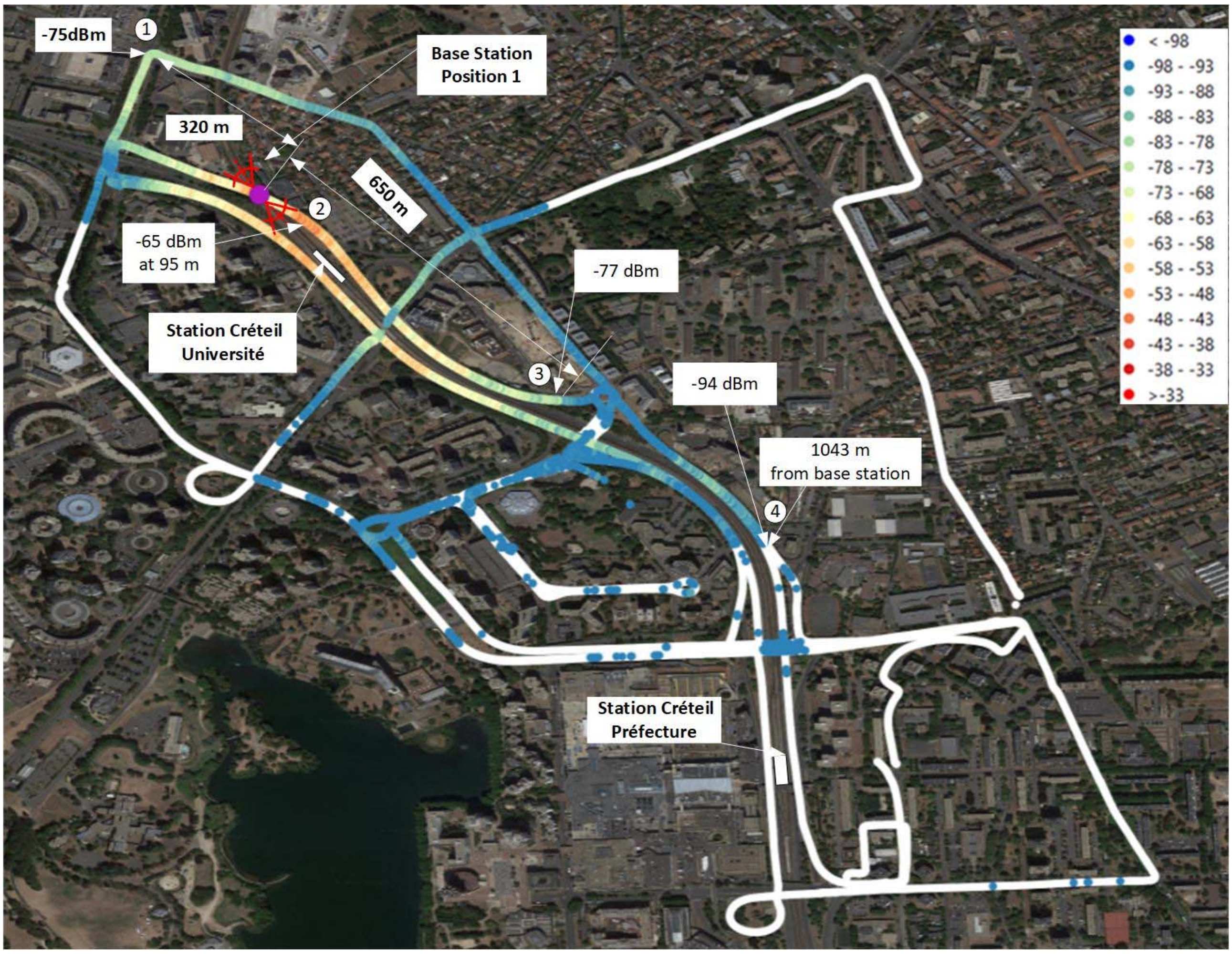

Figure 63: Line 8 section 2-3 level received from two vehicles by base station at position 1 (Map Source Google Earth: © Google)

The measurement performed with the base station at position 1 covers the scenarios 1, 5 and 7.

The levels on the figures are in dBm/10 MHz.

The base station at position 1 was located at 150 m from the extremity of the metro station Créteil-Université. The antennas of the Base station are at a height of 5 m above the ground.

The point of interest 1 is located at 320 m from the base station at position 1 and is behind a building. The packet transmitted by the vehicles at point of interest 1 are received with a level around - 75 dBm/10 MHz, in the main lobe of the base station antenna. In the path between the point of interest 1 and the base station there are buildings that create shadowing.

The point of interest 2 is located at around 95 m from the base station. The level received from the vehicles is around -65 dBm/10 MHz. This level is relatively low compared to a simple computation based on Friis space loss that gives a value of -44 dBm/10 MHz or a simple urban rail model (see annex B) that gives -50 dBm/10 MHz. A strong impact of the environment can be the explanation. A difference of level between the roads and the tracks and the presence of road signs on the path.

The point of interest 3 is in the main lobe of the base station antenna at 650 m from this one. The average level is around -77 dBm/10 MHz. At this distance the level obtained with a simple urban propagation model (see annex B) gives - 91 dBm/10 MHz and the level obtained by a sub urban propagation modem gives -76 dBm/10 MHz.

It has to be noted that level received by the base station from vehicles located point of interest 1, 2 and 3 are above the interference level accepted by the CBTC system.

The limit of coverage is reached at point of interest 4 located at 1 043 m from the base station where the received level from the vehicles is -94 dBm/10 MHz. The packets transmitted by the vehicles are received by the main lobe of the base station antenna but there are buildings present on the path. This is a non-Line of Sight propagation.

It seems not possible to rely on simple propagation model (see annex B) to estimate the limits of interference area.

8.2.3.2.2.9 Received level from vehicles by Base station at position 2

Figure 64 shows the level received by the Base station at position 2 from the two vehicles transmitting packets at 33 dBm/10 MHz.

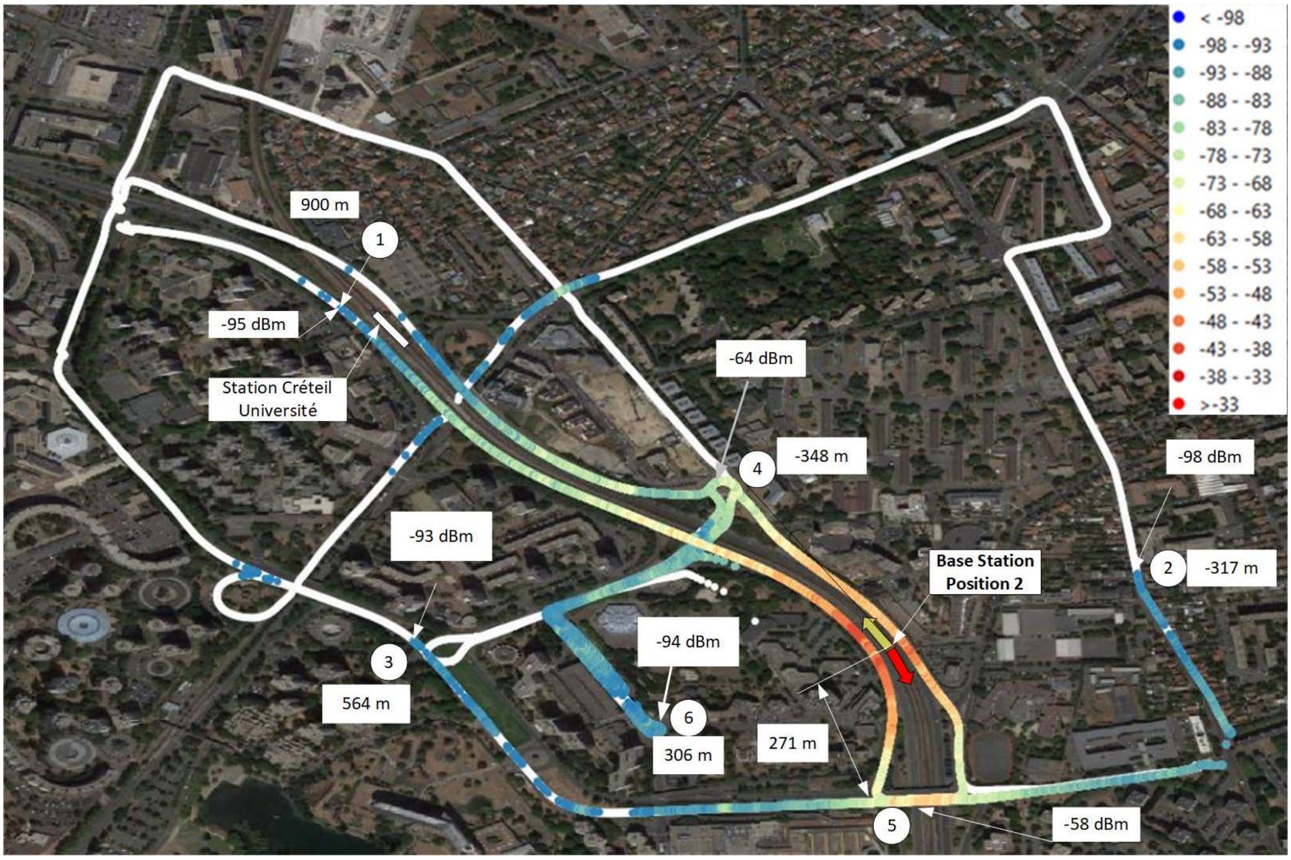

Figure 64: Line 8 section 2-3 level received from two vehicles by base station at position 2 (Map Source Google Earth: © Google)

The measurement performed with the base station at position 1 covers the scenarios 1, 5 and 7.

The level on Figure 64 are in dBm/10 MHz.

The base station at position 2 is located in the middle of a curve at 503 m from the end of the station Créteil-Préfecture. The antennas of the base station are at 5 m above the ground.

On Figure 64, the locations identified with a number in a white circle are point of interest that indicate the limits of radio coverage. Table 25 gives information about each point of interest.

Table 25: Section 2-3 of Line 8 points of interest analysis for base station position 1 and 2

Point of interest number	Description
1 (edge of coverage for the receiver)	This point of interest is located at 900 m from the base station. The level received by this one from vehicles at this location is around -95 dBm/10 MHz. The vehicles are in the main lobe of the base station antenna. On the path between this location and the base station antenna there are buildings. The level computed at the base station reference point for a vehicle EIRP of 33 dBm/10 MHz with a simple urban propagation model (see annex B) is -100 dBm/10 MHz and for the simple suburban propagation model, it is -84 dBm/10 MHz
2 (edge of coverage for the receiver)	The point of interest 2 is at 317 m of the base station. The packets transmitted by the vehicles are received with a level of -98 dBm/10 MHz. The packets transmitted by the vehicles are received under an angle of 83° from the axis of the antenna pointing to the station Créteil Université (red on figure 64) and 117° from the axis of the other antenna. The gain at these angles of the base station antenna system is between -5 dB and -7 dB. No simple propagation model (see annex B) provides a value close to the -98 dBm/10 MHz. On the path there are buildings. This a non-Line of Sight propagation.
3	The point of interest is located at 564 m from the base station at the received level is -93 dBm/10 MHz. The conclusion is similar to the one of previous point of interest. No simple propagation model (see annex B) provides a value close to -93 dBm/10 MHz. On the path there are buildings. This is not a Line-of-sight propagation.
4	The point of interest 4 is located at 348 m from the base station antenna and in its main lobe. The received level from the vehicles is -64 dBm/10 MHz. It is Line-of-sight propagation but with trees on the path. The level obtained at this location are -74 dBm/10 MHz for the simple urban propagation model (see annex B) and -60 dBm/10 MHz for the simple suburban propagation model.
5	This point of interest is on a bridge above the track at 271 m from the base station. The transmissions of the vehicles are received by the main lobe of the base station antenna pointing to the station Créteil-Préfecture (in red on figure 64). This a perfect Line-of-sight propagation. The level received by the base station from the vehicle is -58 dBm/10 MHz. The level received at base station reference point from the vehicle computed by the Friis propagation model is -53 dBm/10 MHz and -54 dBm by the simple suburban propagation model. The simple urban propagation modem gives a level of -67 dBm/10 MHz.
6	The point of interest 6 is located at 306 m from the base station. The level received from the vehicle is around -94 dBm/10 MHz. The arrival angle is around 90° from the axis of the two antennas of the base station. There are a set of buildings on the path, this not a Line-of-sight propagation. No simple propagation model provides a value close to -94 dBm/10 MHz.

8.2.3.2.2.10 Received level from vehicles by Base station at position 3

Figure 65 shows the level received by the base station at position 3 from the two vehicles transmitting packets at 33 dBm/10 MHz.

Figure 65: Line 8 section 2-3 level received from two vehicles by base station at position 3 (Map Source Google Earth: © Google)

The measurement performed with the base station at position 1 covers the scenarios 1, 5 and 7.

The levels on Figure 65 are in dBm/10 MHz.

The base station at position 3 was located at 40 m from the station Créteil-Préfecture.

The locations identified with a number in a white circle indicate the limit of radio coverage.

Table 26 and Table 27 give information about each location.

Table 26: Section 2-3 of Line 8 Points of interest analysis for base station 3 from 1 to 8

Point of interest number	Description
1 (edge of coverage for the receiver)	The first point of interest is located at 1 127 m from the base station, close to station Créteil Université. The level received from the vehicles is around -93 dBm/10 MHz. The vehicles at this location are a above the limit of the main lobe of the base station antenna. On the path there are several buildings. This is not a Line-of-sight propagation. No simple propagation model (see annex B) provides a level close enough to -93 dBm/10MHz.
2 (edge of coverage for the receiver)	The conclusion is similar to the point of interest 1. The distance is 759 m, the received level is -95 dBbm/10 MHz. There are building on the path and the vehicles are not in the main lobe.
3	This third point of interest is located at 771 m from the base station. The received level is -93 dBm/10 MHz. The vehicles are in the main lobe of the base station antenna. The simple urban propagation model (see annex B) gives a value of -96 dBm/10 MHz and the simple urban propagation mode gives a value of -81 dBm/10 MHz. This is a Line-of-sight propagation.
4	The point of interest 4 is located at 650 m and the received level is -83 dBm/10 MHz. The vehicles are in the main lobe of the base station antenna. There are buildings on the path but with low height. Levels obtained by the simple urban and suburban propagation model (see annex B) are respectively -91 dBm/10 MHz and -76 dBm/10 MHz.
5	This point of interest is located at 347 m from the base station. The level received is -88 dBm/10 MHz. The vehicles are in the main lobe of the base station antenna. There are buildings on the path. No simple propagation model (see annex B) provides a level close enough to the received level.
6 and 7 (edge of coverage for the receivers)	Points of interest 6 and 7 are located at 424 m and 430 m respectively. The received levels are -93 dBm/10 MHz for point 6 and -95 dBm/10 MHz for point 7 The arrival angles of TF signal from point of interest 6 and 7 are 73° from the axis of the base station antenna pointing to station Créteil-Université. The Gain of the base station antenna is around 0 dB for both paths, there are buildings present. No simple propagation model (see annex B) provides a value lose enough to -93 dBm/10 MHz or -95 dBm/10 MHz.
8	This point of interest is located at 442 m from the base station antenna. The received level is -92 dBm. The vehicles are in the main lobe of the base station antenna. There are buildings on the path. This is a non-Line of Sight propagation. No simple propagation model (see annex B) provides a value lose enough to -92 dBm/10 MHz.

Table 27: Section 2-3 of Line 8 Points of interest analysis for base station 9 and 10

Point of interest number	Description
9	The point of interest 9 is located on a bridge that cross the track at 342 m from the base station. The received level is -67 dBm/10 MHz. The vehicles are in the main lobe of the antenna pointing to the station Créteil-Préfecture. On the path there is the station Créteil-Préfecture. The antenna of the base station is pointing to the station Créteil Université. The level obtained with the free space loss propagation model (Friis formula) is -55 dBm/10 MHz, with the simple urban propagation model is -74 dBm and via the simple suburban propagation model (see annex B) is -60 dBm/10 MHz. It has to be noted that the vehicles were driving on the lane on the bridge that is farer from the base station antenna.
10	This last point of interest is located at 189 m from the antenna pointing to Créteil Université. The received level is -49 dBm/10 MHz. The vehicles are driving on the bridge and are in the main lobe of the antenna. The level computed via the Friis formula gives a value of -50 dBm/10 MHz.

8.2.3.2.3 Summary L8 section 2-3

The measurements performed on section 2-3 have covered the scenarios 1, 5, 6 and 7.

The measurements performed on the section 2-3 of Line 8 with trains at 4 locations with front and rear cab and base stations at three locations confirm what has been discovered with the simulation: levels received from vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]) on parallel roads, on bridge above or below the tracks and in different areas in the surrounding of the Line are above the defined protection levels of the CBTC communications.

It has been observed that vehicles are received over a relative long distance via the back lobe of train antenna in non-Line of Sight propagation condition: up to 500 m for received level of -83 dBm/10 MHz.

For the train, the longest observed distance in non-Line of Sight condition of propagation with vehicles in the main lobe is 1 088 m.

When vehicles are driving below a bridge with a train antenna above this one, levels are received up to -47 dBm/10 MHz. In this this is a non-Line of Sight propagation.

For the base station, the longest observed distance for non-Line of Sight propagation is 1 127 m.

All the mentioned distances for point of interest are between this one and the base station.

Over a distance of 400 m each side of the axis of the Line, the levels received from vehicles exceed the threshold defined in Table 2.

8.2.4 Measurement results summary

The measurements performed on the three sections of Line 6 and on the 3 sections of Line 8 with Trains and Base stations confirm what has been discovered with the simulations of propagation to identify these relevant areas: the levels received by trains and base stations from vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP driving on parallel roads, on bridge above or below the tracks and in different areas in the surrounding of a metro Line are above the defined protection level.

Specific considerations have to be taken when the train is located above or below a bridge.

It has been observed that vehicles are received over a relative long distance via the back lobe of train antenna in non-Line of Sight propagation condition: up to 500 m for received level up to -83 dBm/10 MHz.

On Line 6 for the section 3, the base stations have been deployed on a viaduct that is on the Bercy bridge over the Seine river. It has been observed that the level received by base stations from the vehicles driving on the two adjacent bridges located at a distance of 644 m and 743 m are above -70 dBm/10 MHz.

On Line 6, for section 1 with base stations installed on a viaduct, the level received from the vehicles driving on the parallel roads is of the same order of magnitude as if the tracks and parallel roads are at the same level.

For all sections of Line 6 and Line 8, it has been observed that in case of non-Line of Sight propagation the vehicles can be received up to a maximum distance of 1 127 m from the base station antenna.

As a preliminary estimation, based on visual inspection, it can be considered that for a suburban environment (Line 8) over a distance of around 400 m from each side of the axis of the Line, the received level from vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP is above the defined protection levels for CBTC communication. For an urban environment the distance is around 650 m.

8.3 Detailed analysis for some scenarios

8.3.1 Detailed measurements on parallel roads and perpendicular roads

8.3.1.1 Description of the scenarios

In this clause, a detailed analysis on selected scenarios is presented. A differentiation between the environments of Line 8 (sub-urban), Line 6 (deep urban) and the Bercy Bridge (open-field) is made, since the propagation conditions vary considerably, making otherwise a comparison and the drawing of conclusions difficult. In this regard, also a differentiation between the reception at a train and a base station is made. For every scenario, environment and receiver type, the interference level is quantified for vehicles moving either parallel to the tracks (meaning to the axis of the train or base station antenna) or perpendicular to these ones. In Figure 66, vehicle A is placed in an area parallel to the axis of the train antenna, whereas vehicle B is in the area perpendicular to this one.

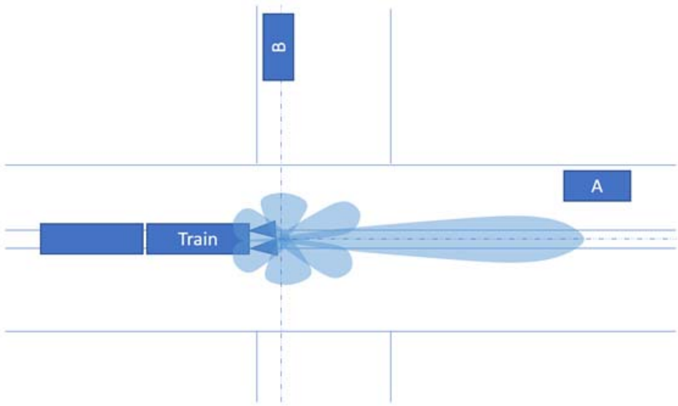

Figure 66: Identifications of scenarios parallel and perpendicular roads

Clause 8.3.1.2 briefly describes the measurement data processing and the subsequent clauses present the results on the interference levels that were measured for vehicles on parallel and perpendicular roads for different environments and receiver types.

8.3.1.2 Description of data processing method

For the evaluation the received levels measured during the field tests at the rx side (RF tool installed in Train or Base station), as well as the tx position of vehicle 1 and vehicle 2 have been used as inputs.

The tx positions have been up sampled and interpolated to match the tx rate and the received levels have been shifted to match a tx power of 33 dBm/10 MHz (see clause 8.1). For this present analysis, the tx positions have then been converted to a local east-north frame centred at the corresponding receiver.

The tx positions have been classified into parallel road and perpendicular road depending on their relative position to the rx antenna and the orientation of a Line drawn from the tx position to the position of the rx antenna (see Figure 67). Two conditions have to be met for the tx to be classified on a parallel road: the angle α between the Line and the antenna axis has to be lower than a certain threshold (typically ±17,5°) and the lateral distance d2 between the axis of the rx antenna main lobe and the vehicle has to be lower than another threshold (typically 40 m). For perpendicular road the previous definition is used by replacing the "axis of the rx antenna main lobe" with the "axis perpendicular to the axis of the rx antenna main lobe".

The results of the analysis are presented on figures composed of two plots. The first plots on the left side shows the tx positions and the second plot of the right side shows all the received levels at the rx antenna versus the rx-tx distance.

The parallel road tx positions have been marked in blue and the perpendicular road sections have been marked in red on the first plot. On the right plot, all received levels at the antenna versus rx-tx distance are marked with the same colours.

$$\tan(\alpha) = d2/d1$$

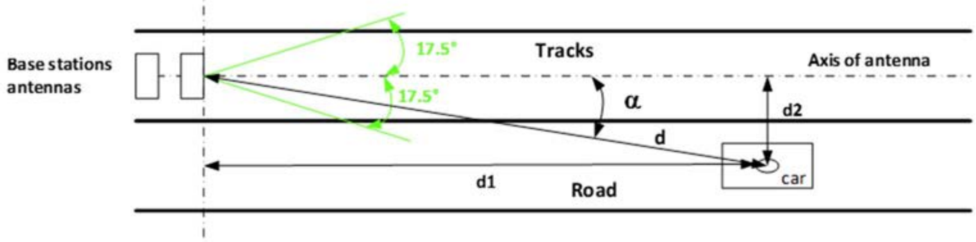

Figure 67: Parallel road selection of measurement methods

Figure 67 is a sketch showing the geometrical relationship between a vehicle and a base station antenna. α is the opening angle between the vehicle and the base station antenna axis, while d2 is the lateral distance between the vehicle and the base station antenna axis.

8.3.1.3 Selected Scenarios for Line 8 - Suburban environment

8.3.1.3.0 Introduction

In this clause, four train scenarios and two base station scenarios of Line 8 have been selected. For each, the relative position of tx to rx and the received level over distance is shown for parallel and perpendicular roads. Selected sections have been marked with letters in the plots and described in Table 28.

8.3.1.3.1 Train rear cab at position 1 on Line 8 section 2-3

The first considered train scenario for detailed analysis is the train at position 1 on Line 8 Section 2-3. The measurements have been performed with the rear cab and the RF source is vehicle 2.

For this scenario the Train is on highway-centred railroad with bridge above.

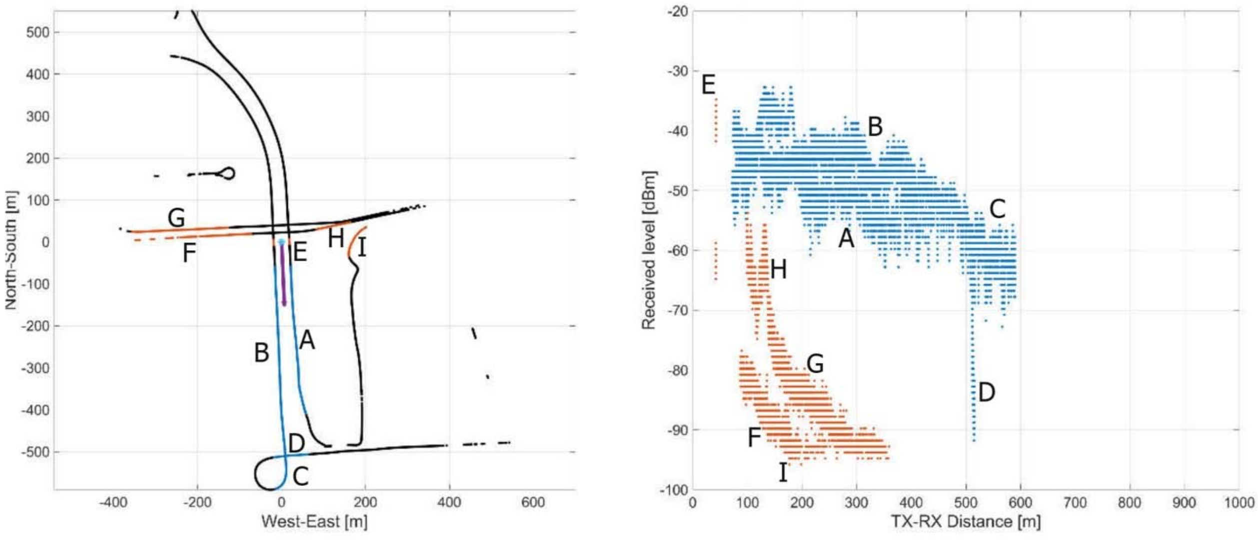

Figure 68: Train rear cab at position 1 on Line 8 Section 2-3

On Figure 68 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 28 shows the results of the analysis for the train rear cab at position 1 on Line 8 Section 2-3 with RF source vehicle 2.

Table 28: Results of analysis for Train rear cab at position 1 on Line 8 Section 2-3 with RF source vehicle 2

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	80/410	-37/-46	LoS	Same height on east highway
B	Parallel	80/600	-30/60	LoS	Same height on west highway
C	Parallel	500 to 600	-55	LoS below bridge	
D	Parallel	500	-60 to -90	Vegetation	
E	Perpendicular	42	-34 and -58	LoS	Overtaking on highway
F	Perpendicular	89/340	-76/-92	Bridge above	Vehicle on Bridge above train
G	Perpendicular	140/340	-70/-92	Bridge above	Vehicle on Bridge above train
H	Perpendicular	100/180	-53/-77	Bridge above	Vehicle on Bridge above train
I	Perpendicular	170	-85	Buildings and vegetation	

8.3.1.3.2 Train front cab at position 3 on Line 8 section 2-3 measurements with vehicle 1

The second considered train scenario for detailed analysis is for the train at position 3 for Line 8 Section 2-3. The measurements have been performed with the front cab with RF source vehicle 1.

The train on highway-centred railroad with road crossing below.

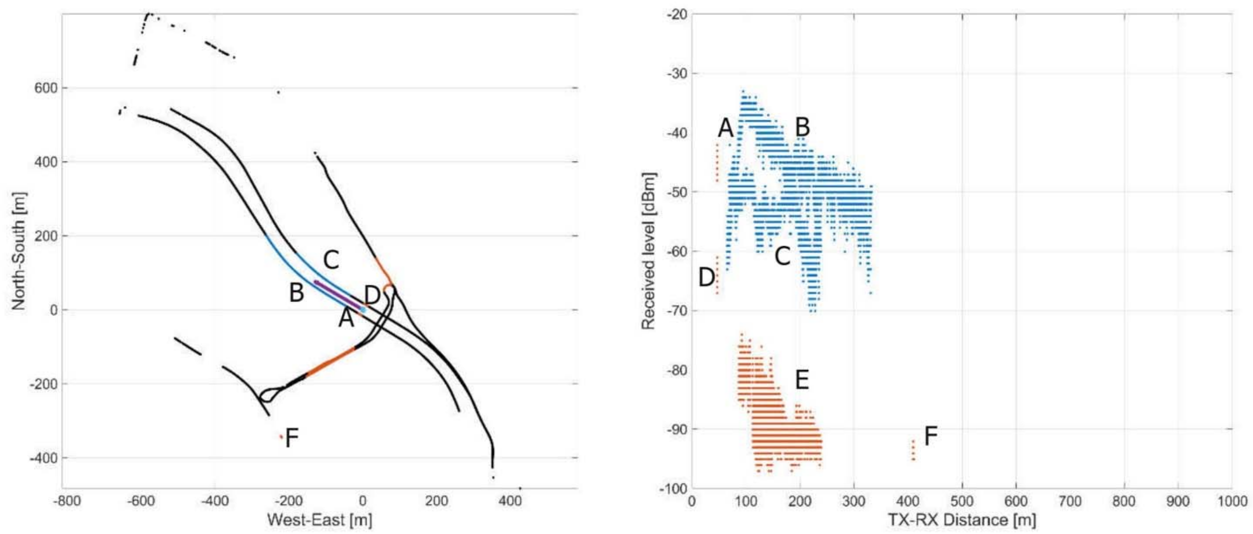

Figure 69: Train front cab at position 3 on Line 8 section 2-3 with RF source vehicle 1

On Figure 69 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 29 shows the results of the analysis for the train front cab at position 3 on Line 8 Section 2-3.

Table 29: Results of analysis for train front cab at position 3 on Line 8 section 2-3 with RF source vehicle 1

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	65/95	-56/-33	LoS	Same level
B	Parallel	95/330	-33/-48	LoS	Same level
C	Parallel	70/235	-46/-54	LoS	Less rx signal due to bended highway shape
D	Perpendicular	45	-41/ -61	LoS	Overtaking at highway
E	Perpendicular	85/240	-75/-90	Vegetation	Vehicle below train
F	Perpendicular	400	-92	Buildings/vegetation	Short LoS visibility (between buildings)

8.3.1.3.3 Train front cab at position 3 on Line 8 section 2-3 measurements with vehicle 2

The third considered train scenario for detailed analysis is train at position 3 on Line 8 Section 2-3 Train. The measurements have been performed with the front cab with RF source vehicle 2.

This is the same scenario as the previous one, but with vehicle 2 as RF source. The antenna heigh of vehicle 1 (a Van) is 3,2 m and the antenna height of vehicle 2 (a SUV) is 2,5 m.

The train is on highway-centred railroad with road crossing below.

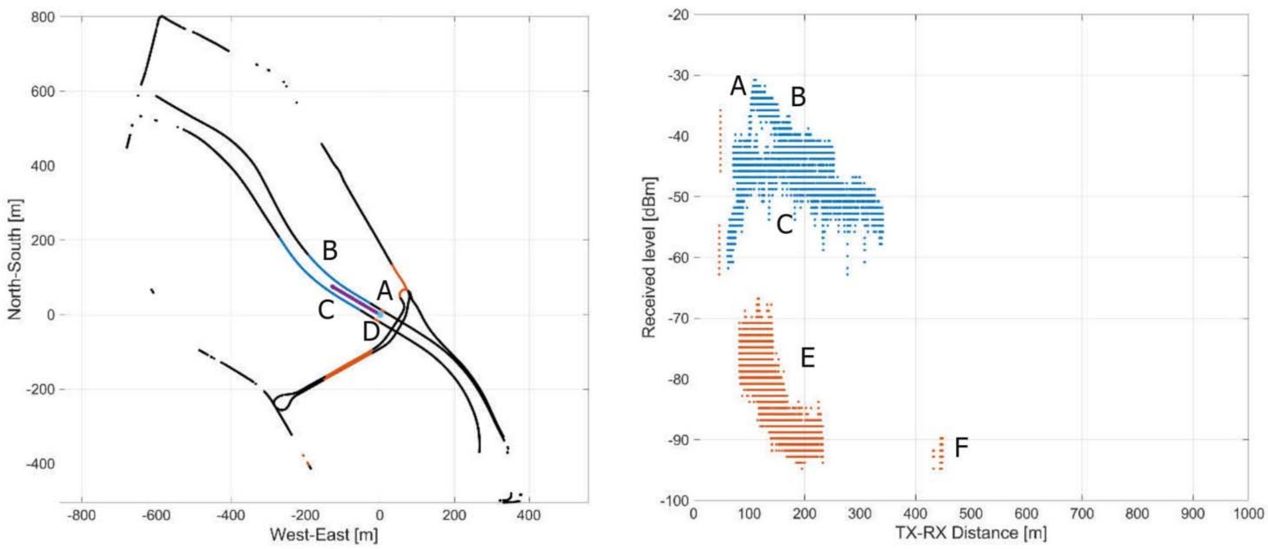

Figure 70: Train front cab at position 3 on Line 8 section 2-3 with RF source vehicle 2

For Figure 70 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 30 shows the results of the analysis for the train front cab at position 3 on Line 8 Section 2-3.

Table 30: Results of analysis for train front cab at position 3 on Line 8 section 2-3 with RF source vehicle 2

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	65/110	-55/-30	LoS	North-highway: Same level
B	Parallel	110/250	-30/-41	LoS	North-highway: Same level
C	Parallel	75/340	-39/-51	LoS	South- highway: less rx signal due to bended highway shape
D	Perpendicular	45	-35/-54	LoS	Overtaking at highway
E	Perpendicular	85/230	-70/-85	Vegetation	Vehicle below train
F	Perpendicular	450	-90	Buildings/vegetation	Short LoS visibility (between buildings)

When driving on the highway vehicle 2 produces 3 dB higher interference. The perpendicular interference from vehicles driving on the highway is +6 dB higher for vehicle 2.

8.3.1.3.4 Train front cab at position 4 on Line 8 section 2-3

The fourth considered train scenario for detailed analysis is train at position 4 on Line 8 section 2-3. The measurements have been performed front cab with vehicle 2 as RF source.

The Train is on highway-centred rail and vehicles in suburban area below tracks.

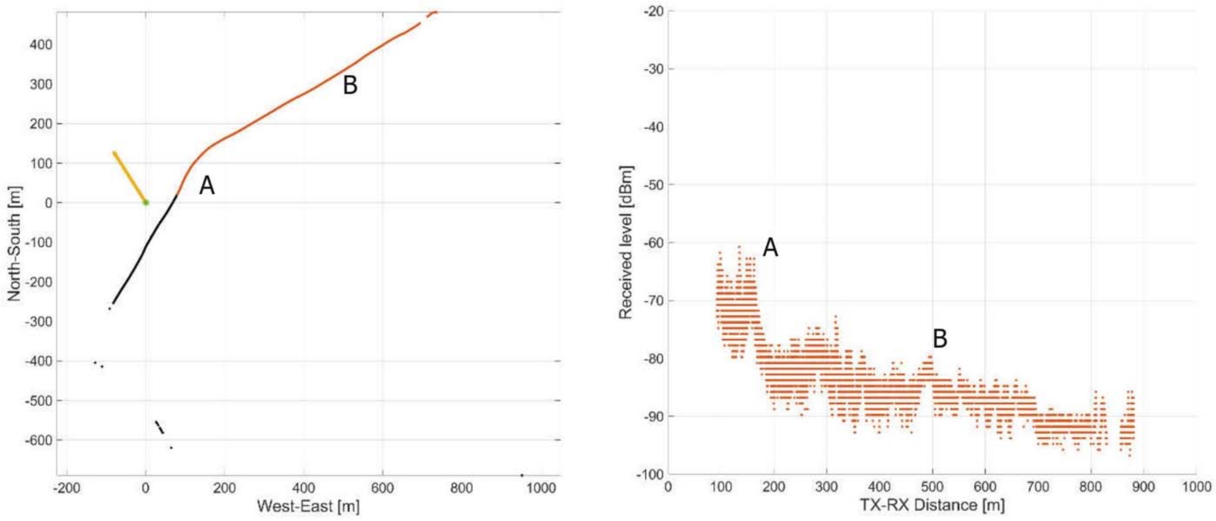

Figure 71: Train front cab at position 4 on Line 8 section 2-3 with RF source vehicle 2

Figure 71 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being perpendicular road (red).

Table 31 shows the results of the analysis for the train front cab at position 4 on Line 8 section 2-3.

Table 31: Results of analysis for train front cab at position 4 on Line 8 section 2-3 with RF source vehicle 2

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Perpendicular	100/160	-62	Vegetation	Train above vehicles
B	Perpendicular	200/870	-77/-85	Vegetation	Road to north-east is an alley with thick foliage

8.3.1.3.5 Base station at position 1 on Line 8 section 2-3

The first considered base station scenario is the base station at position 1 on Line 8 section 1. The measurements have been performed with the vehicle 2 as RF source.

The Base station has been installed in the middle of a curve in suburban area.

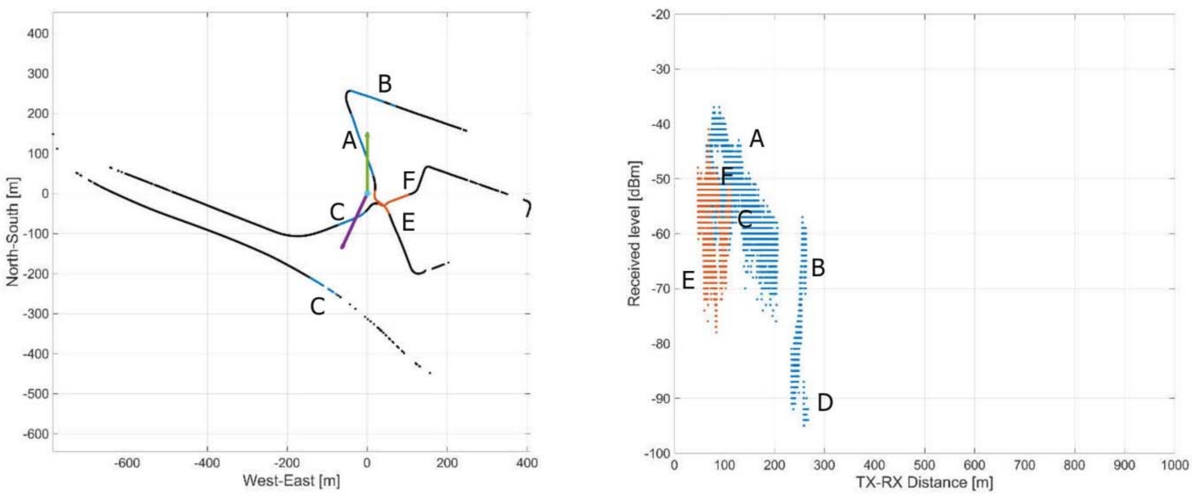

Figure 72: Base station at position 1 on Line 8 section 1 with vehicle 2 as RF source

On Figure 72 left side, tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 32 shows the results of the analysis for Base station at position 1 on Line 8 section 1.

Table 32: Results of analysis for Base station 1 on Line 8 section 1 with vehicle 2 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	80/205	-37/-58	LoS	Base station on rails higher than road.
B	Parallel	250	-56	LoS	Vehicle about to turn behind concrete bridge.
C	Parallel	65/110	-45/-50	LoS	
D	Parallel	260	-87	Vegetation	Nearby highway.
E	Perpendicular	45/85	-48/-70	LoS after vegetation/office building blockage	
F	Perpendicular	60/110	-50/-52	LoS	

8.3.1.3.6 Base station at position 3 on Line 8 section 2-3

The second considered base station scenario is for the base station at position 3 for Line 8 Section 2-3. The measurements have been performed with vehicle 1 as RF source.

The tracks have two roads with two lanes on each side.

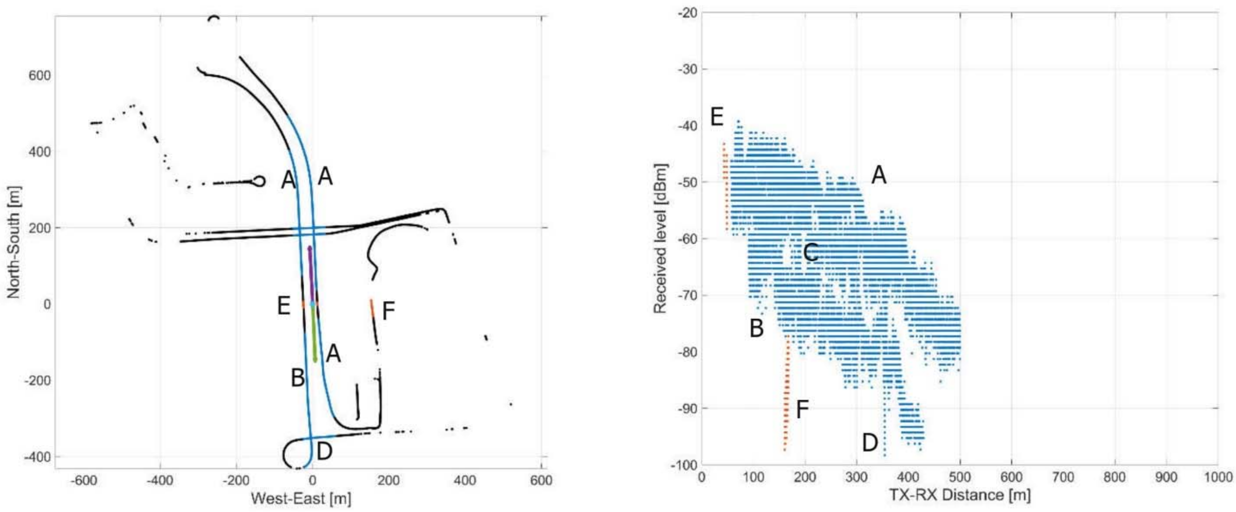

Figure 73: Base station at position 3 on Line 8 section 2-3 with vehicle 1 as RF source

On Figure 73 left side, tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Figure 74 shows the environment around the base station.

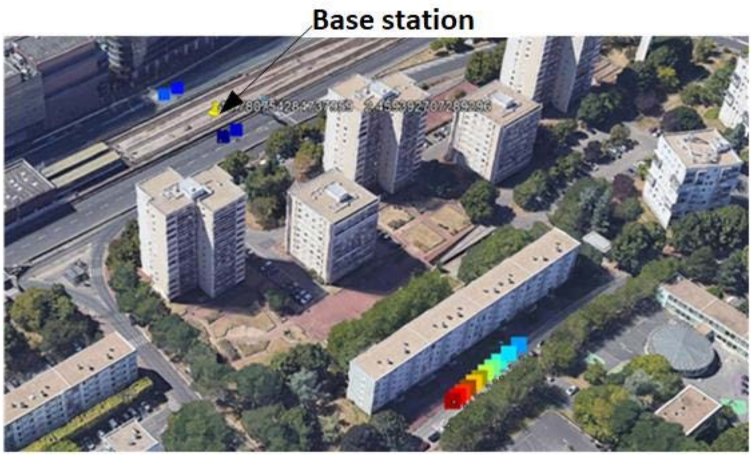

Figure 74: Environment around the base station, Buildings blocking the LoS to the base station (Map Source Google Earth: © Google)

Table 33 shows the results of the analysis for Base station at position 3 on Line 8 section 2-3.

Table 33: Results of analysis for Base station 3 on Line 8 section 2-3

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	70/500	-40/-72	LoS	Highway: east and north-west
B	Parallel	150/420	-62/-90	Obstruction Créteil station	Highway: south-west
C	Parallel	200	-47	LoS	Bridge in main lobe
D	Parallel	350	-62	Obstruction Créteil station	Bridge in main lobe
E	Perpendicular	45	-45	LoS	Highway next to base station
F	Perpendicular	165	-80	Building (6)	

8.3.1.4 Selected Scenarios for Line 6 - Urban environment

8.3.1.4.0 Introduction

Seven scenarios have been selected for the detailed analysis of scenarios for Line 6.

On Line 6, all the measurements have been performed with base stations installed along the tracks. Train have been simulated by adjusting the antennas height above the ground at 3,5 m and real base station with the antenna height at 5 m. For each analysis, the configuration of the base station antenna will be indicated.

8.3.1.4.1 Base station configured as train at position 1 on Line 6 section 1

The first considered scenario for detailed analysis is the base station configured to simulate a train at position 1 on Line 6 section 1. The analysis has been made with level received from vehicle 2.

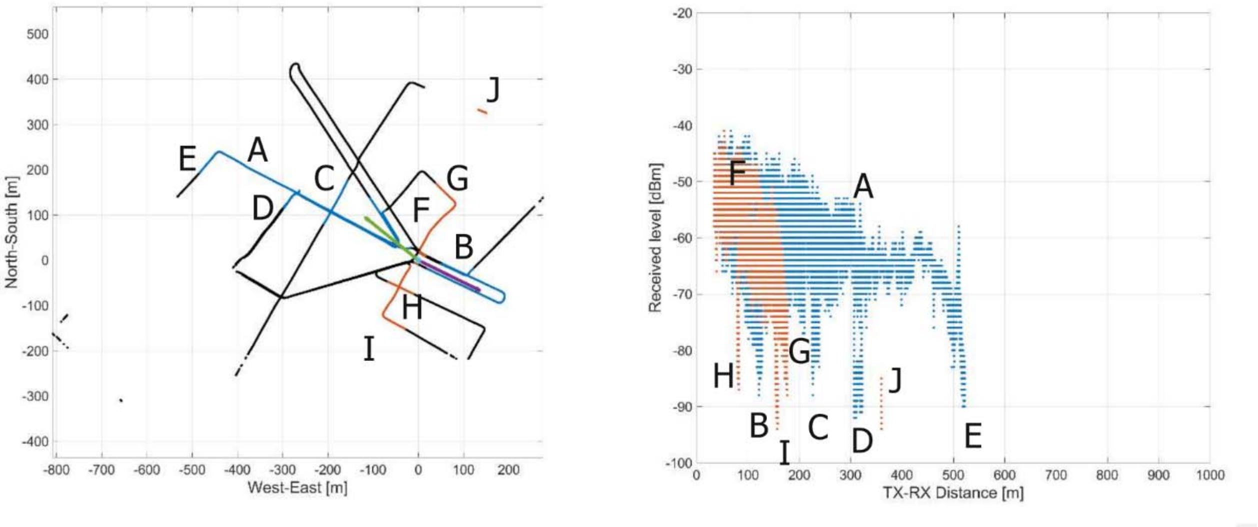

Figure 75: Base station configured as train at position 1 on Line 6 Section 1 with vehicle 2 as RF source

On Figure 75 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 34 shows the results of the analysis for Base station configured at position 1 on Line 6 section 1 with vehicle 2 as RF source.

Table 34: Results of analysis for Base station configured as train at position 1 on Line 6 section 1

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	50/510	-43/-57	LoS	Urban canyon
B	Parallel	110	-67	Obstruction building	Turn behind building (8 st.)
C	Parallel	238	-68	Obstruction building	Perpendicular drive behind building (10 st.)
D	Parallel	315	-81	Obstruction building	Turn behind building (8 st.)
E	Parallel	510	-78	Obstruction building	Turn behind building (8 st.)
F	Perpendicular	55/165	-42/-60	LoS	Urban canyon
G	Perpendicular	165/175	-60/-71	Obstruction building	Turn behind building
H	Perpendicular	80	20 dB drop wrt LoS	Obstruction building	buildings (4-8 st.)
I	Perpendicular	155	20 dB drop wrt LoS	Obstruction building	buildings (4-8 st.)
J	Perpendicular	350	-85	Obstruction building	LoS obstructed by 4 to 6 Lines of 6-9 storey buildings

8.3.1.4.2 Base station configured as train at position 3 on Line 6 section 1

The second considered scenario for detailed analysis is the base station configured as train at position 3 on Line 6 section 1. The analysis has been made with level received from vehicle 2.

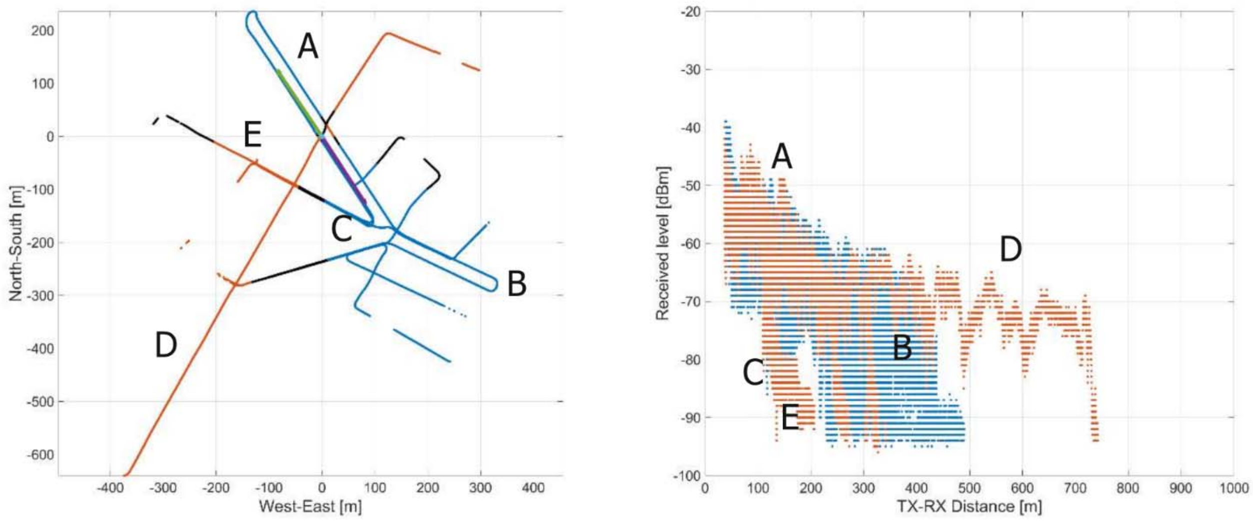

Figure 76: Base station configured as train at position 3 on Line 6 section 1 with vehicle 2 as RF source

For Figure 76: Left: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 35 shows the results of the analysis for Base station configured as train at position 3 on Line 6 section 1.

Table 35: Results of analysis for Base station configured as train at position 3 on Line 6 section 1

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	41/330	-40/-63	Viaduct	Urban canyon. Train on viaduct
B	Parallel	330/430	-63/-77	Viaduct, buildings	Bended urban canyon. Train on viaduct
C	Parallel	125	-74	Buildings	Building on parallel street (14 st.)
D	Perpendicular	36/718	-39/-69	LoS	Perpendicular street
E	Perpendicular	132/287	-75/-82	Line of buildings	Parallel street. 2 Lines of buildings (15-20 st.)

8.3.1.4.3 Base station configured as train at position 2 on Line 6 section 2 measurements with vehicle 1

The third considered scenario for detailed analysis is the base station configured as train at position 2 on Line 6 section 2. The analysis has been made with level received from vehicle 1.

The fourth scenario is the same as the third scenario but with the vehicle 1 as RF source.

For this analysis the angle alpha = ±17,5° and d2 = 100 m.

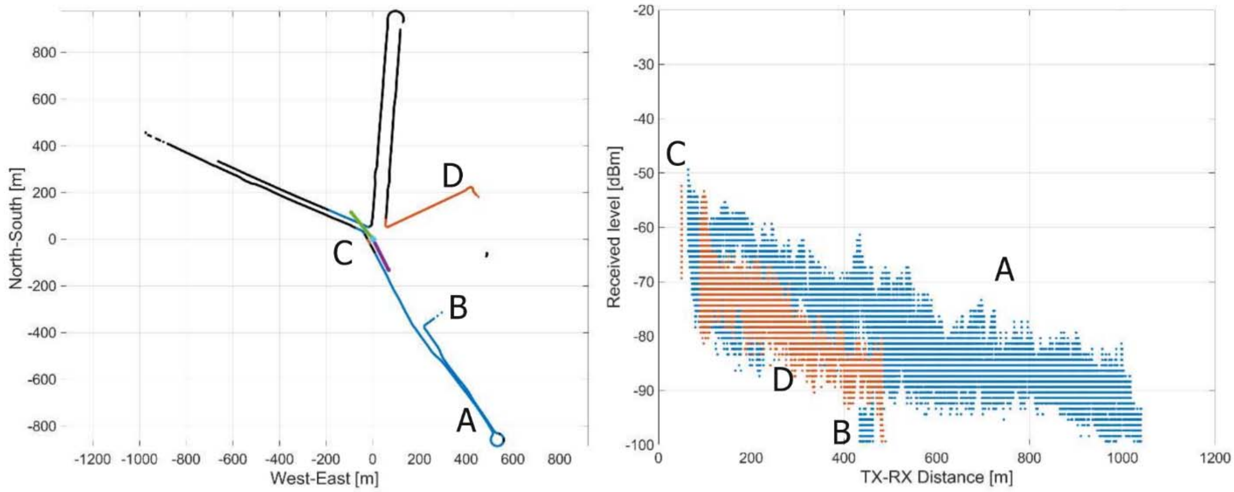

Figure 77: Base station configured as train at position 2 on Line 6 section 2 with vehicle 1 as RF source

On figure 77 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 36 shows the results of the analysis for Base station configured as train at position 2 on Line 6 section 2 with vehicle 2 as RF source.

Table 36: Results of analysis for Base station configured as train at position 2 on Line 6 section 2 with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	60/1 010	-50/-88	LoS with foliage from trees	Train on viaduct inside urban canyon.
B	Parallel	450	-95	Buildings	Turn into a perpendicular street. Buildings (8 st.).
C	Perpendicular	49	-53	Viaduct	Drive by train.
D	Perpendicular	100/480	-54/-81	LoS	Urban canyon.

8.3.1.4.4 Base station configured as train at position 2 on Line 6 section 1 measurement with vehicle 2

The fourth considered scenario for detailed analysis is the base station (antenna height 5 m) at position 2 on Line 6 section 1. The analysis has been made with level received from vehicle 2.

For this analysis the angle alpha = ±17,5° and d2 = 100 m.

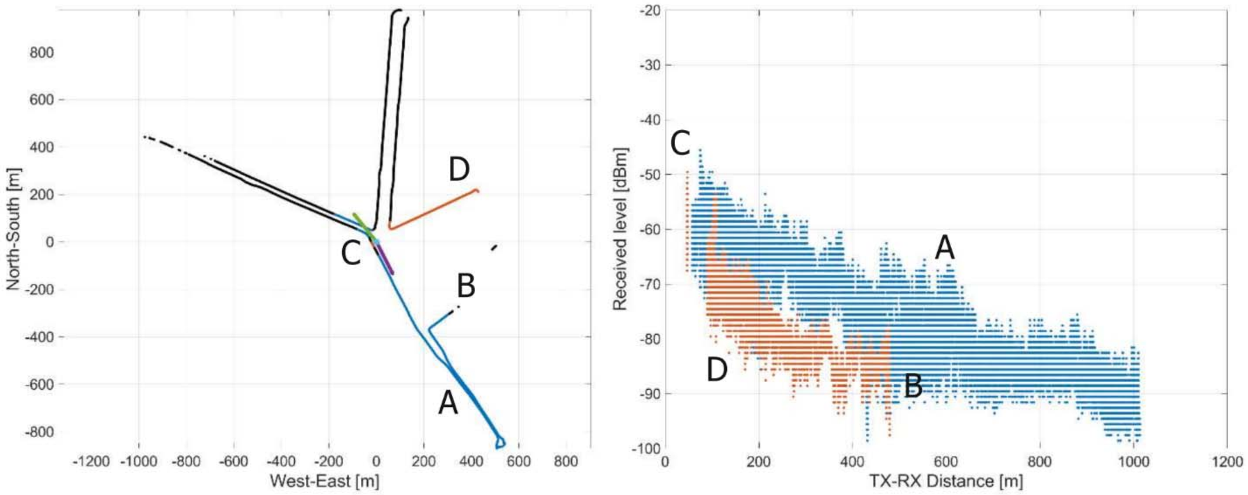

Figure 78: Base station at position 2 on Line 6 section 1 with vehicle 2 as RF source

For Figure 78 left side, tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 37 shows the results of the analysis for Base station (antenna height 5 m) on Line 6 section 1 with vehicle 1 as RF source.

Table 37: Results of analysis for Base station at position 2 on Line 6 section 1 with vehicle 2 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	60/1 010	-50/-83	LoS with foliage from trees	Train on viaduct inside urban canyon.
B	Parallel	450	-87	Buildings	Turn into a perpendicular street. Buildings (8 st.)
C	Perpendicular	46	-51	Viaduct	Drive by train.
D	Perpendicular	100/480	-54/-78	LoS	Urban canyon.

8.3.1.4.5 Base station configured as train at position 2 on Line 6 section 2 focus on perpendicular road

The fifth considered scenario for detailed analysis is the base station configured as train at position 2 on Line 6 section 2. The analysis has been made with level received from vehicle 1.

For this analysis the angle alpha = ±17,5° and d2 = 100 m.

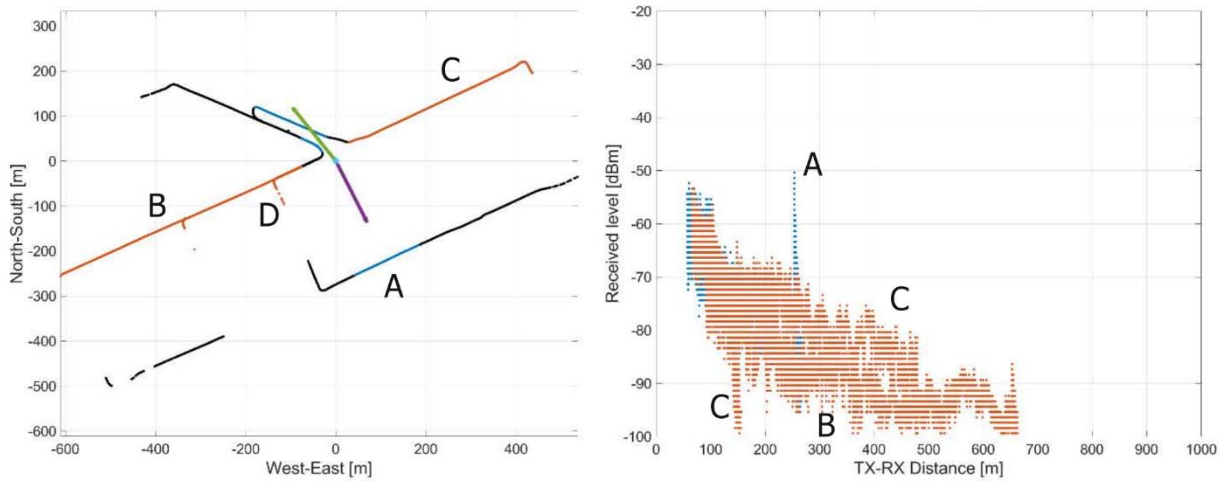

Figure 79: Base station configured as train at position 2 on Line 6 section 2 with vehicle 1 as RF source

On Figure 79 left side: the tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 38 shows the results of the analysis for Base station configured as train at position 2 on Line 6 section 2 with the vehicle 1 as RF source.

Table 38: Results of analysis for Base station configured as train at position 2 on Line 6 section 2 with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	250/270	-51/-80	LoS / Buildings	Train antenna higher that vehicle. Tunnel entrance below vehicle
B	Perpendicular	66/650	-54/-88	LoS	Road to the south-west
C	Perpendicular	66/480	-54/-82	LoS	Road to the north-east
D	Perpendicular	150	-86	Buildings	Drive into perpendicular road behind buildings (8 st.)

8.3.1.4.6 Base station at position 2 on Line 6 section 2

The sixth considered scenario for detailed analysis is the base station (antenna height 5 m) at position 2 on Line 6 section 1. The analysis has been made with level received from vehicle 1.

For this analysis the angle alpha = ±17,5° and d2 = 40 m.

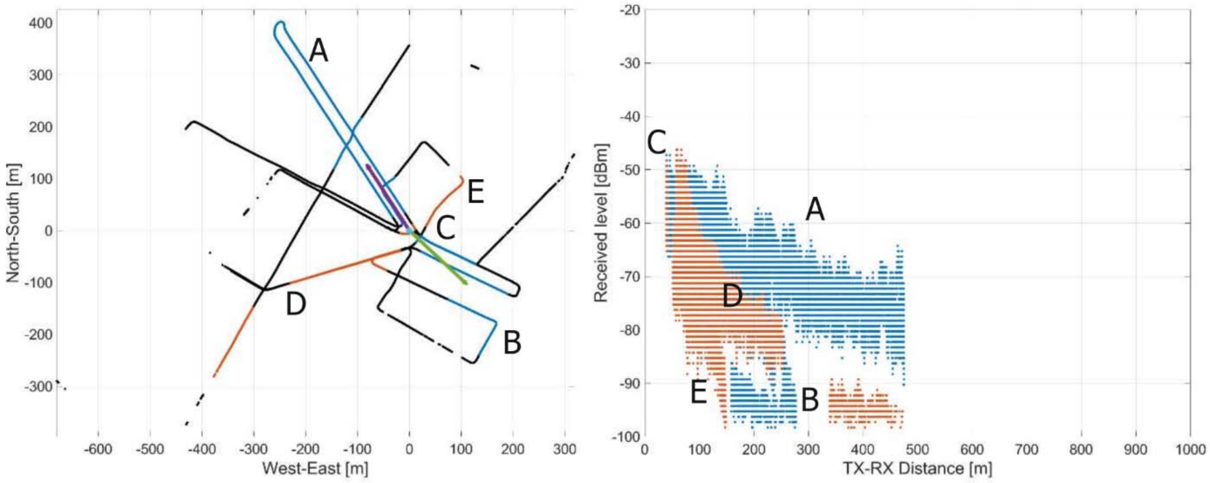

Figure 80: Base station at position 2 on Line 6 section 1 with vehicle 1 as RF source

On Figure 80 left side, the tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 39 shows the results of the analysis for Base station at position 2 on Line 6 section 1 with the vehicle 1 as RF source.

Table 39: Results of analysis for Base station at position 2 on Line 6 section 1 with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	45/470	-50/-66	Los on Viaduct	Base station on viaduct above vehicles.
B	Parallel	160/270	-89	Buildings	Los-Blockage by two blocks of buildings (8-10)
C	Perpendicular	40	-50	LoS/Viaduct	Vehicle below base station.
D	Perpendicular	55/460	-46/-95	Obstructed-LoS Buildings	Urban canyon.
E	Perpendicular	54/146	-62/-88	Buildings	Urban canyon.

8.3.1.4.7 Base station at position 1 on Line 6 section 2

The seventh considered scenario for detailed analysis is the base station (antenna height 5 m) at position 1 on Line 6 section 2. The analysis has been made with level received from vehicle 1.

For the analysis of this scenario, the maximum distance d2 (see figure 67) has been increased to 100 m.

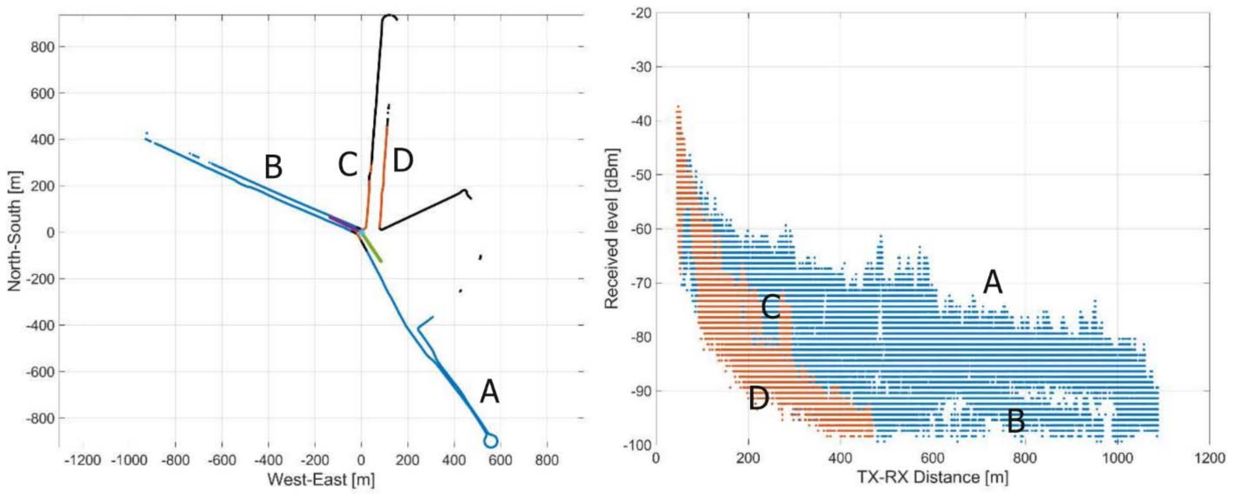

Figure 81: Base station at position 1 on Line 6 section 2 with vehicle 1 as RF source

On Figure 81 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 40 shows the results of the analysis for Base station at position 1 on Line 6 section 2 with vehicle 1 as RF source.

Table 40: Results of analysis for Base station at position 1 on Line 6 section 2 with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	73/1 090	-46/-89	LoS, Viaduct, Trees	South-east road. Base station on viaduct.
B	Parallel	57/1 005	-51/-94	LoS, Viaduct	North-west road. Base station on viaduct.
C	Perpendicular	45/290	-39/-75	LoS, Trees	North-west road. Large alley with park.
D	Perpendicular	90/460	-65/-93	LoS, Trees	North-east road. Large alley with park.

8.3.1.5 Selected Scenarios for Line 6 section 3 - Bercy Bridge

8.3.1.5.0 Introduction

The detailed analysis of scenarios for Line 6 section 3 cannot be considered as an Urban environment or a suburban environment. The measurements have been performed with the base station installed on a viaduct that is on bridge above the Seine river. This is a particular environment.

Four scenarios have been considered for this particular environment.

8.3.1.5.1 Base station configured as train at position 1 on Line 6 section 3 (Bercy Bridge) measurements with vehicle 1

The first considered scenario for detailed analysis is the base station configured as train at position 1 on Line 6 section 3 (Bercy Bridge). The analysis has been made with level received from vehicle 1.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 100 m. The detailed analysis concerns the road parallel to the tracks and the perpendicular road going to the North-west.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 100 m.

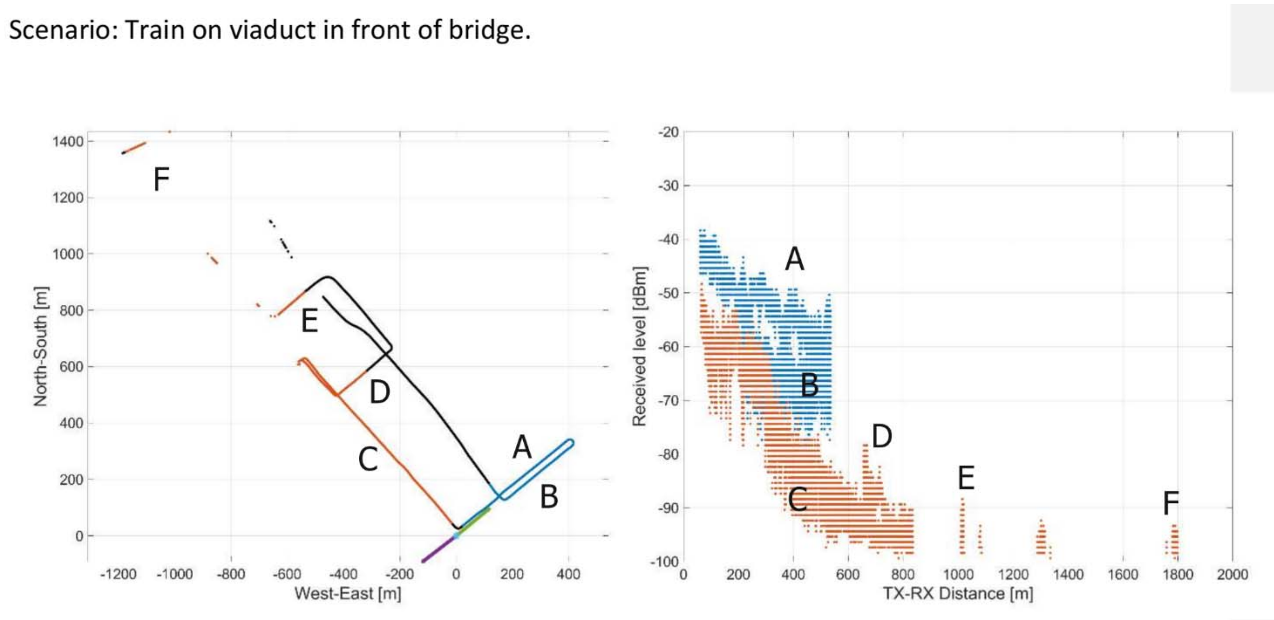

Figure 82: Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with vehicle 1 as RF source

On Figure 82 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 41 shows the results of the analysis for Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with the vehicle 1 as RF source.

Table 41: Results of analysis for Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	60/530	-38/-52	Los/Viaduct	Road section north. Train on viaduct above vehicle.
B	Parallel	210/530	-50/-60	Los/Viaduct	Road section south. Train on viaduct above vehicle.
C	Perpendicular	65/820	-49/-90	LoS, high trees	Road perpendicular to viaduct and parallel to river.
D	Perpendicular	680	-89	LoS	Bridge.
E	Perpendicular	1 000	-93	LoS	Bridge.
F	Perpendicular	1 780	-93	LoS	Bridge.

8.3.1.5.2 Base station configured as train at position 1 on Line 6 section 3 (Bercy Bridge) measurements with vehicle 2

The second considered scenario for detailed analysis is the same base station configured as train at position 1 on Line 6 section 3 (Bercy Bridge). The analysis has been made with level received from vehicle 2.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 100 m. The detailed analysis focuses on the perpendicular road to the Line on the west side of the river.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 100 m.

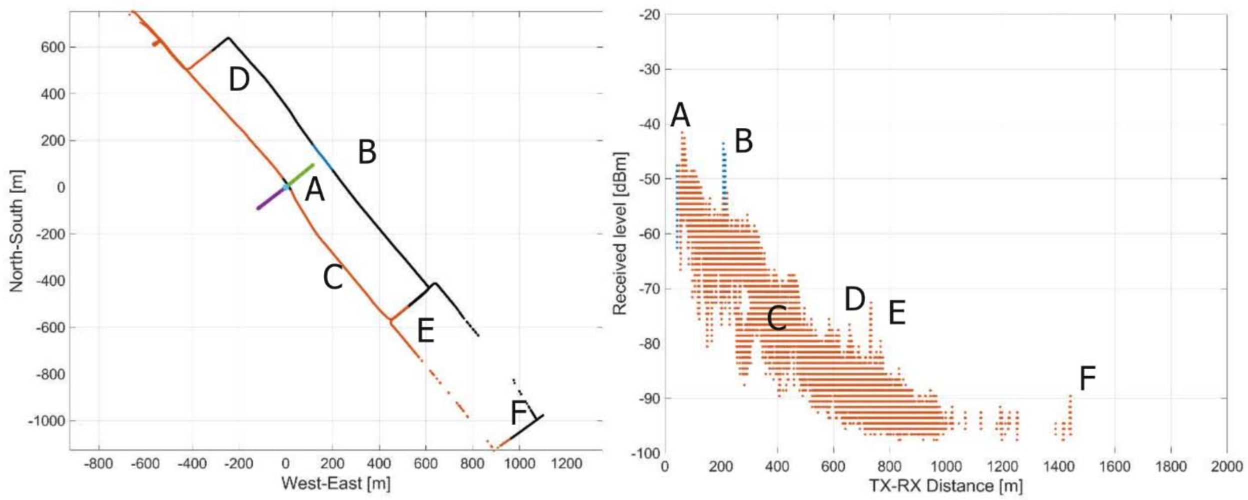

Figure 83: Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with vehicle 2 as RF source with a focus on perpendicular road west side of the river

On Figure 83 left side: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 42 shows the results of the analysis for Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with the vehicle 2 as RF source. A focus is made on the perpendicular road on the west side of the river.

Table 42: Results of analysis for Base station configured as train at position 1 on Line 6 section 3 (Bercy bridge) with vehicle 2 as RF source with a focus on perpendicular road west side of the river

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	42	-48	Viaduct	Drive perpendicular through tunnel below viaduct.
B	Parallel	208	-45	Viaduct and Tunnel	Drive perpendicular through tunnel below viaduct.
C	Perpendicular	60/1 440	-43/-91	LoS and tall trees	
D	Perpendicular	650	-77	LoS	Bridge to north.
E	Perpendicular	733	-74	LoS	Bridge to south.
F	Perpendicular	1 440	-91	LoS	Bridge to south.

8.3.1.5.3 Base station at position 2 on Line 6 section 3 (Bercy bridge)

The third considered scenario for detailed analysis is the base station (antenna height 5 m) at position 2 on Line 6 section 3 (Bercy Bridge). The analysis has been made with level received from vehicle 1.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 200 m.

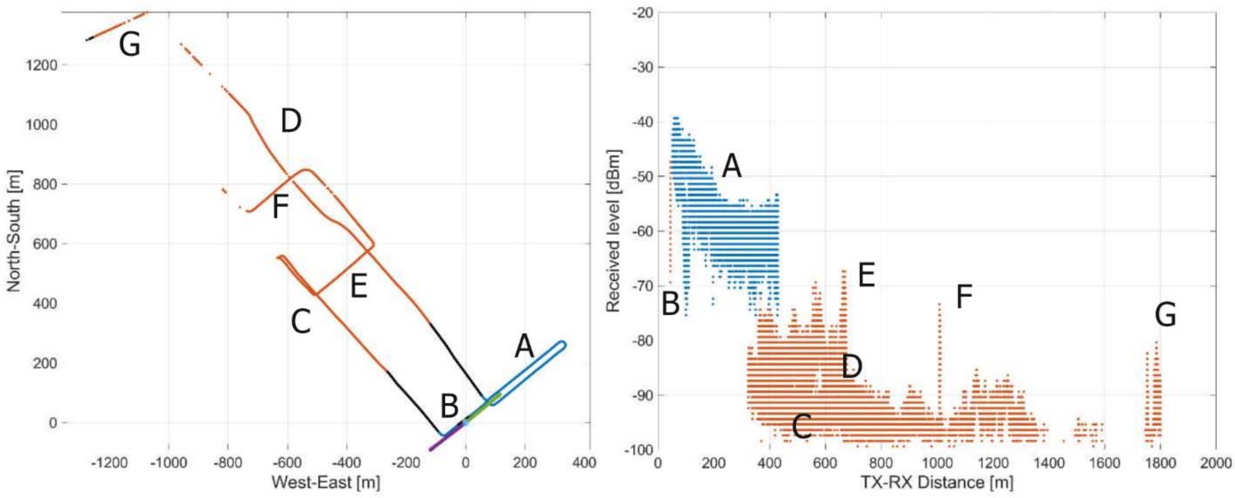

Figure 84: Base station at position 2 on Line 6 section 3 (Bercy bridge) with vehicle 1 as RF source

On Figure 84 left side t: tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 43 shows the results of the analysis for base station at position 2 on Line 6 section 3 (Bercy bridge) with the vehicle 1 as RF source.

Table 43: Results of analysis for base station at position 2 on Line 6 section 3 (Bercy bridge) with vehicle 1 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	58/430	-38/-53	LoS/Viaduct	Vehicles driving left and right of viaduct.
B	Perpendicular	44	-48	Viaduct	Pass next to base station.
C	Perpendicular	325/830	-81/-93	Trees and buildings	Street parallel to river on south side.
D	Perpendicular	360/1 570	-74/-94	Trees	Street parallel to river on north side.
E	Perpendicular	660	-67	LoS	Bridge.
F	Perpendicular	1 010	-74	LoS	Bridge.
G	Perpendicular	1 790	-82	LoS	Bridge.

8.3.1.5.4 Base station at position 2 on Line 6 section 3 (Bercy bridge)

The fourth considered scenario for detailed analysis is the base station (antenna height 5 m) at position 2 on Line 6 section 3 (Bercy Bridge). The analysis has been made with level received from vehicle 2.

This is the same base station as for the third scenario, but the analysis is made with level received from vehicle 2 instead of vehicle 1.

For the analysis of this scenario, the maximum distance d2 (see Figure 67) has been increased to 200 m.

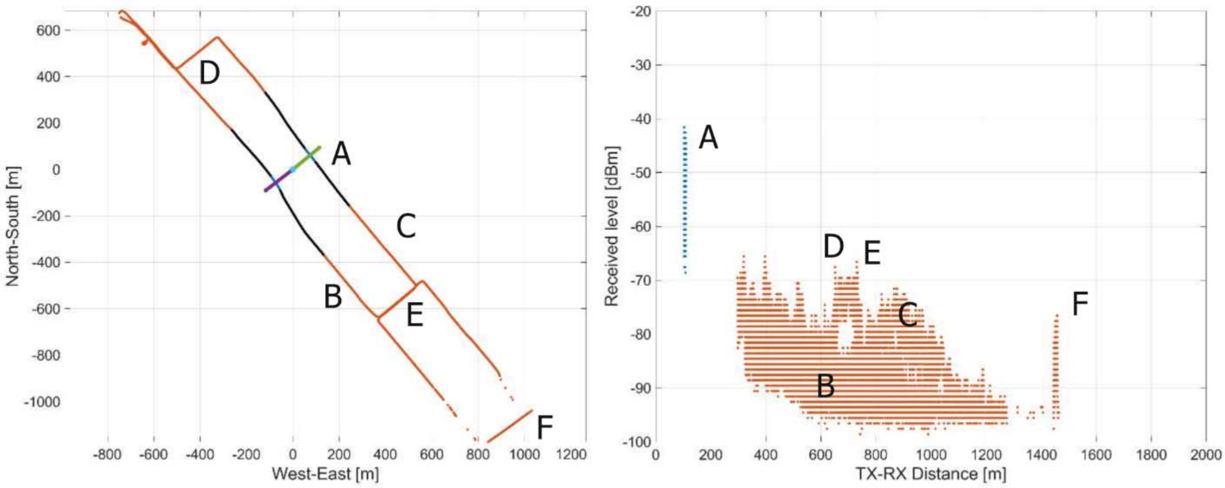

Figure 85: Base station at position 2 on Line 6 section 3 (Bercy bridge) with vehicle 2 as RF source

On Figure 85 left side: The tx positions where packets were received at the rx (black) and the tx positions classified as being parallel road (blue) and perpendicular road (red). Right side: received level for a 33 dBm transmitter over distance for being parallel road (blue) and perpendicular road (red).

Table 44 shows the results of the analysis for base station at position 2 on Line 6 section 3 (Bercy bridge) with the vehicle 2 as RF source.

Table 44: Results of analysis for base station at position 2 on Line 6 section 3 (Bercy bridge) with vehicle 2 as RF source

		Distance (m)	Received Level (dBm)	Obstruction	Comment
A	Parallel	105	-42	LoS/Viaduct	
B	Perpendicular	325/1 215	-79/-92	LoS/Trees	South-west road next to river
C	Perpendicular	315/1 035	-68/-80	LoS/Trees	North-east road next to river
D	Perpendicular	650	-68	LoS	Bridge
E	Perpendicular	730	-69	LoS	Bridge
F	Perpendicular	1 460	-77	LoS	Bridge

8.3.1.6 Overall received levels versus distance

In this clause, the signal levels versus distance are given for all measurements performed on Line 8, Line 6 and have been aggregated in one plot per Line and per receiver for parallel road and for perpendicular road.

There are two plots per figure. The first one gives the received level versus distance for parallel road (in blue) and the second plot gives the received levels versus distance for the perpendicular road.

Figures 88 to 93 are divided in two parts, the left part is dedicated to the aggregated levels received from vehicles driving on parallel roads (blue curve) and the right part is dedicated to the aggregated levels received by trains and base stations from vehicles driving on perpentidular roads (orange curve).

Figure 86 shows the overall attenuation for parallel road and perpendicular road for all train receivers on Line 8.

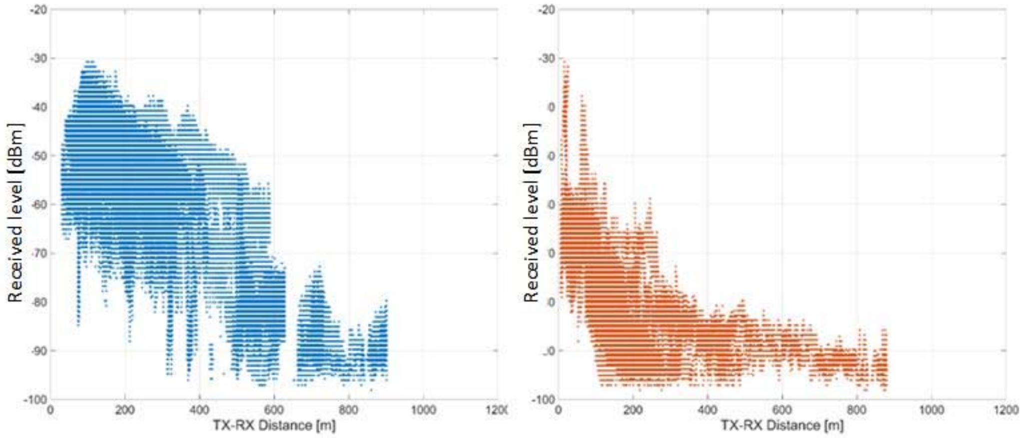

Figure 86: Aggregated received levels for all the measurements with train of Line 8 for parallel road (left) and perpendicular road (right)

Figure 87 shows the overall attenuation for parallel road and perpendicular road for all base station receivers on Line 8.

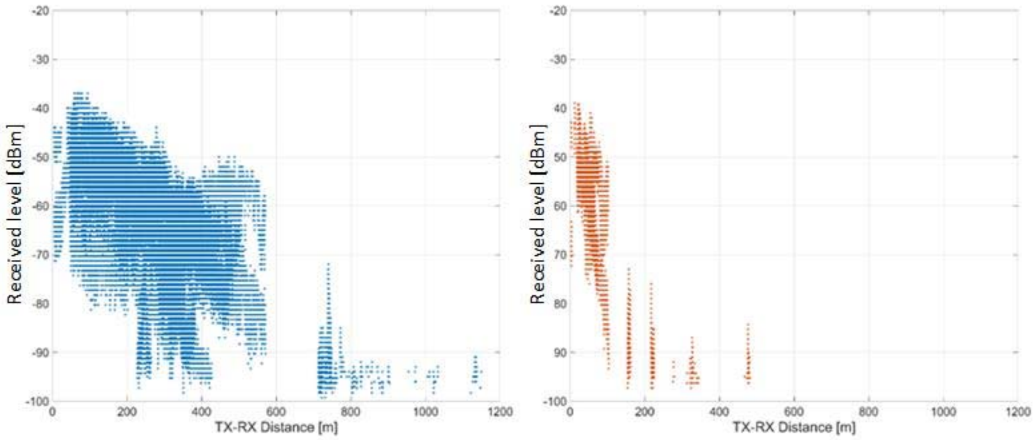

Figure 87: Aggregated attenuation for all the measurements with base station on Line 8 for parallel road (left) and perpendicular road (right)

For obtaining the aggregated figures for Line 6, the default d2 threshold of 40 m has been increased for all scenarios to 100 m. In cases where a road crossing was not perpendicular to the antenna axis, the angle alpha and distance d2 were further increased up to 40° and 1 000 m correspondingly.

Figure 88 shows the overall attenuation for parallel road and perpendicular road for all base station configured as train on Line 6.

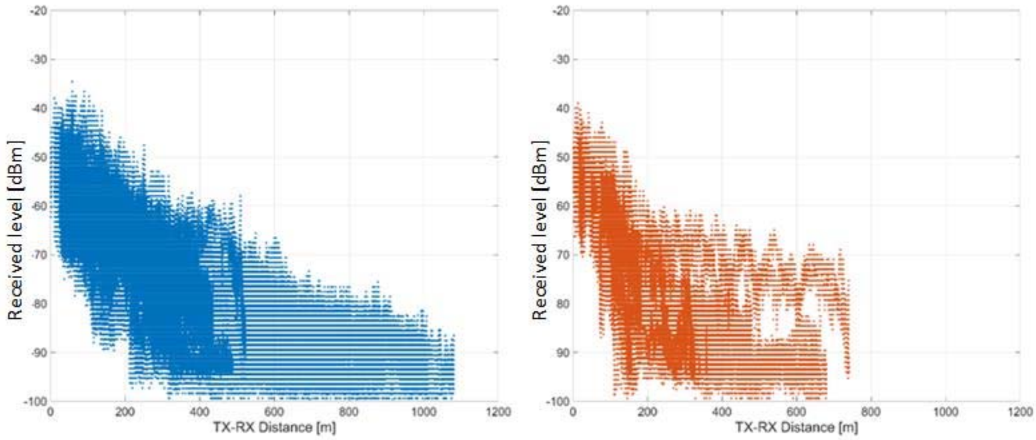

Figure 88: Aggregated attenuation for all the measurements with base station configured as train on Line 6 for parallel road (left) and perpendicular road (right)

Figure 89 shows the overall attenuation for parallel road and perpendicular road for all base station receivers on Line 8.

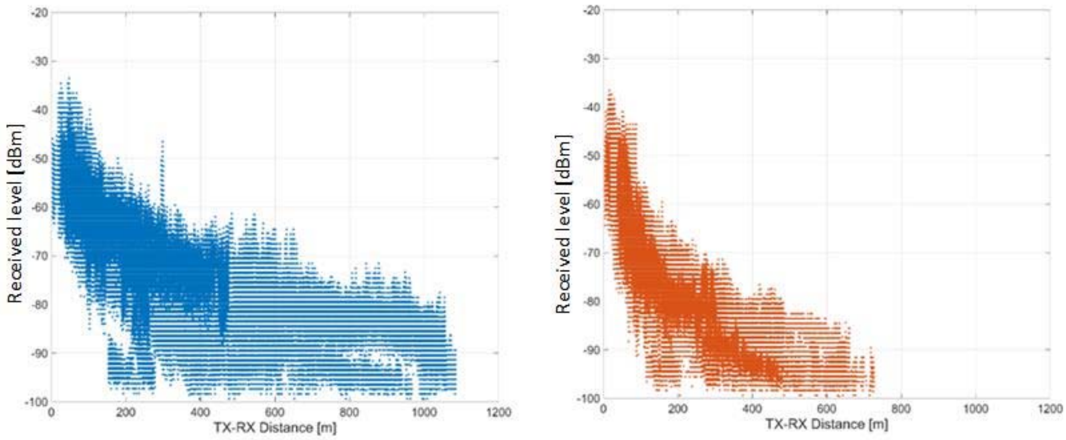

Figure 89: Aggregated attenuation for all the measurements with base station on Line 6 for parallel road (left) and perpendicular road (right)

For generating the overall attenuation plots for Bercy bridge, the distance d2 has been increased for all scenarios to 200 m. Figure 90 and Figure 92 show the overall received level over distance for the base station configured as train and base stations at Bercy bridge.

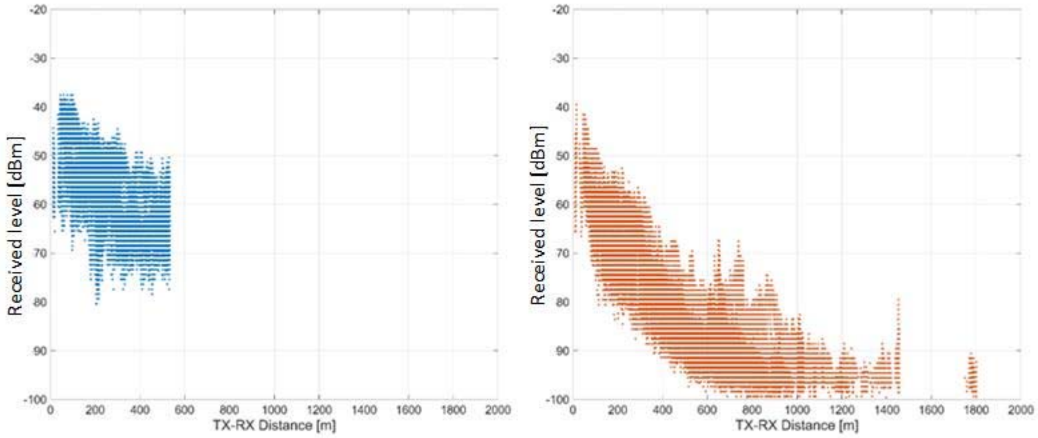

Figure 90: Aggregated attenuation for all the measurements with base station configured as train on Line 6 Bercy bridge for parallel road (left) and perpendicular road (right)

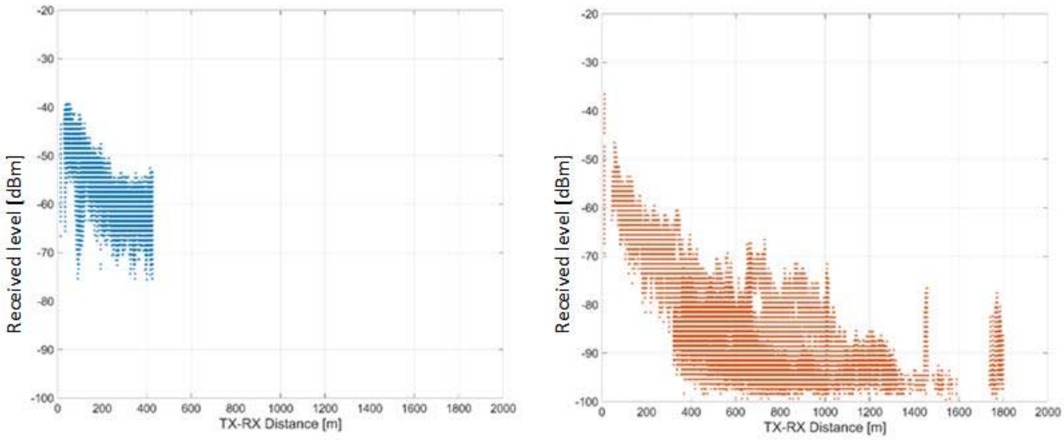

Figure 91: Aggregated attenuation for all the measurements with base station on Line 6 Bercy Bridge for parallel road (left) and perpendicular road (right)

8.3.2 Effect of antenna directivity

The following compares the power from a vehicle transmitting at the maximum allowed EIRP (33 dBm/10 MHz) received at the CBTC antenna connector (referred to as uplink in the following), and the power received in the reverse link (referred to as downlink in the following), i.e. when the CBTC antenna is radiating at the maximum allowed EIRP (33 dBm/10 MHz) and the vehicle is receiving.

Real propagation conditions are taken from the measurement results.

The antenna used during the measurements is considered with a gain of 15 dBi and 3 dB beamwidth of 35° in the horizontal plane.

Figure 92 shows the model considered.

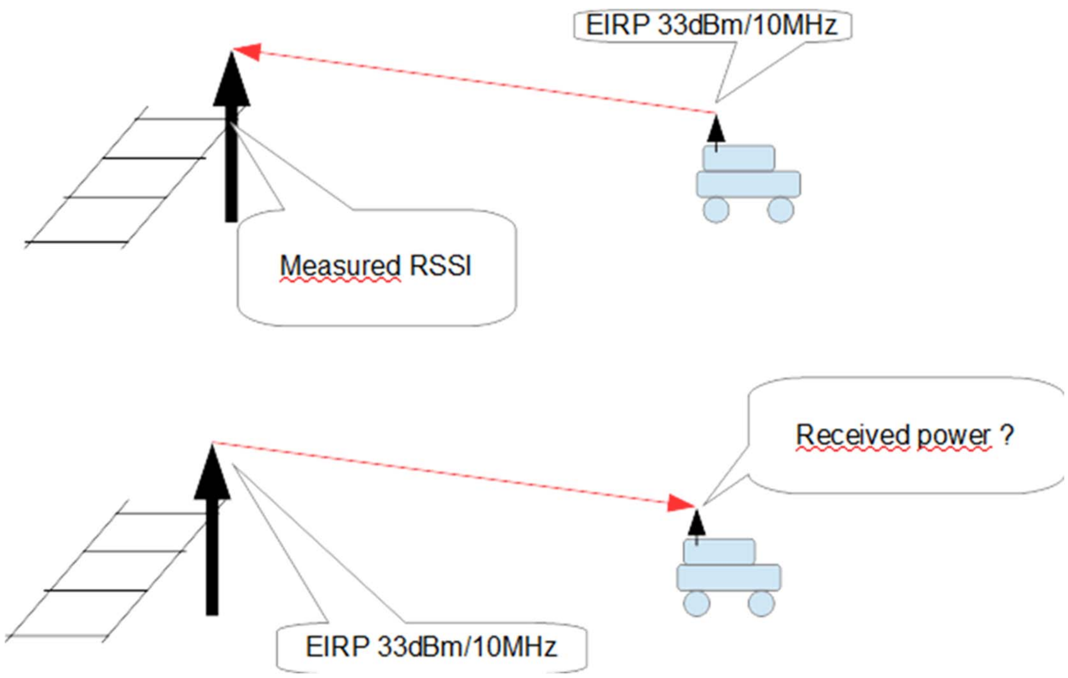

Figure 92: Model considered

The following equation gives the power received by the vehicle in the downlink, expressed as a function of the measured received level. The equation is obtained by comparing the link budget of the measurement and the link budget of the hypothetical coverage.

$$Pdl=Pm+ EIRPdl + Gvehicle - EIRPm - Gm + Flm \tag{1}$$

Where:

- Pdl is the received power at the vehicle antenna connector.
- Pm is the measured received level that is function of condition of propagation and the radiating pattern of the measurement antenna used for Train and CBTC base station.
- EIRPdl is the maximum allowed EIRP.
- Gvehicle is the antenna gain of the vehicle.
- EIRPm is the EIRP of the vehicle used for the measurement.
- Gm is the maximum receiver antenna gain (CBTC antenna).
- Flm is the measurement receiver feeder losses.

The equation above is applied with the following values:

- EIRPdl = 33 dBm/10 MHz.
- Gvehicle = 3 dBi.
- EIRPm = 37,1 dBm/10 MHz.
- Gm = 15 dBi.
- Flm = 4,66 dB.

and the result is:

$$Pdl= Pm + Correction\ Factor$$

where:

- Correction Factor = EIRPdl + Gvehicle - EIRPm - Gm + Flm= -11,44 dB

This approach has been applied on Line 6 section 2 for the base station 3 configured as a train (antenna height 3,5 m above the ground) and located at 163 m from the station Sèvres-Lecourbe).

Figure 93 shows the area where the uplink received power (correction factor applied, hence corresponding to the interfering power) at the CBTC antenna connector exceeds -94 dBm/5 MHz or -91 dBm/10 MHz according to Table 2.

These points are coloured green where the received power in the downlink is higher than -85 dBm/10 MHz (ITS receiver sensitivity according to ETSI EN 302 571 [i.3]) and red where the received power in the downlink is lower than -85 dBm/10 MHz and an ITS packet could not be properly received by an ITS receiver. At red points, a kind of "hidden node" effect is present: the CBTC receiver may be interfered but the vehicle may not be able to detect the CBTC transmitter.

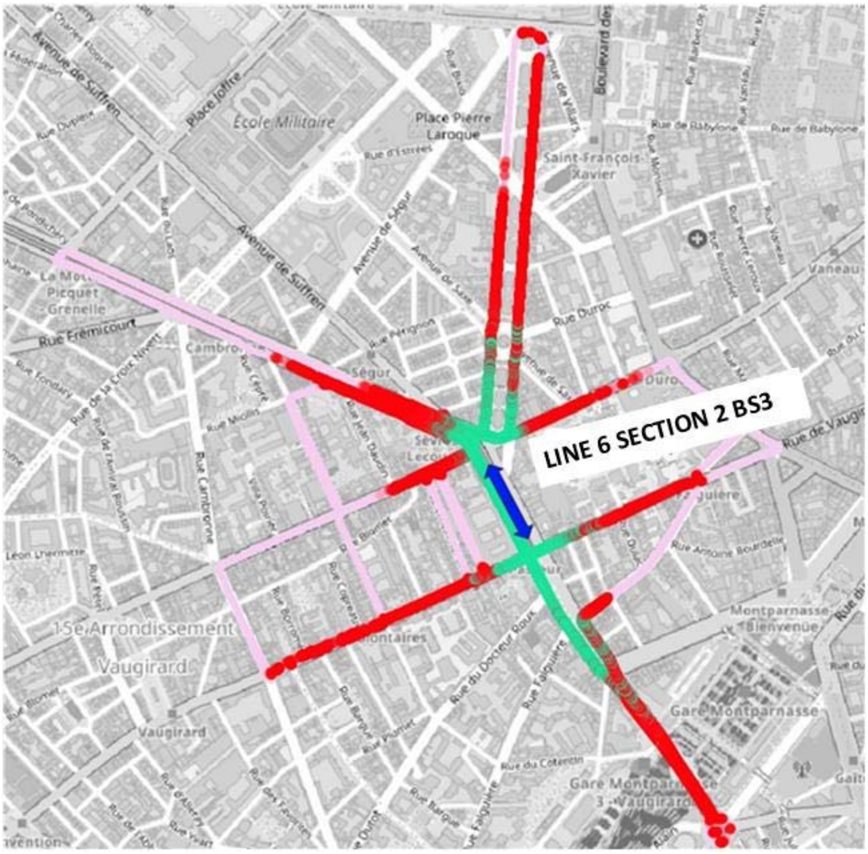

Figure 93: Points where the received power in the CBTC receiver is greater than -91 dBm/10 MHz, green where the reverse downlink received power by the vehicle is greater than -85 dBm/10 MHz and red otherwise (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

8.4 Comparison of measurements with simulations for some base stations and trains

8.4.1 Propagation simulator

The propagation simulator is HTZ communications.

A short description of the simulator is given in annex D.

8.4.2 Analysis of the results of comparison

The received levels obtained by simulation tend to be higher than the measurements in the close vicinity of the receivers (typically, in the streets immediately adjacent and parallel to the railways). This result was expected because at short distances, the simulation tools may assume Line-of Sight propagation where measurements paths were shadowed in reality, e.g. by trains parked nearby as shown on Figure 102 for the base station at position 1 for Line 8 section 1 (see B1H_0607) or Figure 95 for viaduct fences for base station configured as a train at position 3 on Line 6 section 1(B3L_1213), etc. In addition, the vertical antenna attenuation has not been included in the simulations, logically resulting in overestimating the received power in the immediate vicinity. However, this is not a critical problem because these non-Line of Sight paths may be very local or temporary situations, and the received levels are in any case quite large in the streets adjacent to the railways.

The received levels obtained by simulations tend to be lower than the measurements for non-Line of Sight streets. This was mitigated by taking into account lateral diffractions and reflections. However, the simulation is improved only for some streets exhibiting good Line-of-sight conditions of propagation to the crossroad, being itself in Line-of-sight condition of propagation from the base station or train antenna. The received levels obtained by simulation remain significantly lower than the measured received levels for the other streets in non-Line of Sight condition of propagation.

For the determination of the protected zones, this may be mitigated by simulating victim CBTC receivers installed onboard trains all along the tracks (see clause 8.4.3). Indeed, for such a setup, most streets may be for some receiver locations in a configuration where the reflected paths would be adequately modelled.

A good property of the simulation is also its ability to provide satisfactory results for areas exhibiting singularities as well, such as for Line 6 on the Bercy bridge. Simulations therefore allow to identify singular areas, including the not so obvious ones, that may be missed otherwise.

In conclusion, in the current setup, simulations may be useful to evaluate "minimum" or "optimistic" protection zones. With additional care and further improvements of the multipath algorithm, a more detailed descriptions of the protected zones may become possible under the following conditions:

- Using an improved multipath algorithm
- Using maps with improved accuracy (including Lidar data) or, at least, post-treating legacy maps
- Calibrating the reflection coefficients.

The improvements brought by these enhancements are yet to be investigated.

Figure 94 to Figure 107 show differences between the measured received levels and the levels obtained by simulation. Hence, for negative values that are identified in orange and red on the figures, the levels obtained by simulation are too high. For positive values identified in blue and purple on the figures, the levels obtained by simulation are too low.

In addition, points where the received level obtained by simulation would be below -114 dBm are not stored, because the best sensitivity of the RF measurement tools is about -96 dBm to -98 dBm. When for a particular point, there is a measured received level above sensitivity level, but the collocated received level obtained by simulation is missing because below - 114 dBm, the simulation is at least 16 dB lower than the measurement. For such cases, the differences are however plotted systematically at 50 dB as highlighted on Figure 95.

Figure 94 shows the comparison between measurements and simulations for the base station at position 3 with antenna height at 3,5 m on Line 6 section 1 (B3L_1213).

Figure 94: Comparison Line 6 section 1 Base station at position 3 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 95 shows the statistical distribution of differences between measurements and simulations for the base station with antenna height at 3,5 m at position 3 on section 1 of Line 6.

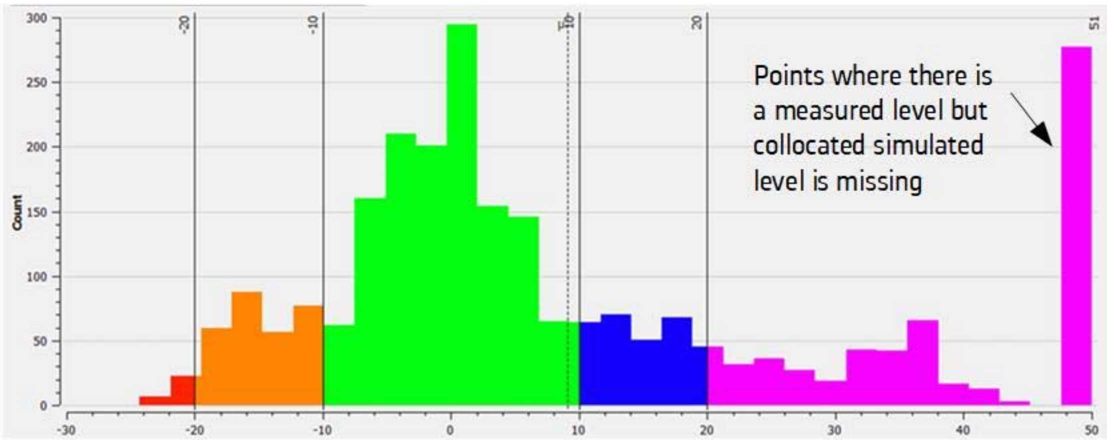

Figure 95: Statistical distribution of differences Line 6 section 1 Base station at position 3

Figure 97 shows the comparison between measurements and simulations for the base station at position 2 with antenna height at 5 m on Line 6 section 1 (B2H_1213).

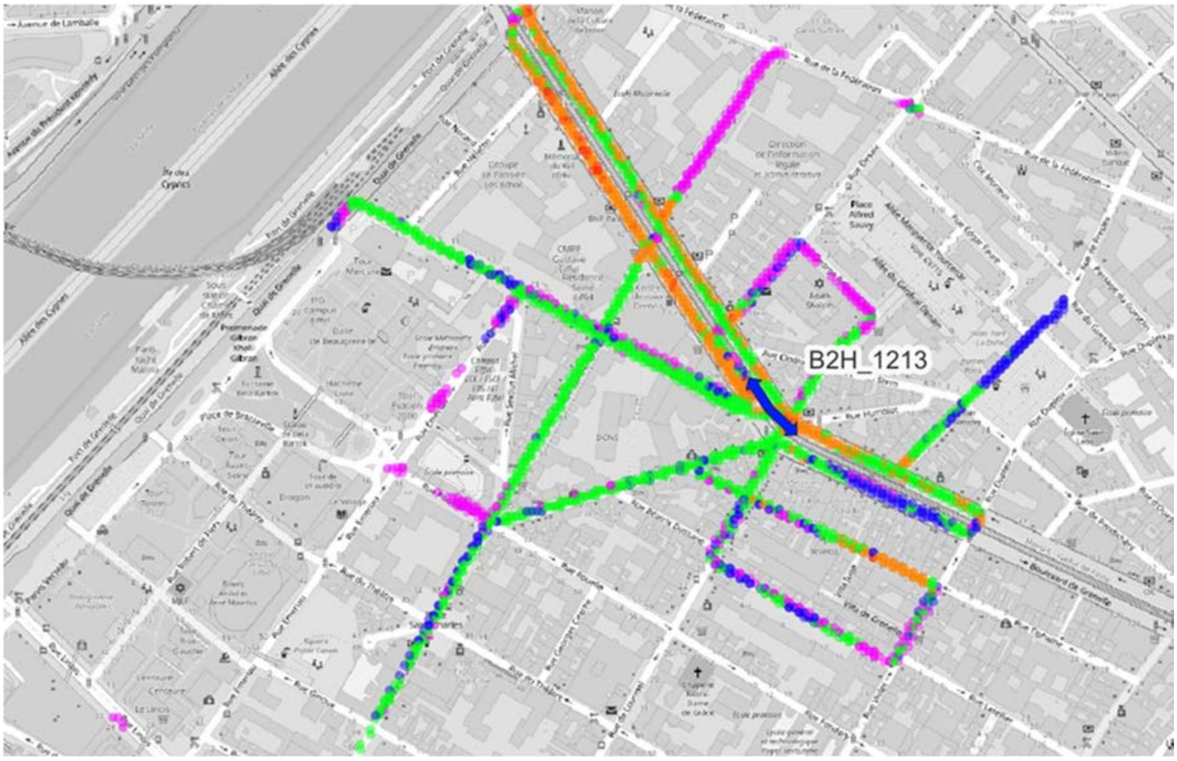

Figure 96: Comparison Line 6 section 1 Base station at position 2

Figure 97 shows the comparison between measurements and simulations for the base station at position 3 with antenna height at 3,5 m on Line 6 section 2 (B3L_1314).

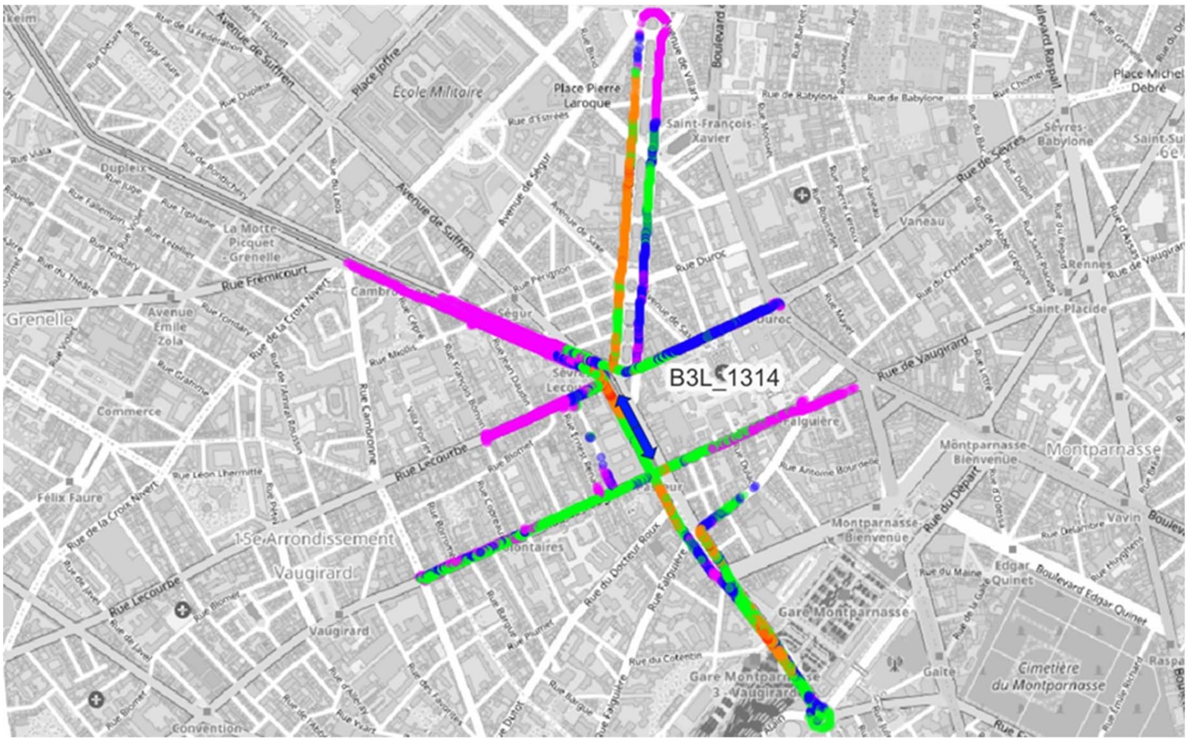

Figure 97: Comparison Line 6 section 2 Base station at position 3
(© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 98 shows the statistical distribution of differences between measurements and simulations for the base station with antenna height at 3,5 m at position 3 on section 2 of Line 6.

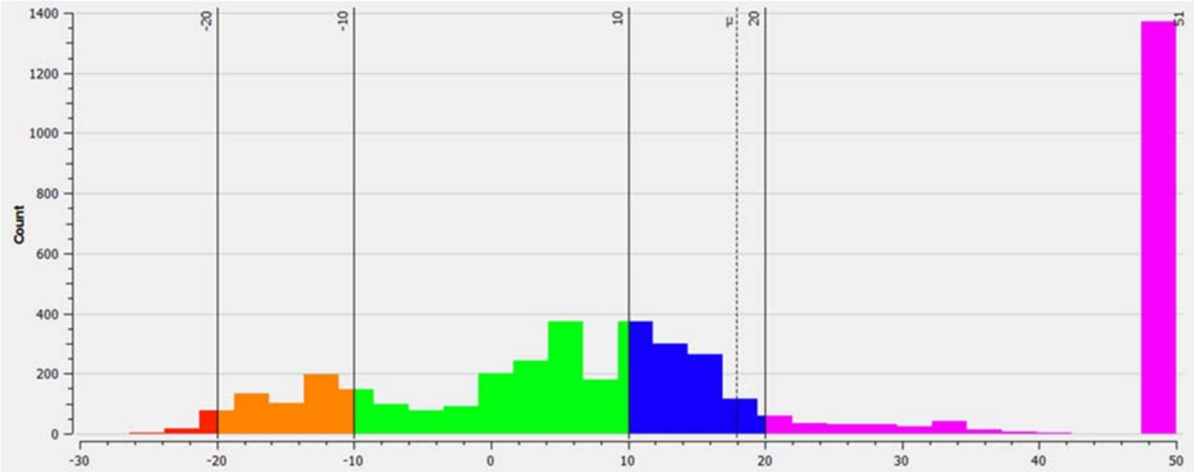

Figure 98: Statistical distribution of differences Line 6 section 2 Base station at position 3

Figure 99 shows the comparison between measurements and simulations for the base station at position 2 with antenna height at 5 m on Line 6 section 3 on the Bercy bridge (B2H_1415).

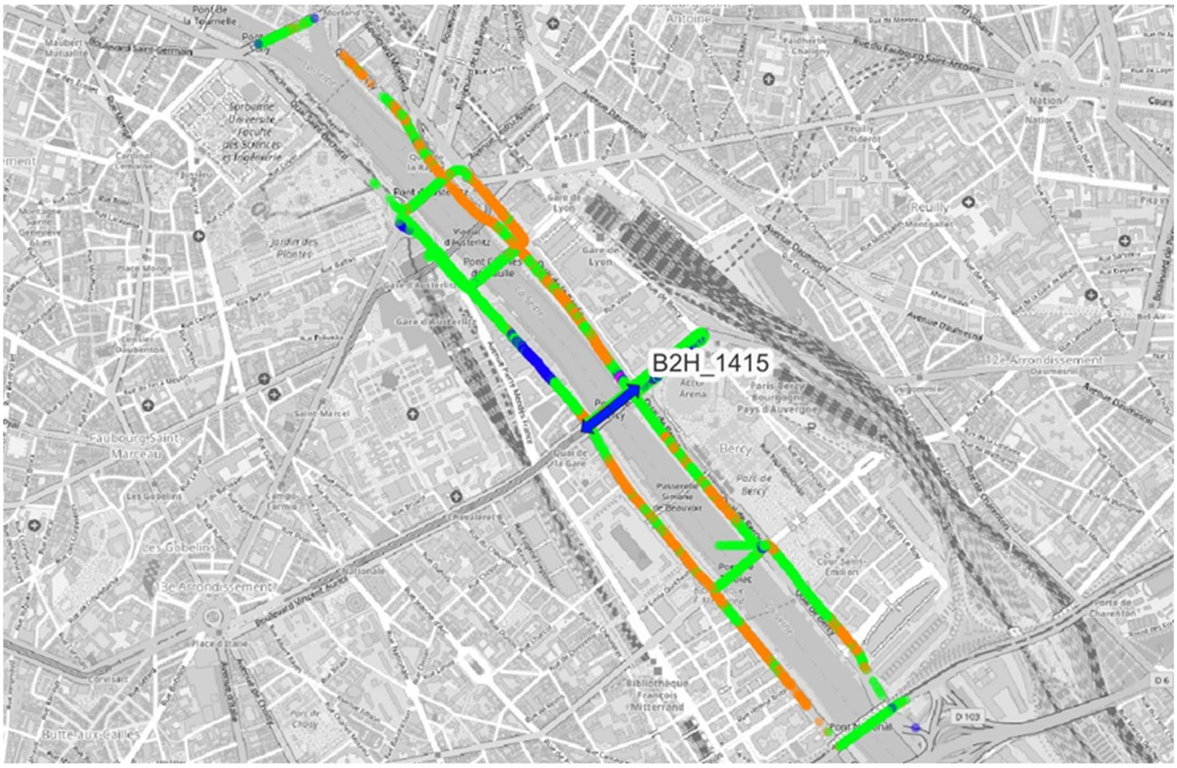

Figure 99: Comparison Line 6 section 2 Base station at position
(© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 100 shows the statistical distribution of differences between measurements and simulations for the base station with antenna height at 5 m at position 2 on section 2 of Line 6.

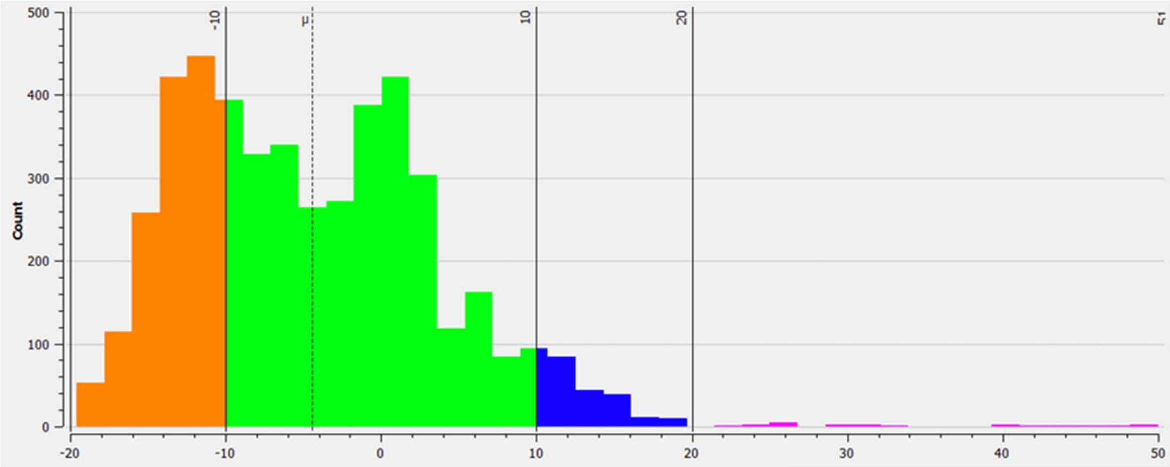

Figure 100: Statistical distribution of differences Line 6 section 2 Base station at position 3

Figure 101 shows the comparison between measurements and simulations for the base station at position 1 with antenna height at 5 m on Line 8 section 1 (B1H_0607).

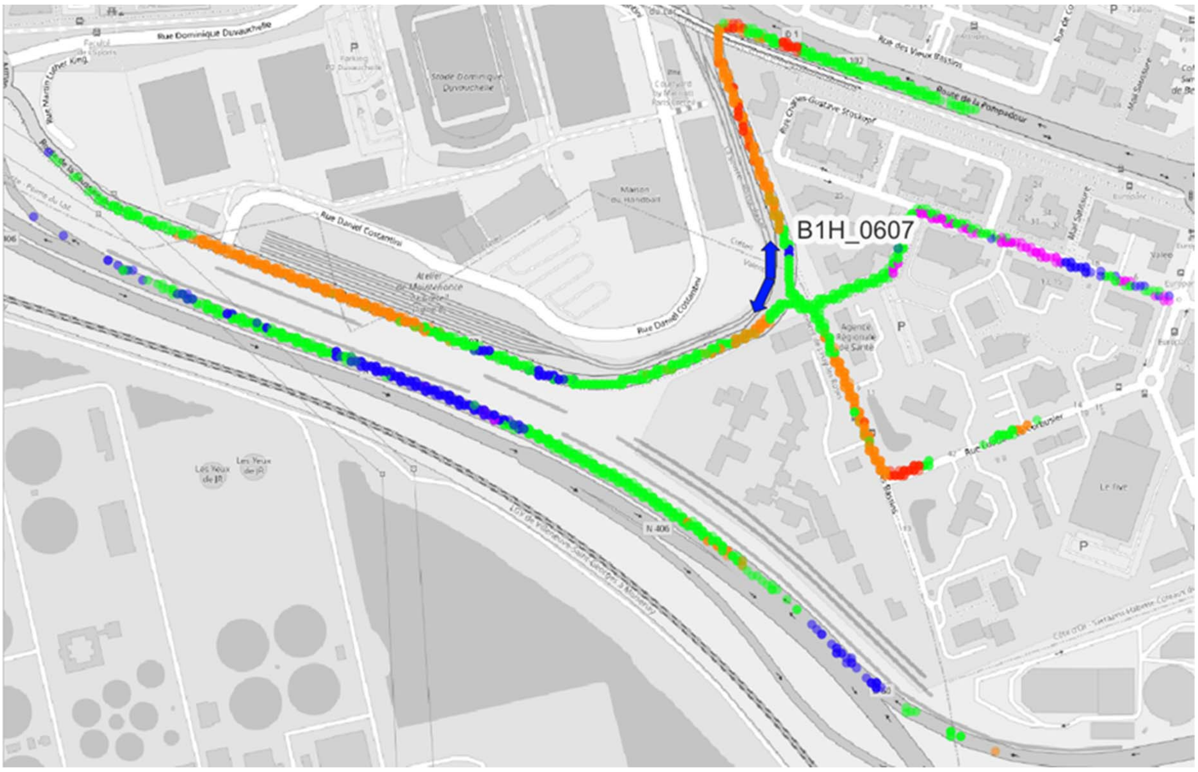

Figure 101: Comparison Line 8 section 1 Base station at position 1
(© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 102 shows the statistical distribution of differences between measurements and simulations for the base station with antenna height at 5 m at position 1 on section 1 of Line 8.

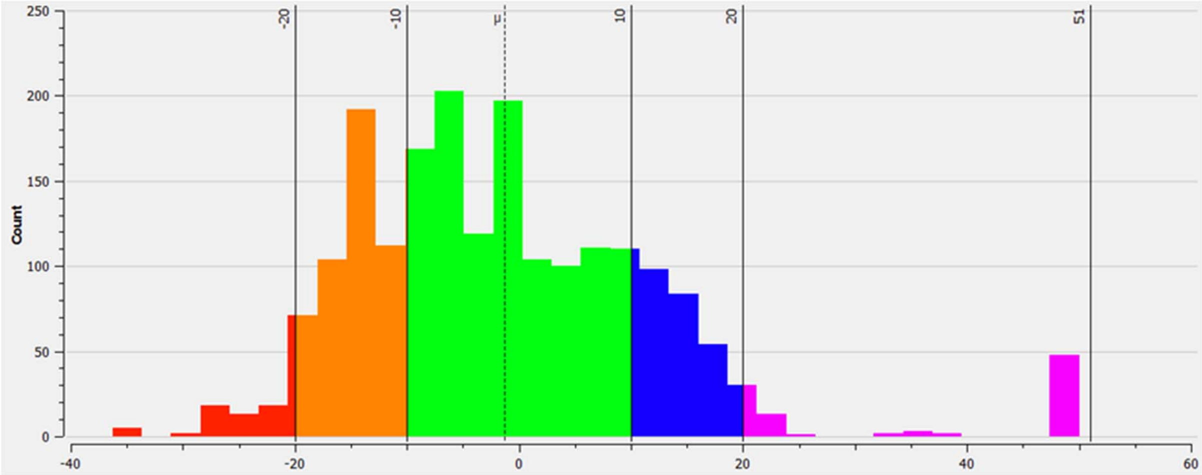

Figure 102: Statistical distribution of differences Line 8 section 1 Base station at position 1

Figure 103 shows the comparison between measurements and simulations for the train at position 2 rear cab on Line 8 section 1 (T2B_0607).

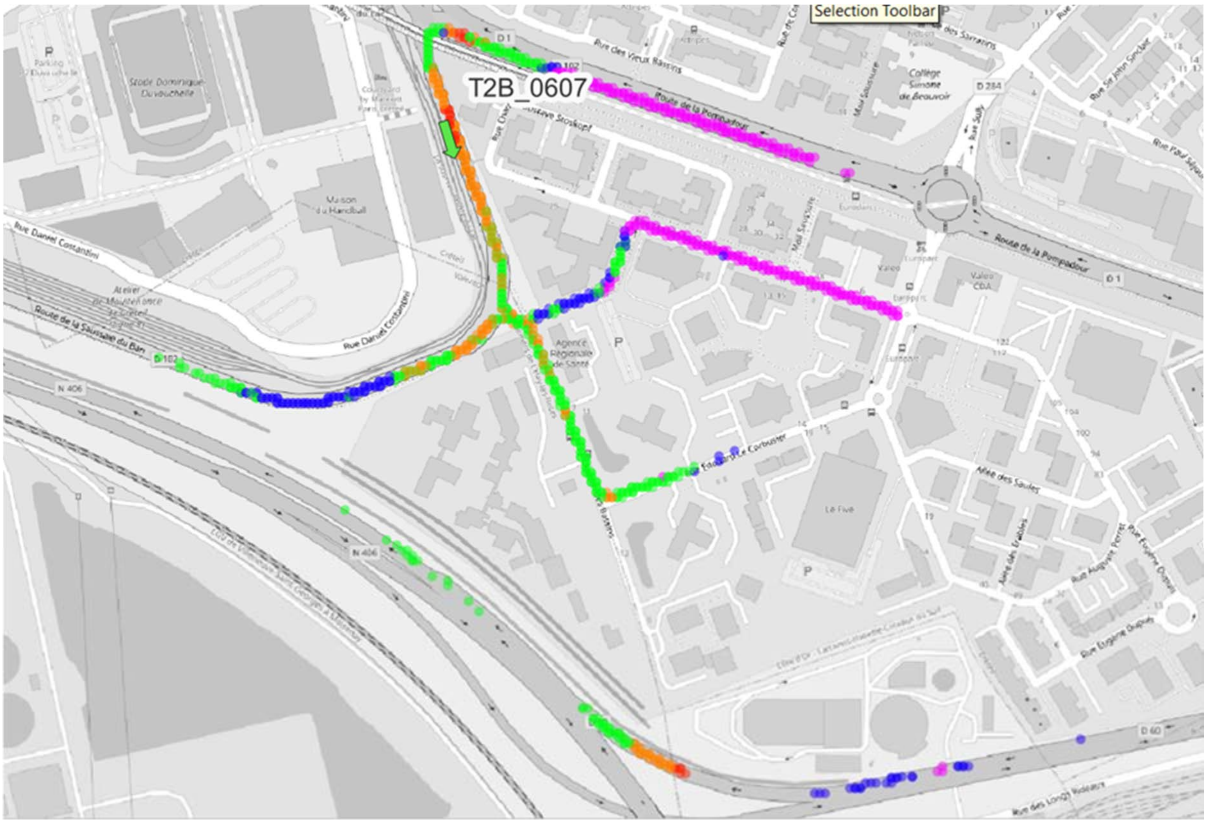

Figure 103: Comparison Line 8 section 1 Train at position 2 rear cab (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 104 shows the statistical distribution of differences between measurements and simulations for the train rear cab at position 2 on section 1 of Line 8.

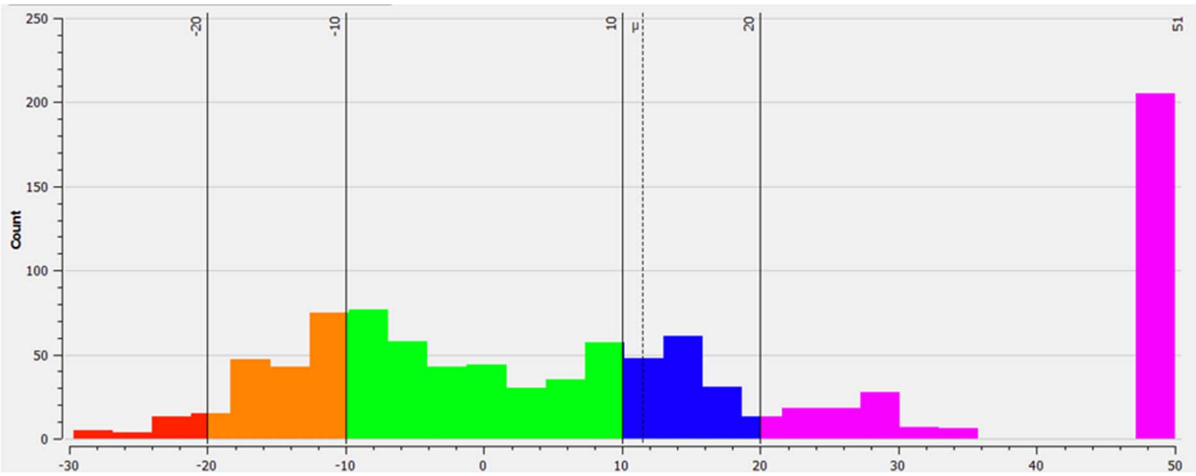

Figure 104: Statistical distribution of differences Line 8 section 1 Train at position 2 rear cab

Figure 104 and Figure 105 above exhibit received level obtained by simulation much lower than the measurements in streets where reflected paths are very likely. The analysis of the simulation results shows that simulated reflected paths are likely to be missing in some directions.

Based on this observation, an improved multipath algorithm (provided on purpose by the software editor) has been tested, along with a specific processing of the maps where a buffer of 5 m has been applied around road vectors. This processing limits the impact of an artefact caused by the gridded nature of the map raster's which causes some narrow streets (typical case street width < 15 m) to appear significatively narrower than reality.

By comparing Figure 104 and Figure 105, it can be observed that the simulations are significatively improved by these enhancements. This approach seems promising and is worth investigating further.

Figure 105 shows the impact of the improved algorithm.

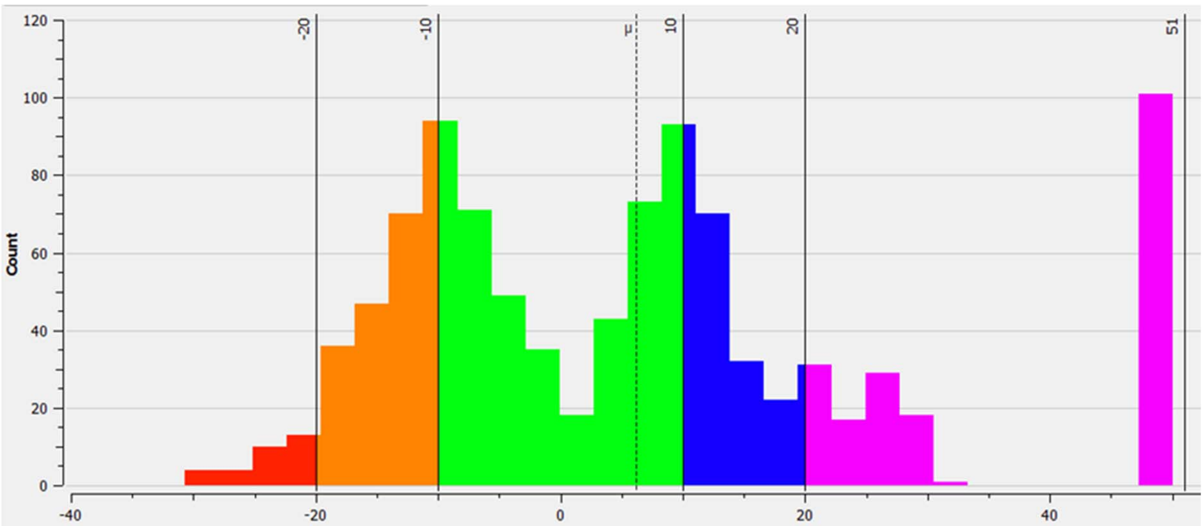

Figure 105: Improved simulation, to be compared with previous Figure 104

Figure 106 shows the comparison between measurements and simulations for the base station with antenna height at 5 m at position 3 on section 2-3 of Line 8 (B3H_0809).

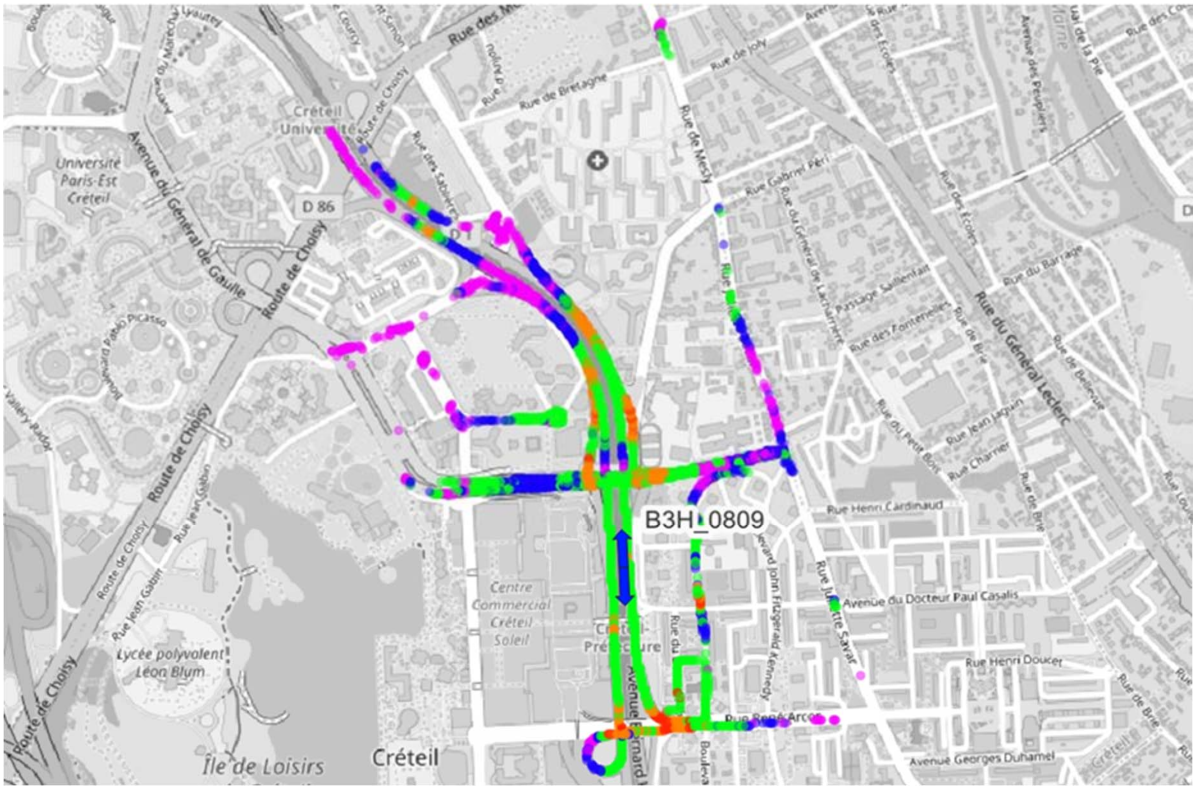

Figure 106: Comparison Line 8 section 2-3 Base station at position 2-3 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 107 shows the statistical distribution of differences between measurements and simulations for the base station with antenna height 5 m at position 3 on section 2-3 of Line 8.

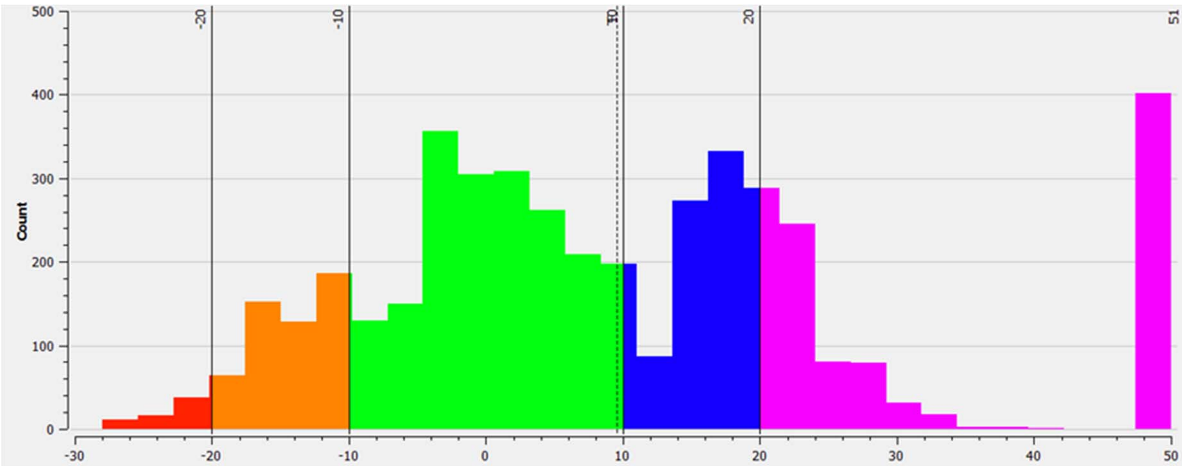

Figure 107: Statistical distribution of differences Line 8 section 2-3 Base station at position 3

8.4.3 Points simulated all along the tracks

This clause investigates to what extent simulating points every 10 m along the tracks may still lead to underestimate the measurements performed at one point.

Indeed, it is expected that simulating from numerous points along the tracks would lead to identify reflected or Line-of-sight paths to most of the neighbouring streets. Nevertheless, it is very likely that several reception points along the tracks would be measured at higher levels than the maximum simulated level from the many points. The only conclusion that holds is that the protection zone for one single receiving points derived by simulating many points along the tracks is likely to be fully covered. This cannot be generalized to the protection zone of the whole tracks.

At each measurement point, Figure 108 shows the comparison between the measured received levels by the Train Rear Cab at position 2 on Line 8 section 1 (T2B_0607) with the maximum value of received level obtained by simulation from many points along the tracks (every 10 m over about 870 m).

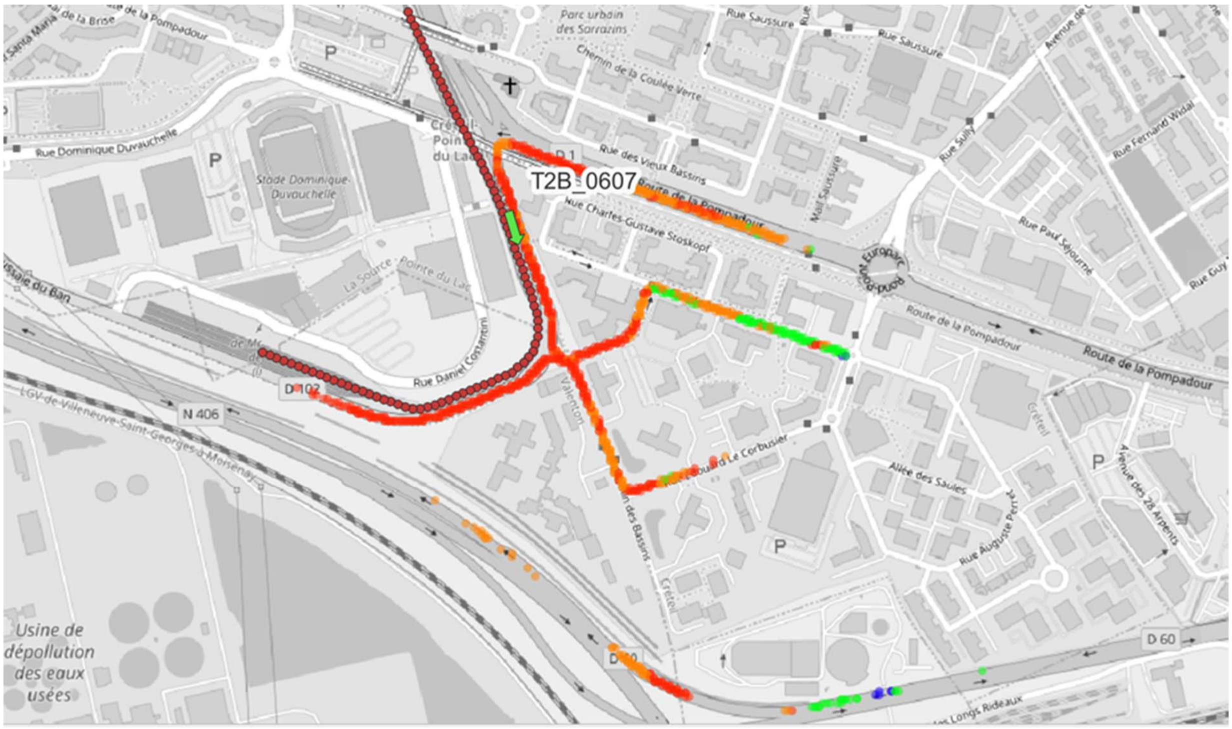

Figure 108: Line 8 section 1 Train rear cab at position 2 received level from many RF sources (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Figure 108 shows that only for a very limited number of locations remain under-estimated. It can be concluded that, by computing protection zones for the whole track length, the size of the simulated protection zone may better match the size of the real protection zone, compared to the inference that could be made from the comparison of the protection zones of individual points. This process remains completely safe from over-protection.

8.4.4 Comparison between 3,2 m and 2,5 m vehicles antenna heights

Figure 109 below gives the histogram of the difference between the simulated received level by the Train Rear Cab at position 2 on Line 8 section (T2B_0607) from a vehicle with antenna at 3,2 m and form another vehicle having antenna at 2,5 m.

On the x axis, the difference between received obtained by simulation for vehicle antenna height 3,2 m and 2,5 m is given in dB. On the y axis the number of occurrences is given per difference.

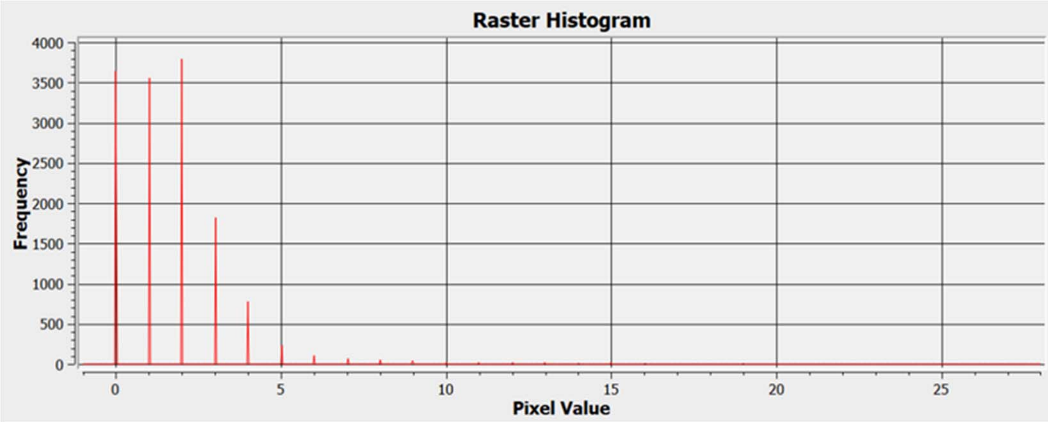

Figure 109: Statistical distribution of differences between received levels from vehicles with different antenna heights

Figure 110 shows the location of vehicles for which the difference between received level obtained by simulation for vehicles with antenna height of 3,2 m and 2,5 m.

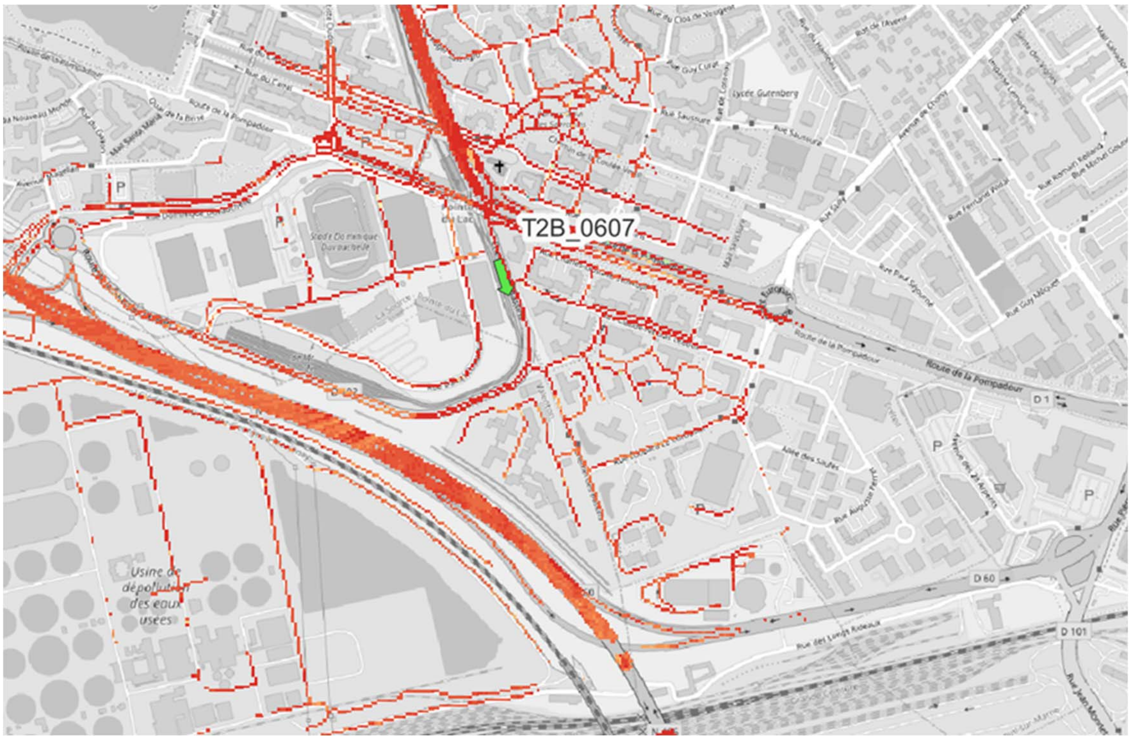

Figure 110: Points where different vehicle heights have been simulated and compared (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

The difference of the received levels between vehicle antenna heights of 3,2 m and 2,5 m is 0 dB, 1 dB, 2 dB or 3 dB for respectively 25 %, 25 %, 26 % and 12 % of occurrences. 88 % of differences are below 3 dB. However, the measurement results do not exhibit such a clear-cut trend, as shown in Figure 111. This is consistent with the observation of clause 8.5.2, where the effect of the receiving antenna height between 3,5 m and 5 m appears rather limited compared to the inherent signal variation.

Figure 111 shows the distribution of difference between received measured levels from vehicle with antenna height of 3,2 m and vehicle with antenna height 2,5 m.

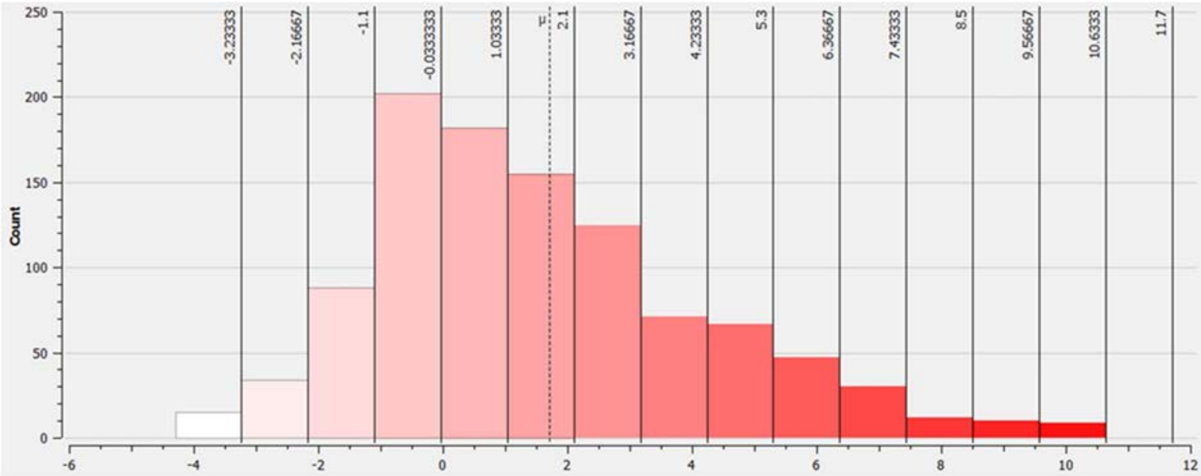

Figure 111: Difference between measured received levels from two vehicles with different heights (3,2 m and 2,5 m)

8.4.5 Summary of the comparison between the measurements and simulations

The simulations tend to underestimate the received power originating from non-Line of Sight streets.

For the assessment of the protection zones, simulations may therefore be useful to evaluate "minimum" or "optimistic" protection zones. The tendency of the simulations to under-estimate the received power may be mitigated, to some extent, by simulating victim CBTC receivers installed onboard trains all along the tracks instead of considering few isolated receiver locations.

A good property of the simulation is also its ability to predict consistently the received power for both regular areas and areas exhibiting singularities from a radio-propagation perspective.

Further enhancements of the simulation results are achieved with an improved multipath algorithm and calibrating the reflection coefficients. A dedicated processing of the terrain maps has also shown to improve greatly the simulations, hence a better map accuracy (post-treating legacy maps or using lidar data) is therefore expected to improve the prediction of the protected zones.

The improvements brought by these enhancements are yet to be investigated.

In conclusion, while simulations could be used to enhance the shape of the protected zones, it is recommended to benchmark the simulation setup against measurement data. The measurement data collected in the context of the measurement campaign introduced in the present report could be used for that purpose.

8.5 Statistical analysis

8.5.1 Ranges of levels received from vehicles

This clause introduces boxplots of the distances between the vehicles and the CBTC receivers. Boxplots are given for ten received power intervals, in 5 dB steps. Hence, it is possible to observe the range at which a given received level is likely to occur.

Assuming the level above which interference are expected is e.g. -84 dBm/10 MHz, one could therefore focus on the ranges of the following intervals: -85 dBm/10 MHz to -80 dBm/10 MHz, -80 dBm/10 MHz to -75 dBm/10 MHz and all the other "higher" intervals.

Statistics are further divided in two broad groups: side lobe (angles more than 45° away from the main beam of the CBTC antenna, green in the following two boxplots), and non-sidelobe (orange in the following two boxplots). This allows to assess the dimensions of the protection zone, in the direction of tracks and of-axis.

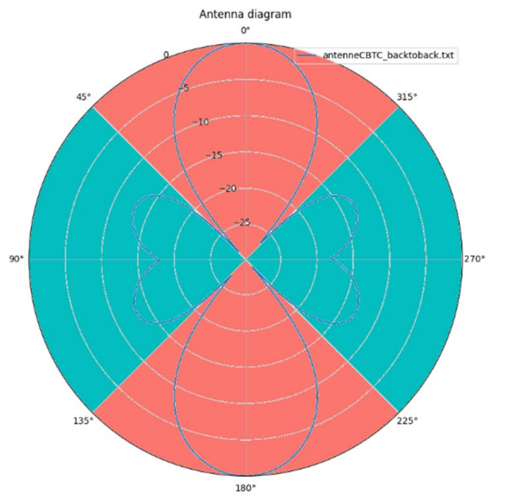

Figure 112: Illustration of side-lobe and non-sidelobe for a back to back antenna

Figure 113 shows the boxplots for access point receivers and the suburban environment.

Figure 114 shows the boxplots for access point receivers and the urban environment (excluding Bercy which is a singular case due to the river).

Figure 115 shows the boxplots for train receivers and the suburban environment.

Figure 116 shows the boxplots for train receivers and the urban environment (excluding Bercy which is a singular case due to the river).

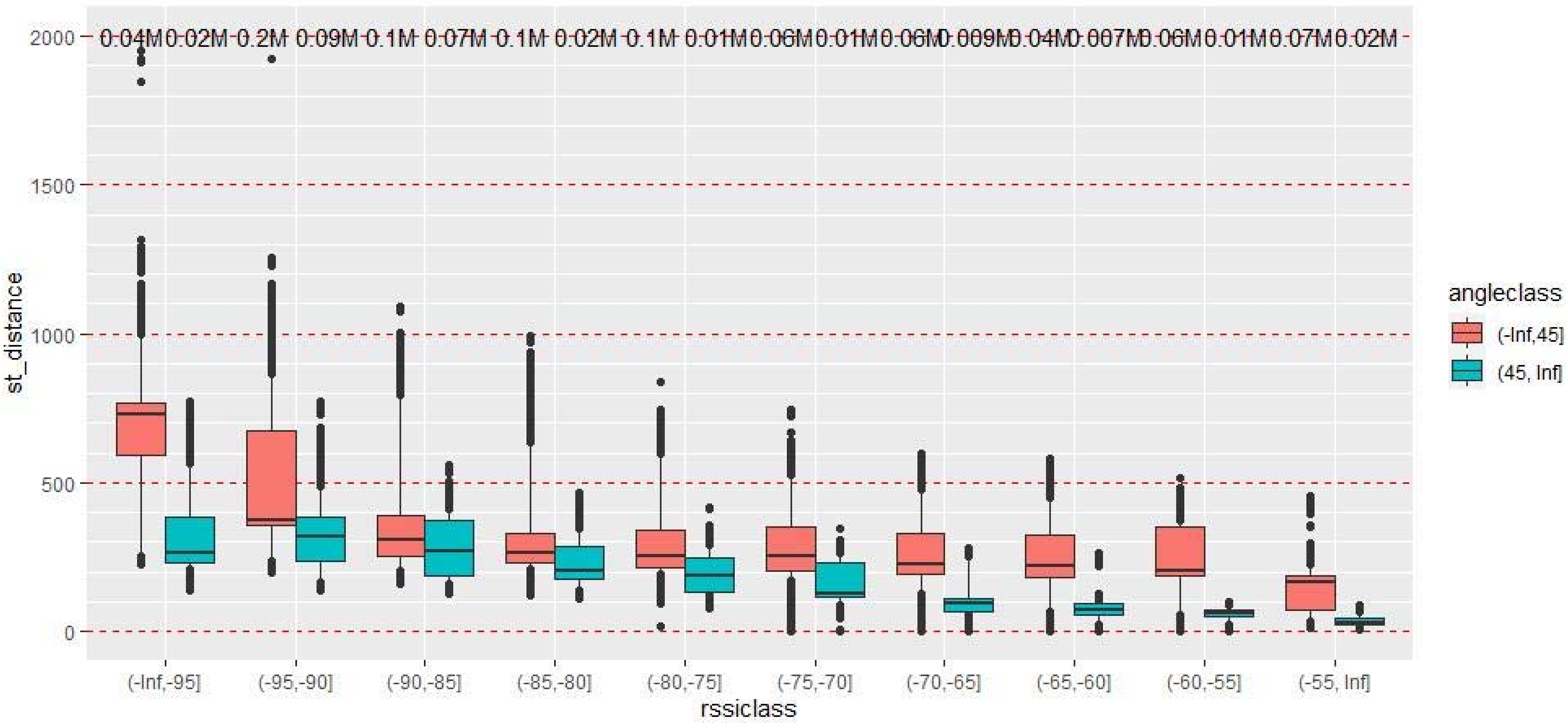

Figure 113: Distance (st_distance, m) per received power interval (rssiclass, dBm/10 MHz) concerning access point receivers. Suburban (Line 8)

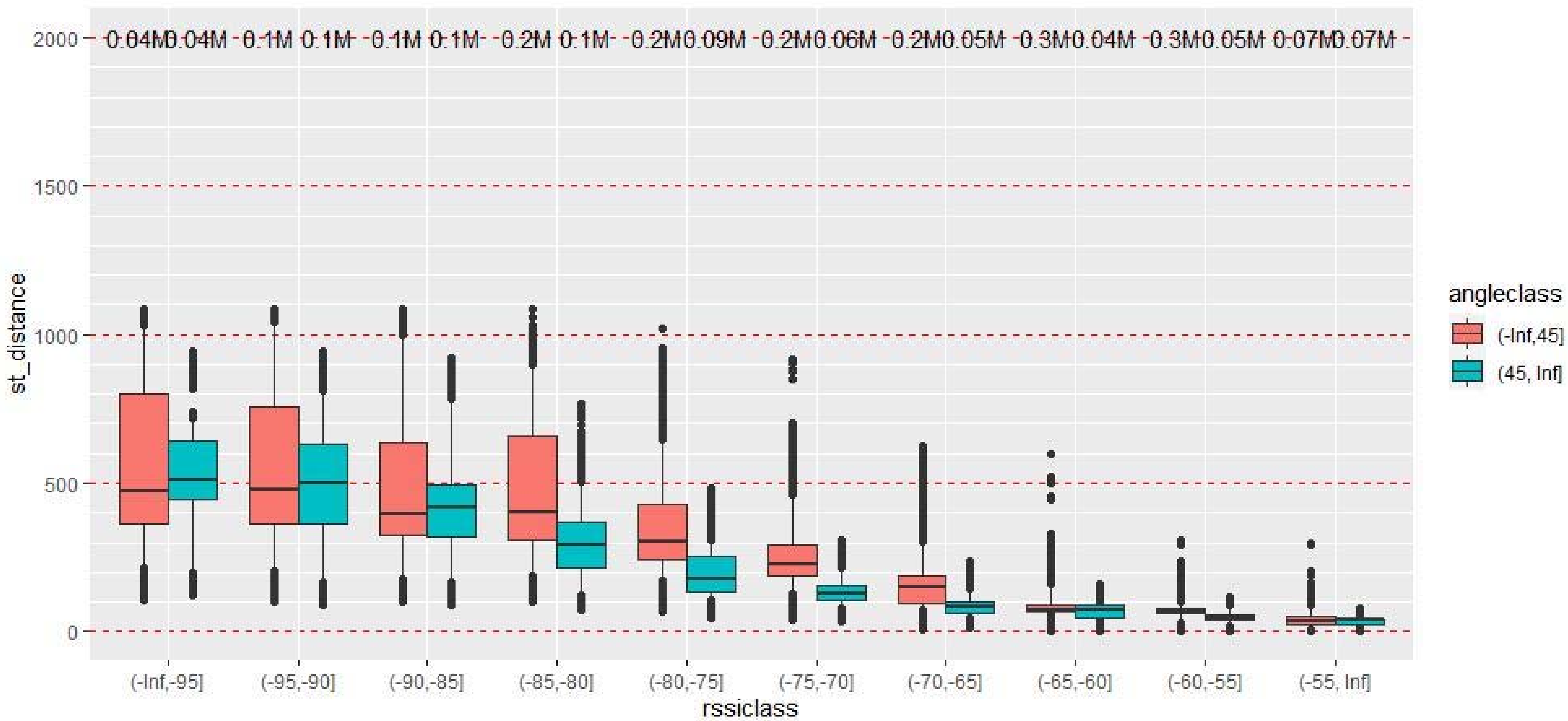

Figure 114: Distance (st_distance, m) per received power interval (rssiclass, dBm/10 MHz) concerning access point receivers. Urban (Line 6, except Bercy)

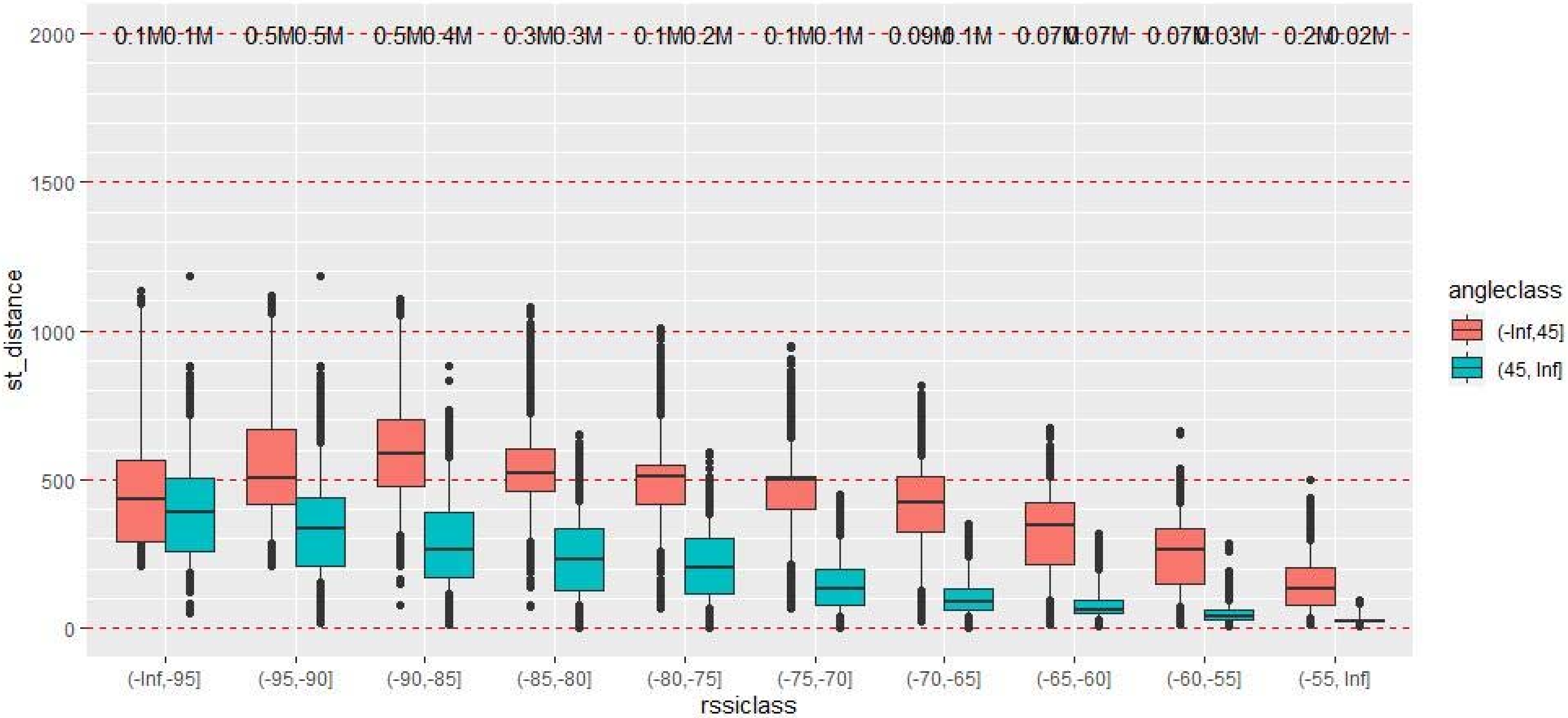

Figure 115: Distance (st_distance, m) per received power interval (rssiclass, dBm/10 MHz) concerning train receivers. Suburban (Line 8)

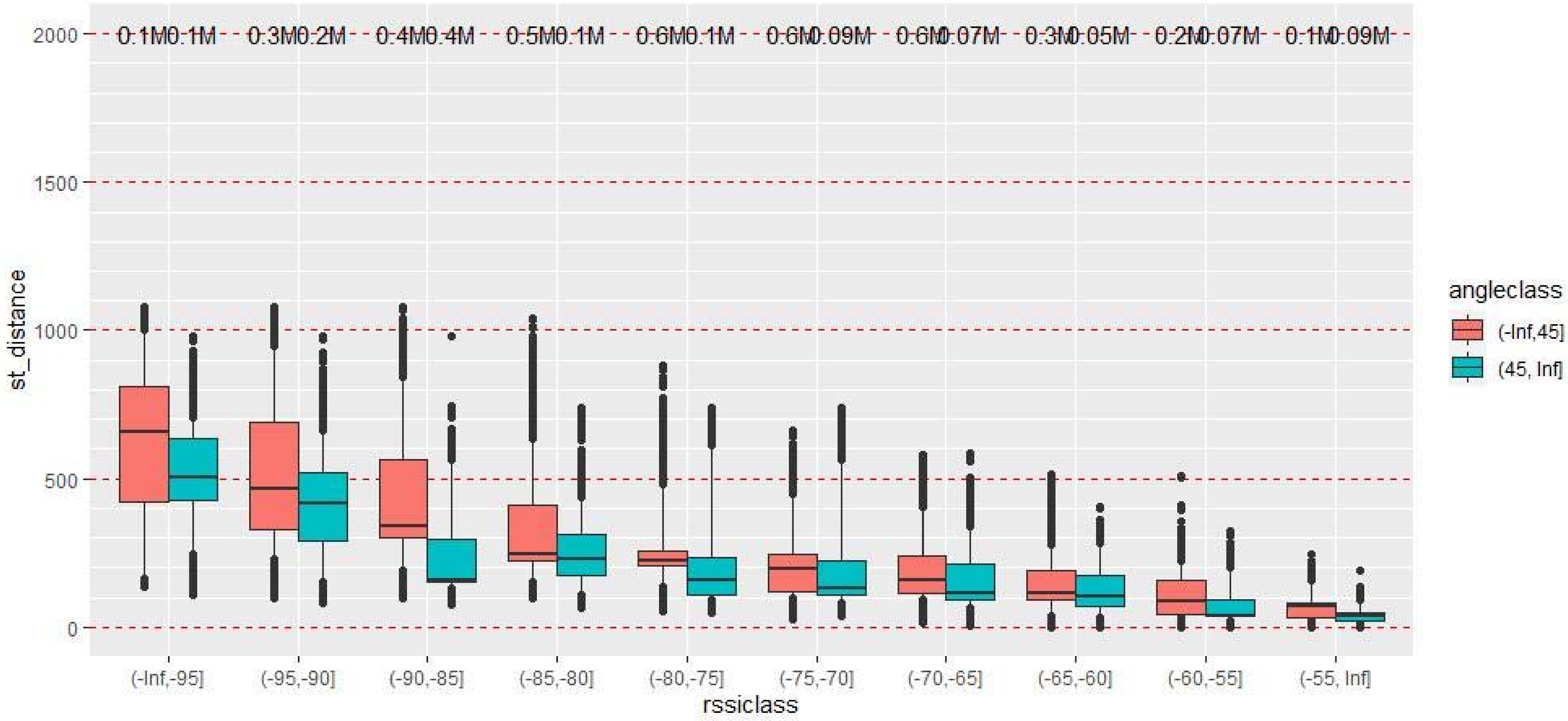

Figure 116: Distance (st_distance, m) per received power interval (rssiclass, dBm/10 MHz) concerning train receivers. Urban (Line 6, except Bercy)

As expected, it can be observed that the lower the received level is, the greater the distance.

However, it appears that ranges in urban environment are sometimes greater than suburban environment ranges. It may be due to the fact that for Line 6 (urban), there are perpendicular roads directly Line-of-Sight from the receivers, while for Line 8, this happens less often. In these streets, the attenuation is expected to be rather low compared to non-Line of Sight situations. It is not clear whether this "street configuration" is endogenous to the urban environment or simply a result of the design of the measurement campaign.

Figure 117 compares the "typical" urban environment (orange) with Bercy (green), and clearly exhibits the effect of the propagation over the Seine river. This kind of singularities suggests that using simple analytical models with no additional information on the land cover could not give acceptable results if the aim is to simultaneously identify the whole extent of a protection zone while not overshooting by a great extend its size.

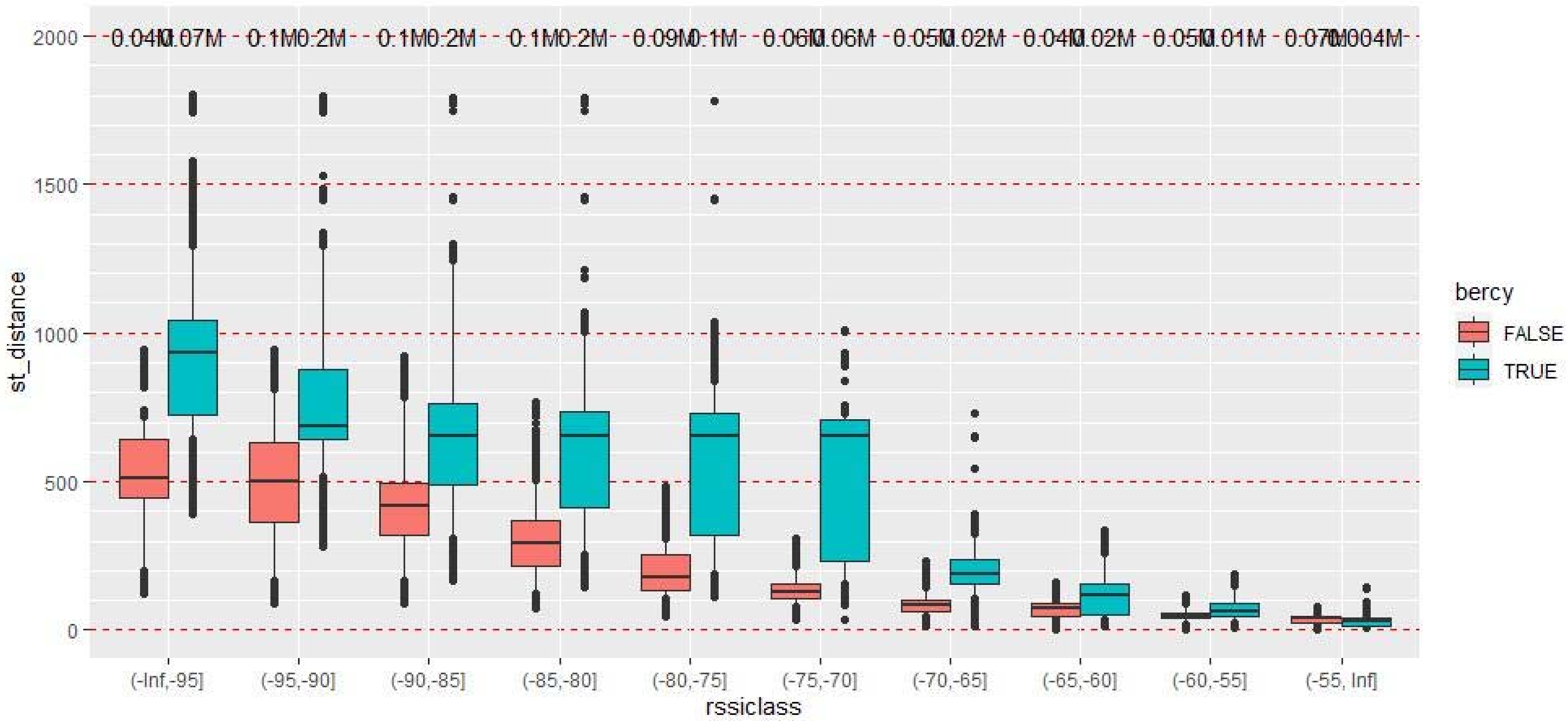

Figure 117: Distance (st_distance, m) per received power interval (rssiclass, dBm/10 MHz) concerning access point receivers. Urban except Bercy (Orange) and Bercy (Green)

8.5.2 Comparison between the two vehicles' antenna heights

The two vehicles transmitting vehicles used have two different antenna heights. Vehicle 1 is approximately 3,2 m and vehicle 2 is approximately 2,5 m.

Figure 117 and Figure 119 show statistics of the received power levels per distance intervals, received from each vehicle, at respectively base stations and train receivers.

This allows to investigate possible effects of the antenna heights, for various distance ranges between the vehicles and receivers.

It can be observed that the difference between the two vehicles is small and, for some cases, counter-intuitive: higher median RSSI values are obtained for the lower vehicle for base stations. The observation does not hold for 95-percentile values, nor for train receivers.

It is worth noting that EIRP for both vehicles have been measured, and a correction factor was applied in order to normalize the EIRPs of both vehicles to 33 dBm/10 MHz. A measurement error of the EIRP would lead to over or under-estimating the corrected received levels, in a biased way for each vehicle. Because the magnitude of the EIRP measurement uncertainty is unknown, one can only conclude that the effect of an antenna height difference of around 70 cm seems rather limited.

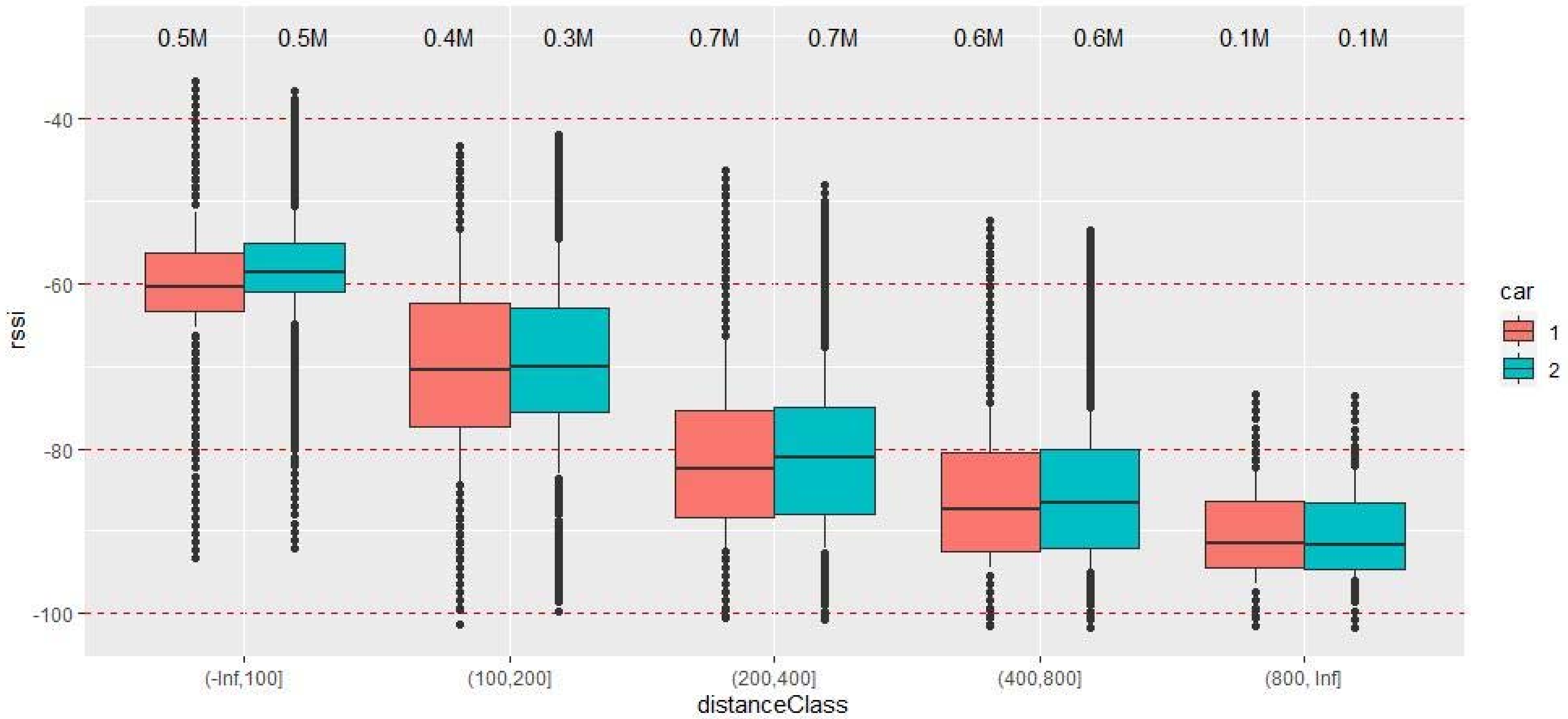

Figure 118: Received power levels (rssi) for base stations per distance intervals (distanceClass) with orange box concerning vehicle 1 (3,2 m Antenna height) and blue box vehicle 2 (2,5 m antenna height)

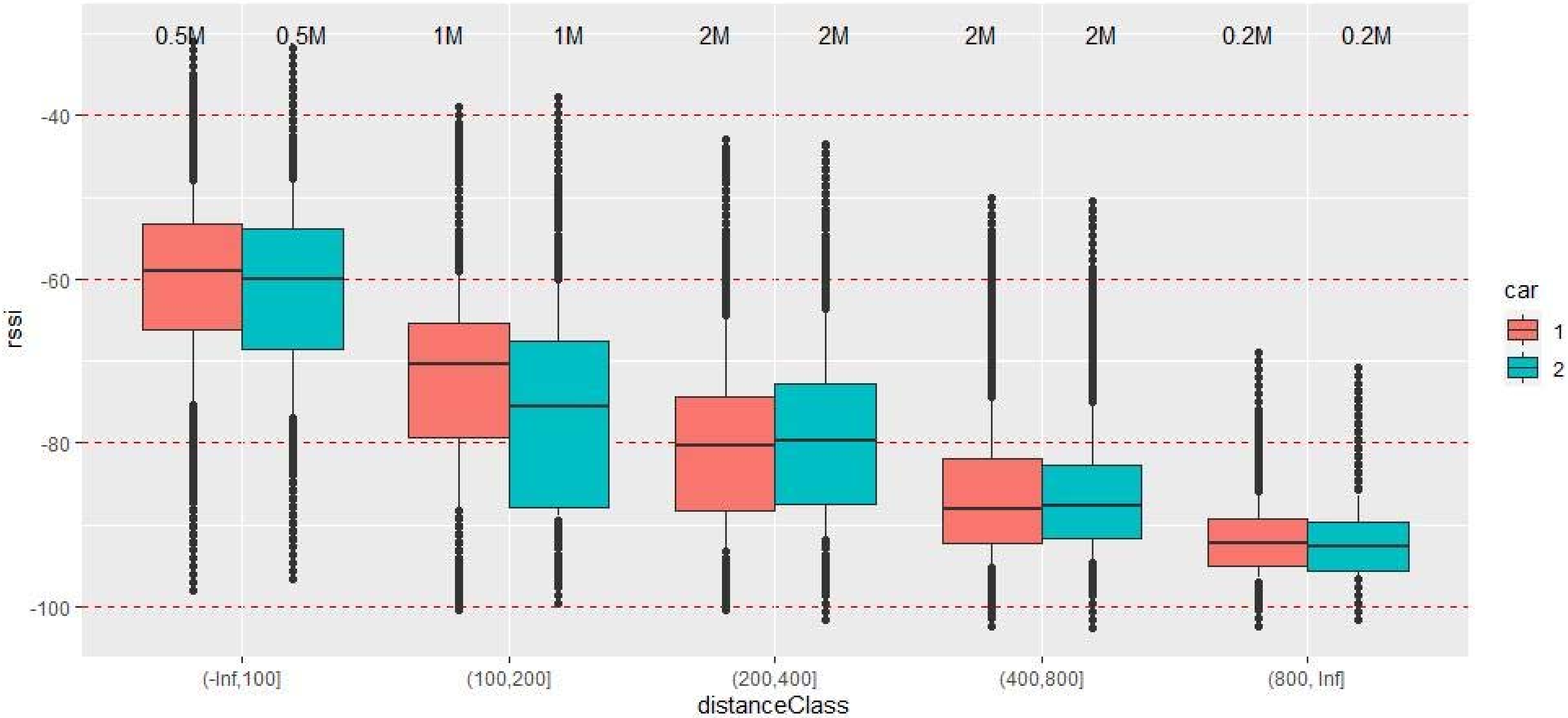

Figure 119: Received power levels (rssi) for trains per distance intervals (distanceClass) with orange box concerning vehicle 1 (3,2 m Antenna height) and blue box vehicle 2 (2,5 m antenna height)

8.5.3 Comparison between base stations and train receivers

Figure 120 compares the received power levels from one base station whose height has been changed from about 5 m to about 3,5 m.

To allow the comparison, a vehicle repeated twice the same route.

The x-axis is the distance between the receiver and vehicle location, projected on a vector corresponding to the main driving direction (here the river direction).

This seems to show that the effect of the receiving antenna height between 3,5 m and 5 m is rather limited compared to the inherent signal variation, at least for such an open environment on an elevated viaduct on the bridge, like it was the case at Bercy along the river.

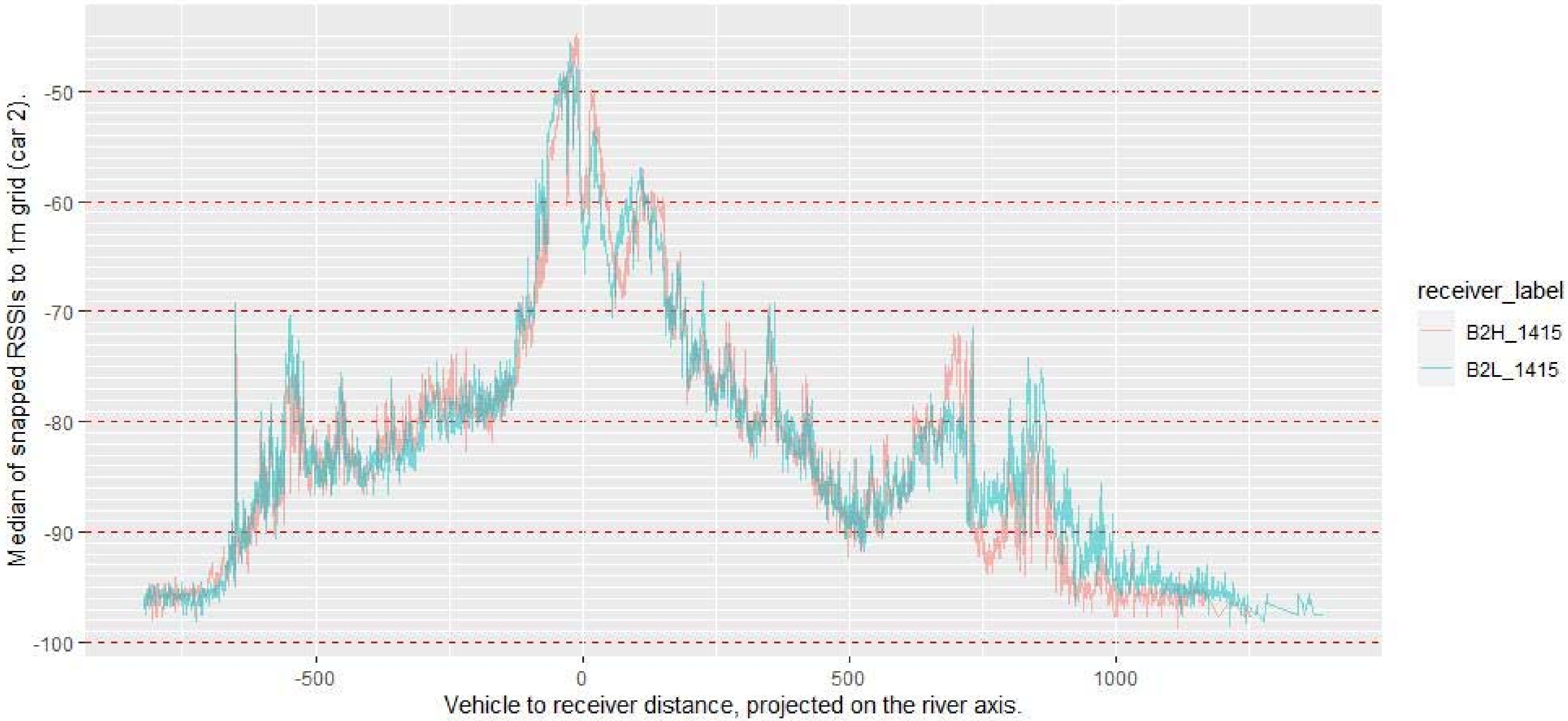

Figure 120: Power level received as a function of the distance between vehicle and a base station configured as either an access point (5 m, red curve) or a train (3,5 m, green curve)

8.5.4 Summary of statistical analysis

The following observations can be drawn from the measurement results regarding vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP:

- For CBTC access points, in suburban areas and off-axis of the antenna, more than 5 % of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 400 m from the receiver.
- For CBTC access points, in urban areas and off-axis of the antenna, more than 5 % of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 500 m from the receiver.
- For CBTC onboard units, in suburban areas and off-axis of the antenna, more than 5 % of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 400 m from the receiver.
- For CBTC onboard units, in urban areas and off-axis of the antenna, more than 5 % of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 600 m from the receiver.
- Areas in the antenna axis are typically close from the tracks and would therefore be located in the protection zones anyway. However, this does not hold when the tracks turn or nearby tunnel entrances, where more than 5 % of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 900 m from the receiver.
- The size of the protection zone could be significantly influenced by the environment (river, bridges, etc.). For instance, a receiver deployed on a viaduct over the Seine river measured more than 5 % of off-axis points with received power from the vehicles greater than -80 dBm/10 MHz up to 1 000 m from the receiver. Therefore, relying on simple analytical models with no additional information on the land cover could be misleading.

The distances for different received power thresholds can be read from the boxplots in clauses 8.5.1 and 8.5.2. A value of -80 dBm/10 MHz has been used for illustration only, and the assessment of the appropriate interfering threshold is not in the scope of the present document.

- The effect of varying vehicle antenna heights between 2,5 m and 3,2 m cannot be inferred from the measurements performed.
- The effect of varying CBTC antenna heights between 3,5 m and 5 m cannot be inferred from the measurements performed.

9 Conclusion and proposal

A measurement campaign to evaluate the received power at CBTC antenna reference point and originating from vehicles equipped with Road ITS was completed in September 2021, in Paris. The measurement campaign covers both urban and suburban areas and, altogether, 15 million of measurement points have been recorded, from 28 fixed CBTC measurement locations. Additional measurements were also performed with the train on the move.

The following observations can be drawn from the measurement results regarding vehicles transmitting with the maximum allowed output power of 33 dBm/10 MHz EIRP:

- For CBTC access points, in suburban areas and off-axis of the antenna, a significant number of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 400 m from the receiver.
- For CBTC base stations, in urban areas and off-axis of the antenna, a significant number of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 500 m from the receiver.
- For CBTC onboard units, in suburban areas and off-axis of the antenna, a significant number of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 400 m from the receivers.
- For CBTC onboard units, in urban areas and off-axis of the antenna, a significant number of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 600 m from the receivers.

- Areas in the main lobe of base station and train antennas and at a short distance from to antennas axis are typically close from the tracks and would therefore be in the protection zones anyway. However, this is no longer true when the tracks turn or nearby tunnel entrances, where a significant number of points have been measured with received power from the vehicles greater than -80 dBm/10 MHz up to 900 m from the Base station or train antennas.

- The size of the protection zone could be significantly influenced by the environment (river, bridges, etc.). For instance, a receiver deployed on a viaduct over the Seine river measured a significant number of off-axis points with received power from the vehicles greater than -80 dBm/10 MHz up to 1 000 m from the receiver. Therefore, relying on simple analytical models with no additional information on the land cover could be misleading.

The distance for different received power thresholds can be read from the boxplots in clause 8.5. A value of -80 dBm/10 MHz has been used for illustration only, and the assessment of the appropriate interfering threshold is not in the scope of the present document.

- The effect of varying vehicle antenna heights between 2,5 m and 3,2 m cannot be inferred from the measurements performed.

- A simulation shows that the difference of the received levels between vehicle antenna heights of 3,2 m and 2,5 m. 88 % of differences are below 3 dB. However, the measurement results do not exhibit such a clear-cut trend.

- The effect of varying CBTC antenna heights between 3,5 m and 5 m cannot be inferred from the measurements performed.

Although the received levels in the present document are displayed for vehicles transmitting at maximum output power (33 dBm/10 MHz as defined in Commission Implementing Decision (EU) 2020/1426 [i.8]), the results could be scaled down for different transmit powers (e.g. 10 dB decrease for vehicles transmitting 23 dBm/10 MHz).

The aggregated power from multiple vehicles transmitting has not been investigated in the present document, however this could be investigated later with the measurement data available.

Measurements results have subsequently been compared with simulated received power levels in order to investigate the possibility to identify protection zones through simulations.

However, the simulations tend to underestimate the received power originating from non-Line of Sight streets.

For the assessment of the protection zones, simulations may therefore be useful to evaluate "minimum" or "optimistic" protection zones. The tendency of the simulations to under-estimate the received power may be mitigated, to some extent, by simulating victim CBTC receivers installed onboard trains all along the tracks instead of considering few isolated receiver locations.

A good property of the simulation is also its ability to predict consistently the received level for both regular areas and areas exhibiting singularities from a radio-propagation perspective.

Further enhancements of the simulation results are achieved with an improved multipath algorithm and calibrating the reflection coefficients. A dedicated processing of the terrain maps has also shown to improve greatly the simulations, hence a better map accuracy (post-treating legacy maps or using lidar data) is therefore expected to improve the prediction of the protected zones.

The improvements brought by these enhancements are yet to be investigated.

In conclusion, while simulations could be used to enhance the shape of the protected zones, it is recommended to benchmark the simulation setup against measurement data. The measurement data collected in the context of the measurement campaign introduced in the present document could be used for that purpose.

Subsequent to the measurement campaign presented in the present document, a revision of ETSI TR 103 580 [i.2] will be required. The revision will focus on identifying the most appropriate mitigation techniques and will be the basis of future normative work.

Annex A: List of test equipment

A.1 Detailed description of the RF measurement tool

The RF measurement tool is the Cohda Wireless MK5 DSRC On-Board Uni (OBU). The MK5 is designed to provide a compact platform for the deployment of advanced connected vehicle applications and protocol stacks.

This platform has been selected for its ease of use and the availability specific test functions that allow to generate packets at mac layer with configurable length, modulation scheme and frequency of generation.

The Codha wireless platform MK5 on the tx side records for each transmitted packet, a time stamp derived from the GPS signal, its latitude and longitude, packet length, sequence number.

On the Rx side, the Codha wireless platform MK5, synchronize its clock with the transmit side and record, time stamp of tx, Time stamp of rx, Latitude and longitude of tx and its Latitude and longitude, received packet length, sequence number, modulation index, received level for each antenna, noise level of each antenna and mac address of the issuer.

More information about the Codha wireless platform MK5 can be find at: https://www.cohdawireless.com/.

A.2 Antenna for CBTC Base station and train

The antenna of choice is one with a high directivity that will look along the track of the train. Its polarization is vertical with a gain of 15 dBi at 5 880 MHz (measurement frequency according to the issued measurement licence).

The 3 dB beamwidth is 35° in the vertical and horizontal plane.

The front to back ratio is 20 dB.

Figure A.1 shows the radiating pattern in the horizontal plane.

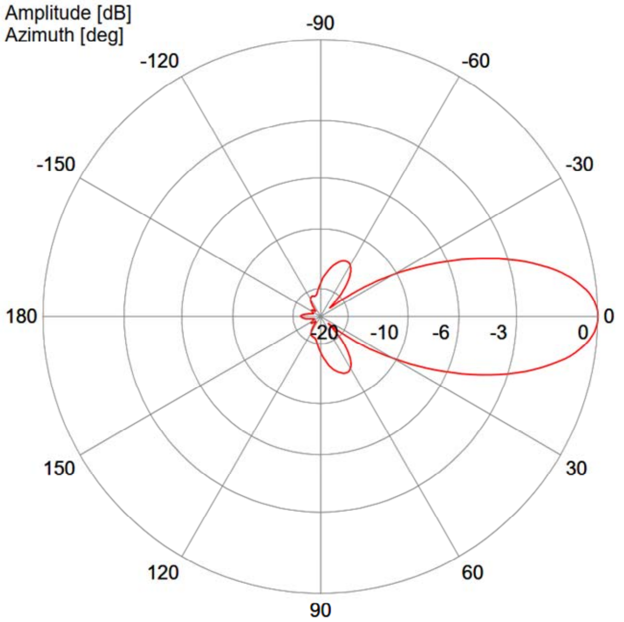

Figure A.1: Radiating pattern in the horizontal plane

Figure A.2 shows the radiating pattern in the plane.

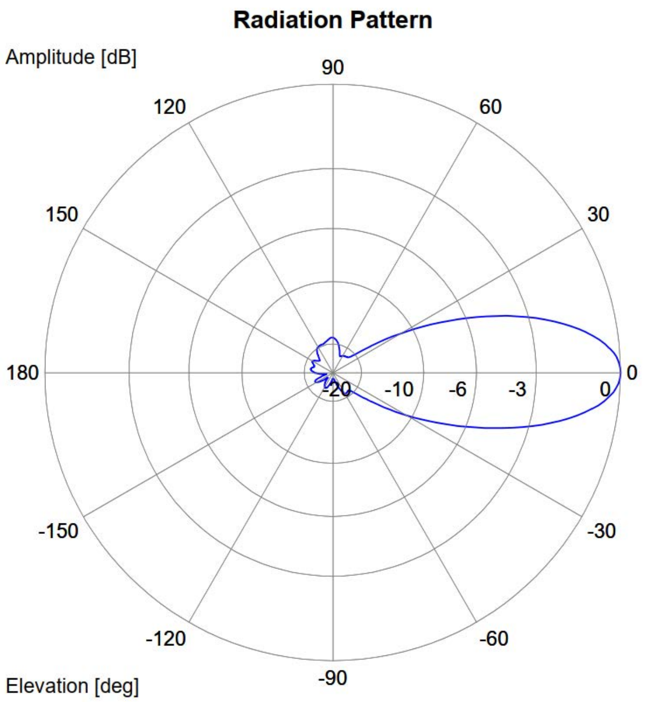

Figure A.2: Radiating pattern in the horizontal plane

A.3 Choice vehicle roof-top antenna for measurements

A.3.1 Introduction

Antennas for road vehicles can be installed in different locations on the vehicle. The desired radiation characteristic is always omnidirectional in the horizontal plane similar to an ideal monopole on an infinite ground plane. The reason behind this is that the sender and receiver can be located in any direction towards each other. The ideal location would be the highest point in the centre of the roof. Unfortunately, this is not possible if there is a large glass sunroof or if the vehicle is a convertible or a truck with changing trailers. In addition, the design sometimes does not allow for the ideal placement.

Therefore, the most common placement is not the centre of the roof but near the backlight window at the rear of the roof. In case of convertibles or trucks it can also be in the mirrors or the near the placement of the rear viewing cameras substituting the mirrors.

This placement is a compromise and changes the ideal behaviour of a monopole antenna. Since the ground plane is not infinite anymore, effects of the corners and rectangular shape of the roof, as well as the curvature and asymmetrical placement influence the radiation diagram see [i.9]. Taking the same monopole type of antenna, on different vehicle designs, as is common with vehicle manufacturers, results in slightly different antenna pattern for each design.

The finite ground plane/roof leads primarily to raised main lobes and due to multipath effects from the edge of the ground plane to a multilobe antenna diagram in elevation. Therefore, directing energy in non-preferred directions.

The most common change is in the raise of the antenna lobe near the end of the ground plane / roof. Since e.g. with sportive designs, the roof at the back of the vehicle is on a downward slope the rearward-looking antenna lope is also tilted towards the horizon, whereas the forward-looking lobe is drawn towards the larger ground plane and therefore to some extend compensate for the unsymmetrical mounting position. But as soon as the same vehicle is built with a glass sunroof, roof racks etc. the antenna diagram changes significantly, see [i.10].

The height of an antenna installed on a road vehicle above the ground will depend on the type of road vehicle and its location rooftop or side mirror.

Three types of vehicles can be considered to the range of antenna height: Sports vehicle, Off roader vehicle and Truck:

- Sports vehicle:
  - Antenna Rooftop installation height: 1,2 m to 1,4 m
  - Antenna Side mirror installation height: 0,6 m to 0,9 m

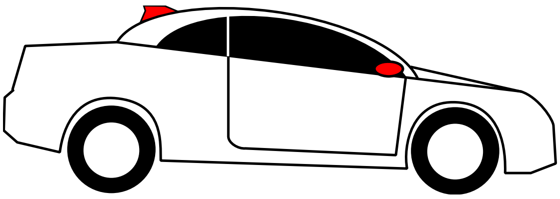

Figure A.3: Sports vehicle possible antenna locations

- Off roader vehicle:
  - Antenna Rooftop installation height: 1,9 m
  - Antenna Side mirror installation height: 1,2 m

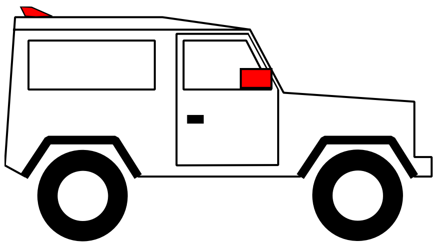

Figure A.4: Off roader vehicle possible antenna locations

- Truck:
  - Antenna Rooftop installation height: 3,8 m to 4 m (unusual)
  - Antenna Side mirror installation height: ~ 2 m (typical mounting)

The measurement will deliver attenuation values of the channel between the vehicle and the CBTC-Train and the CBTC-Base station to verify or modify the simulations done for ETSI TR 103 580 [i.2].

It was discussed that not only the Line-of-Sight propagation is of interest, but also the reflected signal under higher elevation angles that may arrive at the CBTC transceiver in non-Line of Sight situations. E.g. vehicle in a road perpendicular to the train rails and the train receiving a reflected signal from a rainwater pipe or a lamp post.

Choice of vehicle antenna for the measurements is the 3 dBi monopole with an equally distributed gain over a wide elevation range, therewith covering possible antenna patterns with main lobes at higher elevation angles. It covers these higher elevation angles to incorporate reflected signals from buildings, bridges, etc. At the same time the gain difference in all elevation sectors is relatively small and can be sorted into elevation bins. This can be used for the simulation using different antenna models for different vehicles.

In Cost Action 2100 TD (10)12036 the placement of different antenna types in different scenarios was investigated and shown that this has a strong influence on the channel parameters and the need for realistic antennas in the simulation environment.

The 3 dBi monopole approximates a standard roof antenna. Vehicle manufacturers around the world will use their own design of a V2X antenna. It may be conformal (integrated into the hull of the vehicle) or a roof antenna system that contains several antennas for different systems. These different configurations influence the antenna diagram and the gain in certain directions. So, there are different antenna configurations that need to be statistically evaluated.

In addition to the multitude of manufacturers there is the dependency on the vehicle design. One Original Equipment Manufacturer (OEM) will use one antenna for all his models ranging from cabriolets (antenna mounted on the trunk), sedans (antenna on the curved roof), Sports Utility Vehicle (SUV) (roof with/without racks, with small or large glass roofs, etc.) to small, medium and heavy trucks (installation in the side mirrors or rear-view camera housing).

Fortunately, the target is always to design a radiation pattern that is similar to an ideal monopole to fulfil an omnidirectional characteristic in the horizontal plane for the reliability of the V2V communication.

The gain of this multitude of antennas and mounting options can be approximated by defining typical sectors with an average gain inside these sectors.

For the measurement campaign the use of this very well-defined antenna allows to measure the path loss also for a Non-Line of sigth Signal path at higher elevation angles. The measured path loss could be "increased" by the gain of the measurement antenna to derive a path loss for an isotropic radiator. In case of a "typical" vehicle antenna it could be observed a typical gain of 5 dBi to7 dBi in a certain sector (e.g. elevation angle around 6° to 15°), this gain can be used to decrease the path loss for this simulation run for this sector of the antenna diagram view. Since the Line-of-sight path loss is always the shortest possible path, any multipath component will have to take a longer path and therewith have an increased loss in comparison to the Line-of-sight path.

Preferred antenna for the measurement campaign is a single monopole (3 dBi) on a large ground plane for the height of 1,5 m to 2 m. For the mirror antenna of a truck at the height of 3 m. (According to truck manufacturers this will be a standard height for future camera based rear-view systems on Trucks), the monopole ground plane may have to be smaller. Preferable it could be a simple dipole that in "free space" having in theory the same diagram as the monopole but with 3 dB less gain.

The ECC report 101 [i.4] has considered for analysis purposes a generic roof-top antenna that has the following specification:

- Maximum gain 5 dB at 10° elevation above the roof
- Omnidirectional in the horizontal plane
- Antenna pattern met the recommendation of Recommendation ITU-R F.1336 [i.13] with the factor k = 1,2 see ECC Report 101 [i.4].

Figure A.5 shows an example of pattern of a commercially developed antenna for rooftop installation on a road vehicle (source ECC Report 101 [i.4]).

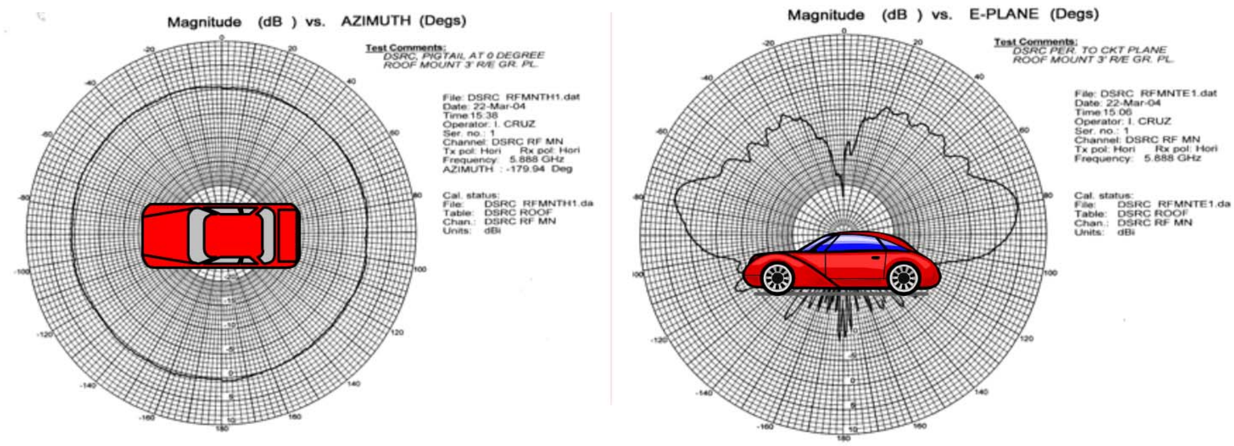

Figure A.5: Pattern a commercially developed antenna for rooftop installation on a Road vehicle

Figure A.6 shows a comparison between the Recommendation ITU-R F.1336 [i.13] with k = 1,2 model and the pattern of the commercial antenna.

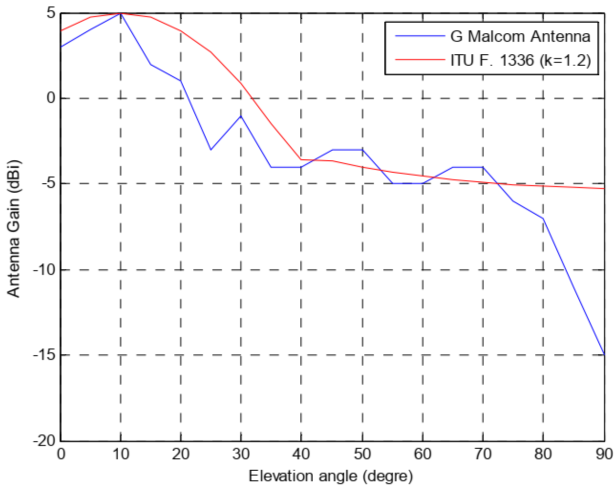

Figure A.6: comparison between the Recommendation ITU-R F.1336 [i.13] with k = 1,2 model and pattern of a commercial antenna

A.3.2 Choice of Antenna

Looking at different monopole antennas, the antenna diagrams for an evenly distributed gain over elevation angles up to 60° measured from the horizontal plane were evaluated. It could be observed that the same antenna measured with or without ground plane showed quite different radiation patterns. The desired pattern is achieved without ground plane shown in Figure A.7. Figure A.8 depicts the radiation pattern with a 1 m ground plane.

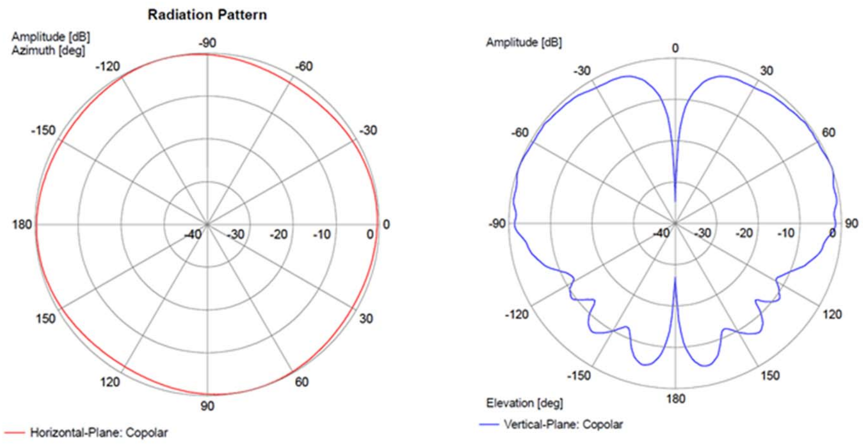

Figure A.7: Monopole roof antenna measured without ground plane

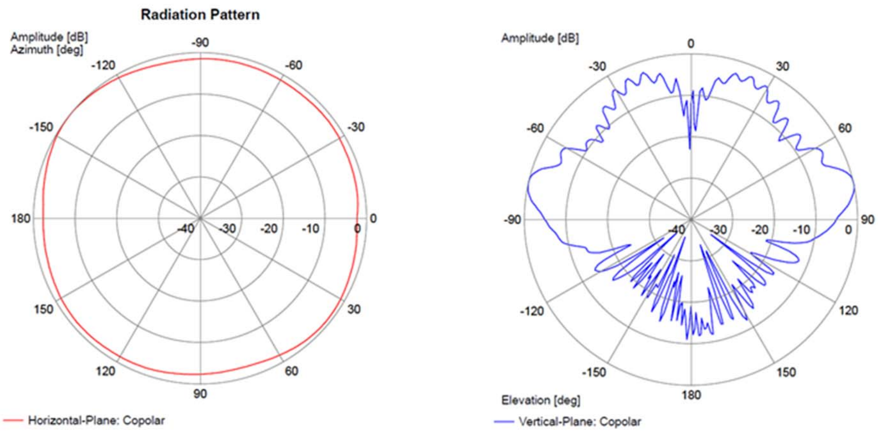

Figure A.8: Roof antenna measured while mounted on a 1 m diameter ground plane

A.3.3 Choice of Antenna height above the roof

To get an idea about the distance above a roof that could deliver a diagram equal to a measurement without ground plane, a monopole above a rectangular metal plate as it could be mounted on the test vehicles was simulated.

The results are obtained with the CST simulation tool. A 1,10 cm Monopole on a 6 cm ground plane (i.e. mounting plate of the real antenna) at the height h above a metallic plate 1 m x 2 m at the centre of the plate. Height was varied from h = 15 cm, h = 20 cm, h =30 cm to h = 40 cm.

The following plots for Phi = 0° show an elevation cut along the short centre Line. Plots for Phi = 90° show an elevation cut along the long centre Line of the metallic plate. i.e. along the vehicle centre Line.

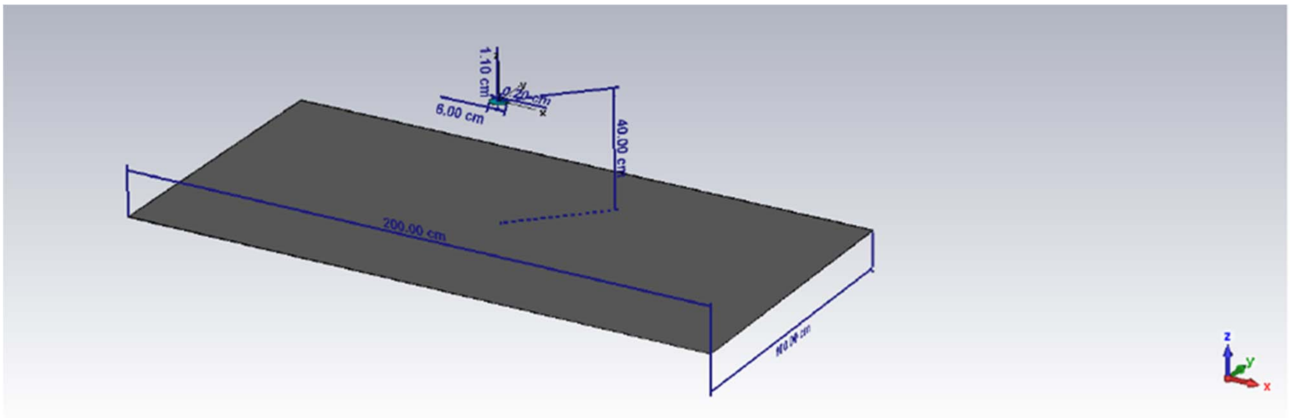

Figure A.9: Schematic drawing of the simulated parts together with the coordinate system

The radiation diagram plots are generated by the simulation system and cannot be changed in the way they are displayed.

All elevation angles start at the z-axis. i.e. Theta =0° is parallel to the z-axis looking into the "sky". Increasing to Theta =90°, where it is parallel to the x-y plane

The azimuth angel Phi = 0° is parallel to the y axis and increases to Phi = 90° in the x-y plain, being than parallel to the x-axis.

To better compare the results with the schematic drawing in figure A.9, rotate the diagrams by 90° counterclockwise. The elevation angle of interest from 0° (= the horizontal plane) up to elevation angles of 30° corresponds to Theta =90° "up" to Theta = 60° and on the other side to Theta = 270° up to 330°.

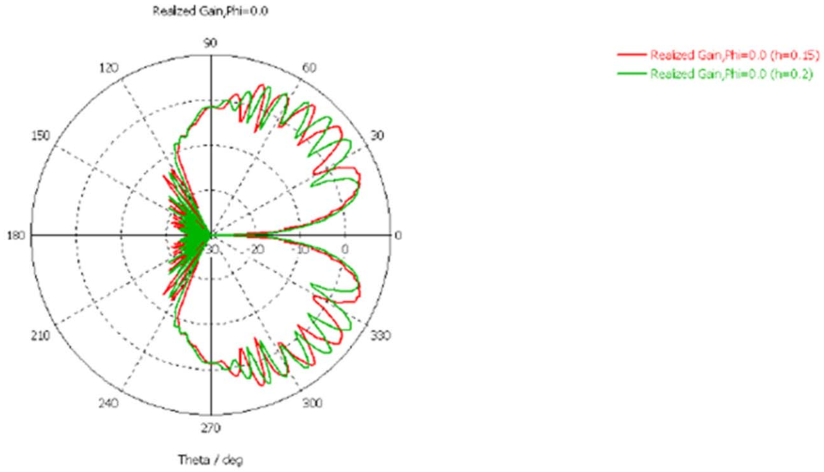

Figure A.10: Elevation cut through the short side of the ground plane (perpendicular to the driving direction) with gain for 15 cm (red) and 20 cm height (blue)

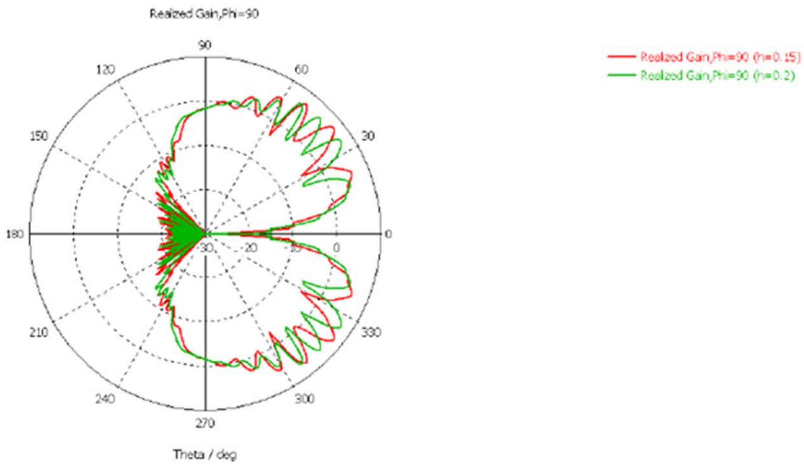

Figure A.11: Elevation cut through the long side of the ground plane (parallel to the driving direction) with gain for 15 cm (red) and 20 cm height (green)

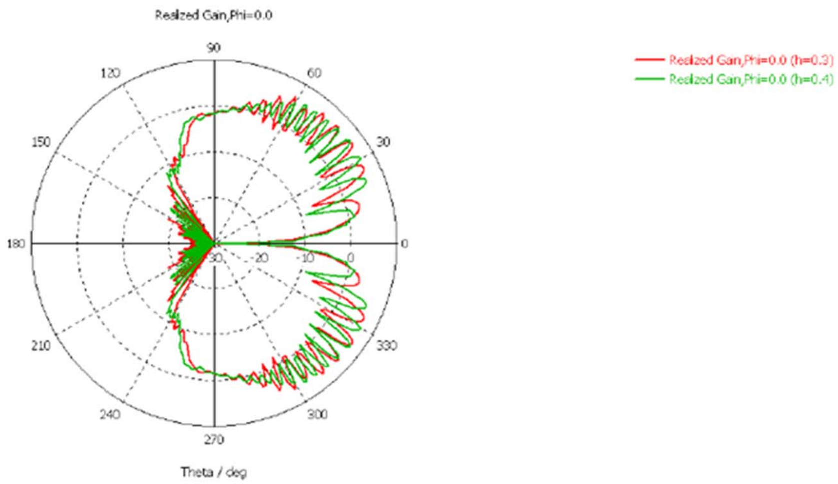

Figure A.12: Elevation cut through the short side of the ground plane (perpendicular to the driving direction) with gain for 30 cm (red) and 40 cm height (green)

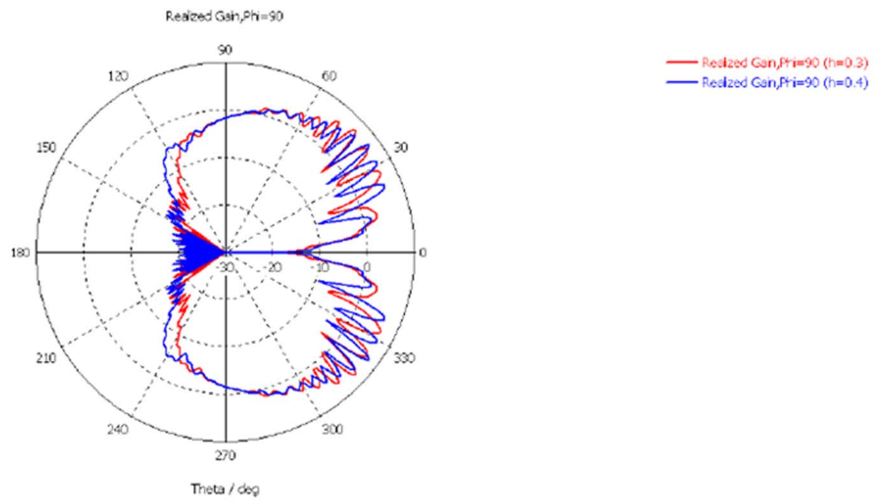

Figure A.13: Elevation cut through the long side of the ground plane (parallel to the driving direction) with gain for 30 cm (red) and 40 cm height (blue)

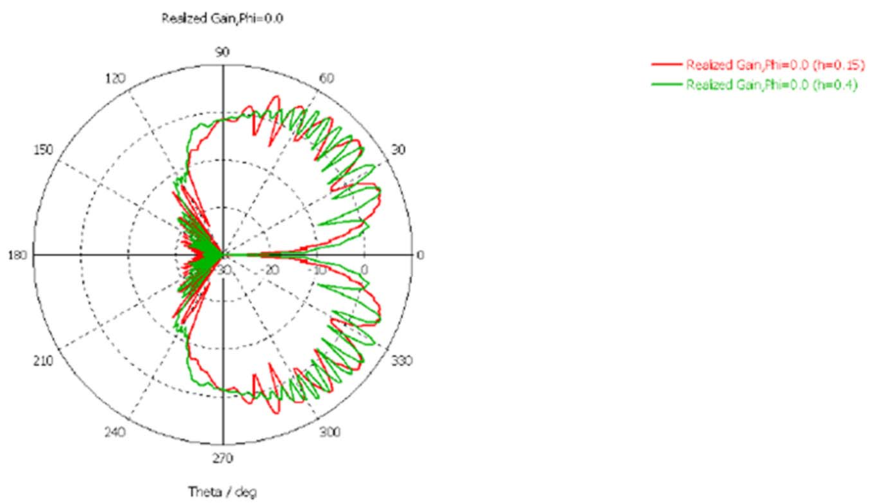

Figure A.14: Elevation cut through the short side of the ground plane (perpendicular to the driving direction) with gain for 15 cm (red) and 40 cm height (green)

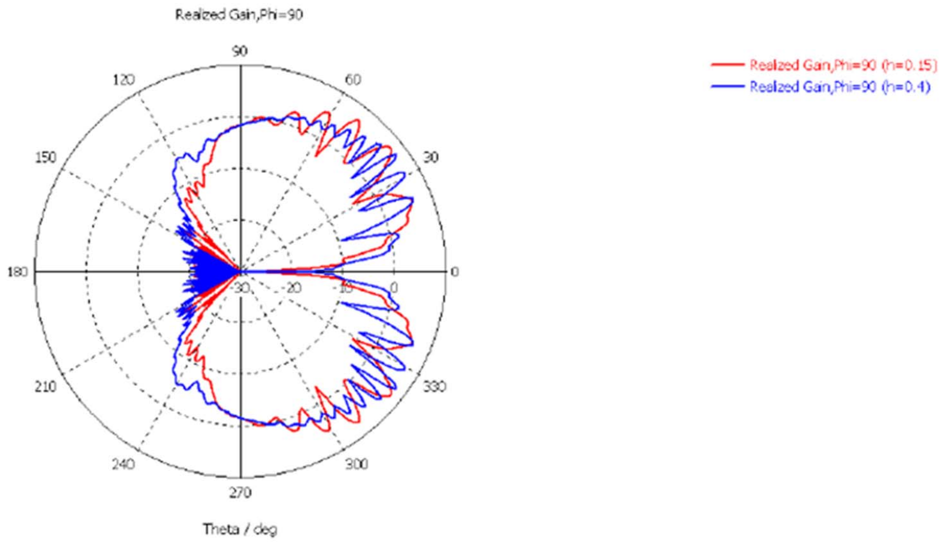

Figure A.15: Elevation cut through the long side of the ground plane (parallel to the driving direction) with gain for 15 cm (red) and 40 cm height (blue)

It can be seen that, to obtain a relative smooth elevation behaviour up to 30° elevation, a height above 40 cm is required.

To verify the simulations this configuration was also measured in the European Microwave Signature Laboratory (EMSL) of the Joint Research Centre (JRC) of the European Commission in Ispra, Italy, with the antenna used in the measurement campaign on the vehicles and with the similar mounting, see clause A.4.

A.4 Antenna reference measurements

A.4.1 Introduction

For the measurements performed in the scope of the present document, a specific antenna setup has been developed for the antenna to be used in the mobile unite of the overall scenario. In order to be able to use the resulting measurement values a detailed reference measurement of the used antennas are required. Furthermore, the optimal antenna height above the vehicle roof needs to be determined to ensure a smooth antenna diagram and to optimize the mechanical stability of the construction.

These reference measurements have been performed in July 2021 in the European Microwave Signature Laboratory (EMSL) of the Joint Research Centre (JRC) of the European Commission in Ispra, Italy.

In this annex a short overview of the measurements and the obtained results will be given. The main content of this annex has been provided by the JRC team in Ispra.

A.4.2 Scope of the measurements

The objective of the measurement campaigns executed in July 2021 in the Joint Research Centre facilities in Ispra, Italy was to evaluate the radiation pattern of the ITS-G5 antenna which have been used in the field measurements in Paris. This evaluation was needed to support the measurements which in turn are used to support the propagation simulations, which have been performed to evaluate the level received by Urban-Rail-ITS base station and train onboard units.

The main goal was to find an optimal compromise between the antenna height above the vehicle roof and omnidirectional antenna diagram.

A.4.3 Measurement setup

The reference antenna has been provided to the JRC in Ispra. In order to emulate the metal roof of a vehicle, a metal plate with a a length of 2 m, a width of 1 m and a thickness of 1,5 mm has been built by the JRC technical team.

The placement of the antenna on the platform in the EMSL is shown in Figure A.16, while the details of the antenna and its components are shown in Figure A.17.

The referential framework used to collect the radio frequency measurements is shown in Figure A.18. This notation will be used in the subsequent results.

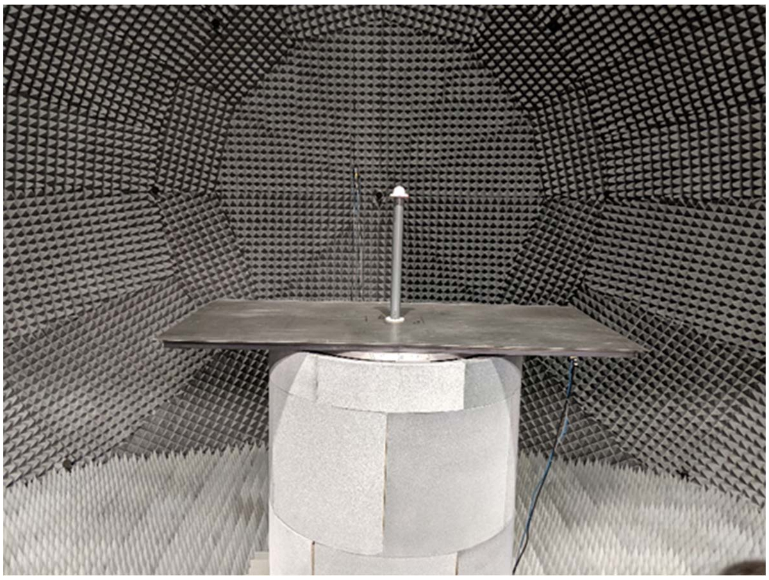

Figure A.16: Placement of the antenna in the centre of the EMSL positioned over the metallic support to simulate the roof of the vehicle

Figure A.17: Details on the antenna and the support used in the experimental measurements

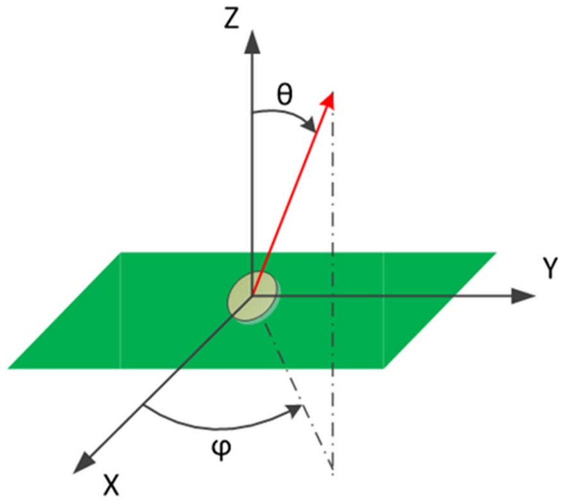

Figure A.18: Referential framework used for the measurement setup with azimuth ϕ and elevation angle θ

This clause describes the results of the experimental campaign done in the JRC for the measurement campaign.

Most of the measurements were done at a frequency of 5 880 MHz and some measurements were done at 5 920 MHz for comparison.

The results are shown for different views of the radiation pattern and for different heights of the plastic tube used to distance the antenna from the metallic platform. Measurements were performed both for horizontal and vertical polarization.

Figure A.19 shows the 3D-view, with a colour bar that expresses the gain in dBi, of the radiation pattern with 50 cm height of the antenna support and vertical polarization. The radiation pattern is quite uniform apart from the appearance of 'ripples' or 'gaps' on the surface of the radiation pattern.

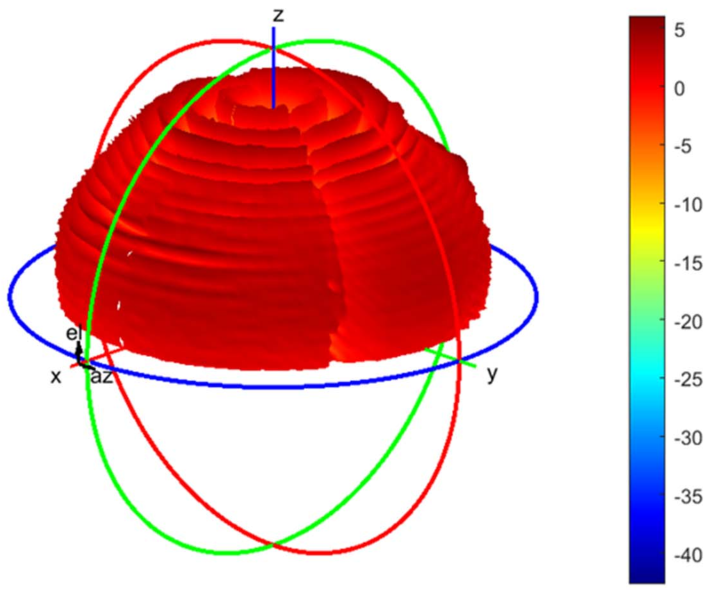

Figure A.19: 3D view of the Radiation pattern of the antenna with 50 cm support height for vertical polarization, the colour bar expresses the gain in dBi

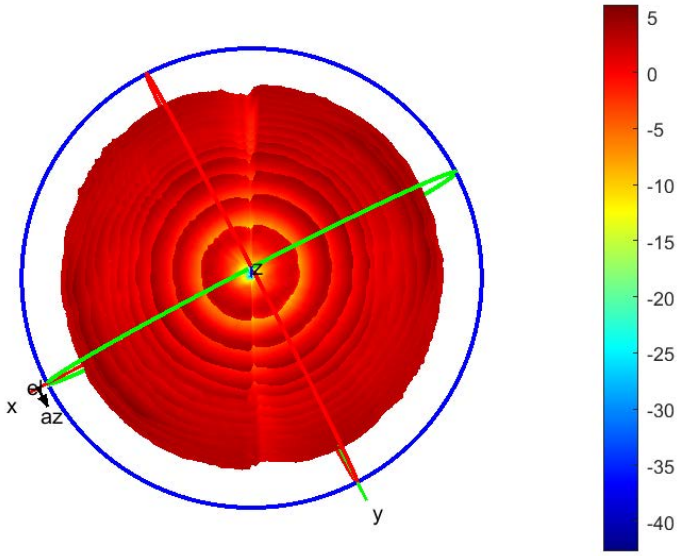

Figure A.20: Vertical view with a colour bar indicating the gain in dBi of the antenna radiation pattern with 50 cm support height

The presence of such discontinuities is even more visible in Figure A.22, which shows the vertical view of the antenna radiation pattern with 50 cm support height.

A more detailed view of the radiation patterns (still with vertical polarization) is visible in:

- Figure A.21, which shows the horizontal cut at different values in degrees of the elevation θ with height of the support of 40 cm; and
- Figure A.22, which shows the horizontal cut at different elevation θ degrees with height of the support = 50 cm.

The presence of ripples is more evident in Figure A.23, which shows the vertical cuts at different degrees with height of the support = 40 cm and Figure A.24, which shows the vertical cuts at different degrees with height of the support = 50 cm.

The 'ripples' are slightly less pronounced in the height with support of 50 cm rather than the support of 40 cm. The ripples are more present with smaller heights. A possible reason for this behaviour is that the metallic support (which represents in the real world the roof of the automotive vehicle) creates disturbances to the radiation pattern of the antenna.

To evaluate this hypothesis, measurements were collected with different heights of the support both for horizontal and vertical polarization in Figure A.25 and Figure A.26 respectively for azimuth $\phi = 0°$ and $\phi = 90°$. It can be seen from Figure A.25 and Figure A.26 that the lower is the height of the antenna and the more the discontinuities are pronounced in the radiation pattern for both polarizations.

An analysis of the radiation pattern at the frequency of 5 920 MHz was also performed. Figure A.27 and Figure A.28 show the different radiation patterns (for both horizontal and vertical polarization) for the different frequencies of 5 880 MHz and 5 920 MHz respectively for azimuth $\phi = 0°$ and $\phi = 90°$.

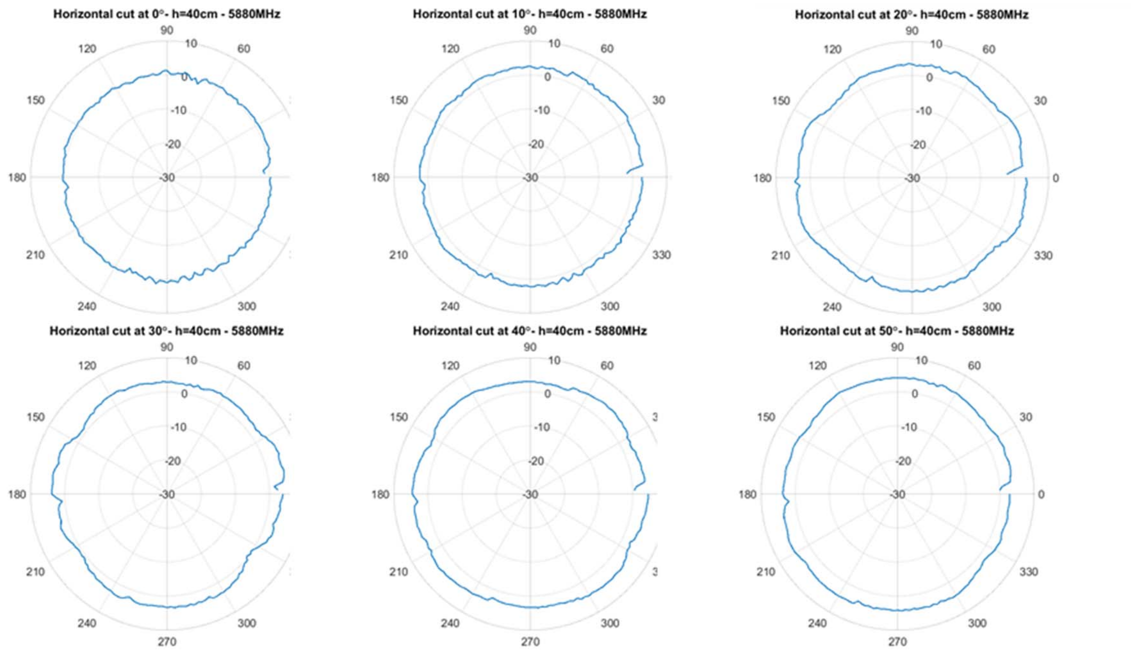

Figure A.21: Radiating Pattern for vertical polarization, for horizontal cut at different elevation angles θ with support height of 40 cm

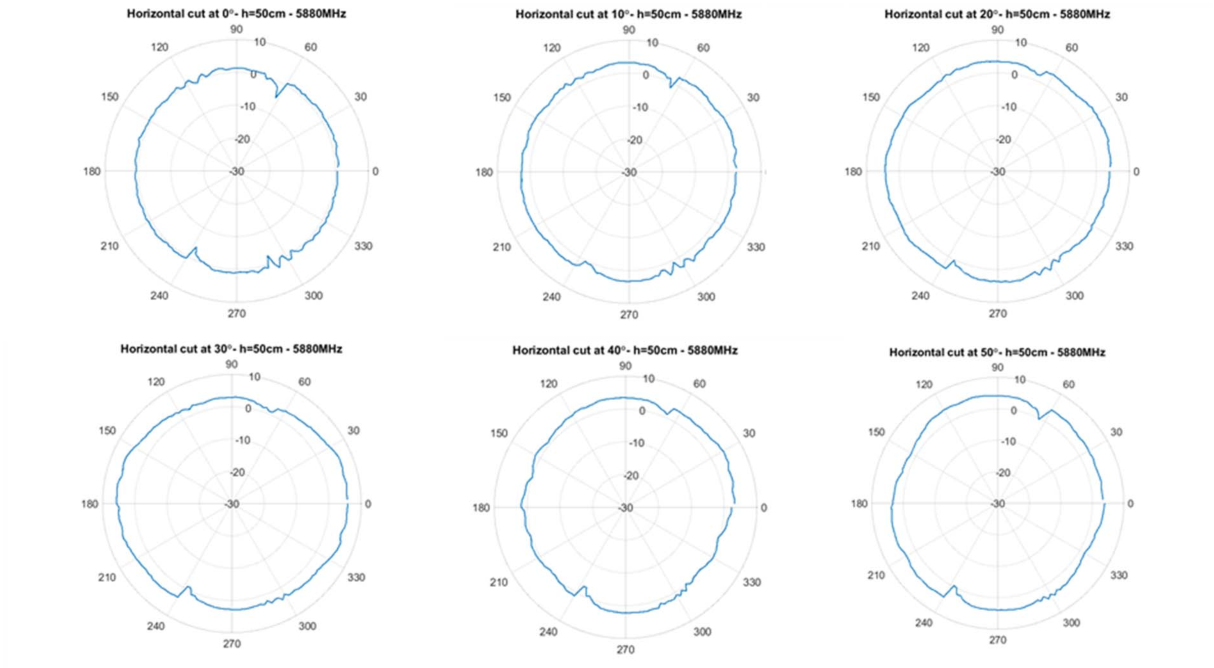

Figure A.22: Radiating pattern for vertical plorization for horizontal cut at different elevation angles θ with support height of 50 cm

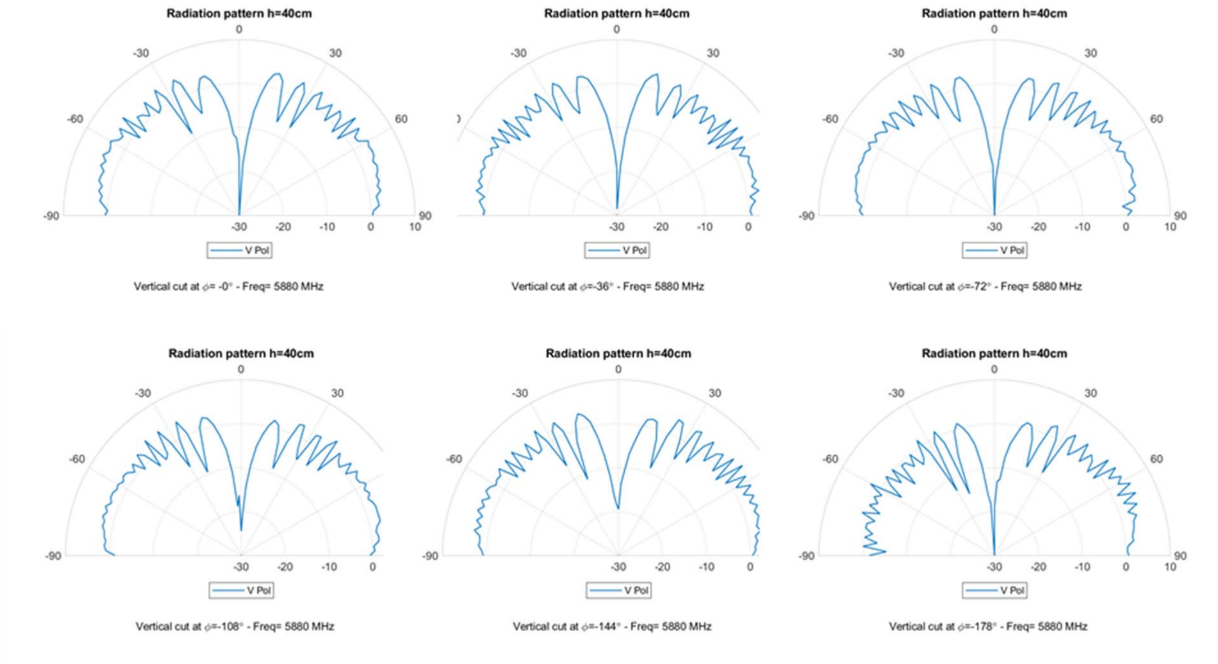

Figure A.23: Radiating pattern for vertical polarization for vertical cut at different elevation angles θ with support height of 40 cm at 5 880 MHz

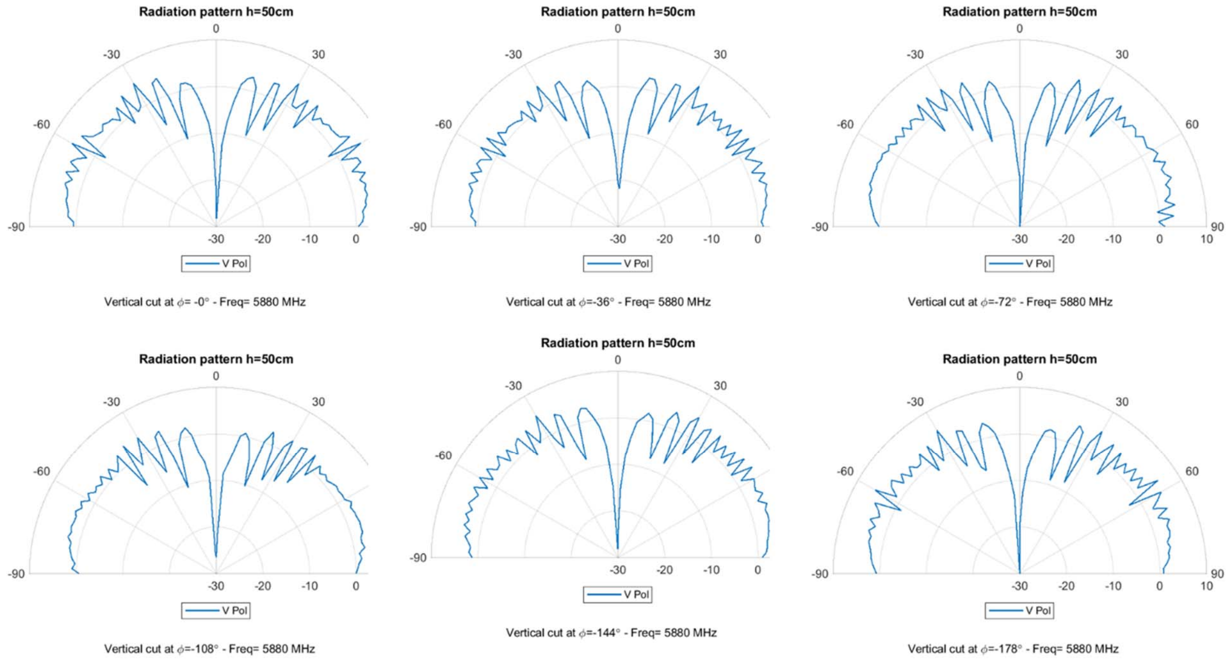

Figure A.24: Radiating pattern for vertical plorization for vertical cut at different elevation angles θ with support height of 50 cm at 5 880 MHz

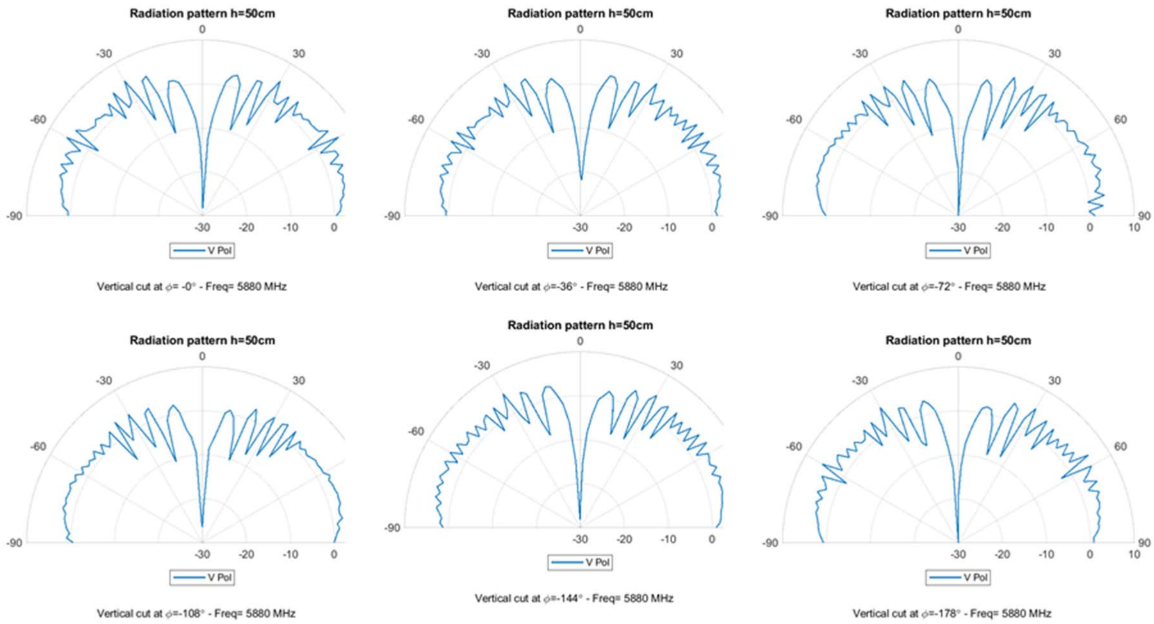

Figure A.25: Comparison of vertical and horizontal polarization with vertical cuts at azimuth ϕ = 0° with different heights of the support at 5 880 MHz

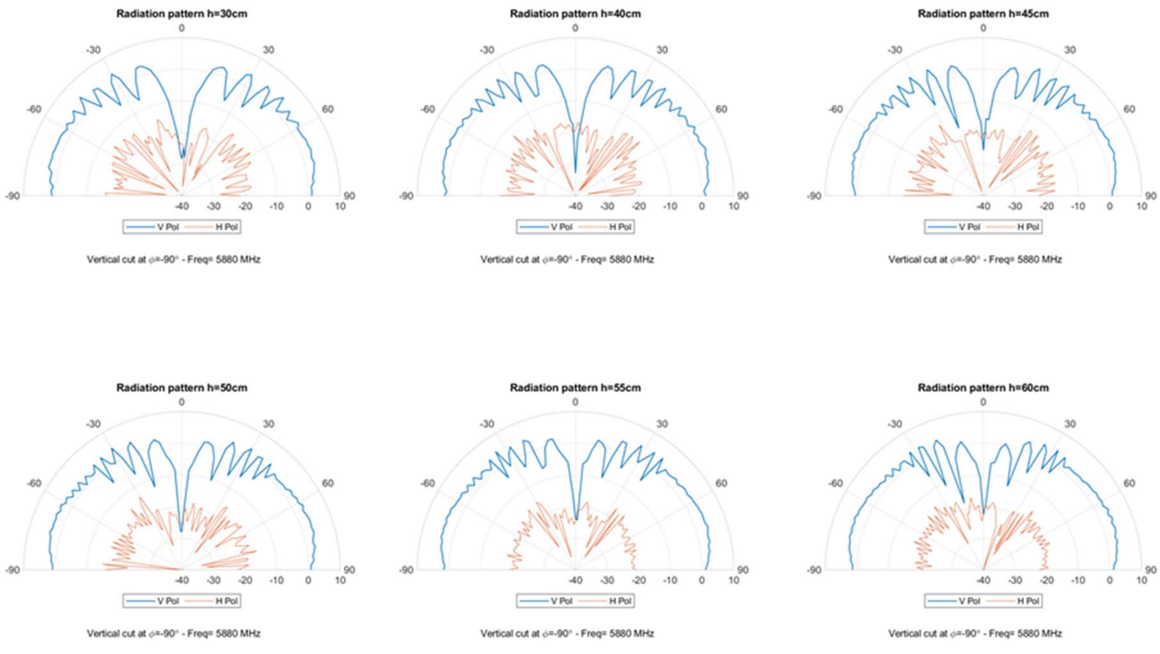

Figure A.26: Comparison of vertical and horizontal polarization with vertical cuts at azimuth ϕ = 90° with different heights of the support at 5 880 MHz

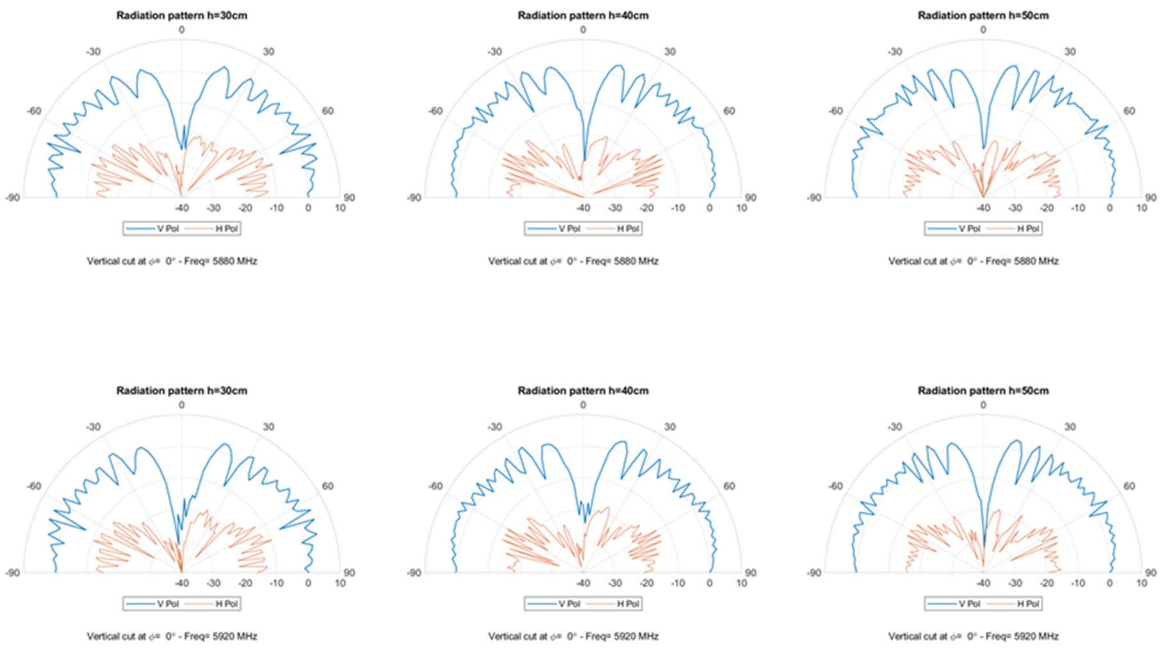

Figure A.27: Comparison of vertical and horizontal polarization with vertical cuts at azimuth ϕ = 0° with different heights of the support and different frequencies of 5 880 MHz and 5 920 MHz

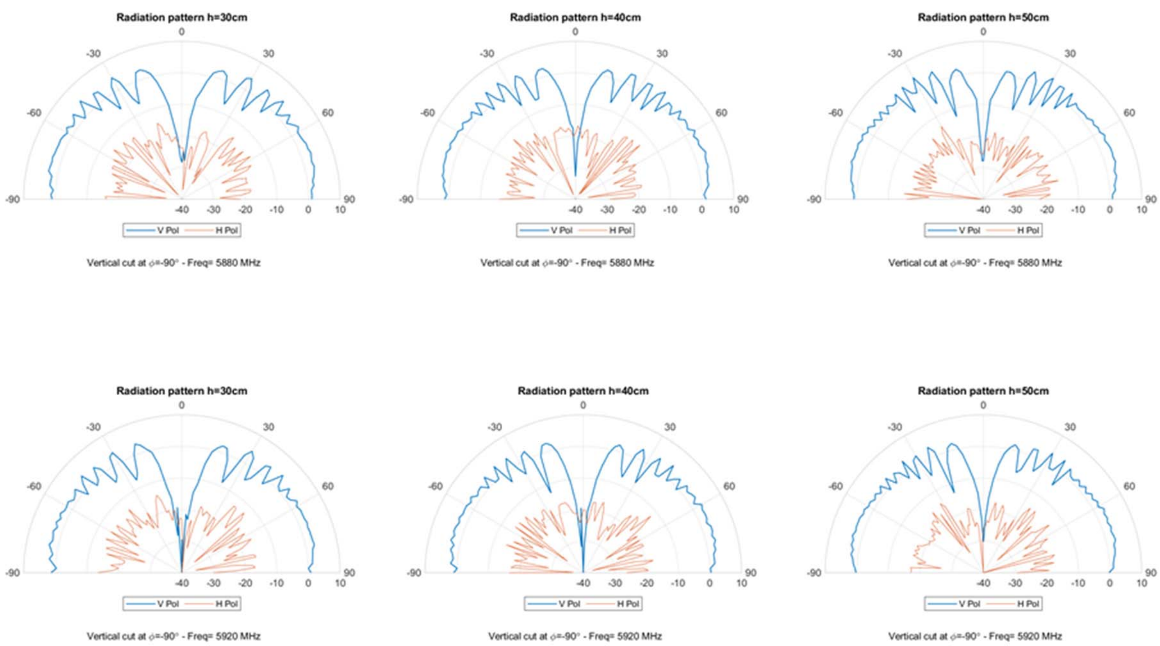

Figure A.28: Comparison of vertical and horizontal polarization with vertical cuts at azimuth ϕ = 90° with different heights of the support and different frequencies of 5 880 MHz and 5 920 MHz

Finally, Figure A.29 and Figure A.30 summarize the dispersion of the radiation pattern to give a quantitative evaluation of the discontinuities with the standard deviation measure.

Figure A.29 and Figure A.30 show the distribution of the gain (in dBi) of the radiation pattern for vertical polarization for height of the support of 40 cm and 50 cm. These two graphs include all azimuth angles. For each elevation angle, each dot represents the gain at a given azimuth angle.

Figure A.29 and Figure A.30 report the standard deviation values, which shows that the standard deviation of the distribution of the gain in dBi at 50 cm is less than the standard deviation of the gain at 40 cm. This result provides a quantitative evaluation of the perception that increasing the height of the antenna in relation to the metallic support which represents the roof of the automotive vehicle decrease the discontinuities in the radiation pattern.

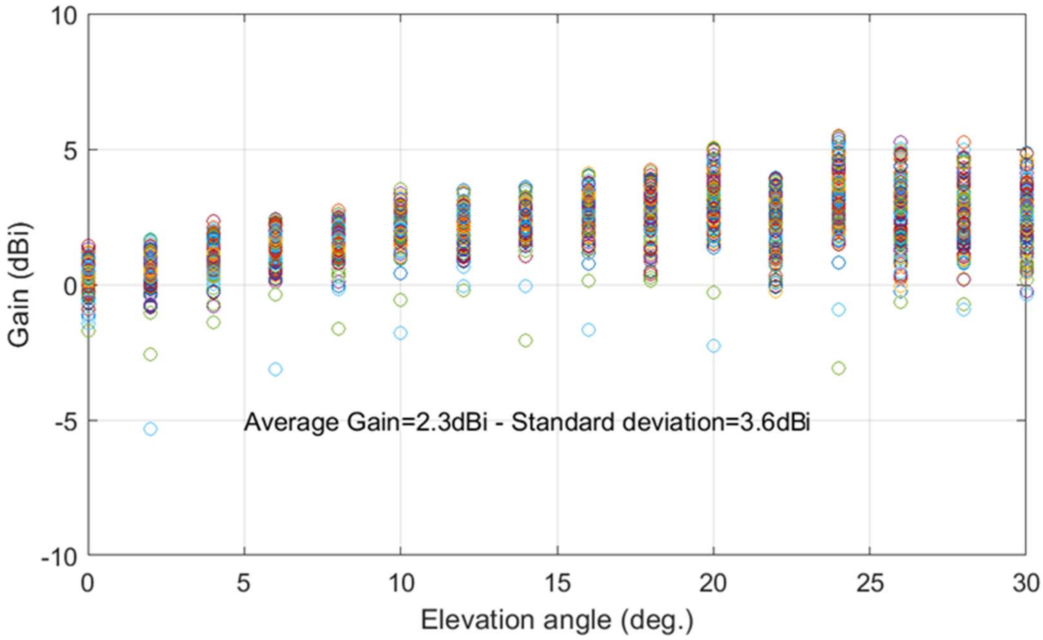

Figure A.29: Distribution of the Gain in dBi in relation to the elevation angle for height of the support equal to 40 cm, vertical polarization

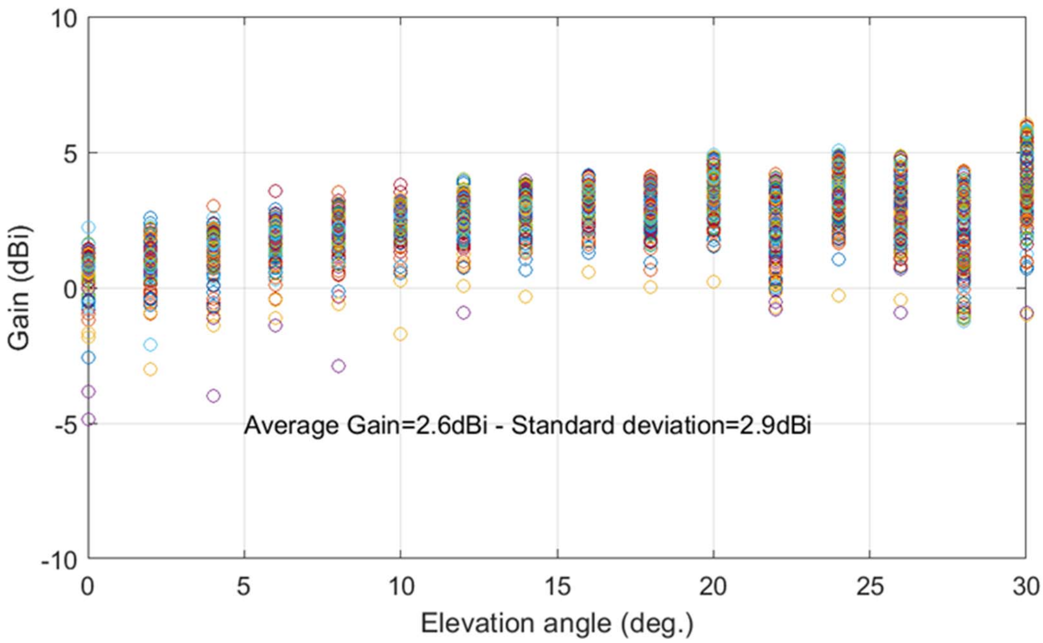

Figure A.30: Distribution of the Gain in relation to the elevation angle for height of the support equal to 50 cm, vertical polarization

A.4.4 Conclusion

This clause provides the results of the measurements conducted at the JRC facilities in July 2021 on the coexistence between the Urban Rail ITS and road ITS in the 5,9 GHz band. The measurement campaign was focused on the evaluation of the radiation pattern of the ITS-G5 antenna, which has been used during the field measurements in September 2021. The results indicated the presence of discontinuities in the radiation pattern which varies depending on the height of the antenna in relation to the metallic surface representing the roof of the vehicle.

Based on the presented measurement results an antenna height of 50 cm has been used during the field measurements as a compromise between a smooth antenna pattern and a stable installation possibility.

This annex has been developed based on an internal JRC report collecting the measurement results and the used set-up.

A.4.5 List of equipment used in the measurements

Equipment used for radiation pattern measurement is as follows.

Table A.1: List of equipment for radiation pattern measurement

Description	Manufacturer	Model	Serial Number	Calibration Date
Network Analyser	Agilent	E8362B	MY43020265	08 June 2021
Power amplifier	Hewlett Packard	83020A		NA
Directional coupler	M/A COM	2026-6009-20		NA
Probe antenna	Singer	6100		NA
Reference antenna	Hubert & Suhner	H+S 1356.17.0043		NA

A.5 GNSS

A.5.1 Introduction

A.5.1.1 Scope

This clause describes the role of the GNSS including the used equipment, service and implementation to perform the field-strength measurements.

A.5.1.2 Document Structure

This clause is organized as follows. Clause A.5.2 gives an overview of the GNSS along with GNSS corrections and its principle. Clause A.5.3 elaborates the details, equipment needed and the implementation.

A.5.1.3 Background

For the measurements performed, dedicated GNSS equipment were equipped with the RF measurements. The role of the GNSS equipment in the test setup is important to perform the field-strength measurements because the accurate location of the two vehicles and the train are recorded and associated with the received field strength.

In annex A the detailed list and description of the RF measurement tools used for the measurement activity is described.

All the measurement originating from the two used vehicles in the test concept, which transmit the messages, are associated with an accurate time stamp. The time stamps are generated by an internal clock synchronized with the internal GNSS receiver of the RF-measurement equipment. In the train, the RF tool stored the received messages associated with received level and a time stamp generated by the internal clock synchronized with the internal GNSS receiver.

The GNSS receiver which is included in an ITS platform is used for the precise time stamp generation. The standalone position or SBAS-supported-position measured by the GNSS receiver is usually provided with an accuracy in meter-level and thus its quality is for localization not good enough. Hence there is need to refine the position and to improve the accuracy for this measurement campaign. The used solution within this measurement campaign was the usage of RTK correction for GNSS which allows to have centimetre level accuracy.

A.5.2 GNSS Overview

A.5.2.1 Definitions

GNSS: Global Navigation Satellite System is an umbrella term, which constitutes a group of satellites involving four main satellite technologies: GPS, GLONASS, GALILEO and BEIDOU in order to provide location coordinates all over the globe.

GNSS Receiver: is an electronic device that uses the signals transmitted by GNSS satellites to determine its location (Latitude, Longitude, Elevation). GNSS receiver measures the transmitting time of signals from the GNSS satellites, and these measures are used to obtain its position.

GNSS Antenna: is a device designed to receive and amplify the radio signals transmitted on specific frequencies by GNSS satellites and convert them to an electronic signal for use by a GNSS receiver. The output of the GNSS antenna is fed into the receiver that can compute the position.

GNSS Error correction: GNSS receiver cannot correct satellite and atmospheric errors by itself and relies on data provided by an external source. To overcome both satellite and atmospheric errors a reference station also known as a base station, can be used. A reference station is a GNSS receiver installed at a fixed and precisely known location, estimating GNSS errors and sending them in the form of GNSS corrections to the user receiver. A reference network consists of interconnected reference receivers spread over an area.

In general, the GNSS receiver receive the GNSS corrections via a subscription service, delivered via Internet (using NTRIP protocol). Depending on the network density and quality of the error modelling, different initialization times and accuracies can be achieved. This means that positioning quality can vary from one service provider to another.

Correction Service: for the use case relays on the use case location and the service area and the use case accuracy reliability needs.

A.5.2.2 Type of correction for high accuracy positioning

RTK: is the short form of Real time kinematics. RTK is a technique that is used to increase the accuracy of GNSS positions using a fixed base station, that wirelessly sends out correctional data to a moving receiver. It is a differential method that requires at least two receivers: a reference station and a rover whose position is determined by three-dimensional polar appending.

Table A.2: Parameters

Parameter	RTK
Accuracy after initialization	~1 cm (only in best case)
Initialization time	Immediate (in open environment)
Coverage	Local
Bandwidth requirements	High
Infrastructure density	~10 km Topography depended

The principle of the RTK corrections is transmitting in real time the correction data of an observation base to the rover receiver. The rover receiver will then integrate this information into its positioning calculation to gain in accuracy.

Network RTK: is based on the use of several widely spaced permanent stations, which are provided by a private operator or by the surveying administrations Instead of temporary ones. This leads to the principle of the so-called network RTK. Depending on the implementation, positioning data from the permanent stations is regularly communicated to a central processing station. Several reference stations are networked, and correction data is transmitted to the rover via the Internet using the NTRIP protocol.

NTRIP: Networked Transport of RTCM via internet protocol, or NTRIP, is an open standard protocol for streaming differential data over the internet in accordance with specifications published by RTCM. There are three major parts to the NTRIP system: The NTRIP client, the NTRIP server, and the NTRIP caster:

- The NTRIP server is a PC or on-board computer running NTRIP server software communicating directly with a GNSS reference station.
- The NTRIP caster is an HTTP server which receives streaming RTCM data from one or more NTRIP servers and in turn streams the RTCM data to one or more NTRIP clients via the internet.
- The NTRIP client receives streaming RTCM data from the NTRIP caster to apply as real-time corrections to a GNSS receiver.

RTCM: is a binary data protocol for communication of GNSS correction information. In many countries there are special reference services for network RTK applications.

A.5.3 Implementation

A.5.3.1 Equipment

The GNSS equipment was the part of the RF measurement in the two vehicles and in the train. For the measurement campaign in the Paris city, the following test setup was composed with the GNSS equipment.

The following list describes the GNSS measurement equipment:

- GNSS receivers fulfilling the measurement requirements (for the two vehicles and in train)
- GNSS antennas (for the two vehicles and in train)
- GNSS couplers (for the two vehicles and in train)
- Connector cables Receiver-PC (for the two vehicles and in train)
- Laptops with installed control software-application (for the two vehicles and in train)
- Smartphones with mobile network access as hotspot or for the internet connection of the GNSS receiver (for the two vehicles and in train)

The following describes the GNSS Service: GNSS RTK correction service provider.

In this measurement campaign, to achieve the seamless positioning, ublox® ZED F9R [i.12](built-in IMU GNSS Antenna) unit was chosen because it fulfilled the requirements.

The ublox ZED F9R [i.12], is a multi-band GNSS receiver with dead reckoning module and an integrated Inertial Measurement Unit (IMU) suitable for RTK positioning. The built-in algorithms ublox ZED F9R [i.12], is capable of fusing the IMU data, GNSS measurements, wheel ticks, correction data, and a vehicle dynamics model provides optimal positioning accuracy where GNSS alone has problem.

The ublox ZED F9R [i.12] features are:

- 184-channel with:
    - GPS L1C/A L2C
    - GLO L1OF L2OF
    - GAL E1B/C E5b
    - BDS B1I B2I
    - QZSS L1C/A L2C
- support for RTCM

- Nav. update rate Up to 30 Hz
- Position accuracy RTK: 0,01 m + 1 ppm CEP
- ADR position error < 2 % of distance

The GNSS Correction Services used for this measurement campaign in Paris was Orpheon-Geodata Diffusion. Orpheon-Geodata Diffusion is a French multi constellation network with 215 stations and NRTK service with full GNSS coverage.

The Orpheon satellite positioning correction system is based on a network of observation reference stations (OSR: Observation Space Representation). The mount point VRS_RTCM-MSM_FULL or i-Max_RTCM-MSM_FULL were used during the test campaign.

Settings:

- DNS: ntrip.reseau-orpheon.fr
- Port: 8500

The features of this service are:

- Compatible with GNSS RTK receivers of all brands
- Centimetre accuracy
- Extremely fast and simple commissioning everywhere
- Dense, regular and structured coverage of the entire territory
- High quality and service
- Full GNSS: Increased productivity

To assess the localization performance achieved by a GNSS receiver and the dedicated RTK-network for the measurement campaign in Paris, the following test setup is composed with a GNSS equipment. The basic processing flow of Global Navigation Satellite System (GNSS) receiver used for the measurement campaign in Paris is illustrated in Figure A.31.

The Ublox receiver ZED F9R was connected to the GNSS antenna installed on the roof of the vehicles and train via the built-in splitter and was connected to the notebook via an USB interface on which has run the u-centre evaluation software. The signal from GNSS antenna went to the RF measurement tool for synchronization and rough position for the test scripts. RTK positioning was logged via NTRIP in ublox, and a smart phone provided the internet.

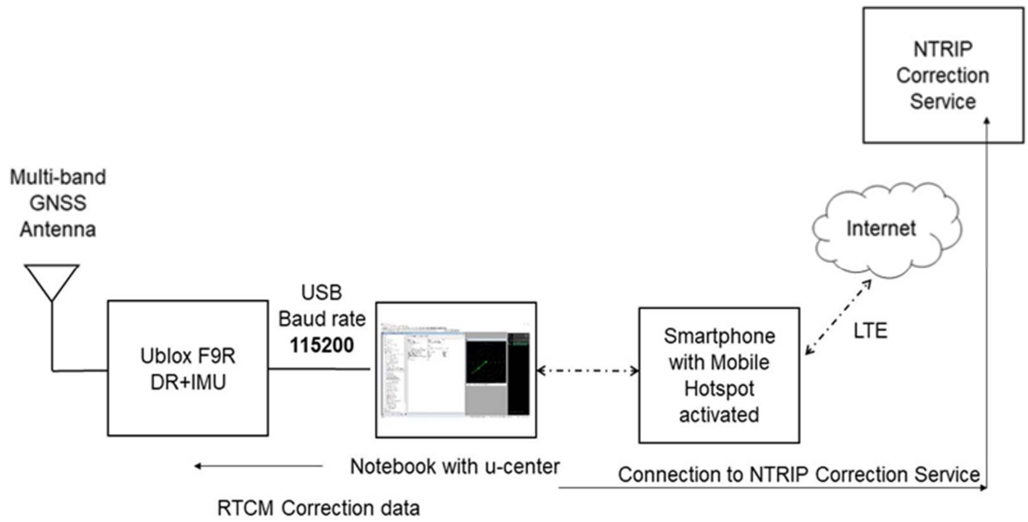

Figure A.31: Hardware Test Setup Schematic diagram

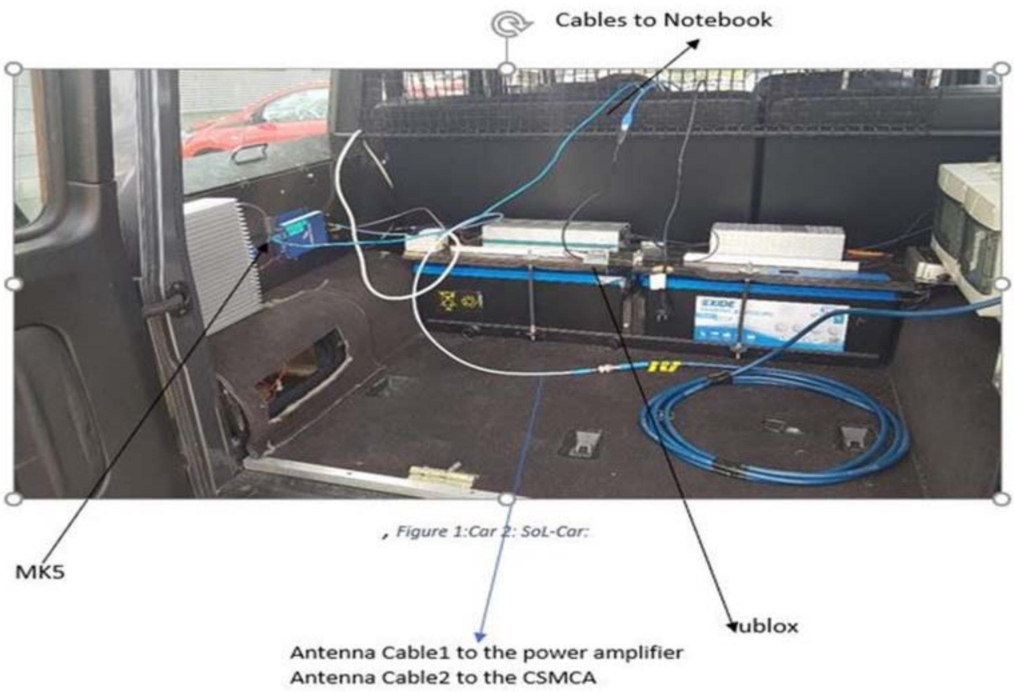

Figure A.32: Example picture of setup in one of the vehicles

As measurement equipment the Ublox which was started and configured like is described in the following:

1) Start-up:

- The Ublox receiver connected to the multi-band GNSS antenna, dedicated power source, the dedicated laptop and antenna with the dedicated cables.
- After the connection procedure was finished the receiver (connected to the serial usb COM port) and the uBlox software control on the laptop were started.

2) RTK-Configuration:

- RTK corrections were applied by a u-centre built-in NTRIP client. On the U-centre receiver menu item, the NTRIP client was selected and filled with the settings provided by the Orpheon-Geodata Diffusion service provider with NTRIP caster, username and password as shown in Figure A.33.
- The Fix Mode changed from 3D to 3D/DGNSS after the RTCM corrections were received.

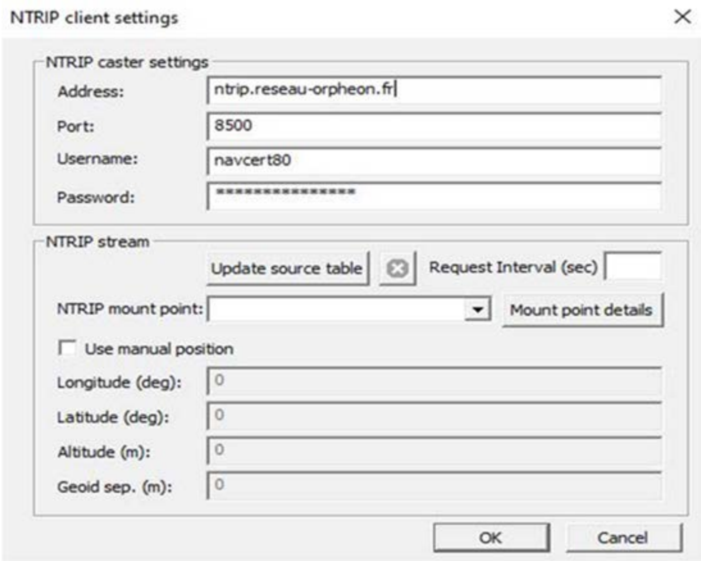

Figure A.33: NTRIP Client Settings

3) GNSS Configuration:
For these measurements, the following configuration was considered as shown in the following pictures:

- The result of a navigation solution is initially classified by the fix type (as detailed in the fix Type field of UBX-NAV-PVT message). This distinguishes between failures to obtain a fix at all ("No Fix") and cases where a fix has been achieved, which are further subdivided into specific types of fixes (e.g. 2D, 3D, dead reckoning) as shown in Figure A.34.

- To prevent message loss, the baud rate and communication speed or the number of enabled messages should be carefully selected so that the expected number of bytes can be transmitted in less than one second. The baud rate was set to 115 200 with 8 data bits as shown in Figure A.31.

- Automotive dynamic model: the dynamic model was used for the vehicles in measurement setup. It combined the GNSS signal with the data from gyroscope, accelerometer, and wheel ticks (or speed measurements). The automotive dynamic model was selected by the configuration item as shown in Figure A.35.

- Vehicle dynamics output: UBX-ESF-INS message outputs information about vehicle dynamics provided by the INS, compensated vehicle angular rates and compensated vehicle accelerations. The acceleration data is free of any gravitational acceleration. Its accuracy is directly dependent on the filter attitude estimation accuracy as shown in next Figure A.36.

- The ublox proprietary output messages are configured in this test setup so that the receiver periodically provides information about position, time, and satellites. With the UBX protocol it is easy to monitor the receiver status and get much deeper information about the receiver status.

- The navigation solution update rate was set to 5 Hz.

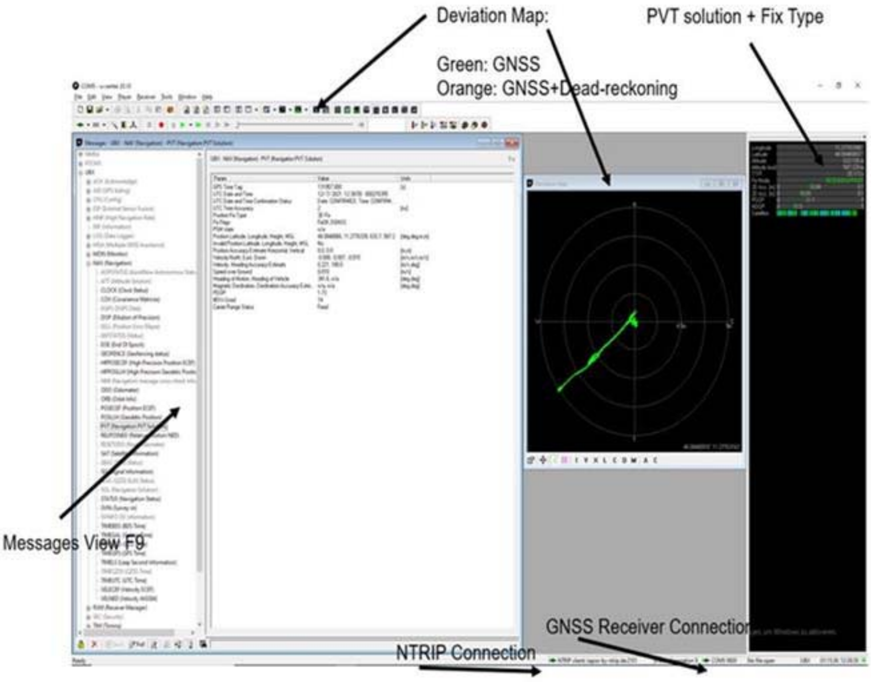

Figure A.34: GNSS Configuration

4) Logging Configuration:

- With the start recording option, the log files were stored under the log directory with a log file name which were considered then for measurement analysis.

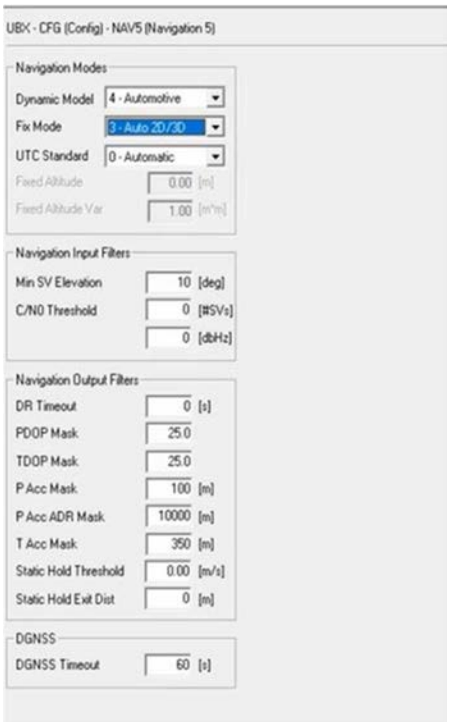

Figure A.35: Automotive Dynamics Model

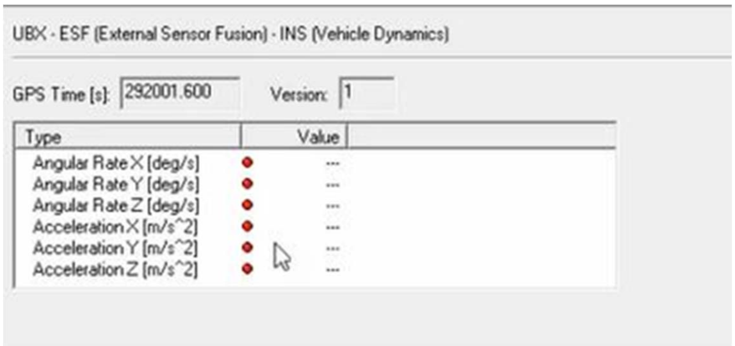

Figure A.36: Automotive Dynamics Model

Annex B:
Simple Urban rail and Suburban rail propagation models

The calculations developed in the different compatibility studies used simple urban and suburban propagation models. These models area derived from Recommendation ITU-R P.1411-6 [i.7]. This recommendation deals with the definition of the propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz.

These simple urban and urban propagation have been used in the ECC report 68 [i.5], in the ECC Report 101 [i.4] and in the ETSI TR 103 580 [i.2] and other ECC reports.

These simple propagation models are based on a three slopes model with two breakpoints. The urban or suburban propagation model are defined with three curves and two breakpoints.

The formula to compute the pathloss is given below:

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & for\ d < d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0Log\left(\frac{d}{d_0}\right) & for\ d_0 < d < d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0Log\left(\frac{d_1}{d_0}\right) - 10n_1Log\left(\frac{d}{d_1}\right) & for\ d_1 < d \end{cases}$$

Table B.1 gives the value of the parameters for each type of environment. For information, parameters are also given for a rural environment and an ETSI propagation model.

Table B.1: Parameters of the propagation models

	Urban	Suburban	Rural	ETSI
Breakpoint distance d0 (m)	64	128	256	15
Pathloss factor n0 beyond the first break point	3,8	3,3	2,8	2,7
Breakpoint distance d1 (m)	128	256	1 024	1 024
Pathloss factor n1 beyond the second breakpoint	4,3	3,8	3,3	2,7

Annex C: Desensitization maps

C.1 Introduction

The following maps show how the measured power levels translate into an interfering power at the CBTC antenna connector.

Although the impact assessment is outside the scope of the present document, it is still possible to convert the measured levels to power levels that would be received by CBTC receivers. These can in turn be compared to self-generated noise level of CBTC receivers and expressed as desensitization values. To this end, a hypothetical receiver having noise factor of 5 dB is considered. This is believed to model a receiver exhibiting good performance, although this has not been investigated.

The following set of figures shows desensitization maps for all the receivers used during the measurement campaign. The labels of the receivers follow the format given in Table C.1.

Table C.1: Label of receivers

Generic format	ENA_D1D2
Letter	**Meaning**
E	B when the measuring equipment is a Base station.
	T when the measuring equipment is a Train.
N	A number between 1 to 4, to identify the receivers during the night.
A	H for High base stations (5 m), hence modelling CBTC access point.
	L for Low base stations (3,5 m), hence modelling CBTC train units.
	F for receivers in the Front cabin of a train.
	B for receivers in the Back cabin of a train.
D1	1st day number of the night, e.g. 09 for the 09th of September 2021.
D2	2nd day number of the night, e.g. 10 for the 10th of September 2021.

C.2 Desensitization maps for Line 6

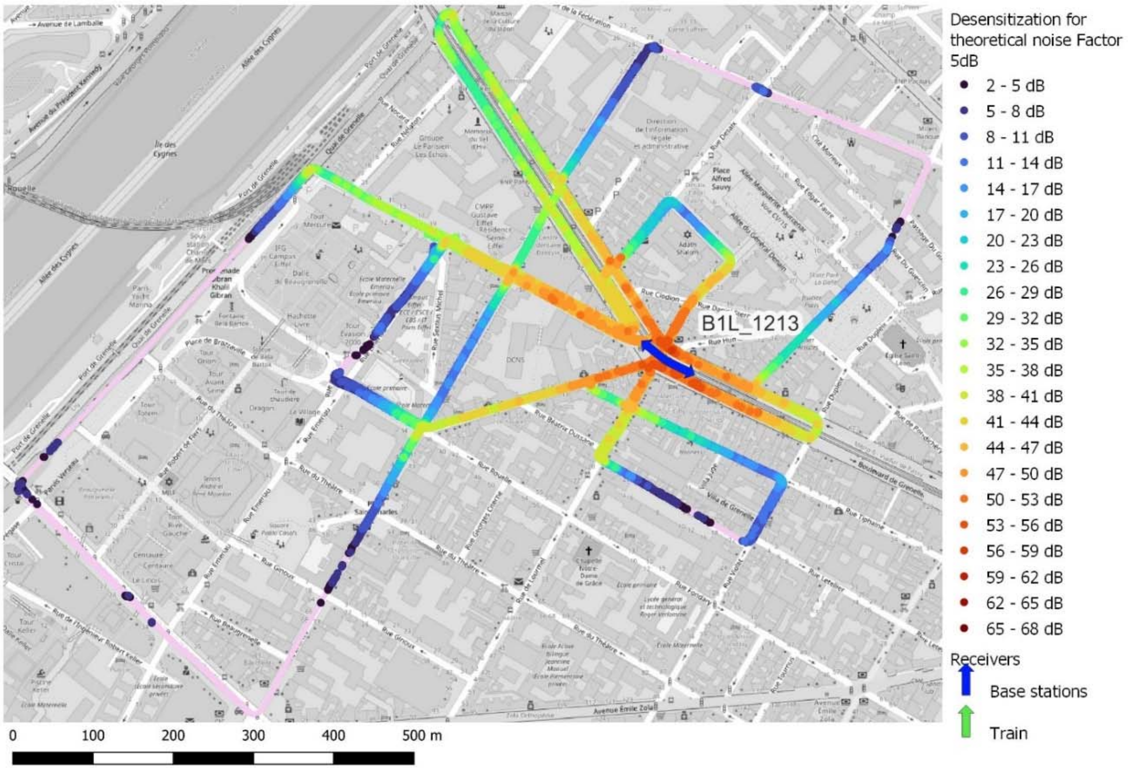

Figure C.1 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

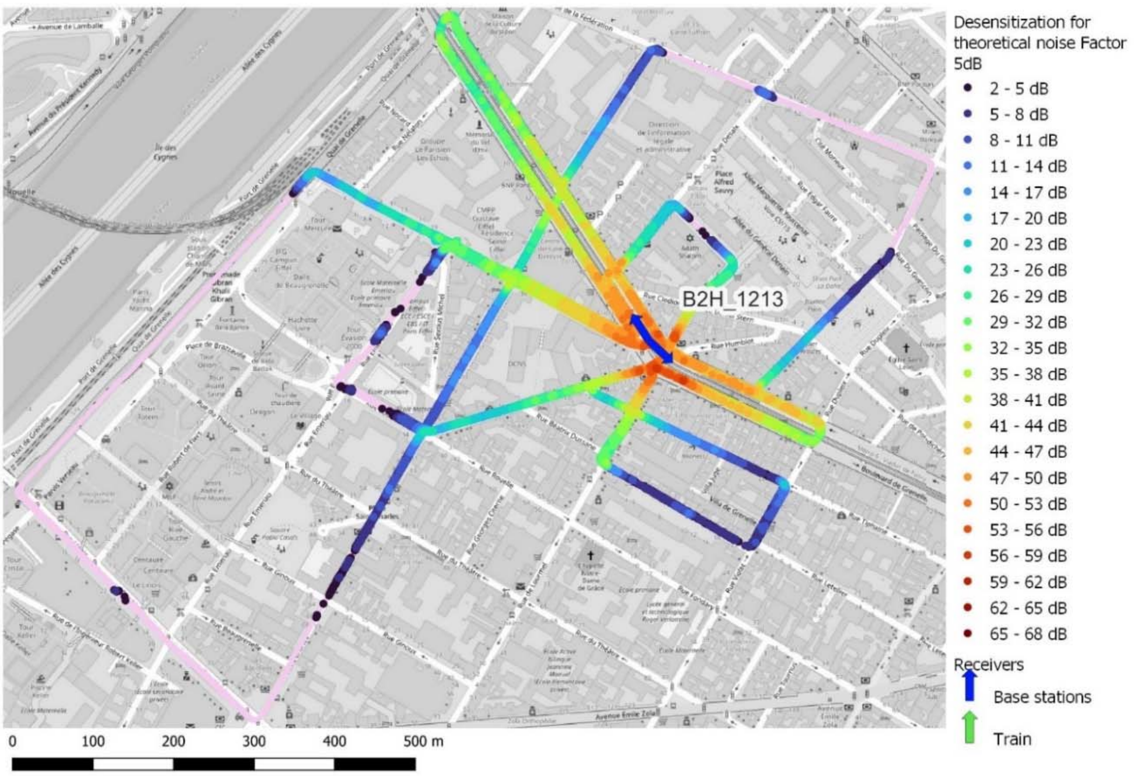

Figure C.2 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

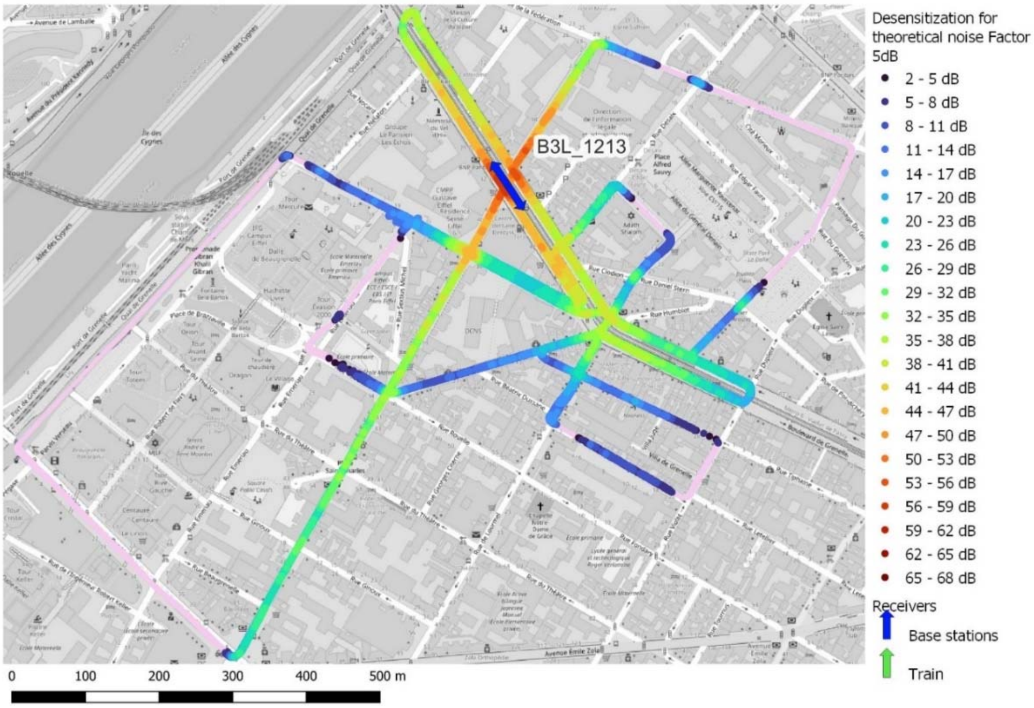

Figure C.3 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

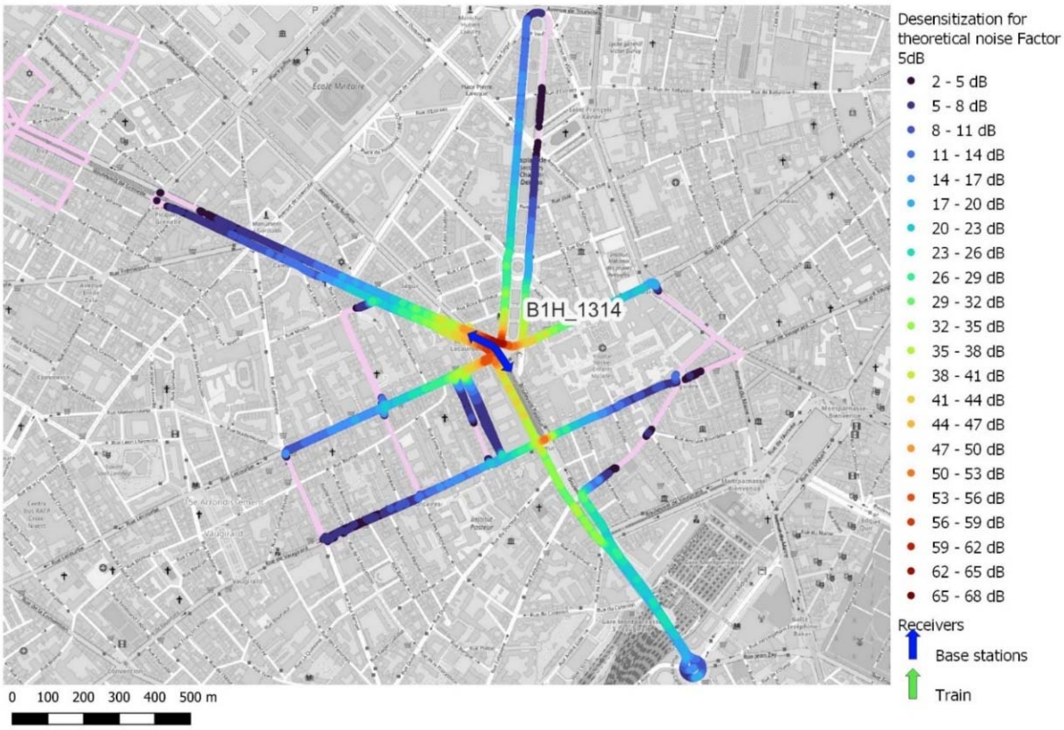

Figure C.4 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

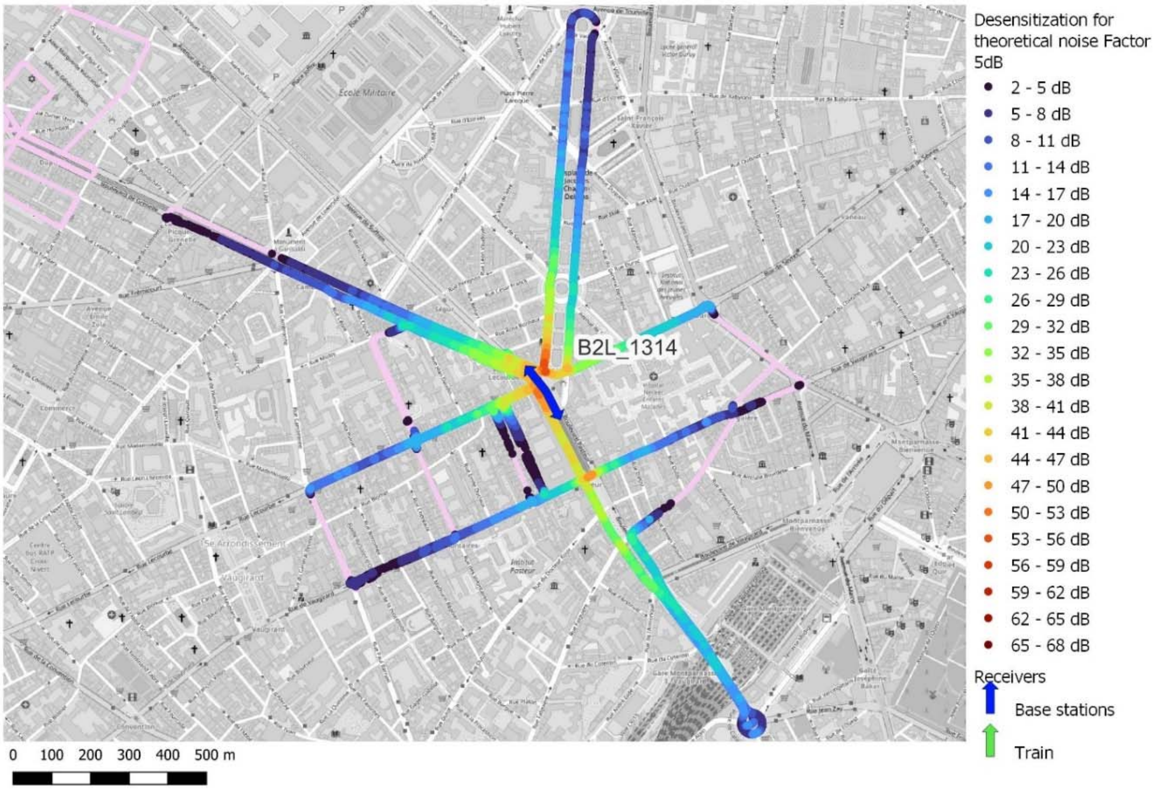

Figure C.5 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

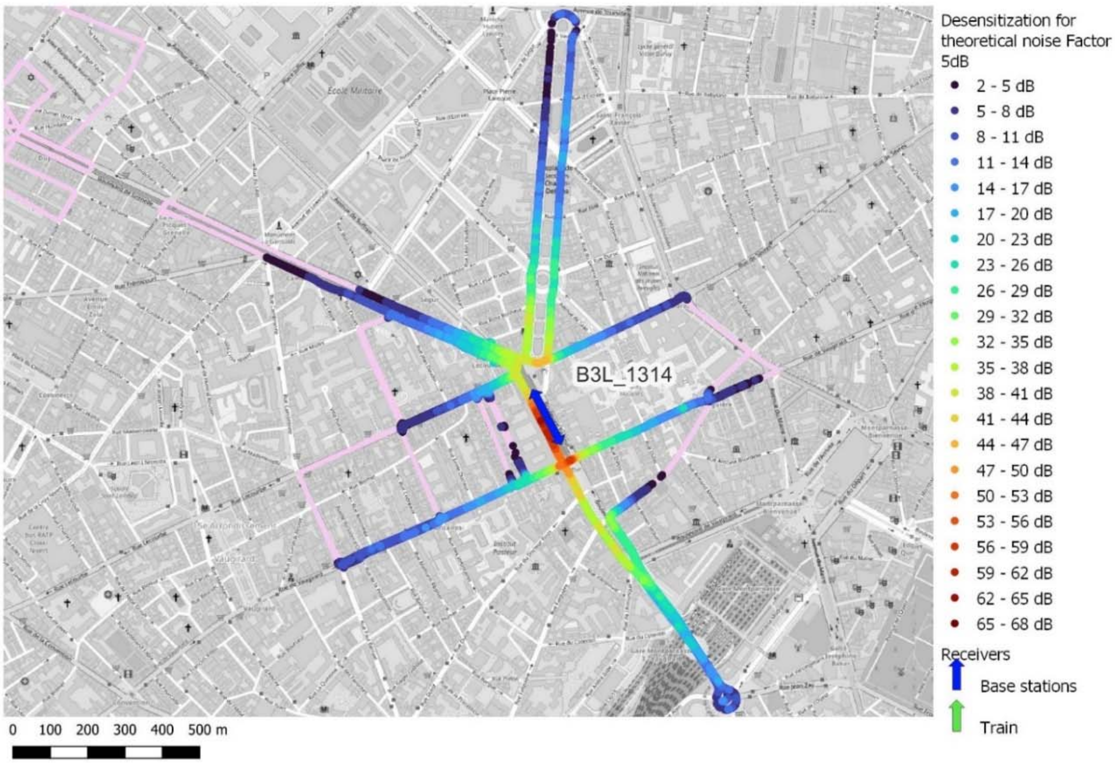

Figure C.6 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

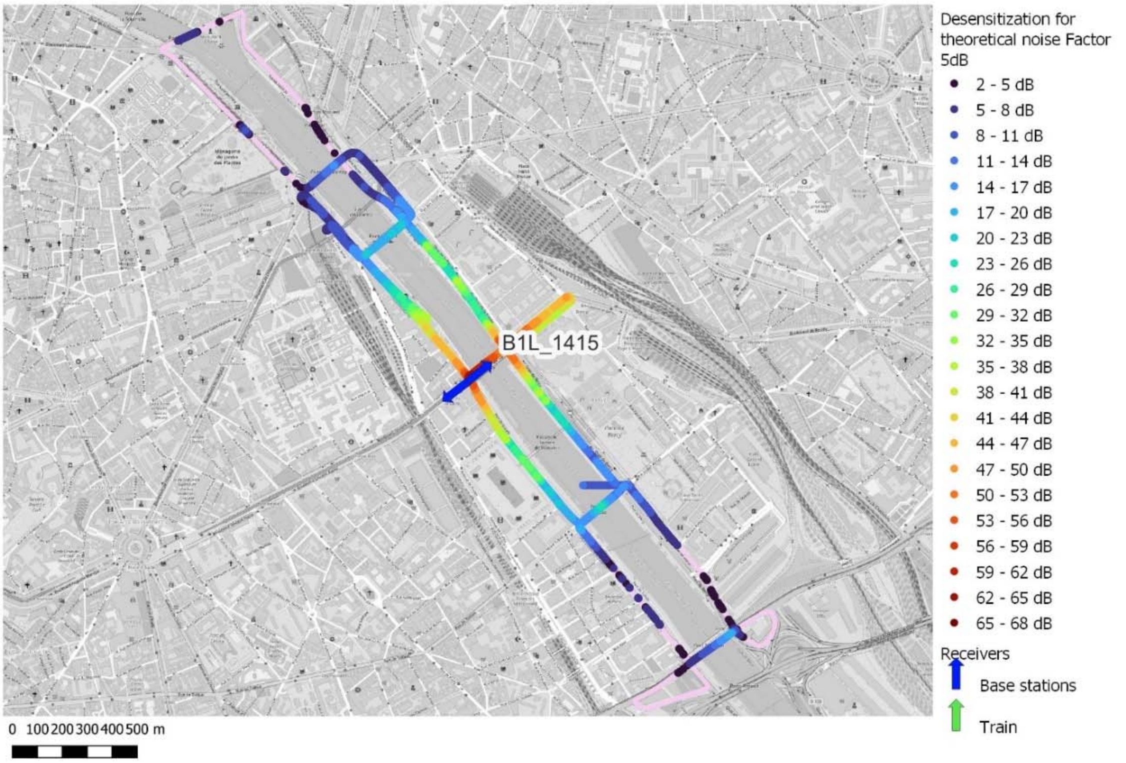

Figure C.7 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

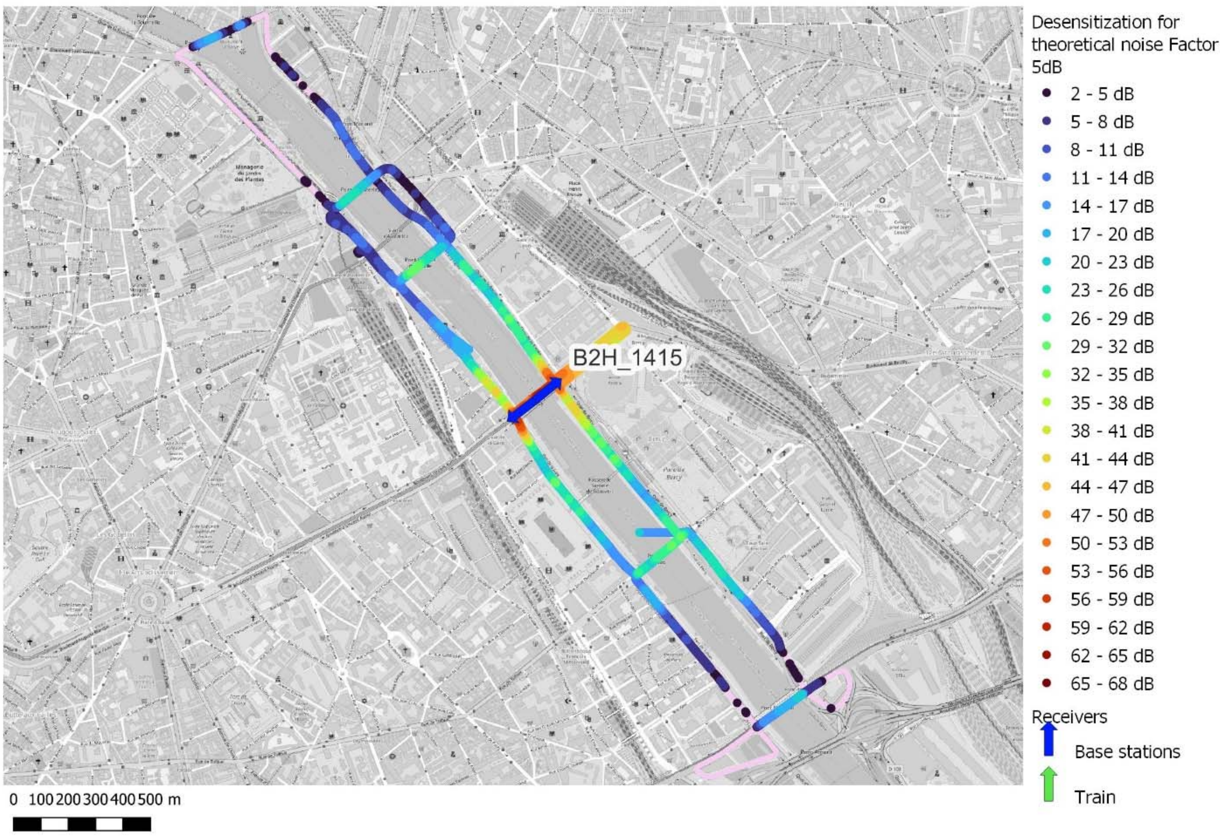

Figure C.8 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

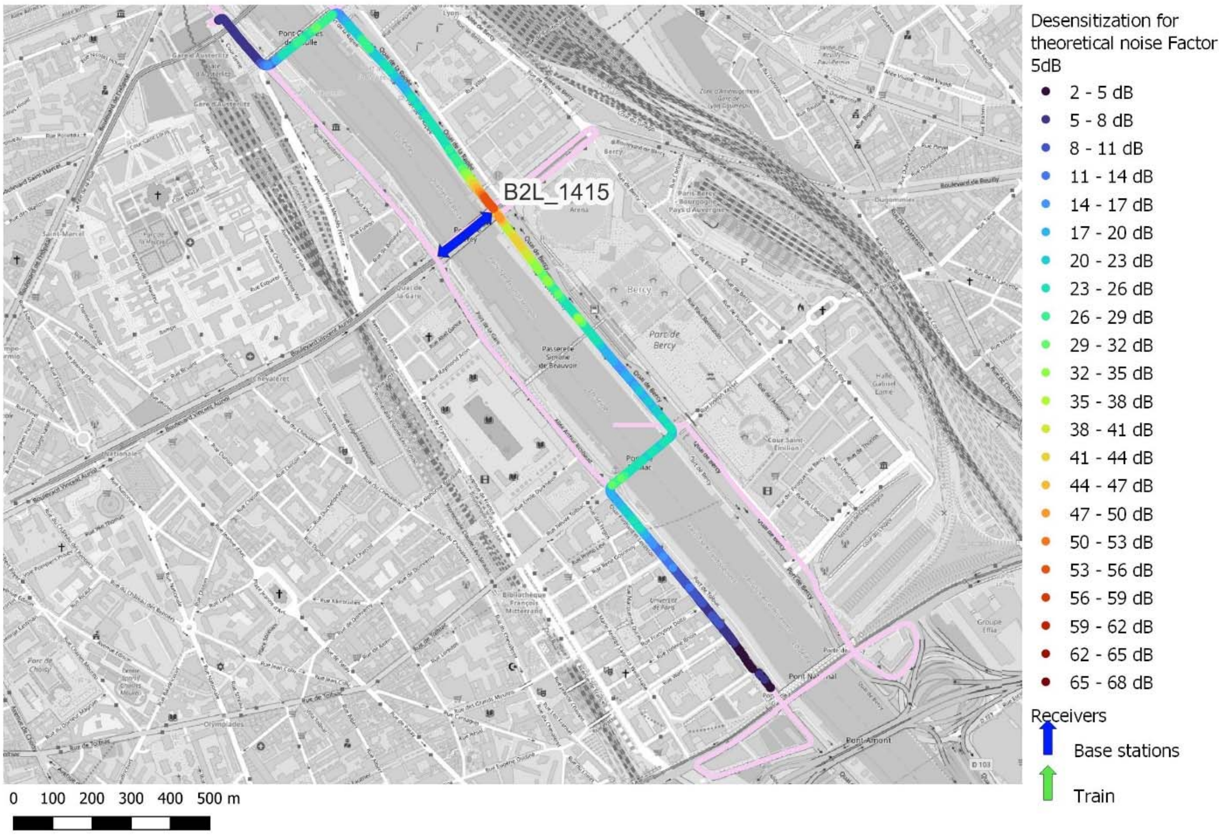

Figure C.9 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

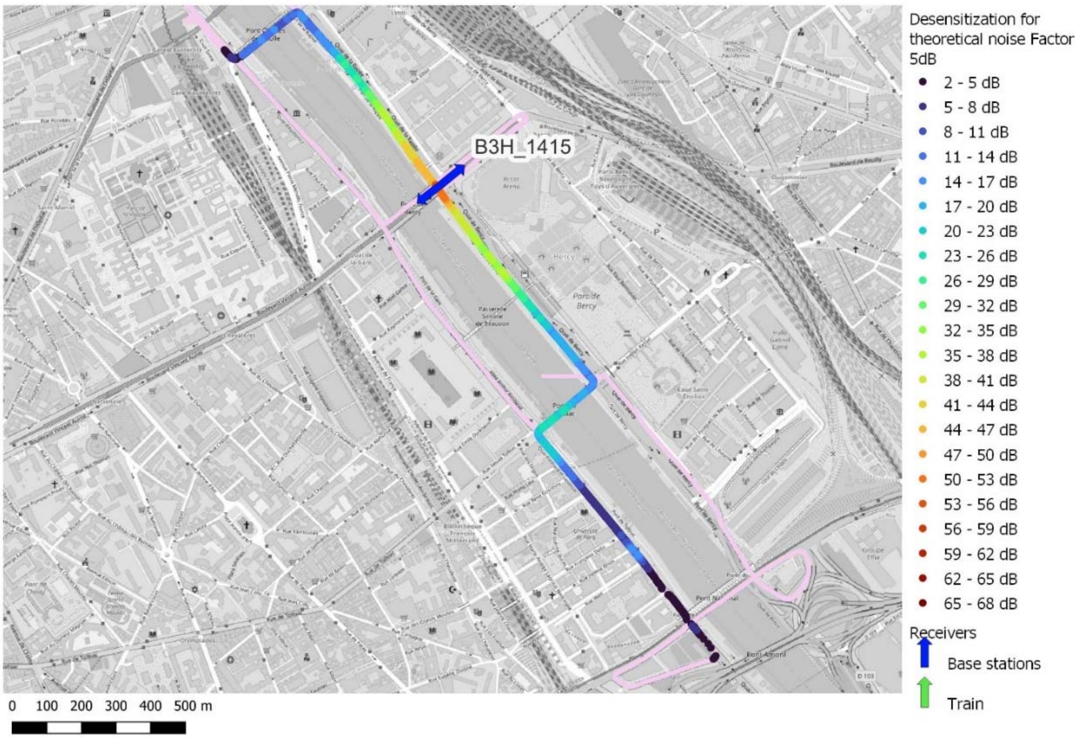

Figure C.10 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

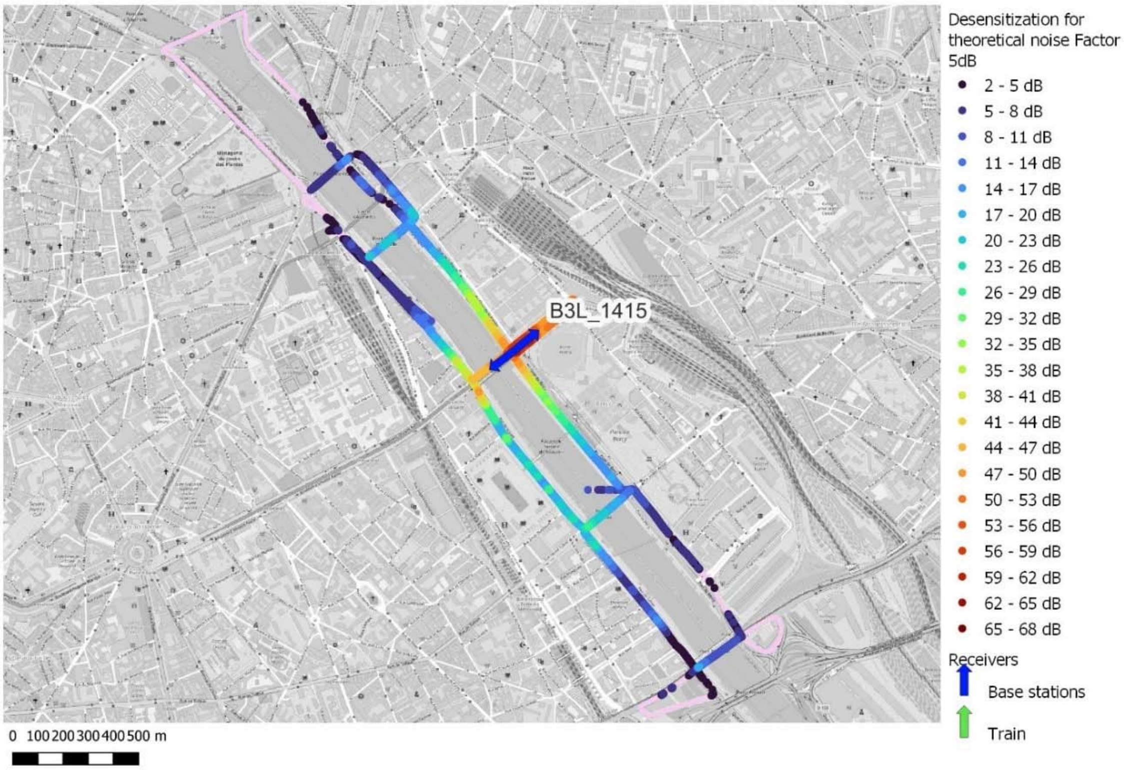

Figure C.11 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

C.3 Desensitization maps for Line 8

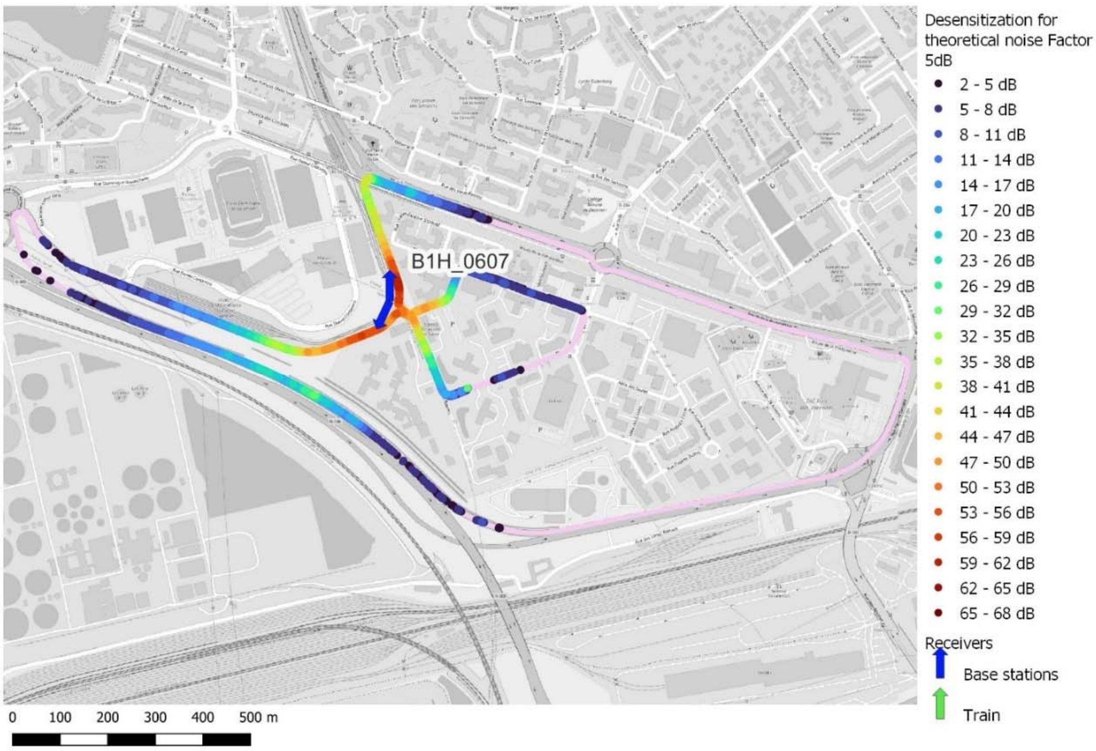

Figure C.12 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

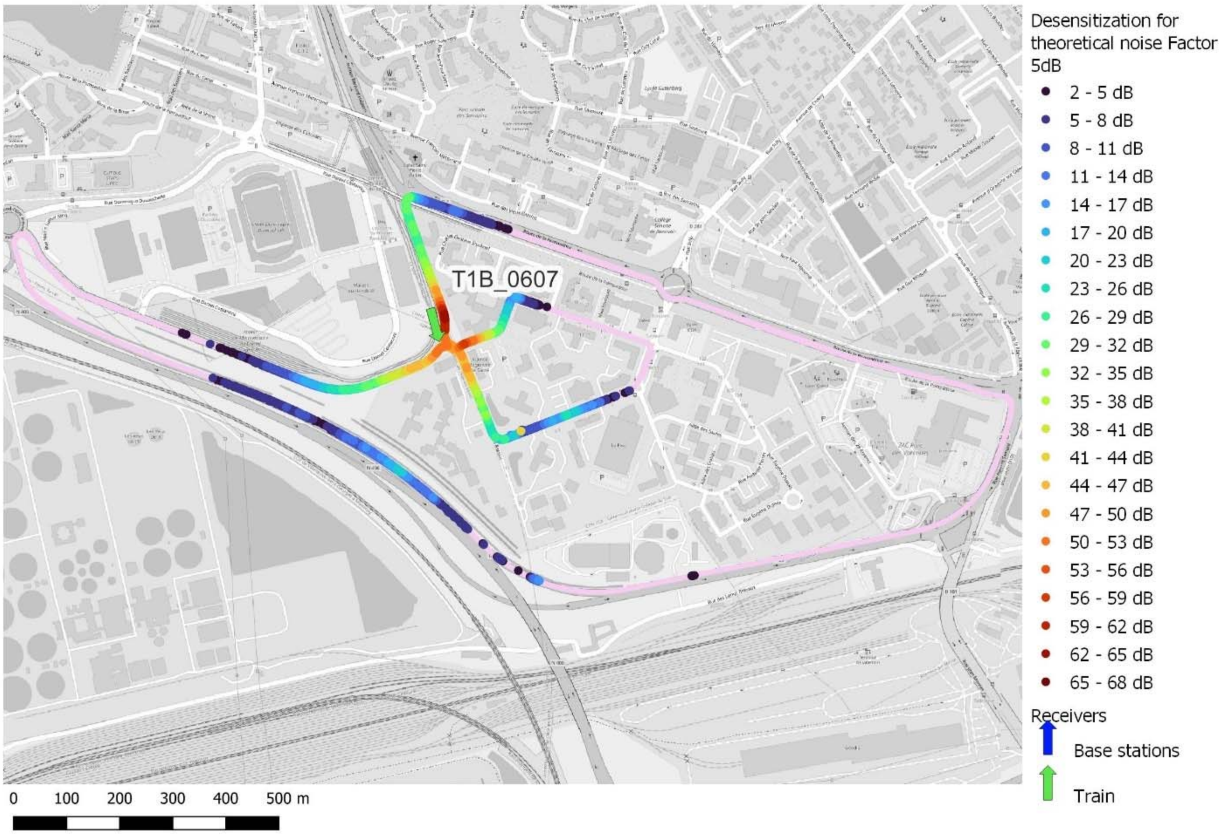

Figure C.13 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

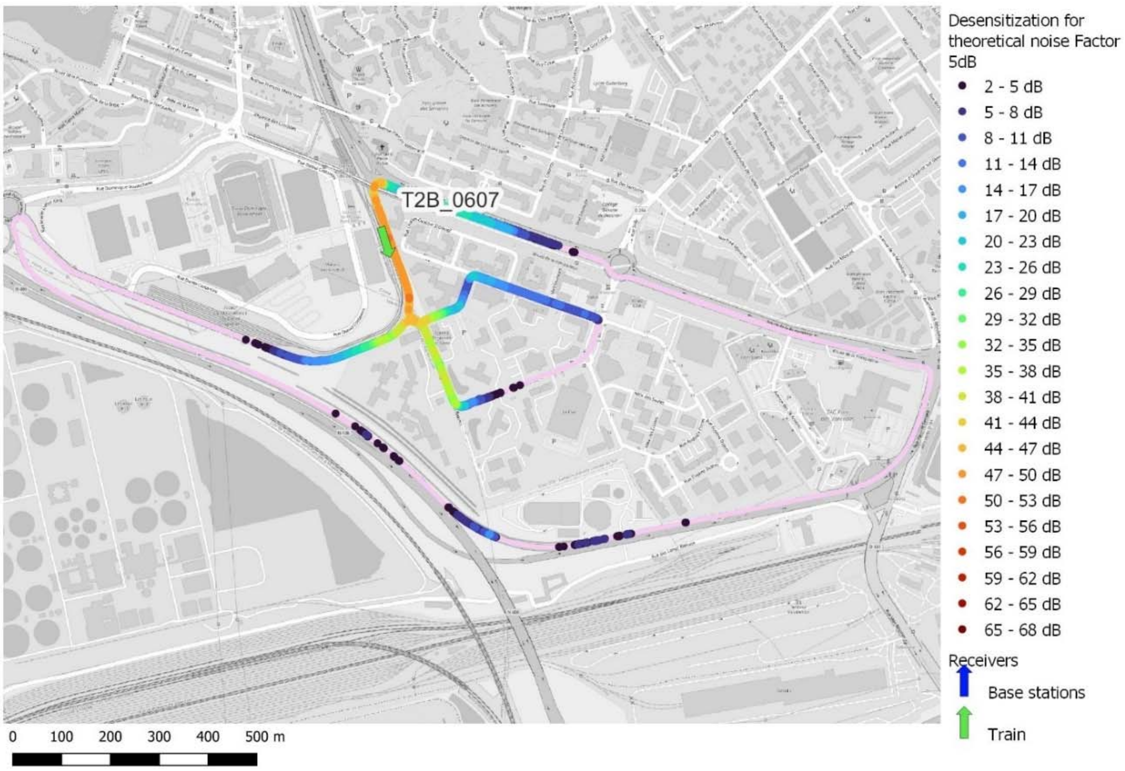

Figure C.14 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

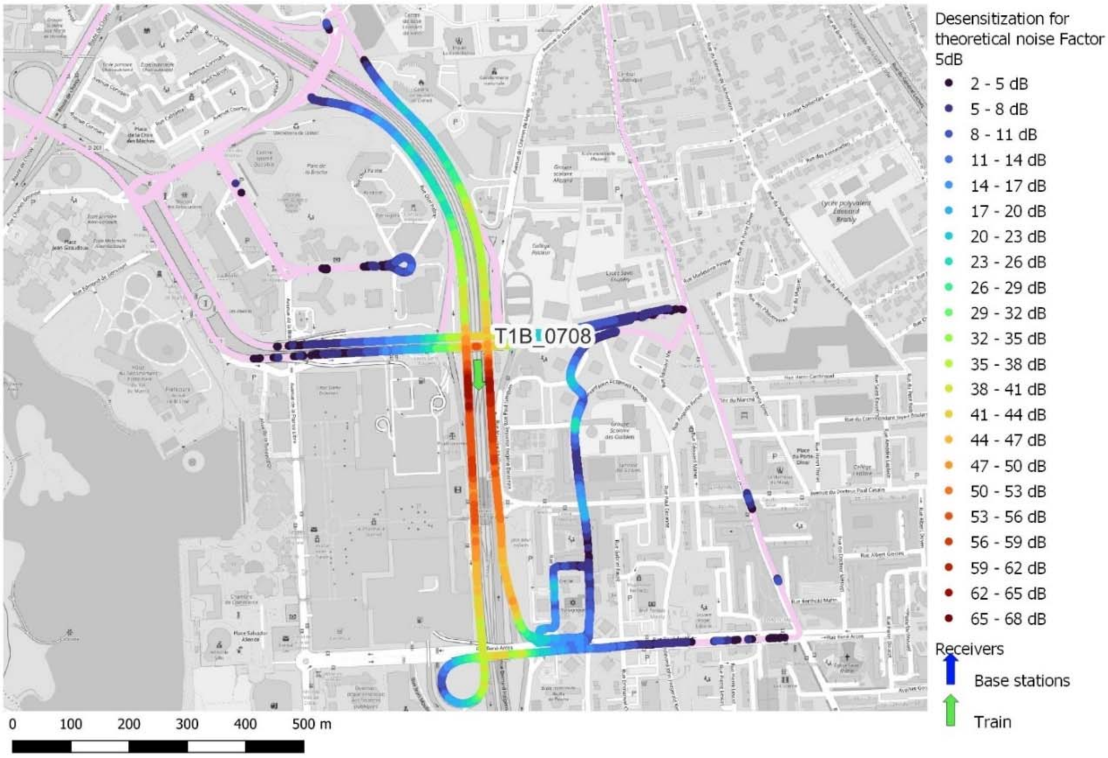

Figure C.15 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

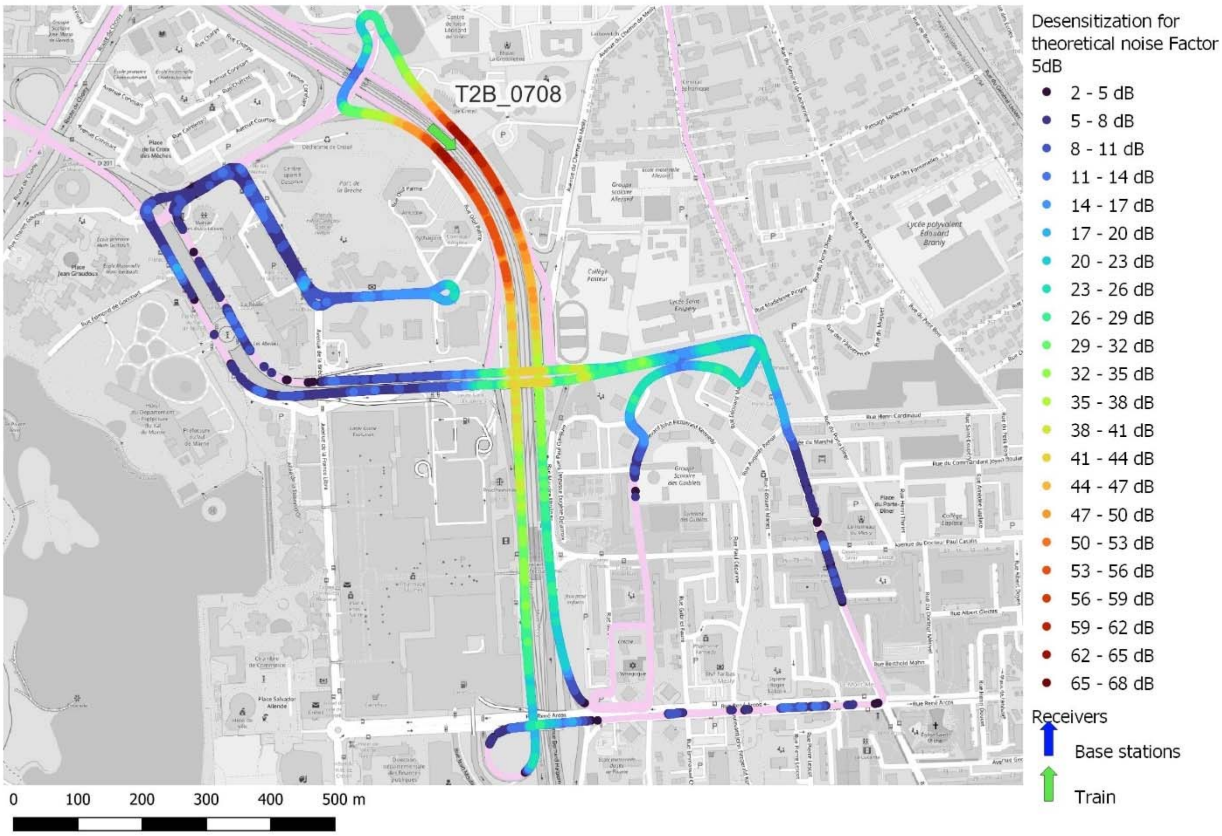

Figure C.16 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

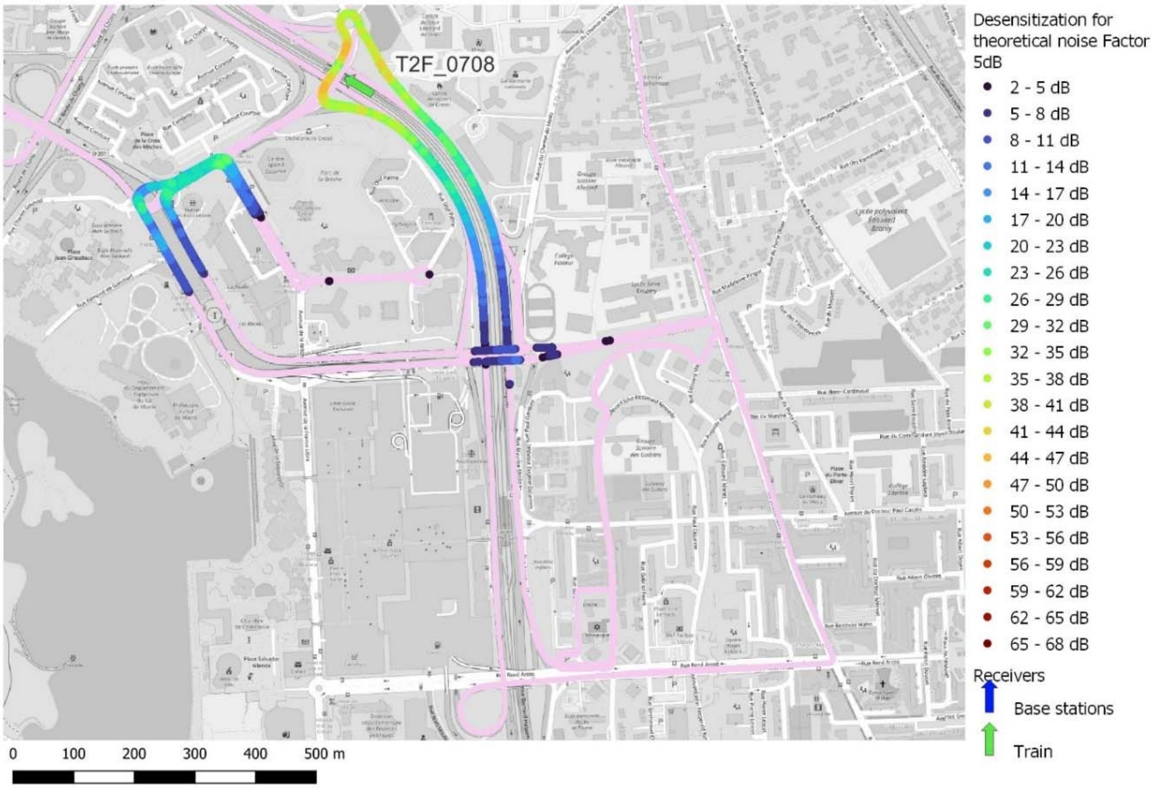

Figure C.17 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

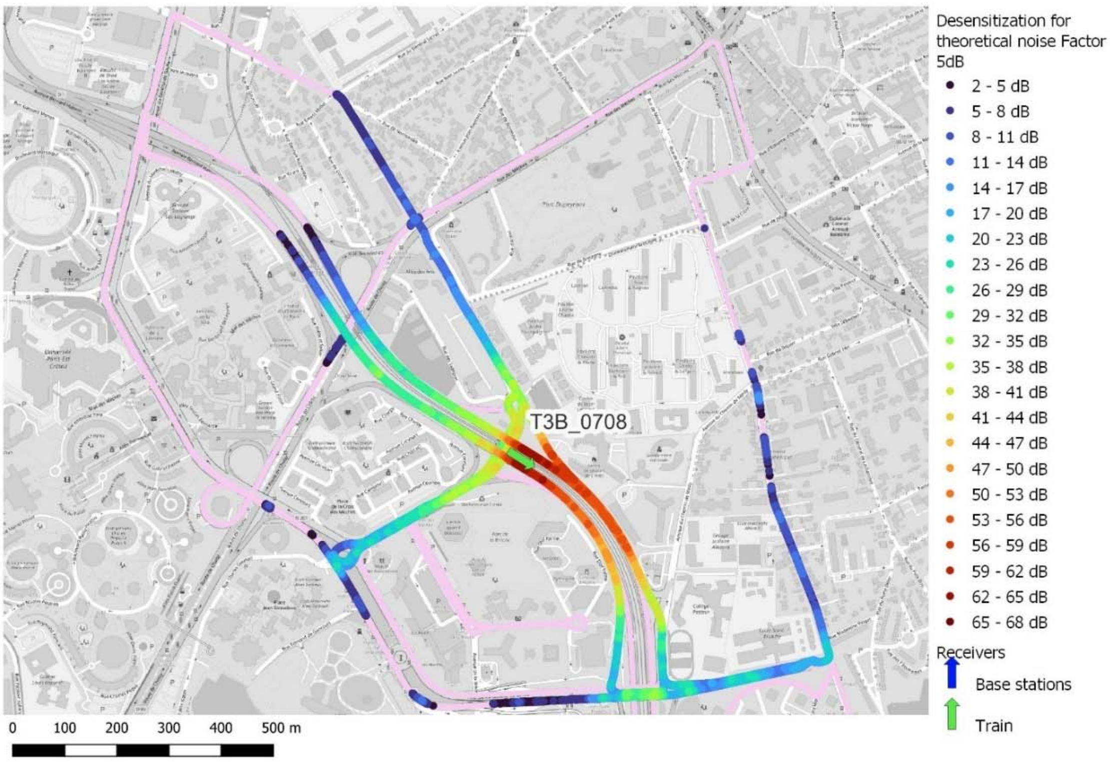

Figure C.18 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

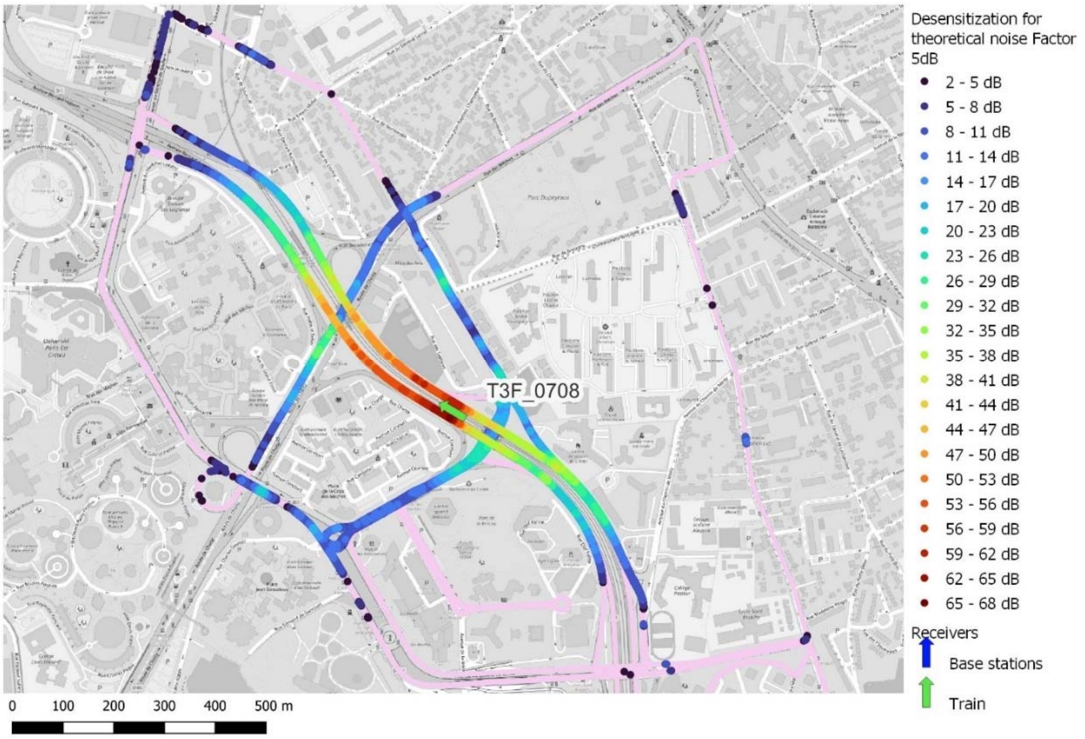

Figure C.19 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

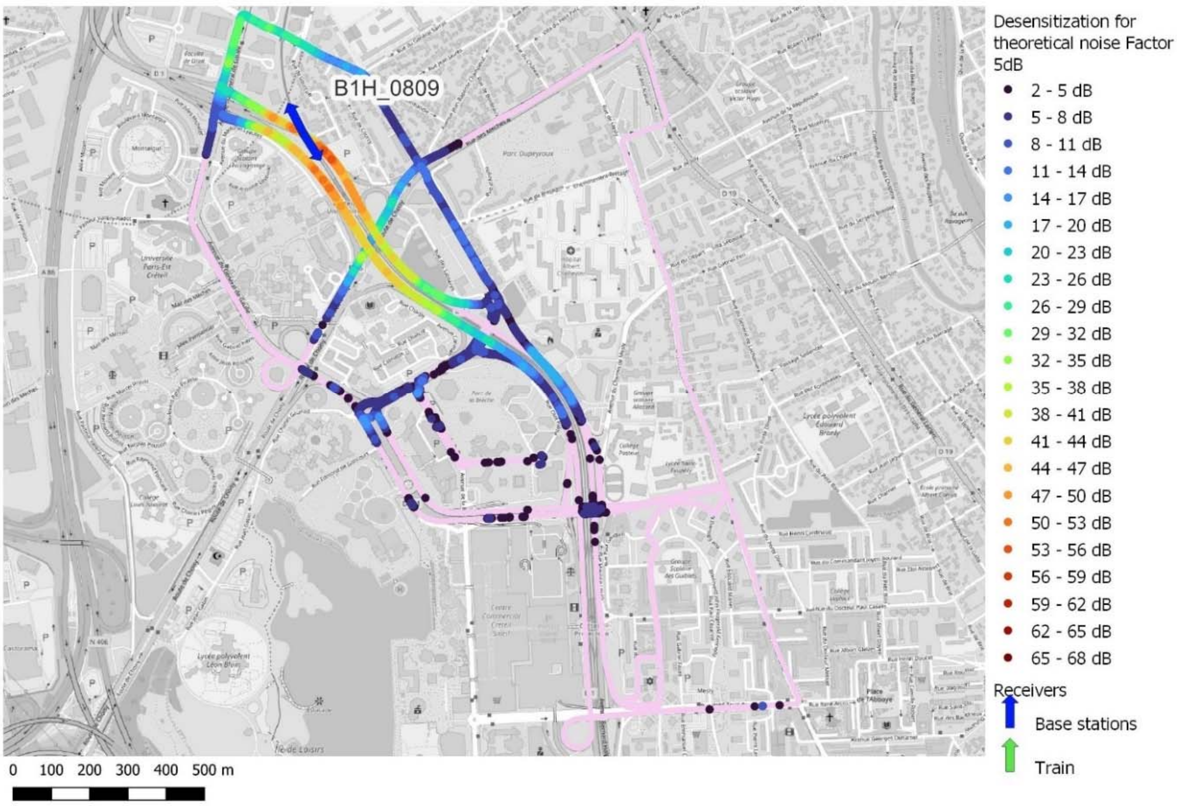

Figure C.20 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

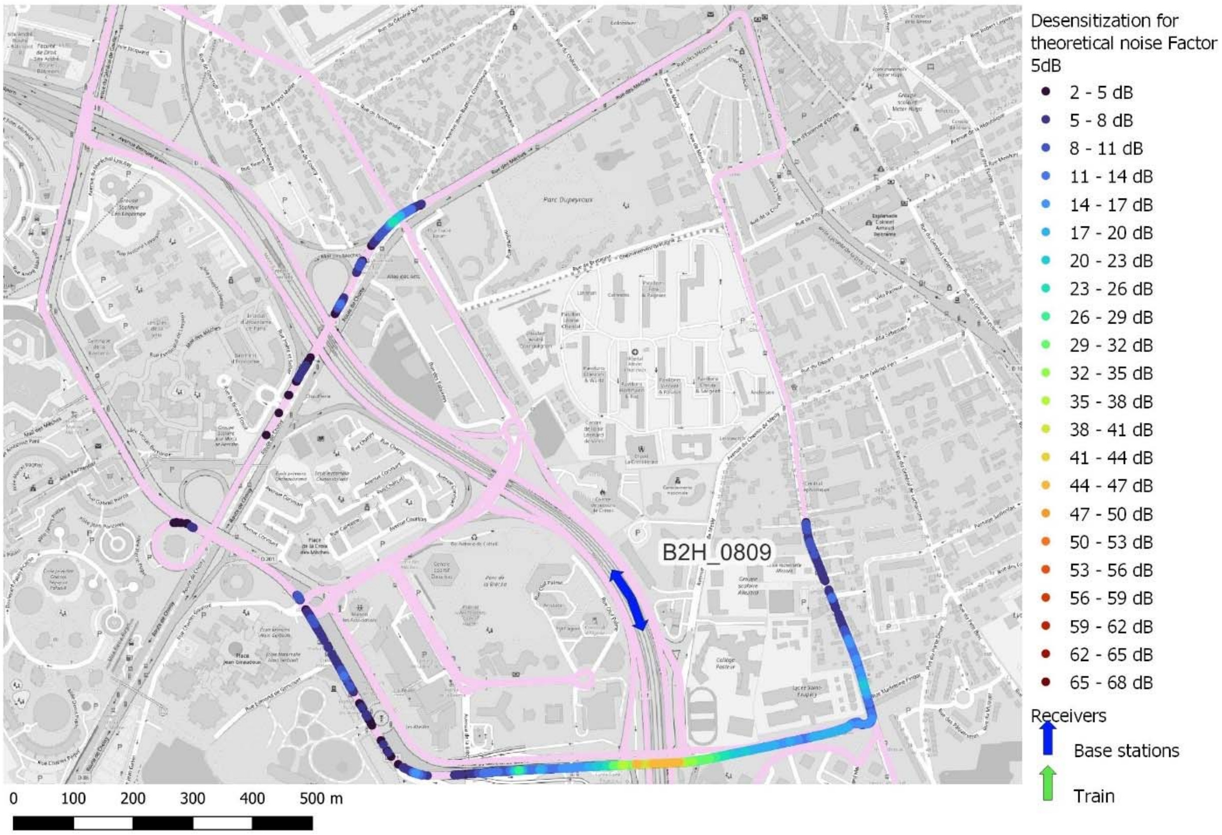

Figure C.21 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

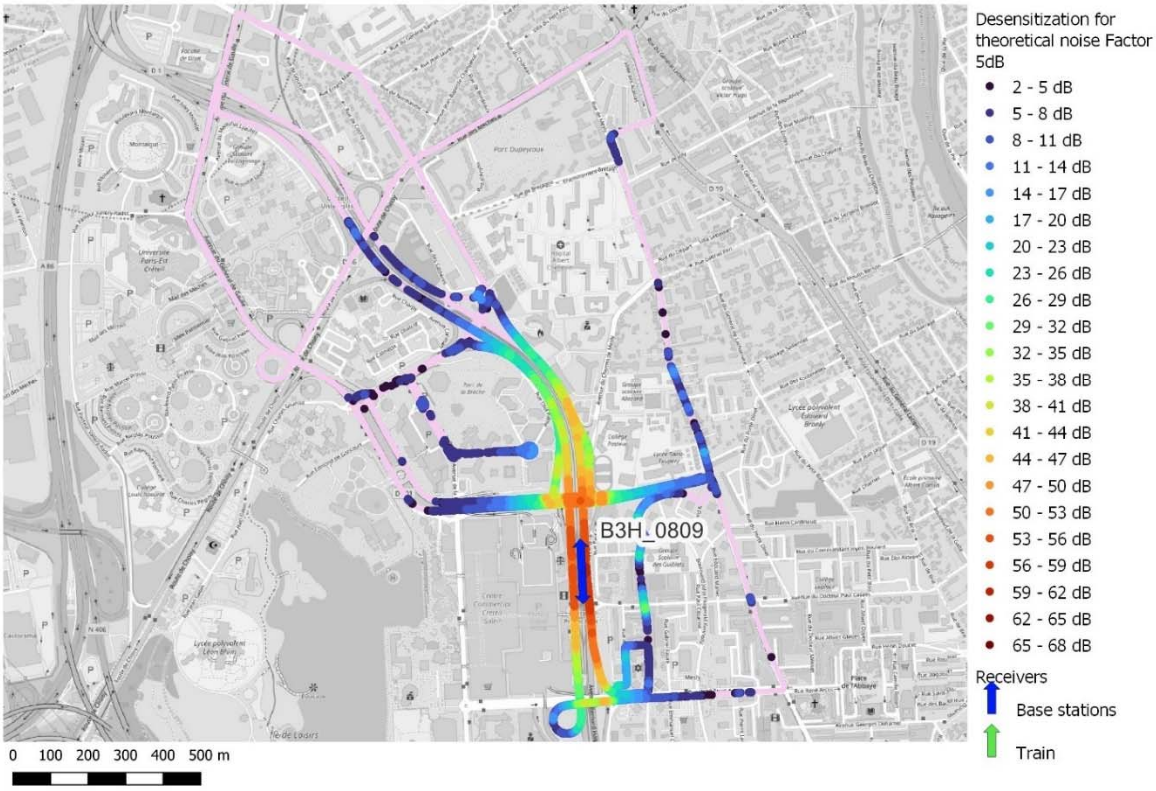

Figure C.22 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

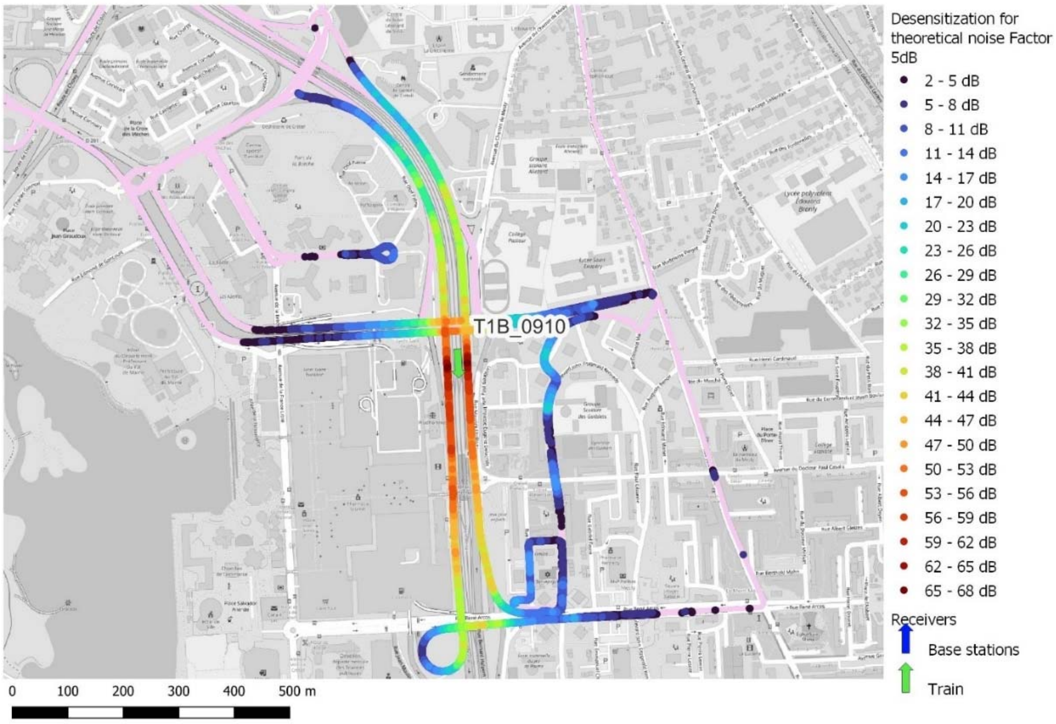

Figure C.23 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

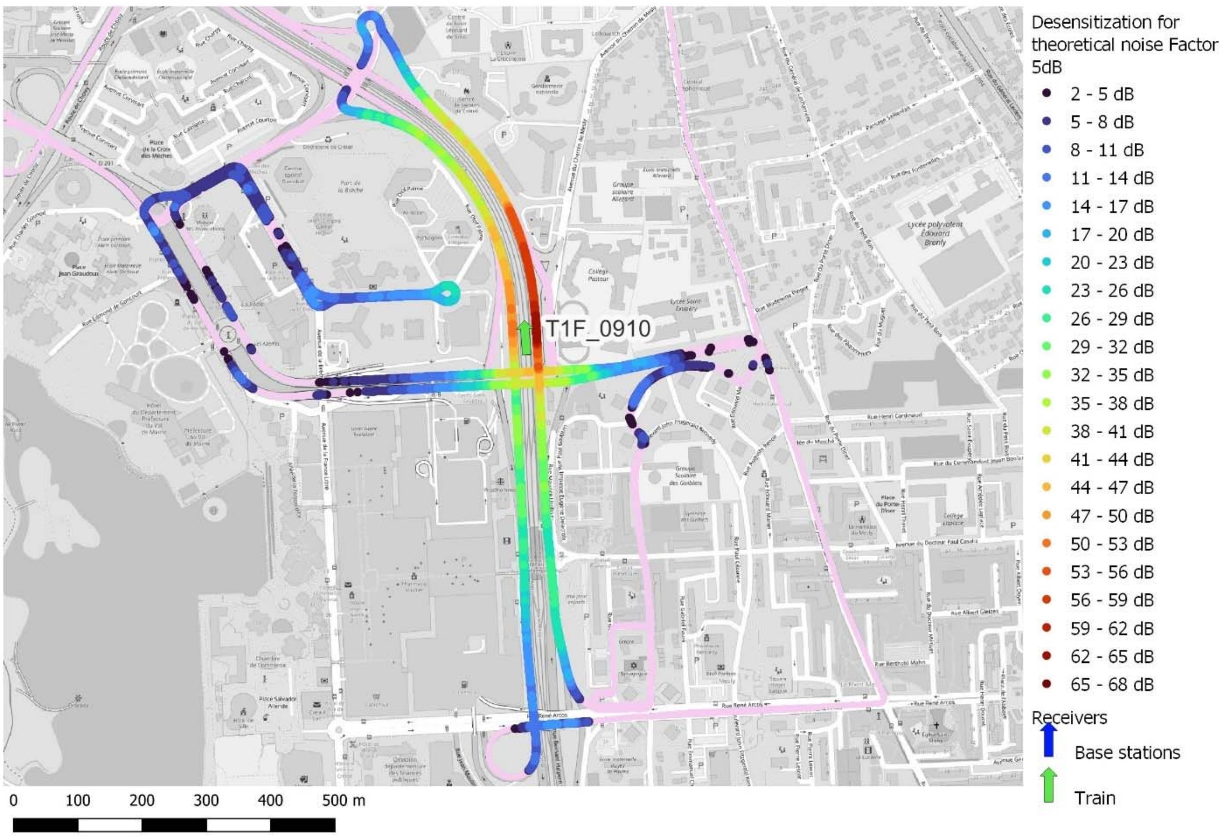

Figure C.24 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

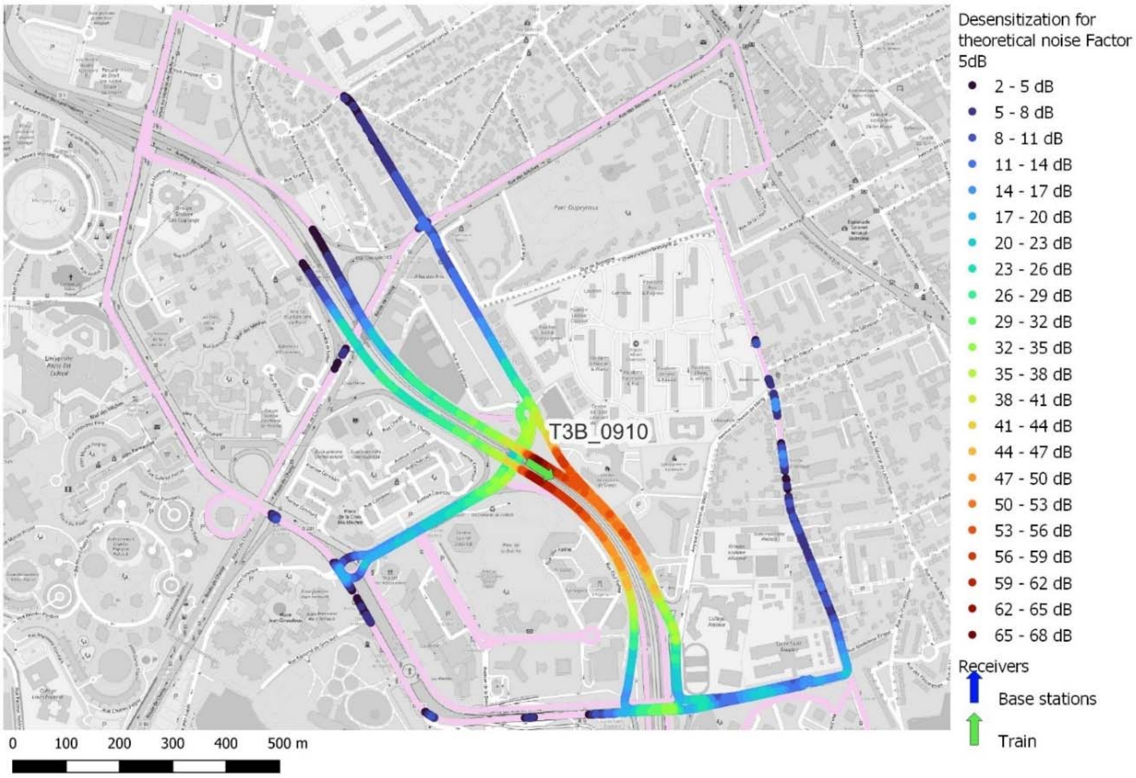

Figure C.25 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

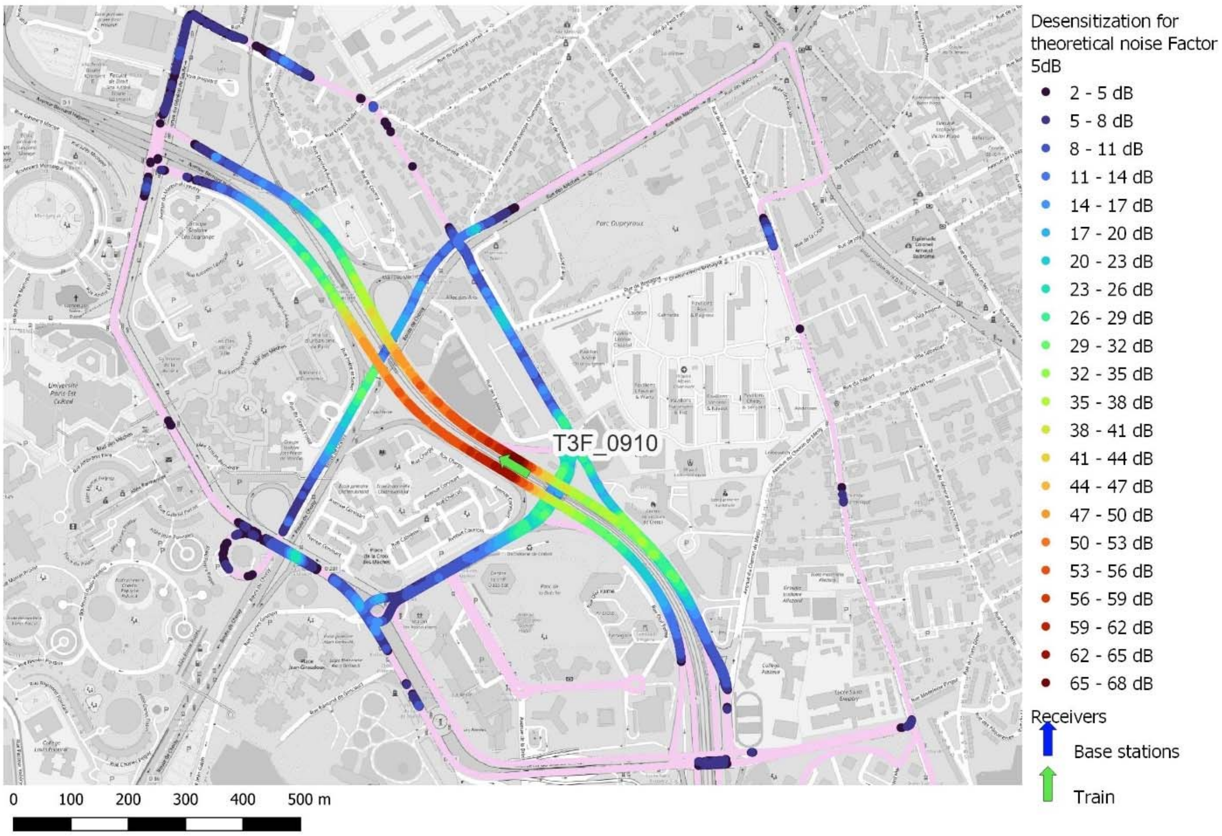

Figure C.26 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

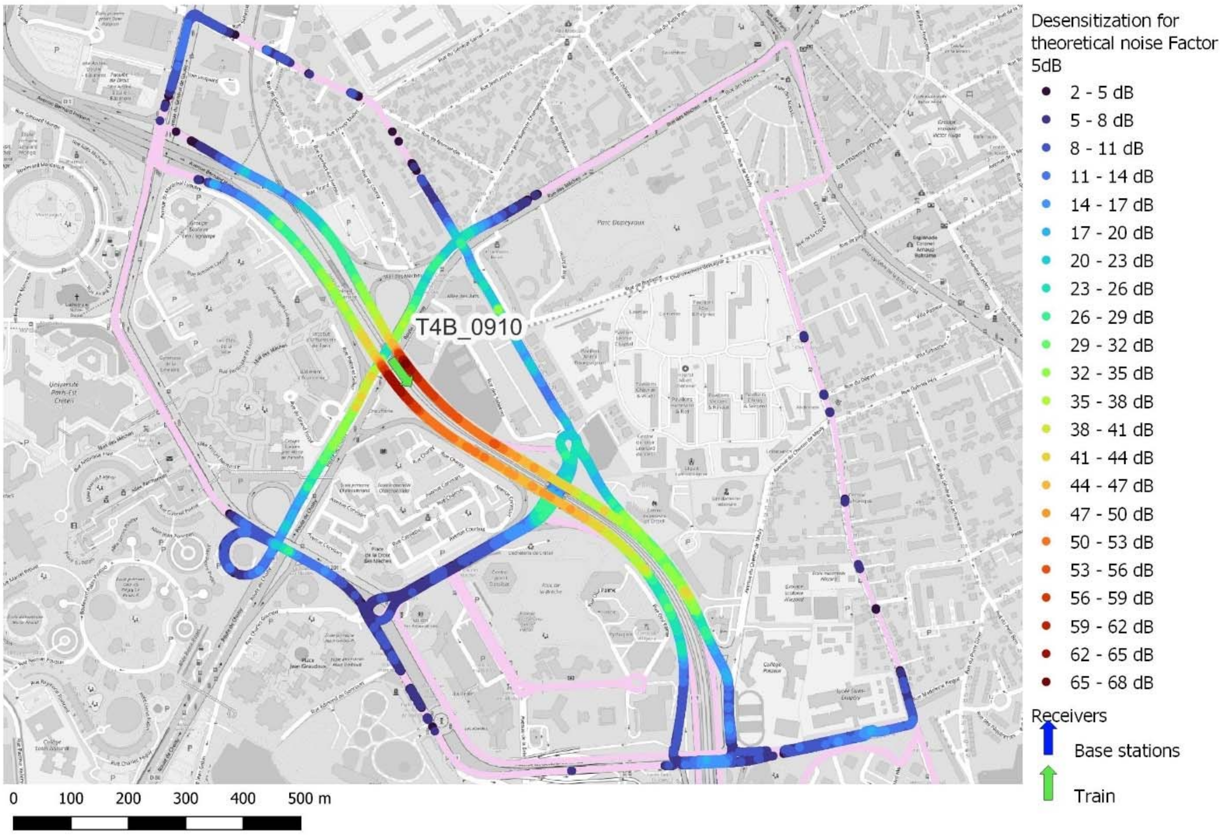

Figure C.27 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

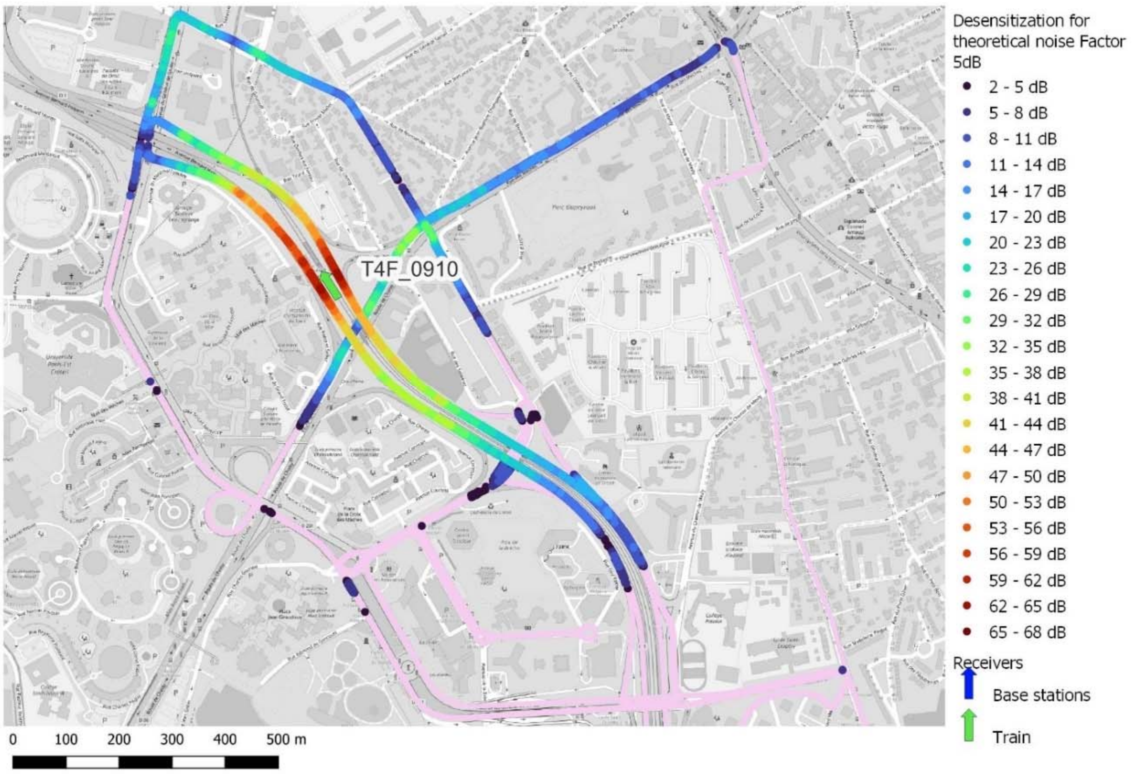

Figure C.28 (© OpenStreetMap contributors - www.openstreetmap.org/copyright)

Annex D: Description of the propagation simulator tool

The propagation simulator is HTZ communications software.

The simulation tool computes diffracted and reflected paths from one or several transmitter locations to a receiving area. It uses three cartographic layers: a digital terrain map, a clutter layer which includes land cover information, and a building layer which includes the building heights.

A wide range of propagation models is available, including referenced ITU models, popular models such as COST or Okumura-Hata, although best results were achieved using the built-in proprietary model. The setup of the propagation tool is provided in this annex for information.

The software allows to import the receivers used during the measurement campaign, with their characteristics, including the antenna patterns. The simulation results are then exported to ascii grids for further processing.

The propagation model computes both diffractions (above rooftop and lateral) and reflections.

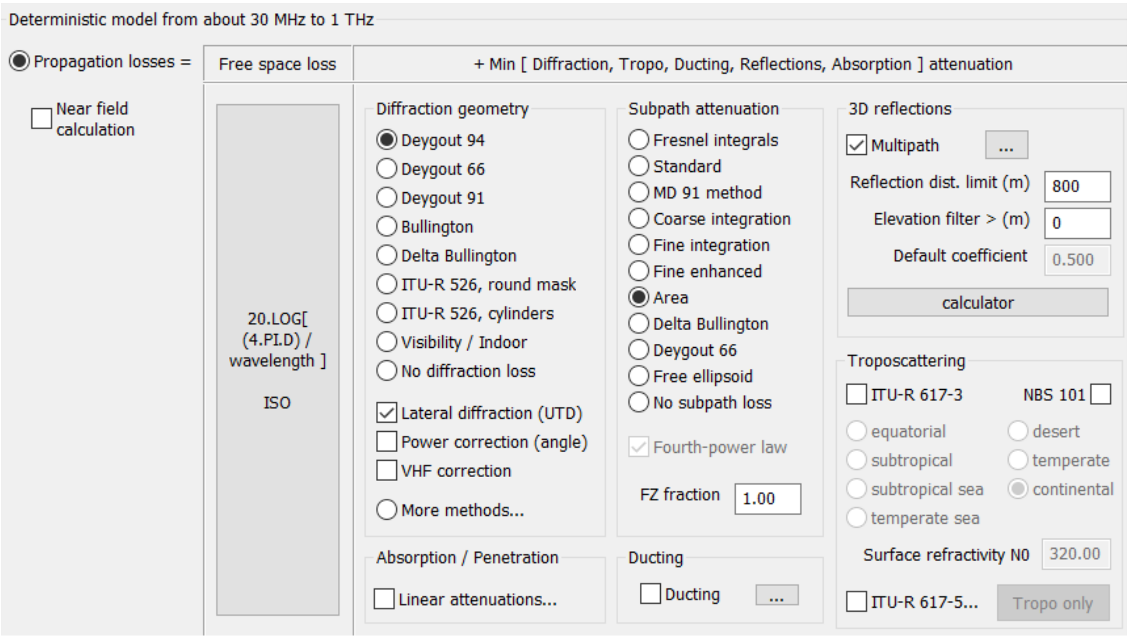

Figure D.1: Simulation parameters

Reflection coefficients are set as follows.

Table D.1: Reflection coefficients

Clutter	Coefficient
Open	0,250
Forest (large trees)	0
Building	0,252
Rail	0
Road	0,058
Rural (small trees)	0,200

These coefficients could be optimized, but it appeared that the greatest mismatches are observed in streets where no reflected paths are found by the simulator despite that reflections probably exist in reality. Greater improvements could probably be achieved using a different algorithm to identify additional reflected paths (e.g. broadening the reflection angles) and improved map accuracy.

The cartographic resolution used was 2 m (X and Y) for Paris downtown and 5 m in the suburban area.

It is also worth noting that the cartographic layers (terrain elevation and buildings) need to be fixed manually at some locations. For instance, at the bridges over the river, the default cartographic altitude is the water height, although for practical reasons, the altitude of the bridge needs to be used. When the rails cross the roads, the altitude and cartographic layers also need to be checked. The trains viaducts also need to be added by hand.

Simulation of propagation performed with vehicle antenna height set to 3 m.

Complementary information about the simulation tool used to prepare the measurement campaign and to compare with measurements is available at: https://atdi.com/products-and-solutions/htz-communications.

Annex E: Reading the box plots

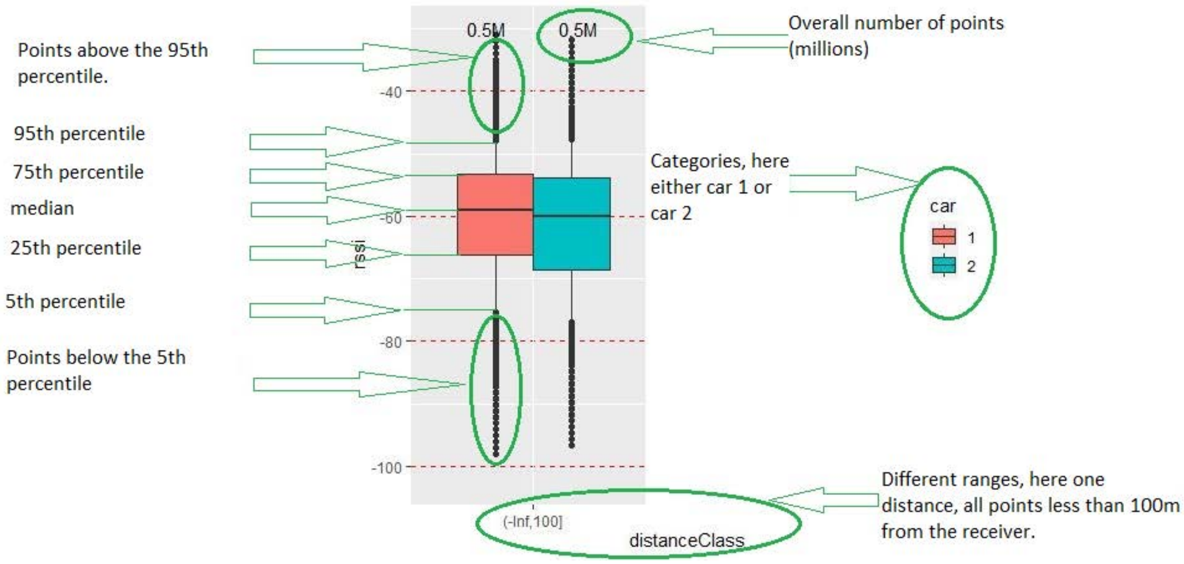

Figure E.1

Annex F: Bibliography

- ECC Report 228: "Compatibility studies between Intelligent Transport Systems (ITS) in the band 5855-5 925 MHz and other systems in adjacent bands".
- ECC Report 290: "Studies to examine the applicability of ECC Reports 101 and 228 for various ITS technologies under EC Mandate (RSCOM 17-26Rev.3)".
- ETSI TR 103 111 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Spectrum requirements for Urban rail Systems in the 5,9 GHz range".
- ETSI EN 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".
- Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.
- Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act).
- Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC Text with EEA relevance.
- Recommendation ITU-R P.2040-1: "Effects of building materials and structures on radio wave propagation above about 100 MHz".
- Teunissen & Montenbruck Handbook of Global Navigation Satellite Systems, Springer, 2017.
- Orpheon-Geodata Diffusion Product sheet.

History

Document history		
V1.1.1	May 2022	Publication