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Urban Rail ITS and Road ITS applications in the 5,9 GHz band; Investigations for the shared use of spectrum

Reference

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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).

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Executive summary

The present document is in response to CEPT's invitation to ETSI to develop sharing and interference mitigation techniques within three years, to ensure co-channel coexistence in the frequency range 5875 MHz to 5925 MHz between Road ITS and Urban Rail radio technologies. It was initiated through the RSC (RSCOM17-26 rev.3 (Final) [i.41]) with the wherein the following recommendation was made:

- *"Mitigation techniques developed through ETSI standardization should be accompanied by technical conditions for spectrum access and relevant harmonised standards, in a technology neutral approach."*

CEPT Report 71 [i.12] proposed that technical solutions already deployed should remain available for maintenance and evolution and the continued rollout of these systems should not be unduly hindered by a change of the spectrum regulatory environment.

The present document proposes methods to allow sharing of Road ITS and Urban Rail in the frequency range 5 915 MHz to 5925 MHz where Urban Rail's priority is respected. Urban Rail intents to use the spectrum from 5875 MHz to 5 915 MHz within closed tunnels where interference with Road ITS services is not expected to be an issue. The regulatory basis for this usage needs to be defined but is outside the scope of the present document. Usage of this spectrum outside of tunnels is not considered in the present document. However, it may be addressed in the future.

The sharing techniques described in the present document should be extendable to other "aggressor" or "victim" channels and bandwidths, if needed, to protect CBTC systems.

The present document proposes:

- Methods to compute the zones where Urban Rail and Road Intelligent Transportation Systems are likely to interfere, based on the outcome of the measurement campaign.
- Principles governing the sharing solution and outline the design of the technical infrastructure allowing Road ITS equipped vehicles to have access to up to date sharing information.
- Appropriate mitigation features to be implemented. These are Restricted Modes of Operations (RMOs) that Road ITS equipped vehicles would activate to avoid interfering with Urban Rail ITS.

It is recommended that:

- a new Technical Specification (ETSI TS 103 745 [i.47]) be developed to address detection and mitigation techniques outlined in the present document; and
- the regulatory and normative frameworks be subsequently updated to enable the use of the 5 915 MHz to 5 925 MHz by Road ITS subject to the implementation of the selected sharing solution.

Introduction

Modern mass-transit Urban Rail systems run trains at short intervals - often 90 seconds apart, sometimes even less. To enable this in complete safety, automatic train control systems are employed, which drive the train, continuously supervise train speed and enforce safe separation between trains.

These systems require continuous, bidirectional data transmission from track to trains, for which radio has been increasingly used over the past fifteen years. Frequencies above 5 905 MHz are used based on national authorizations in several countries (see Annex 1, Table 2b in CEPT Report 71 [i.12]) with proprietary radio technologies and protocols. These radio-based systems are known as Communications Based Train Control (CBTC) systems.

In the context of extensive use of the spectrum, and to enable Public Transport Operators to modernize existing systems and to plan new lines with CBTC, the need for a designated harmonised bandwidth for CBTC, with suitable quality of service, has been expressed in the ETSI TR 103 111 [i.17].

Later, ETSI TR 103 442 [i.10] was developed to present to the ECC a common point of view between TC ITS and TC RT, regarding sharing possibilities between CBTC and Road ITS applications in the 5 875 MHz to 5 925 MHz frequency band. CEPT WGFM invited ETSI to provide a detailed and agreed technical standard allowing practical implementation of both Urban Rail and Road ITS applications in the 5 875 MHz to 5 925 MHz band.

At EU level, the RSCOM mandated an ITS study [i.41] for the extension of 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 and allowing Urban Rail (using Communication Based Train Control, (CBTC)) to use the EC harmonised safety-related ITS band. Its outcome is CEPT Report 71 [i.12]. The RSCOM states, that it is important to note that the potential spectrum expansion is not intended to support segmentation and segregation between technologies and applications within the same band and thus to compensate for any cases of inefficient spectrum use.

CEPT Report 71 [i.12] also mentioned the fact that technical solutions already deployed should remain available for maintenance and evolution and the continued rollout of these systems should not be unduly hindered by a change of the spectrum regulatory environment.

CEPT Report 71 [i.12] responds to that mandate, inviting the European Commission to take into consideration the following improvements in the regulatory framework for ITS: "*The restriction to road transportation system should be withdrawn and should encompass all ground-based land transportation systems including Urban Rail*".

CEPT 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, considering the following from CEPT 71 report:

- *"the frequency band 5875-5925 MHz is designated for all safety-related ITS applications (Road ITS and Urban Rail ITS);*
- *the frequency band 5925-5935 MHz is designated for safety-related Urban Rail ITS applications.*
- *define priority to Road ITS applications below 5915 MHz and to Urban Rail ITS applications above 5915 MHz, so that protection is afforded to the application having priority;".*

CEPT Report 71 [i.12] also mentioned the fact that technical solutions already deployed should stay available for maintenance and evolution and the continued rollout of these systems should not be unduly hindered by a change of the spectrum regulatory environment.

The current frequency allocation is summarized in Figure 1.

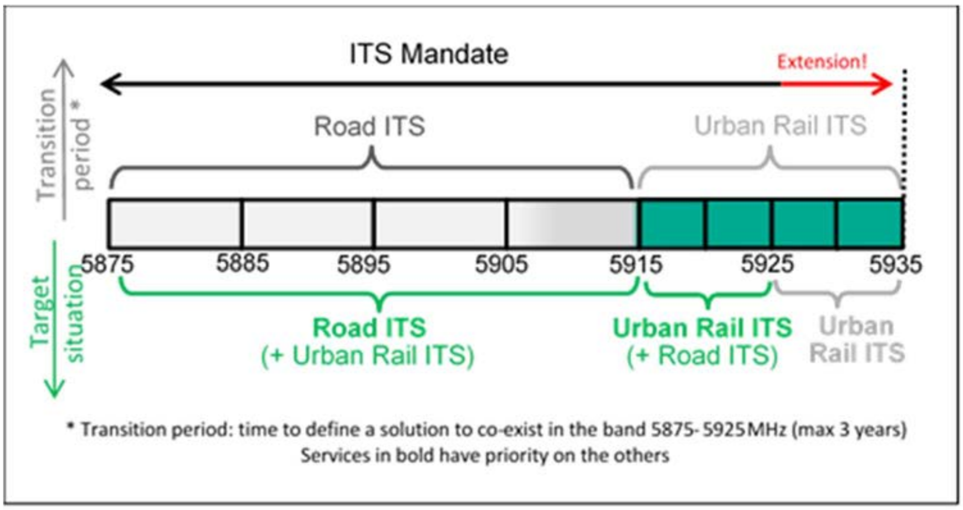


Figure 1: Road ITS and Urban Rail ITS bands

Sharing mechanisms will be specified in a subsequent technical specification which is anticipated to be referenced in a harmonised standard. Indeed, equipment being made available on the market has to be in conformity with the RED, especially article 3.2, and a harmonised standard will have to describe all conditions for the conformity especially with article 3.2. If the manufacturer declares conformity using a notified body the same condition requirements would apply.

The essential requirement according to RED article 3.2. is that radio equipment is constructed so that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference.

1 Scope

The present document proposes methods to ensure co-channel coexistence in the frequency range 5 915 MHz to 5 925 MHz where Urban Rail is the priority application.

In the present document, tramways are considered to be Road ITS because they are not segregated from road or pedestrian traffic.

NOTE: In the present document, no specific sharing methods for the operation of Urban Rail equipment in the bands, where Road ITS has priority, are considered given that Urban Rail equipment is not operating in these bands in areas where ITS equipment needs protection.

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] ETSI TS 102 792: "Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range".

[i.2] ETSI EN 302 637-2 (V1.4.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[i.3] ETSI TS 102 894-2 (V1.3.1): "Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary".

[i.4] Void.

[i.5] ETSI EN 302 637-3 (V1.2.2): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[i.6] ETSI EN 302 663 (V1.2.1): "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[i.7] Void.

[i.8] Void.

[i.9] ETSI EN 302 665 (V1.1.1): "Intelligent Transport Systems (ITS); Communications Architecture".

[i.10] ETSI TR 103 442 (V1.1.1): "Railways Telecommunications (RT); Shared use of spectrum between Communication Based Train Control (CBTC) and ITS applications".

[i.11] Void.

[i.12] 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.13] IEEE 1474.1™-2004: "Communications-Based Train Control (CBTC) Performance and Functional Requirements".

[i.14] IEC 62290.1 (2014): "Railway applications - Urban guided transport management and command/control systems - Part 1: System principles and fundamental concepts".

[i.15] IEEE 802.11™-2016: "IEEE Standard for Information technology -- Telecommunications and information exchange between systems Local and metropolitan area networks -- Specific requirements -- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.16] ETSI EN 301 893 (V2.1.1): "5 GHz RLAN Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

[i.17] 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".

[i.18] Void.

[i.19] Void.

[i.20] Void.

[i.21] Void.

[i.22] ETSI EN 302 931 (V1.1.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Geographical Area Definition".

[i.23] Void.

[i.24] Void.

[i.25] EN 50128: "Railway applications - Communications, signalling and processing systems - Software for railway control and protection systems" (produced by CENELEC).

[i.26] EN 50129: "Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling" (produced by CENELEC).

[i.27] Void.

[i.28] Void.

[i.29] ISO 3166-1: "Codes for the representation of names of countries and their subdivisions -- Part 1: Country codes".

[i.30] ISO 26262 (all parts): "Road vehicles -- Functional safety".

[i.31] IEC 62132-1:2015: "Integrated circuits - Measurement of electromagnetic immunity - Part 1: General conditions and definitions".

[i.32] ETSI TS 103 097: "Intelligent Transport Systems (ITS); Security; Security header and certificate formats".

[i.33] ETSI TS 103 301: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[i.34] Void.

[i.35] AEC - Q100: "Failure Mechanism Based Stress Test Qualification For Integrated Circuits".

[i.36] SAE J2735: "Dedicated Short Range Communications (DSRC) Message Set Dictionary™".

[i.37] Void.

[i.38] 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.

[i.39] Brussels, 13.3.2019 C (2019) 1789 final ANNEX 3 to the Commission Delegated Regulation supplementing Directive 2010/40/EU of the European Parliament and of the Council with regard to the deployment and operational use of cooperative intelligent transport systems.

[i.40] ETSI TR 103 704 (V1.1.1): "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".

[i.41] RSCOM17-26 rev.3 (Final) Brussels, 18 October 2017 DG CONNECT/B4: "Opinion of the RSC pursuant to Advisory Procedure under Article 4 of Regulation 182/2011/EU and Article 4.2 of Radio Spectrum Decision 676/2002/EC - Subject: Mandate to CEPT to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz".

[i.42] Car 2 Car consortium report: "Survey on ITS-G5 CAM statistics", December 2018.

[i.43] 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.44] Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonized technical conditions in the area of radio spectrum use for short-range devices.

[i.45] ETSI EN 303 867: "Rail telecommunications (RT); Urban rail radiocommunications equipment operating in the 5 875 MHz to 5 935 MHz frequency band; Harmonised Standard for access to radio spectrum".

[i.46] ETSI TR 103 853: "System Reference document (SRdoc); Road ITS equipment operating in the 5,9 GHz band with channel bandwidths larger than 10 MHz".

[i.47] ETSI TS 103 745: "Urban Rail ITS and Road ITS applications in the 5855-5925 MHz frequency band; Requirements for the shared use of spectrum".

[i.48] Next Generation V2X - IEEE 8 02.11bd™ as fully backward compatible evolution of IEEE 802.11p - CAR 2 CAR Communication Consortium - 2023-02-02.

[i.49] C-ITS Point of Contact (CPOC) Protocol in the EU C-ITS Security Credential Management System (EU CCMS) - Release 3.0 January 2024.

[i.50] ECC/DEC/(08)01 of 14 March 2008 on the harmonised use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band, latest updated on 18 November 2022.

[i.51] 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".

3 Definitions of terms, symbols and abbreviations

3.1 Terms

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

5 GHz ITS frequency band: band from 5 875 MHz to 5 935 MHz

Communications-Based Train Control (CBTC): Automatic Train Control (ATC) system using radio for train to wayside data communications

NOTE: The general functional requirements of CBTC systems have been standardized by the IEEE in IEEE 1474.1 [i.13], and by the IEC standard 62290.1 [i.14], which give the following definition:

- A CBTC system is a continuous, automatic Communication-Based Train Control system utilizing:
  - high-resolution train location determination, independent of track circuits;
  - continuous, high-capacity, bidirectional train-to-wayside data communications; and
  - train borne and wayside processors capable of implementing Automatic Train Protection (ATP) functions, as well as optional Automatic Train Operation (ATO) and Automatic Train Supervision (ATS) functions.

road ITS: ITS systems based on vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-infrastructure communications for the exchange of information between road vehicles and their environment

NOTE: In the present document Road ITS includes all kinds of ground based ITS except Urban Rail ITS systems.

road ITS station: station transmitting in the 5 GHz ITS frequency band, as defined in ETSI EN 302 665 [i.9]

static detection method: method used by a Road ITS station to detect that it is in a geographical area where Urban Rail protection is requested, even if there is no train in the area and therefore no actual need to mitigate

Urban Rail: public transport system permanently guided at least by one rail, intended for the operation of local, urban and suburban passenger services with self-propelled vehicles and segregated from general road and pedestrian traffic

Urban Rail ITS: Urban Rail system controlled by a CBTC application with communications operating in the 5 GHz ITS frequency band

NOTE: Trams are not included in this definition.

Urban Rail station: Urban Rail device transmitting CBTC messages in the 5 GHz ITS frequency band

vehicle: all types of land mobile device

3.2 Symbols

Void.

3.3 Abbreviations

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

ACK	ACKnowledgment
AP	Access Point
API	Application Programming Interface
ASECAP	Association Européenne des Concessionnaires d'Autoroutes et d'Ouvrages à Péage (European Association of Operators of Road Tolling Infrastructure)
ASIL	Automotive Safety Integrity Level
ASN	Abstract Syntax Notation
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
BS	Base Station
BSS	Basic Service Set
CABS	Cooperative Awareness Basic Service
CAM	Cooperative Awareness Message
CAS	Cooperative Awareness basic Service
CBTC	Communications-Based Train Control

CBTC BS	Communications-Based Train Control Base Station
CCH	Control Channel
CDD	Common Data Dictionary
CEN	Comité Européen de Normalisation (European Committee for Standardization)
C-ITS	Cooperative Intelligent Transportation Systems
C-ITS-S	Cooperative ITS Station
CMS	Certificate Management System
C/N	Carrier-to-Noise
CRA	Communication Relevance Area
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CTS	Clear To Send
DCC	Decentralized Congestion Control
DE	Data Element
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DF	Data Frame
DIFS	Distributed coordination function Interframe space
DSRC	Dedicated Short-Range Communications
DSSS	Direct Sequence Spread Spectrum
E2E	End-to-End
EIRP	Equivalent Isotropic Radiated Power

NOTE: Unless stated otherwise, EIRP denotes the maximum value over all directions.

EMC	ElectroMagnetic Compatibility
FCS	Frame Check Sequence
FWA	Fixed Wireless Access
GN	GeoNetworking
GPS	Global Positioning System
HF	High Frequency
IBSS	Independent Basic Service Set
ID	IDentity
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ISO	International Standards Organization
ITS	Intelligent Transport Systems
ITS-G5	IEEE 802.11 radio access technology in the 5,9 GHz band
ITS-S	Intelligent Transport Systems Station
ITU-R	International Telecommunication Union - Radio
I2V	Infrastructure-to-Vehicle
LDM	Local Dynamic Map
LF	Low Frequency
LTE	Long Term Evolution
MAC	Medium Access Control
MAP	Map data
MCO	MultiChannel Operation
NLOS	No Line Of Sight
OBU	On Board Unit
OCB	Outside the Context of a BSS
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency-Division Multiplexing
OJEU	Official Journal of the European Union
PHY	PHYsical layer
PKI	Public Key Infrastructure
PR	Protection Ratio
PSD	Platform Screen Doors
PZ	Protection Zone
PZM	Protection Zone Message
RATP	Régie Autonome des Transport Parisien

NOTE: Metro operator of Paris.

RED	Radio Equipment Directive
RER	Reseau Express Regional

NOTE: Suburban metro lines in Paris.

RF	Radio Frequency
R-ITS	Road Intelligent Transport Systems
RMO	Restricted Mode of Operations
R-RMO	Region of Restricted Mode of Operations
RSU	Road Side Unit or Rail Side Unit
RSSI	Received Signal Strength Indicator
RTS	Request To Send
SAE	Society of Automotive Engineers
SIFS	Short InterFrame Space
SIL4	Safety Integrity Level 4
SINR	Signal Interference + Noise Ratio
SPAT	Signal Phase and Timing
SRD	Short Term Devices
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
T-ITS-S	Train ITS Station
TS	Technical Specification
TS-ITS-S	Track Side ITS Station
T-OBU	Train OnBoard Unit
TX	Transmitter
UDP	User Datagram Protocol
UR	Urban Rail
UR-CAM	Urban Rail CAM
UR-DENM	Urban Rail DENM-like message
UR-ITS-S	Urban Rail ITS Station

NOTE: An UR-ITS-S is either a T-ITS-S or a TS-ITS-S.

UTC	Coordinated Universal Time
V-ITS-S	Vehicle ITS Station
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WGFM	Working Group Frequency Management
WGS	World Geodetic System
Wi-Fi®	MAC & PHY specified in IEEE 802.11 [i.15]
XML	eXtensible Markup Language
ZC	Zone Controller

4 Spectrum framework and technical descriptions of Urban Rail and Road ITS technologies

4.1 Current spectrum regulatory framework

The present document is compiled on the Commission Implementing Decision (EU) 2020/1426 [i.43].

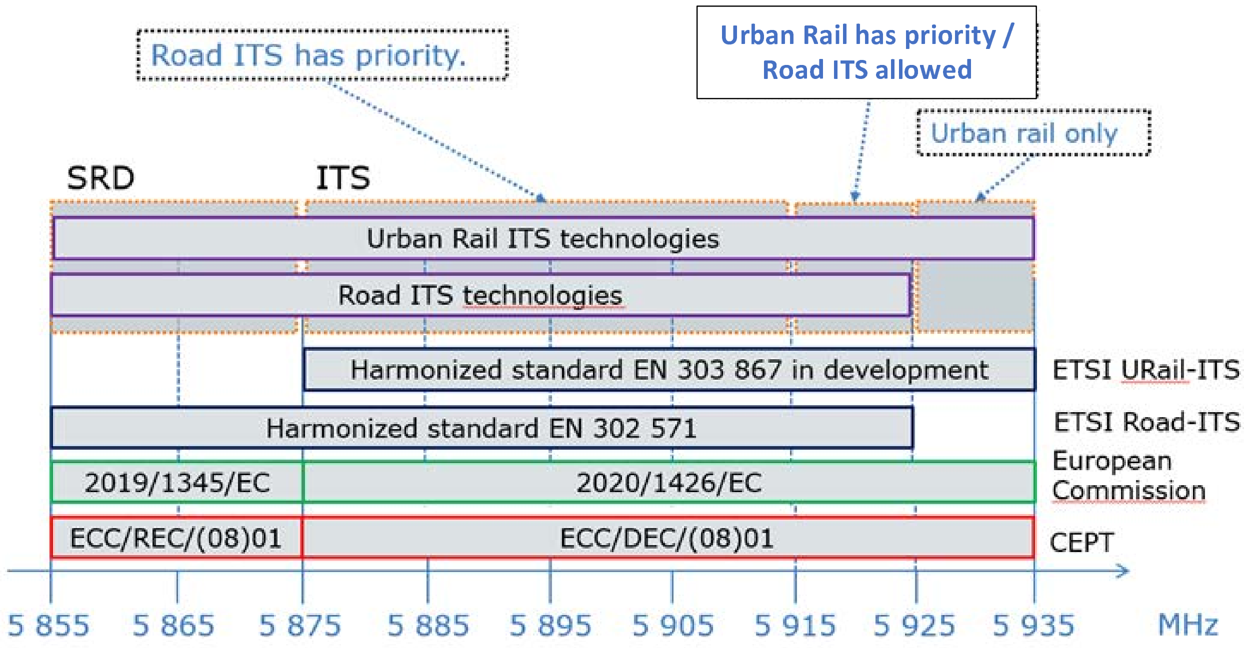


Figure 2: Spectrum status for Road ITS and Urban Rail ITS

Figure 2 depicts the spectrum situation for Road ITS and Urban Rail ITS. The SRD band from 5 855 MHz to 5 875 MHz has a designation for non-safety ITS services and the ITS band from 5 875 MHz to 5 935 MHz for safety related services. The European Commission has decided to follow the CEPT and to designate the SRD band through Decision 2019/1345/EC [i.44] and the ITS band through the Decision 2020/1426/EC [i.43]. On this basis the commission has mandated ETSI to develop the technical standards. ETSI develops the standard ETSI EN 303 867 [i.45] for Urban Rail ITS, which is also planned to become a harmonised standard. It covers the frequency range from 5 875 MHz to 5 935 MHz hereby overlapping the range from 5 875 MHz to 5 925 MHz.

For Road ITS applications, the frequency arrangement is currently based on block sizes of 10 MHz. However, ETSI has provided ETSI TR 103 853 [i.46] as an SRdoc to inform CEPT of benefits of block sizes larger than 10 MHz. This is currently under investigation and should also be taken into in the context of the present document.

The Urban Rail community has concluded that at least 20 MHz of harmonised spectrum is necessary in order to operate Urban Rail Communication-Based Train Control (CBTC) systems, 10 MHz of which (5 915 MHz to 5 925 MHz) is to be shared with Road ITS where a requirement for 70 MHz of spectrum has been identified). The upper 10 MHz from 5 925 MHz to 5 935 MHz shares the band with fixed services. In order to fulfil the needs of both Road ITS and Urban Rail ITS, coexistence has to be assessed carefully in light of the different priorities.

Road ITS applications have priority below 5 915 MHz and Urban Rail ITS applications have priority above 5 915 MHz; protection needs to be afforded to the applications having priority in their respective bands. In the context of the present document, protection/priority of an application is interpreted to mean preservation of the application's proper functioning and availability.

In the absence of suitable mitigation techniques, the priority regime enforces that both systems, Road and Urban Rail, remain confined to their prioritized spectrum until suitable mitigation techniques are defined. There is one exception for infrastructure-to-vehicle Road ITS systems, which can use the 5 915 MHz to 5 925 MHz locally based on licensed regime, if interference can be excluded. The present document will help to define these suitable mitigation techniques so that Road ITS applications can use the band 5 915 MHz to 5 925 MHz without the infrastructure-to-vehicle restriction.

Intelligent Transport Systems (ITS) encompass Road ITS and Urban Rail ITS. Road ITS include cooperative systems based on real-time communications between the vehicle (including cars, trucks, bicycles, motor bicycles, tramways, construction equipment, agricultural equipment, as well as pedestrian and cycling equipment) and its environment (other vehicles, infrastructure, etc.). The separation distance between Road and Urban Rail applications varies from country to country. For example, in Germany, some Urban Rail trains use the long-distance tracks which can include same level crossings with Road ITS users. However, in the context of this work, Urban Rail is considered separated from road vehicle traffic. Crossings are considered managed through proper signalling, hence not requiring direct communications between CBTC systems and Road ITS stations.

It should be noted that vulnerable Road ITS users could use a train thus interfering from the inside with Urban Rail, e.g. as a passenger or with a bicycle/pedelec. Although the technical characteristics and application specific parameters related to such scenarios are not described in the present document, the coexistence solution may apply irrespective of the type of Road ITS device.

The spectrum being a very valuable resource, the scenarios of interference need special considering and therefore the coexistence and mitigation between both applications need careful evaluation.

Any radio equipment to be placed on the market needs to comply to the Radio Equipment Directive (EU) 2014/53 (RED) [i.38] and therefore needs to fulfil the essential requirements (see Article 3.2). For the purpose of the present document Article 3.2 is relevant: "*Radio equipment shall be so constructed that it both effectively uses and supports the efficient use of radio spectrum in order to avoid harmful interference*".

The coexistence and mitigation techniques will form a compromise between the requirements of both applications which are Automatic Train Control (ATC) and the security of the passengers on the one hand and the spectrum needs of Road ITS users on the other hand. Especially in the large cities the need of an ATC comes at the same time and same place as people also are users of Road ITS technologies. Therefore, the proposed techniques for coexistence and mitigation should be state of the art.

It is anticipated that the TS that follows the present document will be referenced in relevant harmonised ENs related to ITS devices.-This reference includes the TS into the legal framework and leads to the presumption of conformity. It imposes legal responsibility on the Commission and opens the way to judicial review. Hence the referencing in the Official Journal of the European Union is subject to careful assessment by the Commission. If the result of the ETSI working group is not sufficiently complying to article 3.2 of the RED referencing in the OJEU is at risk. The present document also helps minimizing these risks by assessing the proposed mitigation procedures.

4.2 Technical description of CBTC system communications

4.2.1 Overview

The description of the CBTC need for communication to operate properly, and the consequences of a disturbed transmission between each train and the wayside has been described in clause 6 of ETSI TR 103 442 [i.10].
The purpose of this clause is to express these requirements in technical terms suitable to allow sharing studies to take place.

The radiocommunications part of a CBTC system is used to exchange data between CBTC devices installed in each train and wayside CBTC equipment connected to a redundant backbone network.

The main wayside CBTC pieces of equipment are the Zone Controllers (ZC) and the Automatic Train Supervision (ATS).

Communications with trains take place via radio equipment deployed along the tracks and connected to the backbone network. A typical deployment scenario is shown in Figure 3.

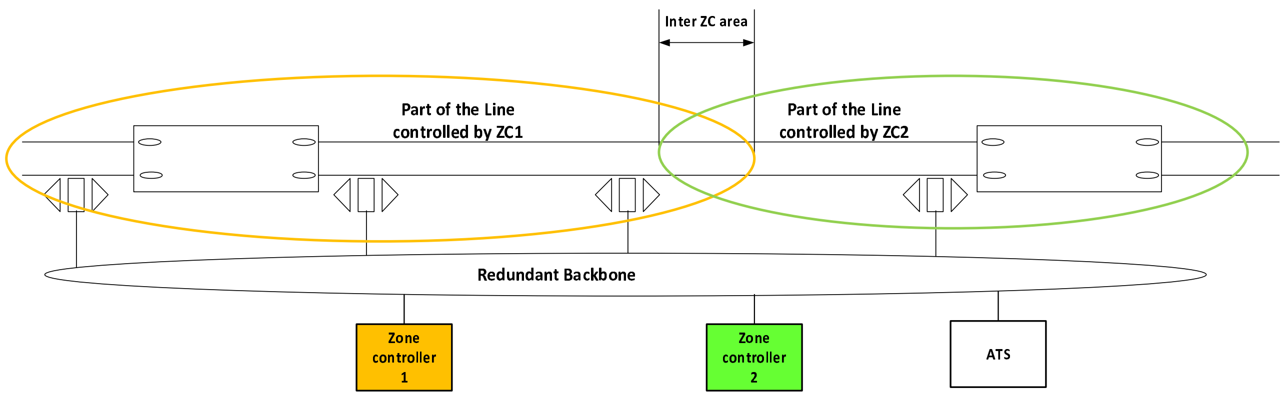


Figure 3: Generic CBTC communication scenario

The back-to-back antennas used by each CBTC access point represented in Figure 3, are connected to the same radio transceiver via a power splitter and are therefore using the same frequency. Successive access points along the track are using a frequency reuse plan, using channels alternatively. Train radios installed at the front and the rear of the train are able to use both channels.

Two Urban Rail ITS CBTC systems are currently used in Europe in the 5 GHz ITS frequency band and are considered in the present document:

- one based on DSSS/TDMA; and
- one based on IEEE 802.11 [i.15] using CSMA//CA.

They have different receiver sensitivity, minimum signal to interference ratio and timing performance requirements, which will be further detailed in clauses 4.2.2 and 4.2.3.

4.2.2 Detailed technical characteristics of CBTC using DSSS/TDMA communication system.

The first CBTC communication system is based on a Direct Spread Spectrum Sequence technique, with a long spreading sequence, and uses a TDMA cycle to share access to the channel between wayside transmission and train transmission. Several individual access points are grouped into large cells (typically 2 inter-station, so up to 3 kms), as shown in Figure 4, controlled by a cell controller which manages the time synchronization, as described in Figure 5.

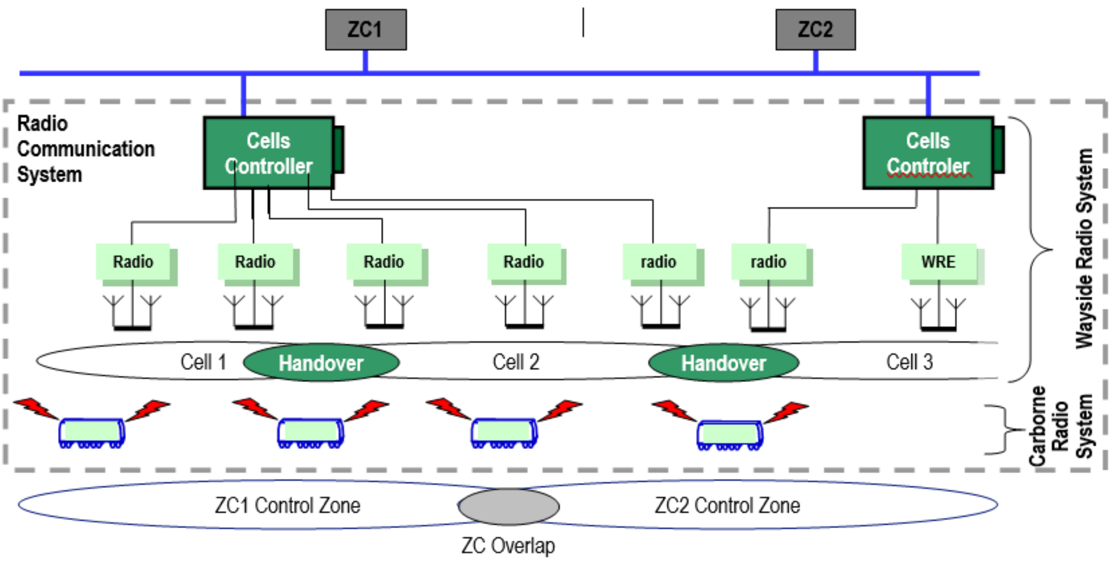
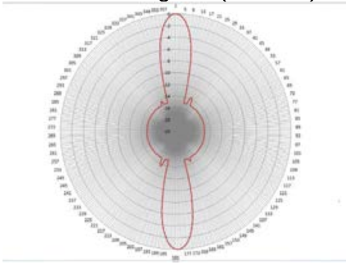
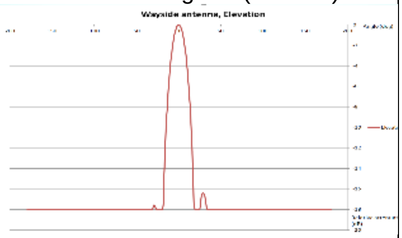
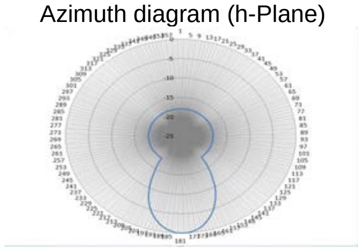
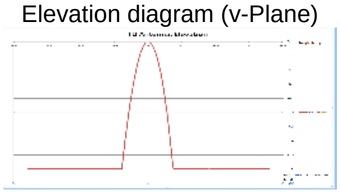


Figure 4: Overview of DSSS/TDMA CBTC communication system

The main characteristics regarding frequency sharing aspects are a high interference immunity, low transmission rate and specific organization of the transmission of the application data in common messages transmitted by wayside devices for all trains in a cell, resulting in a high duty cycle, in particular for wayside transmitters. The basic technical characteristics are summarized in Table 1. The timing characteristics are given in Figure 5.

Table 1: CBTC DSSS/TDMA communication system technical characteristics

Technical characteristics of CBTC TDMA/DSSS based system		
	CBTC wayside Base Station	**CBTC train unit**
Frequency (of currently deployed systems)	5 907,5 MHz/5 912,5 MHz/5 917,5 MHz/5 922,5 MHz/5 927,5 MHz/5 932,5 MHz	5 907,5 MHz/5 912,5 MHz/5 917,5 MHz/5 922,5 MHz/5 927,5 MHz/5 932,5 MHz
Bandwidth	5 MHz	5 MHz
EIRP (dBm/10 MHz)	30 dBm	30 dBm
Antenna gain	18 dBi	14 dBi
Feeder/splitter/shielding losses	9 dB	4 dB
Typical Antenna pattern	Azimuth diagram (h-Plane)  (See note) Bore sight of the antennas are in direction of the tracks Elevation diagram (v-Plane)  Antennas are installed without tilt.	Azimuth diagram (h-Plane)  Bore sight of the antenna is in direction of the tracks Elevation diagram (v-Plane)  Antenna is installed without tilt.
Protection Ratio (PR) (Protection Ratio is the minimum C/N+I criterion ensuring Message Error Rate < 10^{-2})	-3 dB	-3 dB
Sensitivity	=10log10(kTB) + F + PR: -105 dBm	=10log10(kTB) + F + PR: -105 dBm
Adjacent channel rejection (based on internal specifications)	50 dB	50 dB
NOTE: Combined diagram for an antenna array with 2 back-to-back antennas and a power splitter.		

Timing:

Duty cycle for wayside transmitters (all transmitters of the same cell transmitting in a synchronized way):

- T_{on} = 50 ms of transmission - then T_{off} = 68 ms off, resulting in a duty cycle of 42,4 %.

Duty cycle for a train:

- T_{on} = 6,5 ms of transmission - then T_{off} = 111,5 ms off, resulting in a duty cycle of 5,5 %.

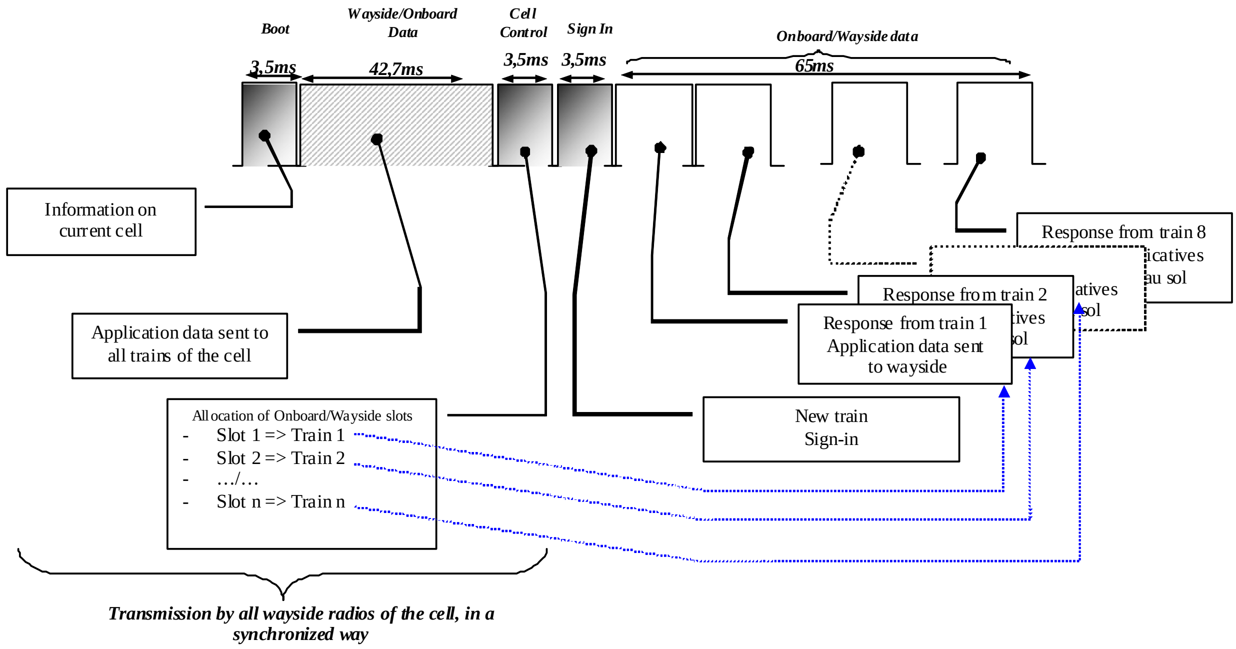


Figure 5: Timing characteristics of DSSS/TDMA CBTC communication system

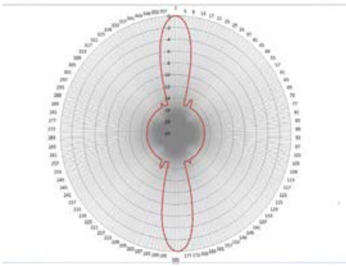
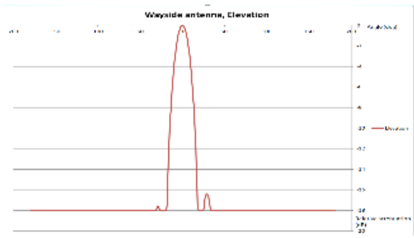
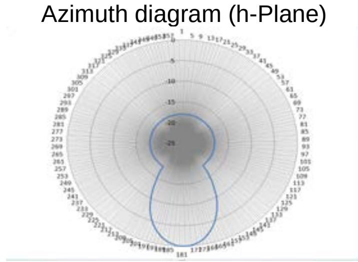
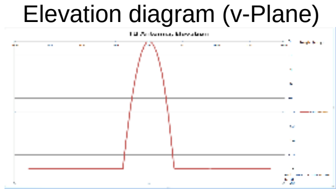
For DSSS/TDMA based CBTC systems no listen before talk mechanism is in place. Sharing based on this mechanism is therefore not possible. The maximum average packet loss ratio at application level, the *Message Error Rate*, has not to exceed 1 %. The link budget between a train unit and an access point is defined such that link quality is reached for at least 99 % of the possible train locations.

4.2.3 Detailed technical characteristics of CBTC using IEEE 802.11 based communications

The second CBTC communication system is based on IEEE 802.11a [i.15], using OFDM as modulation scheme and CSMA/CA as spectrum access technique. In order to balance the CSMA/CA drawbacks (in particular collisions due to the hidden node effect), the channel load during operation is kept well below the maximum limits possible in a CSMA/CA system. In addition, redundancy and several retransmissions of each message are used in some CBTC implementations to ensure the required level of transmission availability. With this system, application data are sent as unicast messages to/from each train.

The communication needs in terms of messages to be sent and received are given in Annex B.

Table 2: CBTC communication system based on IEEE 802.11 [i.15] technical characteristics

Technical characteristics of CBTC IEEE 802.11 based system		
	CBTC wayside Base Station	**CBTC train unit**
Frequency (of currently deployed systems)	5 910 MHz/5 915 MHz/ 5 920 MHz/5 925 MHz/5 930 MHz	5 910 MHz/5 915 MHz / 5 920 MHz/5 925 MHz/5 930 MHz
Bandwidth	5 MHz	5 MHz
Maximum EIRP for a channel of 5 MHz (based on national regulation higher powers are possible)	30 dBm	30 dBm
Typical Antenna gain	18 dBi	14 dBi
Feeder, splitter and shield losses	9 dB	4 dB
Typical Antenna pattern (identical to antenna used with DSSS based system)	Azimuth diagram (h-Plane)  (See note) Bore sight of the antennas are in direction of the tracks Elevation diagram (v-Plane)  Antennas are installed without tilt.	Azimuth diagram (h-Plane)  Bore sight of the antenna is in direction of the tracks Elevation diagram (v-Plane)  Antenna is installed without tilt.
Protection ratio (PR) (Protection Ratio is the minimum C/N+I criterion ensuring Message Error Rate < 10^{-2})	9 dB to 14 dB	9 dB to 14 dB
Minimum wanted signal at CBTC receiver	< -87 dBm to -84 dBm	< -87 dBm to -84 dBm
Minimum Adjacent channel rejection	For 1,5 Mbits/s: > 16 dB For 3 Mbits/s: > 13 dB	For 1,5 Mbits/s: > 32 dB For 3 Mbits/s: > 29 dB
NOTE 1: Combined diagram for an antenna array with 2 back-to-back antennas and a power splitter. NOTE 2: The Protection Ratio (PR) depends on the CBTC line considered. A range is provided. NOTE 3: The minimum wanted signal at CBTC receiver depends on the CBTC line considered. A range is provided.		

NOTE: 1 Uplink and Downlink are unbalanced.

2 Operating mode is TDD

3 As long as ETSI EN 303 867 [i.45] is not available the spectrum mask of ETSI EN 301 893 [i.16] can be assumed

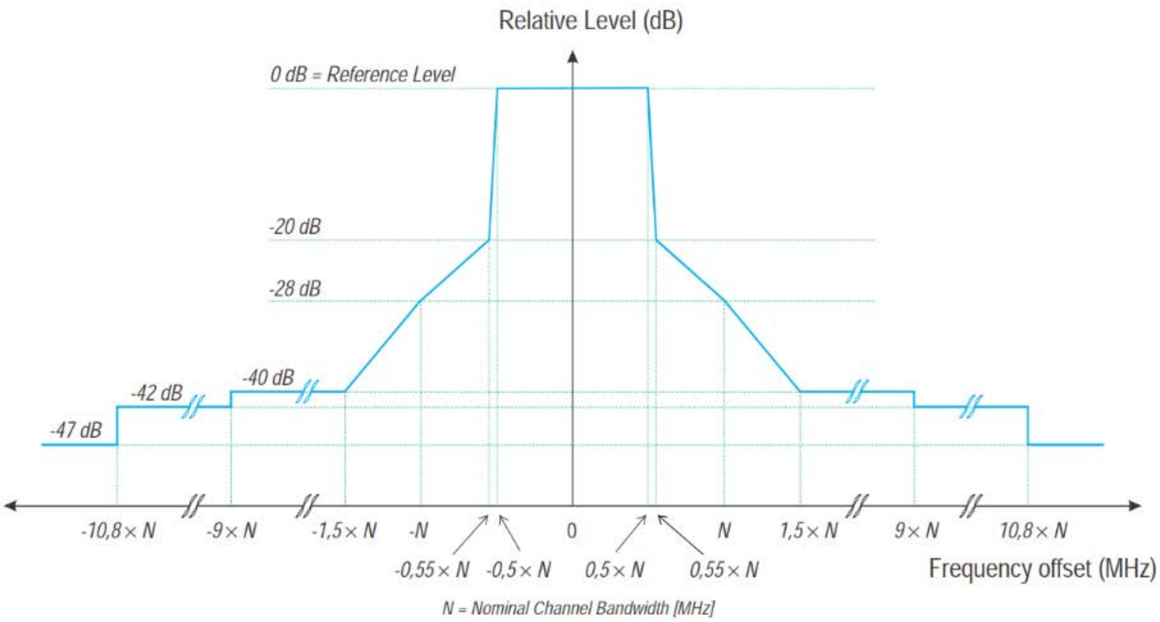


Figure 6: Spectrum mask of an IEEE 802.11 [i.15]-based CBTC system compliant with ETSI EN 301 893 [i.16]

Duty Cycle:

CSMA/CA and Automatic Repeat Request at MAC layer level are used. As shown in the example in Annex B, the duty cycle in uplink and downlink varies with payload size of CBTC application, data rate, number of Zone Controllers, usage of platform screen doors and number of trains sharing an AP.

Table 3 provides a summary of the analysis performed in Annex B for the train and wayside access point. The following cases are considered: average and maximum CBTC throughput for train and wayside access point for communication with one zone controller, with three zone controller and three zone controllers plus platform screen door.

The summary is limited to the % of channel occupancy for a data rate of 3 Mbits/s for combined uplink and downlink.

Table 3:Duty cycle for IEEE 802.11 [i.15]-based CBTC radio systems

Average and maximum % Channel occupancy in a Radio Cell covered by an Wayside Access point						
Number of trains associated to a Wayside Access point	**Communication with one Zone controller**		**Communication with three Zone Controllers**		**Communication with three Zone Controllers plus platform screen doors**	
	Average	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
1	4 %	6 %	6,5 %	7,4 %	14,3 %	14,6 %
2	8 %	12 %	13 %	14,8 %	28 %	29,2 %
6	24 %	36 %	39 %	44,4 %	87 %	87,6 %

The choice of the data rate depends on the metro line. The parameters considered to select the data rate are the CBTC application requirements that depends on the project, the maximum number of trains present simultaneously in a radio cell and in the adjacent ones and the number of trains in a depot. The data rate of 1,5 Mbps, 4,5 Mbps and 6 Mbps are also typical for CBTC projects. Table 3 is only one example of duty cycles values for a specific data rate, 3 Mbps in this case. In addition, these duty cycles depend on the technology and the application requirements which could change in the future.

4.3 Technical characteristics of Road ITS

The studies in the present report consider that the maximum EIRP of road ITS vehicles is 33 dBm, that they are capable of transmit power control, and that frequency arrangement is as per [Commission Implementing Decision (EU) 2020/1426 of 7 October 2020].

In addition, for some studies investigating the coexistence issue in absence of mitigation solutions, the horizontal antenna diagrams of the vehicles are assumed omnidirectional. Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Message (DENM) message lengths are assumed to be respectively < 1 ms and < 2 ms, consistently with ETSI EN 302 637-2 [i.2] and ETSI EN 302 637-3 [i.5]. An average duty cycle value of 1 % over one hour is assumed for the periodic awareness messages (CAM) and a peak value of 3 % for critical event-based messages like DENM. However, those characteristics have no consequence on the coexistence solution.

5 Evaluation of the areas of mutual impact

5.1 Introduction

The clauses 5.2 and 5.3 identify the interference effects of Road ITS devices operated in the vicinity of Urban Rail communication system.

Firstly, clause 5.2 assesses the interference effect on Urban Rail systems of 100 % active Road ITS devices, using the results of a measurement campaign (see Annex D).

The accuracy of the simulation tools and good practices to assess the risk of interference on-site are recalled from in clause 5.3.

This clause does not identify the interference effects of Urban Rail on Road ITS in its channels. It is assumed that Urban Rail devices may use these ITS channels only in areas where no ITS-Stations are likely to be active, for example in tunnels. As a result, no analysis is required.

5.2 Case studies

5.2.1 Methodology

This clause estimates the power received at CBTC antenna connectors in the 10 MHz bandwidth used by Road ITS OBUs to transmit their signals. The exercise is based on real path-loss measurements documented in ETSI TR 103 704 [i.40]. This RF power input to the CBTC receivers is considered interference since the CBTC transmissions are expected to occupy the same 10 MHz bandwidth or a fraction thereof.

Figure 7 illustrates the transmitter and receiver reference points for measurement of Road ITS interference to CBTC receivers in the trains as described in the measurement campaign report ETSI TR 103 704 [i.40].

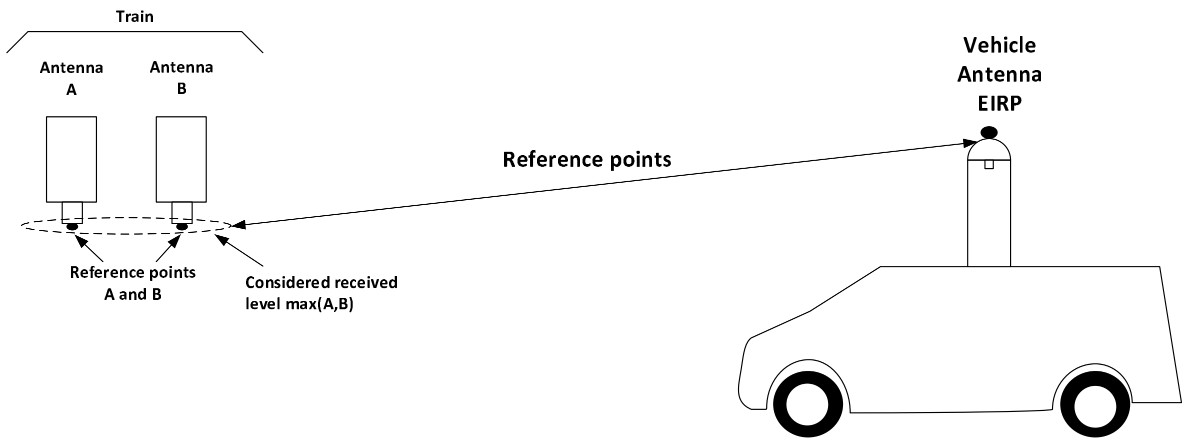


Figure 7: Reference points used in measurement of Road ITS interference to CBTC train-mounted receivers

Figure 8 illustrates the transmitter and receiver reference points for measurement of Road ITS interference to CBTC receivers at the trackside as described in the measurement campaign report ETSI TR 103 704 [i.40].

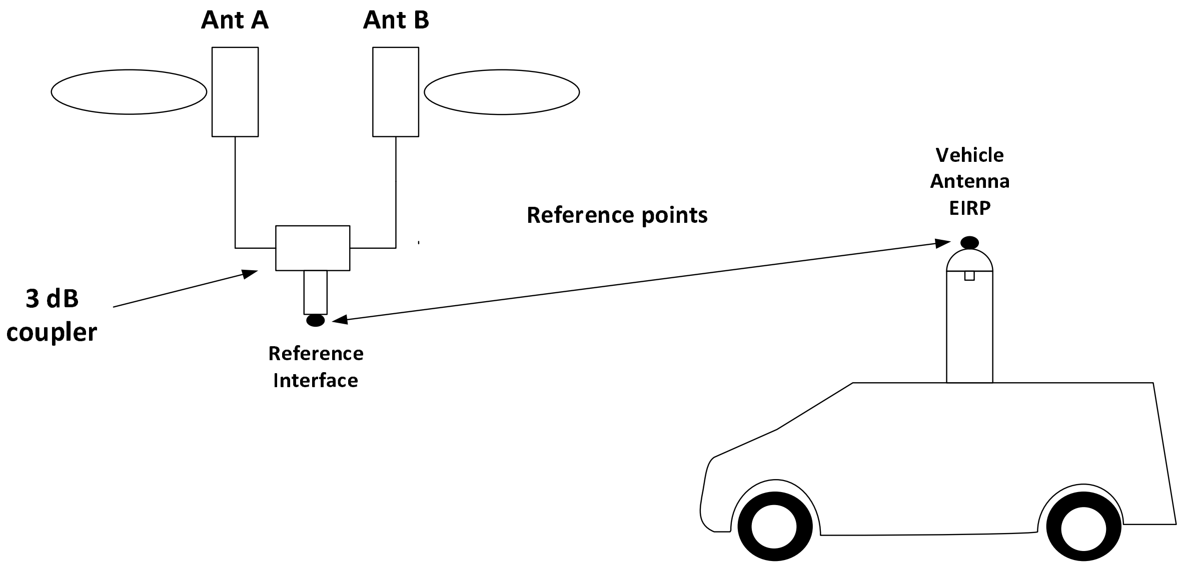


Figure 8: Reference points used in measurement of Road ITS interference to CBTC trackside receivers

Various interference power criteria may be used to define Regions of Restricted Mode of Operations" (R-RMOs, see clause 5.6.1), depending on site-specific considerations. Typical minimum wanted signal at CBTC receivers and protection ratios are given in clause 4. For the definition of the R-RMOs, these may be combined as follows, to determine the maximum admissible interference power:

$$I_{max} = P_{cbtc,min} - PR + B$$

Where:

- I_{max} denotes the maximum admissible interference power (in dBm within e.g. a 10 MHz channel).
- $P_{cbtc,min}$ is the minimum wanted signal at CBTC receiver tailored to the case considered.
- PR is the protection ratio applicable to the CBTC project considered.
- B is a bandwidth correction factor. It is equal to +3 dB if I_{max} is defined in dBm within a10 MHz channel, $P_{cbtc,min}$ in dBm within a 5 MHz channel and PR is a cochannel protection ratio.

The choice of these parameters is a matter for coordination at national level, as they may be tailored to each situation. Indicative values are used in the clauses 5.2.2.1 and 5.2.2.2 for illustration purpose only:

Assuming a system with a minimum wanted signal at CBTC receivers of -84 dBm/5 MHz, and further assuming that outdoor sections of metro lines are affected only, and that CBTC access points are higher than the train heights, $P_{cbtc,min}$ is assumed to be -81 dBm/5 MHz (e.g. if masking impairments from other trains is reduced).

When only short sections of outdoor lines are affected (i.e. of the order of 100 m), or when the interference source is localized (e.g. fixed RSU), $P_{cbtc,min}$ may be increased to -76 dBm/5 MHz, assuming it that shadowing is not impairing significantly the wanted signal, which may be argued if CBTC access points are deployed nearby.

In the calculation of I_{max} that follow, PR and B are assumed to be 9 dB and 3 dB respectively, for illustrative purposes:

- $I_{max} = -87$ dBm/10 MHz when the outdoor section possibly subject to interference is long.
- $I_{max} = -82$ dBm/10 MHz when the outdoor section possibly subject to interference is short.

5.2.2 Results

5.2.2.1 Urban area: RATP Line 6 case

In the figures below, the power levels measured at the receiver antenna connector reference points (also known as interference power) are displayed at the locations of the transmitted (interference) signal (i.e. at the locations of the Road ITS vehicles). As noted earlier, these power levels are the total power (in dBm) measured in the 10 MHz transmit bandwidth used by the Road ITS OBUs.

Figure 9, Figure 10 and Figure 11 show the power levels received by a CBTC trackside unit (also known as a base station) at the reference interface depicted in Figure 8 for vehicle EIRPs of 33, 23, and 10 dBm respectively versus the locations of the transmitters. The CBTC antenna was located on a viaduct between station Dupleix and station Bir Hakeim of RATP line 6.

In Figure 9, Figure 10 and Figure 11, the minimum levels observed on adjacent roads (perpendicular or not) to the RATP line 6 axis are indicated, together with the corresponding distance to the interfered receiver.

The white lines on the figures indicate portions of the circuit followed by the vehicles around the section of RATP line 6 between station Dupleix and station Bir Hakeim during the measurement campaign in which the received power level was below the threshold level -95 dBm.

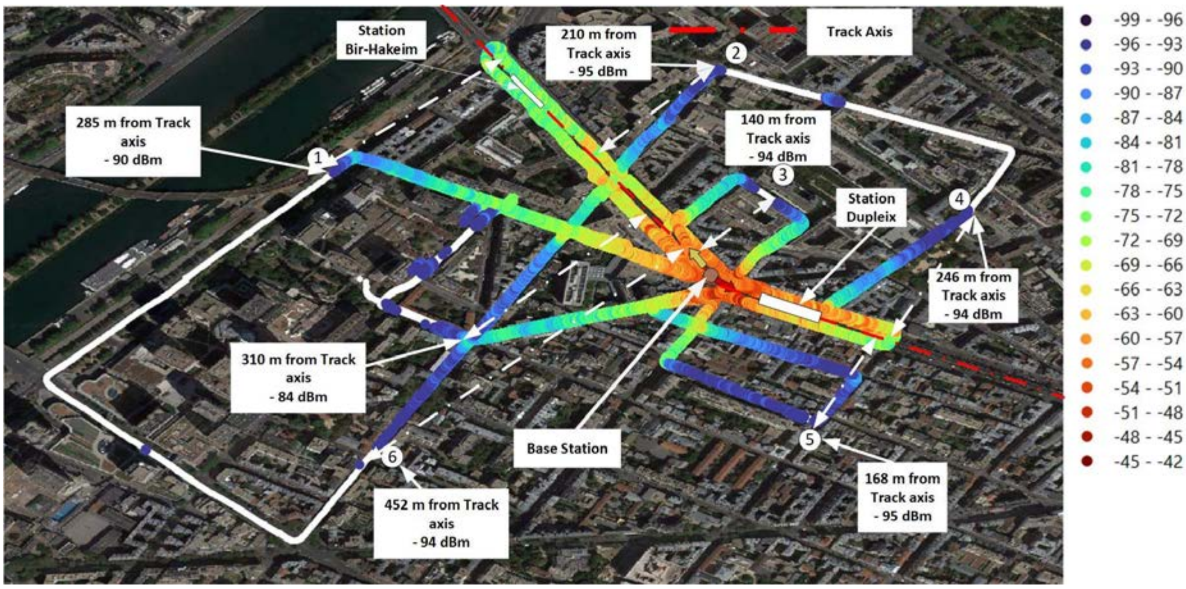


Figure 9: RATP Line 6 Level received by CBTC base station from vehicle transmissions at 33 dBm EIRP (Source: ©Google Maps/Google Earth)

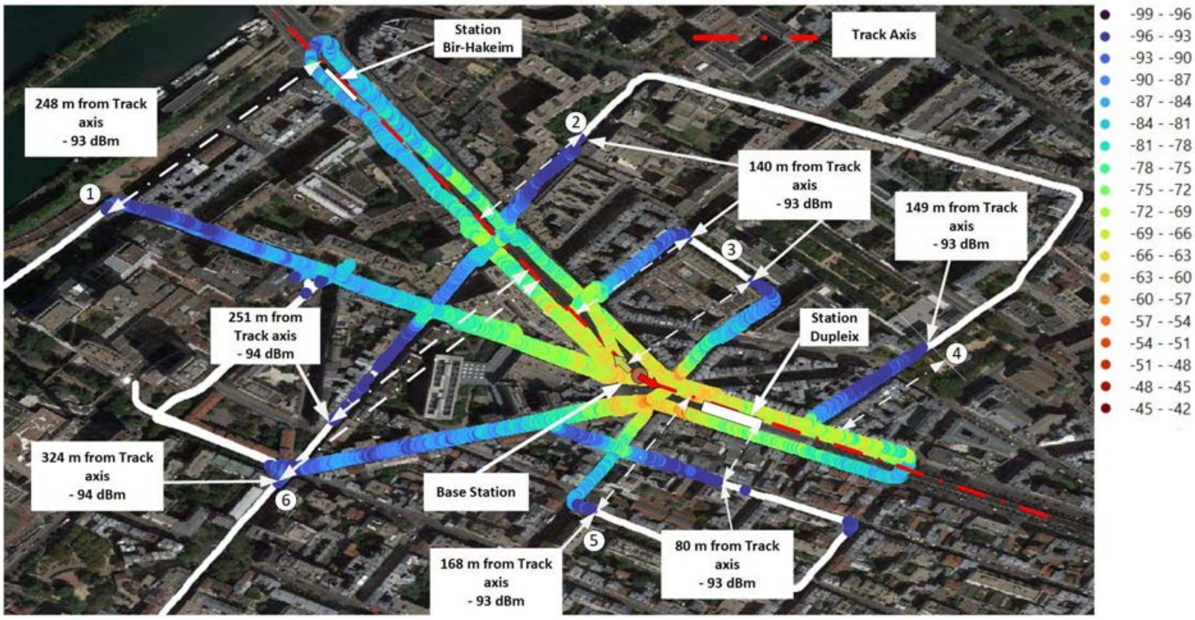


Figure 10: RATP Line 6 Level received by CBTC base station from vehicle transmissions at 23 dBm EIRP(Source: ©Google Maps/Google Earth)

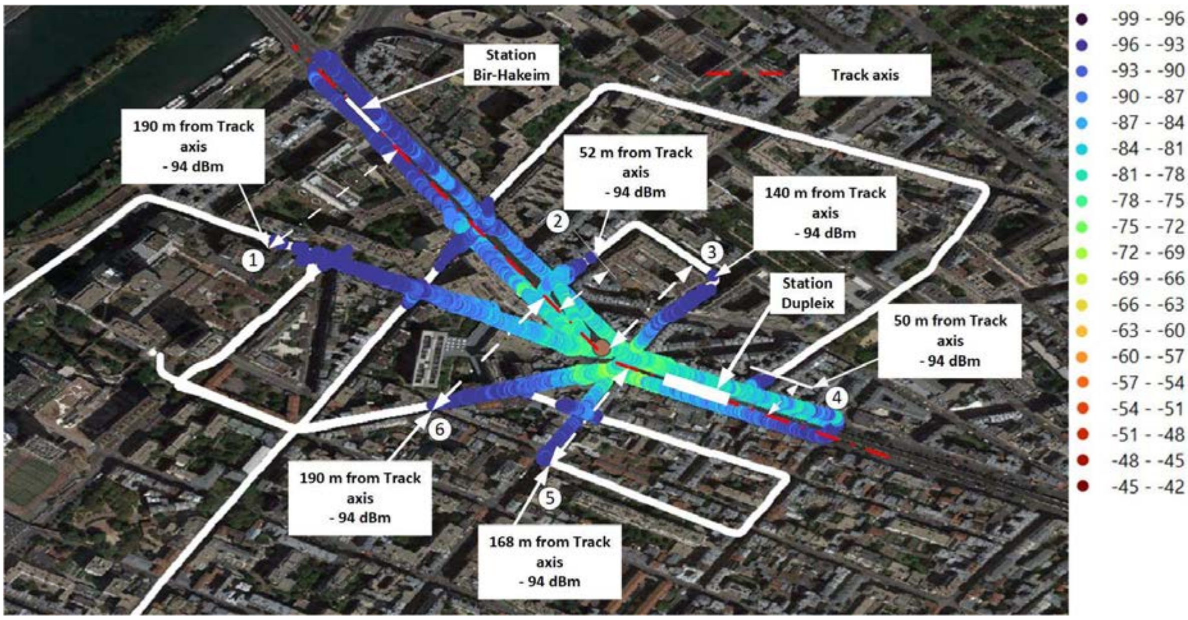


Figure 11: RATP Line 6 level received by CBTC base station from vehicle transmissions at 10 dBm EIRP (Source: ©Google Maps/Google Earth)

The Table 4 summarizes interference power and associated distances observed in Figure 9, Figure 10 and Figure 11. These values are given for illustration purpose only. They are not intended to be interpreted as "typical distances" as these interference power levels are valid only for the CBTC base station located between station Bir-Hakeim and Dupleix.

Note that for CBTC base stations installed at locations on the track where roads or streets intersect the track line, transmissions from the vehicles on these roads/streets will significantly increase the size of the R-RMO due to RF ducting phenomena (i.e. reduced path loss). The same is true for train-mounted receivers at these locations.

Table 4: Interference power and associated distances

Distance from track axis where the received level by CBTC Base station is < or = -93 dBm			
Position	**EIRP Vehicle 33 dBm/**	**EIRP Vehicle 23 dBm**	**EIRP Vehicle 10 dBm**
1	No value observed < -90 dBm at 285 m	248 m	190 m
2	210 m	140 m	52 m
3	140 m	140 m	140 m
4	246 m	149 m	50 m
5	168 m	168 m	168 m
6	452 m	324 m	190 m

Figure 12 shows the interference footprint of the CBTC trackside unit for vehicle EIRPs of 33, 23 and 10 dBm respectively versus the locations of the transmitters, assuming $I_{max} = -87$ dBm/10 MHz, as observed from the measurement campaign on RATP line 6 metro between stations Dupleix and Bir Hakeim and station Bir Hakeim for a CBTC base station identified on Figure 12, as B2H_1213. This is the same location as for the previous Figure 9, Figure 10 and Figure 11.

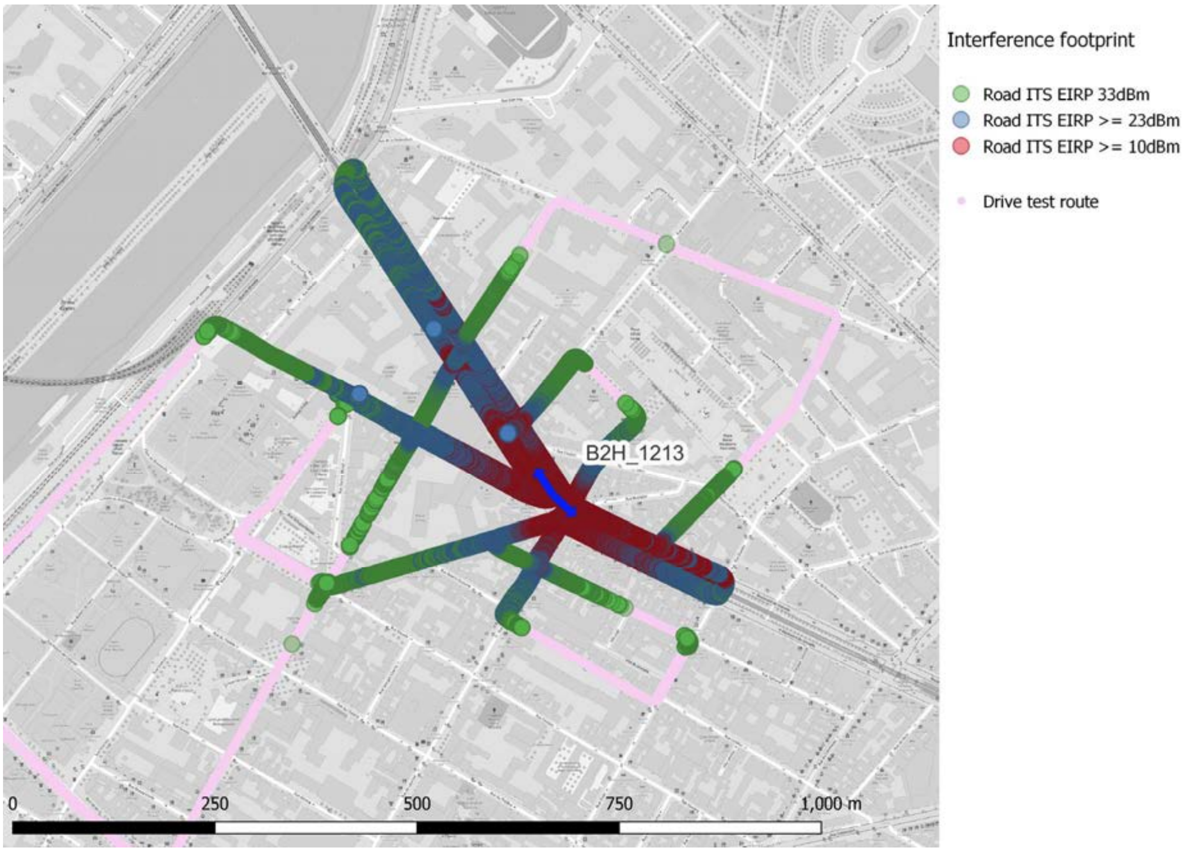


Figure 12: Interference footprint illustration for an access point on RATP line 6 (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

5.2.2.2 Sub-Urban area: RATP Line 8 case

The same exercise as in clause 5.2.2.1 is applied to a sub-urban around RATP line 8 in Paris. show the received power levels at the reference interface shown in Figure 13 for a train-mounted antenna resulting from transmitted EIRPs of 33, 23, and 10 dBm respectively versus the locations of the transmitter (i.e. vehicle). The train mounted unit was located on a bridge between station Créteil-Préfecture and Créteil-Université as shown in the figures. Figure 13, Figure 14 and Figure 15.

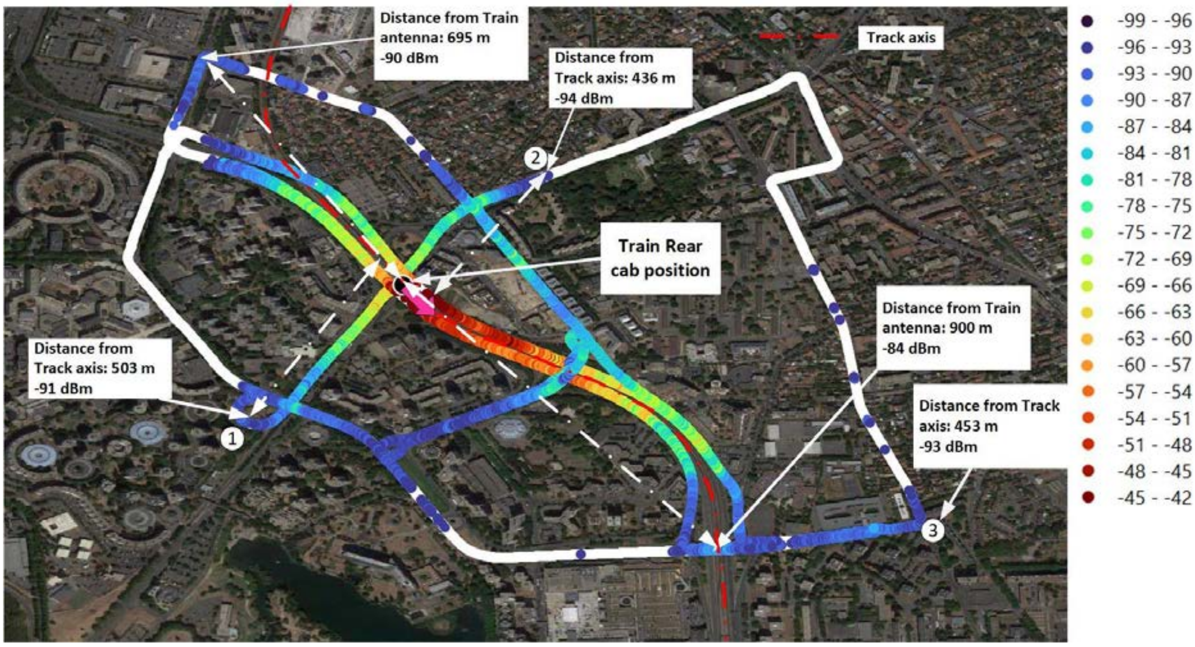


Figure 13: RATP line 8 power level received by CBTC train unit for transmitter EIRP 33 dBm (Source: ©Google Maps/Google Earth)

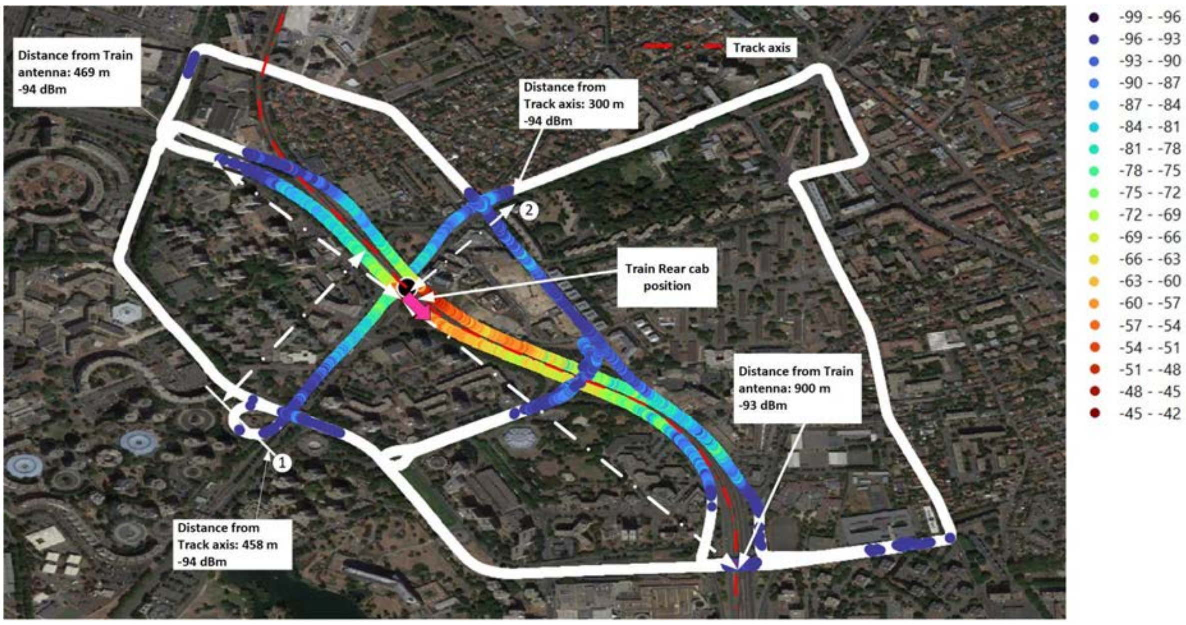


Figure 14: RATP line 8 power level received by CBTC train unit for transmitter EIRP 23 dBm (Source: ©Google Maps/Google Earth)

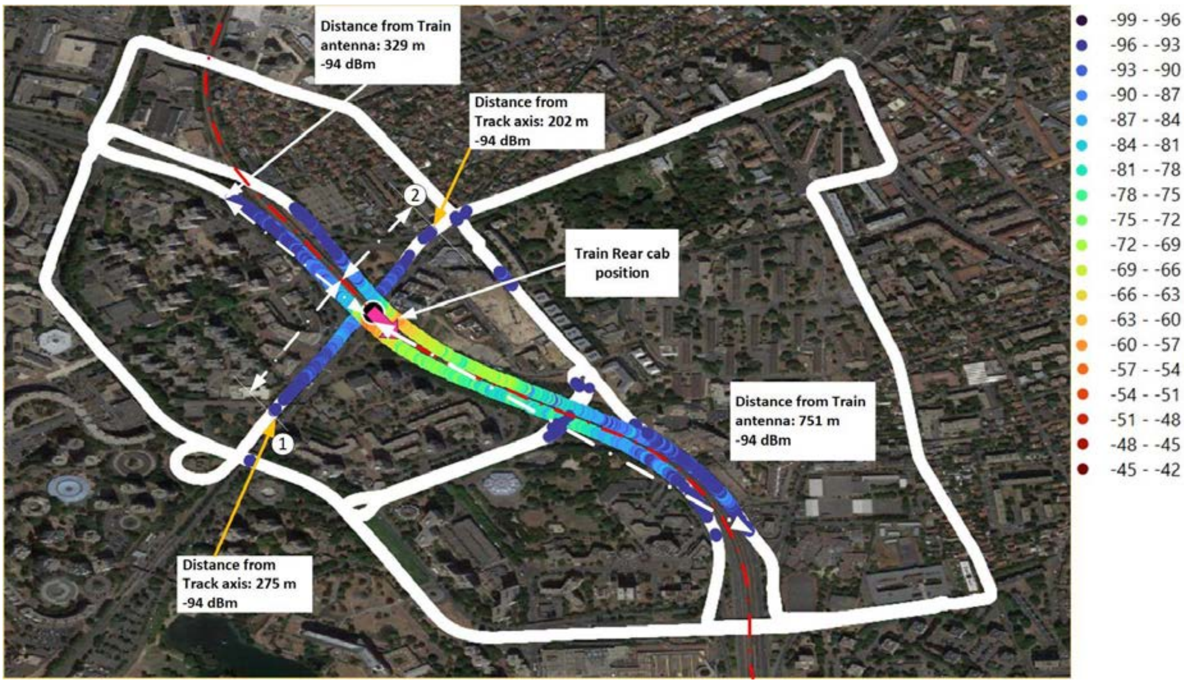


Figure 15: RATP line 8 level received by CBTC train unit for transmitter EIRP 10 dBm (Source: ©Google Maps/Google Earth)

Table 5 summarizes the maximum distance from the track axis as a function of transmitted EIRP at three selected locations.

Table 5 summarizes interference power and associated distances observed in figures in Figure 13, Figure 14 and Figure 15. These values are given for illustration purpose only. They are not intended to be interpreted as "typical distances" as these interference power levels are valid only for the CBTC base station located between station Bir-Hakeim and Dupleix.

Table 5: Interference power and associated distances

Distance from track axis where the received level by CBTC Base station is < or = -93 dBm			
Position	**EIRP Vehicle 33 dBm**	**EIRP Vehicle 23 dBm**	**EIRP Vehicle 10 dBm**
1	at 503 m -91 dBm	458 m	275 m
2	436 m	300 m	202 m
3	453 m	0 m	0 m

Figure 16 shows the interference footprint of the CBTC trackside unit for vehicle EIRPs of 33, 23, and 10 dBm respectively versus the locations of the transmitters, assuming $I_{max} = -87$ dBm, as observed from the measurement campaign on RATP line 8 metro for a train identified as T4B_0910. This is the same location as for Figure 13, Figure 14 and Figure 15.

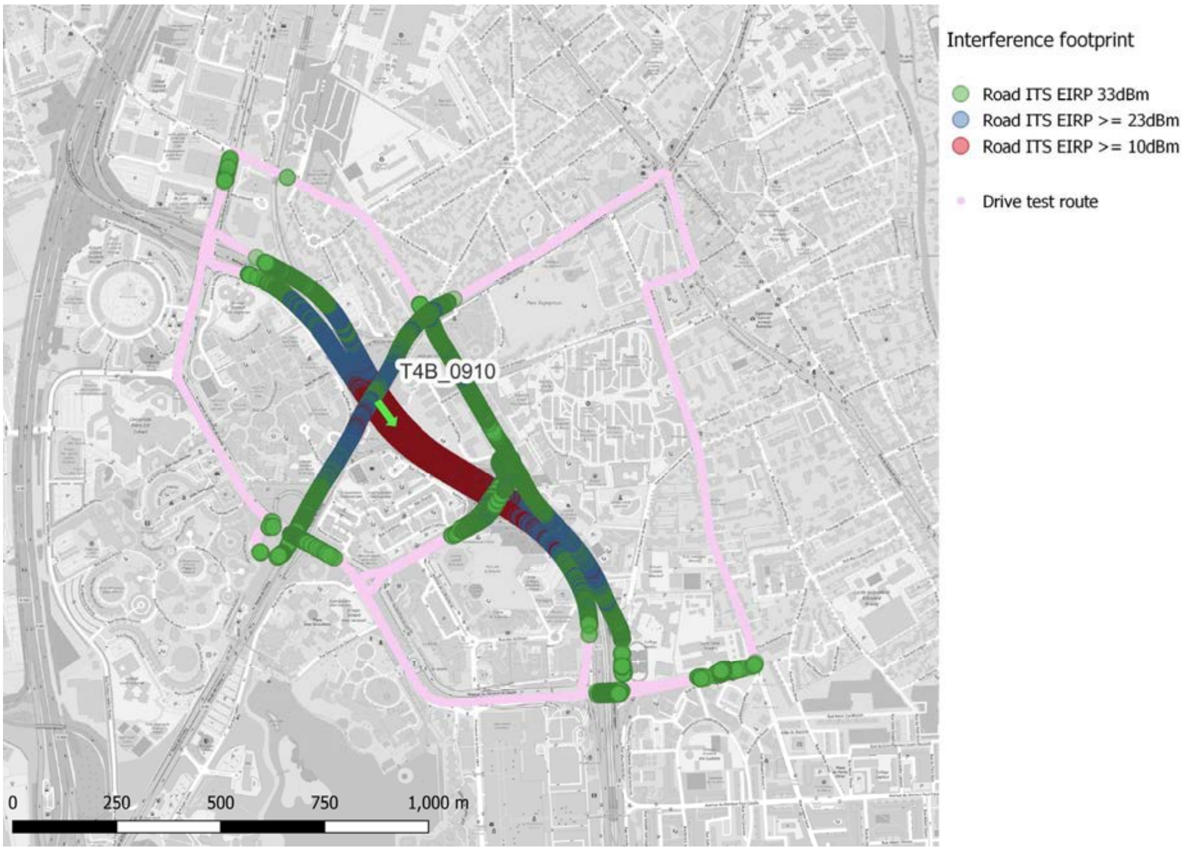


Figure 16: Interference footprint illustration for an access point on Paris line 6 (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

5.3 RF propagation simulations for real situations

The analysis of real scenarios can be performed with radio propagation tools as illustrated in Annex A. The setup of a propagation tool and the accuracy of the results are discussed in ETSI TR 103 704 [i.40].

In the present document, the analysis of different real scenarios was performed using "HTZ Communications©" software. The tool allows modelling of multiple networks and technologies to evaluate the impact of coexistence. Some constraints need to be provided to obtain accurate results from the simulations:

- Technical specifications and parameters for each station: transmit power, frequency and bandwidth, additional gains and losses, coordinates, allowed interference conditions.
- Antenna characteristics: gain, azimuth, radiation patterns, main and side lobes.
- Propagation model.

Coverage of propagated signal is obtained using a set of cartographic layers that contains the terrain model, the land use (clutter), building position as well as heights, and the image for the map. Thus, the quality of results depends on the quality of the cartographic layers and the resolution of the sampled terrain model. Additionally, the propagation model could be configured to include additional propagation conditions:

- Deterministic models that predict signal propagation from physical phenomena (diffraction, reflections, atmospheric conditions and so on).
- Effects of geometries or obstacles that could diffract or obstruct signal propagation between transmitter and receiver.
- Particular propagation characteristics in the clutter that could include additional attenuations or phenomena due to factors that are included there such as, buildings, open areas, urban areas, suburban areas, forests, parks, tunnels and reflections in water, among others.

The different scenarios were analysed using a deterministic propagation model that includes free space losses, diffraction geometry and multipath attenuations.

ETSI TR 103 704 [i.40] explains that the simulation tool gives a good estimate of the protection areas but requires a careful tuning. It is therefore suggested to make use of simulation tools to compute the R-RMOs, after calibration, for which the existing measurements can be leveraged). The conclusions of ETSI TR 103 704 [i.40] in that respect are recalled below:

"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."

5.4 Hidden nodes, exposed nodes and detection

"Listen before talk" techniques can avoid collisions by deferring a new transmission until the channel is available again.

Urban Rail Access Points (AP) use highly directional antennas therefore the receive antenna gain is different between Urban Rail APs and Road ITS stations, and their receiver sensitivity at the antenna is different. These APs can therefore be interfered by many Road ITS devices which cannot detect them. Similar considerations are valid for the Train Radio device which is also connected to a directional antenna:

The mere use of higher gain antenna on CBTC radios compared to Road-ITS radios, make CBTC receivers possibly interfered by the Road ITS stations while these latter cannot necessarily detect the CBTC communications. This can be understood by comparing the interfering Road ITS power level at the CBTC receiver, and the received CBTC power level at the Road ITS receiver, given by the following equations:

$$I_{RoadITS \to CBTC} = EIRP_{RoadITS} - L_{propagation} + G_{CBTC\ antenna}$$

$$P_{CBTC \to RoadITS} = EIRP_{CBTC} - L_{propagation} + G_{ITS\ antenna}$$

And because $G_{CBTC\ antenna} > G_{ITS\ antenna}$, the interfering power tends to be substantially greater than the power of the CBTC signal at the Road ITS receiver. In addition, the minimum interfering level likely to cause interference tends to be lower than energy detection threshold. Therefore, radio detection cannot be relied-on to ensure an adequate protection of CBTC systems.

Clause 8.3.2 of ETSI TR 103 704 [i.40] shows this effect on one of the performed measurements.

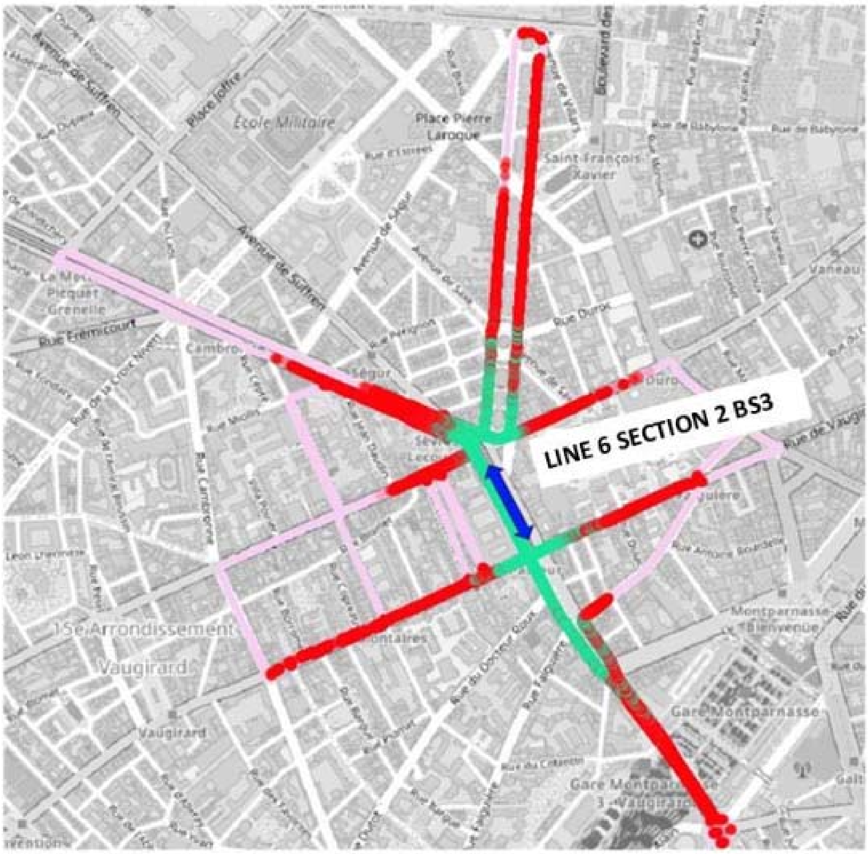


Figure 17: Points where the received power in the CBTC receiver is greater than -91 dBm/10 MHz, green where the reverse downlink received power by the vehicle is greater than -85 dBm/10 MHz and red otherwise (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

The following cases are typical "hidden node" situation caused by directional antennas:

Case 1: The Road ITS device is behind the train and is not able to detect the transmission from the front of the train, whereas its own transmission will be received by the Urban Rail AP, as show in Figure 18.

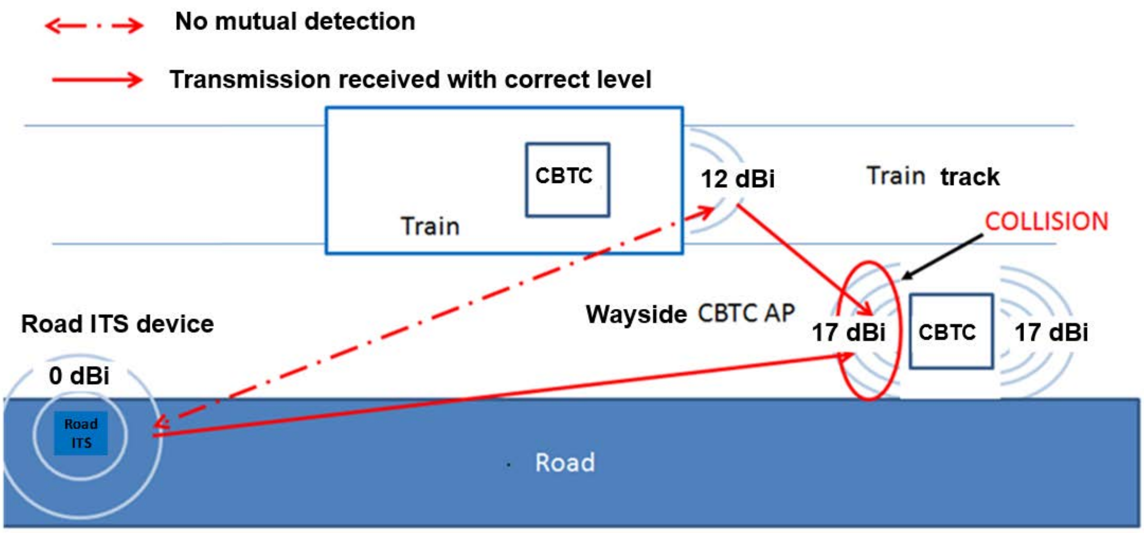


Figure 18: Case 1 of hidden node situation

Case 2: A Road ITS device is located on the opposite side of the AP (which have also directional antenna on that side to receive signal from the train running in the other direction), see Figure 19.

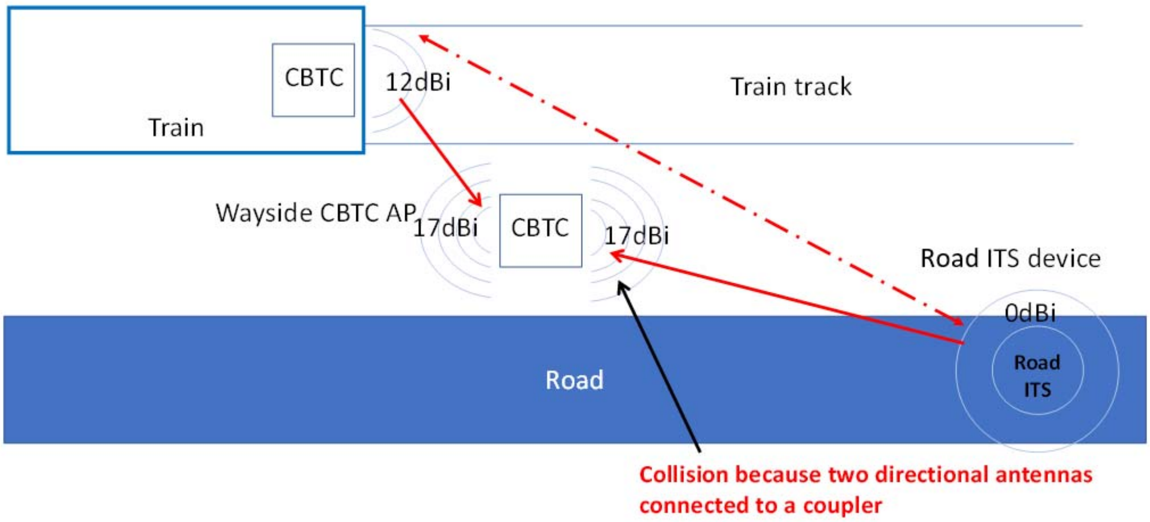


Figure 19: Case 2 of hidden node situation

The following cases are typical "exposed station" situations:

Case 1: The Urban Rail AP does not transmit when detecting Road ITS device transmission, whereas the signal sent by the Road ITS device would not have disturbed reception from the train (too far away), and the Urban Rail AP signal would not have disturbed the Road ITS exchange (17 dB less of antenna gain in the link budget assuming all stations transmitting with maximum EIRP).

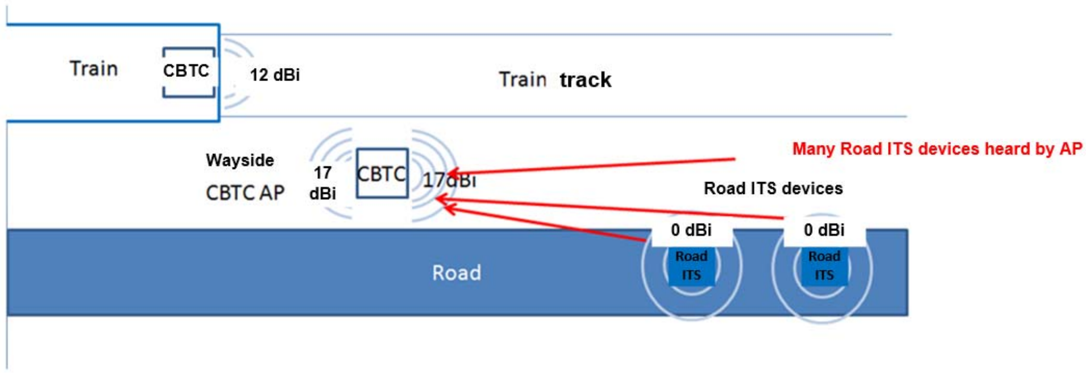


Figure 20: Case 1 of exposed node situation

The Urban Rail transmitters are "exposed" to the Road ITS devices which can block the Urban Rail transmission if the number is too high, whereas the transmission between the train and the Urban Rail Access Point would have no impact on these Road ITS nodes.

DSSS CBTC systems do not implement LBT techniques. Thus, they do not suffer in "exposed station" scenarios but are still affected by "hidden station" scenarios.

5.5 Channel occupancy and aggregated effect

Mutual impact on communication occurs when concurrent transmissions occur (collision), or if simultaneous transmissions are prevented by the detection of channel busy at transmitter level even if it would have no impact at receptors level (exposed node situation).

The probability of collision between packets and/or the aggregated interference level received by the Urban Rail station antenna will depend on transmit power of interferes, their propagation loss and the total percentage of channel occupancy due to the road vehicles transmissions.

Even if the duty cycle of each Road ITS station is limited and a Decentralized Congestion Control (DCC) mechanism has been defined with the target to limit the channel occupancy, the real channel occupancy seen by an Urban Rail station using directional gain antennas can be significantly higher.

Therefore, the mutual impact depends on aggregated channel occupancy rate as seen by the CBTC receiver.

In addition, several vehicles transmitting at the same time would generate a cumulated interference power at the CBTC receiver.

The present clause discusses the channel occupancy and aggregated effect due to the presence of several Road ITS vehicles.

The results of the measurement campaign shows that a Base station antenna and a Train can receive packets from vehicles over a long distance.

The analysis conducted in Annex D is based on a measurement performed on RATP Line 6 between Dupleix and Bir-Hackeim stations (see ETSI TR 103 704 [i.40]) and shows a cumulated road length of 4 340 m where transmission from vehicles can be received by a CBTC base station, although not all surrounding roads have been explored.

In this example the aggregated channel load may reach 50 % and 56 % for vehicle speed of respectively 20 km/h and 30 km/h. This example assumes that all vehicles are transmitting CAM messages according to the specification in ETSI EN 302 637-2 [i.2] on channel 5 915 MHzto 5 925 MHz with maximum allowed EIRP in a wors- case vehicle density with a safe and velocity dependent distance in-between. While the number of vehicles is lower for higher velocity, channel load can be higher due to the increase of CAM generation rate by the vehicle.

A second analysis has evaluated the channel load on a section 2 000 m of parallel road to a metro line. The result of this analysis shows that channel load is also higher when the speed of vehicles increases even if the number of vehicles is reduced in the section. The channel load in this example can exceed 62 %.

Without any mitigations in the Road ITS stations, the CBTC transmissions will be strongly impacted in these scenarios in term of delay and packet failure rate and cannot be considered as reliable.

Because Road ITS and Urban Rail are using different antennas (Urban Rail is using directive antennas with high gain), the channel occupancy seen at Urban Rail receiver level is not the same as the channel occupancy seen by the Road ITS vehicles, as shown in the simplified Figure 21. A CBTC antenna can "see" easily two groups or more of vehicles in which the channel load is limited at 62 % by the DCC mechanism if all the vehicles' transceivers are based on the ITSG5 protocol stack.

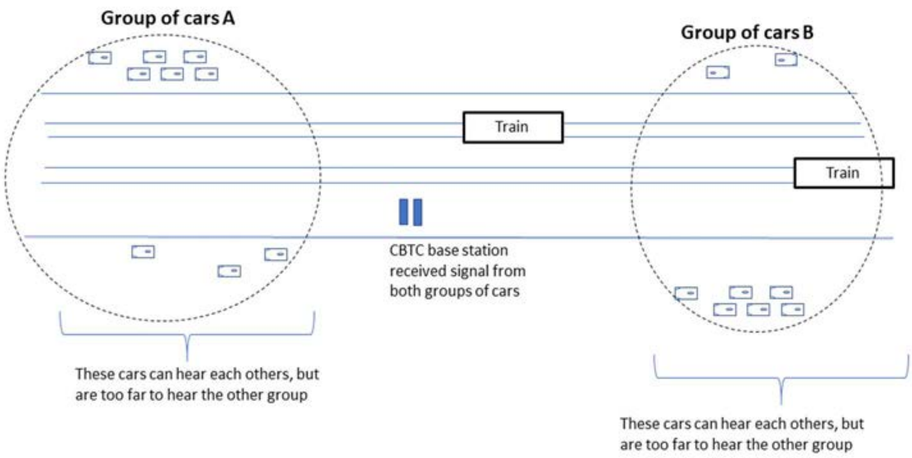


Figure 21: Differences between channel load seen by Urban Rail receiver and channel load used for Road ITS DCC

In that simplified scenario, Road ITS stations in group A are able to receive messages from the other Road ITS stations of the same group, but are not able to receive anything from Road ITS stations of the group B. This is not the case for the Urban Rail base station, which receives RF signals from the Road ITS stations of both groups A and B.

In that situation, CSMA/CA and DCC mechanisms provide their purpose to optimize and limit the use of the channel in the radio environment of each group, but fail to achieve this for the aggregated channel load seen by the Urban Rail stations from all the Groups. Collisions between transmissions of stations of each group can occur and aggregated channel load exceeds the threshold of the DCC mechanism. The same problem occurs for all mitigation methods based on CSMA/CA to limit the channel load.

However, transmissions occurring in each group may overlap, and the total channel occupancy seen by the CBTC receiver is therefore lower than the sum of the channel occupancy of the two groups.

5.6 Suggested methodologies for the definition of restricted zones

5.6.1 Purpose of the R-RMO

In this clause, methods are proposed to compute the zones where Road Intelligent Transportation Systems are likely to interfere with Urban Rail transportation, based on the outcome of the measurement campaign.

CBTC systems are bound to specific sections of railway tracks in distinct and known locations, typically in large cities. The purpose of the R-RMO is to define geographical regions in which the behavior of Road-ITS devices needs to be adjusted in the band 5 915 MHz to 5 925 MHz. In those regions, the interference received by CBTC Base stations and Train Onboard Units due to transmissions from any Road-ITS stations located within a R-RMO, including Roadside (RSUs), Personal, and Vehicular, has to be limited to an acceptable level by mitigation techniques applied in the Road-ITS stations.

The contour of a R-RMO should be defined depending on the particular Restricted Mode of Operations (RMO) (see clause 6) to be implemented and site-specific considerations (e.g. CBTC technologies). The methodology is to be defined through national coordination between stakeholders.

The reference point of the signal power level for CBTC base stations (CBTC BS) and train onboard units (T-OBU) is from the RF modem port of these radio equipment. As a reminder, a CBTC BS is the wayside radio equipment, the T-OBU is the onboard radio equipment.

5.6.2 Computation of R-RMOs

The process of computing R-RMOs is composed of a number of steps. The R-RMOs defined using the process are suitable for use in conjunction with the progressive power restriction in one instantiation of a RMO (see clause 6).

Table 6: List of steps for the computation of R-RMOs

Step #	Description	Comments
1	Identify the maximum allowed interfering signal level.	
2	Compute protected zones.	
3	Identify critical areas where the results of step 2 should be complemented, and perform measurements as needed.	
4	Define final contour of the R-RMO based on simulation and measurements.	
5	Export the defined contour of the R-RMO in an appropriate format.	

Step 1: Identify the maximum allowed interfering signal level, which depends on the technology, minimum wanted signal level, and other technical parameters used by the CBTC Radio system, in a given zone. For this step, the two following issues need to be addressed:

- Maximum allowed interfering signal level.
- Maximum percentage of transmission received from vehicles, road units, smartphone above the maximum interfering level.

Step 2: Compute protected zones.

Several approaches may be used to compute the protected zones. In this step, three alternative approaches are introduced (steps 2a, 2b and 2c), from the simplest to the more sophisticated, and also increasing level of accuracy.

Step 2a: Preliminary calculation of the R-RMO required based on measurement campaign results to obtain an approximate contour.

The preliminary calculation is based on the statistical analysis of the measurements performed during the measurement campaign on RATP line 6 and RATP line 8 in Paris in 2021. The result of this analysis is summarized on the clause 8.5 of ETSI TR 103 704 [i.40] in the form of graphs with boxplots.

There are two graphs with boxplots for both suburban and urban areas (derived from measurements on lines 8 and 6 respectively), one for power levels received by CBTC-BS and another for power levels received by T-OBU.

There is one graph with boxplots concerning the section of tracks on the bridge above the river and tracks parallel to that section (derived from measurement from line 6).

Graphs with boxplots of the distances between the vehicles and the CBTC receivers (both CBTC BSs and T-OBUs) have been set-up based on measurements performed on each environment. Boxplots are given for 10 received power intervals in 5 dB steps.

Two types of boxplots are provided, one for the path between a Road ITS vehicle and nearby CBTC base station or train antenna with angles above +45° or below -45° from the antenna boresight in the horizontal plane and another for angles between ±45° from the CBTC Base station antenna or Train antenna boresight (also known as direction of maximum antenna gain).

The description of the boxplots is given in clause 5.6.4.

Step 2b: Apply a theoretical radio calculation with a pathloss model to obtain a contour.

A second alternative is to compute R-RMOs using analytical pathloss models.

A link budget is applied from the Road ITS interferer to CBTC receivers with a suitable pathloss model to derive minimum distances between potential interferers and CBTC receivers. The antenna directivity of CBTC receivers is considered with different gains in track direction and perpendicular to it. The link budget includes correction factors for safety margin, tunnelling effects in roads and building attenuation.

Based on the resulting distances, ellipsoid contours are calculated at various points along the track and the R-RMO is the union of those ellipsoidal regions.

Step 2c: Perform propagation simulation to obtain a more accurate contour.

A third alternative is to rely on RF propagation simulation tools. The merit of this method is discussed in clause 5.3. For T-OBUs, radio propagation calculations are performed at a set of points along the tracks which are above ground. For CBTC BSs, their exact locations and antenna orientations are used.

Step 3: Identify critical areas where the results of step 2 should be complemented by field measurements as needed.

This optional step aims at identifying critical areas where propagation effects are expected to be poorly reflected by the approach selected for step 2 (e.g. elevated local terrain, bridge over a large river, major roads, etc.).

When the critical areas are identified, some on-site measurements may be performed. The maximum allowed interfering signal level from Road ITS system, as derived from step 1, should be used to select the measurement setup with the right sensitivity level.

Step 4: Define final contour of the R-RMO based on simulation and measurements.

The final contours of the R-RMOs are defined based on the outcomes of step 2 and step 3. The zones could typically take the form of simple geometries (rectangles, circles, ellipsoids), or unions of such simple geometries and are likely to be expressed of polygons regions or rasterization.

Step 5: Export the defined contour of the R-RMO in an appropriate format.

The zones should be exported to the requested format. In Annex J, a GeoJSON representation of the polygons is given.

5.6.3 Improvements of R-RMOs

Because of the complexity to set-up and perform measurement campaigns, a statistical analysis so far has been performed based on the measurements on only one line in an urban area (line 6) and on only one line in a suburban area (line 8).

When complementary measurements are performed, as per step 3, it would be beneficial to collect and report the results, as it would enable to make statistical results more representative and better calibrate the propagation models.

In addition, R-RMOs may be updated on feedback from metro operators, such as:

- Issues in CBTC operation or processing of diagnostic data (e.g. connectivity issues, mute trains, packet drops, emergency brakes) at specific locations or at larger parts of the track.
- Measurements of the interference level at the affected spots along the track.

5.6.4 Examples of application of the process for a CBTC radio system based on IEEE 802.11 technology

5.6.4.1 EIRP of the vehicles to be considered

In clauses 5.6.4.2 and 5.6.4.3, different applications for some steps described in clause 5.6.2 are illustrated, where R-RMOs are defined for three Road ITS stations EIRP limits: 33 dBm, 23 dBm and 10 dBm.

It is expected that most Road ITS stations will transmit at a lower power than the maximum authorized EIRP of 33 dBm.

The application of the methodology illustrated in the clauses 5.6.4.2 and 5.6.4.3 assumes that progressive power restriction is used as the RMO. In practice, considering the typical EIRP used by Road-ITS vehicles, it is reasonable to assume that the R-RMO corresponding to the 23 dBm contour delimits a zone outside which most vehicles will not be impacted by the limitation, while the 10 dBm contour may well delimit a zone inside which the EIRP limitation would preclude most Road ITS applications.

As stated in clauses 5.2 and 5.6.1, the EIRP limits used to define the zones of the progressive power restriction is matter for national coordination.

5.6.4.2 Methodology applied on line 6, with R-RMOs defined with distances derived from existing measurements.

This clause defines the R-RMO for the section of line 6 between big crossroad before Station "Cambronne" and big crossroad after station "Sèvres- Lecourbe", as shown in Figure 22.

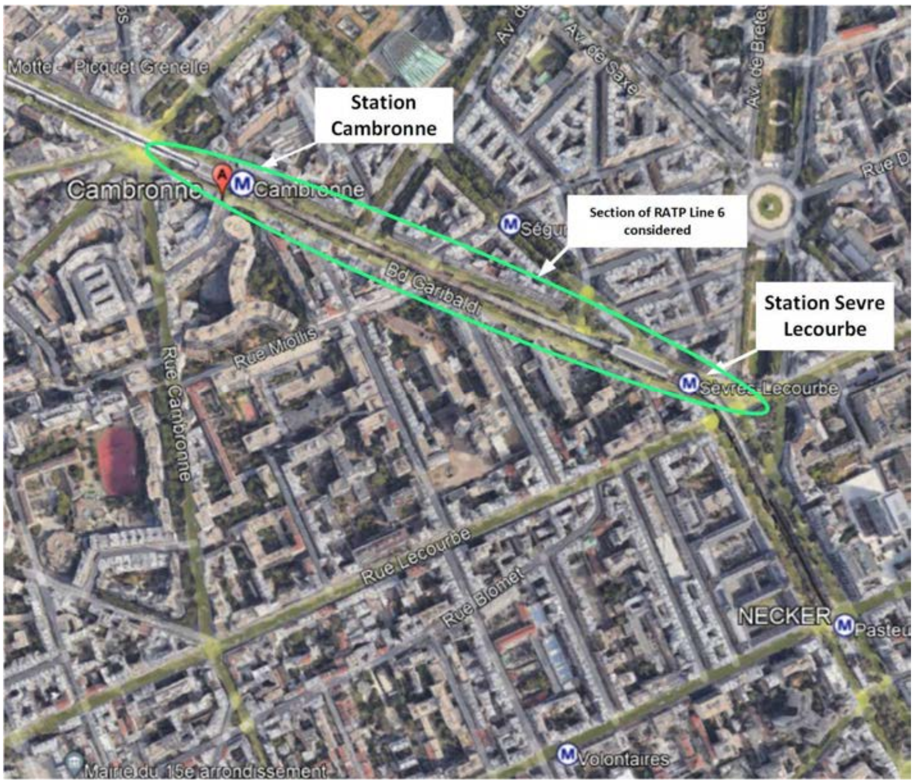


Figure 22: Section of RATP line 6 considered (Source: ©Google Maps/Google Earth)

Step 1: Identify the maximum allowed interfering signal level.

For this exercise, it is assumed that the maximum allowed interfering signal is -87 dBm/10 MHz, as derived in clause 5.2.1

Step 2a: Preliminary calculation of the R-RMO required based on measurement campaign results to obtain an approximate contour. The preliminary calculation is based on the statistical analysis in clause 8.5 of ETSI TR 103 704 [i.40].

Figure 23 and Figure 24 give the boxplots based on measurements from ETSI TR 103 704 [i.40], incidentally, performed on the same RATP line 6 as for the zone considered, with CBTC BS and T-OBU respectively. These results are used for the preliminary evaluation of the R-RMO.

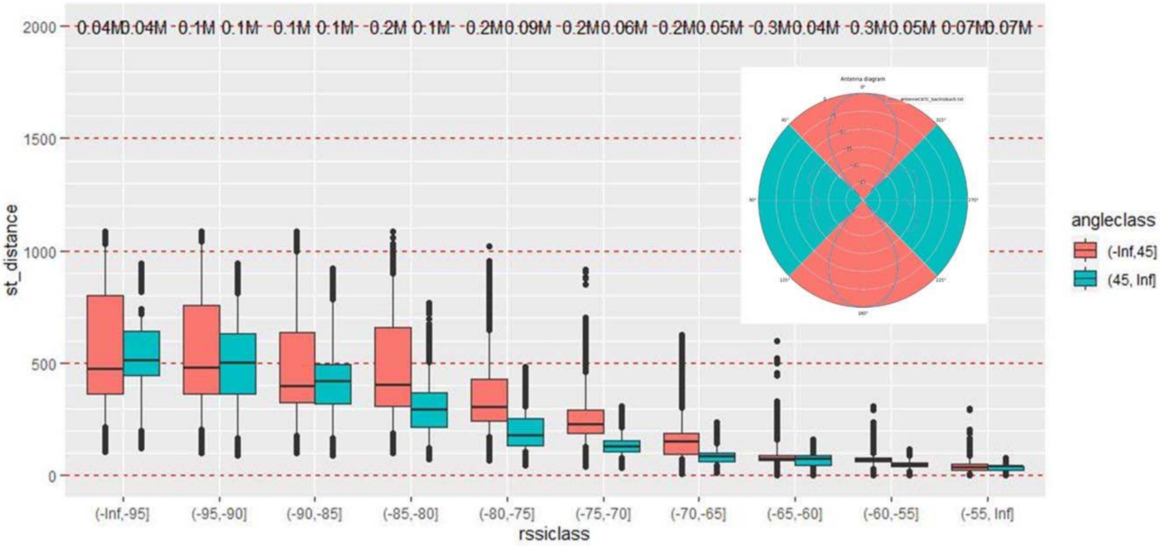


Figure 23: Boxplots from measurements performed on RATP-Line 6 with CBTC BS, RSSI in dBm/10 MHz and distance in meters

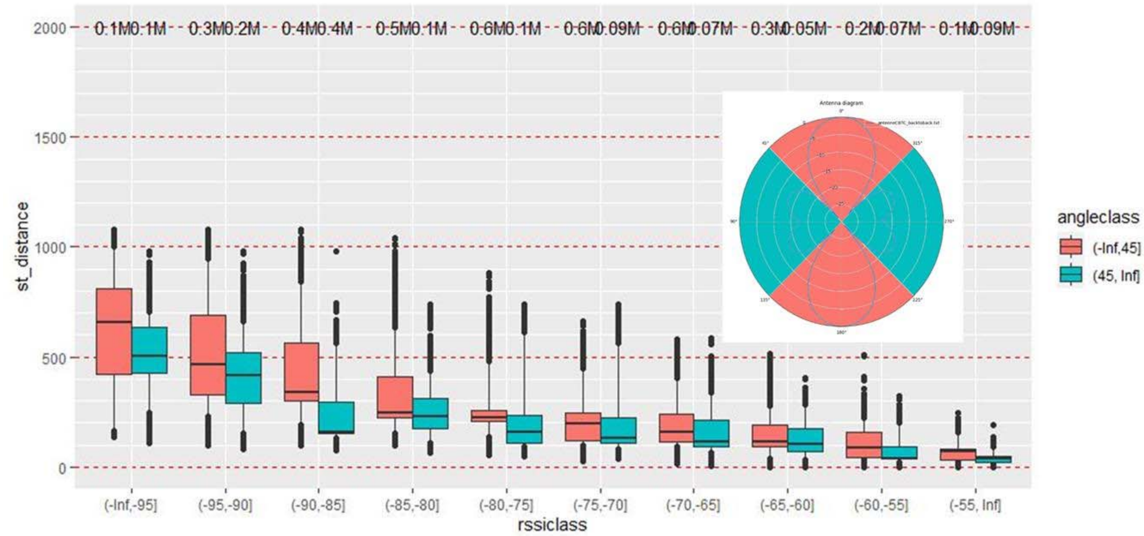


Figure 24: Boxplots from measurements performed on RATP-Line 6 with T-OBU, RSSI in dBm/10 MHz and distance in meters

Figure 25 shows how to read a boxplot.

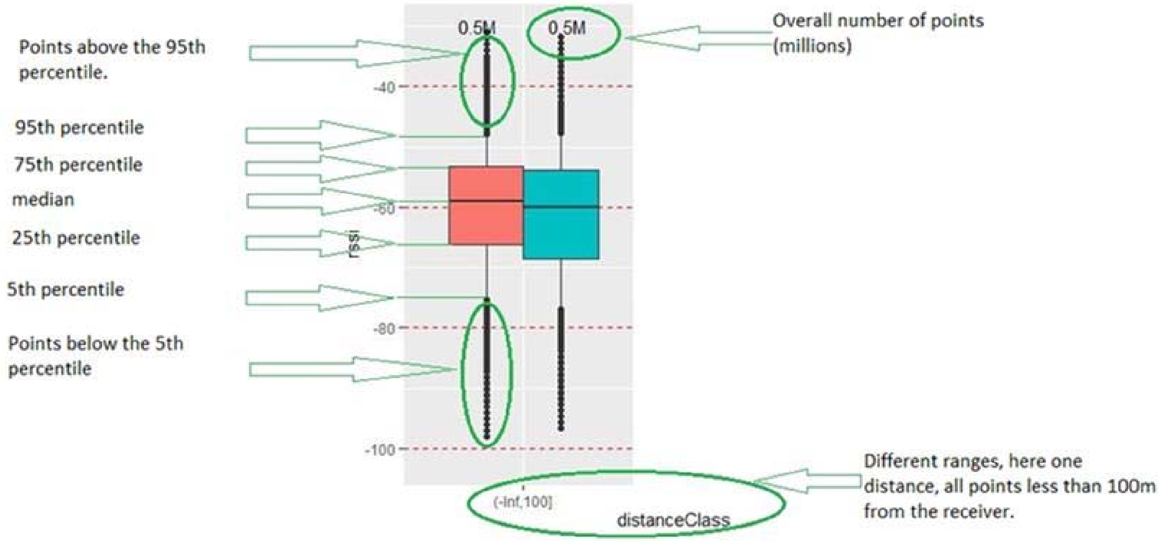


Figure 25: Boxplot definition

The preliminary evaluation is made with the target to obtain a R-RMO contour for 95 % of the vehicles received with a level greater than the maximum allowed interfering signal level, e.g. -87 dBm.

For Road ITS EIRPs of 33 dBm, the limit -87 dBm is reached for a measured RSSI level of -87 dBm because the level of the boxplots is given for a station transmitting at this same EIRP of 33 dBm. For Road ITS EIRPs of 23 dBm, the limit of -87 dBm is reached for a measured RSSI level of -77 dBm. And for Road ITS EIRPs of 10 dBm, the limit -87 dBm is reached for a RSSI level of -64 dBm.

For a given point to be protected along the tracks, depending on the angle between the azimuth of the track (more precisely, the direction of the CBTC antenna) and the direction between the point considered along the track and a point on a street, a boxplot is selected: if the angle is below or equal to 45° the red boxplot is applicable. If the angle is above 45°, the blue boxplot is applicable.

The RSSI interval to be considered to determine the minimum distance of a R-RMO is the lowest power interval whose upper limit is below the required RSSI level. An upper bound of the distance is given by the greatest 95th percentile of this or higher power boxplots.

Table 7 gives the distances from the tracks at which the contours of the protected zones are to be drawn, for the three EIRP considered.

Each distance listed in Table 7 corresponds to the distance between a given point on a line perpendicular to the track.

Table 7: Minimum distance to be considered for various Road ITS stations EIRPs

Road ITS EIRP	Maximum interfering level	Corresponding RSSI class from the box plots	Minimum distance for streets at angles < 45° (from access points box plots, Figure 24)	Distance for streets at angles > 45° (from access points box plots, Figure 24)
33 dBm	-87 dBm	-87 dBm => limit defined from the 95th percentile of the]-95; -90] power class.	1 025 m	800 m
23 dBm	-87 dBm	-77 dBm => limit defined from the 95th percentile of the]-85; -80] power class.	900 m	500 m
10 dBm	-87 dBm	-64 dBm => limit defined from the 95th percentile of the]-70; -65] power class.	400 m	325 m

The preliminary evaluation of the R-RMO requires the computation of the angle and distance between locations on streets surrounding the tracks and the tracks themselves. Streets and tracks are sampled to "road points" and "victim locations" respectively. The following computation is repeated for each road point and each victim location:

- The distance is computed as the distance between the CBTC victim location considered and the road point.
- The angle is the angle between the direction where the CBTC antenna is pointing, and the direction between the CBTC victim location and the road point.

For a given road point, if there is a victim location that falls within the limits of Table 7, the road point is considered within the R-RMO of the lowest matching EIRP.

Figure 26 shows an example of the R-RMOs' contours for the respective EIRP levels (33 dBm, 23 dBm and 10 dBm) required around the section of RATP line 6 between station Cambronne and station Sèvres-Lecourbe for Vehicles transmitting with and the respective EIRP levels (33 dBm, 23 dBm and 10 dBm).

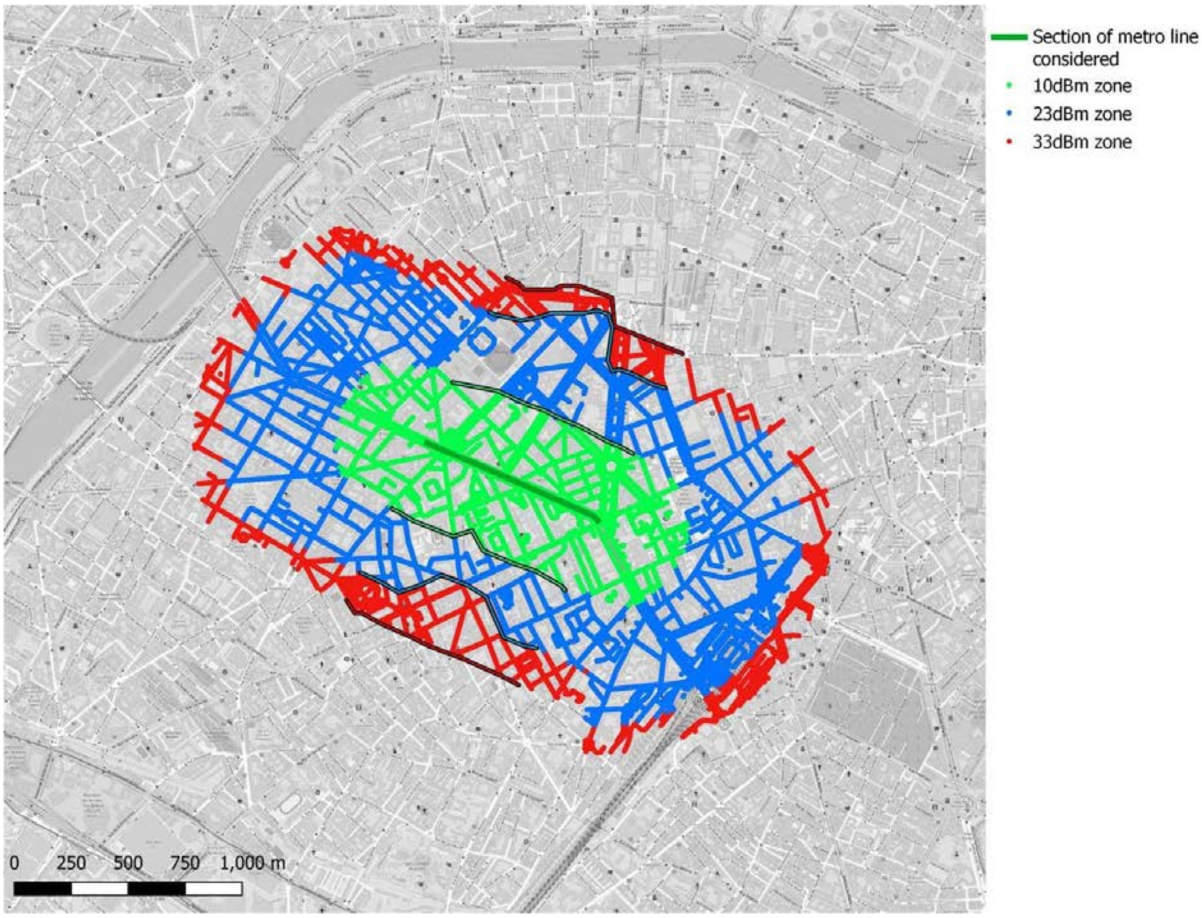


Figure 26: Limits of R-RMO around section between station Cambronne and Sèvres- Lecourbe of RATP line 6 (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Steps 4 and 5 are straight forward and not illustrated in the present clause, and the step 3 is optional.

5.6.4.3 Methodology applied on line 8, with R-RMOs defined from radio simulations.

This clause defines the R-RMO for the southern section of line 8 shown in Figure 27.

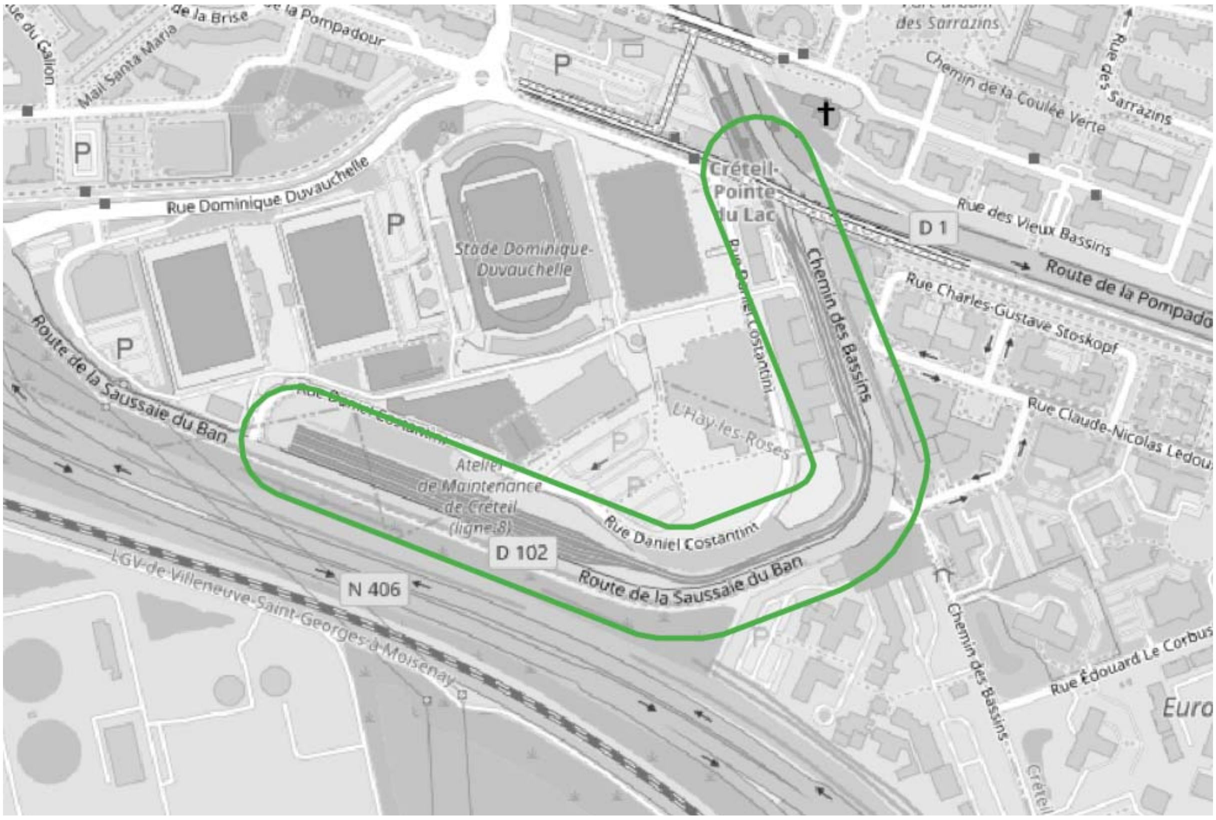


Figure 27: Section of RATP line 8 considered
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Step 1: Identify the maximum allowed interfering signal level.

As for the previous exercise, it is assumed that the maximum allowed interfering signal is -87 dBm/10 MHz, as derived in clause 5.2.1.

Step 2c: Perform propagation simulation to obtain a more accurate contour.

A radio propagation map is simulated with an RF planning software. The tool allows to simulate receivers all along a line, at a desired sampling step (e.g. 5 m in this example), with the receiving antenna oriented to toward the next sample. As an alternative, multiple "radio sites" could be designed, evenly spaced along the tracks.

The calibration of the propagation model is outside the scope of this clause, and already discussed in clause 5.3.

The simulator setup includes the following parameters:

- The EIRP is set to the maximum allowed for Road ITS stations (33 dBm).
- The maximum antenna gain plus cables losses are those of the CBTC Rx chain which in this case is 10 dB.
- The CBTC antenna diagram is modelled, in our case a symmetry is applied to replicate the front diagram (i.e. in front of the train) to the back. By doing so, both the front and back antennas of the trains are treated with a single simulation.
- The height the of Road ITS station is set to 1,5 m and the height of the train antenna is set to 3 m.
- The center frequency is 5 920 MHz.
- The simulation threshold is set below the maximum allowed interfering signal (-87 dBm).

The result of the simulation is shown in Figure 28.

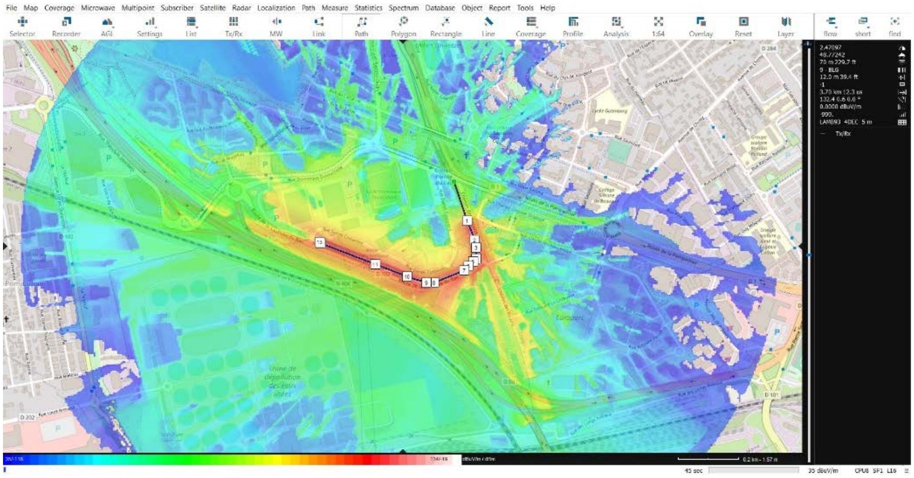


Figure 28: Simulation results for the southern section of RATP line 8 (Source: ©Google Maps/Google Earth)

The results are then exported in GeoTIFF format for further processing.

Step 3: Identify critical areas where the results of step 2 should be complemented, and perform measurements as needed.

Step 3 is skipped as the simulator uses terrain elevation and buildings.

Step 4: Define final contour of the R-RMO based on simulation and measurements.

The GeoTIFF raster previously generated is imported in QGIS software© for further processing. The raster contains received power levels in dBm and is post-processed to a three-level raster, each corresponding to a R-RMO related to one of the three EIRPs of the progressive power restriction. The post processing is achieved with the "Raster calculator" in QGIS and the following formula (see Figure 29), where "coverage_path_creteil" is the name of the input raster:

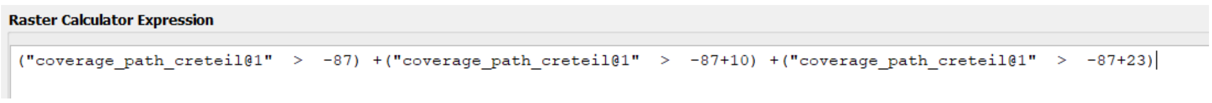


Figure 29: Raster calculator

The three layers raster is then converted to a vector layer containing polygons, with the "Polygonize" processing tool. The result is shown in Figure 30.

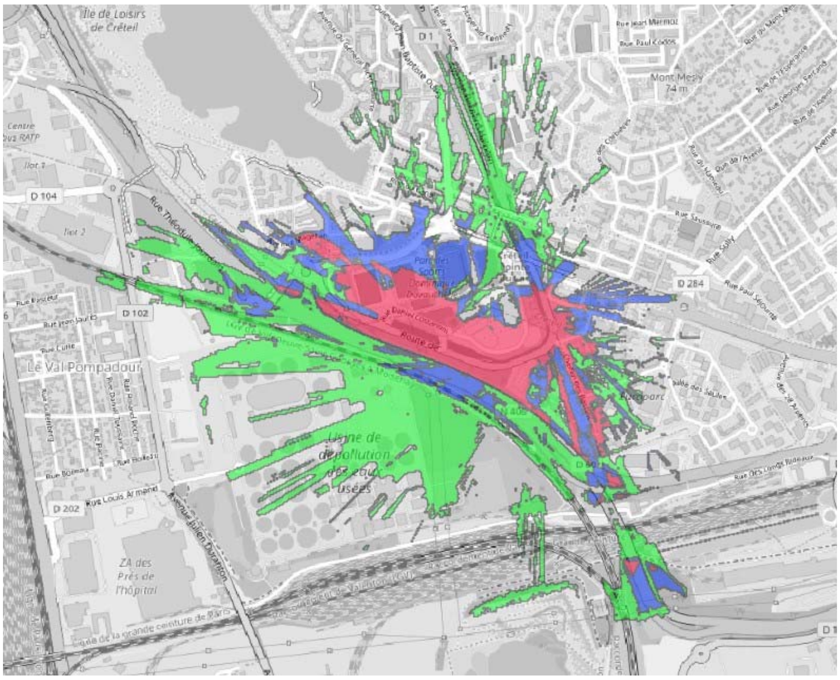


Figure 30: Polygons representing the three protected zones
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

The polygons are then simplified, in order to optimize the size of the data and minimize processing load. The "convex hull" processing toolbox in QGIS is used, the result of which is illustrated in Figure 31. Alternative techniques may be used for this step.

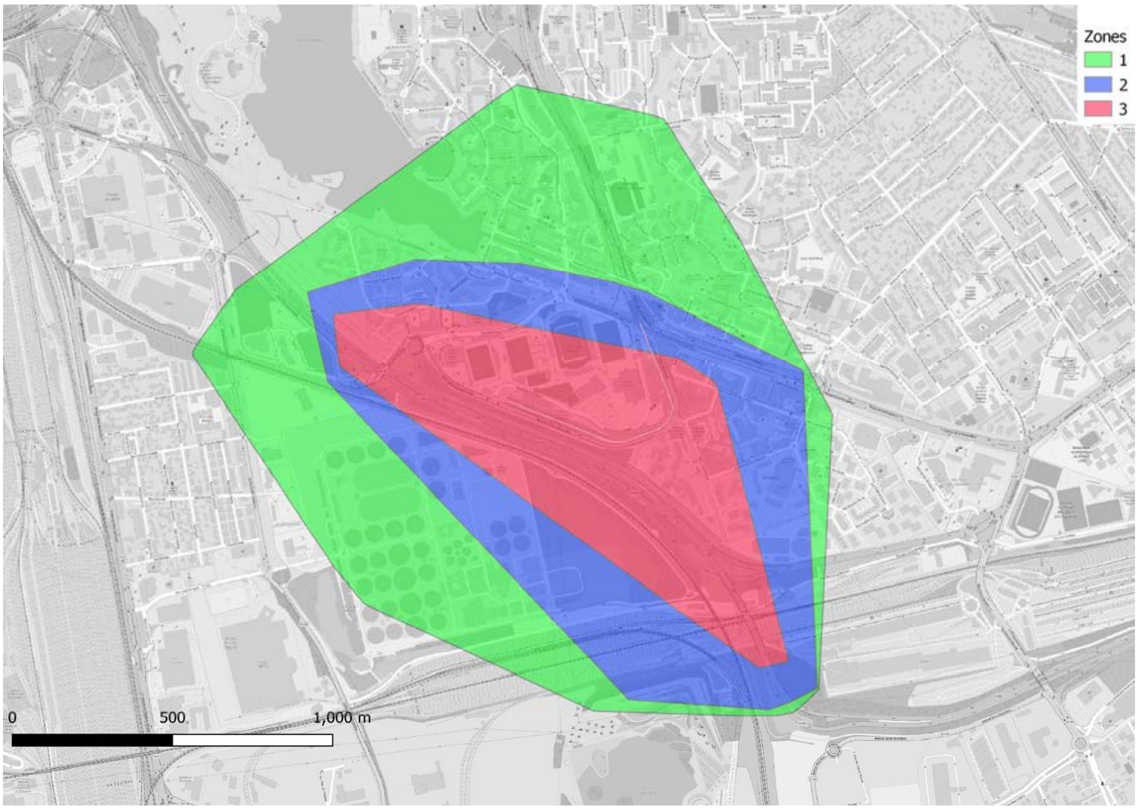


Figure 31:Simplified polygons
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Step 5: Export the defined contours of the R-RMO in an appropriate format. The vertices of the polygons are expressed in a known coordinate system such as WGS-84 G2384 and exported in GeoJSON format. Annex J gives the plaintext of the content of the GeoJSON file for the polygons in Figure 31.

6 Restricted Modes of Operations (RMOs)

6.1 Generalities on RMOs

Four potential Restricted Modes of Operations (RMOs) applicable to Road ITS stations, for using the frequency band 5 915 MHz to 5 925 MHz while respecting the priority of Urban Rail ITS therein have been investigated in the present document. Of those four, the one believed to be most effective given the current status of CBTC deployments is based upon progressive power restrictions, and it is more thoroughly detailed. Progressive power restriction ensures priority to CBTC applications in the band 5 915 to 5 925 MHz, is readily implemented by Road ITS stations, and results in efficient use of the 5 915 to 5 925 MHz channel considering the usage of the spectrum at the time of writing the present document. Alternative modes of operation for ensuring Urban Rail's priority are described in Annex I. Given the fact that new Road ITS services will be deployed in the future, and that new CBTC technologies may be deployed as well, it is unlikely that a single restricted mode of operation will be the best choice in all circumstances.

6.2 Progressive power restriction

Depending on the estimated mitigation distance of a Road ITS station to an Urban Rail station that could receive harmful interference there from, the Road ITS station could reduce its TX power accordingly. Based on the process definition given in clause 5.6, areas could be defined where a specific TX power level would be possible without the risk of harmful interference to the Urban Rail system. The potential power level could be in the range of 10 dBm up to 33 dBm (representing the regulatory maximum value).

In each of these areas, different TX power levels would be allowed. As an example, three mitigation zones and one normal operational zone could be defined:

Zone 0: No mitigation required.

Zone 1: Maximum TX power for Road ITS is 23 dBm EIRP.

Zone 2: Maximum TX power for Road ITS is 10 dBm EIRP.

Zone 3: Road ITS devices are not allowed to transmit.

Figure 32 illustrates this example.

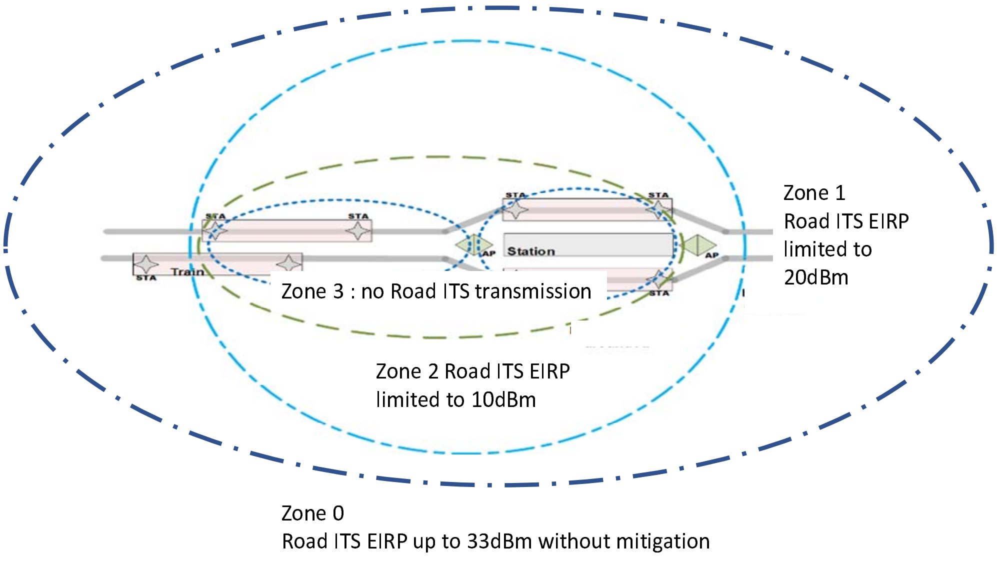


Figure 32: Example of progressive power restriction mitigation zones

Road ITS devices are mandated by [i.43] and [i.50] to support transmit power control at least within the range 3 dBm to the devices' maximum transmit power and they are therefore technically capable of implementing such a solution with no modifications necessary to those devices. For the protection of road tolling operation according to ETSI TS 102 792 [i.1], Road ITS devices are also required to support transmit power reduction to 10 dBm EIRP within the road tolling coexistence zone for some coexistence modes.

Clearly a significant advantage of this progressive sharing solution is increased spectral efficiency. Road-ITS applications can make use of the 5 915 MHz to 5 925 MHz channels within the R-RMOs albeit with decreasing communication range due to output power restrictions as they get closer to Urban Rail operations.

Note that for Zone 3 no Road ITS transmission is allowed, resulting in "no transmit zones". This may restrict the possibility of using the frequency band 5 915 to 5 925 MHz for Road ITS safety applications that would require ubiquitous coverage because no Road ITS message could be sent over this frequency band from Zone 3 areas. For a transmit power reduction (Zones 1 to 2) the communication range for Road ITS will be reduced, but the exchange of messages is still possible.

7 Sharing solution

7.1 Introduction and general considerations

This clause presents technology-neutral key principles for definition and distribution of the R-RMOs. With the knowledge of the R-RMOs Road ITS devices can limit the RMOs to the local areas around fixed Rail ITS deployments.

As part of the work for the present document, also a technology specific MAC/PHY based coexistence was investigated, where Road ITS and Urban Rail ITS use the same technology. This could in principle apply to any future radio technology, nevertheless only the solutions based on IEEE 802.11 [i.15] technology has been studied. In Annex H contains the description of a solution using C-ITS technology for Urban Rail. Although this approach would not fit with the guidance given by ECC to ETSI: "*Solutions for the coexistence between Road ITS and Urban Rail ITS applications should not impose the use of a specific radio technology, topology or a specific protocol for railway signalling*", this could be seen as an optional long-term solution.

Detection of R-RMO through detection of specific radio signals (e.g. beacons, CBTC headers, etc.), or through alert messages are described in Annex G.

However, these solutions do not ensure interference free operation of Urban Rail CBTC by design as coverage holes or failures could lead to interference. In addition, these solutions appear comparatively more complex than the solution described in the present clause. Indeed, these solutions would require dedicated networks of beacons being deployed for this purpose, and several co-localized such networks would be needed if different Road ITS radio technologies co-exist (see details in clause G.4).

7.2 Map server sub-system

Enabling co-channel coexistence of Road ITS and Urban Rail ITS requires the geographic knowledge of the areas where interference mitigation is or is not required. The present clause describes a map server sub-system used as a register to store this geographic information. In order to fulfil the priority regime of the EC Decision, a Road-ITS equipment should comply with the allowable use of the channels in the frequency range 5 915 MHz to 5 925 MHz available on the map server. The precise mitigation applicable (e.g. EIRP reduction) and the means to distribute the maps to the vehicles (e.g. through beacons) are independent matters: the scope of the present clause is shown in Figure 33 .

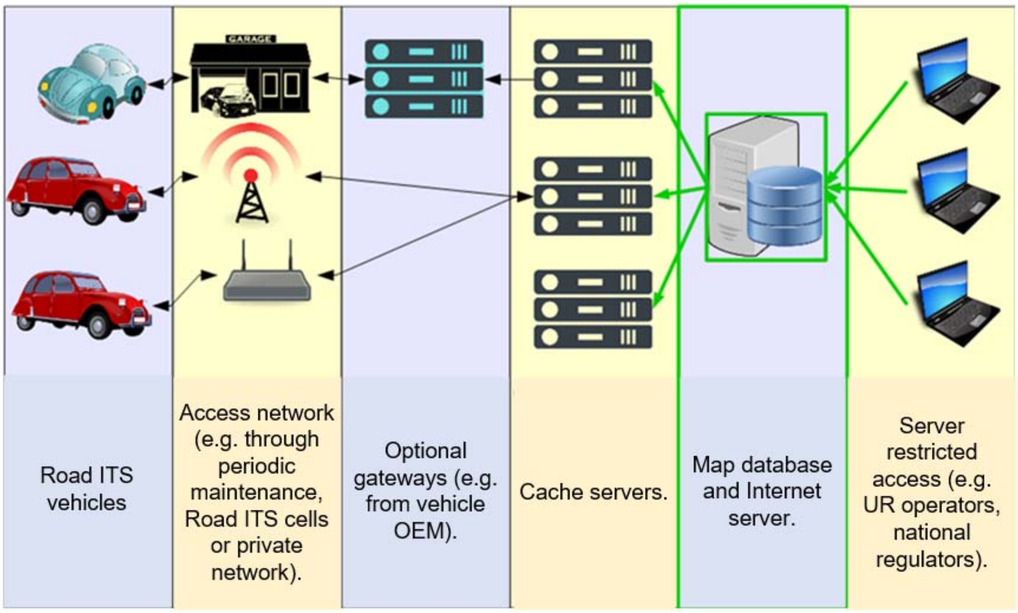


Figure 33: Map server sub-system highlighted in green

7.3 Hosting and uploading data

The data required to implement the coexistence solution may be hosted on a server, offering a well-defined APIs to query the data in a machine-readable format. The responsibility to host the deploy, operate and maintain the server may fall on either CBTC stakeholders, e.g. through a volunteering stakeholder or an association of stakeholders (similar to ASECAP who hosts a database for coexistence with road tolling), or on an administration (similar to EC who hosts the C-ITS Point of Contact). The server may be reachable from a URL, which may be defined in a suitable regulation. A similar principle is used for accessing TLM and CTL from the CPOC of the EU CCMS (EU C-ITS security credential management system, see paragraph I.5.2.from [i.49]). A suitable alternative may be to store the URL in a machine-readable format, and make it available on the CPOC. In this case, the regulation would the CPOC's URL with the subpath allowing to retrieve the maps server's URL.

The data submitted on the server (i.e. the R-RMOs) may be decided at national level, by the relevant spectrum authorities. The national authorities may setup national coordination meetings to involve the relevant stakeholders (i.e. CBTC and Road ITS representatives). The outcomes of these national coordination may be included in an ECC deliverable, or annexed to an EC decision and updated as necessary. The upload of these published data on the server may thereafter be the responsibility of the entity operating the server.

The authenticity of the data used by the vehicles to decide whether or not to apply a RMO should be validated by the ITS station (i.e. Road ITS devices) wishing to use the frequency 5 915 MHz to 5 925 MHz. This would avoid attackers, whose malicious intentions could be manyfold, to alter the functioning of the coexistence solution for e.g. getting around channel restrictions for selfish interests; causing intentional disruption to Urban Rail service; causing intentional disruption to Road ITS service provided on the 5 915 MHz to 5 925 MHz channel, etc.

A reliable solution to ensure authenticity of the input data is to apply digital signatures that typically consist in appending signed hash to the data. This leverage the use of Public Key Infrastructure (PKI), which are ubiquitously used on the Internet. PKI requires the receivers to implement lists of trusted bodies in the form of trusted certificates.

For security and privacy reasons, Road ITS devices mandatorily implement cybersecurity mechanisms relying on PKI infrastructure (defining the C-ITS trust domain). Authenticity (or encryption) mechanisms need to be applied for most typical Road ITS communications, including e.g. sending and receiving CAM messages. Therefore, it would be beneficial to reuse existing mechanisms that are already implemented in the Road ITS stations.

The C-ITS Certificate Policy [i.39] defines common European elements, which include root level servers which could be leveraged to deliver certificates used for signing coexistence input data. The servers hosting the coexistence data may be part of the C-ITS trust domain and therefore considered as a trusted central ITS station by other ITS stations. In this case, the authenticity of the coexistence data could be natively checked by the ITS stations, i.e. there would be no need to implement new mechanisms, nor would it be needed to include additional trusted certification authorities to the receivers.

Leveraging the use of this reliable authentication solution offers various options for disseminating the data, without the need to rely on dedicated secured processes or networks, hence removing the need for their detailed specifications. For instance, the data could be downloaded by the OEM vendor or by the car manufacturers and loaded into the vehicles at manufacturing time. The data could also be safely loaded by any garage staff, possibly not trusted staff, as the authenticity would be checked by the vehicles themselves. Another possibility would be a direct connection from the vehicles to the server, or connecting through a fixed ITS station which could itself safely connect to the map server for downloading authenticated maps.

7.4 On the implementation of maps

The present clause discusses options for the format of the maps available on the server sub-system introduced in clause 7.2. The maps enable the use of the shared channel (5 915 MHz to 5 925 MHz) between Road and Urban Rail ITS, while ensuring interference free operation of the latter.

Appropriate map formats should aim at the following objectives, to the possible extent:

- Interference free operation of Urban Rail CBTC is guaranteed by design. E.g. failure of a network element should not result in possible interference.
- Maps could be disseminated to the vehicles through various type of networks, including cellular networks, home networks, USB sticks and road-ITS beacon infrastructure. If needed, a lossy transcoding should not compromise the interference free operation.
- Maps should rely on royalty free solutions, and it should be independent of third-party components, exception being made for Road-ITS platform components set-out by the EU regulation. E.g. recourse to proprietary APIs or queries sent to proprietary systems should be avoided.
- The maps should rely on well-documented formats, ensuring a straightforward implementation with the main programming languages. E.g. simple data structure, or data structure allowing easy manipulation through existing libraries should be preferred.
- The map format should enable fast processing and easy dissemination. E.g. reduced map size and limited dynamicity would be beneficial.

In the following a "map" refers to a consistent set of zones. Two conceptually distinct types of zones are used: zones where the shared channel can be used for a rather long period of time without causing interference, and zones where restrictions apply (i.e. R-RMO). A possible implementation that meets the above requirement uses a common format for both types of zones, which further enable joint processing.

Every zone, be-it of either type, includes the following components, as illustrated by Figure 34:

- A geometry, such as multipolygon. Note, raster format or a mix of raster and geometry formats may also be used if necessary.
- A unique identifier, which uniqueness is ensured amongst current and deprecated zones.
- A RMO activation date.
- A bounding box. This enables fast processing and could be included either as a geometry or as a non-geometry parameter.
- Possibly additional parameters, describing for instance specific RMO parameters for zones that belongs to R-RMO.

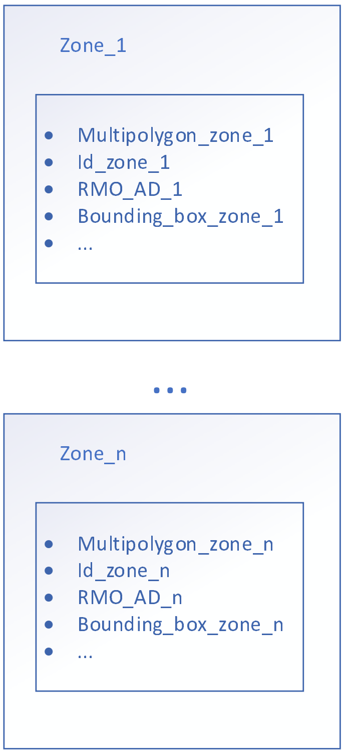
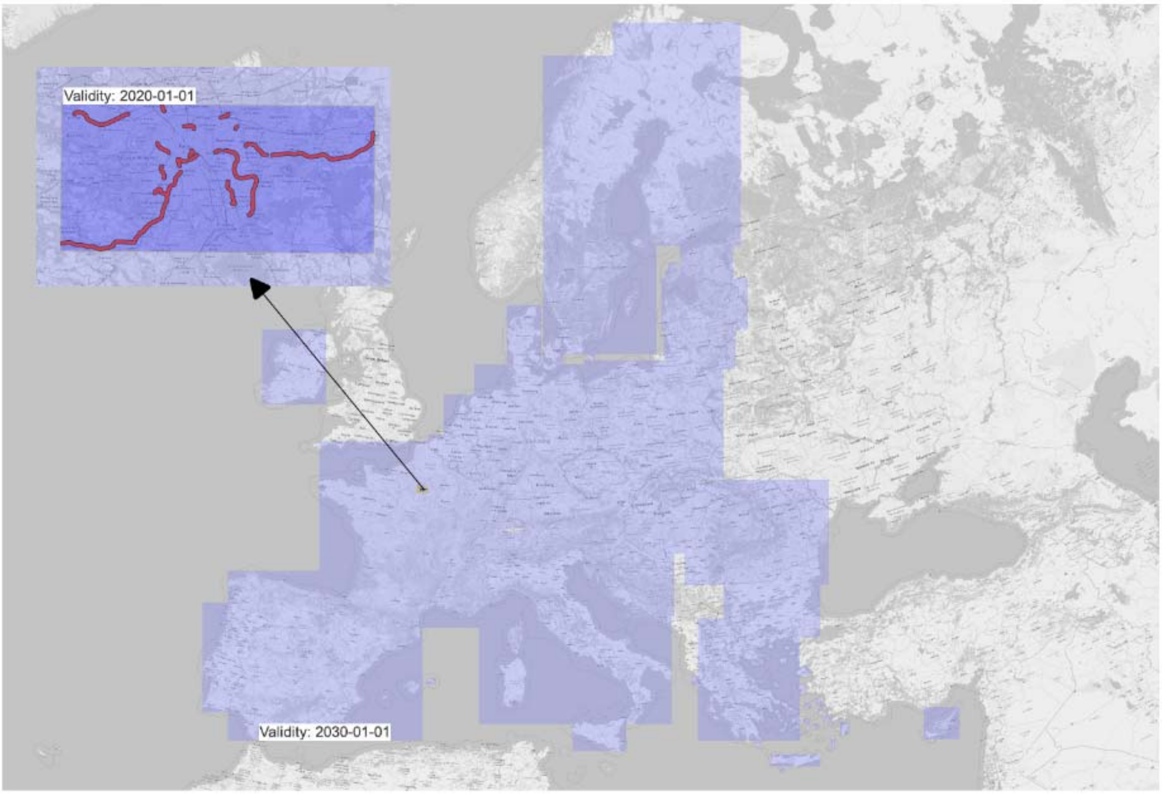


Figure 34: Applicable format for zones

The RMO activation dates of R-RMOs are set to the dates at which the corresponding CBTC systems enter into service, be-it a date in the foreseeable future or a date in the past. This allows to determine straightforwardly whether a given location at a given time instant is subject to a RMO for the use the shared channel: this requires to test whether the given location is within a zone whose RMO activation date is prior to the considered time instant, as illustrated by Figure 35. For zones where the shared channel could be used for a rather long period of time without causing interference, the RMO activation date may be set to a fixed time horizon from the date of retrieval from the server. It has to be a reasonably long-time horizon, representing for instance the time horizon by which unplanned CBTC projects could not reasonably be put into service (e.g. 15 years for a zone remote from 100 000+ inhabitants cities, 5 years overwise). These "Restricted Mode of Operations Activation Dates" would be decided by the relevant bodies (e.g. regulators, stakeholders, etc.) at the time of defining the R-RMO. If the map is absent from the Road ITS station, or if the given location is subject to the regulation but no zone has been defined, the channel 5 915 MHz to 5 925 MHz should not be used for transmitting, although receiving may be allowed. This behaviour only requires a Road ITS station to update its map if the downloaded map is outdated in the visited region and operation in the 5 915 MHz to 5 925 MHz channel is desired (see Figure 36). However, it would be beneficial that Road ITS stations anticipate the download whenever possible, in order to take advantage of e.g. home connectivity and avoid simultaneous downloads from many cars.



NOTE: A restriction free zone has a blue footprint. A single restriction zone is red.

Figure 35: Maps with two zones

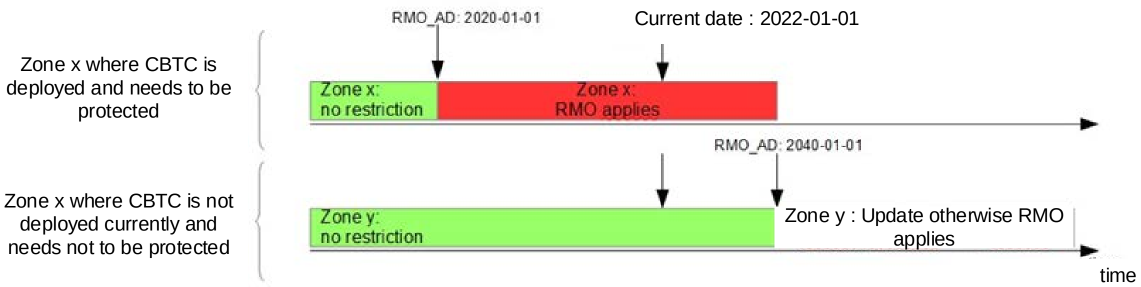


Figure 36: Time dimension of zones

This concept only works for vehicles that have acquired the knowledge of all applicable zones, at least once. Although this set of zones does not necessarily need to be updated regularly, it is beneficial that individual zones may be downloaded independently from the server and subsequently disseminated to the vehicles. In order to ensure the consistency of the downloaded set of zones (i.e. the map), a "map message" would contain all applicable zones at a given moment in time. Therefore, a map message always lists all zones to be considered. A newer map-message replaces older map-messages. This allows to remove zones, by not listing them anymore. The map messages include a collection of the following components, as illustrated by Figure 37:

- A zone identifier (see description of the zone message).
- A URL to download the corresponding zone. Note that, this is optional and bulk download of both map messages and zones could be possible. However, enabling independent downloads increases flexibility in implementing the solution and could significantly reduce the size of the download.

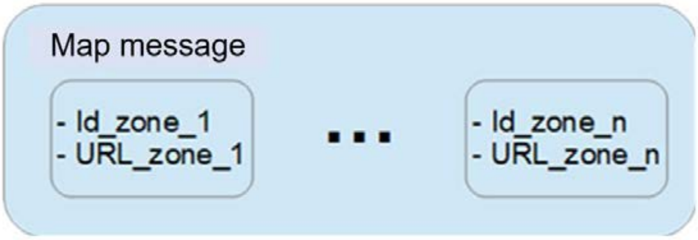


Figure 37: Applicable format for map messages

The messages defined in the present clause (zones and map messages) describe the principles of the solution but should not be interpreted as the definitions of a new network protocols. Existing protocols should be re-used to the possible extend, and providing that they include adequate functionalities.

7.5 On the implementation of distribution networks.

This clause discusses options for the distribution of the maps from the API of the map server to the Road ITS stations. Several solutions may be envisaged, and may be available in parallel, allowing Road ITS stations to choose the preferred option.

Leveraging the authentication mechanisms, the network used to piggyback the maps does not need to be secured.

In its simplest form, the Road ITS stations may send an HTTP query to the map server, in a similar way as TLM and ECTL can be downloaded. The access network may be through users' LAN, cellular networks or RSUs acting as gateways to the Internet. A broadcast service may also be defined for the dissemination of the maps through RSUs. As an alternative, carmakers or OEMs may choose to rely on a gateway or mirroring repository of their own. Another possibility would rely on removable storage, to update the maps.

8 General conclusions and summary

The present document is in response to CEPT's invitation to ETSI to develop sharing and interference mitigation techniques within three years, to ensure co-channel coexistence in the frequency range 5 875 MHz to 5 925 MHz between Road ITS and Urban Rail radio technologies. It was initiated through the RSC (RSCOM17-26 rev.3 (Final) [i.41]) with the wherein the following recommendation was made:

- *"Mitigation techniques developed through ETSI standardisation should be accompanied by technical conditions for spectrum access and relevant harmonised standards, in a technology neutral approach."*

CEPT Report 71 [i.12] proposed that technical solutions already deployed should remain available for maintenance and evolution and the continued rollout of these systems should not be unduly hindered by a change of the spectrum regulatory environment.

The present document proposes methods to allow sharing of Road ITS and Urban Rail in the frequency range 5 915 MHz to 5 925 MHz where Urban Rail's priority is respected. Urban Rail intents to use the spectrum from 5 875 MHz to 5 915 MHz within closed tunnels where interference with Road ITS services is not expected to be an issue. The regulatory basis for this usage needs to be defined but is outside the scope of the present document. Usage of this spectrum outside of tunnels is not considered in the present document. However, it may be addressed in the future.

The sharing techniques described in the present document should be extendable to other "aggressor" or "victim" channels and bandwidths, if needed, to protect CBTC systems The present document proposes:

- Methods to compute the zones where Urban Rail and Road Intelligent Transportation Systems are likely to interfere, based on the outcome of the measurement campaign.
- Principles governing the sharing solution and outline the design of the technical infrastructure allowing Road ITS equipped vehicles to have access to up to date sharing information.
- Appropriate mitigation features to be implemented. These are Restricted Modes of Operations (RMOs) that Road ITS equipped vehicles would activate to avoid interfering with Urban Rail ITS.

It is recommended that:

- a new Technical Specification (ETSI TS 103 745 [i.47]) be developed to address detection and mitigation techniques outlined in the present document, and
- the regulatory and normative frameworks be subsequently updated to enable the use of the 5 915-5 925 MHz by Road ITS subject to the implementation of the selected sharing solution.

Annex A: Simulations of various scenarios performed prior to measurements campaign.

A.1 Scenario 2. Parallel road "Avenida Marcelino Camacho" between Andalucia Tech metro station and depot facilities in Màlaga (Spain), metro line 1. Scenario CBTC depot

Simulation 2.1 was performed based on a map of Malaga for the area between Andalucia Tech station and depot. This scenario consists of one CBTC station and one train (Figure A.1). with the train moving toward the CBTC base station located close to the street cross. The evaluation shows that the CBTC base station can be interfered from a road ITS system transmitting at 33 dBm EIRP in a 10 MHz Road ITS channel (hence, 30 dBm EIRP in the 5 MHz channel of Urban Rail). Figure A.2 shows the protection distances for the different scenarios leading to the colour palette defined in Figure 10.

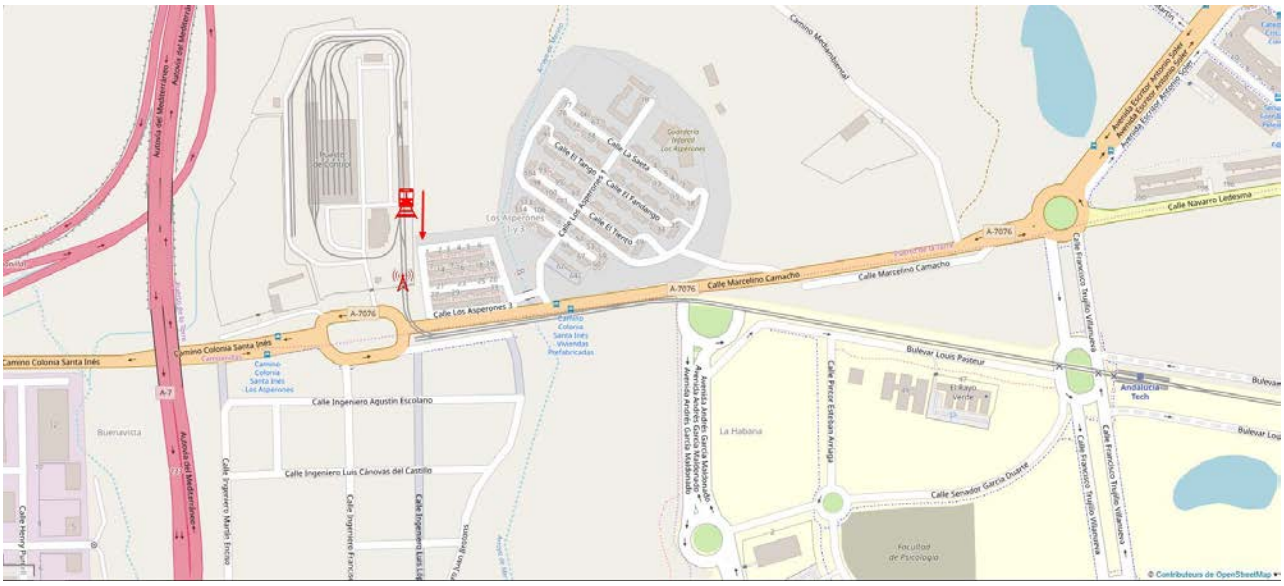


Figure A.1: Malaga metro station and depot facilities map
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

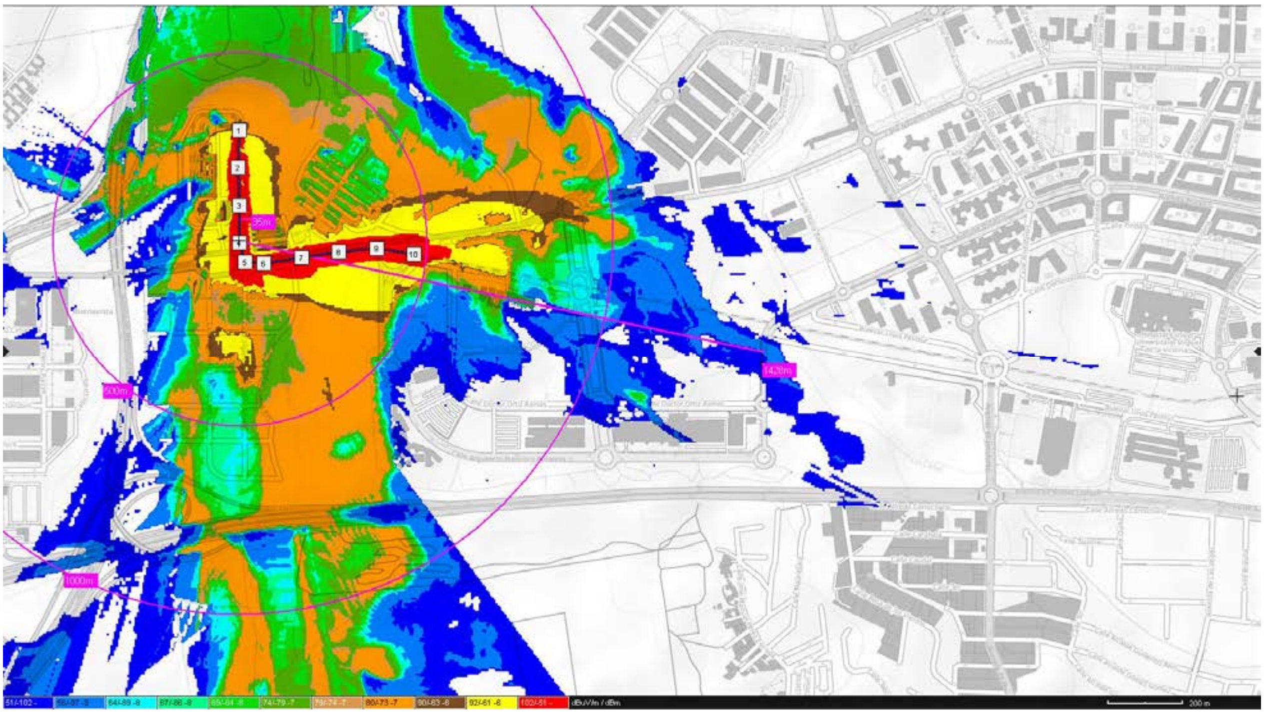
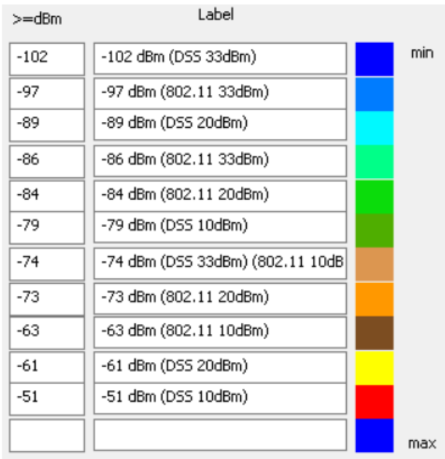


Figure A.2: Malaga depot - Trains Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)



>=dBm	Label		
-102	-102 dBm (DSS 33dBm)		min
-97	-97 dBm (802.11 33dBm)		
-89	-89 dBm (DSS 20dBm)		
-86	-86 dBm (802.11 33dBm)		
-84	-84 dBm (802.11 20dBm)		
-79	-79 dBm (DSS 10dBm)		
-74	-74 dBm (DSS 33dBm) (802.11 10dB		
-73	-73 dBm (802.11 20dBm)		
-63	-63 dBm (802.11 10dBm)		
-61	-61 dBm (DSS 20dBm)		
-51	-51 dBm (DSS 10dBm)		
			max

Figure A.3: Colour palette use for simulation

Simulation 2.2 uses the same Malaga case between Andalucia Tech and depot, only for a CBTC AP. Protection distances are shown in Figure A.4.

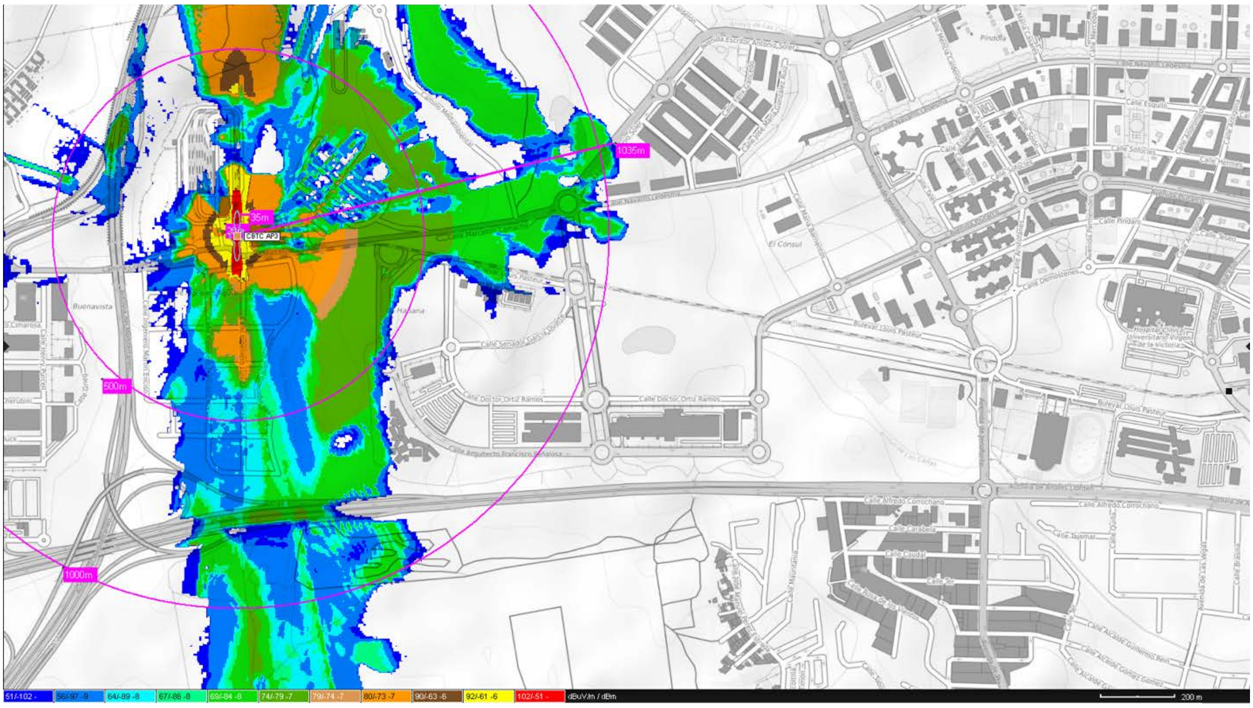


Figure A.4: Malaga depot , Urban Rail AP Protected Zones for different scenarios of Road ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

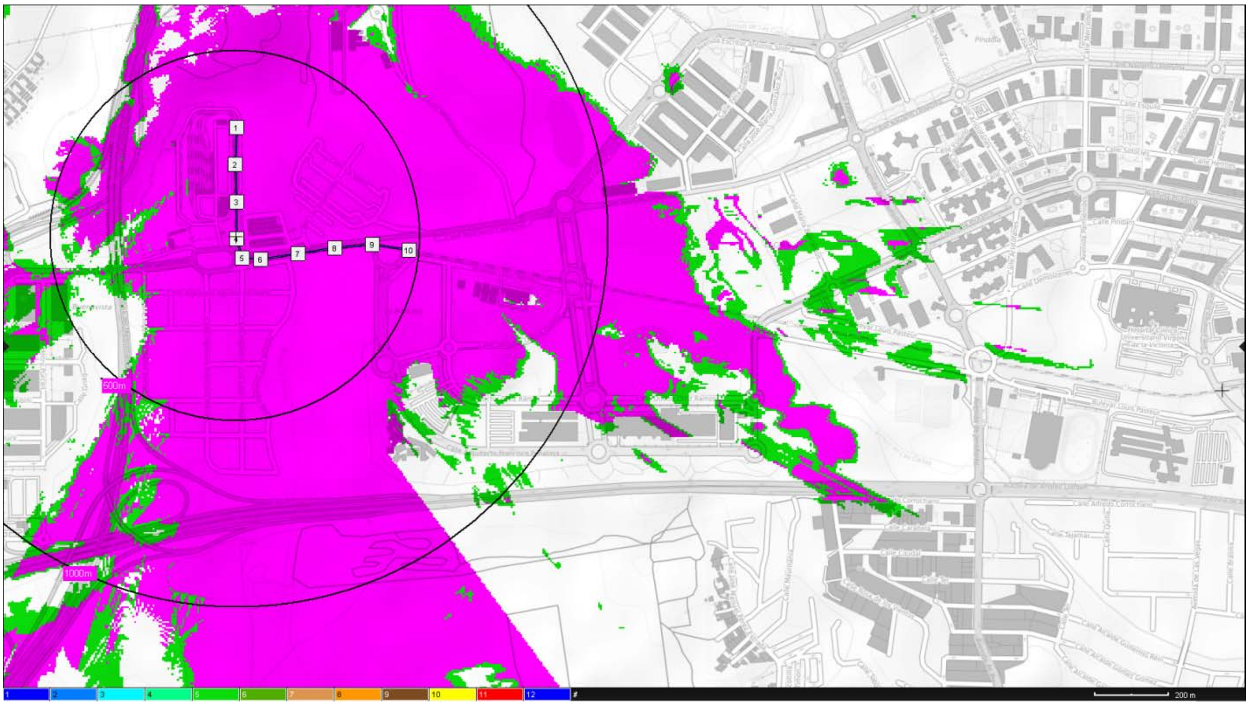


Figure A.5: Malaga depot - Common and additional Protected Zones between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

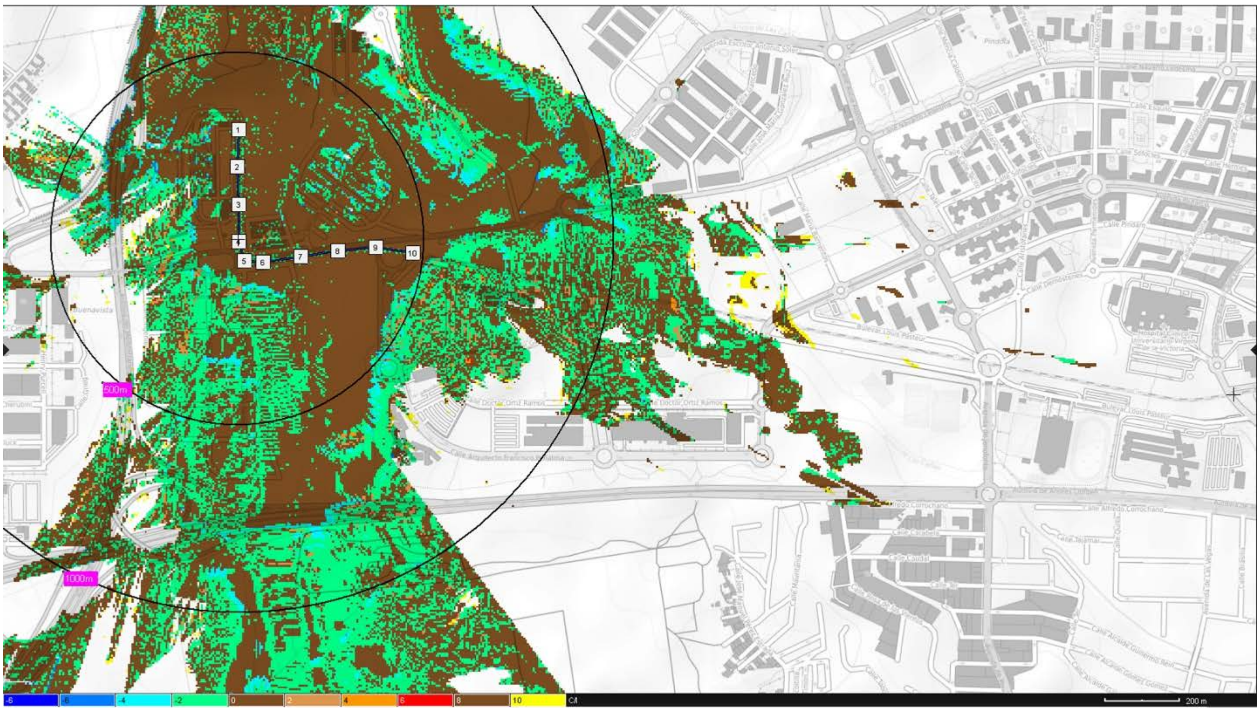


Figure A.6: Malaga depot - Difference of the received interference signal level in dB, due to road-ITS antenna height variations (between 1,5 m and 1,7 m), for a road-ITS EIRP of 33 dBm and CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

A.2 Scenario 3. Parallel road "Boulevard Auguste Blanqui" between Saint-Jacques and Corvisart metro station in Paris (France), metro line 6. Urban Rail tracks and road at same level with buildings (NLOS)

Simulation 3.1 is performed based on a map of Paris considering the road parallel to the metro line at the same height in Boulevard Auguste Blanqui, along the road until the tunnel entrance in Saint-Jacques station. The simulation evaluated the train trajectory between Saint-Jacques and Corvisart metro station. The scenario consists of two CBTC stations and one train were located (Figure A.7). When the train moves toward the CBTC base station located close to the road the simulation shows that the train can be interfered from a road ITS-S that transmits at 33 dBm EIRP in a 10 MHz Road ITS channel. The protection distances are shown in Figure A.8. The geometry of the road consists of three lanes for vehicles. The total width of the street is approximately 9,6 m. Each lane measures in width on average 3,2 m.

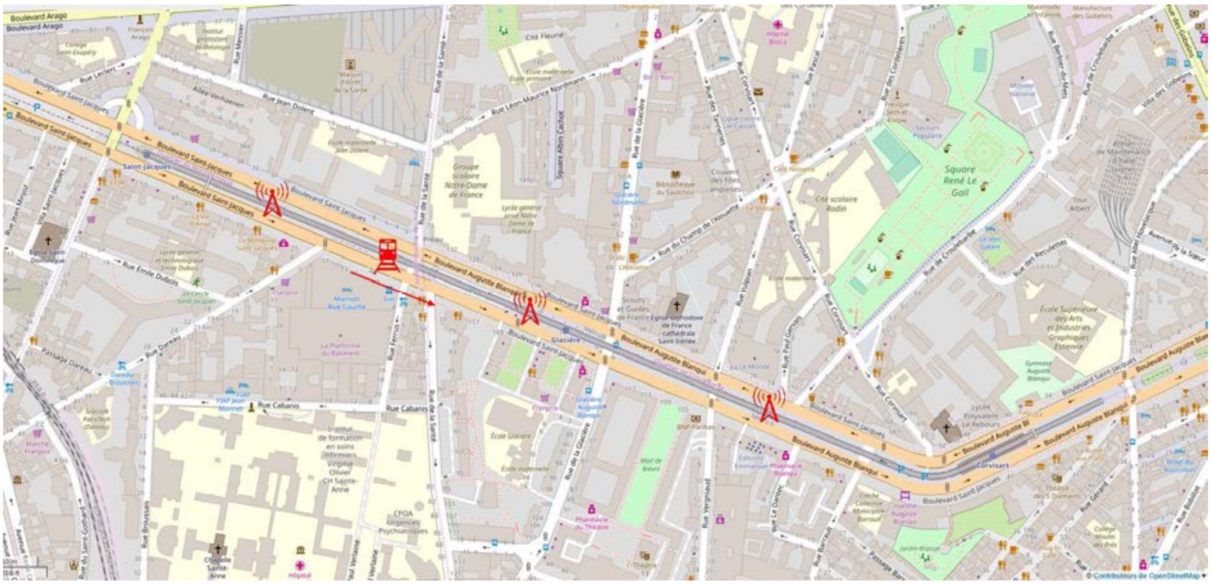


Figure A.7: Paris L6 map
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

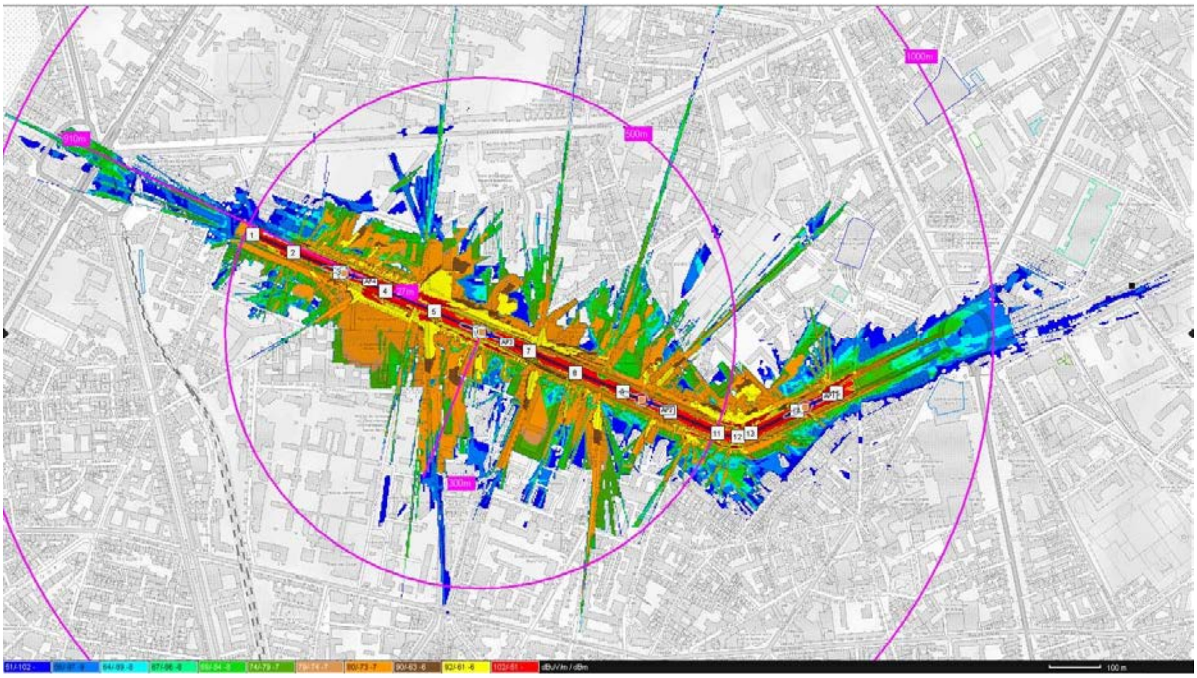


Figure A.8: Paris L6 - Train R-RMOs for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Simulation 3.2 uses the same Paris case in Boulevard Auguste Blanqui, but only for the CBTC APs. Protection distances are shown in Figure A.9.

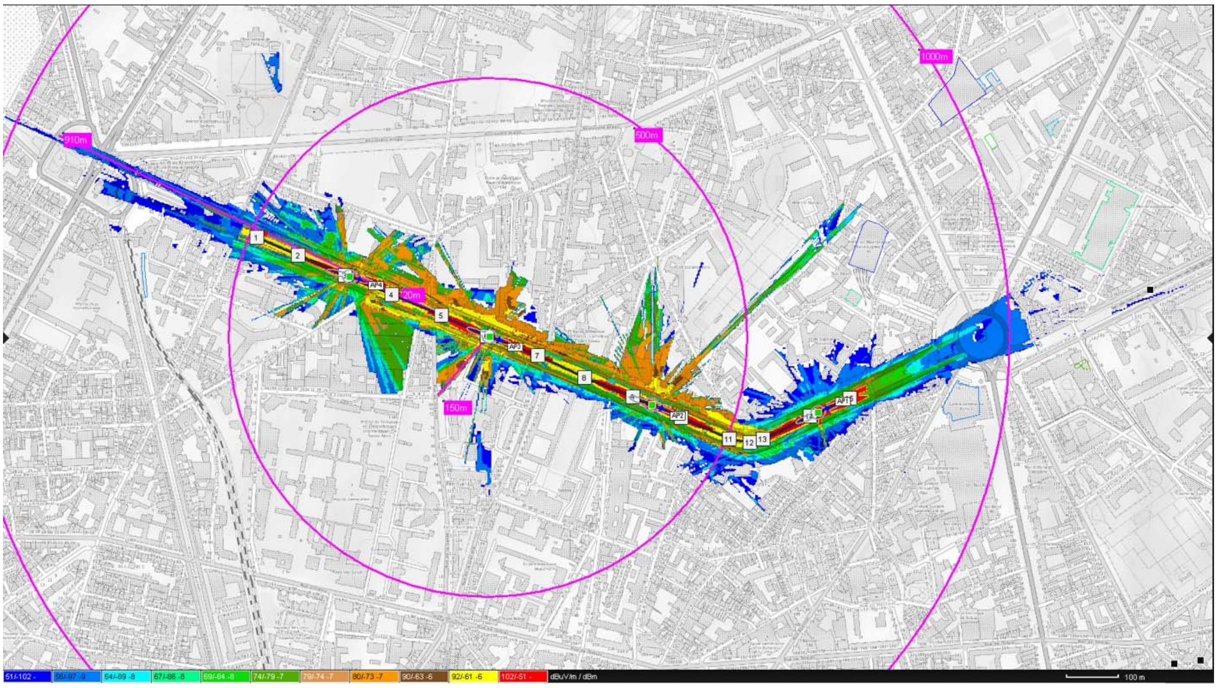


Figure A.9: Paris L6 - Urban Rail AP Protected Zones, for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

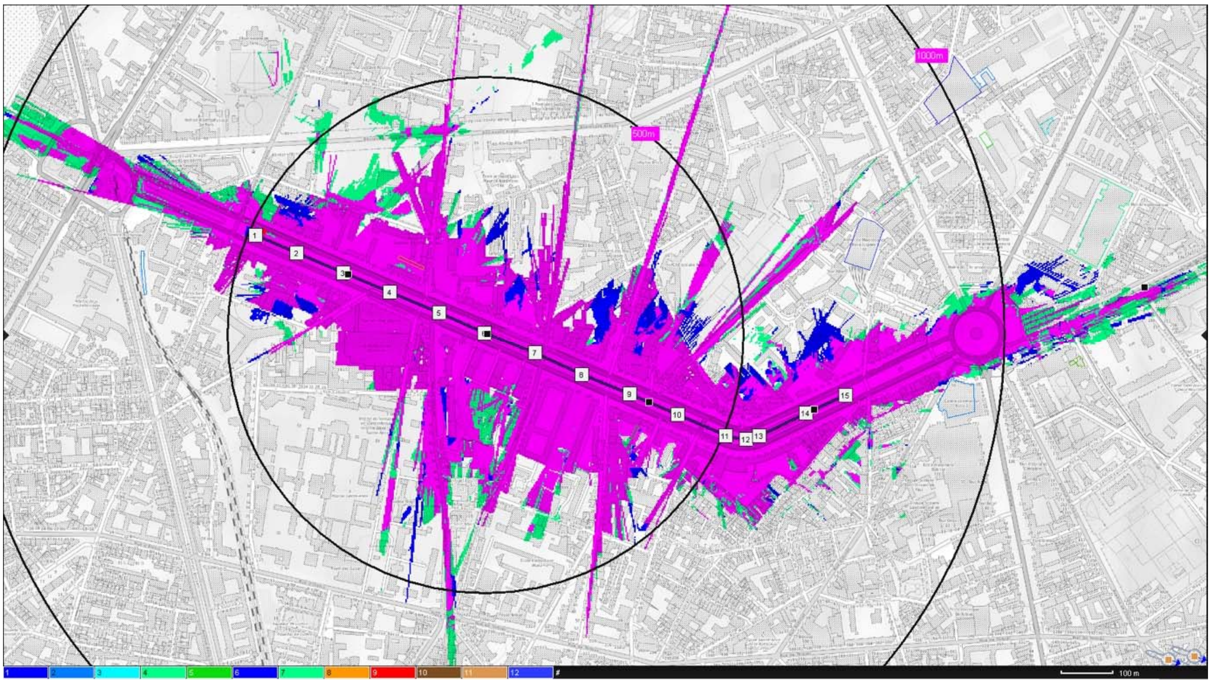


Figure A.10: Paris L6 - Common and additional Protected Zones between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

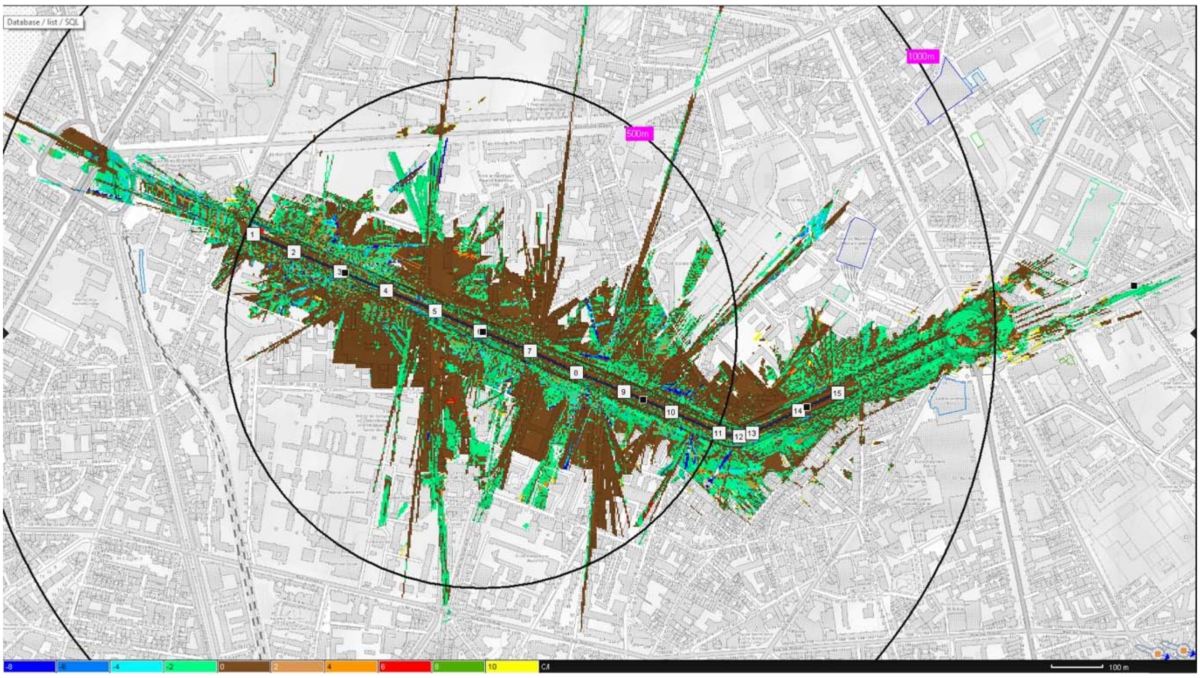


Figure A.11: Paris L6 - Difference of the received interference signal level in dB, for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

A.3 Scenario 4. Parallel highway and bridge in "N13" between La Defense and Les Sablons metro station in Paris (France), metro line 1. Road on a bridge crossing the track

Simulation 4.1 is performed based on a map of Paris using a 2 m cartography resolution, considering the bridge parallel to the metro line at the same height as Pont de Neuilly. The scenario consists of two CBTC base stations and one train (Figure A.12). When the train moves between La Defense and Les Sablons metro station the simulation shows that it can be interfered from a road ITS-S that transmits at 33 dBm EIRP in a 10 MHz Road ITS channel. The protection distances are shown in Figure A.13.

Figure A.12: Paris L1 map
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

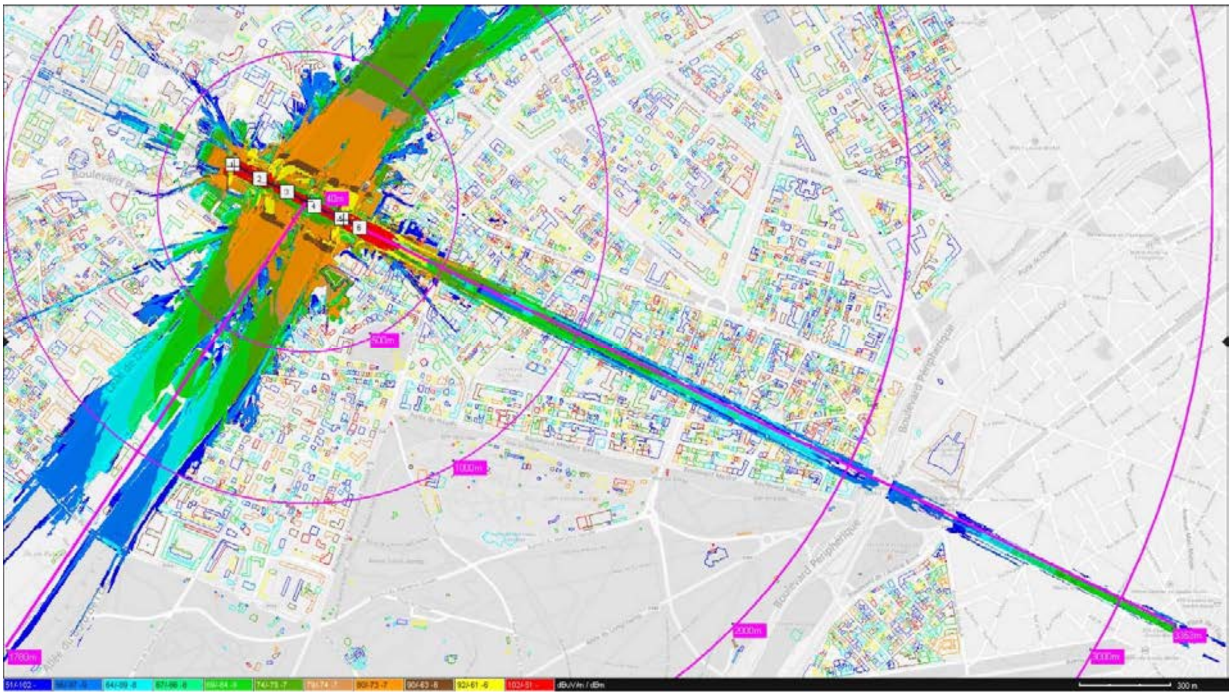


Figure A.13: Paris L1 - Train Protected Zones for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules
(Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Simulation 4.2 uses the same case near to La Défense, but only for the CBTC APs. Protection distances are shown in Figure A.14.

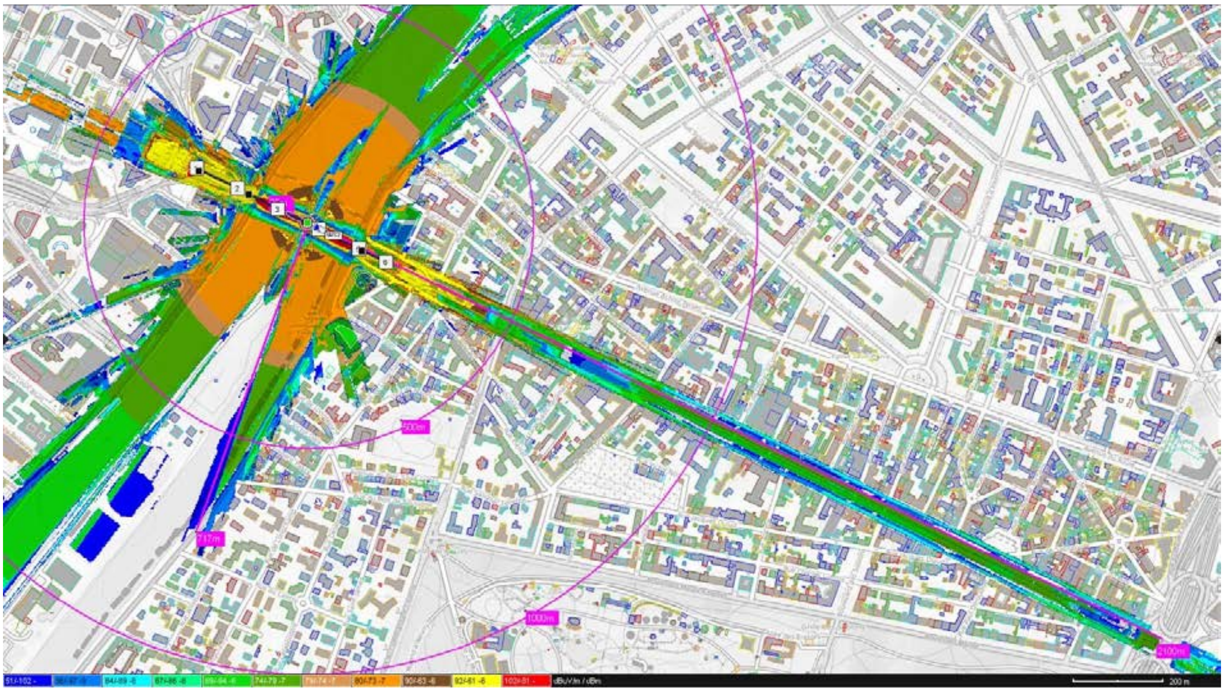


Figure A.14: Paris L1 - Urban Rail AP Protected Zones for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

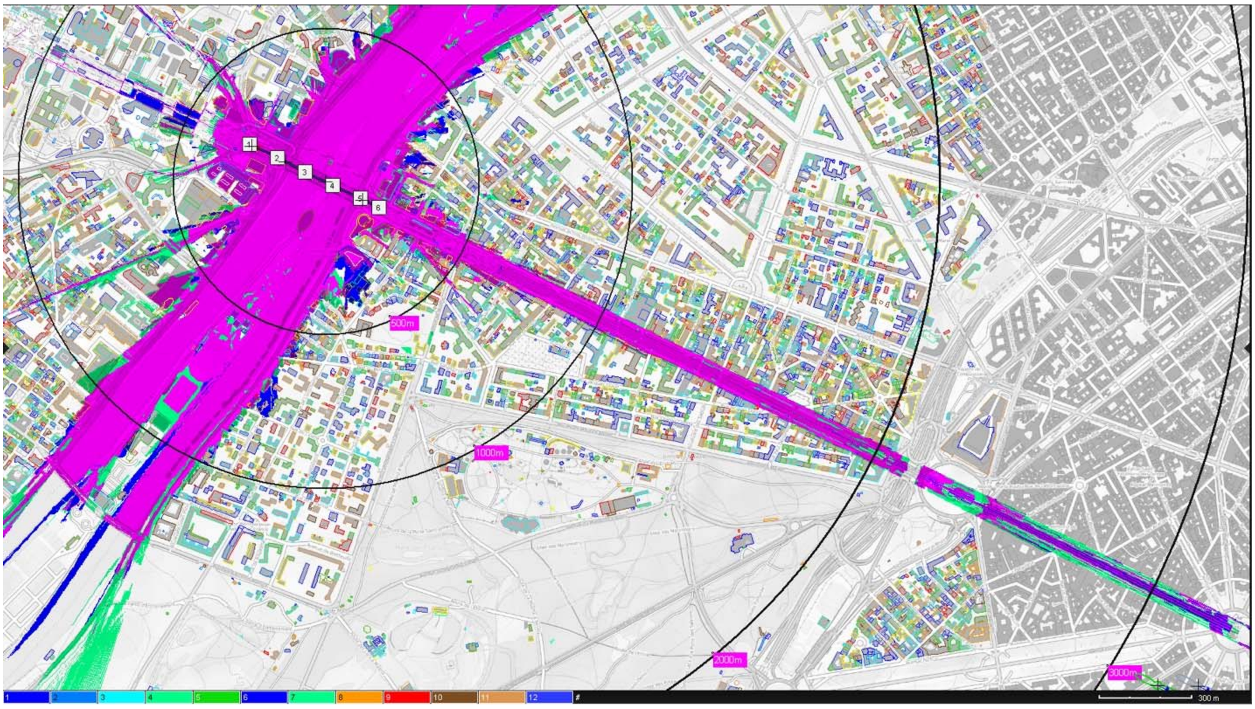


Figure A.15: Paris L1 - Common and additional Protected Zone between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

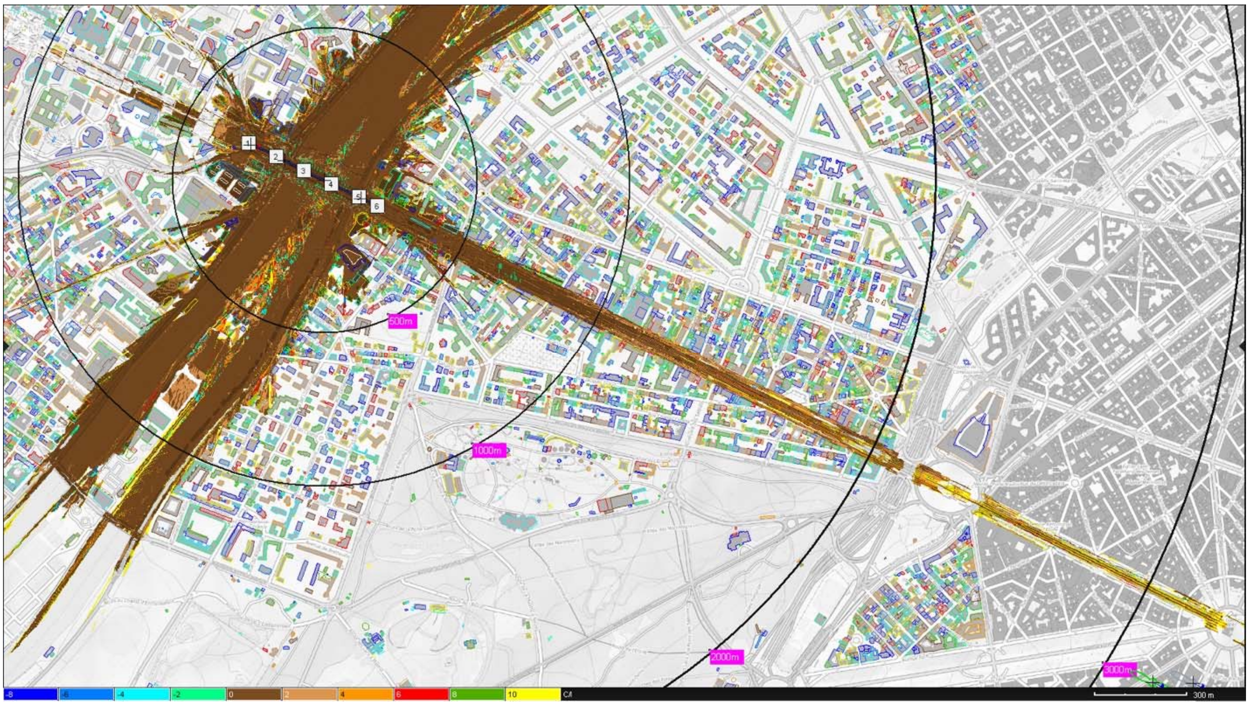


Figure A.16: Paris L1 - Difference of the received interference level in dB, for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

A.4 Scenario 5. A86 Highway is intersecting the railroad between Houilles Carrieres-Sur-Seine and La Garenne-Colombes RER train system. Urban Rail on a viaduct, above the road level

Simulation 5.1 is performed based on a map of Paris considering the train viaduct in A86 highway. The simulation evaluates the train trajectory between Houilles Carrieres-Sur-Seine and La Garenne-Colombes. The scenario consists of a CBTC station and one train (Figure A.17). When the train moves toward the CBTC base station located above the road, the simulation shows that it can be interfered from a road ITS system that transmits at 30 dBm EIRP in a 10 MHz Road ITS channel. Protection distances are shown in Figure A.18. The geometry of the evaluated road consists of three lanes for vehicles and one additional lane to exit or change the road. The total width of the road is approximately 9,6 m and each lane measures on average 3,2 m in width.

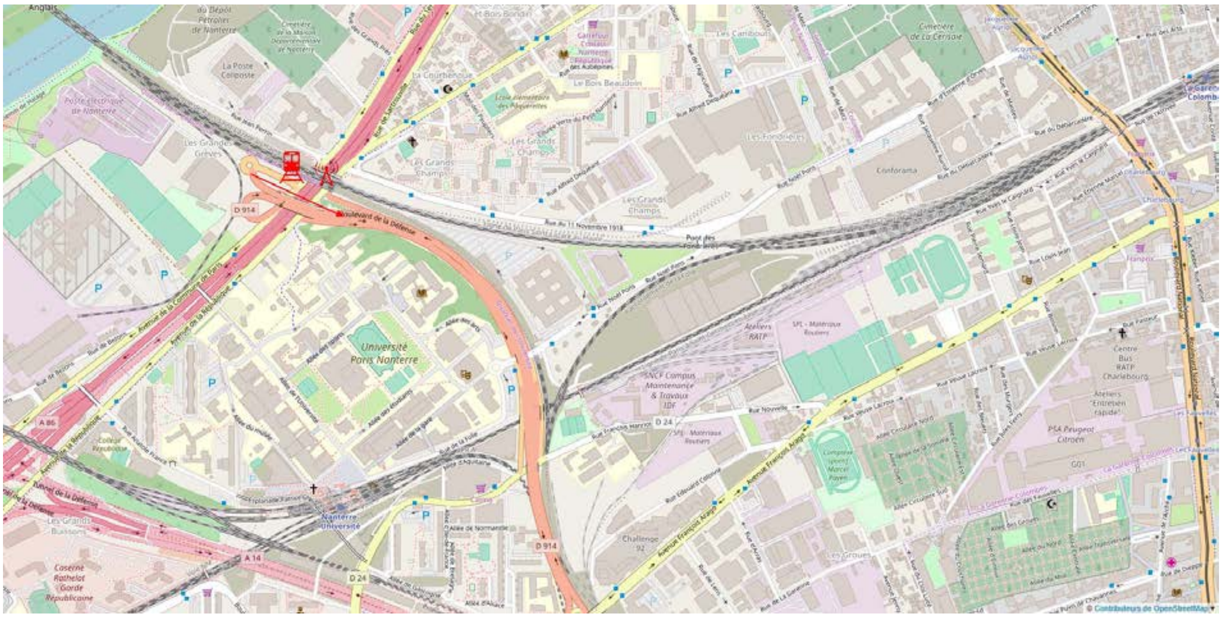


Figure A.17: Paris RER_E and A86 intersection map (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

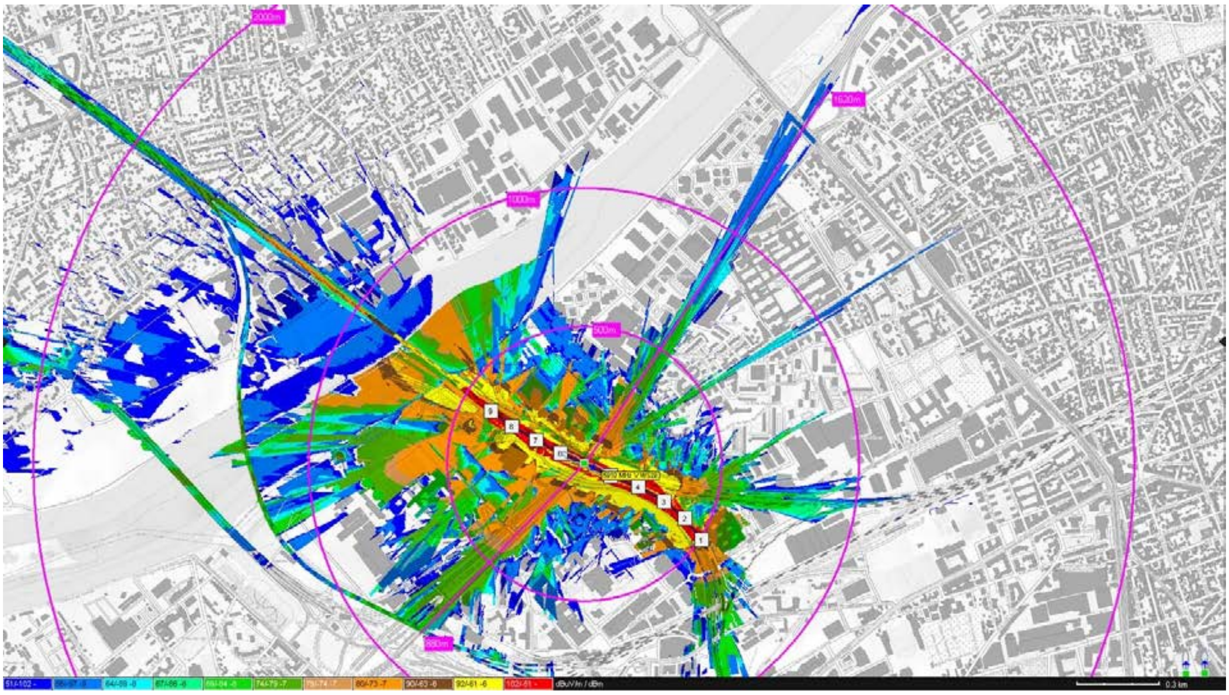


Figure A.18: Paris RER E - Train Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Simulation 5.2 uses the same case in A86 highway, but only for the CBTC APs. Protection distances are shown in Figure A.19.

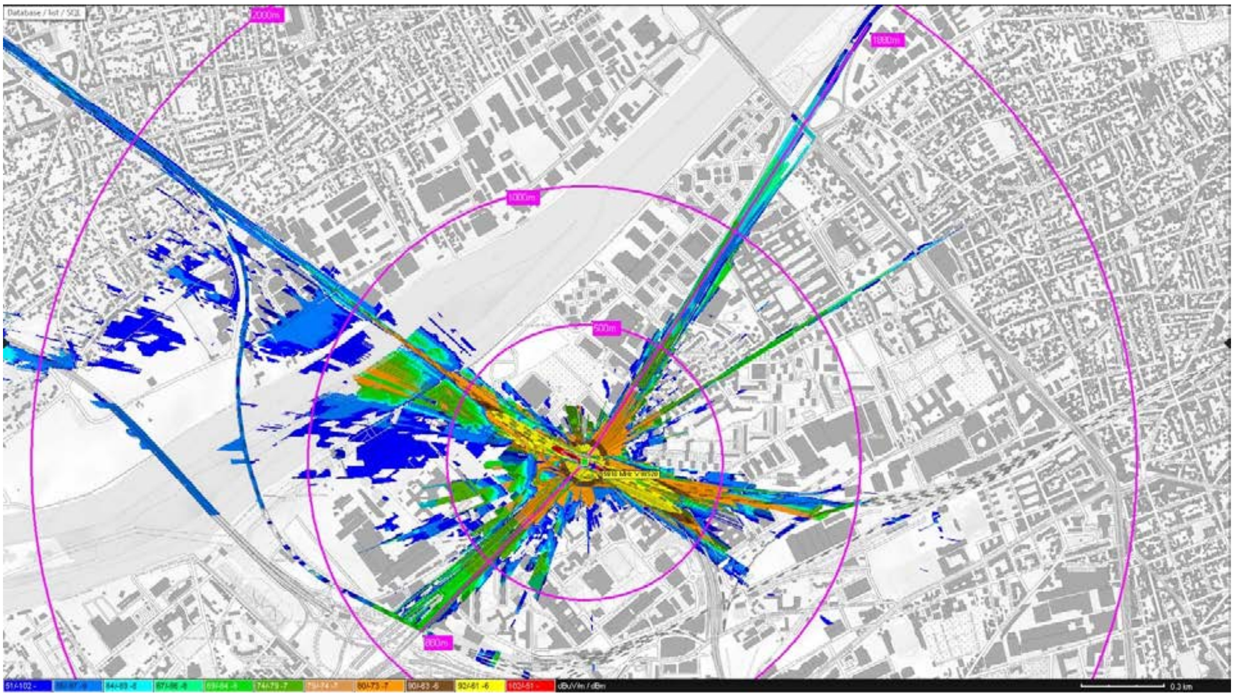


Figure A.19: Paris RER E - Urban Rail AP Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

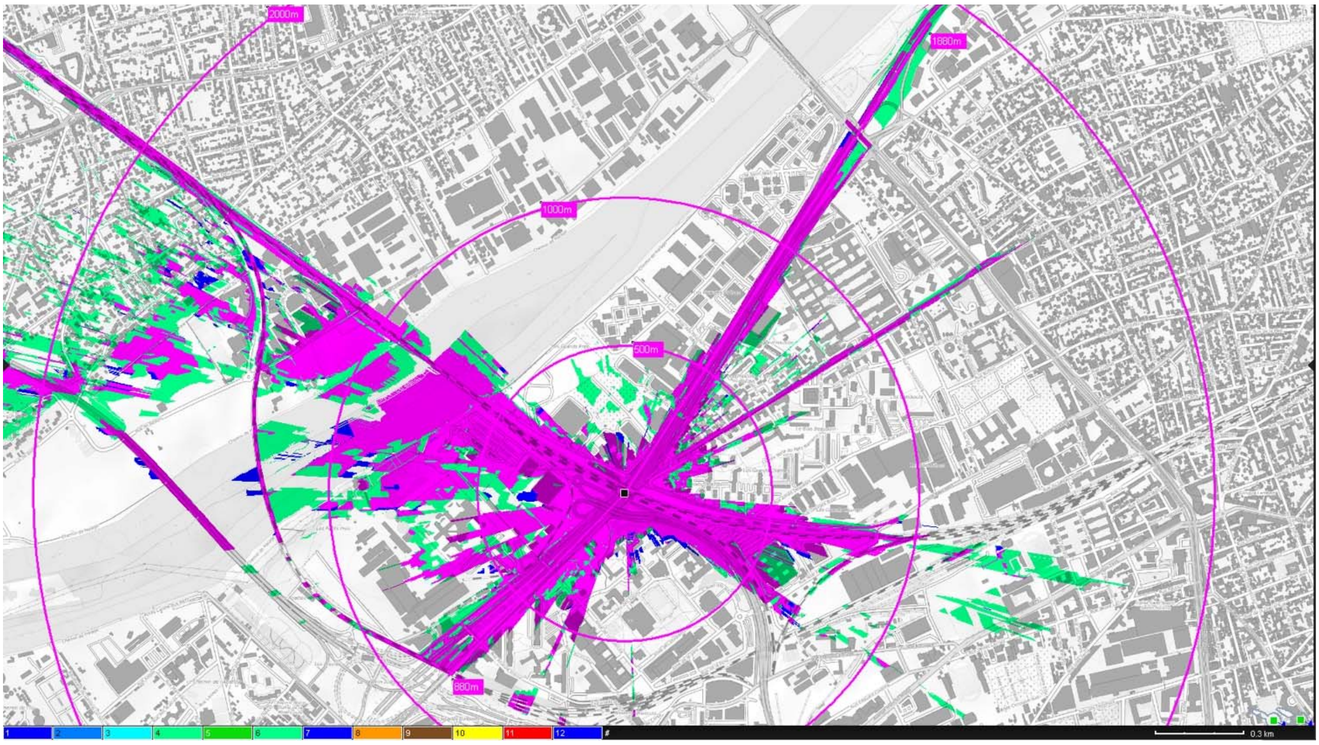


Figure A.20: Paris RER E - Common and additional Protected Zones between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS of 33 dBm EIRP and CBTC DSSS system with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

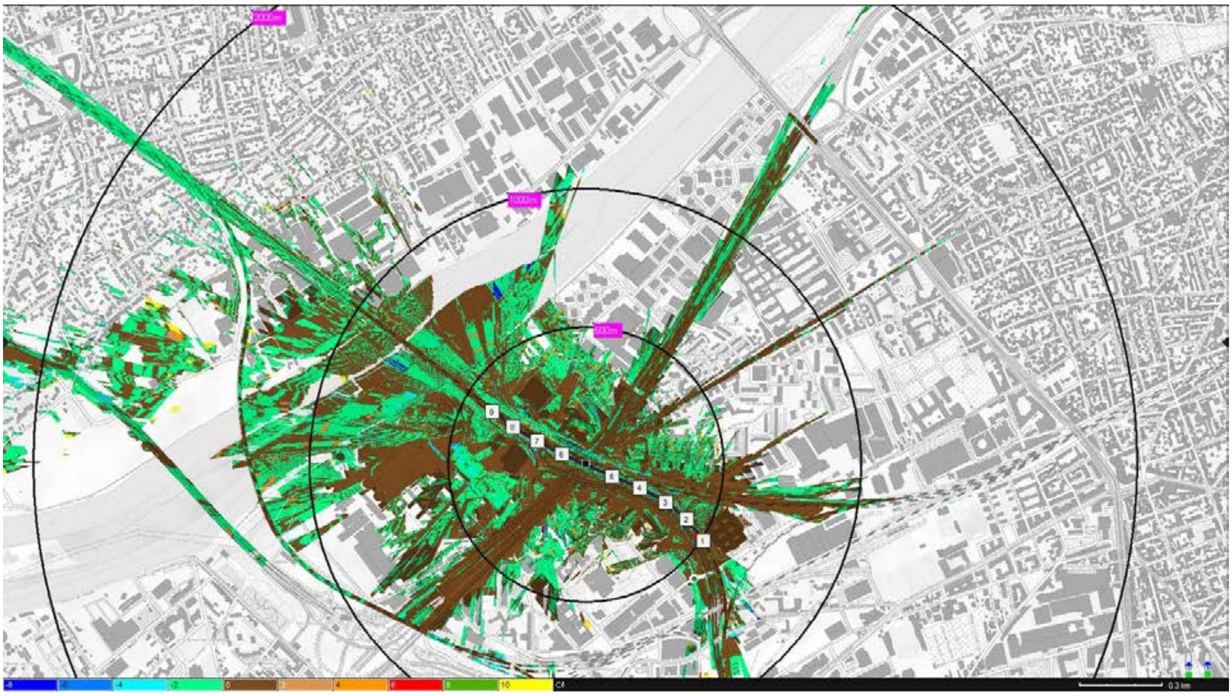


Figure A.21: Paris RER E - Difference of the received interference level in dB for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS system with 3 dB desensitization (Source: ©OpenStreetMap contributors - www.openstreetmap.org/copyright)

Annex B: CBTC communication needs when using IEEE 802.11 based communication system.

B.1 Introduction

This annex describes a typical traffic model for a CBTC system using an IEEE 802.11 [i.15] based communication system.

It does not apply for the CBTC system used with the legacy CBTC systems installed on the RATP lines, based on DSSS proprietary system and TDMA access to channel.

There are three types of throughput requirement for generic CBTC systems:

- Throughput requirement for communication with one ZC.
- Throughput requirement for communication with three ZC.
- **Throughput requirement for communication with three ZC and with PSD (worst case).**

B.2 Throughput needs for communication of a train with one ZC

Table B.1: CBTC application Uplink throughput, for communication of a train with one ZC

CBTC Application services Uplink Throughput One ZC						
CBTC Application services	**Period in ms**	**Average packet length in Bytes**	**Maximum packet length in Bytes**	**Packets /s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Location Report to one ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1 000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Total					**34 666**	**85 334**

Table B.2: CBTC application Downlink throughput, for communication of a train with one ZC

CBTC Application services Downlink Throughput One ZC						
CBTC Application services	**Period in ms**	**Average packet length**	**Maximum packet length**	**Packet/ s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC	400	500	1 400	2,50	10 000	28 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Health train status	500	50	100	2	800	1 600
Total					**17 467**	**54 933**

B.3 Throughput needs for communication for a train with three ZC

Table B.3: CBTC application Uplink throughput, for communication for a train with three ZC

CBTC Application services Uplink Throughput Three ZC						
CBTC Application services	**Period in ms**	**Average packet length in Bytes**	**Maximum packet length in Bytes**	**Packets/s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Location Report to one ZC	200	200	800	5	8 000	32 000
Location Report to a second ZC	200	200	800	5	8 000	32 000
location Report to a third ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1 000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Total					**50 666**	**149 334**

Table B.4: CBTC application Downlink throughput, for communication for a train with three ZC

CBTC Application services Downlink Throughput Three ZC						
CBTC Application services	**Period in ms**	**Average packet length**	**Maximum packet length**	**Packets/s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC 1	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 2	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 3	400	500	1 400	2,50	10 000	28 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Health train status	500	50	100	2	800	1 600
Total					**37 467**	**110 933**

B.4 Throughput needs for communication with for a train three ZC and PSD

Table B.5: CBTC application Uplink throughput, for communication for a train with three ZC and PSD

CBTC Application services Uplink Throughput Three ZC and PSD						
CBTC Application services	**Period in ms**	**Average packet length in Bytes**	**Maximum packet length in Bytes**	**Packets /s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Location Report to one ZC	200	200	800	5	8 000	32 000
Location Report to a second ZC	200	200	800	5	8 000	32 000
location Report to a third ZC	200	200	800	5	8 000	32 000
Periodic Train Functional Status message	300	500	1 000	3,3333	13 333	26 667
On demand specific status message	300	500	1 000	3,3333	13 333	26 667
Platform Screen Door monitoring and control approaching, in station and leaving station	100	50	150	10	4 000	12 000
Total					**54 666**	**161 334**

Table B.6: CBTC application Uplink throughput, for communication for a train with three ZC and PSD

CBTC Application services Downlink Throughput Three ZC and PSD						
	Period in ms	**Average packet length**	**Maximum packet length**	**Packets/s**	**Throughput in Bits/s average**	**Throughput in Bits/s max**
Movement of authority from ZC	600	200	1 000	1,6666	2 667	13 333
Information about Line from ZC 1	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 2	400	500	1 400	2,50	10 000	28 000
Information about Line from ZC 3	400	500	1 400	2,50	10 000	28 000
Platform Screen Door	100	50	200	10	4 000	16 000
Burst Traffic for Track data base update (File transfer)	100	50	150	10	4 000	12 000
Request for Heath train status	500	50	100	2	800	1 600
Total					**41 467**	**126 933**

Annex C: CBTC communication needs when using IEEE 802.11 based communication system with a 5 MHz-channel occupancy

C.1 Protocol key parameters

The evaluation is based on the IEEE 802.11 [i.15] protocol with parameters applicable in a channel of 5 MHz.

Table C.1: Timing parameters

Item	Duration	Unit
SlotTime	36	µs
SIFS	64	µs
DIFS	136	µs
AvgBackoffTime	272	µs
OFDM Symbol-duration	16	µs
ACK Frame	96	µs
RTS Frame	128	µs
CTS Frame	96	µs
Processing delay	40	µs
PHY Preamble	64	µs
PHY Header	16	µs

The Overhead introduce by the IEEE 802.11 [i.15] Mac header and Frame control check is taken into account.

For this evaluation, assumption is made that all packets exchanged between Trackside and Train CBTC applications are UDP Packets.

RTS/CTS process designed to limit the impact of Hidden nodes in infrastructure mode is not considered in this evaluation.

Table C.2: Header capacity

IEEE 802.11 [i.15] MAC HEADER	30	Bytes
FCS	4	Bytes
IP Header	20	Bytes
UDP Header	8	Bytes
Total Header IP/UDP	28	Bytes

An average back-off time of 272 µs has been considered.

C.2 Results of analysis

The evaluation has been made for three data rates:

- 1,5 Mbits/s;
- 2,25 Mbits/s; and
- 3 Mbits/s.

The evaluation is given for all the typical packets length defined in this annex.

Because the IEEE 802.11 [i.15] devices are TDD, the total throughput uplink plus downlink is considered.

Table C.3: CBTC Application services Uplink and Downlink Throughput and timing, for communication with one ZC

Throughputs and time channel occupancies	Average	Max
Uplink Throughput	34 666 Bits/s	85 334 Bits/s
Downlink Throughput	17 467 Bits/s	54 933 bits/s
Total throughput on channel	52 133 Bits/s	140 267 Bits/s
% Time channel occupancy for 1,5 Mbits/s data rate	6 %	12 %
% Time channel occupancy for 2,25 Mbits/s data rate	4,65 %	9 %
% Time channel occupancy for 3 Mbits/s data rate	4 %	6 %

Table C.4: CBTC Application services Uplink and Downlink Throughput and timing, for communication with three ZC

Throughputs and time channel occupancies	Average	Max
Uplink Throughput	50 666 bits/s	149 334 bits/s
Downlink Throughput	37 467 bit/s	110 933 bits/s
Total throughput on channel	88 133 bits/s	260 267 bits/s
% Time channel occupancy for 1,5 Mbits/s data rate	9,94 %	25,45 %
% Time channel occupancy for 2,25 Mbits/s data rate	7,65 %	17,98 %
% Time channel occupancy for 3 Mbits/s data rate	6,52 %	14,32 %

Table C.5: CBTC Application services Uplink and Downlink Throughput and timing, for communication with three ZC and one PSD

Throughputs and time channel occupancies	Average	Max
Uplink Throughput	50 666 bits/s	149 334 bits/s
Downlink Throughput	37 467 bit/s	110 933 bits/s
Total throughput on channel	88 133 bits/s	260 267 bits/s
% Time channel occupancy for 1,5 Mbits/s data rate	10,99 %	25,73 %
% Time channel occupancy for 2,25 Mbits/s data rate	8,58 %	18,26 %
% Time channel occupancy for 3 Mbits/s data rate	7,39 %	14,59 %

Annex D: Channel load as seen by a CBTC receiver

Evaluation of the channel load due to vehicles communication on the channel with 5 920 MHz as centre frequency (IEEE 802.11 [i.15] channel number 184).

The purpose of this clause is to evaluate the channel load and aggregate effect due to the 10 MHz wide transmissions from vehicles on the channel with 5 920 MHz as centre frequency (Channel number 184).

Without information available about the ITS Road application that will use the channel with 5 920 MHz as centre frequency the evaluation of the channel load and aggregate effect has been based on the Cooperative Awareness Basic Service (CAS) specified in ETSI EN 302 637-2 [i.2] Furthermore, no assumptions about sharing mechanisms have been made which means Cooperative Awareness Messages (CAMs) are basically assumed to be sent with their priority set to the maximum value and as such, these simulations represent a "worst case" analysis. The next step in the analysis is to apply appropriate priorities (also known as EDCA parameters) to the messages understanding that Urban Rail has priority in the 5 915 MHz to 5 925 MHz band.

Two cases have been considered:

- Section of RATP line 6 between station Dupleix and station Bier-Hakeim.
- Section of 2 000 m of a road parallel with two lanes with the CBTC Base Station (BS) in the centre of the section

For the first case, the results of the field-strength measurement performed during the measurement campaign (ETSI TR 103 704 [i.40]) on RATP line 6 between station Dupleix and Station Bier-Hakeim have been used.

The Road ITS standard ETSI EN 302 637-2 [i.2] on page 18 specifies that a vehicle has to transmit a Cooperative Awareness Message (CAM) in the following conditions:

- When its heading change by 4°.
- When its position change by 4 m.
- When its speed change by 0,5 m/s.
- No less than once per second.

To simplify the analysis of both cases, only the position change will be considered.

Case 1: Section of RATP line 6 between station Dupleix and Bier-Hakeim

The evaluation has been performed in three steps:

- Evaluation of the total distance at which packets issued by vehicles during the measurement campaign are received by a BS at a level above - 91 dBm/10 MHz.
- Evaluation of the number of vehicles based on the following assumptions:
  - Average vehicle length 4 m
  - Distance between two vehicles: (vehicle speed in km/h)/2 in meters
  - Vehicles are driving at constant speed.
- Evaluation of channel occupancy based on the following assumptions:
  - Data rate: 3 Mbits/s
  - CAM length (payload data): based on the document: Survey on ITS-G5 CAM statistics issued in 2018 by the Car-to-car consortium [i.42].
  - CAM generation frequency rate: vehicle speed in m/s divided by 4. Only the position change is considered.

Figure D.1 shows the results of measurements performed on line 6 for a base station located close to the Dupleix station of RATP Line 6.

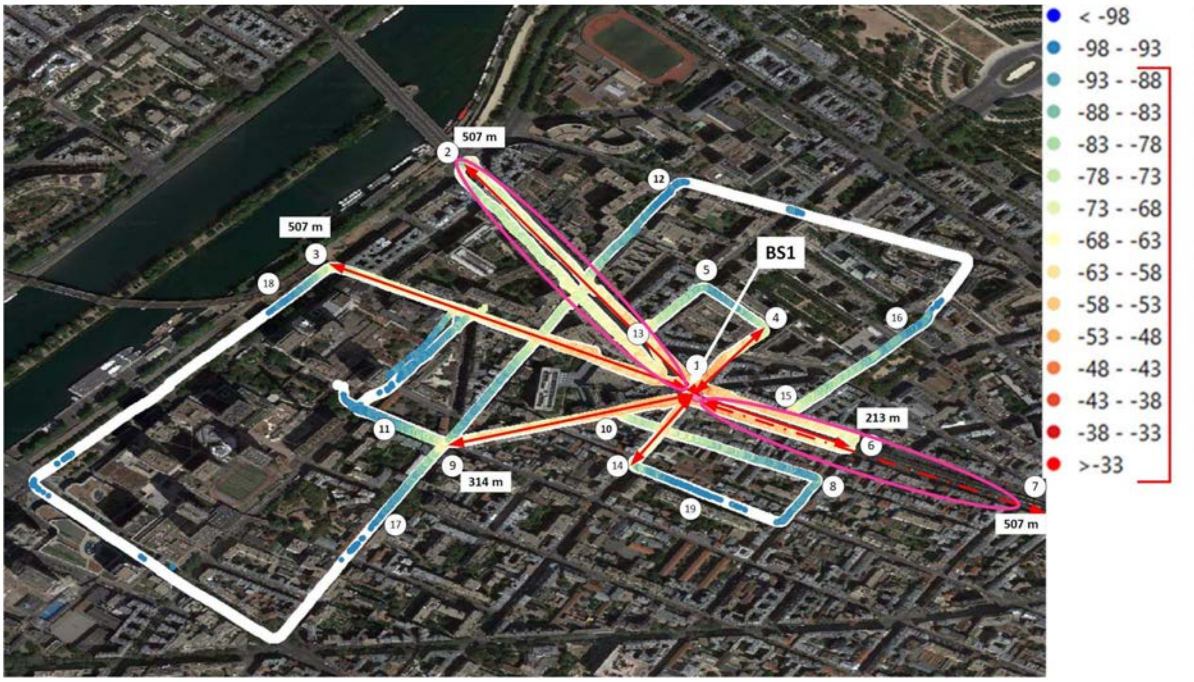


Figure D.1: Measurements on RATP line 6 by a base station close to Dupleix station (Source: ©Google Maps/Google Earth)

The level on the right axis is in dBm/10 MHz.

The received power levels greater than -93 dBm are assumed to be of interest.

The main lobe of the antennas of BS1 are pointing to location 2 and location 7 as shown by the two ellipses. Location 2 is 507 m from BS1 and in the main lobe one of its antennas. The average levels received from vehicles at this location is -79 dBm/10 MHz. It is assumed that average levels received from vehicles at location 7 that is at the same distance from the base station is similar even if no measurements have been performed. Location 7 is in the main lobe of the other BS1 antenna, and the environment is similar.

The Table D.1, the total length of all road or street segments within a given bounded region on which vehicles can be received by the CBTC base station with a level above -91 dBm/10 MHz has been estimated.

This total length can be considered as a perimeter of interference.

Table D.1 List of sections with distance

Section length in m	Length in m	Number of Roads/Lanes to be considered	Total in m
S1-2	507	2	1014
S1-3	507	1	507
S1-4	145	1	145
S1-7	507	2	1014
S1_9	314	1	314
S3-18	60	1	60
S8-10	276	1	276
S5-13	113	1	113
S9-11	75	1	75
S9-12	524	1	524
S9-17	98	1	98
S15-16	160	1	160
S14-19	40	1	40
Total			4340

The total distance of streets and roads over which vehicles present can be received by the base station is 4 340 m. The number of vehicles present will depend on their average speed and their average length.

Assuming an average vehicle length of 4 m and the distance in meters between vehicles approximated by dividing the average speed of the vehicles by 2, the following number of vehicles is obtained over a distance of 4 340 m:

- At an average speed of 20 km/h: 4 340/ (4+10)= 310 vehicles
- At an average speed of 30 km/h: 4 340/ (4+15)= 228 vehicles

The vehicle speed limit in the area around RATP line 6 between Dupleix station and Bir-Hakeim station is 30 km/h.

To simplify the evaluation of the total number of Road ITS packets transmitted per second, only the change of position will be considered: CAM transmitted every 4 m of position change. This gives per average vehicle speed following number of CAMs per second:

- For an average vehicle speed of 20 km/h (5,56 m/s): 1,39 CAMs/second
- For an average vehicle speed of 30 km/h: (8,333 m/s) 2,08 CAMs/second

Based on this evaluation, it is possible to compute the total number of CAMs per second transmitted by all the vehicles this gives per average vehicles speed:

- For an average vehicle speed of 20 km/h: 431 CAMs/Second
- For an average vehicle speed of 30 km/h: 476 CAMs/Second

All these messages will be received by the base station. To evaluate the channel load, it is necessary to consider the average length of CAM, and its distribution.

The Car 2 Car consortium has released a report "Survey on ITS-G5 CAM statistics" [i.42] in December 2018. This report presents the results of analysis of ITS-G5 message traces collected in real test-drives in Europe in 2018.

In the clause 2.1 of the report it is stated that:

"The size of the CAM message is not static. The CAM size depends on the presence of different containers which are only present when needed, as well as on the security content like signatures and certificates. As a result, the CAM size can vary between around 200 Bytes and up to 800 Bytes depending on the message content".

It means that to evaluate the maximum channel load a CAM length of 800 bytes can be considered.

In clause 1.2 executive summary of the document [i.42], the table 1-1 of the document [i.42] lists CAM statistics key observations. Two observations are useful to evaluate channel load:

- Average CAM size (observation #5): 350 bytes
- Approximate CAM size distributions observed (observation #6):
  - Distribution starts around 190 Bytes.
  - Typically, 30 % of the messages are below 300 Bytes.
  - Typically, more than 50 % of the messages are above 350 Bytes.
  - Typically, more than 30 % of the messages are above 450 Bytes.

Based on the approximate CAM size distribution observed, the following CAM size distribution is considered to evaluate the average channel load "seen" by BS1.

Table D.2: CAM size distribution considered

Message length	Percentage	Transmission duration in ms for 3 Mbits/s	Comments
190	10	0,64	
250	10	0,72	
300	10	0,84	30 % of message lengths are below or equal to 300 bytes
350	20	0,98	50 % of messages are below or above 350 bytes
450	20	1,24	30 % of message lengths are above 450 Bytes
500	10	1,38	
550	10	1,51	
800	10	2,18	
Total	100		

To compute the transmission duration of a packet, the transfer rate of 3 Mbits/s is considered.

Based on the distribution the channel occupancy can be estimated for each vehicle average speed:

- Average vehicle speed of 20 km/h: 503,6 ms meaning 50 %
- Average vehicle speed of 30 km/h: 556 ms meaning 56 %

It is important to note that the channel occupancy is higher at 30 km/h even if there are less vehicles. The reason is the increase of the number of messages per second per vehicle.

The 56 % channel load for vehicles driving is probably under-estimated, because a vehicle that change direction will send temporarily more packets per second: one extra packet every 4° heading change. It is difficult to estimate the number of vehicles in the situation to change direction. It is reasonable to assume that 60 % of channel load is closer to reality.

If 100 % of the message lengths are above 450 bytes, the channel occupancy reaches 65 % but in theory the Decentralized Congestion Control mechanism (DCC) will limit the channel load at 62 %.

This is valid only if all the vehicles can listen each other to allow optimal operation of the listen before talk mechanism, this will not be the case for all the vehicles. A part of the vehicles will not be able to "hear" each other, and BS1 will receive packets from different group of vehicles in which DCC operates correctly and limits the channel occupancy at 62 %.

If all the messages transmitted have the maximum length of 800 bytes, the channel load reaches 62 % (DCC limit) with 137 vehicles driving at 30 km/h.

It is reasonable to assume that the base station will "see" at least one group of vehicles with a 62 % channel load and a second group of vehicles that has DCC limitation active. In this case the total channel load "seen" by the base station will be higher than 62 %.

The statistical analysis of the measurements captured during the measurement campaign on RATP line 6 between station Dupleix and Bir-Hakeim shows that 46 % of the level received from the vehicles by the base station are above -65 dBm/10 MHz. It is reasonable to assume that 46 % the vehicles on the perimeter will be in a location where their packets will be received by the base station antenna with a level above -65 dBm/10 MHz.

A CBTC radio transceiver (Access point or onboard unit) based on the IEEE 802.11 [i.15] technology operating on channel with 5 MHz bandwidth can consider the channel as busy if it detects a transmission with a level above -68 dBm/5 MHz (default value for EDCA). In this case, it will delay the transmission of its packet. Without mitigation, the transmission of CBTC packets will experience important transmission delay without guarantee that the transmission will be a success.

For CBTC systems based on the DSSS PHY, CBTC packets are sent in assigned time slots, and the success of any reception depends on the Signal to Noise plus Interference Ratio (SINR).

A CBTC radio transceiver based on IEEE802 technology will not consider the channel as busy if the received level is below -68 dBm/5 MHz (default value for EDCA). In this case success of reception by a CBTC base station or a Train Onboard unit will depend on the Signal to noise plus interference level ratio.

A Road ITS radio transceiver based on the IEEE 802.11p [i.15] technology (ITSG5) can also detect transmission of the CBTC packets at the condition that the received level of this one is above -65 dBm/10 MHz meaning -62 dBm/5 MHz.

Some Road ITS radio transceivers will be able to detect the RF energy when a CBTC base station or a Train onboard unit transmit a packet and delay their transmissions but not all because they are connected to an omnidirectional antenna. The sensitivity of the Road ITS system in a vehicle (Road ITS transceivers plus antenna) is lower than the sensitivity of the Base station.

The estimated channel load on the section of RATP line 6 between Dupleix and Bir-Hakeim station is too high to guarantee a reliable CBTC operation.

Case 2: Section of 2 000 m of a road parallel with two lanes with the CBTC base station in the centre of the section

For this second case, the evaluation of channel load versus average speed of vehicle is performed.

The measurements performed on RATP line 8 as shown that packets transmitted by vehicles can be received over a distance above 1 000 m by a CBTC antenna. The evaluation will be made for a distance of 1 000 m from a CBTC base station antenna. Because a CBTC base station has two antennas with main lobes pointing in opposite directions, a section of 2 000 m of parallel road is considered.

The section of 2 000 m of road is divided in two sub-sections of 1 000 m. The CBTC base station antenna is in the middle of the section with one antenna pointing to the right and another antenna pointing to the left as shown on Figure D.2.

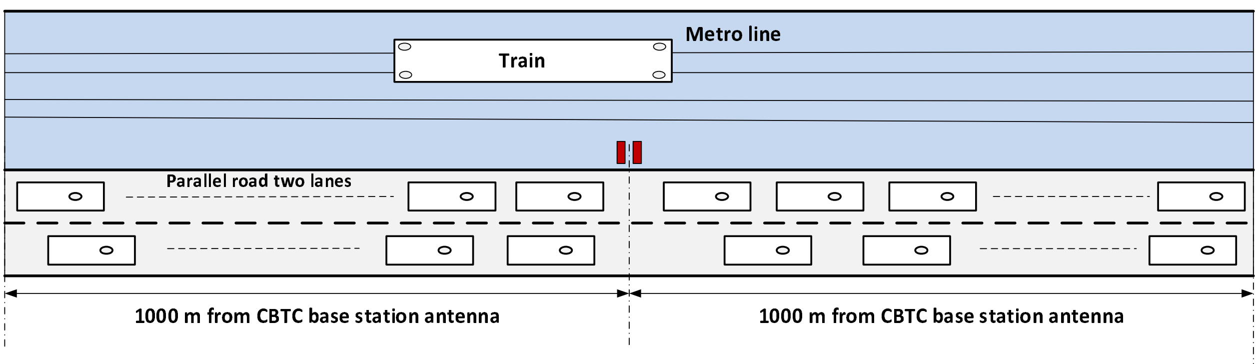


Figure D.2: Parallel Road with two lanes

The evaluation is made assuming vehicles driving at constant speed. Only the messages generated due to the change of vehicle position is considered.

The CAM size distribution defined in Table D.2 is considered.

The considered average length of vehicle is 4 m and the distance between vehicles is the vehicle speed in km/h/2 in meters as for the previous analysis.

Figure D.3 shows the number of vehicles present in a section of 2 000 m of a parallel road and the number of packets received from these ones versus vehicle speed.

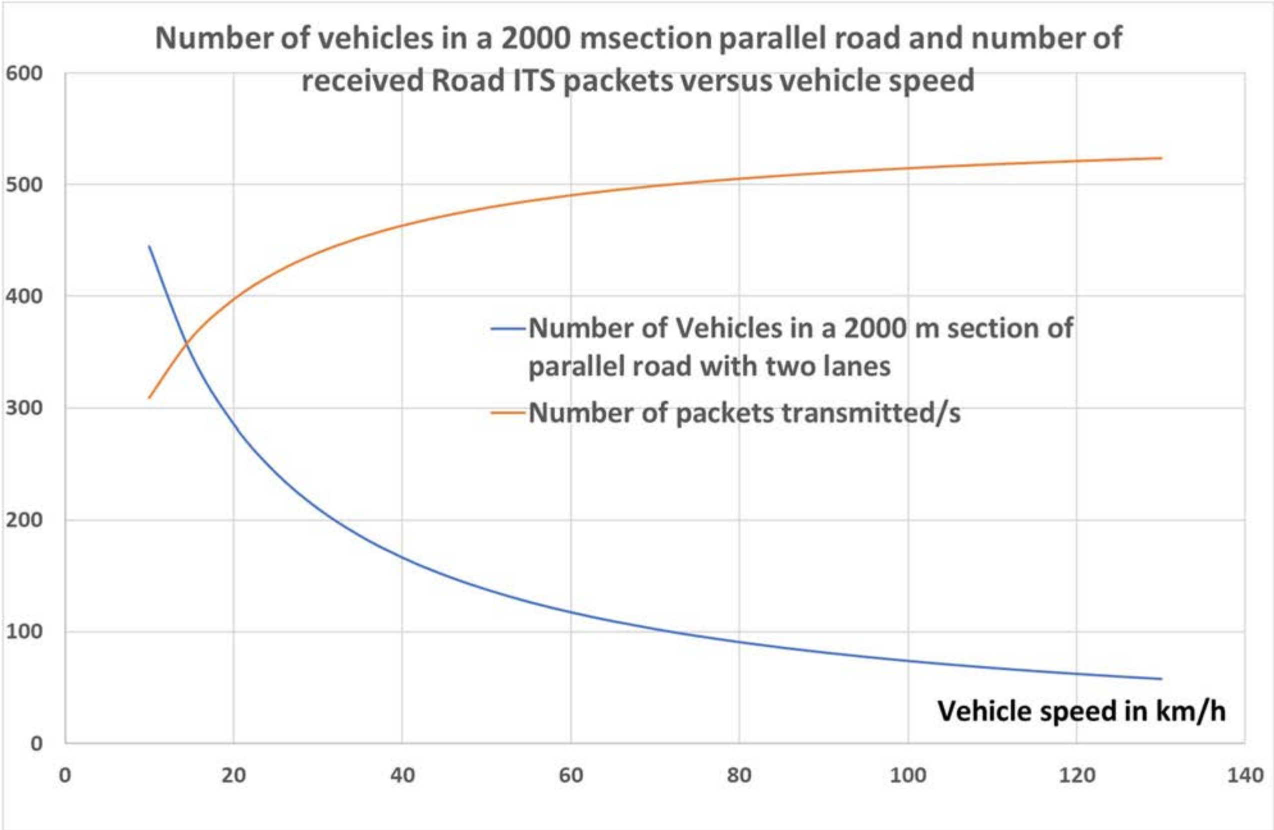


Figure D.3: Number of vehicles and number of received packets in a section of 2 000 m versus vehicle speed

It can be observed that the maximum number of ITS road packets received by a CBTC base station occurs when vehicles are driving at high speed.

Even if the number of vehicles present is less than 100 in the section of 2 000 m, when vehicles are driving at 100 km/h, the number of received packets is above 500 per second. This is due to the fact that the number of packets transmitted per second and per vehicle increases significantly.

Figure D.4 shows the channel load in % versus the number of vehicles and their speed.

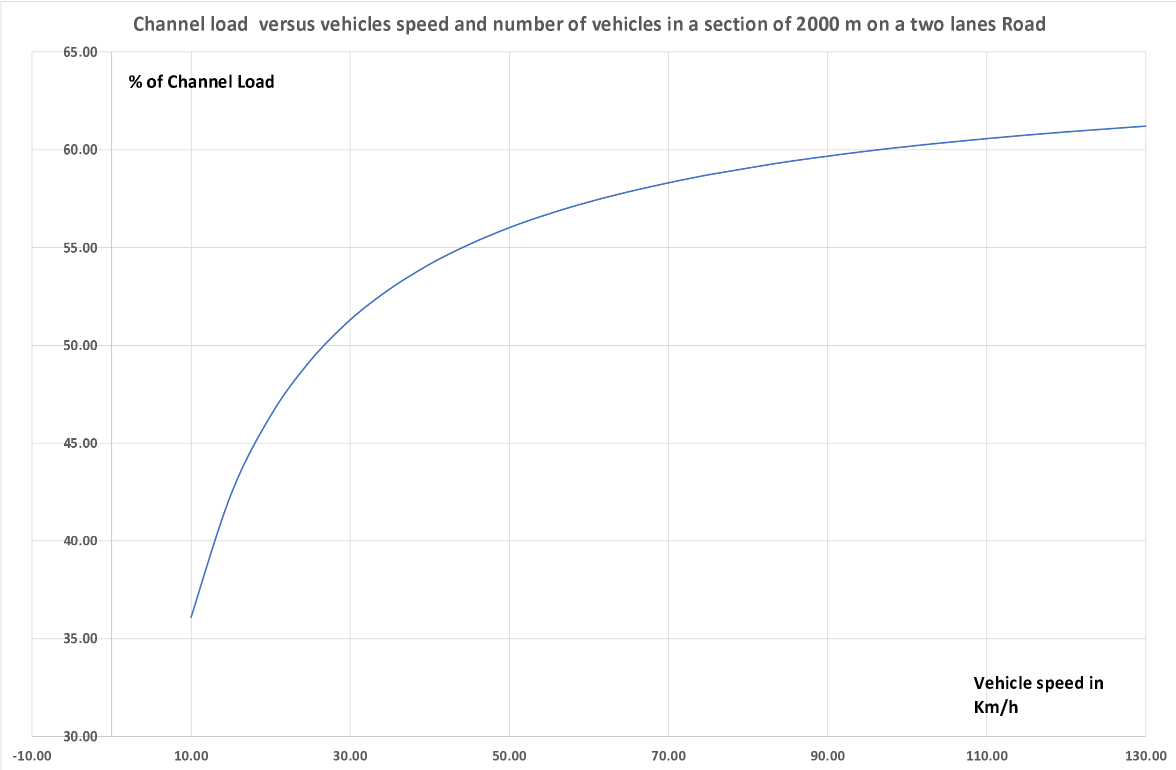


Figure D.4: Channel load versus number of vehicles and their speed

It can be observed that a channel load of 50 % is exceeded at 30 km/h. For vehicle driving at 100 km/h the channel load is 60 % and close to 62 % at 130 km/h.

This simple analysis does not take into account the CAM generated by vehicles that accelerate: one extra message every 0,5 m/s (or 1,8 km/h) increase in speed.

Figure D.5 shows the channel occupancy in % versus number of vehicles and their speed for all the packets with a length equal or above 450 bytes and the following distribution:

- 450 bytes: 40 %
- 500 bytes: 20 %
- 550 bytes: 20 %
- 800 bytes: 20 %

Note that this distribution is not following the results obtained in the Car 2 Car consortium report "Survey on ITS-G5 CAM statistics" [i.42]. It can be considered as an absolute maximum.

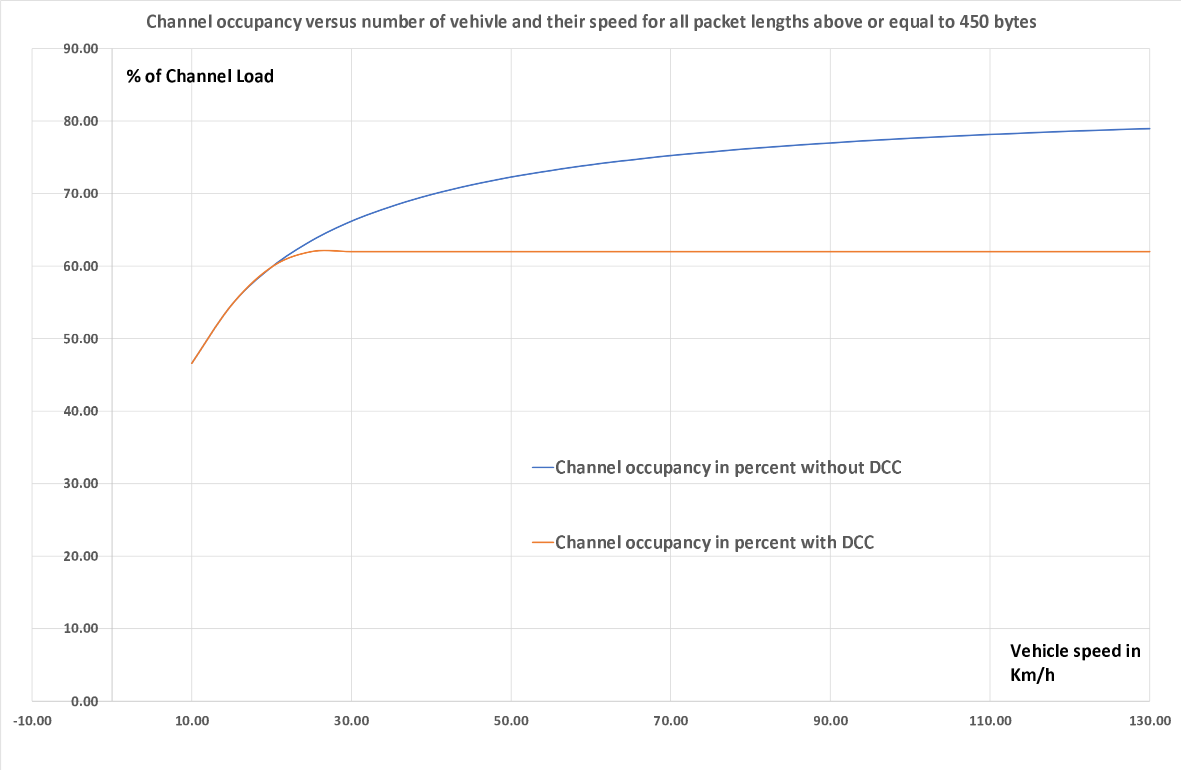


Figure D.5: Channel load versus number of vehicles and their speed for packet length above or equal to 450 bytes

There are two curves. The blue one is the channel load without DCC and the orange one with DCC.

It can be observed that the DCC mechanism will start to limit channel load at 20 km/h. This is valid only for the vehicles that can listen each-other. This will not probably be the case over the distance of 2 000 m but by group of vehicles spread over a shorter distance (500 m). It means that the CBTC antennas will "see" two or three groups of vehicles with a channel load limited locally at 62 %.

Conclusion based on this analysis of two typical cases.

The results of the measurement campaign show that a Base station antenna and a Train can receive packets from vehicles over a long distance.

A first analysis based on measurements performed on RATP Line 6 between Dupleix and Bir-Hackeim stations shows that the transmission of vehicles can be received by a CBTC base station over a perimeter of interference that has a total length of 4 340 m around the RATP line 6.

The number of vehicles on this perimeter depends on the speed. For 20 km/h, 310 vehicles and 228 vehicles can be received for 30 km/h. The channel load is higher at 30 km/h than at 20 km/h even if the number of vehicles is lower. The reason is the increase of CAM generation rate by the vehicle.

A second analysis has evaluated the channel load on a section 2 000 m of parallel road to a metro line. The result of this analysis shows that the channel load is also higher when the speed of vehicles increases even if the number of vehicles is reduced in the section.

The channel load can reach very quickly 62 % and even more. A CBTC antenna can "see" easily two groups or more of vehicles in which the channel load is limited at 62 % by the DCC mechanism if all the vehicle transceivers are based on the ITSG5 protocol stack.

Without any mitigations the CBTC transmissions will be strongly impacted in term of delay and packet failure rate and cannot be considered as reliable.

Annex E: Summary of the Beaconing for the protection of CEN DSRC

Typical CEN DSRC stations operate in the band 5 795 MHz to 5 815 MHz. CEN DSRC RSUs are generally installed in tolling stations and CEN DSRC OBUs in the subscribing vehicles. OBUs are active only when they are located in close vicinity of an RSU.

Studies have shown that there is a potential for harmful interference from ITS-Ss. ITS-Ss can cause blocking at the receiver in a CEN DSRC RSU and/or interference at the receiver in a CEN DSRC RSU or OBU.

To avoided harmful interference, protection mechanisms have been set-up and specified in ETSI TS 102 792 [i.1], in order to avoid harmful interference originated from Road ITS-Ss (OBUs) to CEN DSRC RSU and OBU tolling stations while maintaining an acceptable level of performance of ITS communications.

The procedure defined in ETSI TS 102 792 [i.1] introduces two operational modes for ITS-S:

- **Normal mode:**
  - where transmit duty cycle is not limited;
  - output power level is limited to the legal values;
  - unwanted emissions in the band 5 795 MHz to 5 815 MHz are limited to -30 dBm/MHz.
- **Coexistence mode:**
  - where transmit duty cycle is limited; and/or
  - output power level and unwanted TX emissions are reduced.

Both modes are fully specified in ETSI TS 102 792 [i.1].

In case the Road ITS-S does not fulfil the coexistence mode emission requirements everywhere, the Road ITS-S needs to determine whether it is inside a CEN DSRC Protected Zone (PZ) at any time and apply the coexistence mode restrictions as specified in case it is inside a PZ.

Protected Zones are stored in a European geolocation database. The use of this geolocation database is complemented by beacons, because vehicles are currently not required to update their database. Beacons are implemented through CAM messages providing all required information of the presence of a PZ.

Figure E.1 shows the basic structure of a CAM message according to ETSI EN 302 637-2 [i.2].

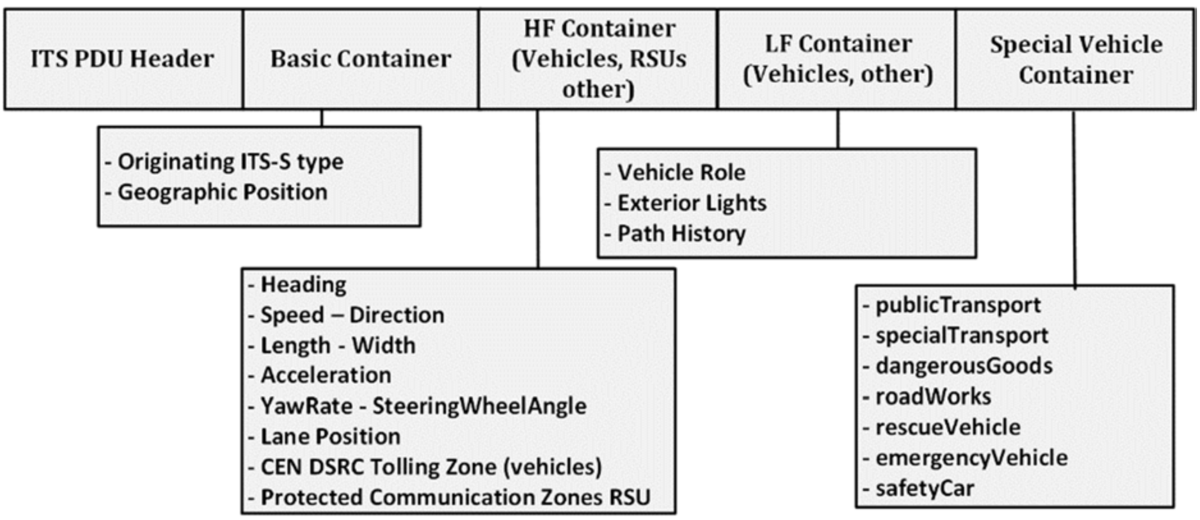


Figure E.1: Basic structure of a CAM message

The Protected Communication Zones RSU field, appearing in the High Frequency Container of an RSU CAM is constructed as follows and specified in the CAM specification ETSI EN 302 637-2 [i.2].

Table E.1: Structure of the CAM with Protected Zone elements

Date element/data frame	Data type (No. in CDD i.3)
CAM	
header	ItsPduHeader (114)
cam	CoopAwareness
generationDeltaTime	GenerationDeltaTime
camParameters	CamParameters
basicContainer	BasicContainer
highFrequencyContainer	HighFrequencyContainer
rsuContainerHighFrequency	RSUContainerHighFrequency
protectedCommunicationZonesRSU	ProtectedCommunicationZonesRSU (122)
ProtectedCommunicationZone	ProtectedCommunicationZone (121)
protectedZoneType	ProtectedZoneType (58)
expiryTime	TimestampIts (82)
protectedZoneLatitude	Latitude (41)
protectedZoneLongitude	Longitude (44)
protectedZoneRadius	ProtectedZoneRadius (57)
protectedZoneID	ProtectedZoneID (56)
NOTE: The numbers in the table resemble the elements as defined in the Common Data Dictionary (CDD) for Road ITS in ETSI TS 102 894-2 [i.3].	

In this field up to 16 different zones can be defined and transmitted to a Road ITS station. The information is saved in a vehicle's internal dynamic data store of protected locations, similar to the Local Dynamic Map. Once it has been received and stored, the data is kept until new protected zone data is received or the vehicle is turned off.

The following definitions apply for the parameters listed above. The Latitude and Longitude parameters define the centre of the zone to protect, e.g. the DSRC RSU location. These parameters can be found in the common data dictionary ETSI TS 102 894-2 [i.3]. The actual definitions are given in Annex A of ETSI TS 102 894-2 [i.3]:

- `ProtectedZoneType::= ENUMERATED { permanentCenDsrcTolling (0), ..., temporaryCenDsrcTolling (1) }`
- `TimestampIts ::= INTEGER {utcStartOf2004(0), oneMillisecAfterUTCStartOf2004(1)} (0..4398046511103)`
- `Latitude ::= INTEGER {oneMicrodegreeNorth (10), oneMicrodegreeSouth (-10), unavailable(900000001) } (-900000000..900000001)`
- `Longitude ::= INTEGER {oneMicrodegreeEast (10), oneMicrodegreeWest (-10), unavailable(1800000001) } (-1800000000..1800000001)`
- `ProtectedZoneRadius ::= INTEGER {oneMeter(1)} (1..255,...)`
- `ProtectedZoneID ::= INTEGER (0..134217727)`

So far, only two types of protected zones are defined for the protection of stationary and mobile tolling stations (see Annex A of ETSI TS 102 894-2 [i.3]).

Annex F: Database for the protection of CEN DSRC

This clause describes a read-only Urban Rail Database solution based on the existing road tolling CEN DSRC protection database mechanism as specified in ETSI TS 102 792 i.1.

For the protection of Tolling zones, the European Association of Operators of Toll Road Infrastructure (ASECAP) maintains a European Protected Zone Database for all CEN DSRC locations in Europe. To ensure that CEN-DSRC tolling stations are protected against harmful interference by Road ITS-Ss, toll chargers and road operators have the opportunity to provide their protected zone data to ASECAP for inclusion into the Tolling Protected Zone Database. The format and mandatory elements in which the information needs to be provided are given in Table F.1 and in Table F.2.

Only permanent tolling installations being included in the database. Temporary toll stations and tolling enforcement vehicles are not included and make use of the beaconing method instead. Road ITS equipment manufacturers such as vehicle OEMs and their suppliers can download the database from https://www.asecap-pzdb.com upon registration. The database download is provided in signed XML format as shown in Table F.2, following the data element definitions of Table F.1.

Table F.1: Data format of the ASECAP Protected Zone Database

Data element name	Data type	M/O (see note)	Description
zones	Object	M	Container of multiple protected zones
zone	Object	M	Container for the attributes of a single protected zone
id	Integer	M	Unique identifier
latitude	Double	M	Latitude of WGS84 coordinates of the protected zone centre position in decimal degrees. Positive values: east of Greenwich, negative values: west of Greenwich
longitude	Double	M	Longitude of WGS84 coordinates of the protected zone centre position in decimal degrees. Positive values: northern hemisphere, negative values: southern hemisphere
ITS	Integer	M	Protection radius [m] applicable to Intelligent Transport Systems (ITS)
N.N.	Integer	O	Protection radius [m] applicable to further applications
start_date	DateTime	O	Start time of the validity period of the zone. If start_date is omitted or empty, the zone is considered valid for a time period infinite in the past. Start_date is given in UTC time in the format "YYYY-MM-DD hh:mm:ss"
expiry_date	DateTime	O	End time of the validity period of the zone. If end_date is omitted or empty, the zone is considered valid for a time period infinite in the future. Expiry_date is given in UTC time in the format "YYYY-MM-DD hh:mm:ss"
protected_zone_type	Integer	O	Type of tolling, corresponding to "protectedZoneType" in ETSI TS 102 894-2 [i.3]. If no type is provided, the default of type "0" for permanent DSRC tolling applies
country	String	M	Country of the protected zone center location
country_code	Integer	M	ISO 3166-1 [i.29] numeric country code
NOTE: M/O: Mandatory/Optional			

Table F.2: Example entry of the ASECAP Protected Zone Database

Example
<?xml version="1.0"?> <zones> <zone> <id>4783</id> <latitude>48.161377</latitude> <longitude>16.012884</longitude> <ITS>68</ITS> <start_date>2018-01-01 00:00:00</start_date> <expiry_date></expiry_date> <country>Austria</country> <country_code>40</country_code> </zone> … </zones>

Vehicles are obligated to implement the database in their vehicles based on the following principle, see also ETSI TS 102 792 [i.1]:

- Authorities keep the database up to date and the vehicle industry integrates the latest version of the database at the moment of production.
- No lifecycle updates are supported, so no new PZ will be supported after sales of the vehicle.
- Additionally, vehicles and other Road ITS-S should implement mitigation based on the reception of mitigation CAM's.

Annex G: Methods of identification studied

G.1 Facility Layer sharing zone identification techniques

G.1.1 Overview

In this clause Facility Layer techniques for the detection of the zone to be protected will be presented. These techniques will allow the identification of Protected Zones (PZ) either statically or dynamically.

G.1.2 ITS beaconing for the protection of Urban Rail

G.1.2.1 General consideration

Beaconing for the protection of Urban Rail would consist of specific signals used by Road ITS devices to detect that they are in an area where the Urban Rail ITS needs to be protected. These signals called "CBTC alert Beacons" would be specific Road ITS messages, transmitted only when and where required. A beacon solution based on the Road ITS CAM announcing Urban Rail zones to be protected is described here, as an extension of the solution that is specified to protect the CEN DSRC tolling zones from harmful interference by ITS-Ss in ETSI TS 102 792 [i.1].

G.1.2.2 Introduction

This clause describes an Urban Rail beaconing solution based on an adaptation of the road tolling CEN DSRC protection mechanisms as specified in ETSI TS 102 792 [i.1]. The main goal is to tailor the protection mechanism to a minimum set of protection rules satisfying the minimum Urban Rail system interference requirements. This solution relies on the Facilities layer and is independent on what communication technology is used.

For the definition of the characteristics of a beacon for the facilitation of the Urban Rail protection, different requirements have to be fulfilled and therefore the following needs to be considered:

- **Frequency band requirement:**
  - The protection should only cover the operational band of the Urban Rail system in order to reduce the impact on Road ITS.
- **Time requirements:**
  - Beacons would only be transmitted when an Urban Rail communication in a PZ is expected. It should be expected that only when an Urban Rail train enters a critical area where interference with Road ITS communication could occur, a warning beacon should be transmitted. The beacon should be active for as long as the train is in the potential interfered area. For example, in case of a straight 1 km track line with a continuous train speed of 80 km/h (22 m/s) the beacon would be active for at least 45 s.
- **Communication Protected Zone (PZ) requirements:**
  - Urban Rail should not be impacted by Road ITS transmissions, so areas where communication interference could happen should be identified. In these Protected Zones (PZs), Urban Rail systems should be protected. The size of a PZ depends on the physical area where Urban Rail and Road ITS stations (ITS-Ss) could suffer from interference. For example, operation in tunnels or areas where no relevant road traffic occurs do not need any specific protection. PZs should be identified during the Urban Rail and Road network design process in such a way that only at identified positions beacons will be required. Clause 8.3.2 of ETSI TR 103 704 [i.40] however demonstrates that beacons deployed on Urban Rail infrastructure only are unlikely to adequately cover the whole extent of a PZ, and deployments on the surrounding areas would be required. In Road ITS these PZs are also called Communication Relevance Areas (CRAs).

- **Range requirements:**
    - The range a beacon should be receivable should be sufficiently large to ensure that ITS-Ss are able decode the information in order to comply to the required mitigation procedure when they enter the PZ.
- **Repetition requirements:**
    - It needs to be ensured that a beacon can be received by an ITS-S in time before it enters a PZ in which it could interfere with the Urban Rail system. As ITS-Ss can move in and out of the PZ or can be switched on within the PZ, beacons need to be transmitted with a sufficient minimum frequency to ensure a low probability of ITS-Ss not being aware of the presence of a PZ. In the PZ of any Urban Rail station the interference probability should be less than 1 % of all transmitted messages, and the interference event should not last longer than 100 ms.
- **Transmission Layer requirements:**
    - Since the beacon has to be received by all ITS-Ss, it needs to be sent via the relevant Road ITS Transport layer(s). This implies that mitigation CAM messages are sent on the defined Road ITS 5,9 GHz ITS safety channel where CAMs are shared.

In the following clauses the possible identification and sharing mechanisms are explained.

G.1.2.3 Urban Rail ITS beacon transmission

An Urban Rail beaconing solution could adapt the CEN DSRC protection mechanisms in one of the following ways:

- The Urban Rail ITS beacon is based on the CAM message specification, extended with new type of PZ as described in clause G.1.2.4. These CAM PZ messages are sent on the Control Channel (CCH).
- The Urban Rail ITS beacon could also be specified as new Protected Zone Message (PZM) service. This could use the same structure as the CAM message. This would be sent on Urban Rail ITS channels that need to be protected.

These two methods are compared in Table G.1.

Table G.1: Comparison between the two possible adaptions of CAM specification to create CBTC alert beacons messages

	Method 1: CAM messages with new PZ types Messages sent on the Road ITS control channel	Method 2: new messages with same structure Messages sent on the channel to be protected	Comparison for each criteria
Multi-technology coexistence and multichannel operation	Fails if a Road ITS station is not tuned to CCH or does not have any connections between operations in CCH an in the Urban Rail priority channel	If the same hardware is used to operate in both CCH and Urban Rail priority channel, Road ITS stations need to listen to the corresponding channel for enough time to ensure reception of an alert beacon message before being allowed to transmit on that channel (balance needs to be found between alert beacon message transmission rate, and delay before transmission)	More studies need to be done in parallel with MCO definition

	Method 1: CAM messages with new PZ types Messages sent on the Road ITS control channel	Method 2: new messages with same structure Messages sent on the channel to be protected	Comparison for each criteria
Number of CBTC alert beacon messages to be sent	The same beacon message, sent on the Road ITS radio technologies used for the control channel in the area, can inform about Protected Zones of different channels. However, alert beacons may need to implement several Road ITS radio technologies.	Need a CBTC alert beacon message on every channel to be protected (that is 5915 MHz to 5925 MHz), using the Road ITS radio technologies used in these channels. PZ beacons in the Urban Rail channel may need to implement several Road ITS radio technologies	No preference
Indication of the channel to be protected	The definition of the PZ type should include the channel(s) to be protected	No need to have different PZ type for different channels to be protected: the receiver should protect the channel on which the beacon is received	Method 2 is preferred
Impact on ITS stations placed on the market before the standard for Urban Rail protection is applicable	An ITS-S should not be allowed to use the channel s in band 5 915 MHz to 5 925 MHz if it does not implement the extension of the CAM standard regarding the new PZ type for Urban Rail protection	An ITS-S should not be allowed to use the channel s in band 5 915 MHz to 5 925 MHz if it does not implement the standard regarding the new PZ type for Urban Rail protection	No preference

Based on that comparison, further studies need to be done to define the final method.

The Protected Zone CAM messages or PZM could be transmitted by an RSU Road ITS-S at appropriate locations surrounding the Urban Rail tracks. In that case the RSU sends protected zone CAM messages to all present Road ITS-Ss in and in the vicinity of the PZ.

In case the Protected Zone CAMs or PZM are transmitted by RSU ITS-S, depending on the size and shape of the identified message broadcast area, the ITS stations should be installed and configured so that relevant ITS-S can receive the Protected Zone messages. RSU ITS-Ss could send Protected Zone message only when a train is approaching, is present in active state or is leaving the PZ. RSU ITS-S should minimize the message transmit rate so that reception is highly likely.

G.1.2.4 Urban Rail ITS beacon message format

Identification of the Urban Rail ITS PZ using CAM messages could be based on ETSI TS 102 792 [i.1] and an extension of the CDD standard ETSI TS 102 894-2 [i.3].

NOTE 1: Other ITS specifications might be impacted and therefore further studies are needed.

To support beaconing for Urban Rail ITS systems the following is proposed:

- Adaptation of the PZ shape to the Urban Rail geometry. The protected zone could be defined as (see ETSI EN 302 931 [i.22]):
  - a circle defined by its centre location and protection radius;
  - an ellipse defined by the length of the long semi-axis; the length of the short semi-axis; the azimuth angle of the long semi-axis; or
  - a rectangle along the track, defined by the distance between the centre point and the short side of the rectangle; the distance between the centre point and the long side of the rectangle; the azimuth angle of the short side of the rectangle.

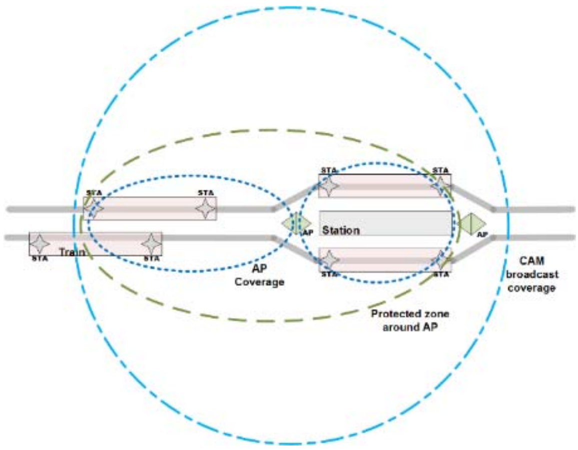


Figure G.1: Protected Zone represented as an ellipse

- Specification of new Protected Zone Types (e.g. type 2, type 3) to define the Urban Rail Protected Zone. The different type could cover different sharing and mitigation mechanisms to be applied (including the channel(s) in which the mitigation needs to be applied).
- Introduction of a field identifying the source of the provided information in order to check the validity of the certificate.
- In addition, there is also a need to define priority between the different types of mitigation for an ITS-S which could be in two or more different zones of different type, as explained below in the example shown in Figure G.2.

EXAMPLE: Assuming the following considerations:

- the PZ type 3 corresponds to an area in which any ITS station transmitting more than 10 dBm EIRP has a risk of collision with an Urban Rail station transmission;
- the PZ type 4 corresponds to an area in which any ITS station transmitting more than 20 dBm EIRP has a risk of collision with an Urban Rail station transmission;
- the PZ type 5 corresponds to an area in which any ITS station transmitting between 20 dBm EIRP and 33 dBm EIRP has a risk of collision with an Urban Rail station transmission.

The mitigation to be applied in the PZ type 3 should be to stop transmitting in the Urban Rail band. The mitigation to be applied outside of PZ3 but inside PZ4 should be to transmit with maximum 10 dBm. The mitigation to be applied outside of PZ4 but inside PZ5 should be to transmit with maximum 20 dBm. Outside of PZ5, no mitigation has to be applied.

A vehicle within PZ type 3 will be also in PZ type 4 and type 5, but it should apply the mitigation technique of PZ type 3.

A vehicle outside of PZ type 3 but inside PZ type 4 will also be in the PZ type 5 but should apply the mitigation technique of PZ4.

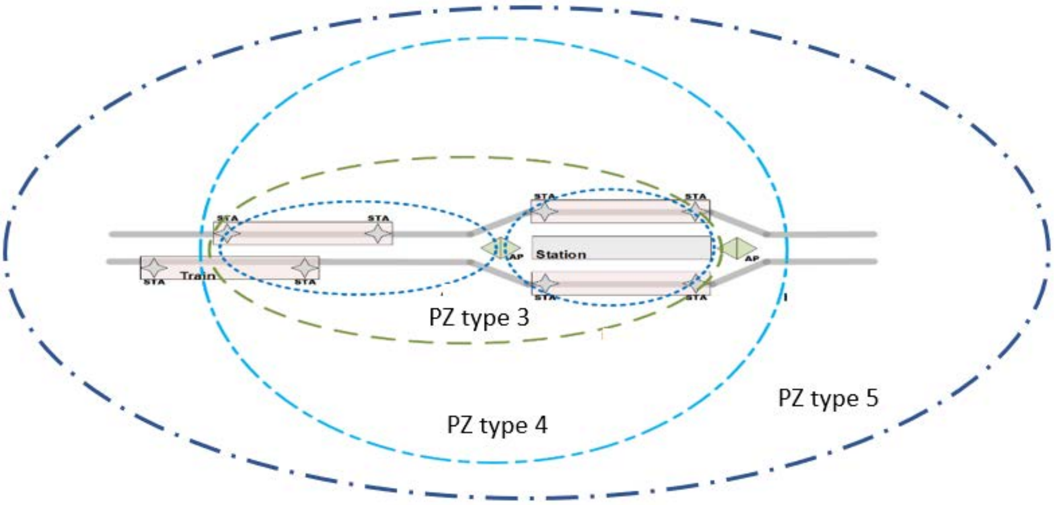


Figure G.2: Concentric Protected Zones

Implementation of this solution would require a new standard for Urban Rail protection, based on ETSI TS 102 792 i.1, which would have to include the following:

- Scope and overview paragraphs, to introduce protection of Urban Rail lines in addition to protection of CEN DSRC equipment.
- New Protected Zone types of definition for Urban Rail protection, as described above.
- Specification of coexistence mode and procedures specific for Urban Rail protection.

These proposed changes would lead to the following proposed update of the ETSI TS 102 894-2 [i.3]:

- DE_ProtectedZoneRadius (A.57) ASN.1 change (in line with point 1 above):
  - This parameter could be used to define the first parameter to define the Urban Rail Protected Zone.

The following parameters would have to be added to protect Urban Rail. These parameters would be used only by devices using the Urban Rail channels:

- DE_ProtectedZonePar1 (A.new1) ASN.1 change (in line with point 1 above):
  - Definition: ProtectedZonePar1 is one of the possible parameters defining the ProtectionZone area. The use of this parameter is defined by the ProtectionZoneType (A.58).
    This DE is used in ProtectedCommunicationZone DF as defined in clause A.121 of ETSI TS 102 894-2 [i.3].
  - ProtectedZonePar1::= INTEGER { oneMeter(1)} (1..255, etc.).
- DE_ProtectedZonePar2 (A.new2) ASN.1 change (in line with above):
  - Definition: ProtectedZonePar2 is one of the possible parameters defining the ProtectionZone area. The use of this parameter is defined by the ProtectionZoneType (A.58).
    This DE is used in ProtectedCommunicationZone DF as defined in clause A.121 of ETSI TS 102 894-2 [i.3].
  - ProtectedZonePar2::= INTEGER { oneMeter(1)} (1..255, etc.).
- DE_ProtectedZoneType (A.58) ASN.1 change (in line with the dedicated standard to be developed based on the ETSI TS 102 792 [i.1] as described above):
  - Definition: The PRotectedZoneType defines the type of protected communication zone, so that an ITS-S is aware of the actions to do while passing by such zone (e.g. reducing the transmit power or other method to ensure that no interference of the expected affected system is ensured).

- The protected zone types should be defined in the new standard. The PZ Type definition includes the information about the channel(s) to be protected, and the kind of mitigation to be used.
  This DE is used in ProtectedCommunicationZone DF as defined in clause A.121 of ETSI TS 102 894-2 [i.3].
- ProtectedZoneType::= ENUMERATED { permanentCenDsrcTolling (0), temporaryCenDsrcTolling (1), permanentUrbanRailCirculair (2), permanentUrbanRailElipseTypeA (3), permanentUrbanRailElipsetypeB (4)..., permanentUrbanRailrectangle (N) }.

- DE_ProtectedCommunicationZone (A.121) ASN.1 change (in Line with point 1 above):
  - Backward compatibility is guaranteed by only a name change for ProtecteZoneRadius into ProtectedZonePar0 and extension by ProtectedZonePar1, ProtectedZonePar2 and ProtectedZoneLegal.
  - Definition:
    - ProtectedCommunicationZone::= Se { ProtectedZoneType, expiryTime TimestampIts OPTIONAL, protectedZoneLatitude Latitude, ProtectedZoneLongitude Longitude, ProtectedZonePar0 ProtextedZoneParameter0
      OPTIONAL,ProtectedZoneID ProtectedZoneID OPTIONAL, ProtectedZonePar1 ProtextedZoneParameter1 OPTIONAL, ProtectedZonePar2 ProtextedZoneParameter2 OPTIONAL, ProtectedZoneLegal OPTIONAL }
- DE_ProtectedZoneLegal (A.new3) ASN.1 change (in line with point 1 above):
  - This is a new field to identify legal responsible organization.
  - Definition: ProtectedZoneLegal is legal organization identifier. Allowing the user group representing organization to manage the possible members group.
    This DE is used in ProtectedCommunicationZone DF as defined in clause A.121 of ETSI TS 102 894-2 [i.3].
  - ProtectedZoneLegal::= Se { ProtectedZoneOrganisation, ProtectedZoneMember OPTIONAL }.
- DE_ProtectedZoneOrganisation (A.new4) ASN.1 change (in line with point 1 above):
  - This is a new field to identify legal responsible organization.
  - Definition: ProtectedZoneOrganisation is legal organization identifier. Allowing the user group representing organization to manage the possible membersgroup.
    This DE is used in ProtectedCommunicationZone DF as defined in the description of the data type A.new3 above.

NOTE 2: Necessity to be checked, seems to be duplicated to data element ProtectedZoneType.

  - ProtectedZoneOrganisation::= ENUMERATED { ProtectionZoneDSRCTolling (0), ProtectionZoneUrbanRail (1)}.
- DE_ProtectedZoneMember (A.new5) ASN.1 change (in line with point 1 above):
  - This is a new field to identify legal responsible organization.
  - Definition: Allowing the user group representing organization to manage the possible membersgroup.
    This DE is used in ProtectedCommunicationZone DF as defined in the description of the data type A.new3 above.
  - ProtectedZoneMember::= INTEGER (1..255).

G.2 ITS Database for the protection of Urban Rail systems

G.2.1 General consideration

Two types of database, storing information on Urban Rail ITS PZ, can be used:

- a read-only database as currently used for the CEN-DSRC coexistence;
- an updatable database not yet defined.

Considerations regarding Read-only database solutions are given in clause G.2.2.

Considerations regarding updatable database are given in clause G.2.3.

G.2.2 Read-only database proposal for the protection of Urban Rail ITS

For the identification of the Protected Zone (PZ) of an Urban Rail system, the same static mechanisms as used for the protection of CEN DSRC could be adopted. This mechanism can be based on the solution developed for CEN DSRC (ETSI TS 102 792 [i.1]) and an extension of the CDD standard ETSI TS 102 894-2 [i.3].

All European or regional PZs could be collected and provided in a central database, installed in each Road ITS device as a read only database. This solution restricts the creation of mitigation zones to predetermined fixed locations that were established at the time of vehicle assembly, and may lead to mitigation also in case when mitigation is not strictly needed. Based on their read-only database, Road ITS-Ss will mitigate continuously when they are within a registered PZ. This solution could be a possible identification method for existing Urban Rail installations.

An update of the current Tolling CEN-DSRC database is proposed to support the Urban Rail requirements. Proposed improvement of the current Tolling database format:

- Introduction of a PZ type field.
- Introduction of an originating field (identifying the source of the provided PZ information).
- Introduction of a PZ form type field and allocate a few fields to support the specific related parameters for the different types. Types and parameters for Urban Rail to be investigated.

The general optimum would be to have one single organization to maintain the database and manage the format of the database.

G.2.3 Updatable database

The updatable database principle is similar to the Read-only device database described above, with the additional capability to update the database in each ITS station when the central database is updated, for each new Urban Rail line introduction or line extension.

The decision to construct a new Urban Rail line is taken several years before commissioning and operational service. Such a timeline, typically years in advance, allows reasonable delay for the update of the database in each ITS station after the introduction of the new Urban Rail Protected Zones in the central database. The same principle applies for Urban Rail line extension or line characteristics update.

The central database should be unique, secured and managed by a trusted entity. This database should record all Urban Rail lines information both in commercial service, under construction or already planned. To avoid active mitigation by Road-ITS stations when the need of protection is not yet there, each Protected Zone should be associated with a start date (and optionally a stop date) as explained below.

The road vehicle should be capable of downloading data from a server. This updateable database in the road-vehicle can be defined as a configuration file, for example an XML file. A secure method for downloading the new file to check its authenticity would need to be used.

Assuming that the road vehicles are becoming more and more connected, several solutions exist or will exist in the near future to allow reliable and secured communication between a secure server on which the central database can be stored, and the updateable device database.

Such a process should occur during 2 main phases of its life cycle:

- During road-vehicle manufacturing, an initial download from the central database into the vehicle could be performed.
- During road-vehicle operation life cycle, a periodic and automatic versioning mechanism would force the road-vehicle system to check regularly if a new version of central database is available, and if yes, an update would have to be triggered within a given time limit.

Typically:

- two successive updates of the central database would rarely happen in less than two years;
- the periodic check of version would need to be done by the vehicle at least every year;

In case the updatable device database version had not been checked, or is not up to date at the due date, a mechanism should forbid the vehicle to use the channels used by Urban Rail systems.

The central database update and the related updatable device, are considered as an addition of one or several record(s) identifying new Protected Zone(s) with the relevant information, like (but not limited to):

- Protection area.
- Protection mechanism start date.
- Protection mechanism stop date.
- Protection type(s): execute appropriate actions when entering a Protected Zone.
- Protection value(s): level(s) of restriction(s) to be applied.

The update of the road-vehicle file could be done using one of the following connectivity links:

- Embedded connected-vehicle cellular, Wi-Fi® or Bluetooth® connectivity.
- Driver's mobile phone connectivity, itself connected to the vehicle system.
- Driver's home-based Wi-Fi® connectivity.
- Vehicle-workshop connectivity, during annual car revision, maintenance or repair.
- Connectivity provided by RSUs, if available.

Any other connectivity proposed by the vehicle or its driver ecosystem could also be used, considering that new road vehicles will be directly or indirectly connected with existing or future technologies.

Such an update could be grouped with other type of vehicle data update occurring at least once a year.

Regarding the data size, it is reasonable to assume that over a period of 10 years, the number of Urban Rail lines in European cities will be multiplied by a factor of less than two. Then, the dimensioning of the memory capacity in road vehicle with two times the dimension required to store the first version of the Urban Rail data base will cover the needs for a period a minimum 10 years. It is possible to find a solution now to dimension the memory required in road vehicle to store the Urban Rail data base.

G.3 Combined beacon and database solution

G.3.1 Database combined with Urban Rail PZ beaconing

Similar alternatives are specified for protection of tolling systems in ETSI TS 102 792 [i.1].

A combination of beaconing/static database could also be a solution for Urban Rail ITS.

G.3.2 Updatable database combined with permissive beaconing

An Updatable database solution could be a stand-alone solution for Urban Rail PZ detection but is a static detection method. To allow dynamic detection using an Updatable database, it could be combined with some CBTC beaconing messages sent to withdraw temporary the need for mitigation when there is no train in the area.

These new permissive beaconing messages would have to be defined in a new standard, applicable to Road ITS devices willing to use channels in which Urban Rail ITS has priority.

G.4 Comparisons of different identification methods

In all cases ETSI TS 102 894-2 [i.3] would have to be updated as described in clause G.1 if CAM are used, and in clause G.2 if a database is used. In addition, a new specification based on ETSI TS 102 792 [i.1] would need to be developed to specify details of the necessary mitigation techniques.

Table G.2 provides a comparison between the identification methods.

The following identification solutions are considered:

- **Static Alert Beacon:**
  - The beacons send CAM-based restriction messages to restrict ITS-Road usage with or without train presence.
- **Dynamic Alert Beacon:**
  - The beacons send CAM-based restriction message to restrict ITS-Road usage only when a train is present.
- **Read-only database:**
  - A central database is regularly populated with the up-to-date relevant information about all Urban Rail PZs. The vehicles integrate the latest central database version during production, with no further update in the vehicles.
- **Read-only database + Static Alert Beacon:**
  - A central database is regularly populated with the up-to-date relevant information about all Urban Rail PZs. The vehicles integrate the latest central database version during production, with no further update. New Urban Rail lines will be protected by deploying beacons sending CAM-based restriction messages with or without train presence.
- **Read-only database + Dynamic Alert Beacon:**

- A central database is regularly populated with the up-to-date relevant information about all Urban Rail PZs. The vehicles integrate the latest central database version during production, with no further update. New Urban Rail lines will be protected by deploying beacons sending CAM-based restriction messages only when the train is present.

- **Updatable database:**
    - A central database is regularly populated with the up-to-date relevant information about all Urban Rail PZs. The vehicles integrate the latest central database version during production. A mechanism is implemented to regularly update the vehicles, during their life, with the latest central database version.

- **Updatable database + Dynamic Permission Beacon:**
    - A central database is regularly populated with the up-to-date relevant information about all Urban Rail PZs. The vehicles integrate the latest central database version during production. A mechanism is implemented to regularly update the vehicles, during their life, with the latest central database version. For low traffic Urban Rail zones, beacons can be deployed sending CAM-based permission messages whenever there are no trains.

All solutions were designed to avoid additional hardware for Road ITS.

Table G.2: Comparison between the different identification methods

Identification Solutions	PROS	CONS
Static Alert Beacon	One mechanism only. Protection for existing and new lines Re-use of existing principles based on tolling mitigation including all security aspects.	Needs additional equipment and related maintenance in the vicinity of overground Urban Rail lines. No protection for Urban Rail ITS if beacon transmission fails or is corrupted (for all cars in the area). If several physical layers are used for V2X, several beacon transceivers would be necessary (see note). ITS-Road restriction even if no train in the PZ. Potential increased complexity for Urban Rail. Heavy and costly infrastructure. Deployment of a new system which needs specific monitoring (less reliable than a database device). Redundancy of the ITS beaconing system.
Dynamic Alert Beacon	One mechanism only. Protection for existing and new lines Re-use of existing principles based on tolling mitigation including all security aspects. ITS-Road restriction only when train is present.	Needs additional equipment and related maintenance in the vicinity of overground Urban Rail lines. No protection for Urban Rail ITS if beacon transmission fails or is corrupted (for all cars in the area). If several physical layers are used for V2X, several beacon transceivers would be necessary. Potential increased complexity for Urban Rail. Heavy and costly infrastructure. Deployment of a new system which needs specific monitoring (less reliable than a database device). Redundancy of the ITS beaconing system. Needs dynamic interface between beacon and Urban Rail ITS for sending beaconing only when train circulate on the track. Such a feature needs a specific interface with wayside CBTC equipment and especially with CBTC software layers.
Read-only database	One mechanism only Reliable: Urban Rail ITS protection does not depend on PZ messages reception. Re-use of existing principles based on tolling mitigation. Cost effective solution. Independent of the radio technologies used by Road ITS.	No protection guaranteed for new lines and no flexibility in case of new situation. ITS-Road restriction even if no train is in the PZ.
Read-only database +	Re-use of existing principles based on tolling mitigation.	Two mechanisms to be specified.

Identification Solutions	PROS	CONS
Static Alert Beacon	Protection for existing and new lines Cost effective solution for existing lines only.	Needs additional equipment and related maintenance in the vicinity of overground Urban Rail lines for new lines. No protection for Urban Rail ITS if beacon transmission fails or is corrupted (for all cars in the area) for new lines. If several physical layers are used for V2X, several beacon transceivers would be necessary. ITS-Road restriction even if no train in the PZ. Potential increased complexity for Urban Rail. Heavy and costly infrastructure for new lines. Deployment of a new system which needs specific monitoring (less reliable than a database device). Redundancy of the ITS beaconing system.
Read-only database + Dynamic Alert Beacon	Re-use of existing principles based on tolling mitigation. Protection for existing and new lines Cost effective solution for existing lines only. ITS-Road restriction only when train is present for new lines.	Two mechanisms to be specified. ITS-Road restriction even if no train is in the PZ for existing lines. For new lines: Needs additional equipment and related maintenance in the vicinity of overground Urban Rail lines. No protection for Urban Rail ITS if beacon transmission fails or is corrupted (for all cars in the area). If several physical layers are used for V2X, several beacon transceivers would be necessary. Potential increased complexity for Urban Rail. Heavy and costly infrastructure. Deployment of a new system which needs specific monitoring (less reliable than a database device). Redundancy of the ITS beaconing system. Needs dynamic interface between beacon and Urban Rail ITS for sending beaconing only when train circulate on the track. Such a feature needs a specific interface with wayside CBTC equipment and especially with CBTC software layers.
Updatable database	One mechanism only Reliable: Urban Rail ITS protection does not depend on PZ messages reception. Re-use of existing principles based on tolling mitigation. Cost effective solution. Independent of the radio technologies used by Road ITS. Protection for existing and new lines.	ITS-Road restriction even if no train is in the PZ. New database update mechanism to be defined and implemented guarantying the integrity and reliability of the database update.

Identification Solutions	PROS	CONS
Updatable database + Dynamic Permission Beacon	Reliable: Urban Rail ITS protection does not depend on PZ messages reception. Re-use of existing principles based on tolling mitigation. Protection for existing and new lines. ITS-Road restriction only when train is present.	Two mechanisms to be specified. ITS-Road restriction even if no train is in the PZ. New database update mechanism to be defined and implemented guarantying the integrity and reliability of the database update. Needs additional equipment and related maintenance in the vicinity of overground Urban Rail lines. If several physical layers are used for V2X, several beacon transceivers would be necessary. Potential increased complexity for Urban Rail. Heavy and costly infrastructure. Deployment of a new system which needs specific monitoring. Needs dynamic interface between beacon and Urban Rail ITS for sending beaconing only when train circulate on the track. Such a feature needs a specific interface with wayside CBTC equipment and especially with CBTC software layers.
NOTE: The upcoming IEEE 802.11bd [i.15] will be backward compatible with 11p and would not need a new transceiver.		

Beaconing-based solutions should adapt and send messages which are specific to each Road ITS technology (LTE-V2X, ITS-G5). The dynamic beaconing-based solutions need a modification of CBTC software layers, which is a safety system of level 4. Database-based solutions avoid such heavy and complex operation as a sharing solution.

Annex H: Integration of Urban Rail systems in C-ITS

H.1 Introduction

Clause H.1 describes how Urban Rail ITS could use the Cooperative ITS architecture defined in ETSI EN 302 665 [i.9]. This proposal should be seen as a first stage of a possible long-term evolution that would allow re-using common components and entities for both systems.

This can be done in two ways, with different levels of integration:

Option 1: Connection (or unicast)-based solution.

Option 2: Broadcast-based solution.

These options cannot protect existing Urban Rail ITS using a different radio technology, so they cannot be considered as a universal solution. In addition, Option 2 assumes a new communication architecture for CBTC. It would require a modification of the way the CBTC communication interfaces with the transport of different messages in the network.

In addition, this integration would make sense in the context of spectrum sharing only if the same technology is used for all ITS stations and for Urban Rail stations used in a given area. Therefore, the integration of Urban Rail in the Road ITS protocol would impose a specific technology on CBTC that may not be appropriate.

Moreover, ITS stations could use different radio technologies with a sharing mechanism. In order to ensure the protection of CBTC communication using technology A, the ITS station using technology B would need to detect the presence of Urban Rail messages sent out with technology A. This would imply that an ITS station using technology B can also decode messages from technology A, or the PZ geometry is disseminated by CAM beaconing or a database.

Therefore, this clause cannot be considered as a complete sharing solution.

Accordingly, these options would not fit with the guidance given by ECC to ETSI: "Solutions for the coexistence between Road ITS and Urban Rail ITS applications should not impose the use of a specific radio technology, topology or a specific protocol for railway signalling.", but could be seen as a long-term solution.

It should be noted that the fine analysis of these options in terms of safety has not been performed in the present document. For example, for any ITS Road solution to achieve the same level of safety currently existing in the Urban Railway domain, the principles below need to be adopted:

- Block system: strictly only one vehicle in a block at any time.
- Interlocking, which prevents any conflicts between movement authorities to trains and the position of wayside elements.
- Failsafe logic: any failure of any element in the chain places the system in its most restrictive state, usually resulting in stopping the train.

The two options are introduced in more details in the following. They could also be considered as two steps with different levels of integration:

- **Connection (or unicast)-based solution:**
  - Uses an architecture similar to existing Urban Rail systems using communication in the context of a BSS. This solution assumes a 10 MHz channel bandwidth. The used message set including the PHY/MAC headers would support the detection of the messages and the inclusion of the Urban Rail ITS load into the operation of the Road ITS system.
- **Broadcast-based solution:**
  - Use broadcast-based ITS protocols, including update of the protocol using communication Outside the Context of the BSS (OCB). This solution uses the whole ITS protocol stack.

H.2 Description of Option 1: Connection-based solution

This first solution proposes short and medium-term arrangements that enable Urban Rail systems to work in a manner very close to their existing operation. It uses ITS-capable transceivers to deploy 10 MHz channels and headers in compliance with ITS-G5 protocols (IEEE 802.11 [i.15] header). The architecture and protocol remain connection-based, using unicast communication and operation in the context of a service set (IBSS operation of IEEE 802.11 [i.15] standard). The sharing is done mainly at the access layer level and relies on mechanisms available in ITS-G5. This option has not been checked for other radio technologies that could be used for the physical layer of the ITS communication system.

In this option, the operation is performed in the context of a BSS, as in standard Wi-Fi® operation. Because the communications now use 10 MHz channels to comply with existing regulation, the duty cycle is lower than in 5 MHz channels and can be estimated to be around 50 % of existing duty cycle, while respecting the time between messages imposed by the safety case.

ITS-enabled radio transmitters guarantee robust communication with enhanced link budget. Using these radios ensures that the Urban Rail ITS complies with existing EN and regulation, while no further change is necessary for CBTC. Under assumption of reduced duty cycle, Urban Rail ITS could operate without implementing the DCC algorithms. This would give Urban Rail ITS an inherent level of prioritization. In addition, the Road ITS radios would need to support the higher duty cycle. because the current duty cycle limit of 3 % is considered to be insufficient for CBTC, even with 10 MHz.

Furthermore, CSMA/CA based systems can detect each other and an ITS-G5 station is able to perform mitigation when needed using DCC-like mechanism, meaning that ITS stations would decrease the transmission activity from e.g. 60 % load down to 50 % and thus give the other systems without DCC reasonable capabilities to access the channel. The limitation similar to DCC limits is applied only when a protected zone CAM is received. For DCC limits it has to be considered, that due to the directional antennas of CBTC, channel load perceived by CBTC can be much higher, than perceived by the surrounding Road ITS devices (see clauses 5.5 and 5.6).

H.3 Description of Option 2: Broadcast-based solution

H.3.1 Overview

This second option proposes a more future-proof solution. It also makes use of 10 MHz channels and ITS capable transceivers, but it integrates the CBTC communications in the ITS architecture [i.9] and relies on the broadcast capabilities. Urban Rail communication is transported in specific messages mostly V2I, which need to be added to existing ITS standards. The sharing is thus done at the entire system level, including any communicating CBTC equipment, on board as well as wayside, which all become ITS stations. The Urban Rail AP is hereafter named TS-ITS-S for Track Side ITS-S, while the equipment in the trains is hereafter named T-ITS-S for Train ITS-S. As this equipment is safety-related, changing their communications would obviously induce the need for a detailed analysis in terms of safety and the updated components would have to be recertified before any deployment of such solution .

H.3.2 ITS protocols: nomenclature and main properties

ITS applications make use of radio communications between mobile ITS stations (vehicles), or V2V, and between mobile ITS stations and fixed ITS stations (roadside installations), or V2I/I2V, with single-hop or multiple hops between the source and destination.

ITS technology and architecture are ultimately based on the harmonised content of the generalized notion of an ITS communication station (referenced as ITS-S in the sequel), which can be implemented in various forms with different functionality and configurations. ITS-S is the actual implementation of a communication station concept with particular functionality providing the complete feature set of the C-ITS communications protocol stack. A specific implementation of an ITS-S is referenced as roadside station (R-ITS-S) providing direct access to the infrastructure, central station (C-ITS-S) providing server functionality in the infrastructure, moreover, vehicle station (V-ITS-S) or onboard unit, which are the most frequently used devices in the architecture. An ITS-S is specified as a secured managed domain in the standards in order to lower the risk of unauthorized or illegal usage. This nomenclature is compliant with ETSI EN 302 663 [i.6] and with other documents regarding Cooperative Intelligent Transportation Systems (C-ITS) Communications Architecture standards.

So far, all operation under the ITS safety mode is broadcast-based operation, which benefits from the fact that there is no need to set up a specific connection between the stations involved. Measures implemented for security and privacy are based on downloaded certificates and encryption.

The technology is required to support many safety-related and non-safety-related use-cases for ITS. Safety-critical and life-saving applications remain at the core of vehicle communications and strictly require the technology to efficiently operate in absence of a network.

Furthermore, the technology should be optimized for mobile conditions in presence of disturbance and obstructions, handling dynamically varying multi-path reflections and Doppler shifts generated by relative speeds as high as 500 km/h providing sufficient robustness against frequency and timing errors.

It needs to operate robustly in a dynamic environment with high relative speeds between transmitters and receivers and to support the extremely low latency of the safety-related applications in highways, urban intersections and tunnels.

Consistent with the above, communication between ITS-Ss, can be classified as safety and non-safety critical.

Unicast mode is generally not used in safety critical scenarios with the rare exception of geo-location-based addressing. ITS protocols introduce GeoNetworking, where the destination position is an inherent part of the communication's addressing. The existing system is optimized for mobile applications to allow for robust communications.

H.3.3 Road ITS communications architecture and protocol stack

The baseline for a European ITS communications architecture for cooperative road traffic systems is described in ETSI EN 302 665 [i.9].The ITS station (ITS-S) reference architecture (Figure H.1) explains the functionality contained in ITS communication stations which are part of all ITS sub-systems in a particular deployment. Beyond the standard access and network layers functionality, the Facilities layer represents the main service set of the vehicular communications architecture and support for common message and data management for data exchange between ITS-S applications.

Applications making use of the ITS-S services to connect to one or more other ITS-S applications are on the top of the protocol stack.

Access and link level protocols follow the respective Access Layer standard and comply with applicable regional spectrum management requirements.

Networking and Transport protocols, beyond standard internet protocols, include GeoNetworking.

Facilities protocols support basic common functionalities of the vehicle communications system that are defined in order to ensure the correct system functioning and to satisfy interoperability. Facilities layer entities manage the ways that information is stored and used at ITS station level, perform data fusion, positioning and database handling, and are key to fully autonomous operation.

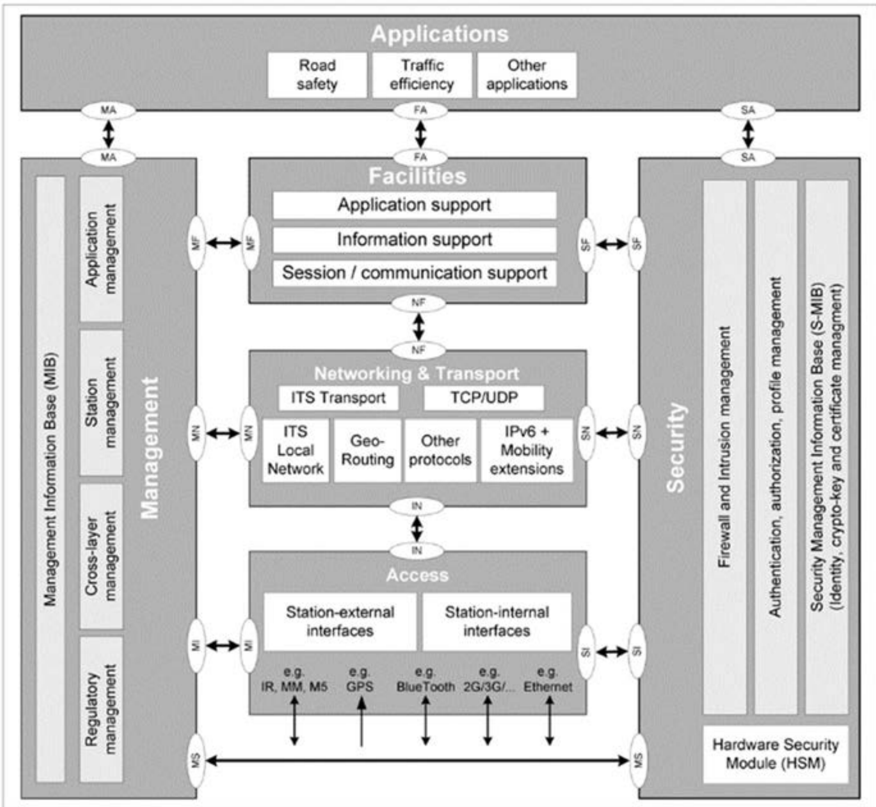


Figure H.1: ITS station reference architecture in accordance with ETSI EN 302 665 [i.9]

Cooperative Awareness Basic Service (CABS), which provides a cooperative awareness service to neighbouring nodes by means of periodic sending of status data is a mandatory functionality. This generates and distributes Cooperative Awareness Messages (CAMs) in the network in a deterministic timely basis (with 1 Hz to 10 Hz frequency, depending on the ITS-S context). This provides information of presence, positions as well as basic movement status of communicating ITS stations to neighbouring ITS stations that are located within a single hop distance.

In contrast to CABS, Decentralized Environmental Notification (DEN) service handles Messages (DENM) in an event driven manner and provides the key messaging functionality for hazard warning.

A local dynamic map (LDM) manages location and status information of communicating vehicles on a small geographical scale, dynamically, collecting digital map and sensory information in a single manageable data-base format.

MAP is the road infrastructure description data structure and SPAT is the communication protocol between vehicles and active elements of the infrastructure, such as e.g. traffic lights and controllers.

H.3.4 Requirements and solutions for safety and security

Certification and functional safety requirements are defined in the package of ISO 26262 [i.30]for road vehicles. This provides requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety is achieved. Risk and hazard analysis determine the Automotive Safety Integrity Level (ASIL) grade by weighting the potential to threaten lives. Since ITS V2X protocols have the capability controlling the vehicle in safety critical use-cases, like in many autonomous drive applications it is assumed that V2X requires the ASIL B grade next to other automotive electronics certifications as various stress test qualification (AEC-Q100 [i.35]), EMC immunity (IEC 62132-1:2015 [i.31]) and functional safety qualification (ISO 26262 [i.30]).

Cyber security and End-to-End (E2E) device security are two main requirements of V2X technology. To enforce E2E device security of a connected vehicle system, including user and vehicle protections such as ensuring secure and trusted information exchange among users to support secure communications one needs to ensure that:

- messages originate from a trustworthy and legitimate device (authentication);

- messages are undamaged and not modified between sender and receiver (integrity);
- misbehaving units and malicious actions are detected and removed from the system (fault tolerance).

Recent ITS security solutions to ensure authenticity, confidentiality, message integrity with non-repudiation maintaining users' privacy between V2X entities are certificate based. The format for the certificates is specified in ETSI TS 103 097 [i.32] Certificate management is the service of Certificate Authority (CA) system which is implemented over the Public Key Infrastructure (PKI), see Figure H.2 .

The security credential system provides secure communication between parties which is practically unbreakable within a reasonable time (minutes). Certificates are only valid for 5 minutes and discarded after use. It uses public key cryptography and digital signatures to provide authentication. Public key cryptography ensures that each entity has a private key (only known to the owner) and a public key that is distributed to all message receivers. A message sent to the receiver contains a digital signature (private key) of the message and a certificate that contains the public key of the sender. CAM, DENM and generic message types are affected as described in ETSI TS 103 097 [i.32].

Cyber security solutions differ from E2E security as they involve interaction with Sensors, Actuators and Cloud entities and are based on trusting and credibility analysis.

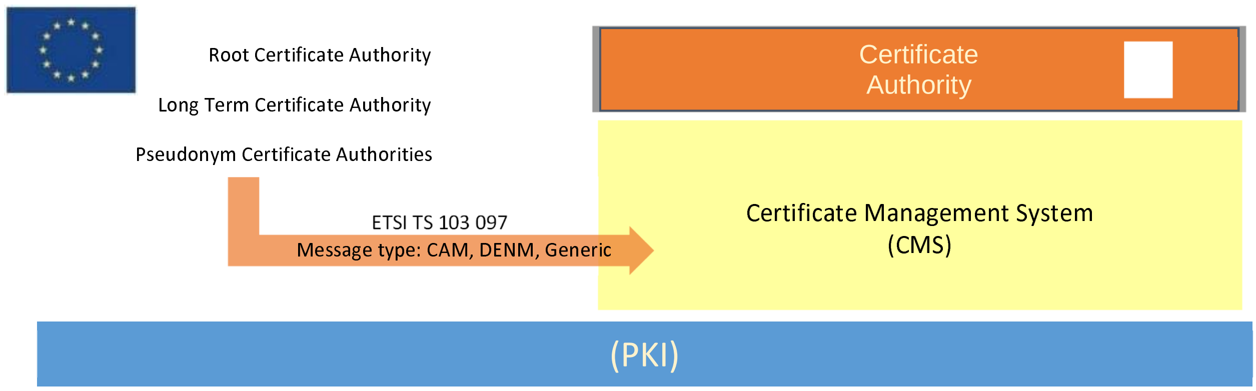


Figure H.2: General overview of the European Road ITS security credential system

H.3.5 Preliminary considerations to the use of broadcast mode

Mapping the concept of CBTC onto a broadcast-based operation means that both TS-ITS-S and T-ITS-S stations are used in broadcast-based GeoNetworking (GN) operation.

In CBTC, the broadcast-based scenario can also be used to enable direct communication between trains when they are in the communication range of each other, without the extra overhead involved in the train-to-wayside communication.

Packet acknowledgement mechanism needs to be handled in this broadcast-based mode, which is not trivial, for example, if geo-addressing was to be used to address the trains located in the area covered by the APs, with the addition of the ITS Station ID defined at Facilities Layer to identify a specific train.

APs (TS-ITS-Ss,) operation can rely on a special type of beacon to advertise itself. A node can connect to the AP simply by receiving this beacon advertisement. This further reduces the overhead associated with a normal IEEE 802.11 [i.15] handover and makes the handover significantly safer in the unicast situations.

The concept of zones defined in CBTC needs to be mapped onto the Local Dynamic Map (LDM) concept. This will allow for the backward compatibility to existing installations, while future extension to new concepts is possible. Broadcast mode could also be suited for multi ZC communications, considering that safety and security concerns are taken into account. However, this concept needs to be extended and adapted to the Urban Rail components such as point machines, axel counters and include interlocking measures.

TS-ITS-S on trackside integrate the C-ITS protocol stack as well. They are entities having the same type of functionality as T-ITS-S and TS-ITS-S can be seen as a distributed sensing network. There is no need to address a TS-ITS-S individually for message transfer, as all TS-ITS-S within the communication range receive the message via broadcast. However, a ZC can be individually addressed using its location information by the application of the GeoNetworking concept (via unicast).

Uplink communication

Vehicle ITS stations (or OBUs) are installed in trains and become T-ITS-S. They broadcast CAM-like messages at a fixed rate. These messages, hereafter named Urban Rail CAM (UR-CAM), are expected to be simpler than automotive CAM in the sense that a smaller set of parameters is needed. They include the train position (location report) and kinematics, and if necessary, some functional status information. Their duty cycle is around 5 messages per second and per ZC with a length between 300 bytes and 1 500 bytes (depends on content and security). They may address only relevant ZCs, PSD controllers or any other relevant devices connected on the wayside network, using the GeoNetworking capability.

For the broadcast on demand messages, it can be performed either by adding a field to UR-CAM or by defining a DENM-like message (UR-DENM).

The trackside ITS stations receive the information from the trains and transfer it to the relevant ZC based on positioning information. The Zone Controller should therefore be modified to implement the C-ITS functionalities. They use GeoNetworking capabilities to address the correct ZC. As far as a ZC could receive several times the same message if this message is routed by several TS-ITS, the ITS Station in the ZC should include a new functional block in their facilities layer, as described below in Figure H.3, which would be responsible to remove duplicated messages received from the two or more TS-ITS via their communication path, in addition to the message decapsulation.

Same also applies for any CBTC devices which need to communicate with trains (platform screen doors, periodic status messages, etc.).

Downlink Communication

Based on the position information received from the train, the ZC transmits movement authorization using SPAT (Signal Phase and Timing) like messages (UR-SPAT).

Line information from the ZC to the train can be communicated using MAP-like messages (UR-MAP) that include positions of TS-ITS-S (or trackside ITS-S) and other trains (if required). Here also new functional block should be added in the on-board CBTC controller to prevent multiple reception of the same message.

H.3.6 Security and availability of CBTC communications

Regarding the cybersecurity, all ITS Stations are required to deploy an infrastructure security certificate. Since the Urban Rail systems are operated in a more controlled environment, the distribution of certificates and the implementation of the certificate management system itself is expected simpler than in the automotive environment.

Regarding the availability, one main difference between Road ITS and Urban Rail ITS is that trains are not operated autonomously. A communication failure of a car will reduce its capability to avoid critical situations and thus reduce its safety, but it will continue to drive. Interrupted communication of a train leads to a full stop of the affected train and in consequence of the complete line. CBTC systems and their communication thus require a very high availability. Traditional CBTC systems (based on unicast technology as described in Option 1, above) apply mitigation techniques to reduce the severity of communication malfunctions as follows:

- Application of two OBUs per train, one in the front, another on the tail.
- Alternating use of two or more frequencies in order to avoid interference with neighboring waysides.
- Application of redundant TS-ITS-S coverage areas by construction or redundant TS-ITS-S per location
- Redundancy TS-ITS-S/trackside backbone networks.

With a switch to C-ITS communications these measures would still be required and therefore the C-ITS solutions would need to be capable of handling these techniques.

H.3.7 Message set proposal

Based on the above discussion an updated set of messages for introducing Urban Rail as part of the ITS system needs to be defined and specified:

- UR-CAM (Urban Rail CAM);

- UR-DENM (Urban Rail DENM);
- other messages required (UR-SPAT, UR-MAP).

Furthermore:

- Update LDM (Local Dynamic Map) to mimic the Zone Concept.
- Update MAP to describe the structure of Urban Railway line infrastructure as well as the layout of Urban Rail/road level crossings.
- Define Facilities Layer Urban Rail ITS functional block to interface with backbone operation and to abstract ITS-G5 functionality.

These messages would be handled by a new component of the Facilities layer dedicated to UR-ITS services as illustrated in Figure H.3.

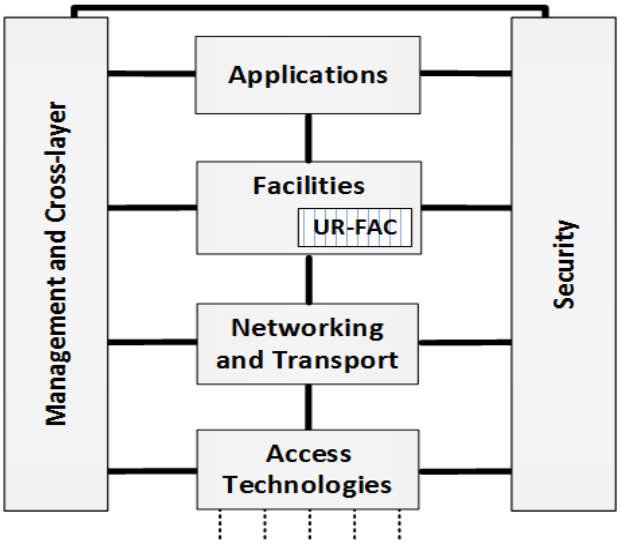


Figure H.3: ITS Station model showing UR-ITS specific component in Facilities layer

UR-CAM

The ITS CAM (ETSI EN 302 637-2 [i.2]) informs neighbouring stations of the presence and of dynamic parameters of the transmitting station. The CAM is broadcasted in a periodic way (1 Hz to 10 Hz when functioning normally) in the geographic area surrounding the transmitting station at a single hop distance.

The CAM content varies depending on the transmitting ITS-S and is split over several "containers". For example, for a V-ITS-S, the basic container provides the type of ITS-S and its geographical position. The High Frequency (HF) container provides information that varies very rapidly: direction, speed, dimensions, steering angle. The LF (Low Frequency) container holds information on more static characteristics of the ITS-S: the vehicle's role, the state of the lights, the opening of doors, etc. Some vehicles may also indicate their role: public transport, emergency priority vehicle or transport of hazardous substances. A R-ITS-S only distributes its characteristics: type, position, etc. in the HF container.

The CAM could be adapted to fit the needs of several CBTC services:

- Location Report to one ZC.
- Periodic Train Functional Status message.
- On demand specific status message.
- Platform Screen Door monitoring and control approaching, in station and leaving station.

The containers would include the following information (more study is needed here):

- Basic container: the type of ITS-S and its geographical position.

- High Frequency (HF) container: direction, speed, dimensions.
- Low Frequency (LF) container: functional status, monitoring of doors.

UR-DENM

The ITS Decentralized Environmental Notification Message (DENM) (ETSI EN 302 637-3 [i.5]) is used to broadcast a time-stamped and geo-localized alert when an event is detected: dangerous weather conditions, road works, animal on the road or severe traffic speed decrease.

The DENM content is also split over several containers:

- The Management Container provides general information: action ID (originating Station ID, sequence number), detection time, reference time, event position, relevance distance, relevance traffic direction, originating station type.
- The Situation Container gives more specific information: information Quality, event Type.

A new message set, with a structure similar to that of DENM, could be defined to fit the needs of several CBTC services:

- Information about Line from ZC.
- Request for Health train status.

The content and structure of this new message set would be identical to that of the DENM message as currently defined, only new values for the field equivalent to the "event Type" field would have to be created to suit the needs of Urban Rail.

UR-SPAT

The ITS Signal Phase and Timing (SPAT) message used in ITS protocols ETSI TS 103 301 [i.33]and SAE J2735 [i.36] is mainly used to inform ITS-S in real-time about the operational states of a signal system, e.g. a traffic light, its current signal state, the residual time before changing to the next signal state and to provide assistance for crossing, including lane information.

The SPAT Message contains the following parameters:

- status of the traffic controller: e.g. active, manual control, stopped, failure, off, etc.;
- timestamp;
- enabled lanes (optional);
- movement state for each lane or group of lanes: signal phase state, time change, advisory speed;
- manoeuvre assistance (optional): traffic queue length, available storage length, wait on Stop, pedestrian or bicycle detected;
- priority state (optional);
- pre-empt state (optional).

The SPAT message could be adapted to fit the needs of the following CBTC service:

- Movement Authority from ZC.

Most of the existing parameters in the SPAT message could be applicable to Urban Rail. The UR SPAT message would need to be simplified by ignoring some of the optional fields in the existing SPAT message and extended by additional parameters for the movement authorities.

UR-MAP

The ITS MAP message used in ITS protocols ETSI TS 103 301 [i.33] and SAE J2735 [i.36] is used to broadcast the topology/geometry of a set of lanes. e.g. considering an intersection, the MAP message defines the topology of the lanes or parts of the topology of the lanes identified by the intersection reference identifier. It includes the lane topology for e.g. vehicles, bicycles, parking, public transportation and the paths for pedestrian crossings and the allowed manoeuvres within an intersection area or a road segment. It should be noted that the MAP message is quite stable over time.

The MAP message contains the following parameters:

- Geographic layer type (optional): intersection, curve, roadway, parking, etc.
- Definition of intersections/road segments. For each component:
    - Reference point (latitude, longitude, elevation).
    - Lane width (optional).
    - Speed limit (optional).
    - Lanes set, for each lane:
        - Identifier.
        - Ingress approach/egress approach (optional).
        - Attributes: type (vehicle, crosswalk, bicycle, sidewalk, parking), direction of use, sharing (e.g. with bus, taxis, pedestrians, etc.).
        - Allowed manoeuvres (optional).
        - Lane geography defined by a set of points and/or computed segments.
        - Connecting lanes, overlay lanes.

The MAP message could be adapted to fit the needs of the following CBTC service:

- Track database update.

Most of the existing parameters in the MAP message could be applicable to Urban Rail tracks. The new UR-MAP message would only need to be simplified to take into account the constrained geography of tracks. It would also require the definition of a new lane type for Urban Rail tracks.

H.4 Summary

As shown in the introduction, this proposal would make sense in the context of a spectrum sharing study only if the same technology is used for all ITS stations and for Urban Rail stations used in a given area.

It does not fit with the guidance given by ECC to ETSI: "Solutions for the coexistence between Road ITS and Urban Rail ITS applications should not impose the use of a specific radio technology, topology or a specific protocol for railway signalling".

Consequently, this proposal should be seen as a first "toolbox" proposed by Road ITS for a possible long-term evolution of both ITS applications but cannot be considered as a mandatory solution.

The following results should be noted:

- For both options, hidden node situations reported in clause 5.4, are not solved and their impact has not been studied.
- For Option 1:
    - The proposal is applicable only with ITS-G5 and requires modification of the already deployed CBTC systems.

  - Identification of the Urban Rail area by Road ITS, as described in clause 7 are still necessary.

- For Option 2:

  - The proposal could be developed with any Road ITS radio technology, but sophisticated coexistence methods would be necessary when different ITS radio technologies are used on the same radio channel in the same geographical area.

  - This option requires modification of how the CBTC application interacts with the lower layers responsible to transport its messages on the network. It introduces several new technical principles in the CBTC application itself such as a new way to transmit messages (using broadcast and message repetition), together with a new way to define localization (CBTC defines a position based on segment of track and offset on these segments, in Road ITS several methods such as GPS in open sky conditions or any other method like a beacon based solution as used in Rail systems can be used), leveraging the use of GeoNetworking to address the controlled zone, etc. Therefore, it can be only considered as a potential long-term evolution of CBTC.

  - The fine analysis of this concept in terms of safety has not been performed in this preliminary version. For any ITS road solution to achieve the same level of safety currently existing in the Urban Railway domain, the principles of block (strictly only one vehicle in a block at any time) and failsafe logic (any failure of any element in the chain places the system in its most restrictive state, usually resulting in stopping the train) needs to be adopted.

  - Consequences of the proposal on the wayside to train communication quality are not assessed (reception of too many messages on wayside, risk of missing wayside messages on train side).

  - There is still work to be done to check the completeness of the proposed CBTC specific messages list, and to define them precisely within the ITS protocol.

  - This option would allow re-using common standardized components and entities for both ITS systems.

The two options are compared in the Table H.1.

Table H.1: Comparison of the two options for sharing using MAC/PHY layer mitigation method

	PROS	CONS
Option 1	• No change in basic Urban Rail system architecture needed • Reuse of Road ITS chip sets • Higher capacity in a single link (10 MHz versus 5 MHz) • Soft mitigation possible by duty cycle management on the Road ITS side • Simpler sharing in ITS bands from 5 855 MHz to 5 925 MHz	• Not technology neutral • Requires changes in frequency usage (5 MHz versus 10 MHz): fewer number of independent channels for Urban Rail ITS, so need new concepts to deploy independent Urban Rail lines parallels or crossing each other • Partly re-development of the Urban Rail ITS required (hardware and software) • Not universally usable for existing Urban Rail deployments • Difficult to implement for existing Urban Rail projects and lines • Subject to hidden-node situation leading to Urban Rail ITS channel blocking • Road ITS chip sets need to be adapted, for Urban Rail usage

	PROS	CONS
Option 2	• Reuse of Road ITS chip sets and platforms • Higher capacity in a single link (10 MHz versus 5 MHz) • Soft mitigation possible by duty cycle management and prioritization of Urban Rail ITS on the Road ITS side • Fully integrated and harmonised ITS for Road and Urban Rail deployment possible • Simpler sharing in ITS bands from 5 855 MHz to 5 925 MHz	• Not technology neutral • Requires changes in frequency usage (5 MHz versus 10 MHz): fewer number of independent channels for Urban Rail ITS needs new concepts to deploy independent Urban Rail lines parallels or crossing each other • Requires changes in frequency usage and arrangement (5 MHz versus 10 MHz) • Full re-development of the Urban Rail ITS required including certification and safety • Not universally usable for existing Urban Rail deployments • No short-term or mid-term solution • Update and extension of ITS set of standards in ETSI required • Subject to hidden-node situation leading to Urban Rail ITS channel blocking • ITS architecture should be modified to include a block system, which guarantees that full safe braking distance is always maintained between every vehicle at all times • ITS architecture should be modified to include an interlocking system which is compliant with EN 50128 [i.25] and EN 50129 [i.26] SIL4 and which guarantees that conflicts between positions of points/switches and movement authorities are prevented. • Requires different tests and certification applicable to Urban Rail systems

Annex I:
Alternative RMOs.

I.1 Stop transmission for all the vehicles in a R-RMO

The simplest solution for sharing and mitigation is for Road ITS units to cease all transmissions in the 5 915 MHz to 5925 MHz channel when they are inside a specified geographic area called a "R-RMO"

The interdiction of transmissions for Road ITS stations is limited to the R-RMO around metro lines that are not underground. The zones may be defined using the methodologies described in clause 5.6.

This simple solution provides a high level of protection to Urban Rail systems, and is easily implemented in Road ITS stations. It also requires some effort on the part of the Urban Rail community to define the R-RMOs for each of their lines.

The drawback of this simple approach is that the no Road ITS application can use the channel 5 915 MHz to 5 925 MHz within the R-RMO. Note however that all the other Road ITS channels can currently be used without restriction.

I.2 Duty cycle control

A Road ITS device can adjust its duty cycle based on the actual channel load using congestion control mechanisms. Such mechanisms generally involve each Road ITS device continuously monitoring Road ITS activity on the channel (also known as "channel load") and adjusting its usage of the channel in an attempt to keep the overall Road ITS channel load below a prescribed limit, for example below 62 %.

A variation of this approach is to simply limit the short-term duty cycle of any Road ITS transmitter in a R-RMO to a fixed value determined by the expected maximum number of active Road ITS transmitters in a given zone. Such duty cycle limits for such scenarios are generally in the 1 % to 5 % range. However, they can be larger.

While this approach allows the use of the frequency band 5 915 MHz to 5 925 MHz by Road ITS and Urban Rail CBTC radio systems simultaneously, it does not provide any quantifiable assurance that CBTC operations will not be interfered with going forward as a result of increasing deployment of Road ITS devices.

The congestion control mechanism can only limit the channel occupancy of a cluster or group of vehicles able to listen each other spread on an area. This group of vehicles can have their channel occupancy limited at maximum 5 % or 10 %.

As explained in clause 5.5, even if the duty cycle of each Road ITS station is limited by the congestion control mechanism with a defined target to limit the channel occupancy below 5 % or 10 %, the real channel occupancy "seen" CBTC base station and Train Radio device will be significantly higher.

This is due to the use of higher gain antenna connected to CBTC radio devices in CBTC base stations and Train.

A CBTC base station antenna or a Train antenna can "see" several clusters of vehicles in which the channel occupancy is limited at x %, it means that the total channel occupancy "seen" by CBTC base station and Train Radio devices will be up n times x %.

The number of clusters of vehicles in which the congestion control mechanism will limit the channel occupancy "seen" by CBTC base station antenna and train antenna will depend on the location of the CBTC base station and the train along the track and the local condition of propagation.

It means that to reach a maximum total channel capacity "seen" by a CBTC base station and a Train Radio device of total % (5 % or 10 %) the maximum channel occupancy per cluster or group of vehicles should significantly below xtotal %. The problem is how to define x% per cluster considering the fact that the number of clusters "seen" by CBTC base station or Train radio devices depend on location and condition of propagation.

The definition of the x % also should consider the CBTC channel occupancy that will vary between 4 % to more than 87 %.

The results of the measurement campaign shows that a CBTC Base station antenna and a Train antenna can receive packets from vehicles over a long distance.

In Annex D, an analysis has been made based on the results of the measurement campaign to evaluate the number of vehicles that can be received by a CBTC base station installed on RATP line 6 closes to the station Dupleix. The result of this analysis shows up to 4 346 vehicles can be received by the CBTC base station.

These vehicles are spread in several streets parallel, perpendicular, or not to the track axis. There will be several cluster or groups of vehicles in different streets separated by buildings. These groups of vehicles will not be able to listen each other's. It is reasonable to assume that the CBTC base station installed on RATP line 6 close to the station Dupleix will "see" several groups of vehicles and a total channel occupancy largely above the target of 10 %.

The analysis of the measurements performed on the RATP line 8 in a sub-urban area shows that a CBTC base station radio device can receive vehicle driving on parallel roads over a distance above 1 km per direction. Because of a CBTC base station has two antennas pointing in two opposite directions, transmissions of vehicle driving on parallel road can be received over distance up two kilometers.

Over a distance of two kilometers, it is reasonable to assume that CBTC based station radio devices will "see" several clusters or groups of vehicles in which the channel occupancy is limited at x%. A simulation about channel occupancy on parallel can be found in Annex D.

Based on the previous analysis, allowing a maximum percentage for channel occupancy for transmission between vehicles would allow usage of a very low duty cycles/channel occupancy with questionable benefit for the ITS Road application that will used the channel 5 915 MHz to 5 925 MHz and in addition very high difficulty to define the x% channel occupancy per clusters or groups of vehicles to guarantee a maximum xtotal % all over a metro line.

The conclusion is that a maximum % of channel occupancy for Road ITS is not adequately protecting CBTC receivers because they can be interfered by transmissions from several or extended clusters of vehicles unable to listen to each other. The definition of the maximum % of channel occupancy will depend on location along the track and will be complex to define. The solution based on duty cycle control is not feasible.

I.3 Combined methods

A sharing and mitigation solution based on a combination of progressive power reduction with duty cycle control can be considered.

However, the set of parameters to allow optimal protection of Urban Rail systems will be very complex to define and, as explained in clause I.2, solutions based on duty channel control cannot guarantee a high level of protection of the Urbain rail systems.

I.4 Comparison of solutions for sharing and mitigation

Table I.1 gives a comparison of the four potential solutions for sharing and mitigation. The following items are compared:

- Level of guarantee for protection of Urban Rail system.
- Availability of the channel 5 915 MHz to 5 925 MHz for Road ITS applications.
- Complexity and Feasibility:
    - The complexity for Road-ITS in term of implementation of the processing.
    - The complexity for Urban Rail concerning the definition of the R-RMO.
    - The feasibility is derived from the complexity.

Table I.1: Comparison of four potential solutions for sharing and mitigation

Solution for sharing and mitigation	Level of guarantee for protection of Urban Rail system	Availability of the channel 5915-5925 MHz for Road ITS applications	Complexity and Feasibility
Stop Transmission for all the vehicles in a R-RMO	High Level of protection	The vehicles cannot transmit over typical distance of 1 000 m both sides of track axis in urban area and 800 m in sub-urban area	The complexity is low for the implementation by Road-ITS (processing) and Urban-rail (definition of R-RMO). The definition of the R-RMOs will require a reasonable workload for Urban-Rail The feasibility is possible and easy
Progressive power restriction	High level of protection	The area in which the vehicles cannot transmit will be significantly smaller.	The complexity is low for the implementation by Road-ITS (processing) and higher than complete stop of transmission for Urban-rail (definition of R-RMO). The definition of the R-RMOs will require a higher workload for Urban-Rail than the one required complete stop of transmission. The feasibility is possible
Duty cycle control	Impossible to assess that Urban Rail systems will be protected in all place and time along the section of a metro line in open air	A very low duty cycle will be allocated to expect an acceptable total channel "see" by the Urban-rail radio systems, it means a questionable benefit	The complexity is mainly on the side of Urban-Rail. Very high complexity to define the optimal duty cycle limit along the open-air section of a metro line. This approach is not achievable
Combined methods	Impossible to assess that Urban Rail systems will be protected along the section of a metro line in open air due to the Duty Cycle control	Same considerations as above	Same considerations as above

This comparison shows that the solution for sharing and mitigation based on progressive power restriction seems to be the best compromised because its complexity of implementation is acceptable, the approach is achievable and a Road ITS application can use partially the channel.

The first solution that consist of stopping the transmission of all the vehicles in the R-RMO, can be considered, in some way, as a variant of the solution based progressive power restriction.

Depending on the environment of a line in open air, it would make sense to analyse the possibility to define R-RMOs for the solution based on progressive restriction and if the conclusion of the analysis is negative, a R-RMO could be defined for the first solution.

Annex J: Plaint text GeoJSON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Annex K: Change History

Date	Version	Information about changes
04-2024	v1.2.1	Update of the clause 5 with the addition of the clause 5.6 about the Region of Restricted mode of operation definition, update of the clause 6 about the RMOs and the clause 7 about the sharing solution. Addition of annexes about alternatives RMOs (Annex I) and plaint test GeoJSON (Annex J). Deletion of annexes about Minimum Coupling loss simulations, the interference received from Road Vehicles by Urban Rail Access points and the proposed process for the Urban rail Updatable database.

History

Document history		
V1.1.1	August 2019	Publication
V1.2.1	July 2024	Publication