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TECHNICAL REPORT

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

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

Siret N° 348 623 562 00017 - NAF 742 C
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Contents

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Foreword

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

Modal verbs terminology

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Executive summary

The present document answers to CEPT 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 applications, and between Road ITS radio technologies, considering the following:

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

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

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.

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. No specific sharing methods for the operation of Urban Rail equipment in the Road ITS bands are considered.

The sharing techniques described in the present document are applicable to other frequency bands, if required to protect legacy CBTC systems (example: Malaga CBTC system uses the 5 905 MHz to 5 925 MHz band).

The present document proposes:

- Methods to define protected zones.
- Protected Zone detection methods.
- Mitigation techniques to apply in protected zones.

Regarding the definition of protected zones, several methods have been identified. A measurement campaign will be needed to validate these results and to confirm the simulation parameters which should be used to define the proper mitigation area to protect Urban Rail communications.

Considering Protected Zone detection, the present document evaluated several solutions, but the choice of the final one is still to be done among the following:

- Read-only database combined with alert beacons.
- Updatable database combined with optional permissive beacons.

Additional requirements such as regulatory, operational and installation aspects should be taken into account for final decision.

The two solutions described in the present document based on MAC/PHY layer may be considered as long-term solutions, however existing Urban Rail lines will not be protected. Urban Rail safety and availability concepts are essential and are not guaranteed. These solutions need further investigation before confirming feasibility.

Regarding the mitigation method, adjustment of Road ITS EIRP is a possible way and can be implemented. It could be a progressive reduction with several steps when approaching the urban Rail line, up to stopping transmission on Urban Rail channels. Indeed, in critical situations like parallel roads to the Urban Rail tracks (see Malaga example) an ITS device needs to stop using the relevant Urban Rail channel in the identified mitigation area.

It is recommended that:

- standards ETSI EN 302 571 [i.4] and ETSI TS 102 894-2 [i.3] are modified; and
- a new Technical Specification is developed to address detection and mitigation techniques outlined in the present document.

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 on the basis of 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 harmonized 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, an ITS mandate has been prepared to study the extension of the upper edge of the EC harmonized safety-related ITS band (5 875 MHz to 5 905 MHz) by 20 MHz up to 5 925 MHz, and to allow Urban Rail (using Communication Based Train Control, (CBTC)) to use the EC harmonized safety-related ITS band.

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:

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

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

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.

This situation is summarized in Figure 1.

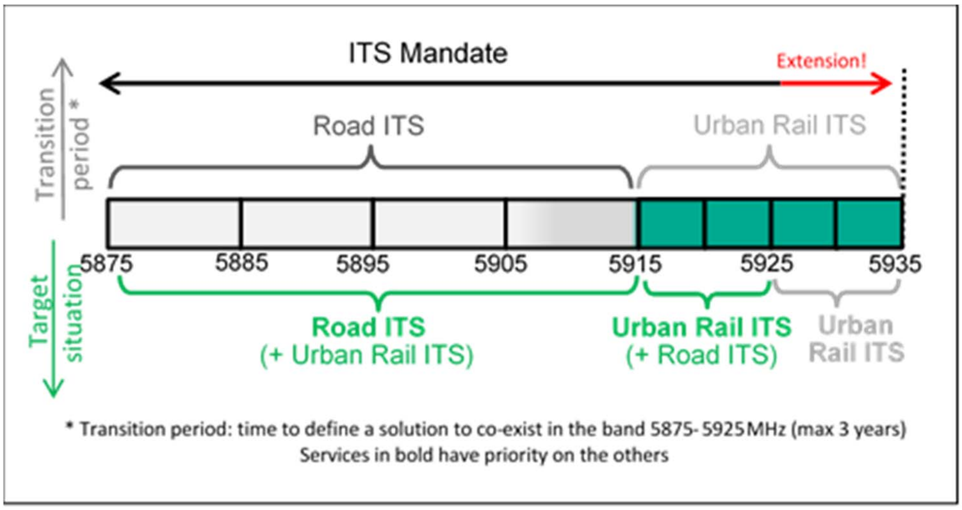


Figure 1: Road ITS and Urban Rail ITS bands

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

NOTE 2: The sharing techniques described in the present document are applicable to other frequency bands, if required to protect legacy CBTC systems (example: Malaga CBTC system uses the 5 905 MHz to 5 925 MHz band).

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 with regard to 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: "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: "Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary".

[i.4] ETSI EN 302 571 (V2.1.1): "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU".

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

[i.8] ECC Report 228: "Compatibility studies between Intelligent Transport Systems (ITS) in the band 5855-5 925 MHz and other systems in adjacent bands".

[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] ECC Report 290: "Studies to examine the applicability of ECC Reports 101 and 228 for various ITS technologies under EC Mandate (RSCOM 17-26Rev.3)".

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

[i.19] ETSI TR 102 492-1 (V1.1.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Intelligent Transport Systems (ITS); Part 1: Technical characteristics for pan-European harmonized communications equipment operating in the 5 GHz frequency range and intended for critical road-safety applications; System Reference Document".

[i.20] ETSI TR 102 492-2: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Intelligent Transport Systems (ITS); Part 2: Technical characteristics for pan European harmonized communications equipment operating in the 5 GHz frequency range intended for road safety and traffic management, and for non-safety related ITS applications; System Reference Document".

[i.21] IEEE Transactions on Vehicular Technology: "A Measurement Based Mutlilink Shadowing Model for V2V Network Simulations of Highway Scenarios", Mikael G. Nilsson, Carl Gustafsol, Taimoor Abbas, Fredrik Tufvesson, Volume 66, pp 8632-8643.

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

[i.23] 3GPP TR 36.786 (V14.0.0) (2017-03): "Vehicle-to-Everything (V2X) services based on LTE; User Equipment (UE) radio transmission and reception (Release 14)".

[i.24] ETSI TS 136 101 (V14.7.0) (2018-04): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (3GPP TS 36.101 version 14.7.0 Release 14)".

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

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

[i.27] Directive 2010/40/EU on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport.

[i.28] Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act).

[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 format".

[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] Recommendation ITU-R P.2040-1: "Effects of building materials and structures on radio wave propagation above about 100 MHz".

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

[i.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.

3 Definition 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 5 925 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 train control system utilizing:

- high-resolution train location determination, independent of track circuits;
- continuous, high-capacity, bidirectional train-to-wayside data communications; and
- trainborne 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.

dynamic detection method: method used by an ITS station to detect that it is in a geographical area where Urban Rail protection is requested only if there is a train in the area and therefore an actual need to mitigate

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

movement authority: authorization for a train to run safely to a specific location

redundant: resilient, in that it has duplicated components that increase reliability

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.

static detection method: method used by an 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
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
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
BSS	Basic Service Set
CABS	Cooperative Awareness Basic Service
CAM	Cooperative Awareness Message
CBTC	Communications-Based Train Control
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	Central ITS Station
CRA	Communication Relevance Area
CS	Central Station
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
EMC	ElectroMagnetic Compatibility
FCS	Frame Check Sequence
FWA	Fixed Wireless Access
GN	GeoNetworking
GPS	Global Positioning System
HDR	High Data Rate
HF	High Frequency
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	802.11p radio access technology in the 5,9 GHz band
ITS-S	Intelligent Transport Systems Station
ITU-R	International Telecommunication Union - Radio
LDM	Local Dynamic Map
LF	Low Frequency
LFS	propagation Loss
LoS	Line of Sight
MAC	Medium Access Control
MAP	Map data
MCL	Minimum Coupling Loss
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
OOB	Out Of Band
PHY	PHYsical
PKI	Public Key Infrastructure
PR	Protection Ratio
PSD	Plateform Screen Doors
PZ	Protected Zone
PZM	Protected Zone Message
QPSK	Quadrature Phase Shift Keying
RATP	Régie Autonome des Transport Parisien (Metro operator of Paris)
RER	Reseau Express Regional (suburban metro lines in Paris)
RF	Radio Frequency
RSU	Road Side Unit or Rail Side Unit
RTS	request To Send
RX	Receiver
S_RX	Signal Received
S_TX	Signal Transmitted
SAE	Society of Automotive Engineers
SIFS	Short Interframe Spece
SPAT	Signal Phase and Timing
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
T-ITS-S	Train ITS Station
TPC	Transmit Power Control
TS	Technical Specification
TS	Terminal Station
TS-ITS-S	Track Side ITS Station
TX	Transmiter
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: Either T-ITS-S or TS-ITS-S.

UTC	Coordinated Universal Time
V-ITS-S	Vehicle ITS station
WGFM	Working Group Frequency Management
WIFI	IEEE 802.11 family of standards
XML	eXtensible Markup Language
ZC	Zone Controller

4 Technical system description

4.1 Technical description of CBTC system communications

4.1.1 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 clause 4.1 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 as shown in Figure 2.

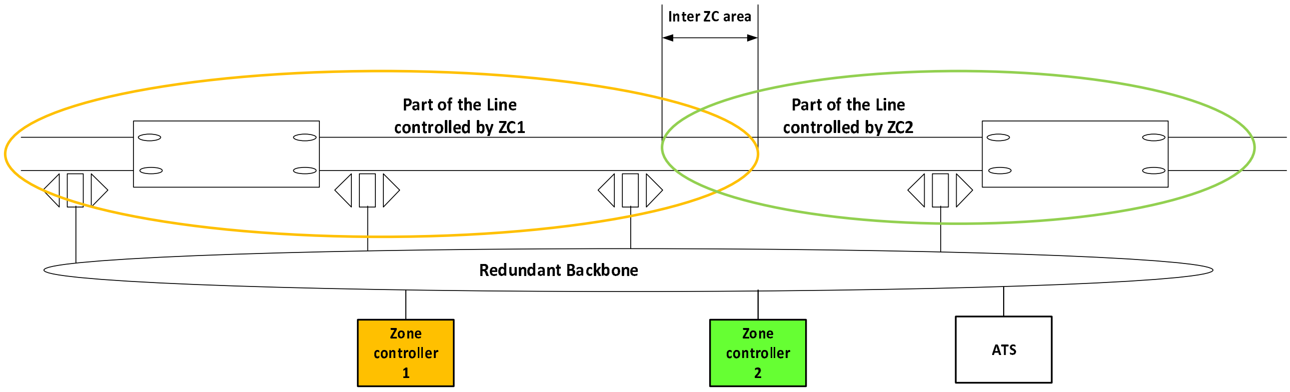


Figure 2: Generic CBTC communication scenario

The back to back antennas used by each CBTC access point represented in Figure 2, in Figure 3 and in Figure 4 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.

When the line divides in two branches, each branch is controlled by its own ZC. In the example shown in Figure 3, the line is controlled by three ZC.

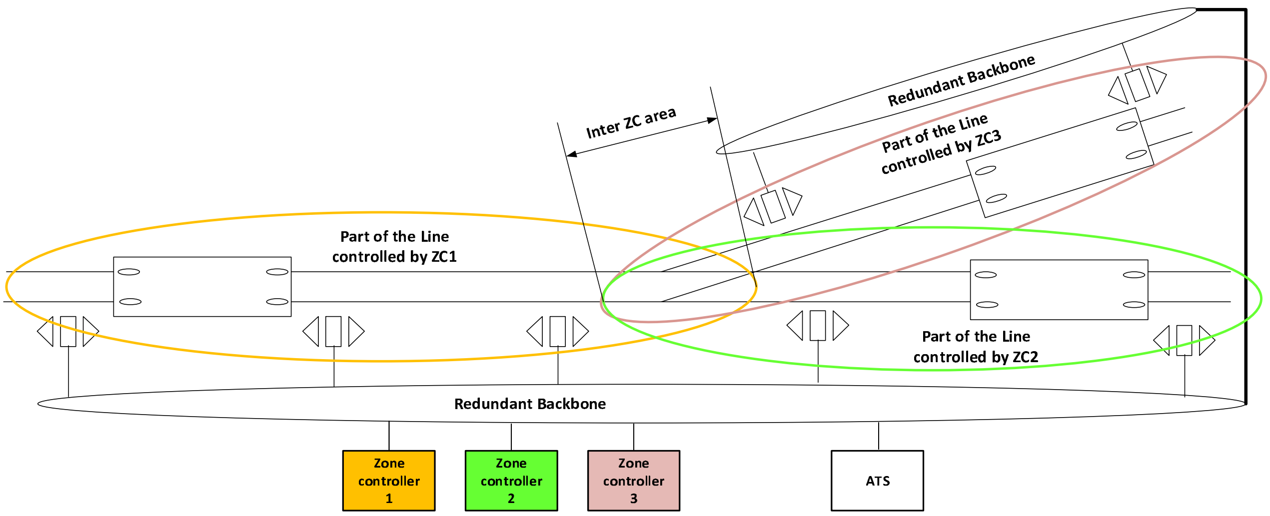


Figure 3: CBTC communication scenario with 3 ZC

It is important to note that between the ZC (shown as Inter ZC area) is a critical area where the trains perform a handover between ZC and exchange information with up to three different ZC.

In this area the downlink and uplink throughput per Access Point can be higher than 150 Kbits/s per train.

In case of a driverless line, Platform Screen Doors (PSD) are installed inside stations. The platform screen doors are controlled by the trains for the opening and closing of the doors when the train is docked in station.

The Platform Screen Doors are controlled via a PSD controller connected to the redundant backbone as shown in Figure 4.

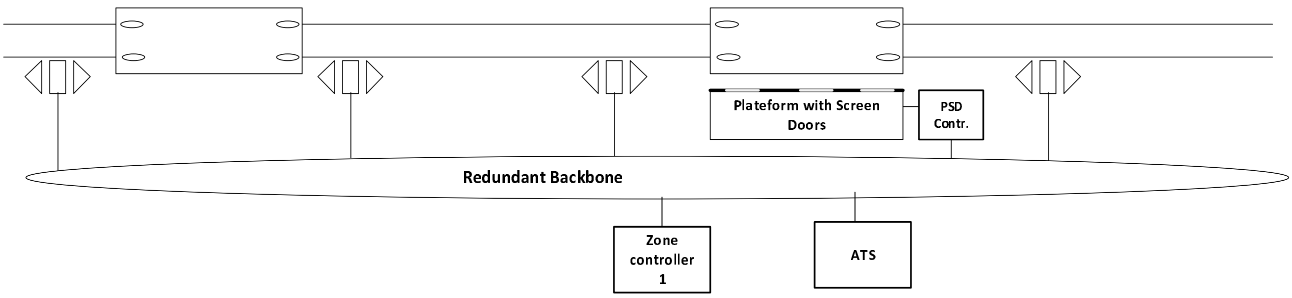


Figure 4: Additional CBTC communication need due to PSD

Wayside radio antennas are installed at around 5 to 6 m above ground level and are close to the tracks (typically 1 m from one track, and therefore typically 5 m from the other track).

The last use case is the one for depot, stabling or maintenance areas, where the density of trains can be high, as trains can be parked with less than 2 m between them on the same tracks, and large number of parallel tracks can be present.

These trains need communication in order to:

- be operated and controlled by CBTC, to enter or move in the depot;
- allow maintenance operations such as:
  - checking conformity of the communication system of the CBTC on-board unit;
  - reconfiguration and update of radio or CBTC on-board units.

Therefore, in these areas, the total available capacity of the channel can be used, so specific radio coverage rules can be applied to ensure coverage (including the use of less directional antennas than is usual).

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 OFDM and CSMA-CA.

They have different receiver sensitivity, minimum signal to interference ratio and timing performance requirements, which will be further detailed in clauses 4.1.2 and 4.1.3.

4.1.2 Detailed technical characteristics of CBTC communication system 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 5, controlled by a cell controller which manages the time synchronization, as described in Figure 6.

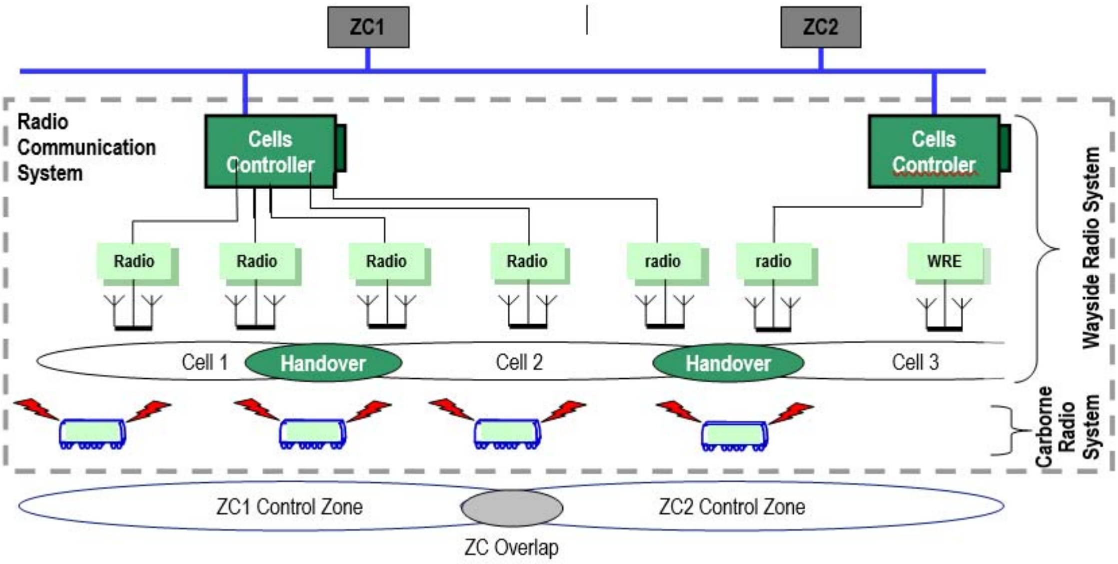
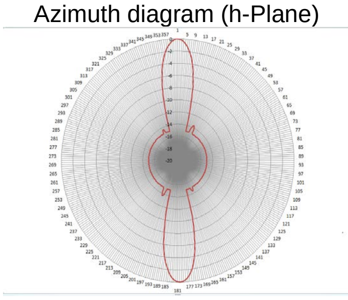
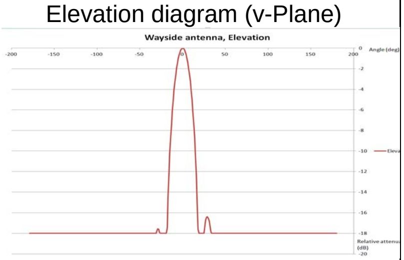
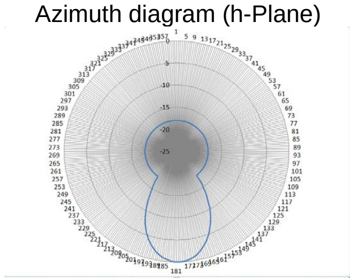
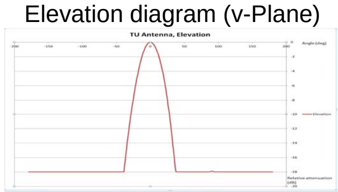


Figure 5: Overview of DSSS/TDMA CBTC communication system

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 6.

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	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. Refer to archive tr_103580v010101p0.zip which accompanies the present document for more information	Azimuth diagram (h-Plane)  Bore sight of the antenna is in direction of the tracks Elevation diagram (v-Plane)  Antenna is installed without tilt. Refer to archive tr_103580v010101p0.zip which accompanies the present document for more information
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 %.

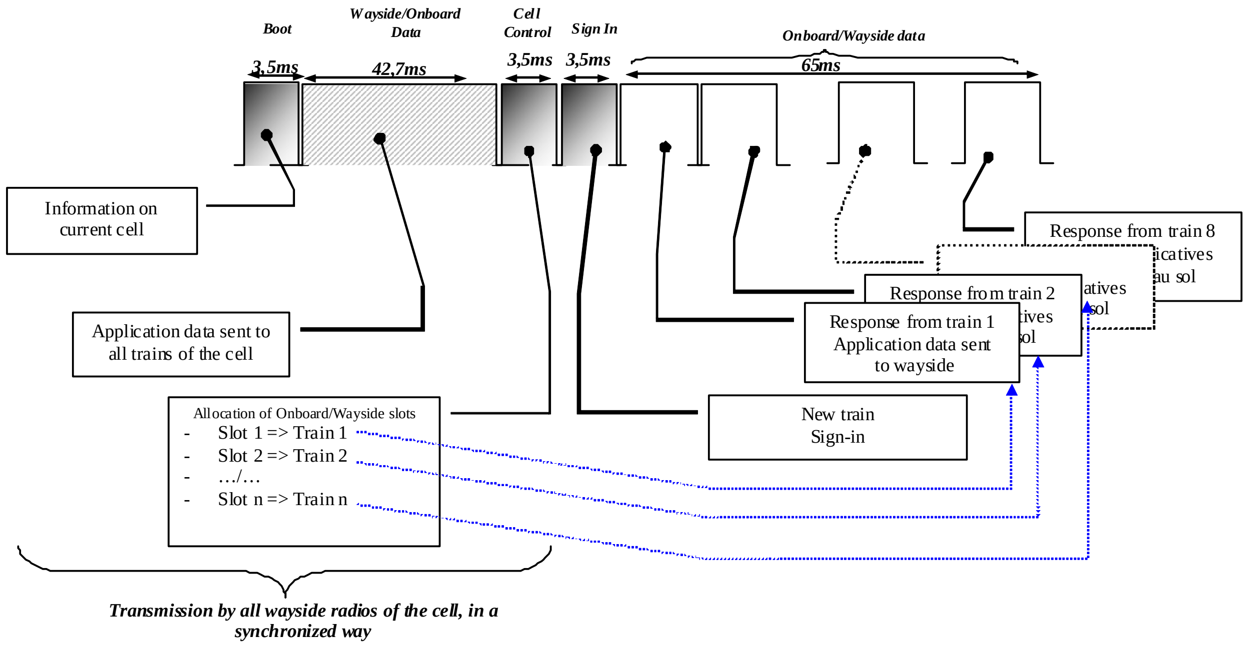


Figure 6: Timing characteristics of DSSS/TDMA CBTC communication system

Maximum packet loss allowed at application level: ***Message Error Rate*** **< 1 %**

For DSSS/TDMA based CBTC systems no listen before talk mechanism is in place. Sharing based on this mechanism is therefore not possible:

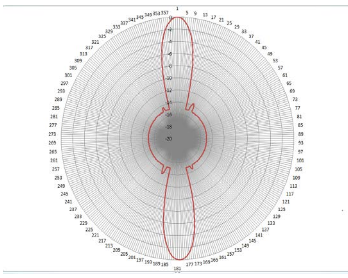
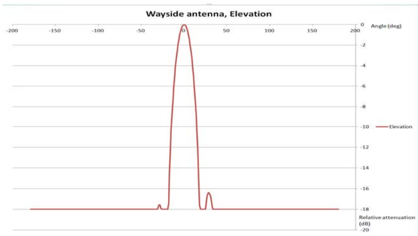
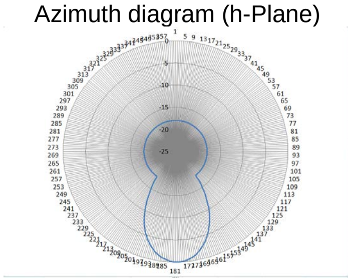
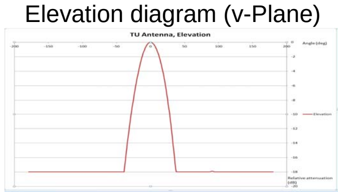
- Radio Planning rules:
  - In order to guarantee a link between train and wayside in better than 99 % locations, a fade margin of 15 dB is used.

4.1.3 Detailed technical description of CBTC communication system IEEE 802.11 based

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 repetitions of each message are used 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 technical characteristics

Technical characteristics of CBTC IEEE 802.11 based system.		
	CBTC wayside Base Station	**CBTC train unit**
Frequency	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. Refer to archive tr_10358010101v010101p0.zip which accompanies the present document for more information	Azimuth diagram (h-Plane)  Bore sight of the antenna is in direction of the tracks Elevation diagram (v-Plane)  Antenna is installed without tilt. Refer to archive tr_103580v010101p0.zip which accompanies the present document for more information
Protection ratio (PR) (Protection Ratio is the minimum C/N+I criterion ensuring Message Error Rate < 10^{-2})	9 dB	9 dB
Radio Transmission speed 1,5 Mbits/s. Modulation BPSK and Coding rate 1/2 Sensitivity (for BER 10^{-5})	< -88 dBm	< -88 dBm
Radio Transmission speed 3 Mbits/s Modulation QPSK coding rate ½ (for BER 10^{-5}) Minimum Sensitivity (QPSK modulation)	< -85 dBm	< -85 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: Combined diagram for an antenna array with 2 back-to-back antennas and a power splitter.		

NOTE: 1. Uplink and Downlink are unbalanced.

2. Operating mode is TDD.

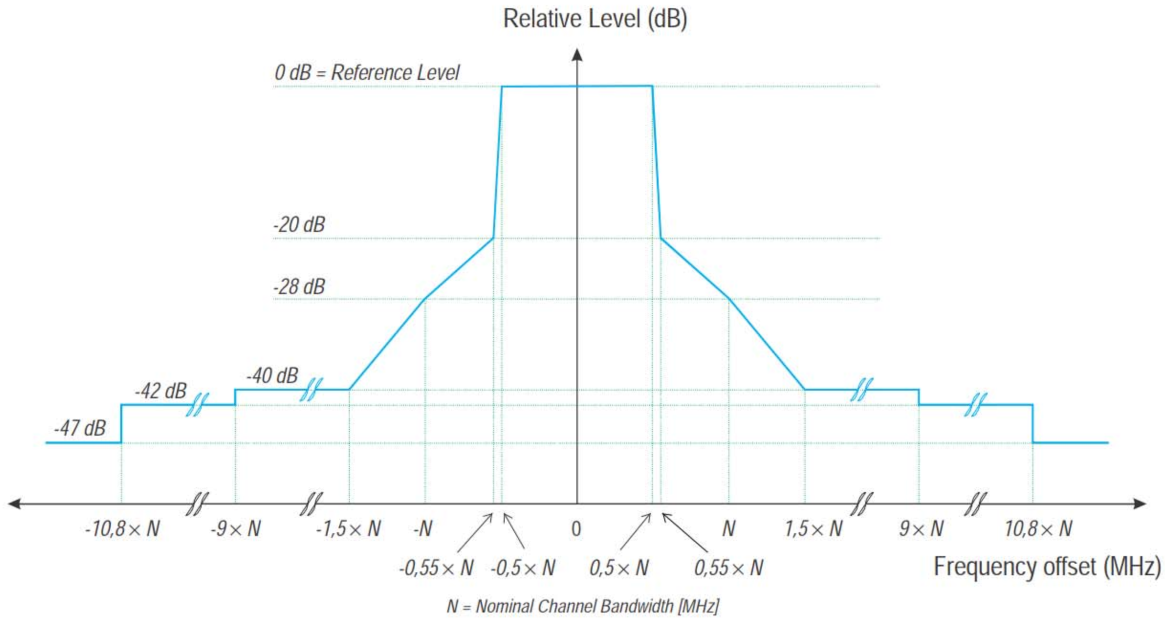


Figure 7: Spectrum mask of an IEEE 802.11-based CBTC system compliant with ETSI EN 301 893 [i.16]

CBTC systems based on IEEE 802.11 technology can use an additional filter with the following characteristics:

- In-band 5 875 MHz to 5 925 MHz:
  - Additional rejection 15 dBc @ 5 855 MHz and 5 945 MHz.

For a channel using central frequency 5 920 MHz:

- Rejection 5 927,5 MHz < f < 5 940 MHz: -40 dBr.
- Rejection for f > 5 945 MHz: -55 dBr.

Timing: (see also Annex C).

CSMA/CA and Automatic Repeat Request at MAC layer level are used:

- Duty cycle for wayside transmitters:
  - Between 6 % to 60 % for a wayside access point (worst-case when 6 trains are associated with a wayside access point).
- Duty cycle for a train:
  - Average value between 6 % and 12 %. In particular circumstances (Train communication with three ZC and entering a station with platform screen doors) the throughput of a train can reach up to 25 % of duty cycle temporarily.
- Maximum allowed packet loss at application layer:
  - Message Error Rate ≤ 1 %.
- Maximum allowed application layer latency:
  - $T_{lat} \leq 100$ ms.

- Radio Planning rules:
  - In order to guarantee a link between train and wayside in more than 99 % locations, a fade margin of 15 dB is used.

4.2 Technical description of the LTE-V2X System

LTE-V2X is one of the Road ITS technologies. Its main characteristics are summarized in Table 3 and Table 4.

Table 3: Technical parameters of LTE-V2X

Parameter	Value	Comments
Maximum radiated power (EIRP.)	33 dBm EIRP with 6 dBi antenna gain and 23 dBm/MHz max power spectral density (PSD). 14 PRB (Physical Resource Block): 27 dBm EIRP 20 PRB: 28,5 dBm EIRP	**According to 3GPP TR 36.786 [i.23]** Table 6.2.2.2-1: Simulation assumptions: V2X communications
Antenna beam shape/gain	0 dBi or 6 dBi	**According to 3GPP TR 36.786 [i.23]** Table 6.2.2.2-1: Simulation assumptions: V2X communications
Polarization	Omni Antenna or Recommendation ITU-R F.1336-1 [i.37] in ECC Report 101 [i.7]	**According to 3GPP TR 36.786 [i.23]** (See note 1)
Modulation and Coding Scheme	QPSK, target rate 1/2; QPSK, target rate 3/4; 16QAM, target rate 1/2; 16QAM, target rate 3/4.	**According to 3GPP TR 36.786 [i.23], clause 5.3.1.1** QPSK, target rate 1/2; QPSK, target rate 3/4; 16QAM, target rate 1/2; 16QAM, target rate ¾
Data rates	56,6 kbps to 15,1 Mbps	Calculated based on various modulation and coding scheme
Channel Bandwidth	10 MHz	
Communication mode	TDD, broadcast	Half-duplex and broadcast are believed to be adequate for most applications considered to date
Receiver noise power	-91 dBm	**According to 3GPP TR 36.786 [i.23], clause 5.3.2** Where noise floor is -91 dBm coming from thermal noise of -104 dBm and noise figure of 13 dB
TPC	TPC with range > 30 dB (The minimum output power is down to -40 dBm)	**According to ETSI TS 136 101 [i.24]** Clause 6.3.2G defines minimum output power to -40 dBm
Duty Cycle	2 % based on the assumptions given in note 2	1 % based on the assumptions given in note 3. Peak rate of 2 % is assumed in case of retransmissions
Message length	190 Bytes/300 Bytes	**According to 3GPP TR 36.786 [i.23]** Table 6.2.2.2-1: Simulation assumptions: V2X communications
Transmitter unwanted emissions	See Table 4	**According to ETSI TS 136 101 [i.24], clause 6.6.2.2.4**
NOTE 1: For coexistence scenarios such as CEN DSRC vs LTE-V2X studied in 3GPP, omni antennas are assumed. Nevertheless, the antenna pattern assumed in ECC Report 101 [i.7] based on an ITU-R F.1336 model could also be used/supported. NOTE 2: In ECC Report 101 [i.7], duty cycle is defined as "possibility for active ITS devices to transmit messages simultaneously". It is assumed that one vehicle is transmitting at a time within a given communication range (Clause 3.2.1.1.3 in ECC Report 101 [i.7]), while in LTE-V2X one or several transmissions may occur simultaneously. Information on ITS message generation was not available at the time of writing ECC Report 101 [i.7]. NOTE 3: For the duty cycle calculation for LTE-V2X it is considered: i) the fact that multiple vehicles may transmit simultaneously; ii) the availability of information on CAM message generation. The results are based on assumptions following the given references. CAMs are the dominant factor for duty cycle 1 CAM transmission every 100 ms (10 Hz maximum as of ETSI EN 302 637-2 [i.2]). Each message has 1ms duration (190 Bytes to 300 Bytes as of 3GPP TR 36.786 [i.23]). No repetition of messages has been considered.		

Table 4: LTE-V2X TX mask based on ETSI EN 302 571 [i.4]

Spectrum emission limit (dBm)/ Channel bandwidth		
Δf_{OOB} (MHz)	**For 10 MHz channel bandwidth**	**Measurement bandwidth**
±0,5	$[-13 - 12\left(^{\lvert\Delta fOOB\rvert}/_{MHz}\right)]$	100 kHz
-5 to -0,5 0,5 to 5	$[-19 - \frac{16}{9}\left(^{\lvert\Delta fOOB\rvert}/_{MHz} - 0{,}5\right)]$	100 kHz
-10 to 5 5 to 10	$[-27 - 2\left(^{\lvert\Delta fOOB\rvert}/_{MHz} - 5{,}0\right)]$	100 kHz

4.3 Technical description of the ITS-G5 system

ITS-G5 is one of the Road ITS technologies. Its main characteristics are summarized in the Table 5 and Table 6.

Table 5: ITS-G5 technical parameters

Parameter	Value	Comments
Maximum radiated power (EIRP.)	33 dBm, 23 dBm/MHz	According to existing regulation
Antenna beam shape/gain	Typical antenna modelRecommendation ITU-R F.1336-1 [i.37] with parameters G0 5 dB, k 1.2, max gain in +10 deg elevation	Typical performance from ECC report 101 [i.7] and ECC Report 228 [i.8]
Polarization	Vertical linear	The antenna performance is not described in ITS-G5 however vertical linear polarization is dominant
Modulation and Coding Scheme	BPSK QPSK 16QAM 64QAM	According to ETSI EN 302 571 [i.4] and ETSI EN 302 663 [i.6]
Data rates	3/4,5 /6/9/12/18 /24/27 Mbit/s Mandatory: 3/6/12 Mbit/s	According to ETSI EN 302 663 [i.6]
Channel Bandwidth	10 MHz	
Communication mode	TDD, broadcast	TDD and broadcast are believed to be adequate for most applications considered to date
Receiver noise power	-100 dBm	Typical performance
Receiver sensitivity	-92 dBm/MHz minimum limit at default 6 Mbit/s Typical performance 10 dB better	According to ETSI EN 302 571 [i.4]
TPC	30 dB	According to existing regulation
Duty Cycle	Typically < 1,0 % over one hour, maximum 3 % in one second	The duty cycle of the ITS systems is under control of mandatory congestion control and dynamic message generation rules in order to guarantee an access to the channel for safety critical message. The average duty cycle value of 1 % over one hour is assumed for the periodic awareness messages (CAM) of an ITS station. The peak value of 3 % is assumed to be related to safety critical event based messages like DENM. In addition to the periodic CAM messages. Higher duty cycle for specific application might be required in the future. The presented duty cycles are will cover the day one application requirements
Additional Mitigation techniques	See ETSI TS 102 792 [i.1]	ETSI TS 102 792 [i.1] defines a set of mitigation techniques to protect CEN DSRC tolling systems in the band 5 795 MHz to 5 815 MHz. These techniques are mandatory included in the harmonized standard ETSI EN 302 571 [i.4]. In addition, a specific message set has been specified in the CAM specification (ETSI EN 302 637-2 [i.2]) which will allow for the protection of a tolling station

Parameter	Value	Comments
Message length	Cooperative awareness messages (CAM): < 1 ms Decentralized Environmental Notification Message (DENM): < 2 ms	According to ETSI EN 302 637-2 [i.2] and ETSI EN 302 637-3 [i.5]
Transmitter unwanted emissions	See Table 6	According to ETSI EN 302 571 [i.4]

Table 6: Transmitter spectrum mask for 10 MHz channel bandwidth in ETSI EN 302 571 [i.4]

Carrier frequency fc (dBc)	±4,5 MHz offset (dBc)	±5,0 MHz offset (dBc)	±5,5 MHz offset (dBc)	±10 MHz offset (dBc)	±15 MHz offset (dBc)
0	0	-26	-32	-40	-50

5 Evaluation of the mutual impact areas

5.1 Introduction

The following clauses identify the interference effects of Road ITS devices in the vicinity of an Urban Rail communication system in the designated Urban Rail channels. Firstly, the pure interference effect of a 100 % active Road ITS device is evaluated using different levels of modelling accuracy from an MCL calculation over a 2-ray model to the deployment of the wireless network planning tool. Then some timing considerations and listen-before-talk calculations are addressed.

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-Ss are likely to be active, for example in tunnels. As a result, no analysis is required.

5.2 Signal to Interference considerations

5.2.1 MCL calculations

5.2.1.1 Overview

An initial Minimum Coupling Loss (MCL) calculation for the evaluation of the interference potential from an ITS device towards an Urban Rail communication system is given. The MCL calculation is based on a multi-slope pathloss model for different environments ranging from Urban over Sub Urban to Rural areas. In addition, a model from ECC Report 101 [i.7] and a Line-of-Sight (LoS) model is being used.

5.2.1.2 Pathloss models

The calculations developed in the impact studies using MCL calculations use the same propagation model as in ECC Report 68 [i.18]. In Table 6.2.2 of ECC Report 68 [i.18], data about FWA Central Station (CS) is provided, representative of all FWA devices located at high elevations, whereas the FWA Terminal Station (TS) models FWA devices deployed at low elevations. It is then proposed to consider ITS system as TS, therefore the breakpoints and exponents corresponding to the TS case will be used.

It means that propagation losses L_{FS} are considered as the conventional expression up to d_0 and corrected expression beyond. The formula to calculate the losses is given as follows:

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & for\ d < d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d}{d_0}\right) & for\ d_0 < d < d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d_1}{d_0}\right) - 10n_1 Log\left(\frac{d}{d_1}\right) & for\ d_1 < d \end{cases}$$

Another propagation model is also proposed in ITS SRDoc ETSI TR 102 492-1 [i.19] and ETSI TR 102 492-2 [i.20]. Assumptions are a first breakpoint distance d_o at 15m and exponent beyond $n_o=2.7$. Separation distances presented below will investigate both cases.

Table 7: Parameters of propagation

	Urban	Suburban	Rural	ETSI
Breakpoint distance d0 (m)	64	128	256	15
Pathloss factor n0 beyond the first break point	3,8	3,3	2,8	2,7
Breakpoint distance d1 (m)	128	256	1 024	1 024
Pathloss factor n1 beyond the second breakpoint	4,3	3,8	3,3	2,7

These models do not take into account significant shadowing effects in urban canyon conditions, such as the potential blocking of interference from a neighbouring street separated by buildings.

In addition to these slope models a very simple Line-of-sight (LoS) model has been added to show the worst-case situation.

The results are calculated taking into account four different conditions:

- **Main-Lobe-ITS toward Main-Lobe-Urban Rail:**
  - This case is the worst-case conditions where no additional antenna mitigation factors are considered.
- **Main-Lobe-ITS toward Side-Lobe-Urban Rail:**
  - In this case the assumption is that the ITS device is operated in the side lobe of the Urban Rail antenna with an attenuation of 15 dB (Way Side Unit) or 18 dB (Train Unit) compared to the boresight of the Urban Rail device antenna.
- **Side-Lobe-ITS toward Main-Lobe-Urban Rail:**
  - In this case the assumption is that the Side lobe of an ITS device is pointing to the main lobe of the Urban Rail system antenna. A mitigation factor of 5 dB has been included.
- **Side-Lobe-ITS toward Side-Lobe-Urban Rail:**
  - Here only the side lobes of the systems are considered. This leads to a mitigation factor of 20 dB (Wayside Unit) or 23 dB (Train Unit).

Depending on the actual situation one of these four conditions can be assumed.

5.2.1.3 Results summary

The results of the MCL calculations are given in Annex C. The two Urban Rail systems presented in clause 4.1 have been considered separately due to the different protection requirements. The DSSS-TDMA based system is much more robust against potential interference than IEEE 802.11 [i.15] based systems. This robustness comes with the expense of a much higher duty cycle as compared to IEEE 802.11 [i.15] based systems.

The minimum Urban Rail received signal considered was -77 dBm, corresponding to a deployment with system margin as described in ECC Report 290 [i.11]. On site, depending on the deployment rules which had been actually followed, the situation can be worse (down to the level corresponding to the system sensitivity and 3 dB desensitization).

In addition, the interference effects towards the train units and wayside units have been calculated since the two devices deploy different antennas including slightly different losses in the installation and thus leading to different results:

- **DSSS-TDMA Urban Rail system:**
    - For a typical deployment scenario of Urban Rail systems in Urban and Sub-Urban environments the mitigation distance for a Main-Beam to Main-Beam situation ranges from 564 m (33 dBm, Sub-Urban) down to 128 m for a 10 dBm ITS device. In a denser Urban Environment these ranges are 328 m for 33 dBm and 92 m for 10 dBm.
    - For most of the situations and directions, an ITS main beam and an Urban Rail side lobe could be considered. In this case the distance in a Suburban environment would decrease down to 181 m for the 33 dBm and 23 m for the 10 dBm ITS TX case. In urban environments these values will further decrease down to 125 m and 82 m, respectively. These values are calculated using the wayside unit case and represent here the worst case since the train side unit has slightly better antenna conditions.
- **IEEE 802.11 based Urban Rail System:**
    - For a typical deployment scenario of Urban Rail systems in Urban and Sub-Urban environments the mitigation distance for a Main-Beam to Main-Beam situation ranges from 1 168 m (33 dBm, Sub-Urban) down to 290 m for a 10 dBm ITS device. In a denser Urban Environment these ranges are 623 m for 33 dBm and 182 m for 10 dBm.
    - For the most situations and directions an ITS main bean and an Urban Rail side lobe could be considered. In this case the distance in a Suburban environment would decrease down to 471 m for the 33 dBm and 90 m for the 10 dBm ITS TX case. In urban environments these values will further decrease down to 279 m and 77 m, respectively.

These figures give the basic area of further investigations. No additional timing related factors have been considered here. Some initial conclusions can already be drawn by these figures. Since the largest mitigation distance is reached in the main beam of the Urban Rail system, the most critical areas to be considered are the areas covered by the main beam of the Urban Rail system. If in these directions no road traffic can be considered the mitigation area around the Urban Rail system is less important and could be reduced. On the other side, a dense road in the direction of the main beam could lead to more stringent mitigation requirements being required. This situation might specifically occur in open suburban/rural areas like in the Malaga case, see clause 5.2.3. In denser Urban environments this case might materialize for large streets in the direction of the Urban Rail tracks or parallel to the Urban Rail track, see Paris case in Annex A.

For a more detailed analysis of the required mitigation zone, the considered path loss models are not sufficient and have not been designed for that task.

All detailed results and calculations are given in Annex C.

5.2.2 Experimental Propagation model based on 2 ray-model

The interference level received by an Urban Rail base station from road vehicle antennas running on a road parallel to a Urban Rail line has been evaluated using the two-ray propagation model with one ground reflection.

The evaluation has been made for the following scenario:

- Urban Rail base station antenna height above the ground: 5 m.
- Urban Rail base station antenna gain: 18 dBi.
- Axis of the first lane of the road at 20m from the base station antenna.
- Antenna height of the Road Vehicle above the ground; between 1,5 m and 4 m.
- Type of terrain: flat terrain.

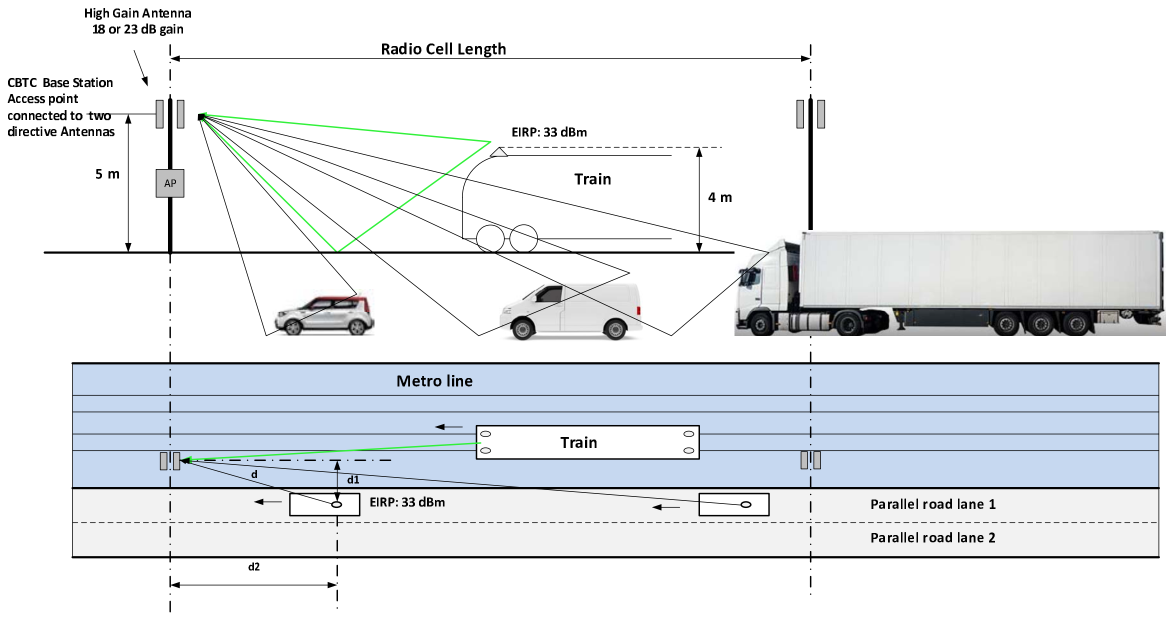


Figure 8: Scenario for the evaluation of interference level received from road vehicles on a road parallel to an Urban Rail line

The evaluation has considered the antenna radiating diagram of the Urban Rail antenna, the antenna height of the road vehicles above the grounds and the complex relative permittivity of the ground.

The simulation analysis has shown that the antenna height of the road vehicles has a strong impact on the interference level received by the Urban Rail antenna. The variation of the received level from a road vehicle located at 600 m can be up to 30 dB depending on the vehicle antenna height variations between 1,5 m and 4 m.

A comparison has been made with other propagations models: free space loss, urban and suburban propagation models.

The results of this comparison show that urban and suburban propagation models are not suitable to evaluate the interference level received because the antenna height of the road vehicle is not considered.

It makes sense to use a model that will consider all possible road vehicle antenna heights above the ground.

This model is derived from the two-ray propagation model with one ground reflection. At each distance from the Urban Rail base station antenna, the path loss to a road vehicle is computed via the two- ray propagation model. The road vehicle antenna height is varied between 1,5 m and 4 m and only the minimum path loss value is kept as a worst-case result for a given distance.

Figure 9 shows the received interference power density value at the CBTC antenna connector for the worst case two-ray propagation model, considering road vehicle antenna height, and for the free space loss, urban and suburban propagation models. The antenna pattern of the Urban Rail antenna base station and a road vehicle EIRP of 23 dBm/MHz are used.

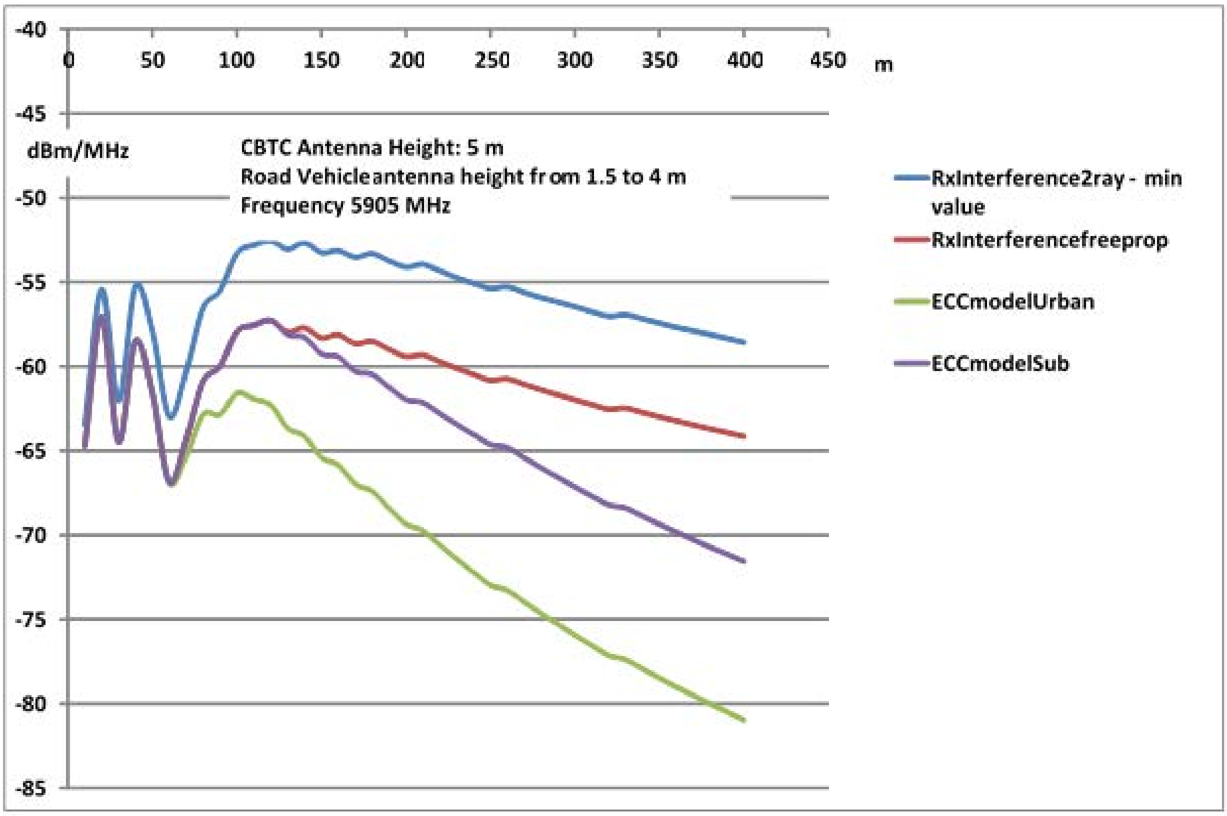


Figure 9: Interference power density received from one single road vehicle for different propagation models

The complete analysis is available in Annex D.

It can be observed that the interference power density level at the antenna connector of an Urban Rail Base station can be up to-52 dBm/MHz for an interferer power density of 23 dBm/MHz (worst-case assumption).

5.2.3 Simulation for real situations for an interferer

The analysis of different real scenarios was performed using *"ICS telecom EV software"*. The ICS telecom EV 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. Likewise, the influence of the clutter and building attenuation from conditions given in Recommendation ITU P.2040-1 [i.34] are comprised in results.

Five case studies were analysed with characteristic propagation conditions:

Situation 1. Parallel road "Bulevar Louis Pasteur" between Universidad and Clînico metro station in Màlaga (Spain), metro line 1.

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

Situation 3. Parallel road "Boulevard Auguste Blanqui" between Saint-Jacques and Corvisart metro station in Paris (France), metro line 6.

Situation 4. Parallel highway and bridge in "N13" between La Defense and Les Sablons metro station in Paris (France), metro line 1.

Situation 5. A86 Highway intersecting the railroad between Houilles Carrieres-Sur-Sein and La Garenne-Colombes RER train system.

In order to evaluate the area of impact where Road ITS can disturb reception of an Urban Rail AP, the following method was used:

- Define the maximum interfering signal level *S_RX*, which can be received from an ITS device at AP radio connector input without disturbance (corresponding to the use case when this AP receives signal from trains at the edge of its coverage area).
- Consider in the simulation a transmission by the Urban Rail AP, using Urban Rail AP antenna diagrams given in clause 4.1 (identical for the two types of Urban Rail communication systems considered), but transmitting a *S_TX* signal, with a power corresponding to the EIRP of the Road ITS.
- Consider that the area where Road ITS vehicles affect Urban Rail communication, is the area where the simulated received level is superior or equal to the level *S_RX*.

This method is based on the concept of symmetry of propagation, considering that if a signal *S_TX*, transmitted from the train at radio device connector, is received with a given level *S_RX* on the ITS station radio connector, then if the signal *S_TX* is transmitted at Road ITS radio connector, it will be received at a level *S_RX* at Urban Rail radio device connector.

It also takes into account the fact that the Road ITS devices are using omni-directional antennas and that their gain is considered into the *S_TX* EIRP value.

All simulations use the same colour palette as shown in Figure 10.

That palette is defined in order to show on the same map the areas where an ITS station could interfere with the Urban Rail communication in the following scenarios:

- ITS station EIRP of 33 dBm and:
  - DSSS/TDMA CBTC deployed with maximum distance corresponding to desensitization of 3 dB.
  - IEEE 802.11 [i.15] based CBTC with maximum distance corresponding to desensitization of 3 dB.
  - DSSS/TDMA CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].
  - IEEE 802.11 [i.15] based CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].
- ITS station EIRP of 20 dBm and:
  - DSSS/TDMA CBTC deployed with maximum distance corresponding to desensitization of 3 dB.
  - IEEE 802.11 [i.15] based CBTC with maximum distance corresponding to desensitization of 3 dB.

  - DSSS/TDMA CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].
  - IEEE 802.11 [i.15] based CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].

- ITS station EIRP of 10 dBm and:
  - DSSS/TDMA CBTC deployed with maximum distance corresponding to desensitization of 3 dB.
  - IEEE 802.11 [i.15] based CBTC with maximum distance corresponding to desensitization of 3 dB.
  - DSSS/TDMA CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].
  - IEEE 802.11 [i.15] based CBTC communication system receiving a minimal signal level of -77 dBm, corresponding to a radio planning with "system margin" as used in ECC report 290 [i.11].

These scenarios are referring to typical situations considered in other studies such as ECC report 290 [i.11] and are provided to give reference for the possible worst-cases situations and show a typical order of magnitude for the required Protected Zones.

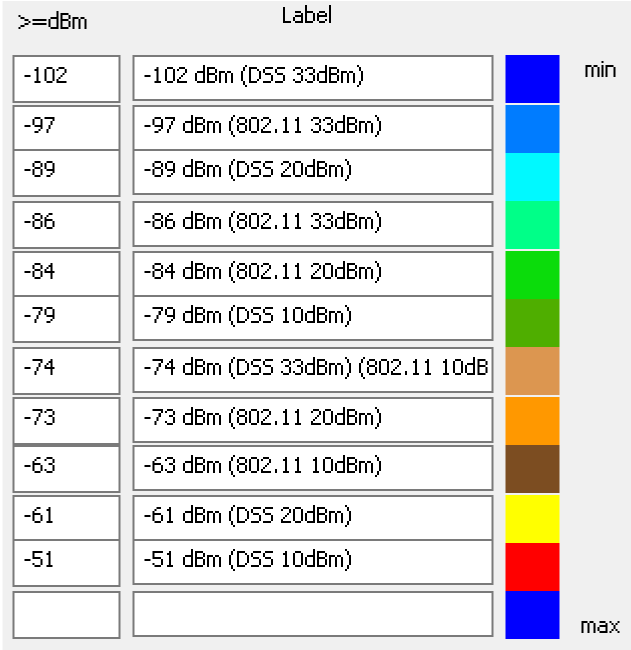
Similarly, both kind of CBTC communication systems have been considered for each geographical area simulated, even if only one kind is actually deployed for a given Urban Rail line.

When analysing a practical case, the communication system to be used should be the deployed one, and the threshold to be used should be based on the actual deployment rules and in particular the actual system margin which has been use. Therefore, a single threshold by scenario will be kept, intermediate between the values used in the present document.

The levels *S_RX* corresponding to the considered scenarios are calculated as shown in Table 8

Table 8: Calculation of level thresholds for the simulation palette

Scenario	*S_RX*
Road ITS EIRP: 33 dBm CBTC: DSSS, desensitization = 3 dB	Sensitivity - Protection Ratio (therefore interference level is equal to Noise level, and C/(I+N) = C/N-3 dB: -105 + 3 = -102 dBm
Road ITS EIRP: 33 dBm CBTC: IEEE 802.11 based, desensitization = 3 dB	Sensitivity - Protection Ratio (therefore interference level is equal to Noise level, and C/(I+N) = C/N-3 dB: -88 - 9 = -97 dBm
Road ITS EIRP: 33 dBm CBTC: DSSS, deployment with system margin	Minimum signal -Protection Ratio: -77 + 3 = -74 dBm
Road ITS EIRP: 33 dBm CBTC: IEEE 802.11 based, deployment with system margin	Minimum signal -Protection Ratio: -77 - 9 = -86 dBm
Road ITS EIRP: 20 dBm CBTC: DSSS, desensitization = 3 dB	Sensitivity - Protection Ratio + Impact of Road ITS Tx reduction: -105 + 3 + 13 = -89 dBm
Road ITS EIRP: 20 dBm CBTC: IEEE 802.11 based, desensitization = 3 dB	Sensitivity - Protection Ratio + Impact of Road ITS Tx reduction: -88 - 9 + 13 = -84 dBm
Road ITS EIRP: 20 dBm CBTC: DSSS, deployment with system margin	Minimum signal -Protection Ratio+ Impact of Road ITS Tx reduction: -77 + 3 + 13 = -61 dBm
Road ITS EIRP: 20 dBm CBTC: IEEE 802.11 based, deployment with system margin	Minimum signal -Protection Ratio+ Impact of Road ITS Tx reduction: -77 - 9 + 13 = -73 dBm
Road ITS EIRP: 10 dBm CBTC: DSSS, desensitization = 3 dB	Sensitivity - Protection Ratio + Impact of Road ITS Tx reduction: -105 + 3 + 23 = -79 dBm
Road ITS EIRP: 10 dBm CBTC: IEEE 802.11 based, desensitization = 3 dB	Sensitivity - Protection Ratio + Impact of Road ITS Tx reduction: -88 - 9 + 23 = -74 dBm
Road ITS EIRP: 10 dBm CBTC: DSSS, deployment with system margin	Minimum signal -Protection Ratio+ Impact of Road ITS Tx reduction: -77 + 3 + 23 = -51 dBm
Road ITS EIRP: 10 dBm CBTC: IEEE 802.11 based, deployment with system margin	Minimum signal -Protection Ratio+ Impact of Road ITS Tx reduction: -77 - 9 + 23 = -63 dBm



>=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 10: Colour palette used for simulation

To define the protection areas depending on the maximum EIRP used by the Road ITS for an actual Urban Rail ITS (i.e. an actual technology and actual deployment rules) the corresponding colours should be used.

EXAMPLE: For a DSSS system deployed in a way to support a desensitization of 3 dB:

- In the area outside of the -102 dBm threshold (dark blue), there is no need for mitigation for the Road ITS maximum EIRP of 33 dBm.
- In the area inside the -102 dBm threshold and outside of the -89 dBm threshold, the Road ITS EIRP should be limited to 20 dBm to avoid the risk of interference to Urban Rail: it corresponds to the areas in dark blue and mid blue.
- In the area inside the -89 dBm threshold and the -79 dBm threshold, the Road ITS EIRP should be limited to 10 dBm to avoid the risk of interference to Urban Rail: it corresponds to the areas in light blue, light green and mid green.

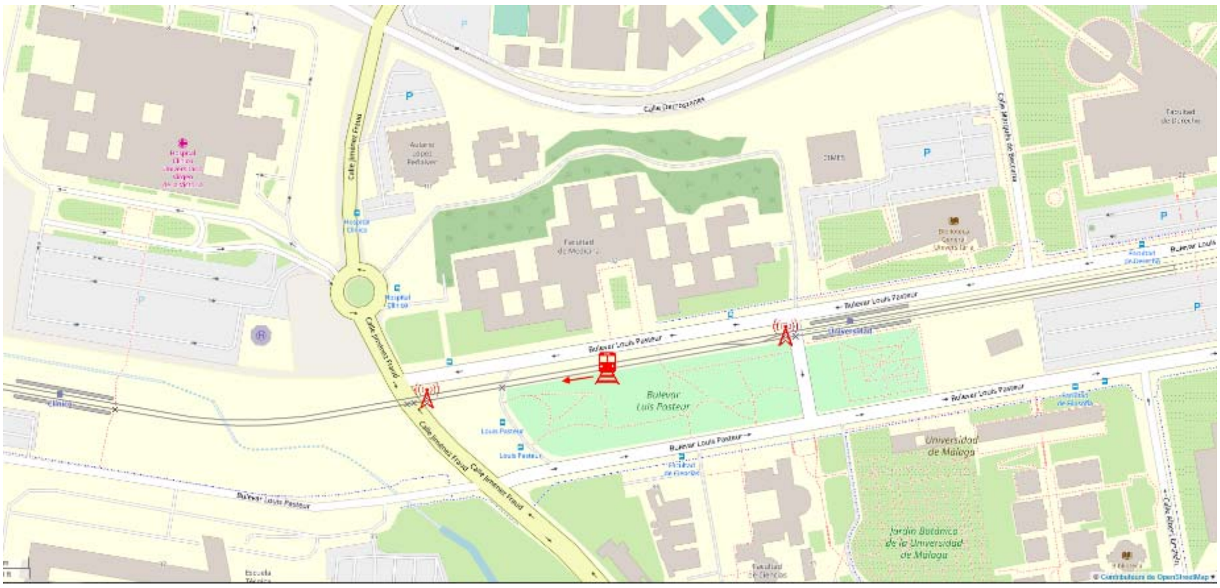


Figure 11: Malaga case map
(Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC)

For this case, two CBTC stations and one train were located as shown in Figure 11.

Simulation 1.1 is performed in the Malaga case study between Clînico and Universidad station. This example illustrates the obtained values when a train moves toward the CBTC base station located close to the street intersection (Station 1) and can be interfered from a Road ITS system which transmits 30 dBm EIRP in the Urban Rail (CBTC) 5 MHz channel (therefore 33 dBm in its 10 MHz channel). Protection distances for the Urban Rail train receiver are shown in Figure 12, for a road vehicle with antennas at a height of 1,5 m above ground level. Additionally, different distances are given for the values shown by the pink labels. These values are measured in the direction of maximum antenna radiation, as well as for the side lobes.

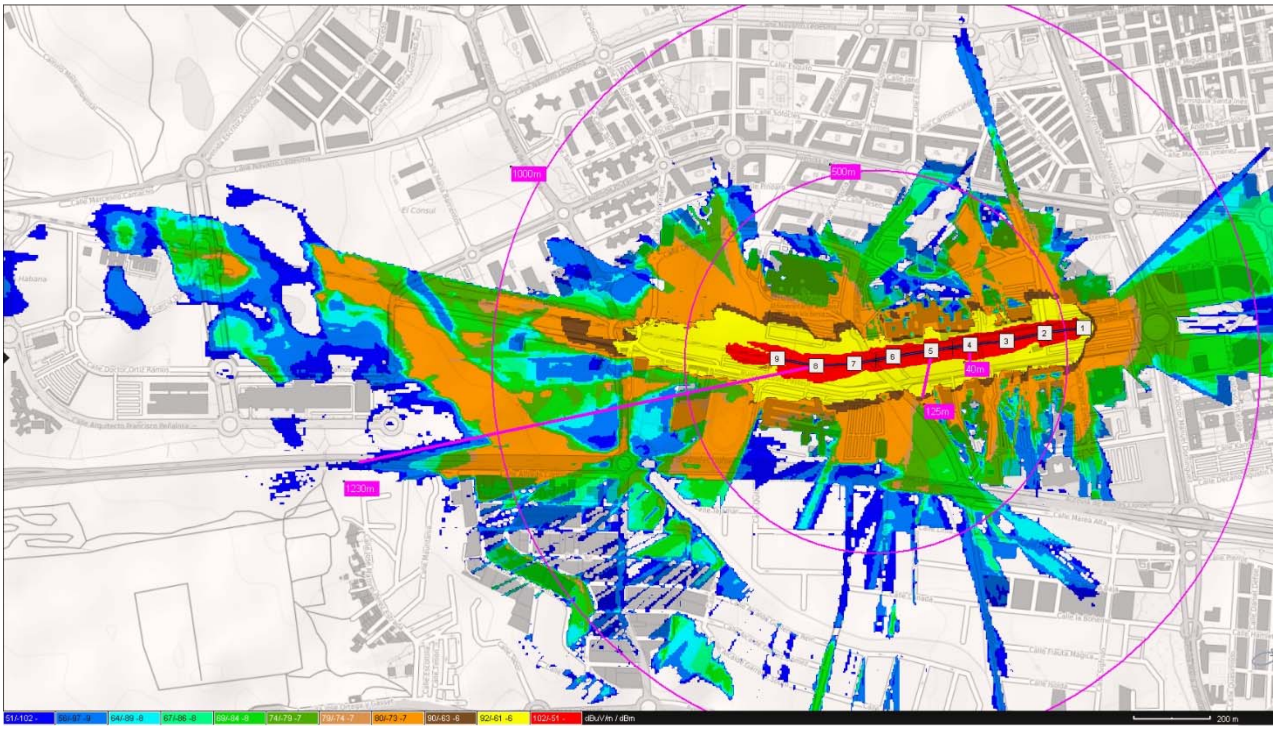


Figure 12 : Malaga simulation 1.1 - Train Protected Zones for different scenarios of Road ITS EIRP with antenna height of 1,5 m, and different Urban Rail systems and radio planning rules

Simulation 1.2 uses the same Malaga case between Clinico and Universidad station, but considering only the potential interference that a Road ITS system could cause to the CBTC base station. Protection distances are shown in Figure 13.

Simulation 1.1 and 1.2 in Malaga corresponds to suburban areas, with buildings of 12 m height on average on one side of the road and open areas with terrain almost flat in the other side of the road. This case could be classified as a typical scenario with the road parallel to Urban Rail track, at same level, without buildings between track and road (LoS). As is shown in simulation results, interference can reach up to 1 230 m in open areas in the same direction of the antenna's main lobe, and 125 m in the side lobes. Finally, the protection distance for the red areas is around 40 m.

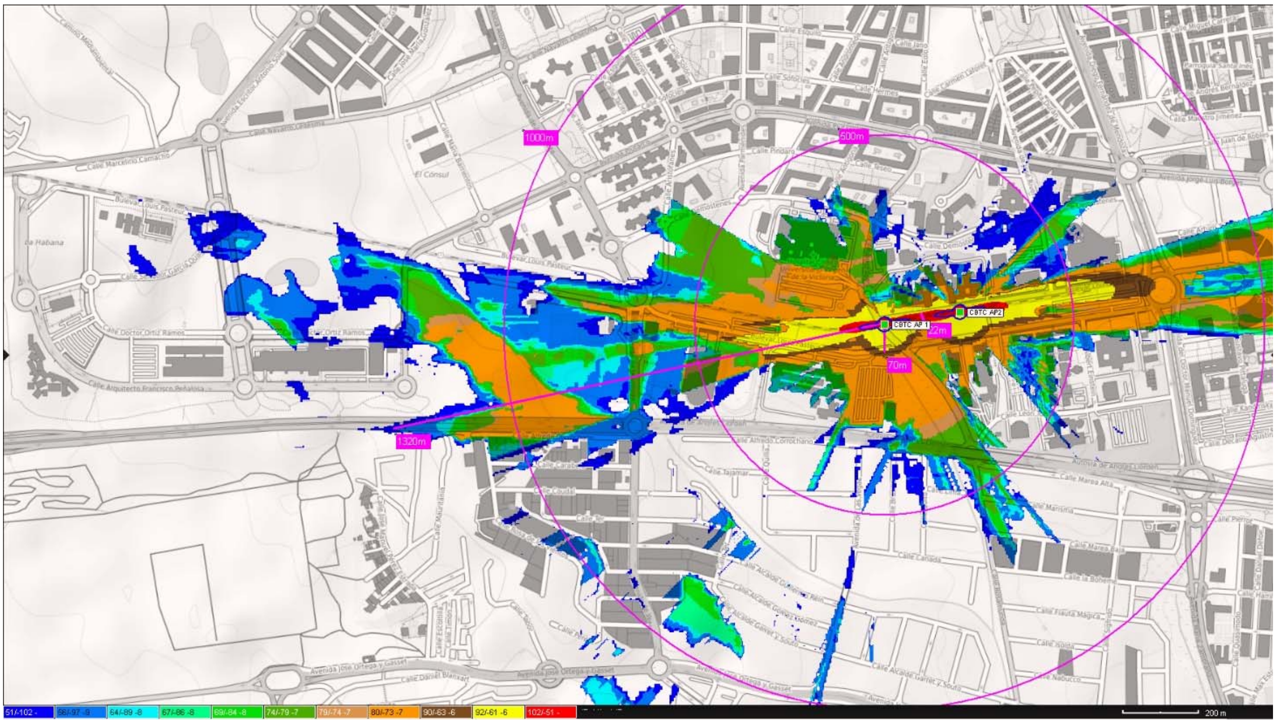


Figure 13: Malaga simulation 1.2 - Urban Rail AP Protected Zones for different scenarios of Road ITS EIRP with antenna height of 1,5 m, and different Urban Rail systems and radio planning rules

Simulation 1.3 shows the additional area where interference to CBTC can happen, considering a truck with an antenna height of 4 m. The pink colour corresponds to the area interfered by both cars (antenna height of 1,5 m) and trucks, considering the worst-case threshold of -102 dBm to define the interference area. The green colour corresponds to the additional area where interference to CBTC from an ITS truck or an ITS car can happen, considering the same threshold.

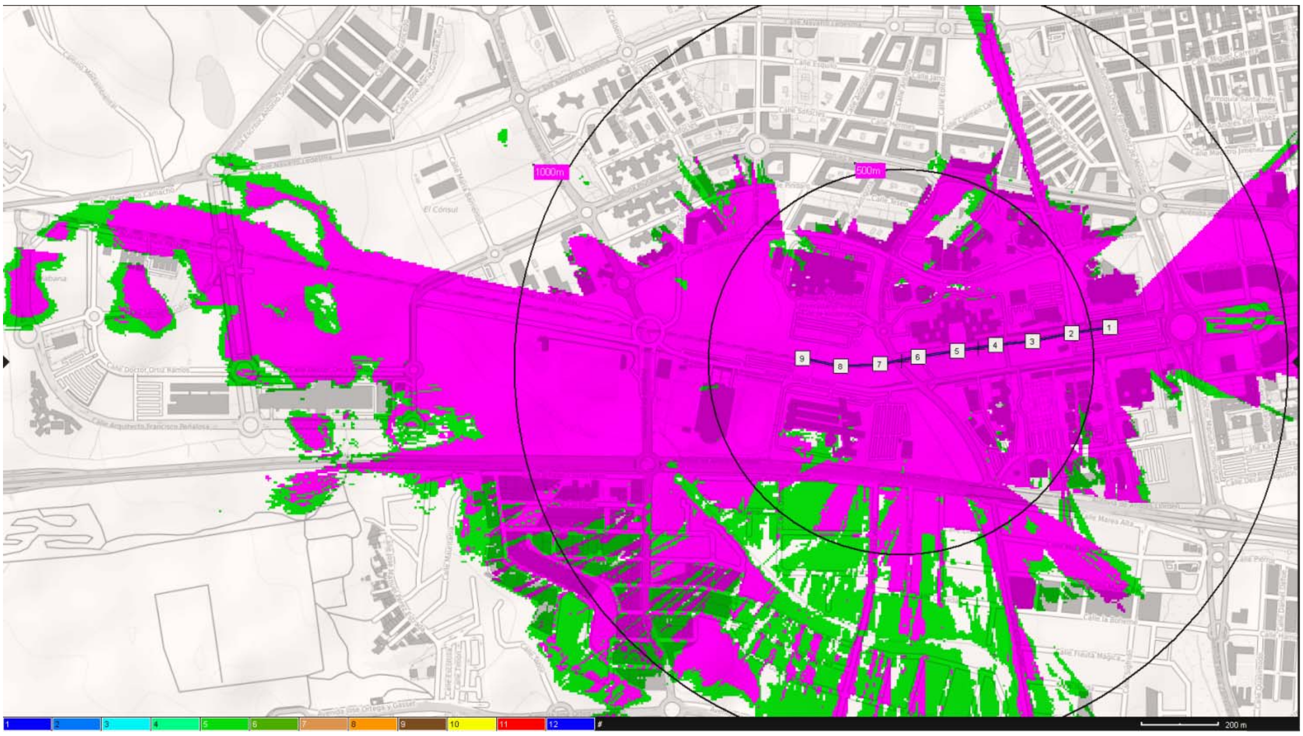


Figure 14: Malaga simulation 1.3 - Common (pink) and additional (green) Protected Zones between car (antenna height = 1,5 m) and truck (antenna height = 4 m), for Road ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization

Finally, simulation 1.4 shows the margin that potentially affects the CBTC system considering cars with an antenna height of 1,5 m and 1,7 m. The palette used is given in the figure. Values can vary between -8 dB and 10 dB depending on the antenna height.

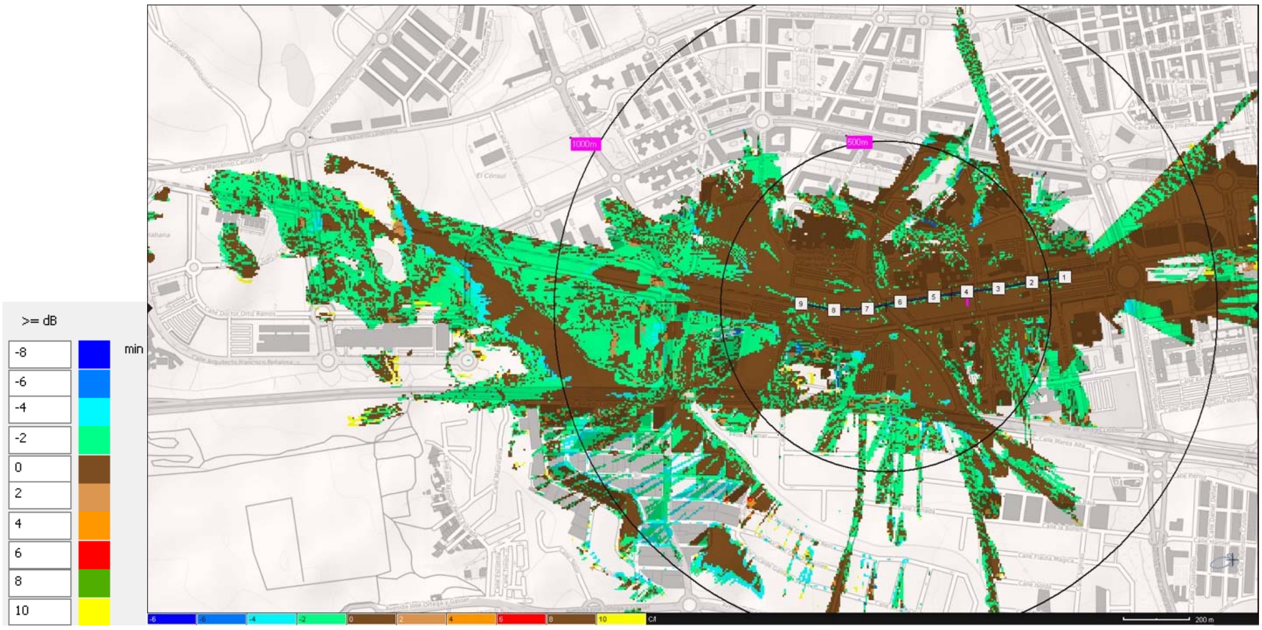


Figure 15: Malaga simulation 1.4 - Differences of received interference level in dB due to variation of the Road-ITS-S antenna height (between 1,5 m and 1,7 m), for a Road ITS EIRP of 33 dBm, and a CBTC DSSS with 3 dB desensitization

The results for Scenario 2 to 5 can be found in Annex A.

5.2.4 Comparison between model and simulations

In this clause different evaluation methods of the impact of Road ITS towards Urban Rail communication systems are evaluated.

Analytical calculations are able to estimate the results for simple geometrical scenarios, but only wave propagation simulation tools can model interference in real situations, taking buildings, hills, slopes and bridges, etc...into account

The analytical estimation is consistent for the most distant roads found via the simulations in the Malaga case, and for the worst cases calculations, this is in line with the propagation model used in the simulations.

Up to 20 dB difference can be seen between the results of the different propagation models used in the present document. Therefore, it is proposed that the calibration of the models should be evaluated by measurements. To define the real worst case situation, these measurements should also take the path loss variations introduced by the different antenna height into account, as simulations have shown a considerable impact of the antenna height on the Protected Zone size. For road vehicles the typical antenna height above ground lies in between 1,5 m and 4 m. Urban Rail receiver antennas are mounted typically at a height of 5m (with variations of ±1 m).

The evaluation of the simulations shows that the following scenarios should be considered for the protection of Urban Rail communications systems:

- Road parallel to an Urban Rail track with limited separation distance including viaduct installations of Urban Rail.
- Bridges over Urban Rail Tracks and large roads perpendicular to tracks.
- Open areas (such as the Malaga case).

5.2.5 Impact of adjacent channel usage

The IEEE 802.11 based system has worst-case adjacent channel rejection, so it is the one studied in this clause.

Adjacent channel rejection is defined in the following way:

- Urban Rail link is attenuated in order that the Urban Rail victim receives a wanted signal corresponding to sensitivity +6 dB: there is no (or negligible) message loss.
- Then interference is added, initially at a low level, and increased step by step up to the level for which the message error rate reaches the required level (1 % for Urban Rail case).

The adjacent-channel rejection corresponds to the difference (in dB) between interference level and the wanted signal level received at victim connector level.

As defined in Table 2, the adjacent channel rejection figures for the IEEE 802.11 based system are the following:

- 16 dB for the first 5 MHz adjacent channel.
- 32 dB for higher 5 MHz adjacent channels.

As ITS stations use 10 MHz channels, for the first Road ITS channel, the first 5 MHz will be rejected by 16 dB, and the last 5 MHz, rejected by 32 dB, but will have negligible additional impact.

Therefore, impact of the first adjacent channel can be visualized using the same simulation method as used for co-channel operation, but with new thresholds as shown below:

- -97 dBm + 16 dB = -81 dBm (Road ITS with 33 dBm EIRP, IEEE 802.11 level at sensitivity level)
- -86 dBm+ 16 dB = -70 dBm (Road ITS with 33 dBm EIRP, IEEE 802.11 level at -77 dBm which includes system margin)
- -84 dBm +16 dB = -68 dBm (Road ITS with 20 dBm EIRP, IEEE 802.11 level at sensitivity level)
- -74 dBm+16 dB = -58 dBm (Road ITS with 10 dBm EIRP, IEEE 802.11 level at sensitivity level)
- -73 dBm+16 dB = -57 dBm (Road ITS with 20 dBm EIRP, IEEE 802.11 level at -77 dBm which includes system margin)
- -63 dBm+16 dB = -47 dBm (Road ITS with 10 dBm EIRP, IEEE 802.11 level at -77 dBm which includes system margin)

Figure 16: Colour palette for adjacent channel impact simulations

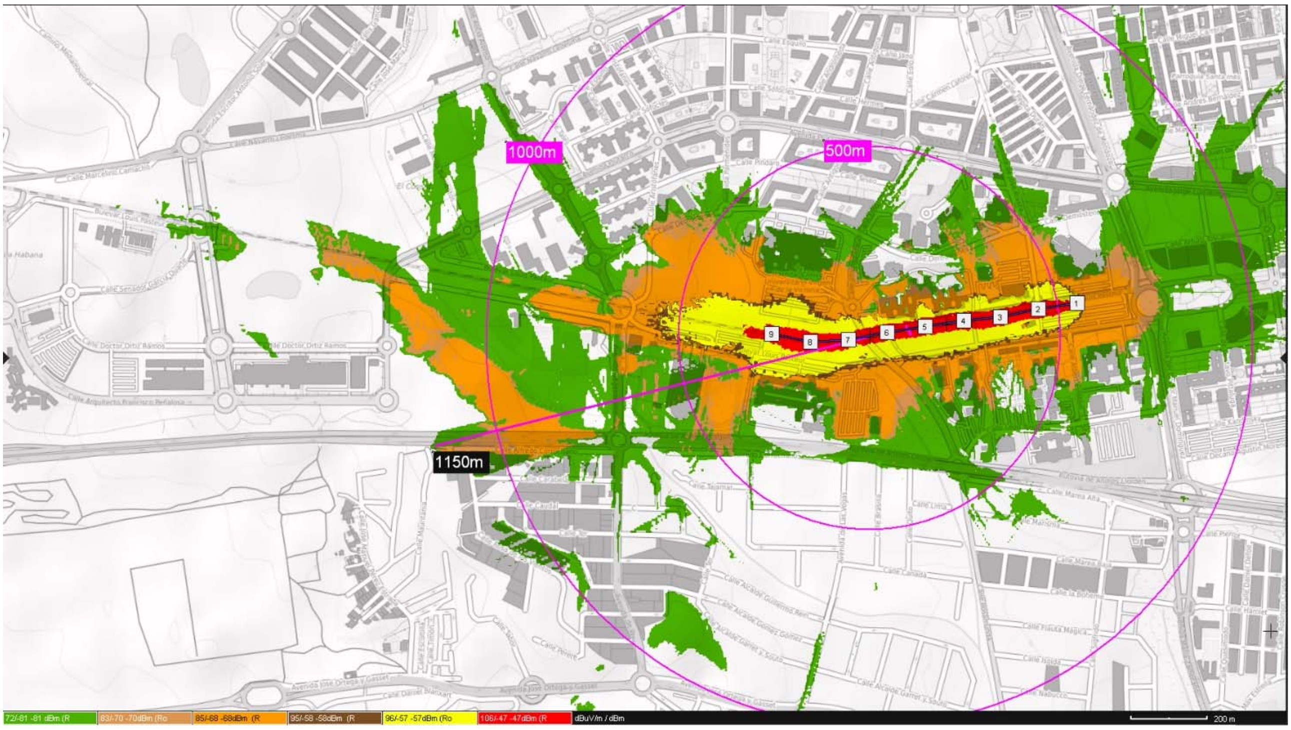


Figure 17: Adjacent channel impact - Train Protected Zones for different scenarios of Road ITS EIRP with antenna height 1,5 m and different CBTC systems and radio planning rules

5.3 Timing considerations

5.3.1 Impact of timing parameters on the evaluation of mutual impact

Mutual impact on communication efficiency occurs only if there are concurrent transmissions (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).

Therefore, the mutual impact depends on:

- channel occupation rate;
- "listen before talk" techniques used by both concurrent systems and their efficiency reduction due to exposed node or hidden node situations.

5.3.2 Channel occupation rate impact

5.3.2.1 Road ITS impact on CBTC

In Urban Rail CBTC systems, to guarantee safe operation, a continuous communication between train onboard computer and ZC is necessary.

CBTC needs a message error rate less than 1 % on any of its links, and its channel occupancy depends on the communication system to be used (either based on DSSS or based on IEEE 802.11) and the configuration (number of ZC and communication with PSD or not). Values are given in Figure 5 for DSSS and in Annex B for IEEE 802.11 based systems.

Impact of the CBTC transmission errors can occur for the following reasons:

- For communication systems based on IEEE 802.11 [i.15] technology:
  - If operating with same channel bandwidth:
    - Collisions between Urban Rail ITS and Road ITS packets due to the hidden node depicted in clause 5.3.3.
    - The impact of collision is an increase of transmission delay due to successive attempts to transmit the Urban Rail ITS packets. After several attempts the packet is dropped.
  - If operating with different channel bandwidth (5 MHz for Urban Rail ITS and 10 MHz for Road ITS):
    - Urban Rail ITS and Road ITS Packets can be received at the same moment by an Urban Rail ITS base station or a Train. The real impact will depend on the carrier to interference (C/I) ratio, where the Urban Rail ITS is considered the "carrier" and the Road ITS signal is the "interference".
- For communication systems based on DSSS technology:
  - CBTC and ITS Packets can be received at the same moment by a Urban Rail base station or a train. The real impact will depend on the carrier to interference (C/I) Ratio where the Urban Rail ITS signal is considered the "carrier" and the Road ITS signal is the "interference".

As a first approach, it can considered that the impact will be similar for communication systems based on DSSS technology and for communication systems based on IEEE 802.11 [i.15] technology but with 5 MHz bandwidth. The difference will be the minimum C/I required for demodulation. If the C/I is high enough the received packet will be demodulated. If the C/I is too low, the packet will be retransmitted and after several attempts it will be dropped.

The probability of collision between packets and/or the Aggregated Interference level received by the Urban Rail base station antenna will depend on propagation and the total percentage of channel occupancy due to the road vehicles transmissions.

Even if the duty cycle of each ITS-S 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 base station antenna or a Train Antenna can be significantly higher.

Indeed, each ITS-S will limit its duty cycle based on the occupancy of the channel that it can detect from its own receiver characteristics. As far as Road ITS and Urban Rail are using different antennas, and as Urban Rail is using directive antennas with high gain, it is not necessarily identical to the occupancy of the channel seen at Urban Rail receiver level, as shown in the simplified Figure 18.

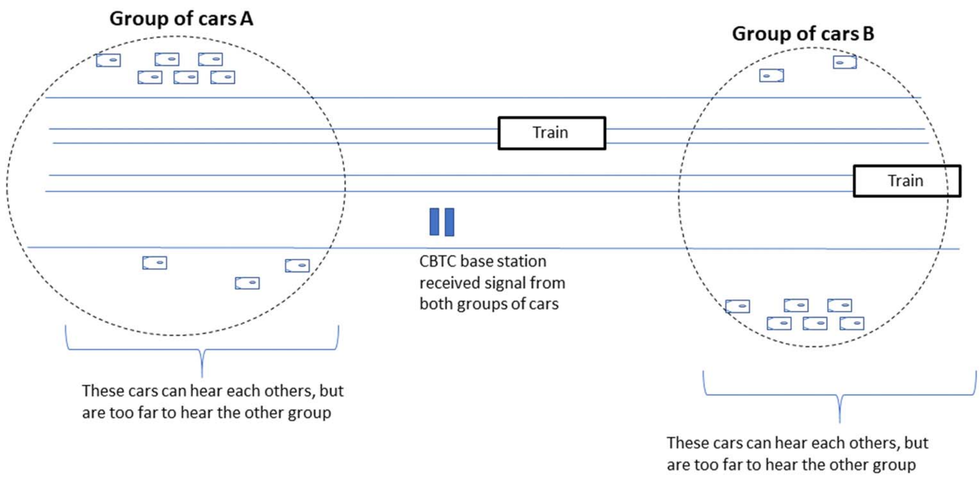


Figure 18: Differences between channel load seen by Urban Rail receiver and channel load used for Road ITS DCC

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

In that situation, CSMA/CA mechanism and DCC operates to optimize and limit the use of the available channel bandwidth in the radio environment of each group.

But the aggregated channel load seen by the Urban Rail base stations from all the Groups can therefore be significantly higher than the one seen by each ITS-S, and collisions between transmissions of station of each group can occur.

NOTE: The case with continuous distribution of the ITS-S is much more complex and could be analysed only with detailed simulations or by monitoring the real situation on site when the Road ITS deployment is widespread enough to be relevant, considering that during peak hours, a density above 200 road vehicles per square km can be observed in urban areas.

5.3.3 Limits of "listen before talk" techniques

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

Case 1: The 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 19.

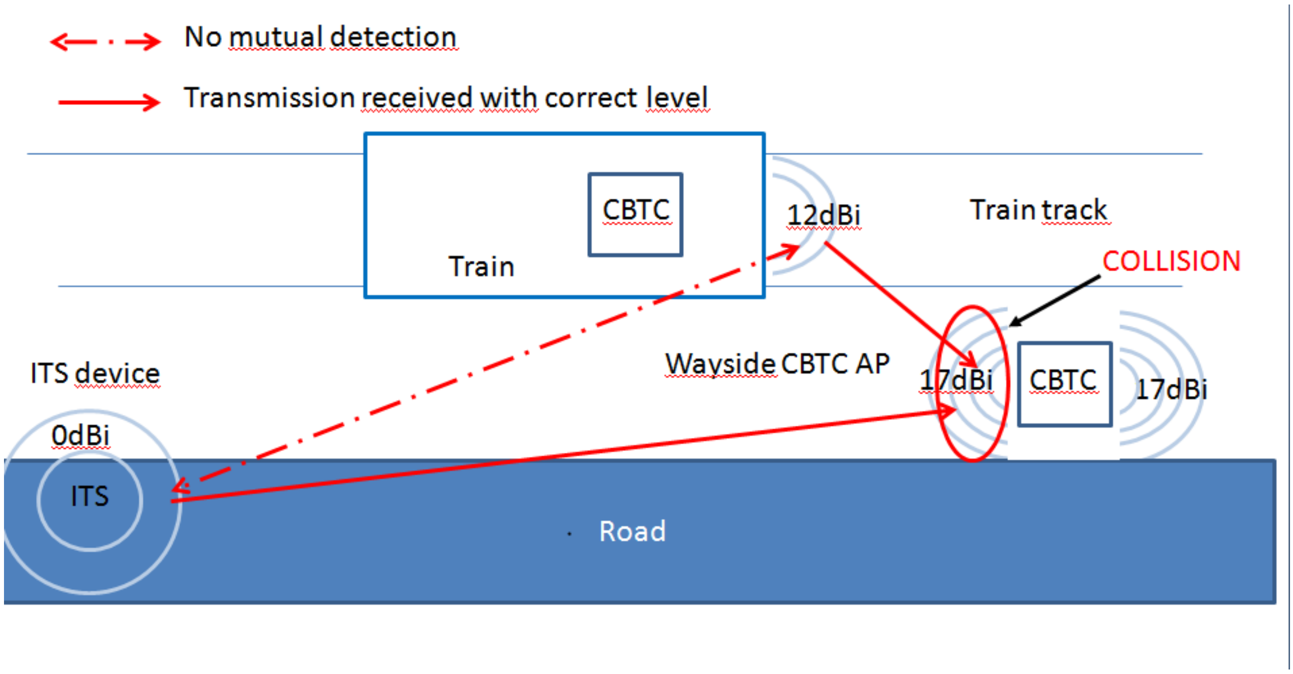


Figure 19: Case 1 of hidden node situation

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 20.

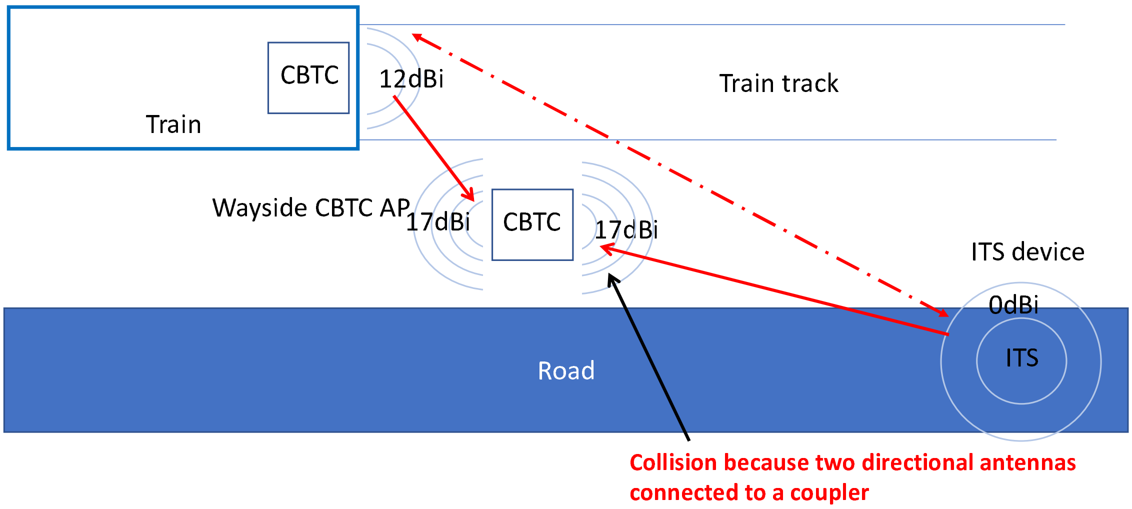


Figure 20: Case 2 of hidden node situation

The following cases are typical "exposed station" situations:

Case 1: The Urban Rail AP does not transmit when detecting ITS device transmission, whereas the signal sent by the ITS device would not have disturbed reception from the train, and the Urban Rail AP signal would not have disturbed the Road ITS exchange.

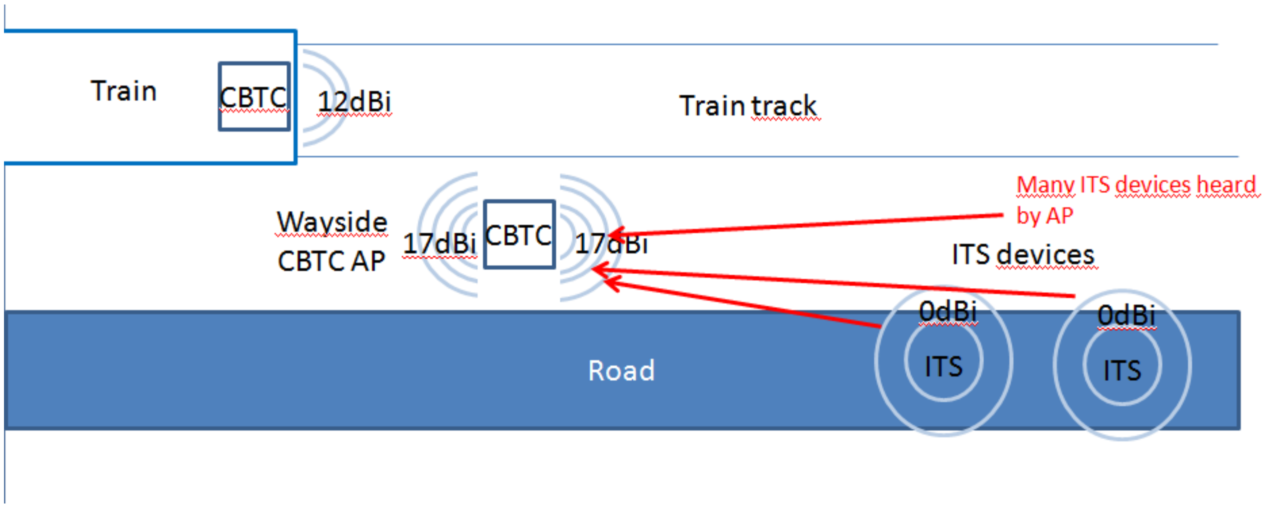


Figure 21: Case 1 of exposed node situation

The Urban Rail transmitters are "exposed" to the 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 ITS nodes. The critical limits should be evaluated in the field using measurements and realistic scenario set-up including a high number of interfering devices.

5.4 Summary

In clause 6 a detailed analysis of the potential interference effects has been undertaken. Three different methods have been considered here:

- Minimum Coupling Loss analysis (MCL) using different propagation models.
- Two ray propagation model.
- Detailed propagation simulations including topographic information.

The results show the potential interference area where a Road ITS could interfere with an Urban Rail system when a packet collision occurs.

Analysis regarding the impact of channel busy ratio and of the duty cycle, as well as the possible control of the duty cycle by the Road ITS DCC mechanism had been undertaken and show what should be measured or monitored regarding DCC behaviour in the future. The limitations of the "listen before talk" mechanism have also been highlighted.

Detailed timing considerations and related interference probability evaluations were not performed. Moreover, considering the high availability required for the Urban Rail ITS operation, a statistical study based on a mean duty cycle or on interference probability is not relevant: any situation, even worst-case, should be taken into account.

The given impact evaluation results are to be confirmed and potentially adapted based on laboratory and field measurements. The simulation system based on real environmental modelling represents a good basis for future planning of potential required mitigation areas used in the database and beacon solutions.

6 Sharing solutions

6.1 Introduction and general considerations

Two families of solutions are studied in the present document. They are based on:

- a technology-neutral detect and mitigation method; or
- a technology specific MAC/PHY layer mitigation method.

The first family is based on the following two phases:

- Identification of the sharing and mitigation area.
- Sharing and mitigation operation.

The identification process can take into account the real presence of a train in the area or not. If the presence of a train is taken into account the identification method will be said to be ***dynamic***, if not, the identification method will be said to be ***static***.

The following identification techniques, using facility layer features, are detailed in clause 6.2:

- Beacon solution (static or dynamic).
- Database solutions (Read-only or Updatable).
- Combinations of beacon and database solution.
- Combination of permissive beacon and updatable database.

After the ITS device has detected that it is located in a mitigation area, a sharing operation should be initiated. Different sharing operations are possible and are defined in clause 6.3:

- Power control.
- Duty cycle control.
- Stop transmitting in the used Urban Rail 5 GHz channels.
- Combination of these solutions.

The solutions of that family are independent of the radio technologies used by Urban Rail ITS and by Road ITS, and do not impose any technology to any application.

Road ITS Ss are expected to give priority to Urban Rail Station when operating in Urban Rail ITS allocated 5 GHz channels. Mitigation measures that can be applied by Road ITS-Ss are described in clause 6.3. These measures are expected only to be applied in relevant Protected Zones (PZ).

The second family is based on MAC/PHY layer mitigation method.

These solutions are technology-specific and require Urban Rail ITS and Road ITS to use the same technology, or these solutions rely on the mitigation techniques provided by the specific technology to ensure the priority to Urban Rail ITS in the dedicated channels.

This family could in principle contain any future radio technology as listed below, nevertheless only the solutions based on IEEE 802.11 technology has been studied:

- Use 10 MHz bandwidth IEEE 802.11a for Urban Rail ITS.
- Usage of ITS-G5 protocol for Urban Rail ITS and Road ITS equipment.
- Use only LTE-V2X/C-V2X for both Urban Rail ITS and Road ITS.
- 5G access layer.

6.2 Facility Layer sharing zone identification techniques

6.2.1 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.

6.2.2 ITS beaconing for the protection of Urban Rail

6.2.2.1 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].

6.2.2.2 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 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 a beacon will 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.

Mitigation measures to be applied by Road ITS equipment are described in clause 6.3.

6.2.2.3 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 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 specified in ETSI EN 302 571 [i.4];
  - 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 ITS-S does not fulfil the coexistence mode emission requirements in its normal mode, the 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.

One of the methods used to allow an ITS-S to identify the presence of a PZ is by enabling the ITS-S to receive CAM messages providing all required information of the presence of a PZ.

The figure below shows the basic structure of a CAM message according to ETSI EN 302 637-2 [i.2].

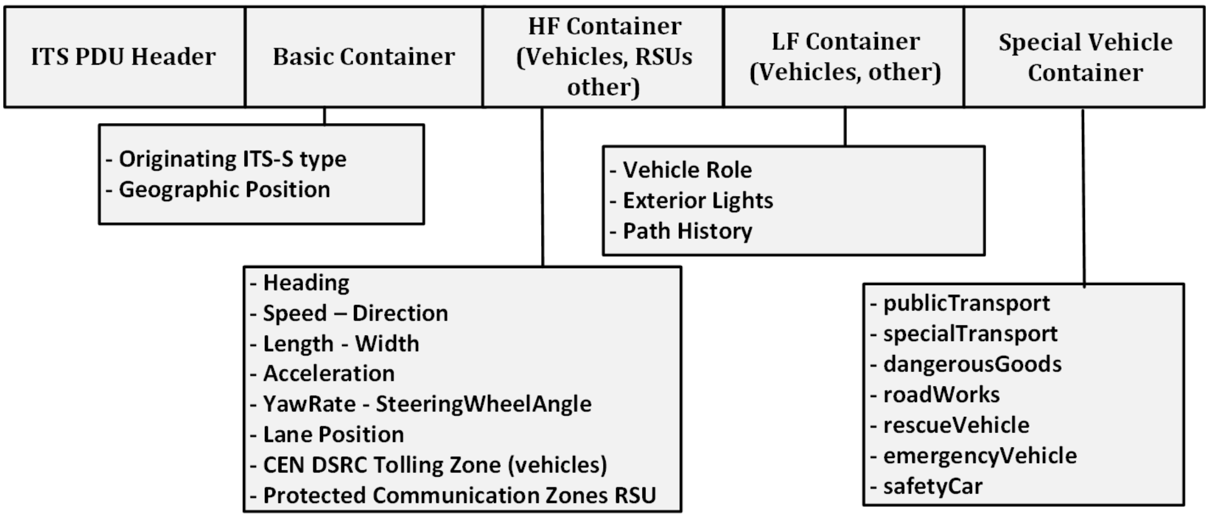


Figure 22: Basic structure of a CAM message

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 9: 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 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 the present document:

- `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)`

The processing of these field is mandatory in the harmonised standard ETSI EN 302 571 [i.4]. So far, only two types of protected zones are defined for the protection of stationary and mobile tolling stations (see Annex A).

6.2.2.4 Beaconing for the protection of Urban Rail ITS

6.2.2.4.1 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 the next clause. 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 10.

Table 10: 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	Need a CBTC alert beacon message on every channel to be protected (that is 5 915 MHz to 5 925MHz), using the Road ITS radio technology of that specific channel. PZ beacons in the Urban Rail channel only need to implement that specific technology	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 channels in band [5 905 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 channels in band [5 905 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 ITS-S at an appropriate location along the Urban rail track or by OBUs installed in trains. In that case the RSU or OBU sends protected zone CAM messages to all present 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.

In case a train is equipped with an ITS-S, the PZ is related to the train position and its size depends on the message transmit rate and on the train speed. This means that the PZ CAM transmission rate could be adapted to the speed of the train, ensuring that a sufficient number of messages are transmitted to achieve the required protection.

6.2.2.4.2 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.

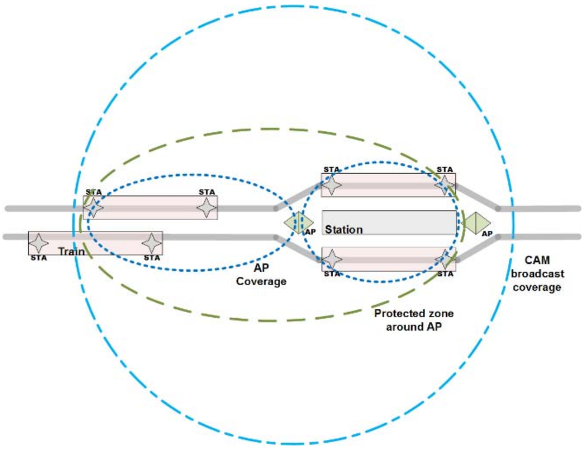


Figure 23: Protected Zone represented as an ellipse

- 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 a ITS-S which could be in two or more different zones of different type, as explained below in the example shown in Figure 24.

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.

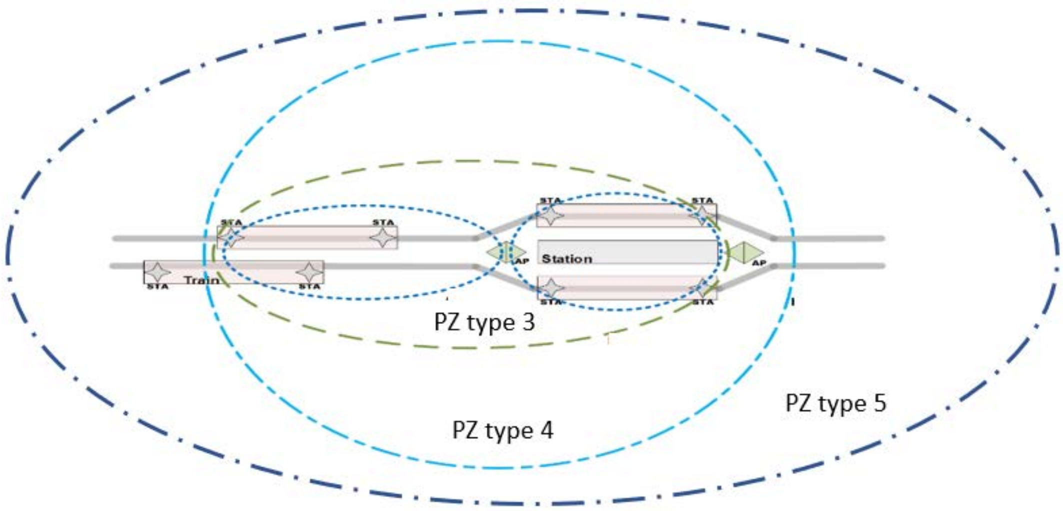


Figure 24: Concentric Protected Zones

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 definition for Urban Rail protection, as described above.
- Specification of coexistence mode and procedures specific for Urban Rail protection.

These proposed changes 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.

It is proposed that following parameters should be added to protect Urban Rail. These parameters should 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 a 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 membersgroup.
    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 clause A.new3.

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 clause A.new3.
  - ProtectedZoneMember::= INTEGER (1..255).

6.2.3 ITS Database for the protection of Urban Rail systems

6.2.3.1 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 clauses 6.2.3.2, 6.2.3.3 and 6.2.3.4.

Considerations regarding updatable database are given in clause 6.2.3.4.

6.2.3.2 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 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 11 and in Table 12.

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 12, following the data element definitions of Table 11.

Table 11: Data format of the ASECAP Protected Zone Database

Data element name	Data type	M/O*	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
*M/O: Mandatory/Optional			

Table 12: 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>

Based on the harmonised standard ETSI EN 302 571 [i.4] 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 ITS-S should implement mitigation based on the reception of mitigation CAM's.

6.2.3.3 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 would only allow for mitigation zones on fixed locations and it leads to mitigation also in case when mitigation is not strictly needed. Based on their read-only database, 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 as identified in clause 6.2.2.4.2.
- 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.

6.2.3.4 Updatable database

The updatable database principle is based on the Read-only device database described above, but 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 certified authority. 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 integrate an updatable device database able to upload the information from the central database. This updateable device database in the road-vehicle can be defined as a configuration file, for example an XML file to avoid the need to update any software nor firmware, thus limiting the impact from a security standpoint. The only provision is that a secure method of uploading the new file and a method to check the authenticity of the locally stored version are defined.

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 upload is done from the central database once into the vehicle updatable device database. This process is similar to the read-only database.
- During road-vehicle operation life cycle:
  - A periodic and automatic versioning mechanism forces the road-vehicle system to check regularly if a new version of central database is available, and if yes, then an upload should be done within a given time to the vehicle updateable device database. This process is specific to the updateable database.

Typically:

- two successive updates of the central database would rarely happen in less than two years;
- the periodic check of version should automatically be done by the vehicle at least every 6 months;
- in case of a new available version of the central database, it should be uploaded into the updateable device database immediately, or at least within the next 6 months.

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, WIFI or Bluetooth connectivity.
- Driver's mobile phone connectivity, itself connected to the vehicle system..
- Driver's home-based WIFI connectivity.
- Vehicle-workshop connectivity, during annual car revision, maintenance or repair.

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.

A process for an Urban rail updatable database is proposed in Annex E

6.2.4 Combined beacon and database solution

6.2.4.1 Database combined with Urban Rail PZ beaconing

A similar method is specified for protection of tolling systems in ETSI EN 302 571 [i.4].

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

6.2.4.2 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.

6.2.5 Comparisons of different identification methods

In all cases ETSI TS 102 894-2 [i.3] should be updated as described in clause 6.2.2.4.2 if CAM are used, and in clause 6.2.3.4 if a database is used. In addition, a new specification based on ETSI TS 102 792 [i.1] should be developed to specify details of the necessary mitigation techniques.

Table 13 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 13: Comparison between the different identification methods

Identification Solutions	PROS	CONS
Static Alert Beacon	One mechanism only No dynamic interface between beacon and CBTC No new database update mechanism including communication link to implement Protection for existing and new lines Re-use of existing principles based on tolling mitigation including all security aspects No need for an operator for a secured data base	Needs additional equipment and related maintenance along Urban Rail lines over ground and if near to roads. No protection for Urban Rail ITS if beacon transmission fails or is corrupter (for all cars in the area) If several physical layers are used for V2X, several beacons transceivers would be necessary. See note.ITS-Road restriction even if no train in the PZ: potential localized spectrum inefficiency. Potential increased complexity for Urban Rail.
Dynamic Alert Beacon	One mechanism only ITS-Road restriction only when train is present, leading to more efficient spectrum usage No new database update mechanism including communication link to implement Protection for existing and new lines Re-use of existing principles based on tolling mitigation including all security aspects No need for an operator of a secured data base	Needs additional equipment and related maintenance along Urban Rail lines over ground and if near to roads. No protection for Urban Rail ITS if beacon transmission fails or is corrupted (for all cars in the area). Needs dynamic interface between beacon and Urban Rail ITS. If several physical layers are used for V2X, several beacons transceivers would be necessary. See note. Potential increased complexity for Urban Rail.
Read-only database	One mechanism only No additional equipment along the Urban Rail lines and no modification in CBTC systems Urban Rail ITS protection does not depend on PZ messages reception No dynamic interface between beacon and CBTC No new database update mechanism to implement No beacon message complexity (as being dependant on V2X technologies) Re-use of existing principles based on tolling mitigation including all security aspects	No protection guaranteed for new lines and no flexibility in case of new situation. No protection for Urban Rail ITS if the database in Road ITS devices is corrupted, damaged or cannot be read for some other reasons. ITS-Road restriction even if no train is in the PZ: potential localized spectrum inefficiency. Additional storage capacity and software function required in Road ITS equipment. Creation, maintenance, operation and security of a central database for Urban Rail ITS PZ is necessary (see [i.27] and [i.28]).

Identification Solutions	PROS	CONS
Read-only database + Static Alert Beacon	No dynamic interface between beacon and CBTC system No new database update mechanism including communication link to implement Protection for existing and new lines Re-use of existing principles based on tolling mitigation including all security aspects	Increased complexity for Urban Rail. Needs additional equipment along the Urban Rail lines over ground and if near to roads. No protection for Urban Rail ITS if beacon transmission fails. ITS-Road restriction even if no train in the PZ: potential localized spectrum inefficiency. If several physical layers are used for V2X, several beacons transceivers would be necessary. See note. Creation, maintenance, operation and security of a central database for Urban Rail ITS PZ is necessary (see [i.27] and [i.28]).
Read-only database + Dynamic Alert Beacon	No new database update mechanism including communication link to implement Protection for existing and new lines ITS-Road restriction only when train is present, leading to more efficient spectrum usage No need for an operator of a secured data base Re-use of existing principles based on tolling mitigation including all security aspects.	Increased complexity for Urban rail. Needs additional equipment along the Urban Rail lines over ground and if near to roads. No protection for Urban Rail ITS if beacon transmission fails. Needs dynamic interface between beacon and CBTC. If several physical layers are used for V2X, several beacons transceivers would be necessary. See note. Creation, maintenance, operation and security of a central database for Urban Rail ITS PZ is necessary (see [i.27] and [i.28]).
Updatable database	One mechanism only No additional equipment along the Urban Rail lines Urban Rail ITS protection does not depend on PZ messages reception No dynamic interface between beacon and CBTC No beacon message complexity (as being dependant on V2X technologies) Protection for existing and new lines Potential re-use of existing principles based on tolling mitigation Possibility to correct corrupted database (but with delay up to 2 years)	Increased complexity for Road ITS compared to read only database (ffs). Creation, maintenance, operation and security of a central database for Urban Rail ITS PZ is necessary (see [i.27] and [i.28]). No protection for Urban Rail ITS if the database in Road ITS devices is corrupted, damaged or cannot be read for some other reasons. ITS-Road restriction even if no train in the PZ: potential localized spectrum inefficiency. New database update mechanism to be defined and implemented guarantying the integrity and reliability of the database update. Needs for an additional certification and verification process for Road ITS. Some Road ITS devices may need additional secured connections. Additional storage capacity and software function required in Road ITS equipment. The corresponding back end services need to be set up and maintained for Urban rail and for each OEM.

Identification Solutions	PROS	CONS
Updatable database + Dynamic Permission Beacon	Urban Rail ITS protection even if beacons fail Protection for existing and new lines ITS-Road restriction only when train is present, leading to more efficient spectrum usage Urban Rail ITS protection does not depend on PZ messages reception Potential re-use of existing principles based on tolling mitigation	Increased complexity for Road ITS. Needs additional equipment along the Urban Rail lines. Needs dynamic interface between beacon and CBTC to activate beacon whenever a train is not in the section. New database update mechanism to be defined and implemented guarantying integrity and reliability of the database update. Needs for an additional certification and verification process for Road ITS. If several physical layers are used for V2X, several beacons transceivers would be necessary. See note. Some Road ITS devices may need additional secured connections. Additional storage capacity and software function required in Road ITS equipment. Creation, maintenance, operation and security of a central database for Urban Rail ITS PZ is necessary (see [i.27] and [i.28]). The corresponding back end services need to be set up and maintained for Urban rail and for each OEM.
NOTE: The upcoming IEEE 802.11bd will be backward compatible with 11p and would not need a new transceiver.		

NOTE: When an argument is assigned as PROS **or** CONS to one or several solution(s) its opposite (CONS or PROS) is assigned to the other solutions.

6.3 Sharing and mitigation operation

6.3.1 Introduction

In this clause the potential solution for a sharing and mitigation operation is presented. The provided methods guarantee the proper operation of the Urban Rail systems in the band 5 915 MHz to 5 925 MHz. The mitigation and sharing operation are proposed for the Road ITS system after the identification of a Protected Zone (PZ).

6.3.2 Progressive power restriction

Depending on the actual mitigation distance of a ITS-S to a potential CBTC station, which could receive harmful interference, the ITS-S could reduce its TX power during the required time of sharing. Based on the impact analysis given in clause 6, areas could be identified 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). The Protected Zones corresponding to different power levels have been calculated in clause 5.

In each of these areas, adapted 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 20 dBm EIRP.

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

Zone 3: ITS-S device is not allowed to transmit any messages during a period with a duration depending on the type of sharing:

- in case of dynamic sharing: when a train is present in the area;
- in case of database solution: so long as the road vehicle is present in zone 3.

Figure 25 illustrates this example.

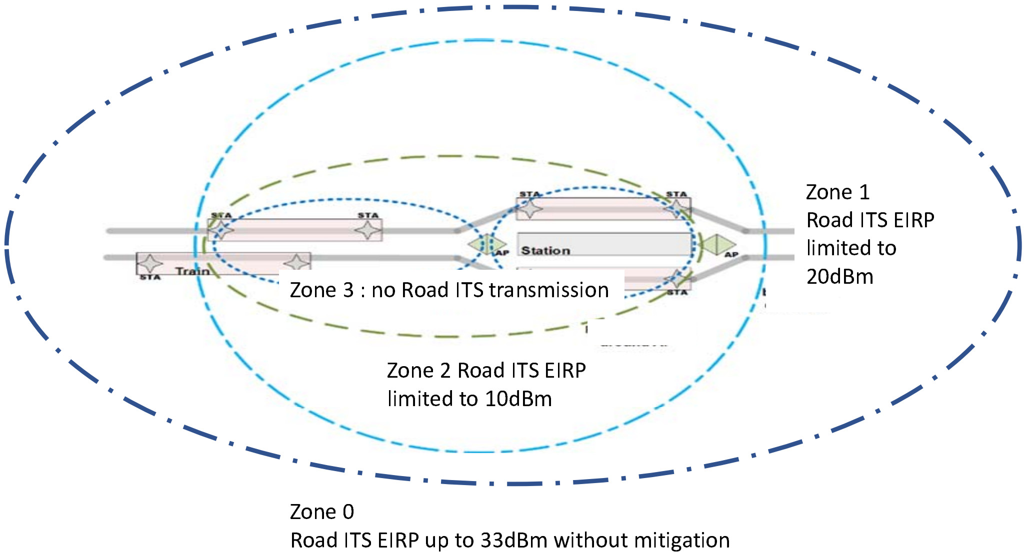


Figure 25: Example of progressive power restriction mitigation zones

6.3.3 Duty cycle control

For channels with a limited deployment density of Road ITS systems and, depending on the applications, the ITS station in an identified PZ could reduce its transmission duty cycle to leave enough capacity available for the operation of the Urban Rail system. In urban environments the typical duty cycle of an individual ITS station is in the range of 0,2 % or below. By limiting the duty cycle down to 0,1 % the channel load in this case would be limited to around 10 % leaving enough capacity for the operation of Urban Rail systems. It should be noted nevertheless that the maximum load of the channel is between 70 % and 75 %.

A Road ITS device can restrict its duty cycle based on the actual channel load using the mandatory DCC mechanism. By defining more stringent limits for the duty cycle in a PZ the overall load in the channel could be reduced to an acceptable level.

Since the required PZ depends on the actual TX power of the Road ITS device, the number of relevant stations to be considered as potential interferers would be reduced when reducing the TX power.

But, as seen in clause 5.3.2.1, a limit given for the duty cycle of each ITS-S is not enough to ensure the limitation of the channel occupancy rate at Urban Rail station receiver. A more detailed investigation of this sharing and mitigation method would therefore be required to define acceptable duty cycle and power limits for each Road ITS-S. In clause 5.3.2.1, it is also shown which simulations, measurements and monitoring of the actual behaviour of DCC applied by ITS stations seen at Urban Rail station receiver level should be used as basis for a possible future limit.

For the protection of areas with a high rail vehicle density, like the operation of Urban Rail ITS in depots and maintenance areas where a high channel capacity is needed the duty cycle restriction might not be sufficient for the protection of Urban Rail.

To define a potential new target value for the limit of channel occupancy for the DCC mechanism, the following aspects and questions should be taken into account:

- The channel occupancy of a train can reach 12 %, and one Urban Rail ITS base station can serve up to six trains within range. This should be considered when defining a new target value for the DCC.
- What is the real efficiency of the DCC in a city for different situations such as traffic jam, dense circulation?
- What is the difference between the DCC threshold defined at ITS station level, and the channel busy rate seen at Urban Rail station receivers?
- How does one evaluate the busy rate when road situations change (the mean value is important but also peaks and stability)?

As a conclusion, a mitigation technique based on duty cycle reduction would require extensive studies and validation, including on-site test campaigns before it could be considered as effective and applicable.

6.3.4 Stop transmission

The most stringent mitigation operation for an ITS station would be to stop transmitting in the channels to be protected during the required communication period of Urban Rail system. This operation could significantly reduce the usability of the band for any Road ITS application.

6.3.5 Combined methods

The sharing and mitigation operations described in clauses 6.3.2 and 6.3.3 can be combined. The combination of TX power control and duty cycle control could significantly reduce the impact on the Road ITS operation without compromising the protection of the Urban Rail system.

6.3.6 Conclusions and summary

In clause 6.3 a set of possible sharing and mitigation operations have been presented and discussed. A solution based on progressive transmit power reduction which could go up to ITS stations stopping transmitting in the relevant PZ seems to be the most appropriate solution.

For future implementations a more sophisticated solution based on duty cycle restriction could be evaluated as it would reduce the operational impact onto the ITS communication.

6.4 Integration of Urban Rail systems in C-ITS

6.4.1 Introduction

Clause 6.4 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 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 uses the Road ITS Access Layer with 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.

6.4.2 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 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 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 WiFi operation. It does not require any change in the overall CBTC architecture or communication scheme. 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.

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.

6.4.3 Description of Option 2: Broadcast-based solution

6.4.3.1 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 of IEEE 802.11-OCB mode. 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 (see clause 6.4.1).

6.4.3.2 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 stationary 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 harmonized 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.

6.4.3.3 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 26) 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.

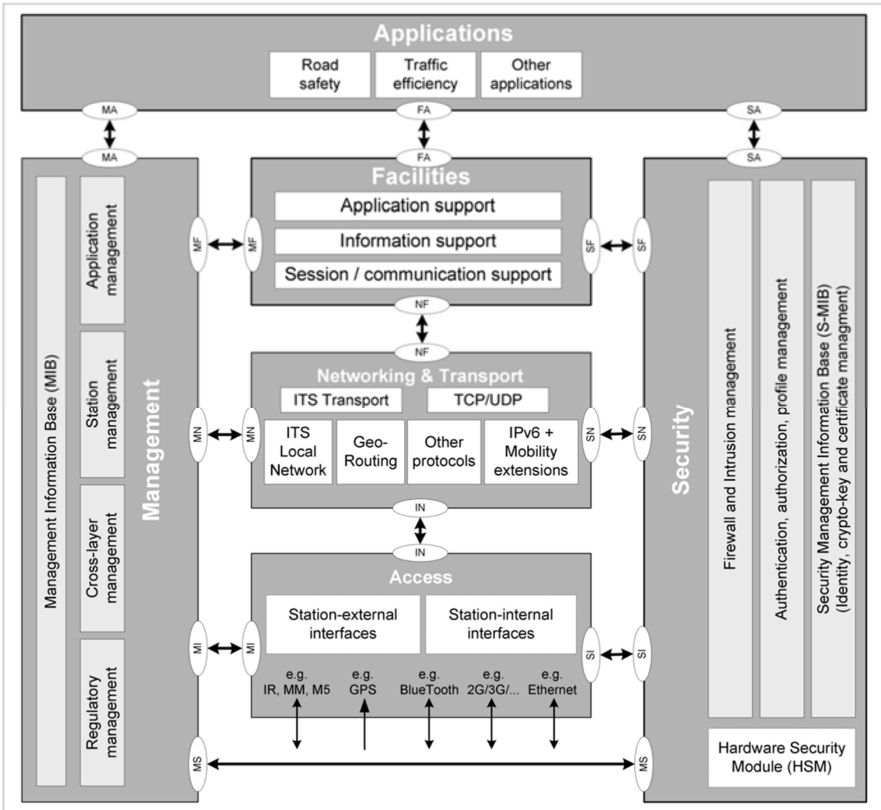


Figure 26: ITS station reference architecture in accordance with ETSI EN 302 665 [i.9]

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 ITS-G5 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.

6.4.3.4 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 27.

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.

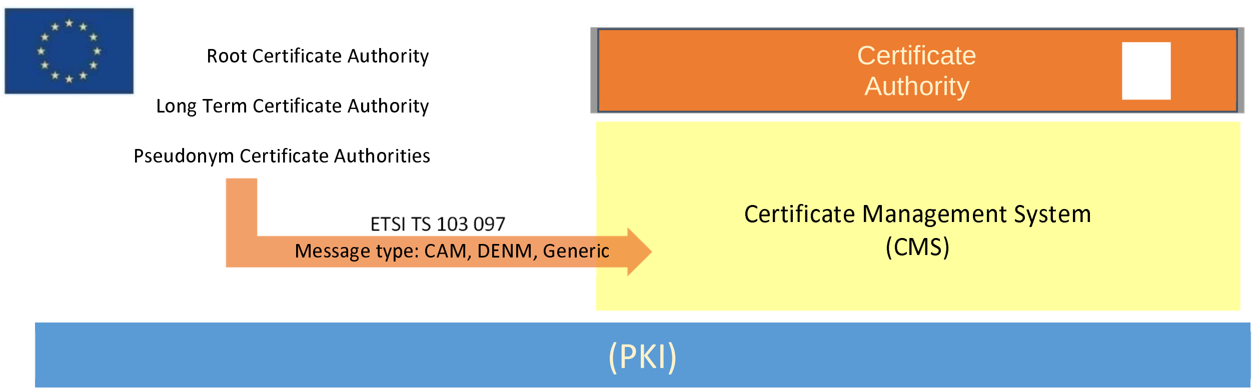


Figure 27: General overview of the European Road ITS security credential system

6.4.3.5 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. For example, geo-addressing can 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 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.

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 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. 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 28, 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, ATS, 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 track-side 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.

6.4.3.6 Safety and security of CBTC communications

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. The extension of road PKI infrastructure to Urban Railway seems straightforward.

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.
- Use of two radios per OBU (less frequent solution).
- Two antennas per radio.
- Alternating use of two or more frequencies in order to avoid interference with neighbouring waysides.
- Application of redundant TS-ITS-S coverage areas by construction.
- Application of redundant TS-ITS-Ss per location.

- Redundancy TS-ITS-S/trackside backbone networks.

6.4.3.7 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 28.

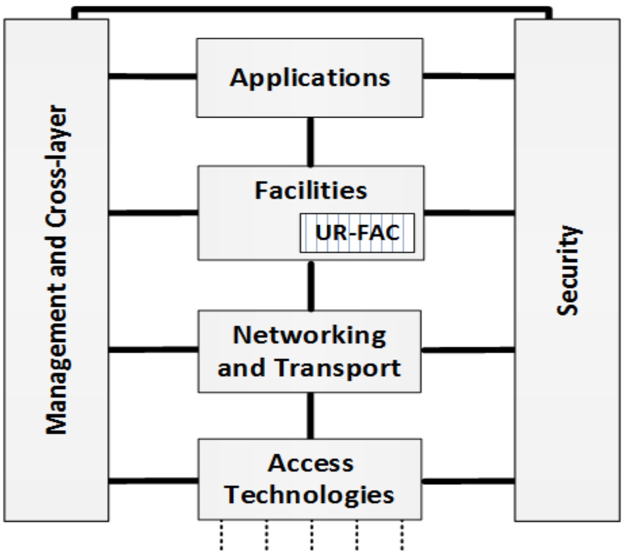


Figure 28: ITS Station model showing UR-ITS specific component in Facilities layer

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 HF (High Frequency) 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 only need to be simplified by ignoring some of the optional fields in the existing SPAT message.

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.

6.4.4 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 "tool box" 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 5.3.3, 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 6.2 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 below:

Table 14: 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	• 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

	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 harmonized 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 • Not suited for existing Urban Rail deployments • 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 CENELEC EN 50128 [i.25] and CENELEC EN 50129 [i.26] SIL4 and which guarantees that conflicts between positions of points/switches and movement authorities are prevented.

7 Proposed modifications to ETSI EN 302 571

ETSI EN 302 571 [i.4] specifies the ITS station minimum technical requirements for presumption of conformity against article 3.2 of the Radio Equipment Directive [i.38]. In order to take into account Urban Rail ITS some modifications to the identified technical requirements might be needed. However, it has to be pointed out that these modifications will depend on the sharing solutions agreed and therefore can be included in ETSI EN 302 571 [i.4] only when the sharing solution to be implemented is identified. Table 15 identifies the requested modifications to consider the use of the 5 GHz ITS band by Urban Rail stations and ITS stations for the two families of solutions.

Table 15: Proposed modifications to ETSI EN 302 571[i.4] to consider UR stations and the proposed sharing solutions

	With Detect and mitigate options (as described in clause 6.2 and clause 6.3)	**With Integration of CBTC in ITS protocol (as described in clause 6.4)**
Transmitter frequency stability	Clause "Definition" [i.4] needs to be extended to allow in case of UR station, 5 MHz channels, and the channelization of the 2 existing Urban Rail ITS communication technologies. No change of the limits	No change
RF output power	No change	No change
Power spectral density	No change	No change
Transmit power control	No change	No change

	With Detect and mitigate options (as described in clause 6.2 and clause 6.3)	With Integration of CBTC in ITS protocol (as described in clause 6.4)
Transmitter unwanted emissions	In the clause "definition" [i.4], a note should indicate that for UR stations, operation in the band 5 925 MHz to 5 935 MHz is allowed. A note should also define a different OOB domain for UR-ITS	In the clause "Definition" [i.4], a note should indicate that for UR-ITS-S, operation in the band 5 925 MHz to 5 935 MHz is allowed
Transmitter spectrum mask	A new transmitter mask for UR stations with 5 MHz channels should be added in clause 4.2.5.2 of ETSI EN 302 571 [i.4]	No change
Receiver spurious emissions	No change	No change
Receiver selectivity	The clause "Definition" [i.4] needs to be modified to consider also channels of 5 MHz for UR stations	No change
Receiver sensitivity	The limits for 5 MHz channels need to be added	No change
Interference mitigation for CEN DSRC and HDR DSRC in the frequency band 5 795 MHz to 5 815 MHz	New Definition and Limits should be added in [i.4] for the UR station case, following results of ECC Report 290 [i.11]	No change
Duty Cycle	A specific use case for Urban Rail ITS should be introduced: a duty cycle limit exists for UR stations but is highly different from the one applicable for a ITS station, and should be fulfilled by the CBTC system itself, so duty cycle limit should not be applicable for UR stations. See notes 1 and 2	A specific use case for Urban Rail ITS should be introduced: a duty cycle limit exists but is highly different from the one applicable for an ITS station, and should be fulfilled by the CBTC system itself, so duty cycle limit should not be applicable for UR station
New technical requirement to be added: "technical requirement to ensure spectrum sharing between Road ITS applications and CBTC applications"	New text should indicate the band in which Urban Rail ITS has priority and the mitigation techniques to be applied in the different PZ, using a reference to the new standards based on ETSI TS 102 792 [i.1] and the updated ETSI TS 102 894-2 [i.3] and to a new standard for the database if applicable	New text should indicate the band in which Urban Rail has priority. A reference to the priority class reserved for UR stations in that band should be added. Other technical parameters specific to each radio technology required to ensure that priority should be also added
NOTE 1: It is not planned to use duty cycle limitation as a mitigation technique at first stage. Therefore, the current limit given to ITS stations should stay unchanged. NOTE 2: ECC Report 290 [i.11] confirms that the proposed modification is acceptable.		

8 General conclusions and summary

The present document, focusing on the 5 915 MHz to 5 925 MHz band where Urban Rail ITS has priority, proposes:

- Methods to define protected zones.
- Protected Zone detection methods.
- Mitigation techniques to apply in protected zones.

Regarding the definition of protected zones, several methods have been identified. A measurement campaign will be needed to validate these results and to confirm the simulation parameters which should be used to define the proper mitigation area to protect Urban Rail communications.

Considering Protected Zone detection, the present document evaluated several solutions, but the choice of the final one is still to be done among the following:

- Read-only database combined with alert beacons.
- Updatable database combined with optional permissive beacons.

Additional requirements such as regulatory, operational and installation aspects should be taken into account for the final decision.

The two solutions described in the present document based on MAC/PHY layer may be considered as long-term solutions, however existing Urban Rail lines will not be protected. Urban Rail safety and availability concepts are essential and are not guaranteed. These solutions need further investigation before confirming feasibility.

Regarding the mitigation method, adjustment of Road ITS EIRP is a possible way and can be implemented. It could be a progressive reduction with several steps when approaching the urban Rail line, up to stopping transmission on Urban Rail channels. Indeed, in critical situations like parallel roads to the Urban Rail tracks (see Malaga example) an ITS device needs to stop using the relevant Urban Rail channel in the identified mitigation area.

It is recommended that:

- standards ETSI EN 302 571 [i.4] and ETSI TS 102 894-2 [i.3] are modified; and
- a new technical specification is developed to address detection and mitigation techniques outlined in the present document.

Annex A:
Use cases simulations

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.

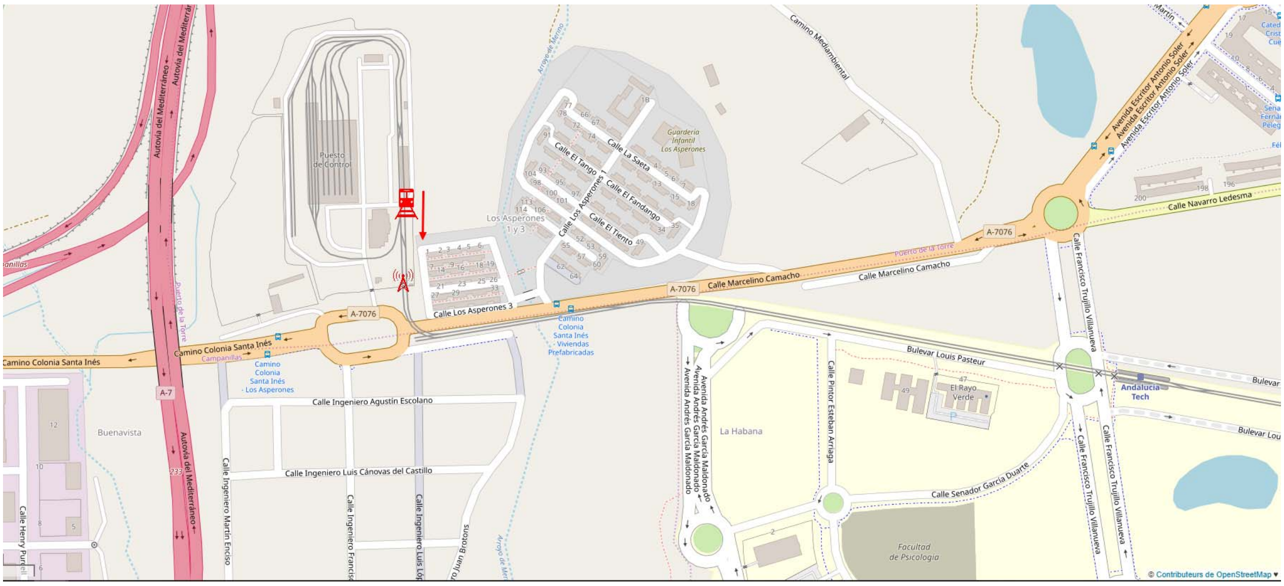


Figure A.1: Malaga metro station and depot facilities map (Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC)

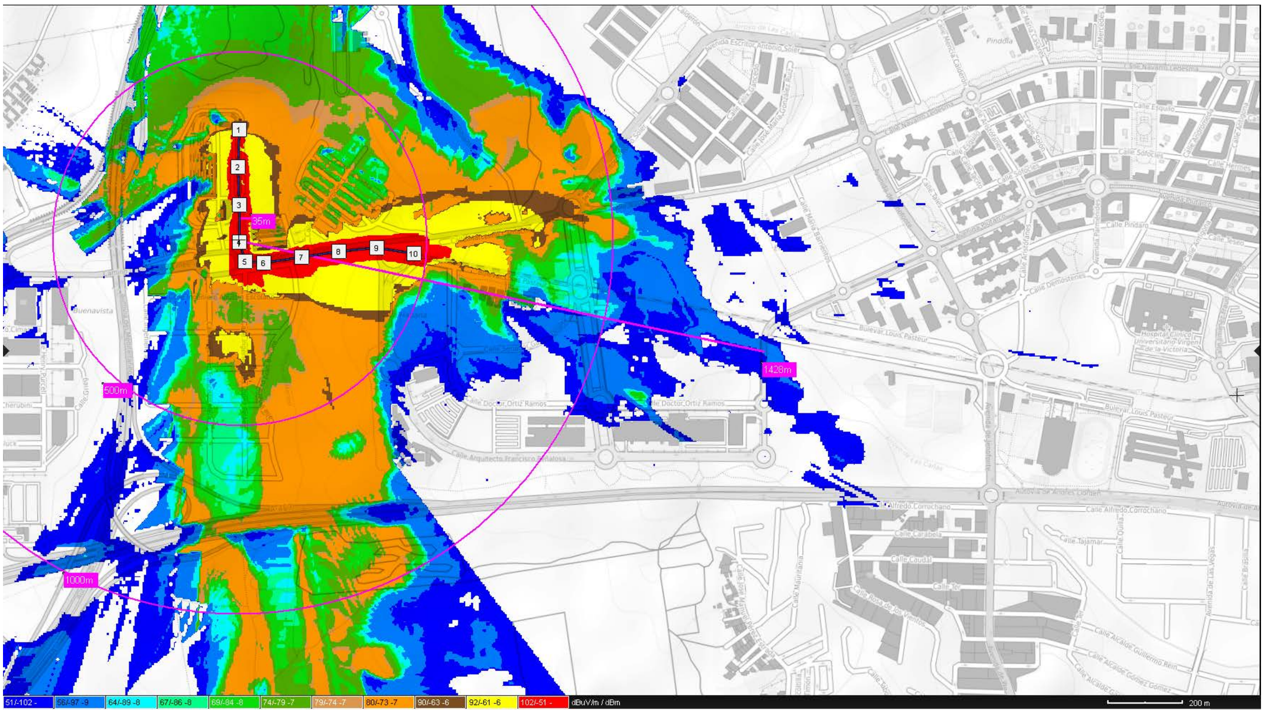


Figure A.2: Malaga depot - Trains Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 1: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

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.3.

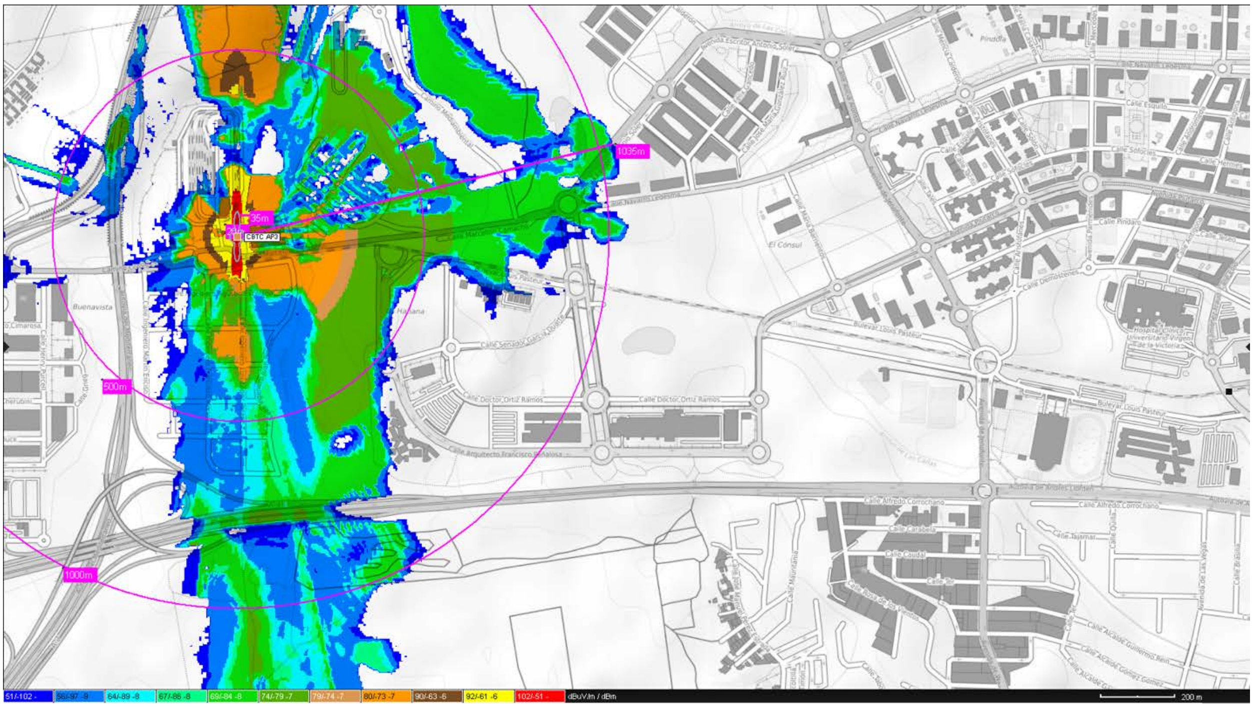


Figure A.3: Malaga depot , Urban Rail AP Protected Zones for different scenarios of Road ITS EIRP and different CBTC systems and radio planning rules

NOTE 2: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

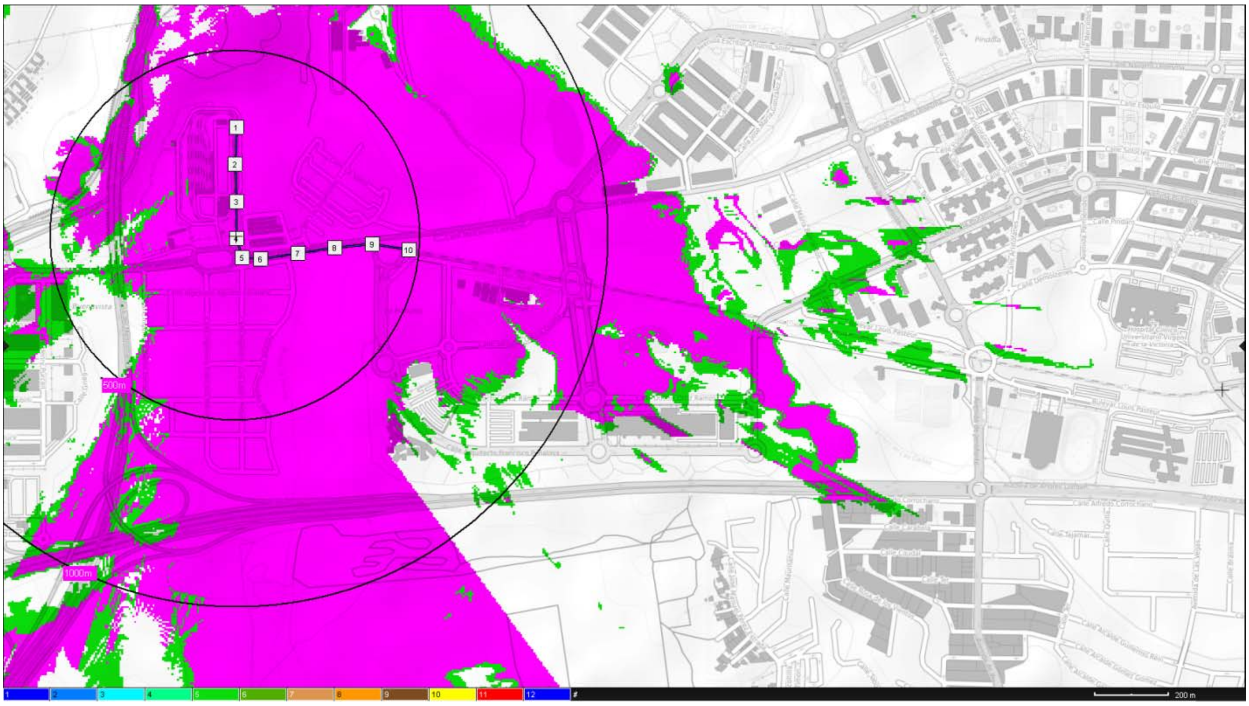


Figure A.4: Malaga depot - Common and additional Protected Zones between car (antenna height=1,7m) and truck (antenna height=4m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitivation

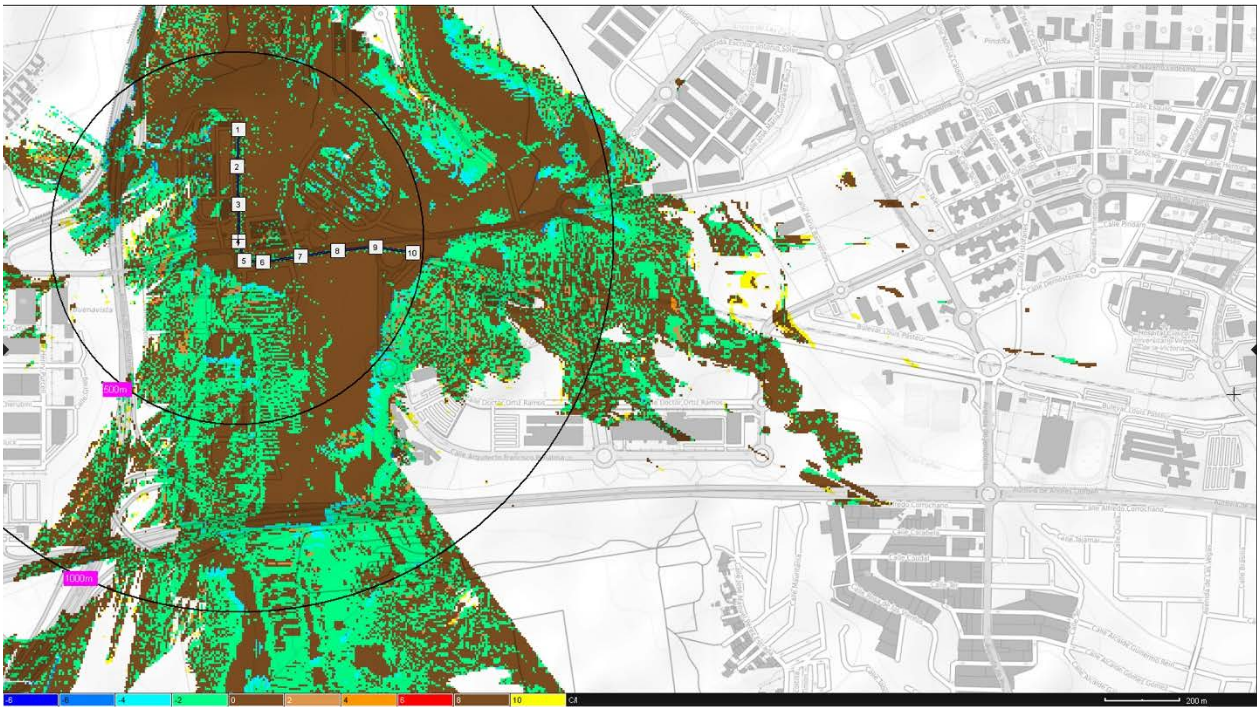


Figure A.5: Malaga depot - Difference of the received interference signal level in dB, due to road-ITS antenna height variations (between 1,5 m and 1,7 m), for a road-ITS EIRP of 33 dBm and CBTC DSSS with 3 dB desensitization

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.6). 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.7. 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.

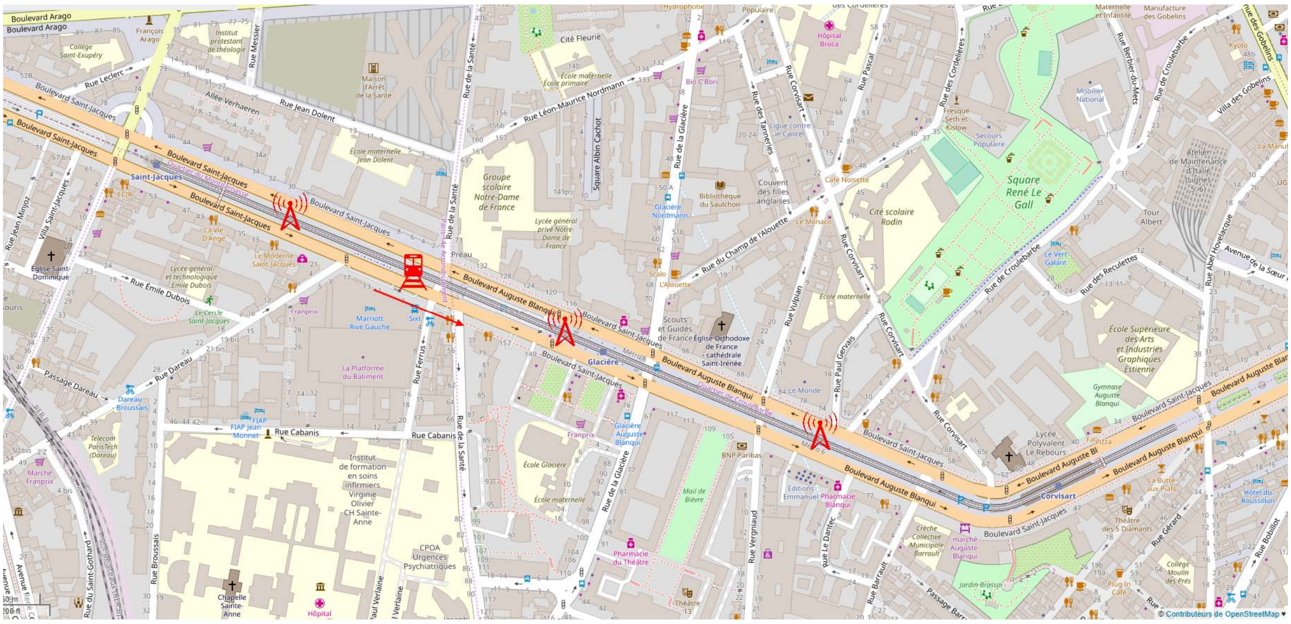


Figure A.6: Paris L6 map
(Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC)

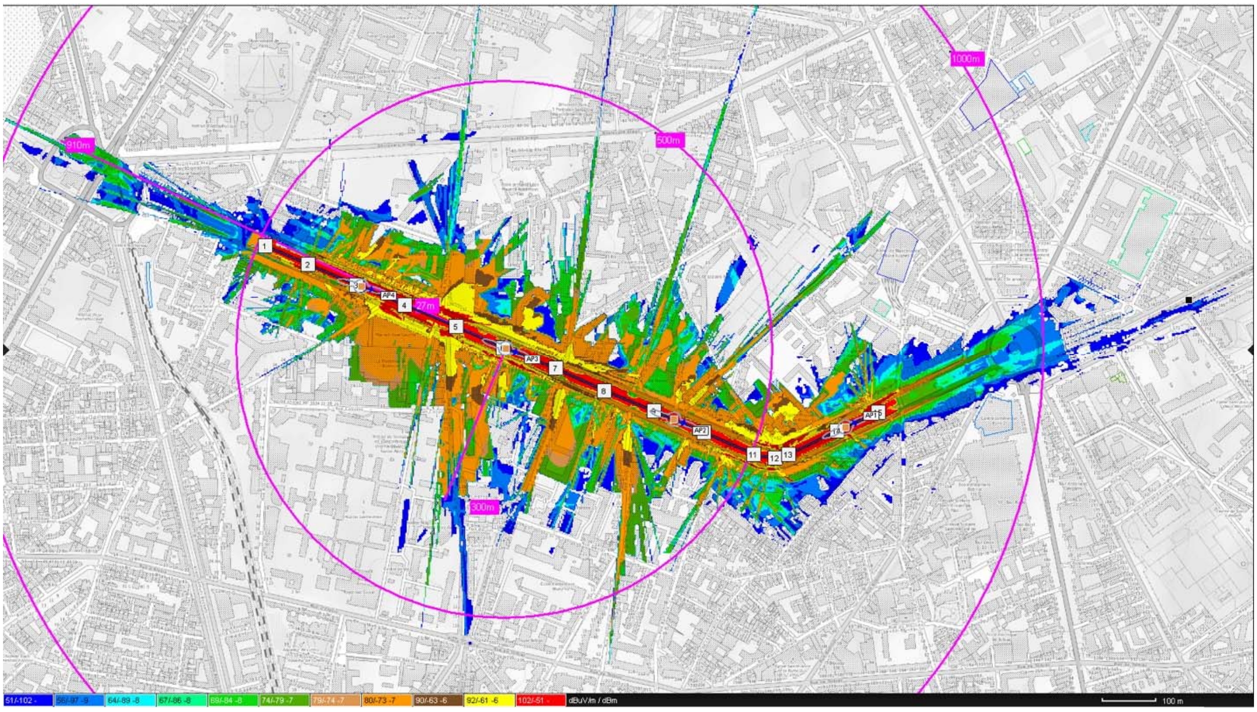


Figure A.7: Paris L6 - Train Protectionzones for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 1: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

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.8.

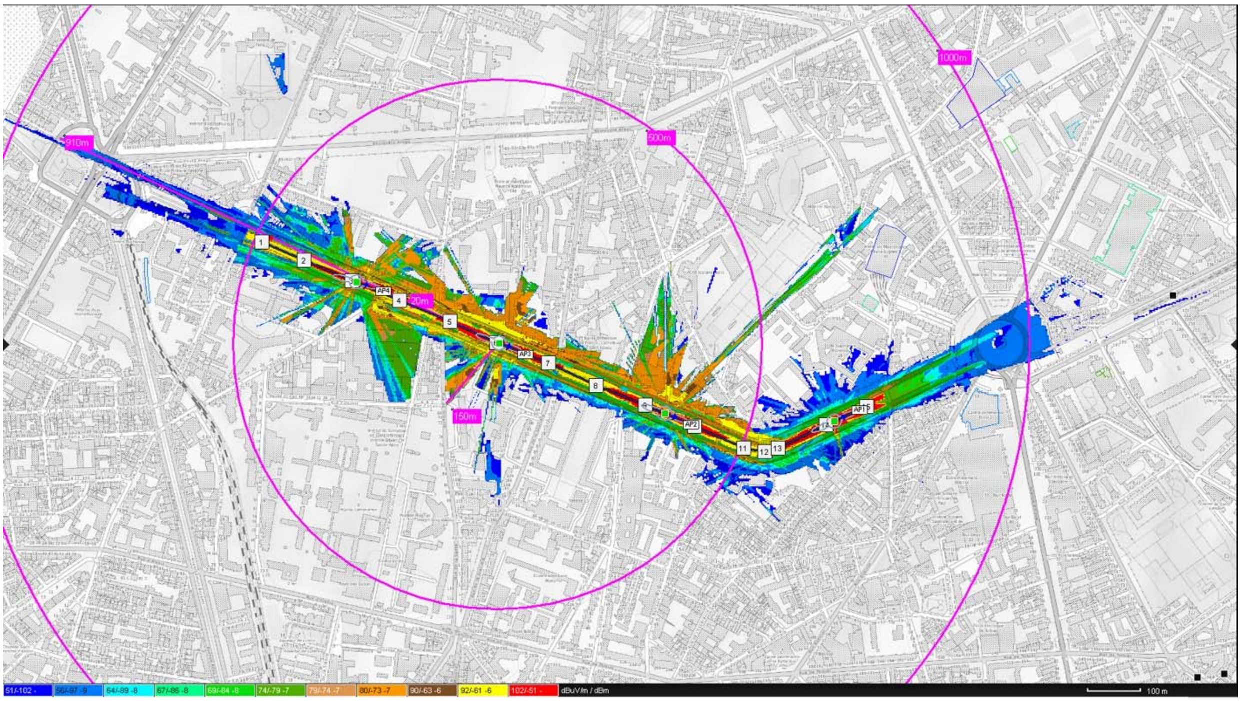


Figure A.8: Paris L6 - Urban Rail AP Protected Zones, for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 2: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

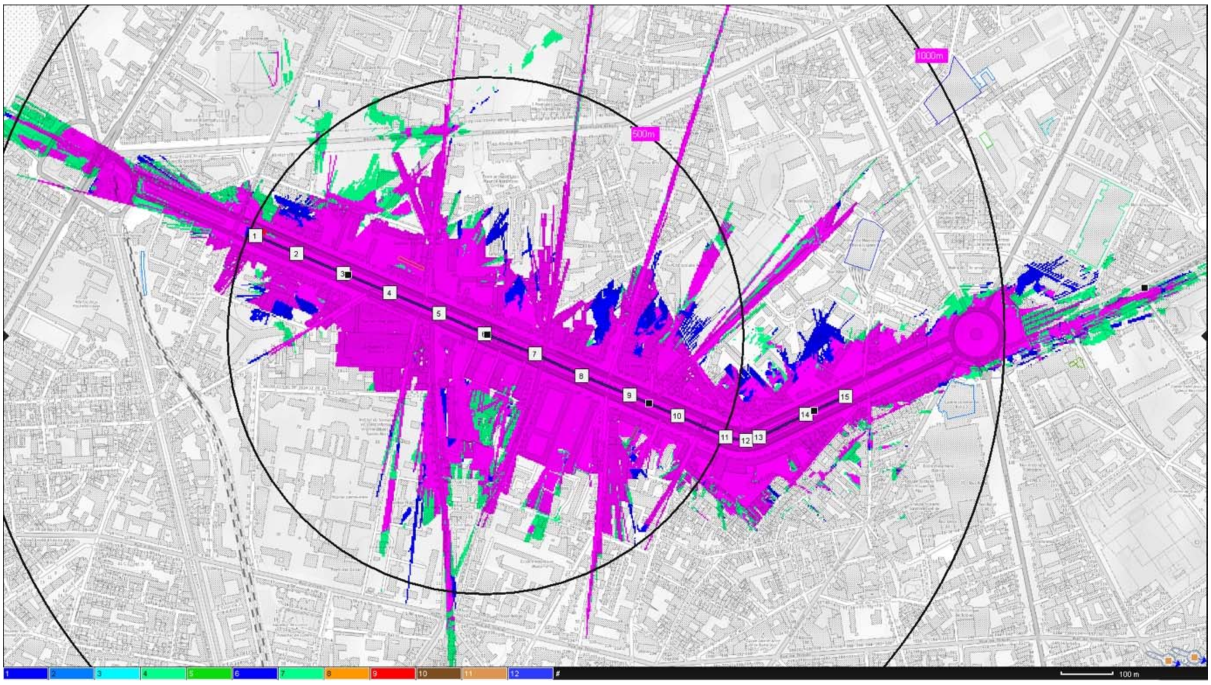


Figure A.9: Paris L6 - Common and additional Protected Zones between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization

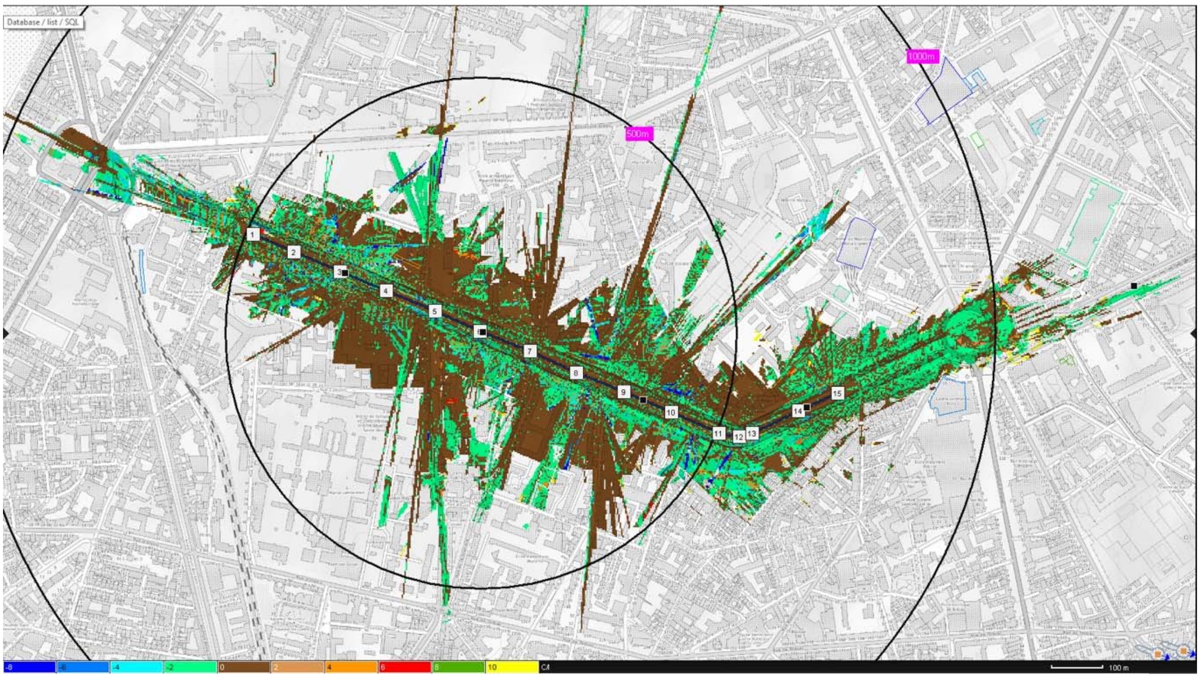


Figure A.10: Paris L6 - Difference of the received interference signal level in dB, for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS with 3 dB desensitization

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.11). 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.12.

Figure A.11: Paris L1 map
(Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC)

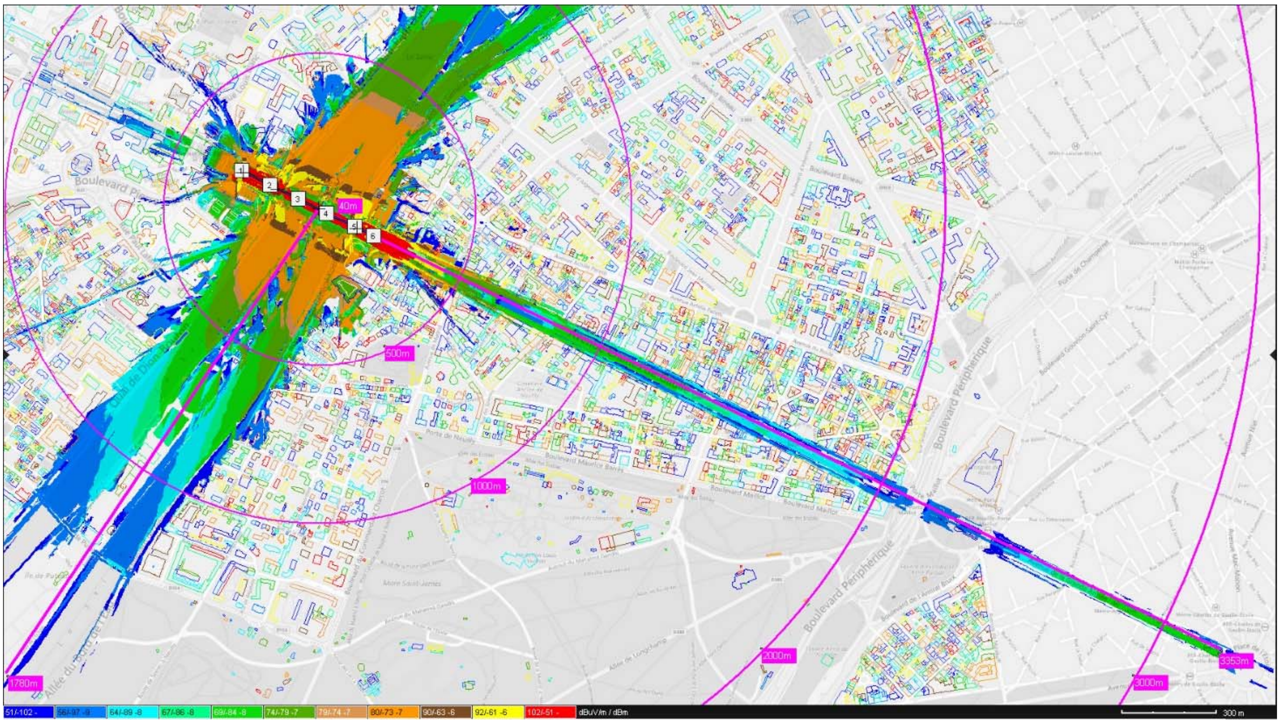


Figure A.12: Paris L1 - Train Protected Zones for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 1: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

Simulation 4.2 uses the same case near to La Defense, but only for the CBTC APs. Protection distances are shown in Figure A.13.

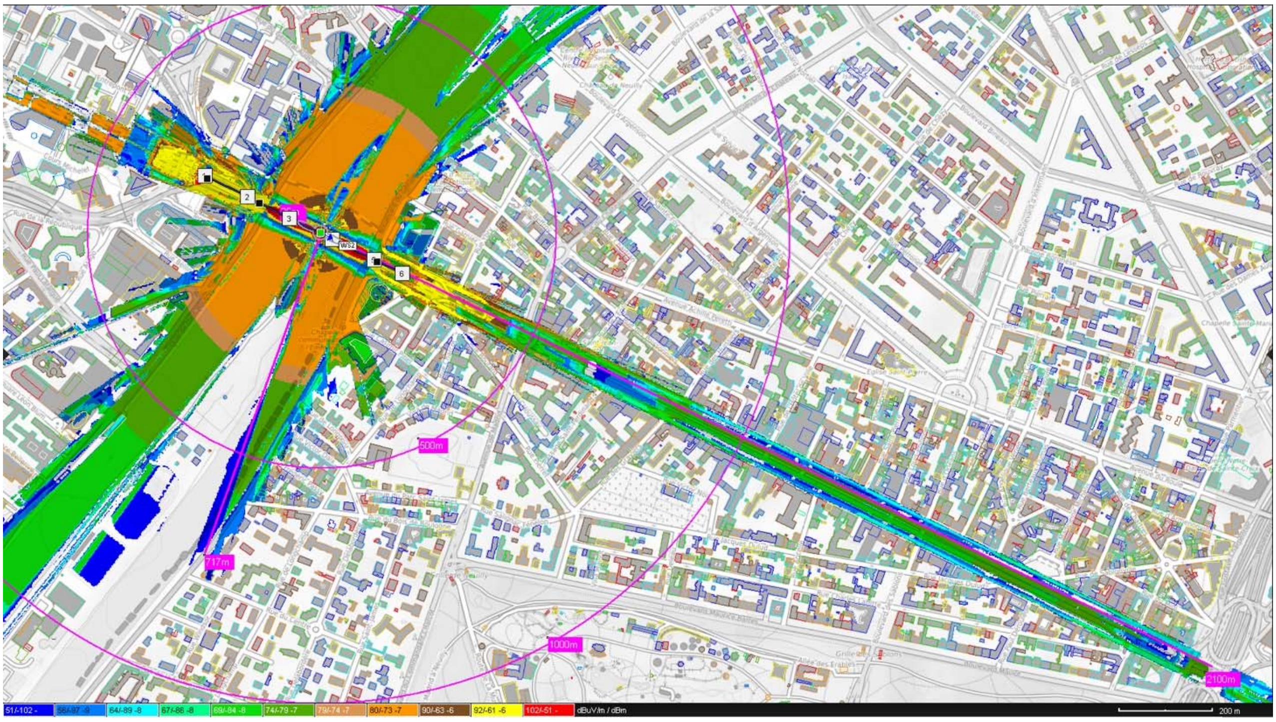


Figure A.13: Paris L1 -Urban Rail AP Protected Zones for different scenarios of road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 2: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

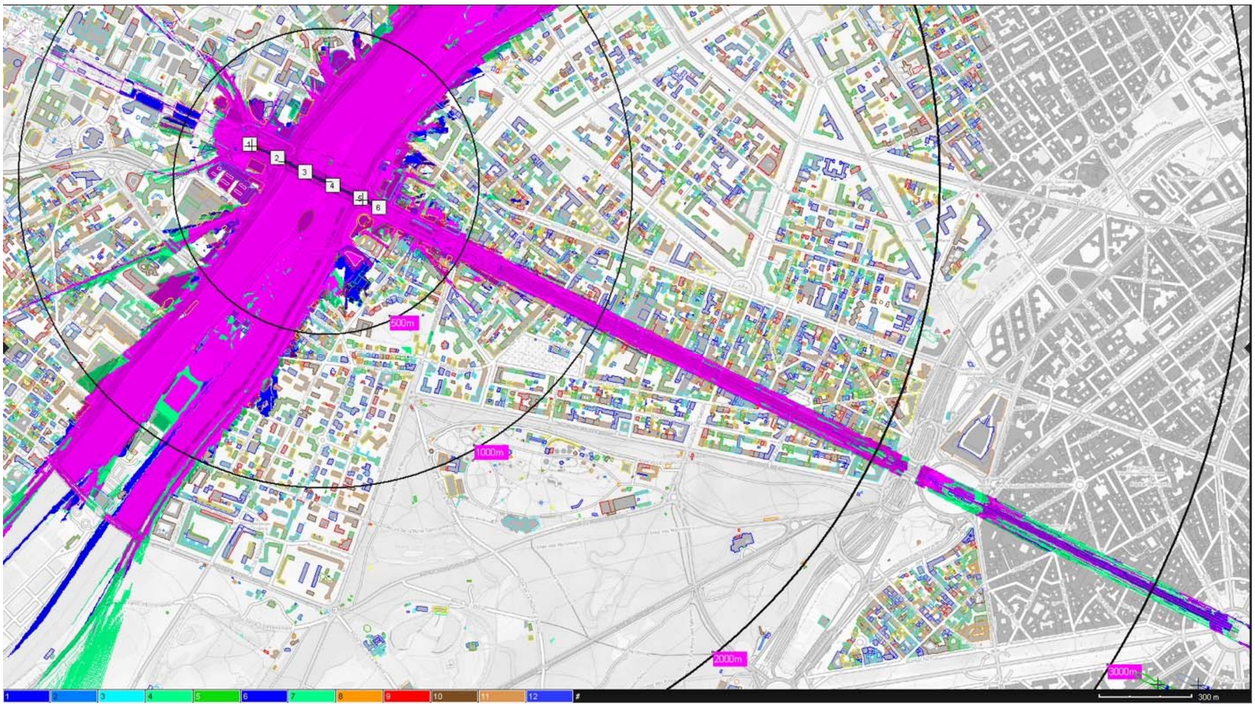


Figure A.14: Paris L1 - Common and additional Protected Zone between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS 33 dBm EIRP and CBTC DSSS with 3 dB desensitization

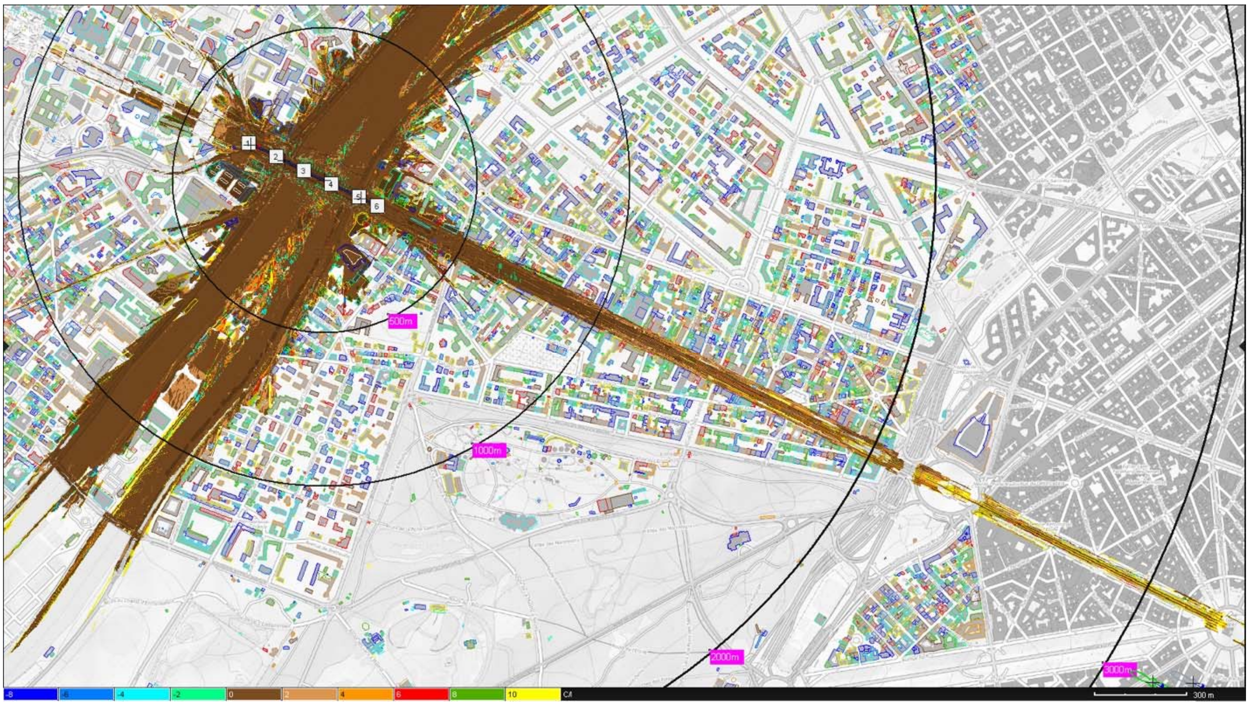


Figure A.15: Paris L1 - Difference of the received interference level in dB, for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS with 3 dB desensitization

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.16). 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.17. 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 9,6m and each lane measures on average 3,2 m in width.

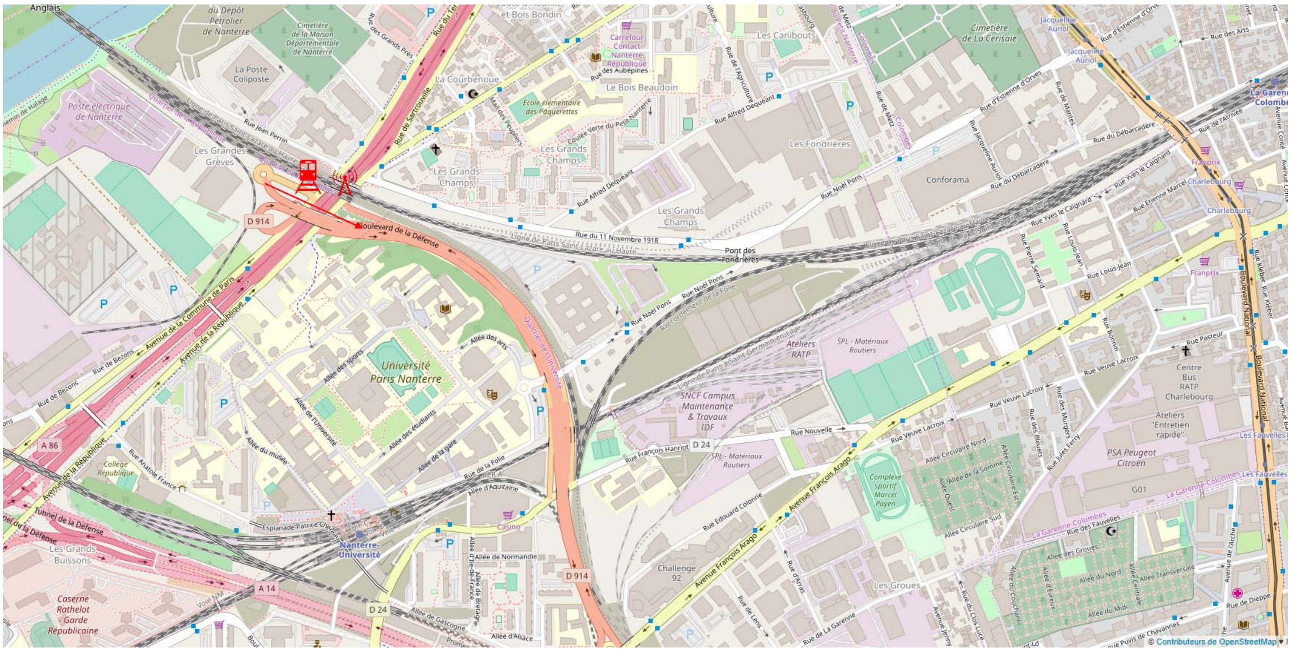


Figure A.16 : Paris RER_E and A86 intersection map (Source: ©2018 Google LLC, used with permission. Google and the Google logo are registered trademarks of Google LLC)

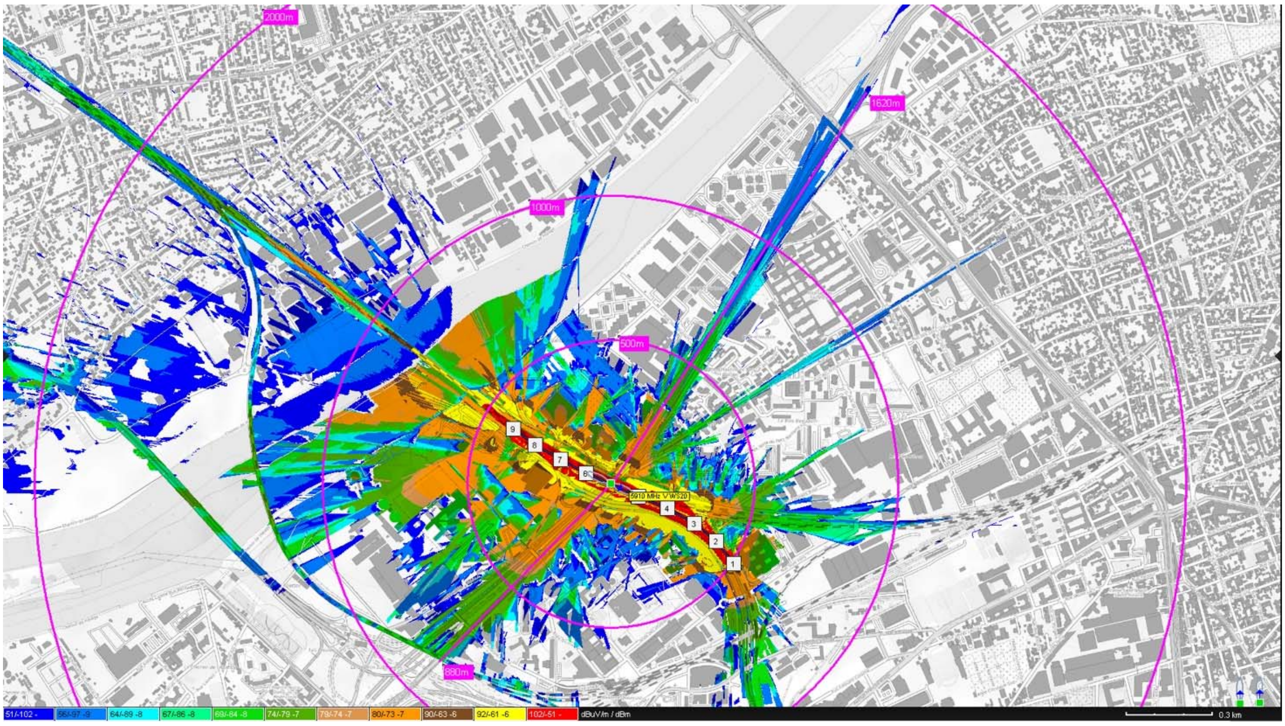


Figure A.17: Paris RER E - Train Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 1: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

Simulation 5.2 uses the same case in A86 highway, but only for the CBTC APs. Protection distances are shown in Figure A.18.

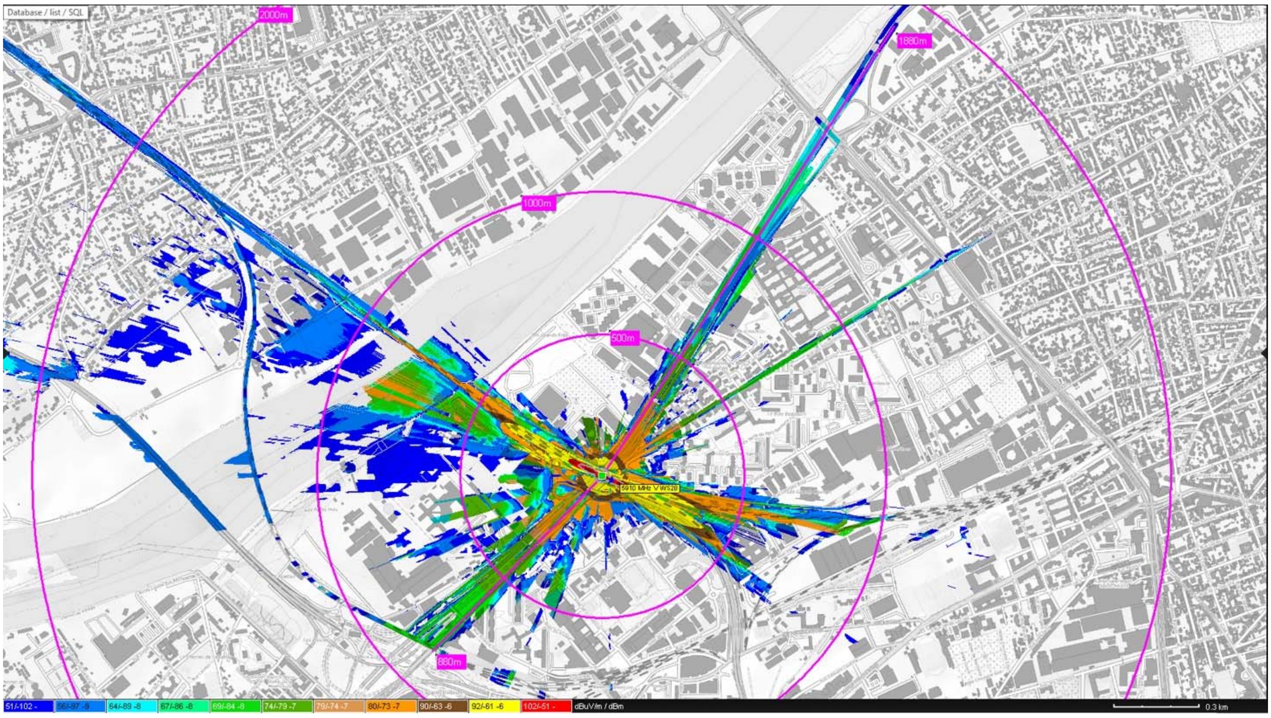


Figure A.18: Paris RER E - Urban Rail AP Protected Zones for different scenarios of Road-ITS EIRP and different CBTC systems and radio planning rules

NOTE 2: The definition of the colour palette and corresponding scenarios are defined in clause 5.2.3.

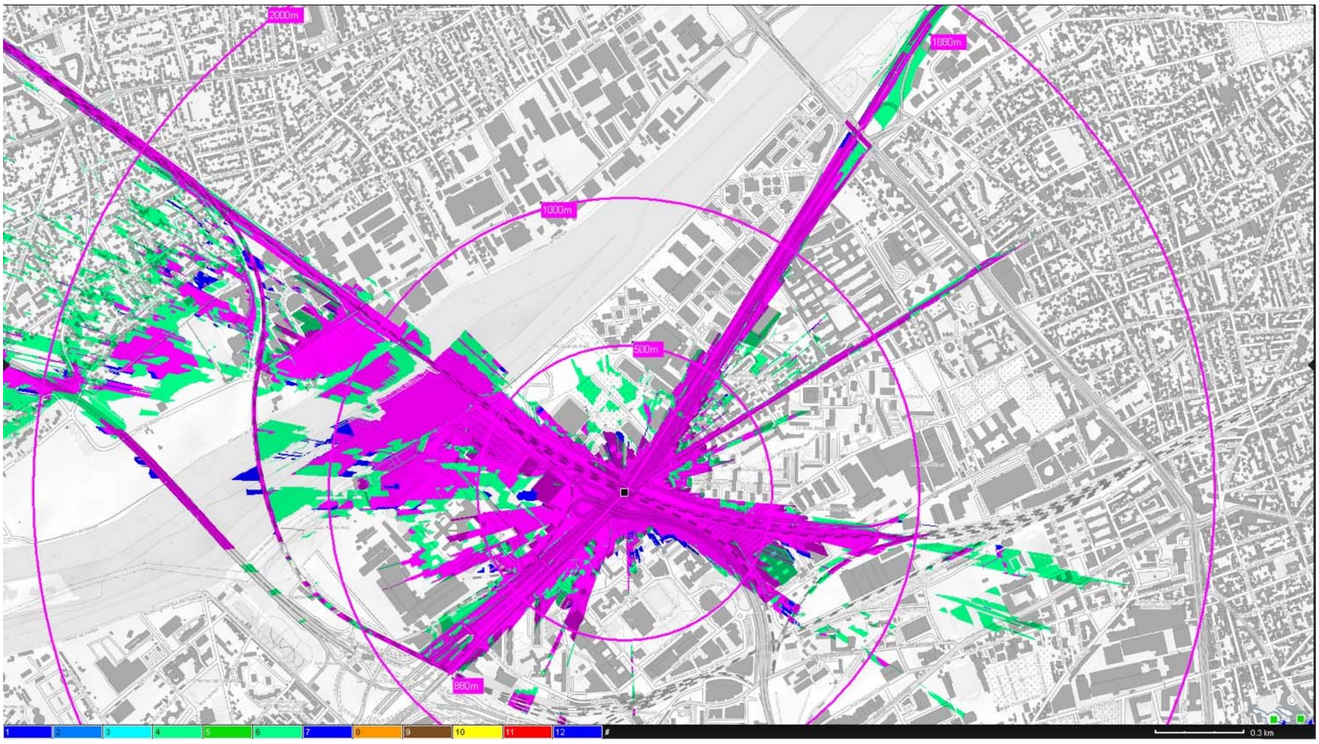


Figure A.19: Paris RER E - Common and additional Protected Zones between car (antenna height = 1,7 m) and truck (antenna height = 4 m) for Road-ITS of 33 dBm EIRP and CBTC DSSS system with 3 dB desensitization

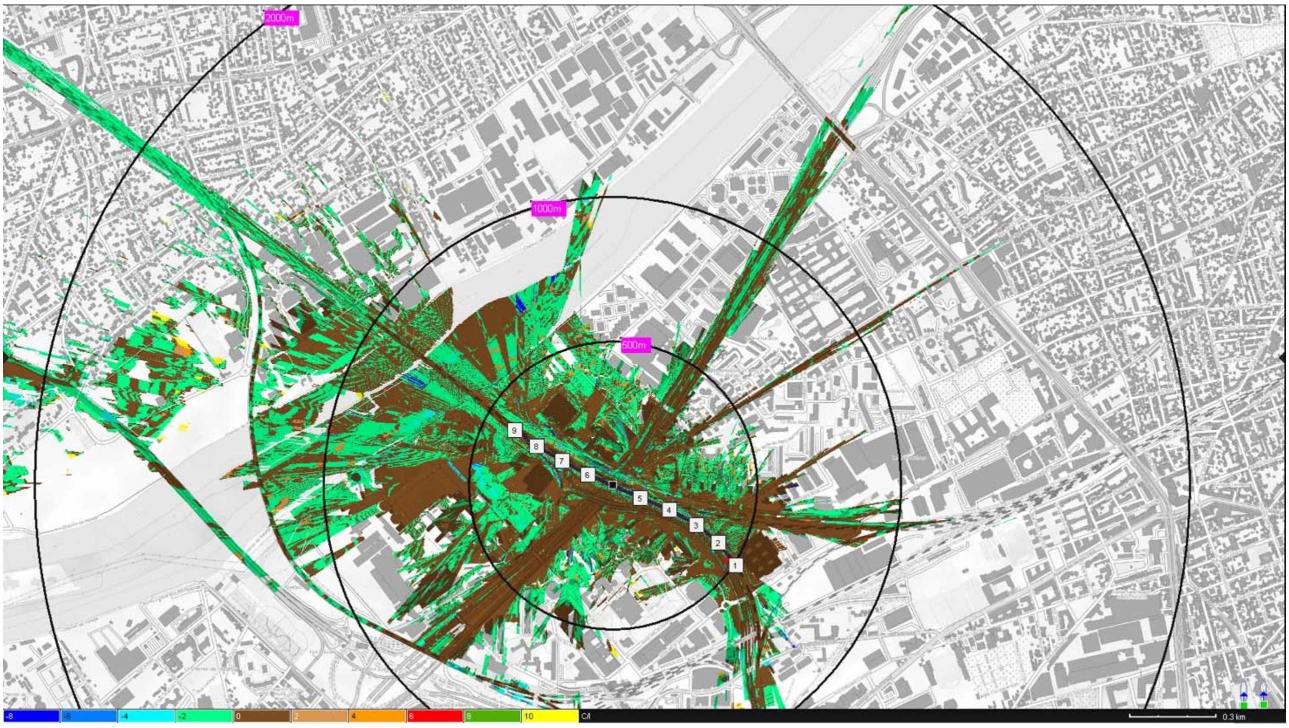


Figure A.20: Paris RER E - Difference of the received interference level in dB for a Road-ITS antenna height variation between 1,5 m and 1,7 m, for Road-ITS EIRP of 33 dBm and a CBTC DSSS system with 3 dB desensitization

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

B.1 Introduction

This annex describes a typical traffic model for a CBTC system using a 802.11 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	1000	3,3333	13 333	26 667
On demand specific status message	300	500	1000	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**

B.5 5 MHz Channel occupancy

B.5.1 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 B.7: 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 B.8

IEEE802.11 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.

B.5.2 Results of analysis

The evaluation has been made for three data rates:

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

Note that these three data rates can be used but the preferred one is 1,5 Mbits/s using BPSK modulation.

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 B.9: CBTC Application services Uplink and Downlink Throughput and timing, for communication with one ZC

	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 B.10: CBTC Application services Uplink and Downlink Throughput and timing, for communication with three ZC

	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 B.11: CBTC Application services Uplink and Downlink Throughput and timing, for communication with three ZC and one PSD

	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 C: Minimum Coupling loss simulations

C.1 Introduction

In this annex a set of minimum coupling loss calculations is given in detail. The calculation considers different TX power level of the Road ITS devices ranging from 10 dBm over 23 dBm to 33 dBm, where the level of 23 dBm can be assume as the typical value implemented in actual cars installations. The applied channel models are presented in clause 5.2.1.

C.2 Road ITS with 10 dB TX power

In this clause the Interference Calculation for Road ITS towards Urban Rail using DSSS and IEEE 802.11a [i.15] with 10 dBm ITS power is depicted.

Table C.1: General parameter for Road ITS with 10 dBm TX power

LINK BUDGET	Value	Units	Urban	Suburban	Rural	ETSI	LoS
Emission part: ITS							
Bandwidth	10	MHz	10	10	10	10	10
Tx out, e.i.r.p.	10	dBm	10	10	10	10	10
Tx Out e.i.r.p. per MHz	0	dBm/MHz	0	23	0	0	0
Net Tx Out eirp	0	dBm/MHz	0	0	0	0	0
Antenna Gain	8	dBi	8	8	8	8	8
Frequency (GHz)	5 900	MHz	5 900	5 900	5 900	5 900	5 900
Propagation models							
first exponent			2	2	2	2	2
first breakpoint (m)		m	64	128	256	15	
Attenuation 1. breakpoint		dB	84,0	90,0	96,0	71,4	
second exponent			3,8	3,3	2,8	2,7	
second breakpoint(m)		m	128	256	1024	1024	
attenuation 2.breackpoint		dB	95,4	99,9	112,9	120,9	
third exponent			4,3	3,8	3,3	2,7	

Table C.2: Urban Rail based on IEEE, Way Side unit

Reception part way side unit: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**102,0**	**102,0**	**102,0**	**102,0**	**102,0**
RX level at "ITS-Input"			**-64,0**	**-64,0**	**-64,0**	**-64,0**	**-64,0**
Separation distance ITS->UR (m)		**m**	**182**	**290**	**418**	**204**	**508**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-87,0	-87,0	-87,0	-87,0	-87,0
Required Attenuation (dB)		**dB**	**87,0**	**87,0**	**87,0**	**87,0**	**87,0**
Separation distance ITS->UR (m)		**m**	**77**	**90**	**90**	**57**	**90**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**97,0**	**97,0**	**97,0**	**97,0**	**97,0**
Separation distance ITS->UR (m)		**m**	**141**	**208**	**277**	**133**	**286**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-82,0	-82,0	-82,0	-82,0	-82,0
Required Attenuation (dB)		**dB**	**82,0**	**82,0**	**82,0**	**82,0**	**82,0**
Separation distance ITS->UR (m)		**m**	**51**	**51**	**51**	**37**	**51**

Table C.3: Urban Rail based on IEEE, Train unit

Reception part train unit: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**102,0**	**102,0**	**102,0**	**102,0**	**102,0**
Separation distance ITS->UR (m)		**m**	**182**	**290**	**418**	**204**	**508**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-84,0	-84,0	-84,0	-84,0	-84,0
Required Attenuation (dB)		**dB**	**84,0**	**84,0**	**84,0**	**84,0**	**84,0**
Separation distance ITS->UR (m)		**m**	**64**	**64**	**64**	**44**	**64**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**97,0**	**97,0**	**97,0**	**97,0**	**97,0**
Separation distance ITS->UR (m)		**m**	**141**	**208**	**277**	**133**	**286**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-79,0	-79,0	-79,0	-79,0	-79,0
Required Attenuation (dB)		**dB**	**79,0**	**79,0**	**79,0**	**79,0**	**79,0**
Separation distance ITS->UR (m)		**m**	**36**	**36**	**36**	**29**	**36**

Table C.4: Urban Rail based on DSSS, way side unit

Reception part: way side unit UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level '*I*' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**90,0**	**90,0**	**90,0**	**90,0**	**90,0**
RX level at "ITS-Input"			**-52,0**	**-52,0**	**-52,0**	**-52,0**	**-52,0**
Separation distance ITS->UR (m)		**m**	**92**	**128**	**128**	**73**	**128**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-75,0	-75,0	-75,0	-75,0	-75,0
Required Attenuation (dB)		**dB**	**75,0**	**75,0**	**75,0**	**75,0**	**75,0**
RX level at "ITS-Input"			**-52,0**	**-52,0**	**-52,0**	**-52,0**	**-52,0**
Separation distance ITS->UR (m)		**m**	**23**	**23**	**23**	**20**	**23**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**85,0**	**85,0**	**85,0**	**85,0**	**85,0**
Separation distance ITS->UR (m)		**m**	**68**	**72**	**72**	**48**	**72**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-70,0	-70,0	-70,0	-70,0	-70,0
Required Attenuation (dB)		**dB**	**70,0**	**70,0**	**70,0**	**70,0**	**70,0**
Separation distance ITS->UR (m)		**m**	**13**	**13**	**13**	**13**	**13**

Table C.5: Urban Rail based on DSSS, train unit

Reception part train unit: UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**90,0**	**90,0**	**90,0**	**90,0**	**90,0**
Separation distance ITS->UR (m)		**m**	**92**	**128**	**128**	**73**	**128**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-72,0	-72,0	-72,0	-72,0	-72,0
Required Attenuation (dB)		**dB**	**72,0**	**72,0**	**72,0**	**72,0**	**72,0**
Separation distance ITS->UR (m)		**m**	**16**	**16**	**16**	**16**	**16**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**85,0**	**85,0**	**85,0**	**85,0**	**85,0**
Separation distance ITS->UR (m)		**m**	**68**	**72**	**72**	**48**	**72**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-67,0	-67,0	-67,0	-67,0	-67,0
Required Attenuation (dB)		**dB**	**67,0**	**67,0**	**67,0**	**67,0**	**67,0**
Separation distance ITS->UR (m)		**m**	**9**	**9**	**9**	**9**	**9**

C.3 Road ITS with 23 dB TX power

In this clause the calculation results of interference from Road ITS with a power level of 23 dBm towards Urban Rail transmission using DSSS and IEEE 802.11a [i.15] are listed.

Table C.6: General parameter for Road ITS with 23 dBm TX power

LINK BUDGET	Value	Units	Urban	Suburban	Rural	ETSI	LoS
Emission part: ITS							
Bandwidth	10	MHz	10	10	10	10	10
Tx out, eirp	23	dBm	23	23	23	23	23
Tx Out eirp per MHz	13	dBm/MHz	13	23	13	13	13
Net Tx Out eirp	13	dBm/MHz	13	13	13	13	13
Antenna Gain	8	dBi	8	8	8	8	8
Frequency (GHz)	5 900	MHz	5 900	5 900	5 900	5 900	5 900
Propagation models							
first exponent			2	2	2	2	2
first breakpoint (m)		**M**	64	128	256	15	
attenuation 1. breakpoint		**dB**	84,0	90,0	96,0	71,4	
second exponent			3,8	3,3	2,8	2,7	
second breakpoint(m)		**M**	128	256	1 024	1 024	
attenuation 2.breackpoint		**dB**	95,4	99,9	112,9	120,9	
third exponent			4,3	3,8	3,3	2,7	

Table C.7: Urban Rail based on IEEE, way side unit

Reception part way side: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level '*I*' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**115,0**	**115,0**	**115,0**	**115,0**	**115,0**
RX level at "ITS-Input"			**-77,0**	**-77,0**	**-77,0**	**-77,0**	**-77,0**
Separation distance ITS->UR (m)		**m**	**365**	**637**	**1 186**	**618**	**2 271**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-87,0	-87,0	-87,0	-87,0	-87,0
Required Attenuation (dB)		**dB**	**100,0**	**100,0**	**100,0**	**100,0**	**100,0**
Separation distance ITS->UR (m)		**m**	**163**	**257**	**354**	**172**	**404**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**110,0**	**110,0**	**110,0**	**110,0**	**110,0**
Separation distance ITS->UR (m)		**m**	**309**	**516**	**807**	**403**	**1 277**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-82,0	-82,0	-82,0	-82,0	-82,0
Required Attenuation (dB)		**dB**	**95,0**	**95,0**	**95,0**	**95,0**	**95,0**
Separation distance ITS->UR (m)		**m**	**125**	**181**	**227**	**112**	**227**

Table C.8: Urban Rail based on IEEE, train unit

Reception part train unit: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**115,0**	**115,0**	**115,0**	**115,0**	**115,0**
Separation distance ITS->UR (m)		**m**	**365**	**637**	**1 186**	**618**	**2 271**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-84,0	-84,0	-84,0	-84,0	-84,0
Required Attenuation (dB)		**dB**	**97,0**	**97,0**	**97,0**	**97,0**	**97,0**
Separation distance ITS->UR (m)		**m**	**139**	**208**	**277**	**133**	**286**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**110,0**	**110,0**	**110,0**	**110,0**	**110,0**
Separation distance ITS->UR (m)		**m**	**309**	**516**	**807**	**403**	**1 277**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-79,0	-79,0	-79,0	-79,0	-79,0
Required Attenuation (dB)		**dB**	**92,0**	**92,0**	**92,0**	**92,0**	**92,0**
Separation distance ITS->UR (m)		**m**	**104**	**147**	**161**	**87**	**161**

Table C.9: Urban Rail based on DSSS, way side unit

Reception part Way side unit: UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**103,0**	**103,0**	**103,0**	**103,0**	**103,0**
RX level at "ITS-Input"			**-65,0**	**-65,0**	**-65,0**	**-65,0**	**-65,0**
Separation distance ITS->UR (m)		**m**	**192**	**308**	**454**	**222**	**570**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-75,0	-75,0	-75,0	-75,0	-75,0
Required Attenuation (dB)		**dB**	**88,0**	**88,0**	**88,0**	**88,0**	**88,0**
RX level at "ITS-Input"			**-65,0**	**-65,0**	**-65,0**	**-65,0**	**-65,0**
Separation distance ITS->UR (m)		**m**	**82**	**101**	**101**	**62**	**101**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**98,0**	**98,0**	**98,0**	**98,0**	**98,0**
Separation distance ITS->UR (m)		**m**	**149**	**223**	**301**	**145**	**321**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-70,0	-70,0	-70,0	-70,0	-70,0
Required Attenuation (dB)		**dB**	**83,0**	**83,0**	**83,0**	**83,0**	**83,0**
Separation distance ITS->UR (m)		**m**	**57**	**57**	**57**	**40**	**57**

Table C.10: Urban Rail based on DSSS, train unit

Reception part train unit: UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**103,0**	**103,0**	**103,0**	**103,0**	**103,0**
Separation distance ITS->UR (m)		**m**	**192**	**308**	**454**	**222**	**570**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-72,0	-72,0	-72,0	-72,0	-72,0
Required Attenuation (dB)		**dB**	**85,0**	**85,0**	**85,0**	**85,0**	**85,0**
Separation distance ITS->UR (m)		**m**	**68**	**72**	**72**	**48**	**72**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**98,0**	**98,0**	**98,0**	**98,0**	**98,0**
Separation distance ITS->UR (m)		**m**	**149**	**223**	**301**	**145**	**321**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-67,0	-67,0	-67,0	-67,0	-67,0
Required Attenuation (dB)		**dB**	**80,0**	**80,0**	**80,0**	**80,0**	**80,0**
Separation distance ITS->UR (m)		**m**	**40**	**40**	**40**	**31**	**40**

C.4 Road ITS with 33 dB TX power

In this clause the calculation results of interference from Road ITS with a power level of 33 dBm towards Urban Rail transmissions using DSSS and IEEE 802.11a [i.15] are depicted.

Table C.11: General parameter for Road ITS with 33 dBm TX power

LINK BUDGET	Value	Units	Urban	Suburban	Rural	ETSI	LoS
Emission part: ITS							
Bandwidth	10	MHz	10	10	10	10	10
Tx out, eirp	33	dBm	33	33	33	33	33
Tx Out eirp per MHz	23	dBm/MHz	23	23	23	23	23
Net Tx Out eirp	23	dBm/MHz	23	23	23	23	23
Antenna Gain	8	dBi	8	8	8	8	8
Frequency (GHz)	5 900	MHz	5 900	5 900	5 900	5 900	5 900
Propagation models							
first exponent			2	2	2	2	2
first breakpoint (m)		**m**	64	128	256	15	
attenuation 1. breakpoint		**dB**	84,0	90,0	96,0	71,4	
second exponent			3,8	3,3	2,8	2,7	
second breakpoint(m)		**m**	128	256	1024	1024	
attenuation 2.breakpoint		**dB**	95,4	99,9	112,9	120,9	
third exponent			4,3	3,8	3,3	2,7	

Table C.12: Urban Rail based on IEEE, way side unit

Reception part way side unit: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector (ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**125,0**	**125,0**	**125,0**	**125,0**	**125,0**
RX level at "ITS-Input"			**-87,0**	**-87,0**	**-87,0**	**-87,0**	**-87,0**
Separation distance ITS->UR (m)		**m**	**623**	**1 168**	**2 382**	**1 450**	**7 180**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-87,0	-87,0	-87,0	-87,0	-87,0
Required Attenuation (dB)		**dB**	**110,0**	**110,0**	**110,0**	**110,0**	**110,0**
Separation distance ITS->UR (m)		**m**	**279**	**471**	**807**	**403**	**1 277**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**120,0**	**120,0**	**120,0**	**120,0**	**120,0**
Separation distance ITS->UR (m)		**m**	**567**	**1 037**	**1 836**	**947**	**4 038**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-82,0	-82,0	-82,0	-82,0	-82,0
Required Attenuation (dB)		**dB**	**105,0**	**105,0**	**105,0**	**105,0**	**105,0**
Separation distance ITS->UR (m)		**m**	**214**	**348**	**535**	**263**	**718**

Table C.13: Urban Rail based on IEEE, train unit

Reception part train unit: UR-IEEE							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	9	dB	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-102,0**	**-102,0**	**-102,0**	**-102,0**	**-102,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-102,0	-102,0	-102,0	-102,0	-102,0
Required Attenuation (dB)			**125,0**	**125,0**	**125,0**	**125,0**	**125,0**
Separation distance ITS->UR (m)		**m**	**623**	**1 168**	**2 382**	**1 450**	**7 180**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-84,0	-84,0	-84,0	-84,0	-84,0
Required Attenuation (dB)		**dB**	**107,0**	**107,0**	**107,0**	**107,0**	**107,0**
Separation distance ITS->UR (m)		**m**	**238**	**392**	**630**	**312**	**904**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-97,0	-97,0	-97,0	-97,0	-97,0
Required Attenuation (dB)		**dB**	**120,0**	**120,0**	**120,0**	**120,0**	**120,0**
Separation distance ITS->UR (m)		**m**	**567**	**1 037**	**1 836**	**947**	**4 038**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-79,0	-79,0	-79,0	-79,0	-79,0
Required Attenuation (dB)		**dB**	**102,0**	**102,0**	**102,0**	**102,0**	**102,0**
Separation distance ITS->UR (m)		**m**	**182**	**290**	**418**	**204**	**508**

Table C.14: Urban Rail based on DSSS, way side unit

Reception part way side unit: UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-77	dBm	-77	-77	-77	-77	-77
Antenna gain (including feeder and splitter loss)	9	dBi	9	9	9	9	9
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**113,0**	**113,0**	**113,0**	**113,0**	**113,0**
RX level at "ITS-Input"			**-75,0**	**-75,0**	**-75,0**	**-75,0**	**-75,0**
Separation distance ITS->UR (m)		**m**	**328**	**564**	**1031**	**521**	**1 804**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	15	dB	15	15	15	15	15
Allowable Interfering power level at receiver antenna input		dBm/MHz	-75,0	-75,0	-75,0	-75,0	-75,0
Required Attenuation (dB)		**dB**	**98,0**	**98,0**	**98,0**	**98,0**	**98,0**
RX level at "ITS-Input"			**-75,0**	**-75,0**	**-75,0**	**-75,0**	**-75,0**
Separation distance ITS->UR (m)		**m**	**147**	**223**	**301**	**145**	**321**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**108,0**	**108,0**	**108,0**	**108,0**	**108,0**
Separation distance ITS->UR (m)		**m**	**274**	**449**	**684**	**340**	**1 014**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	20	dB	20	20	20	20	20
Allowable Interfering power level at receiver antenna input		dBm/MHz	-70,0	-70,0	-70,0	-70,0	-70,0
Required Attenuation (dB)		**dB**	**93,0**	**93,0**	**93,0**	**93,0**	**93,0**
Separation distance ITS->UR (m)		**m**	**110**	**158**	**180**	**95**	**180**

Table C.15: Urban Rail based on DSSS, train unit

Reception part train unit: UR-DSSS							
Receiver Noise bandwidth	5	MHz	5	5	5	5	5
Received signal at connector(ECC Report 290 [i.11])	-76	dBm	-76	-76	-76	-76	-76
Antenna gain (including feeder and splitter loss)	10	dBi	10	10	10	10	10
Allowed C/I	-3	dB	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input		dBm/MHz	**-90,0**	**-90,0**	**-90,0**	**-90,0**	**-90,0**
MAIN LOBE ITS - MAIN LOBE UR							
Allowable Interfering power level at receiver antenna input		dBm/MHz	-90,0	-90,0	-90,0	-90,0	-90,0
Required Attenuation (dB)			**113,0**	**113,0**	**113,0**	**113,0**	**113,0**
Separation distance ITS->UR (m)		**m**	**328**	**564**	**1031**	**521**	**1 804**
MAIN LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	18	dB	18	18	18	18	18
Allowable Interfering power level at receiver antenna input		dBm/MHz	-72,0	-72,0	-72,0	-72,0	-72,0
Required Attenuation (dB)		**dB**	**95,0**	**95,0**	**95,0**	**95,0**	**95,0**
Separation distance ITS->UR (m)		**m**	**125**	**181**	**227**	**112**	**227**
SIDE LOBE ITS - MAIN LOBE UR							
Sidelobe attenuation (dB)	5	dB	5	5	5	5	5
Allowable Interfering power level at receiver antenna input		dBm/MHz	-85,0	-85,0	-85,0	-85,0	-85,0
Required Attenuation (dB)		**dB**	**108,0**	**108,0**	**108,0**	**108,0**	**108,0**
Separation distance ITS->UR (m)		**m**	**274**	**449**	**684**	**340**	**1 014**
SIDE LOBE ITS - SIDE LOBE UR							
Sidelobe attenuation (dB)	23	dB	23	23	23	23	23
Allowable Interfering power level at receiver antenna input		dBm/MHz	-67,0	-67,0	-67,0	-67,0	-67,0
Required Attenuation (dB)		**dB**	**90,0**	**90,0**	**90,0**	**90,0**	**90,0**
Separation distance ITS->UR (m)		**m**	**92**	**128**	**128**	**73**	**128**

Annex D: Interference received from Road Vehicles by Urban Rail Access points

D.1 Introduction

Annex D identifies the optimal propagation model to evaluate the interference signal level received by an Urban Rail access point from road vehicles running on a road parallel to an Urban Rail Line.

The received interference signal level from the road vehicles is evaluated using different propagation models considering the antenna radiating pattern of an Urban Rail access point.

The impact of the antenna height of the Road Vehicle is taken into consideration and it is demonstrated that it has a strong impact on the propagation model that is not reflected in the Urban or Rural propagation model described in clause 5.2.1.

This strong impact is important to be considered when evaluating the interference signal level from the road vehicles.

The Signal to Interference ratio at the Access point RF connector input is evaluated based on the minimum interference power level received by the Urban Rail access point from a Train Radio equipment.

All evaluations are performed for a directive antenna from H&S with 18 dB gain.

D.2 Description of the scenarios analysed

The first scenario analysed evaluates the interference signal level received from road vehicles running on a lane of a road close to a Metro Line. For the analysis 20 m distance between the Road vehicle trajectory and the axis of the Urban Rail base station antenna is considered.

Figure D.1 shows this first scenario.

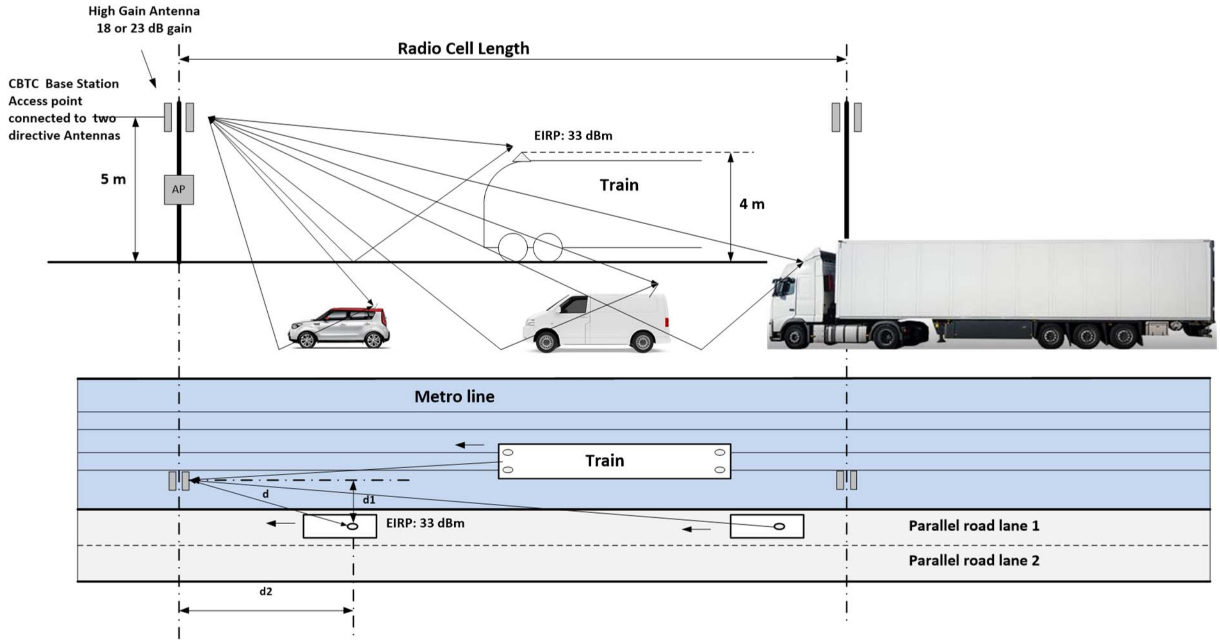


Figure D.1: First scenario road vehicle located at 20 m from the Urban rail base station antenna axis

The following parameters are considered for the analysis:

- Urban Rail base station antenna height 5 m above ground.
- Road vehicle antenna height from 1,5 m to 4 m above ground.
- Distance d1 of road vehicle antenna from the axis of the Urban Rail base station antenna: 20 m.
- The distance of the Road vehicle from the Urban Rail base station varies between 0 and 8 000 m.
- EIRP road vehicle: 23 dBm/MHz.

The interference power density level received from a road vehicle will be computed in dBm/Mhz.

The distance d = sqrt(d1^2+d2^2).

The analysis is performed for an Urban Rail base station antenna having a gain of 18 dB.

The second scenario is similar but the impact of the distance between the road vehicle antenna and the axis of the Urban Rail base station antenna (distance d1) is analysed.

The estimation of the received interference power density level from a road vehicle is done for d1 = 20 m, 25 m, 30 m and 35 m. For each value of d1, d2 varies between 0 m to 8 000 m.

The purpose of the evaluation is to estimate the interference power density level received from road vehicles located on other lanes of the road. A road with four lanes is considered. The distance between the two axes of the two lanes is assumed to be 5 m.

Figure D.2 shows this second scenario.

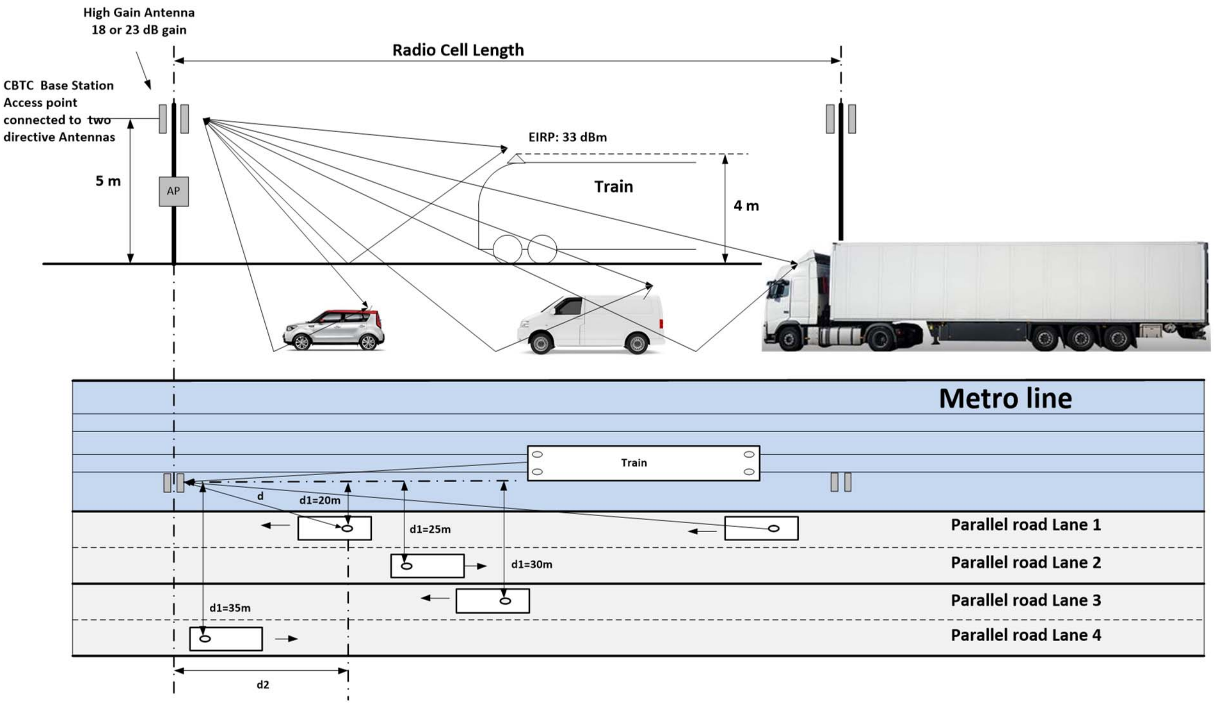


Figure D.2: Second scenario road vehicle located at 20 m, 25 m, 30 m and 35 m from the Urban Rail base station antenna axis

Figure D.3 shows a typical installation of an Urban Rail base station.

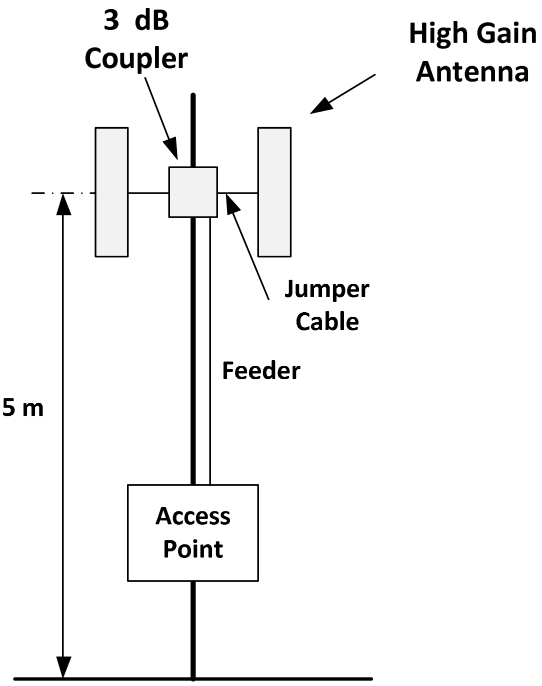


Figure D.3: Typical installation of an Urban Rail AP station

A typical Urban Rail base station is composed of an access point connected to two high gain antennas pointing in two opposite directions via a coaxial feeder, over a 3 dB coupler and two jumper cables.

The typical attenuation of the coaxial feeder is 1,5 to 2 dB and the typical attenuation of the jumper cable is between 0,5 dB and 1 dB.

D.3 Identification of the optimal Propagation model

D.3.1 Comparison of propagation models

Four propagation models are used in the comparison:

- Free space loss.
- Two rays with one ground reflexion.
- Urban propagation model.
- Suburban propagation model.

The purpose of this comparison is to identify the best suited model or the best combination of models to calculate the interference power level at the Urban Rail base station antenna connector received from a road vehicle.

A specific propagation model is developed. It takes different antenna height into account.

First, the two ray propagation model with one ground reflexion is analysed to identify the influence of the complex relative permittivity of the reflector (e.g. ground).

Following complex relative permittivity values are analysed:

- Typical road: 5 - 0,2 j.
- Dry Ground: 5 - 0,003 j.

- Average Ground: 5 - 0,015 j.
- Wet Ground: 27 - 0,06 j.

A typical toad permittivity has been proposed in the document [i.21].

The simulation has been performed at a frequency of 5 905 MHz, the height of the Urban Rail base station antenna is installed 5 m above the ground and the Road vehicle antenna is 1,5 m above the ground.

Figure D.4 shows the propagation loss computed with the two-ray propagation model with different complex relative permittivity values of the reflector.

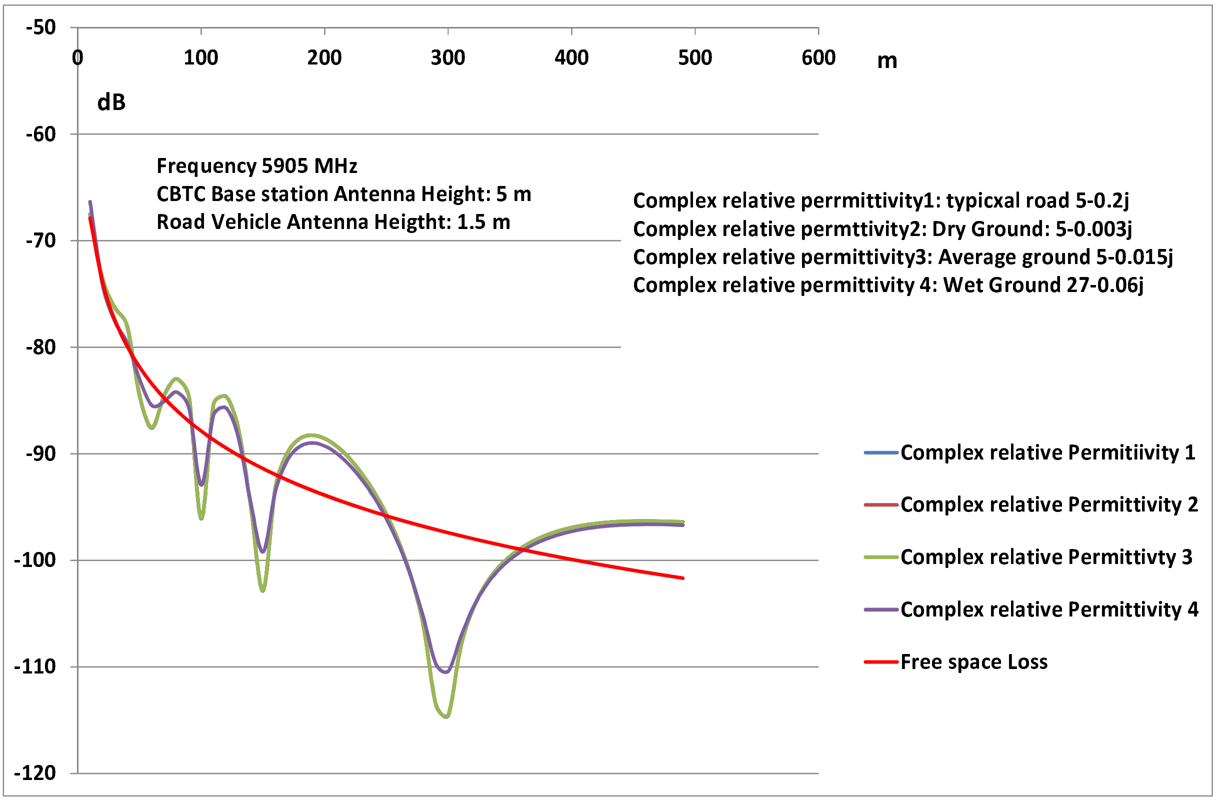


Figure D.4: Analysis of the influence of the complex relative permittivity

It can be observed that the impact of the complex relative permittivity value is limited. On the Figure D.4, the curve computed with the average complex permittivity of the ground reflections exhibits slightly lower attenuation for "peaks" and higher attenuation for "deep drops". The maximum difference with the other curves is 4 dB in the "deep drops" and 1,2 dB at the "peaks". The maximum attenuation difference between the curves computed for the complex relative permittivity of a typical road, a dry ground and a wet ground is 1,6 dB.

The attenuation value for the interference power level "peaks" received by the Urban Rail Base station is important for the evaluation of the worst-case interference scenarios.

The complex permittivity proposed by REF 1 (typical road 5 - 0,2 j can be considered as a good compromise and will be used in the following analysis.

This analysis compares the attenuation between the antenna of a road vehicle and the antenna of Urban Rail base station for four propagation models:

- Two rays propagation model with one ground reflexion.
- Free space loss.
- Urban propagation model.
- Rural propagation model.

The analysis considers a road vehicle running on a road with its antenna located at 20 m from the axis of the Urban Rail station antenna.

The antenna radiating pattern of the CBTC antenna is not taken into account. The Antenna height of the Urban Rail base station antenna is 5 m and the antenna height of the road vehicle is 1,5 m above ground.

Figure D.5 shows the results of the simulation with these parameters.

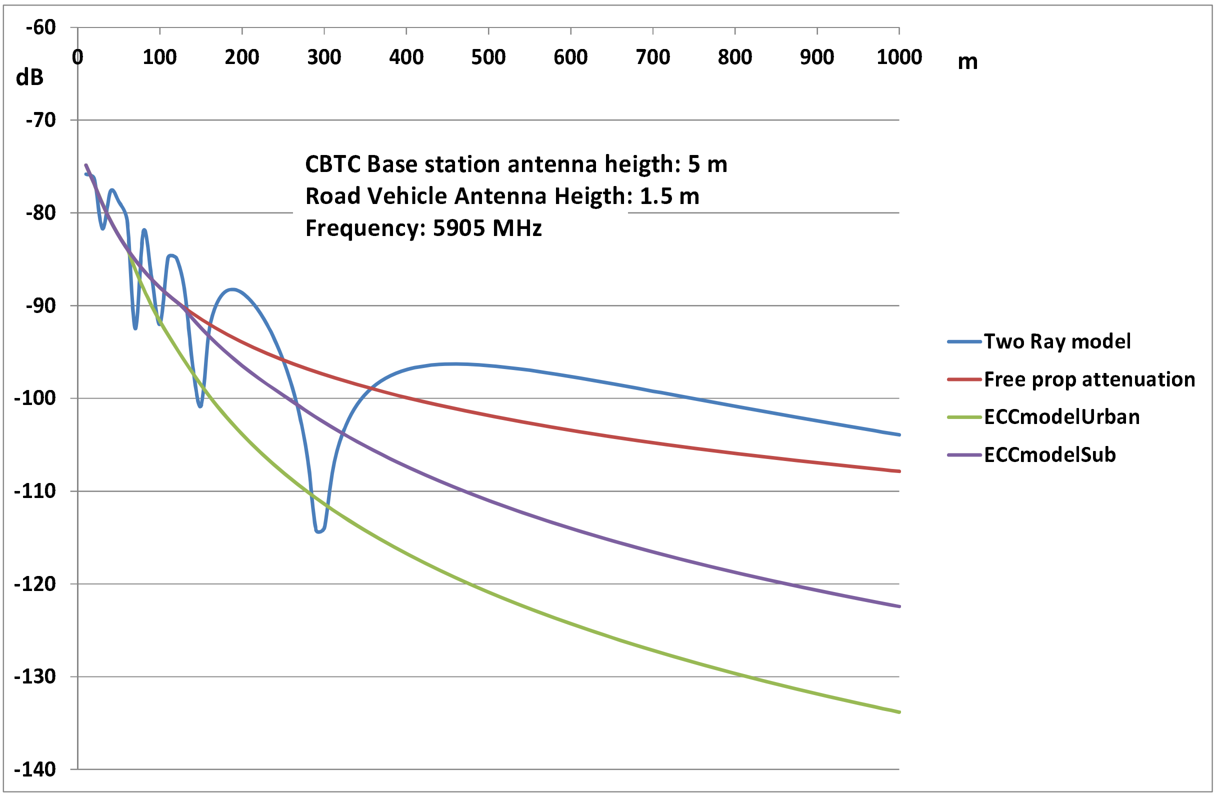


Figure D.5: Attenuation versus for four propagation models and for road vehicle with an antenna height of 1,5 m

The same analysis is done for a road vehicle antenna height of 4 m above ground as shown on Figure D.6.

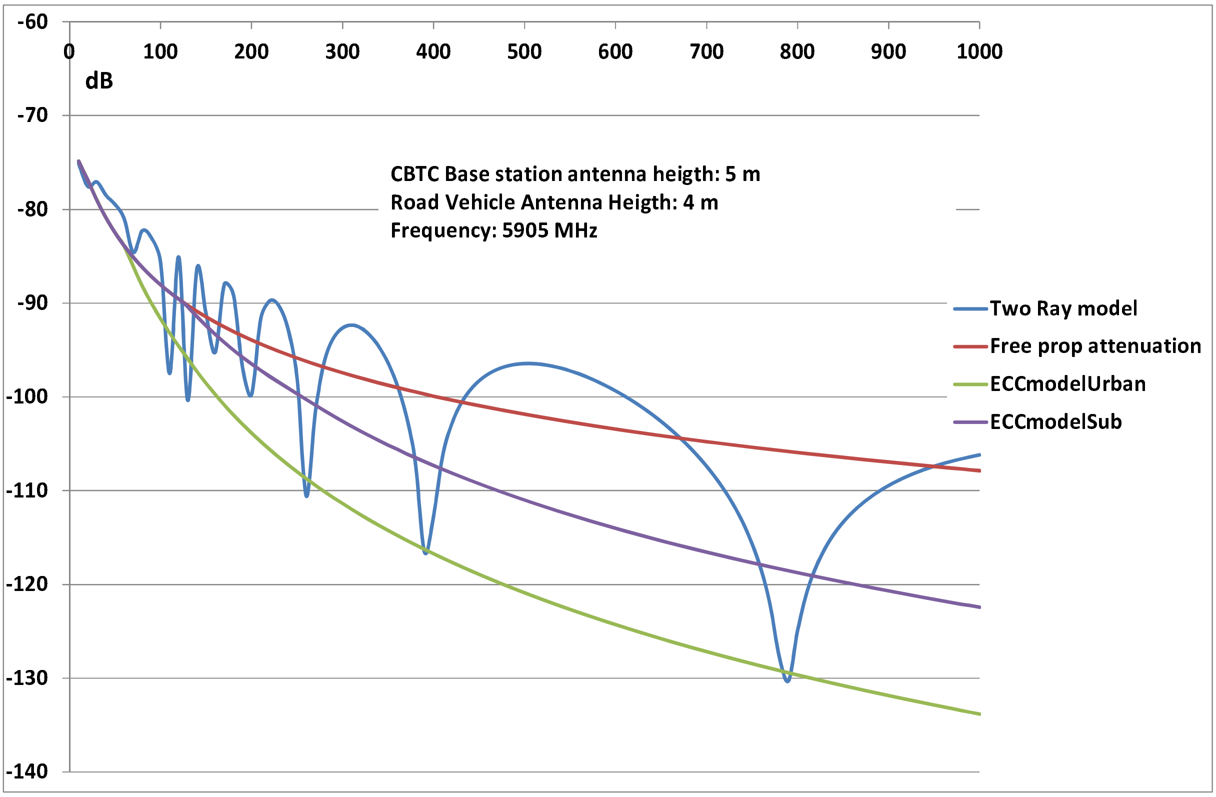


Figure D.6: Attenuation versus distance for four propagation models for a road vehicle with an antenna at 4 m above ground

It can be observed that the urban propagation model is very close to the attenuation of the "deep drops" of the two-ray propagation model with one ground reflexion.

The curve computed with the urban propagation model is like an envelope of two ray with one ground reflexion propagation model.

The urban propagation model is a good candidate to dimension a radio coverage that covers more than 95 % of an area in an urban environment.

The attenuation obtained from the free space loss propagation model is on an average 5 dB below the two rays propagation model. This model cannot be used for dimensioning the radio coverage because it corresponds to a perfect world without any reflection (Space) and is given for benchmarking only.

The Suburban propagation model is shown for comparison and can be used for the radio cell dimensioning in areas with medium population density.

To evaluate the level received from the Road Vehicle antenna, the lowest attenuation should be considered. It can be observed that the lowest attenuation is obtained with the two rays propagation model and the lengths of the "peak" attenuation are significantly longer than the "deep drops".

For the two-ray propagation model, the attenuation of the "peaks" is around 5 dB lower than the attenuation computed with the free space loss formula.

The Antenna Heights of the road vehicle have a very strong impact on the two-ray propagation model as shown in Figure D.7.

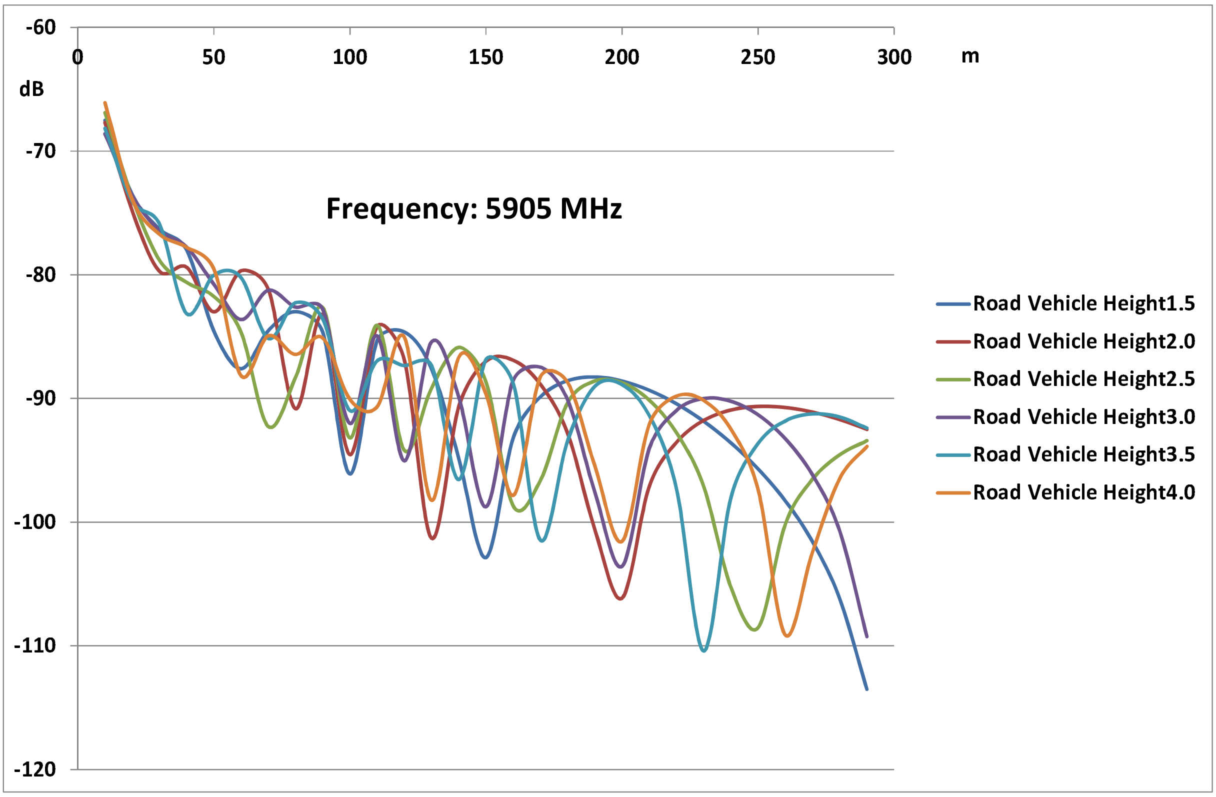


Figure D.7: Impact of the Road Vehicle Antenna height on the propagation

The "deep drops" are not a problem for the evaluation of the level received by the Urban Rail Base Station Antenna but the "peaks" are critical.

The increase of the antenna height of a road vehicle results in an increase of the distance between consecutive attenuation "deep drops".

The propagation model used for the evaluation of the interference level received by the Urban Rail base station antenna from the Road vehicles should take the impact of the antenna height into account.

Without the availability of a representative distribution of the Road Vehicle, the minimum attenuation obtained from a vehicle having an antenna height varying between 1,5 m and 4 m above the ground should be considered.

The attenuation for the evaluation of the interference power level is derived from the two-ray propagation model. For each distance from the Urban Rail base station antenna, the propagation loss with the road vehicles, with antenna height varying from 1,5 m to 4 m, are computed via the two- ray propagation model. Only the minimum value obtained from this variation is considered as the result for each distance.

D.3.2 Propagation model and on-site field strength measurements

Recent field strength measurements have been performed for the Nexteo-projects.

Three Urban Rail base stations have been installed along the tracks. Figure D.8 shows a field-strength measurement performed by a train running on the track.

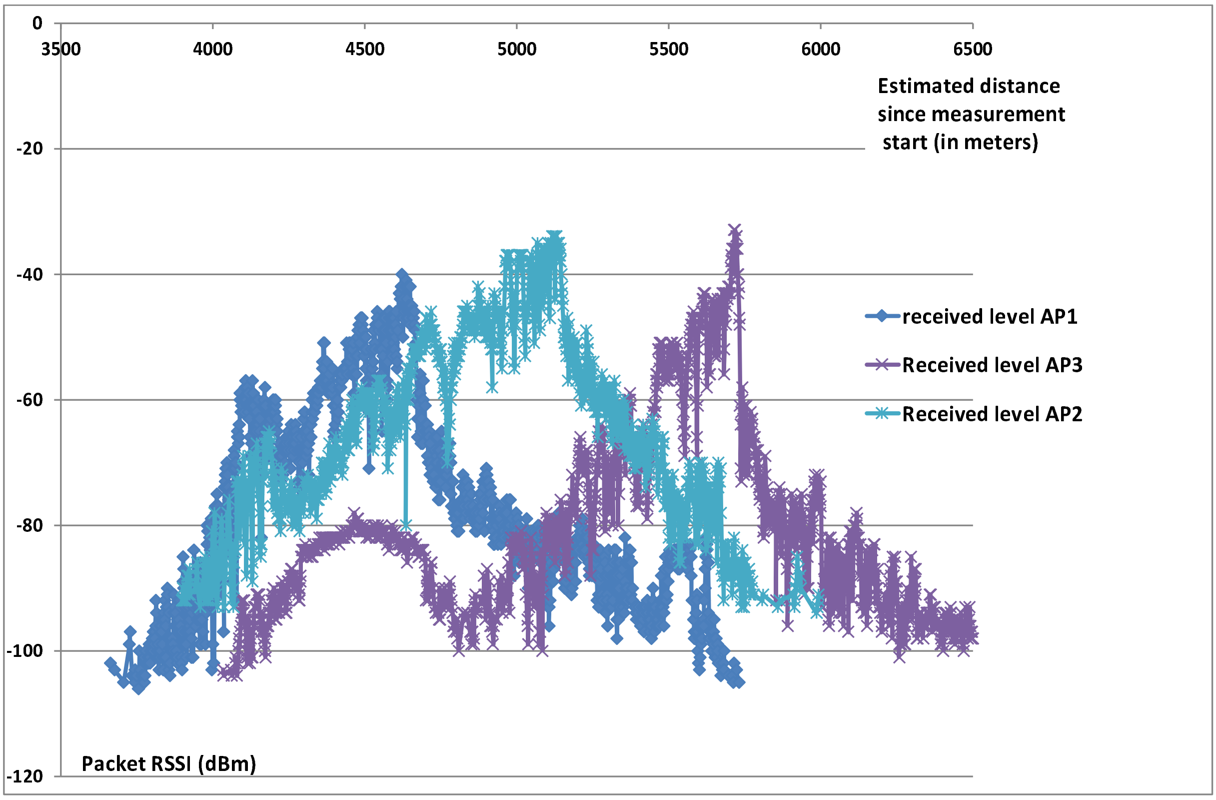


Figure D.8: Field-strength measurements performed with a train on the Nexteo Line

The operating frequency of the Access points of the Urban Rail base stations was 5 910 MHz.

The Urban Rail antenna height is 5,5 m and the train antenna height is 4,5 m.

The results of the field-strength measurements performed with a train are compared with the field strength received level computed with attenuation obtained via three propagation models:

- Free space loss.
- Urban propagation model.
- Sub-urban propagation model.
- Two-ray propagation model.

The following parameters have been used for the two-ray propagation model:

- Frequency: 5 910 MHz.
- Height above the ground of the antenna connected to the access point: 5,5 m.
- Height of the Train antenna: 4,5 m.
- Complex relative permittivity: 5 - 0,003 j.

Figure D.9 shows the results of the comparison.

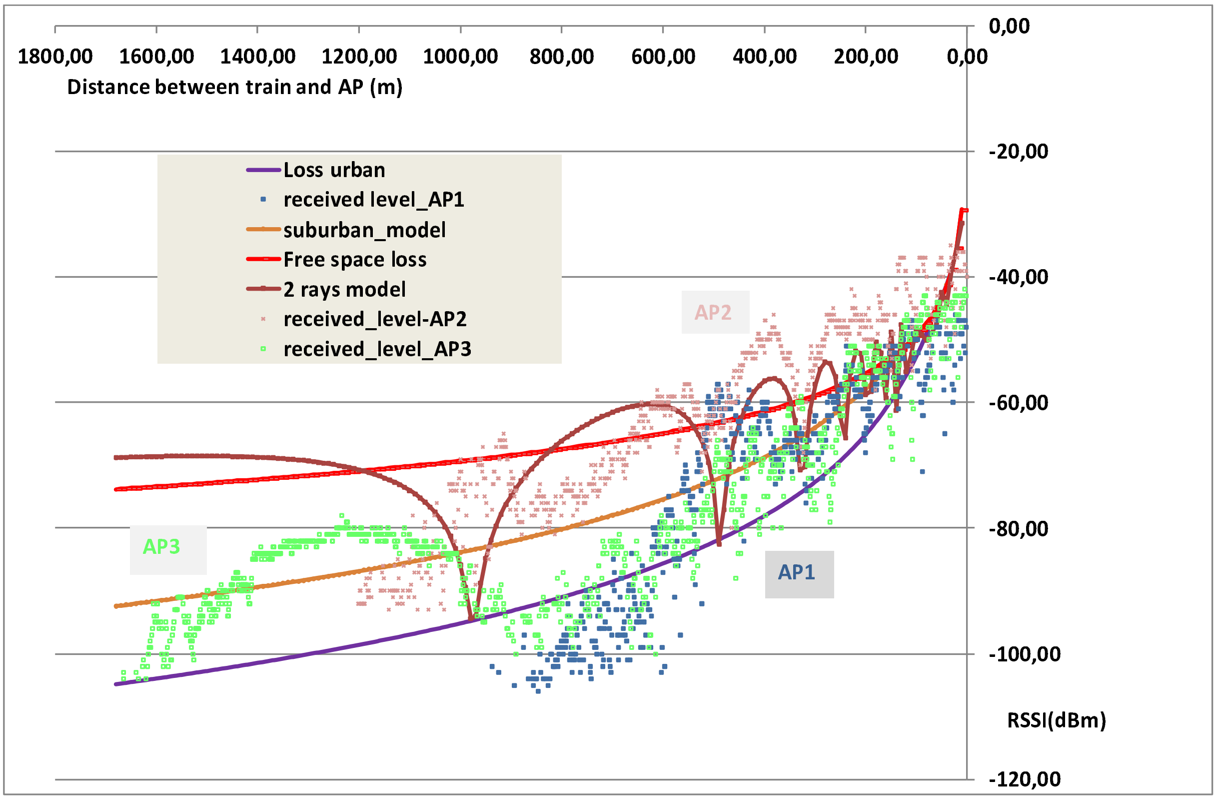


Figure D.9: Comparison of real field-strength measurements with three propagation models

It can be observed that for over 600 m, the two-ray propagation model fits the best to the measured field-strength values received from the access points AP1 and AP3.

The field-strength computed with the two-ray propagation model is close to the field-strength received by the train from the Access Point 2.

D.4 Interference level received from Road vehicles based on the first scenario

The evaluation of the received level from Road vehicle by the Access point takes into account the Urban Rail antenna pattern and also the height of the antenna of road vehicle above the ground.

The Height of the Urban Rail antenna is 5 m above the ground with a gain of 18 dB.

The distance between the Road vehicle antenna and the axis of the Urban Rail antenna is 20 m.

The EIRP of the Road Vehicle is 23 dBm/MHz (Maximum allowed EIRP).

Figure D.10 shows the interference level received versus distance of the Road vehicle from the Urban Rail antenna.

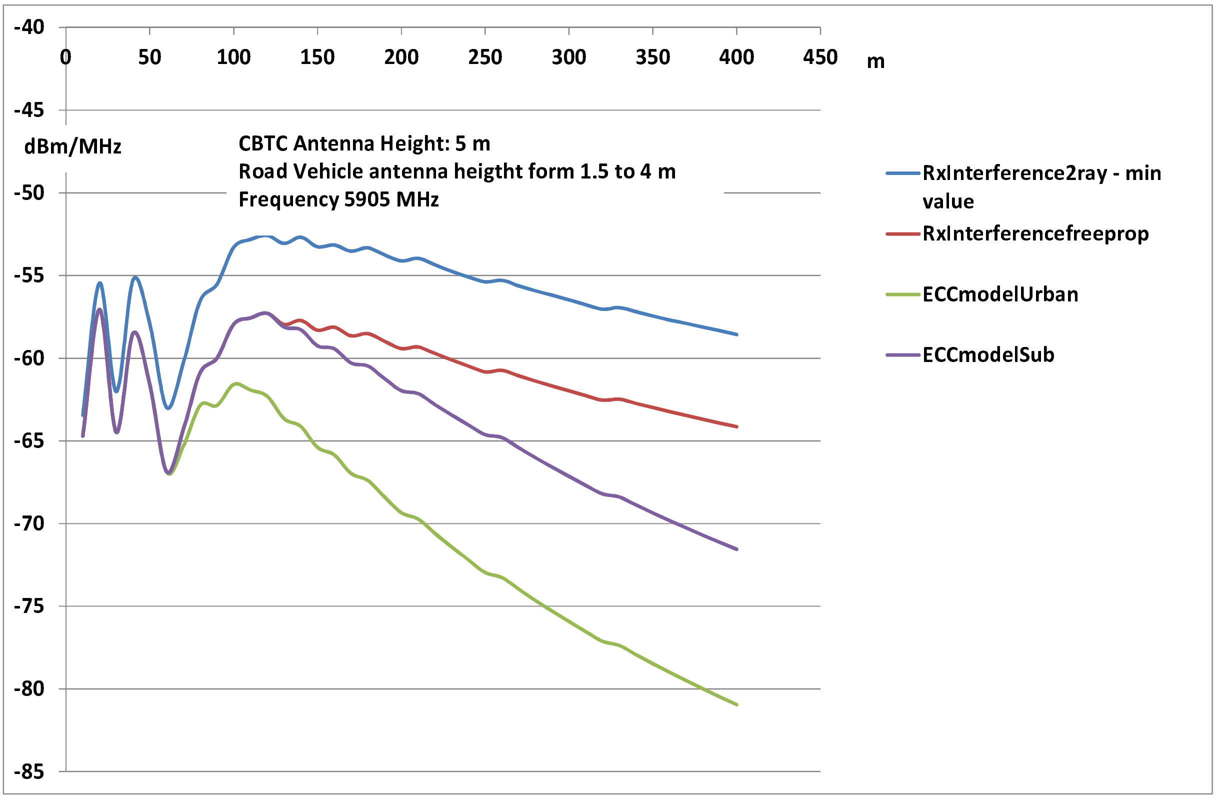


Figure D.10: Interference level received from the Road Vehicles by the Access point connected to a 18 dB antenna

The oscillations that can be observed over the first 50 m distance from the antenna are due to the Urban Rail antenna pattern.

It can be observed that the curve "Rxinterferenc2ray -min value" gives the highest interference level. This curve has been obtained by taking into consideration all the possible antenna heights of the road vehicles.

The curve based on the Urban and Suburban propagation model and also the Free space loss do not reflect all the possible cases.

The impact of road vehicle antenna height on the received interference power level is very strong.

Figure D.11 shows the difference between maximum and minimum attenuations computed with the two-ray propagation model for different Road vehicle antenna heights versus distance.

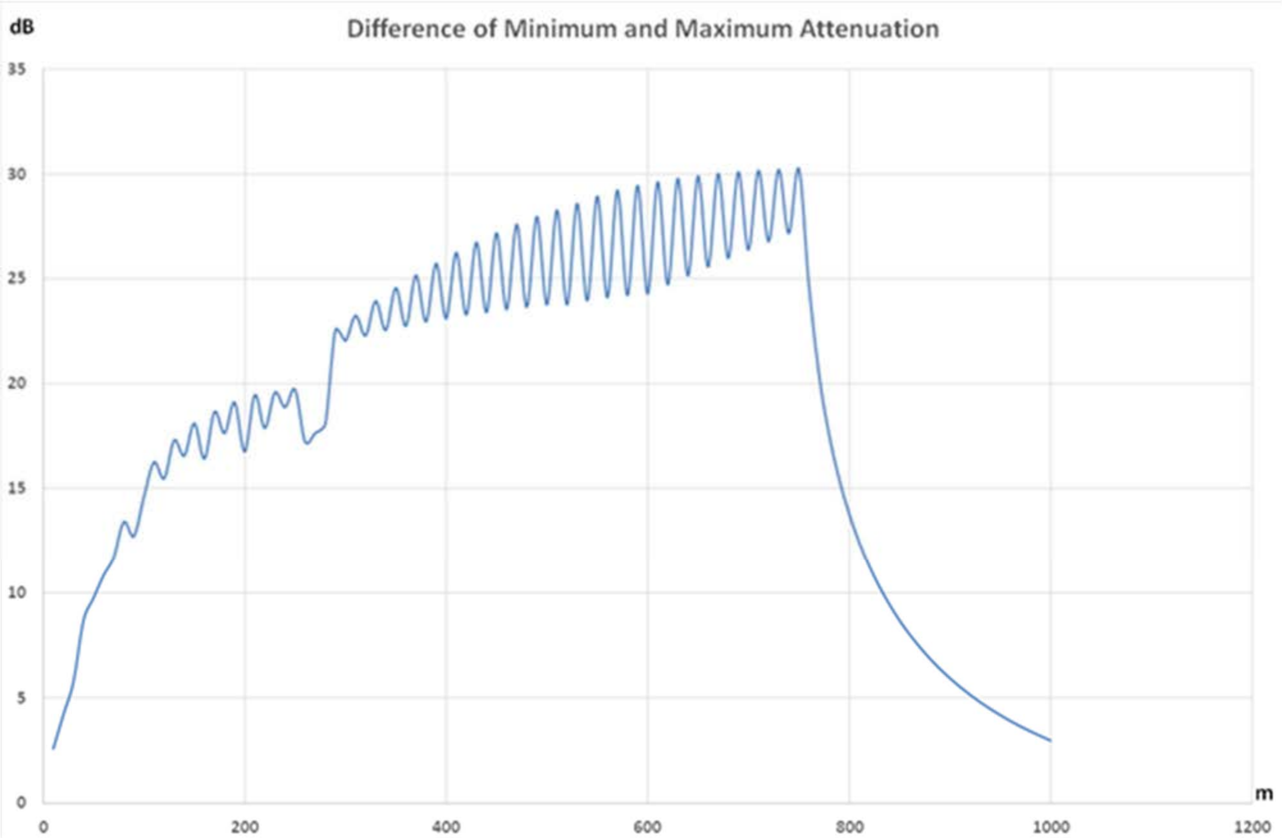


Figure D.11: Difference between minimum and maximum attenuation due to road vehicle antenna height

It can be observed that the strongest influence of the road vehicle antenna height on the propagation loss (30 dB) is obtained between 600 m and 800 m.

Between 0 m and 250 m, minimum attenuation is obtained with a road vehicle antenna height varying between 1,6 m and 2,6 m with same probability.

Between 200 and 380 m, the minimum attenuation is obtained with a road vehicle antenna height varying between 2 m and 3 m in ascending order.

Between 380 m and 520 m, the minimum attenuation is obtained with a road vehicle antenna height varying between 3,1 m and 4 m in ascending order.

Between 530 m and 1 530 m the minimum attenuation is obtained with a road vehicle antenna height varying between 1,6 m and 4 m ascending order.

Above 1 530 m the minimum attenuation is obtained with a vehicle antenna height of 4 m.

Figure D.12 shows the difference of attenuation due to road vehicle antenna height over 8 000 m.

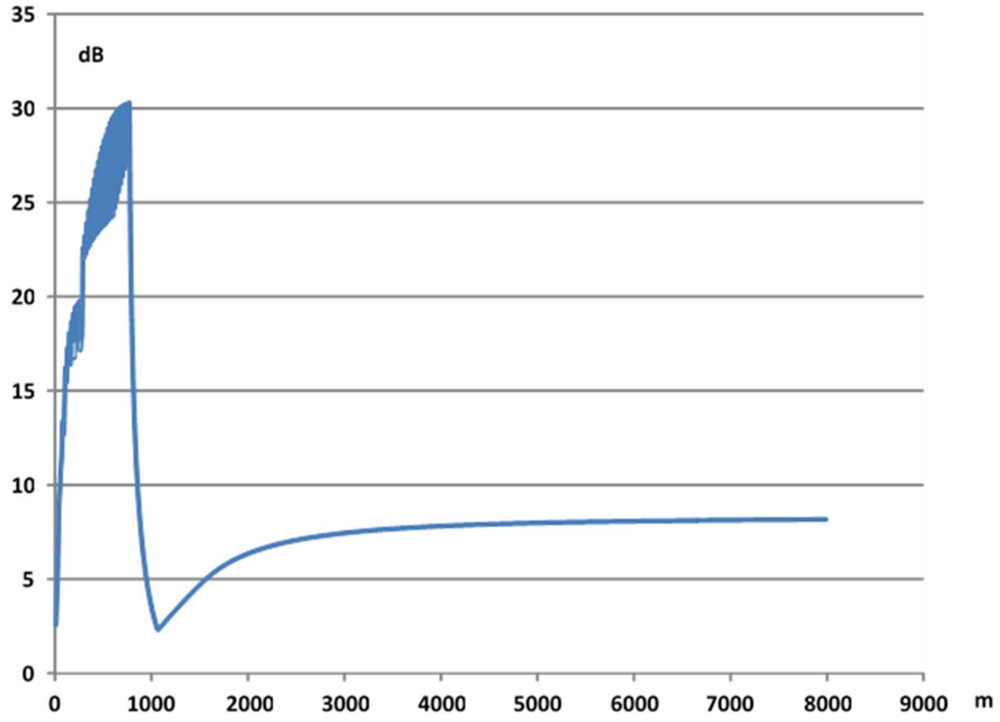


Figure D.12: Difference between attenuation due to the road vehicle antenna height over 8 000 m

These two curves show the strong influence of the road vehicle antenna heights. Hence this impact should be taken into account when evaluating the interference level received from the Road Vehicles running on a road parallel to an Urban Rail line.

D.5 Interference level received from Road vehicles based on the second scenario

The evaluation of the interference level received from the road vehicles located on parallel roads with four lanes takes into account the Road Vehicle antenna heights. The minimum attenuation obtained from road vehicle antenna heights varying from 1,5 m to 4 m is considered to evaluate the interference level on each lane.

Figure D.13 shows the evaluation of interference level for four lanes and for four propagation models:

- Two-ray propagations with minimum attenuation obtained from vehicle antenna heights varying from 1,5 m to 4 m.
- Free space loss.
- Urban propagation model.
- Suburban propagation model.

The EIRP of Road vehicle is 23 dBm/MHz (maximum transmit power).

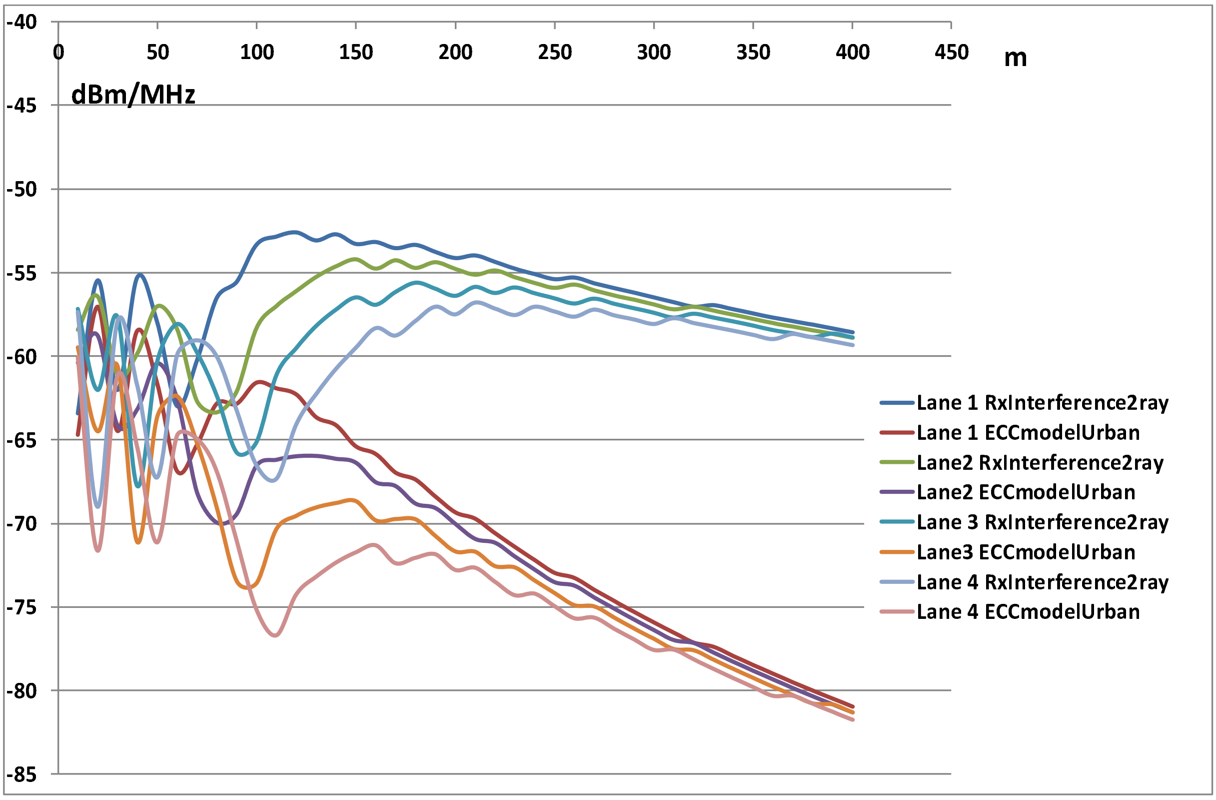


Figure D.13: Interference level received from Road vehicles on four lanes

It can be observed that the difference of interference level received from a road vehicle on the first lane and from a road vehicle on the last lane is significant over the first 150 m from the base station. Above 150 m the difference starts to reduce and can be neglected above 300 m.

The strongest influence on the attenuation difference is the Urban Rail Antenna Pattern.

Figure D.14 shows the interference level received from road vehicle on four lanes over 1 000 m.

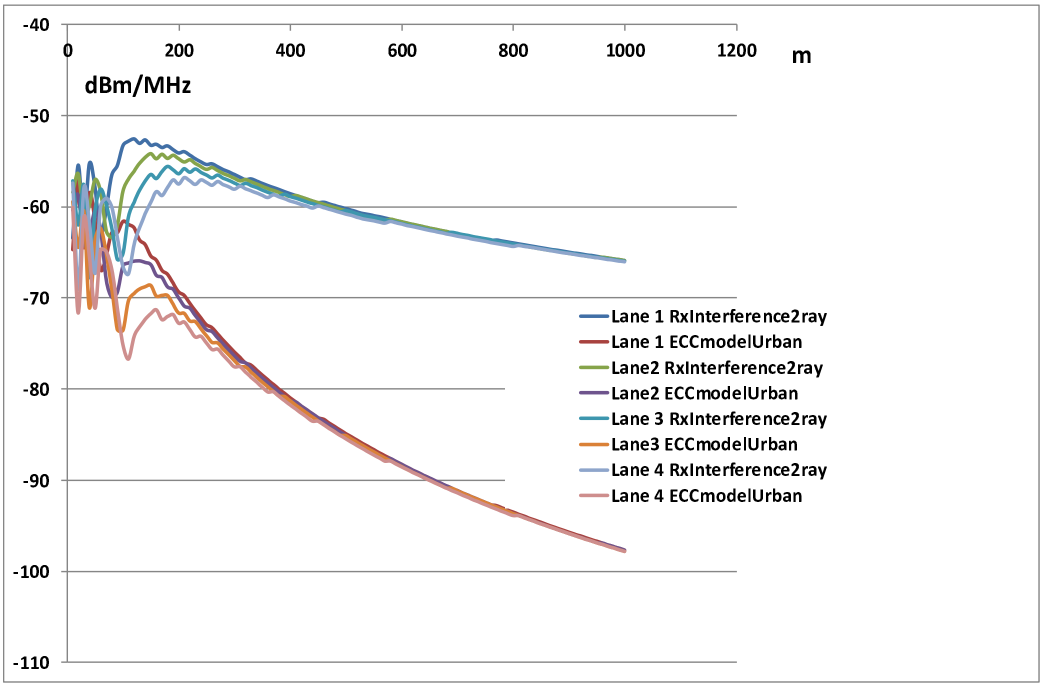


Figure D.14: Interference level received from Road vehicles on four lanes over 1 000 m

D.6 Parameters that should be considered for the definition the EIRP reduction required from Road Vehicles running on parallel road

The interference levels received by the Urban Rail Base station access point from road vehicles are high and can block the Urban Rail transmissions.

A mitigation measure based on power reduction should be considered. The target of the mitigation measure should be to maintain a Signal to interference ratio of minimum 9 dB at the input of the Urban Rail Access point RF input.

For the definition of the level of reduction for the EIRP of Road vehicle running on a road parallel to an Urban Rail line, the minimum attenuation computed using the two-ray propagation model with different road vehicle antenna heights should be considered.

For the train the minimum level received on a Radio cell length should be considered.

Figure D.15 shows the attenuation versus distance between Road Vehicles Antenna on a Road with four lanes and the Urban Rail base station.

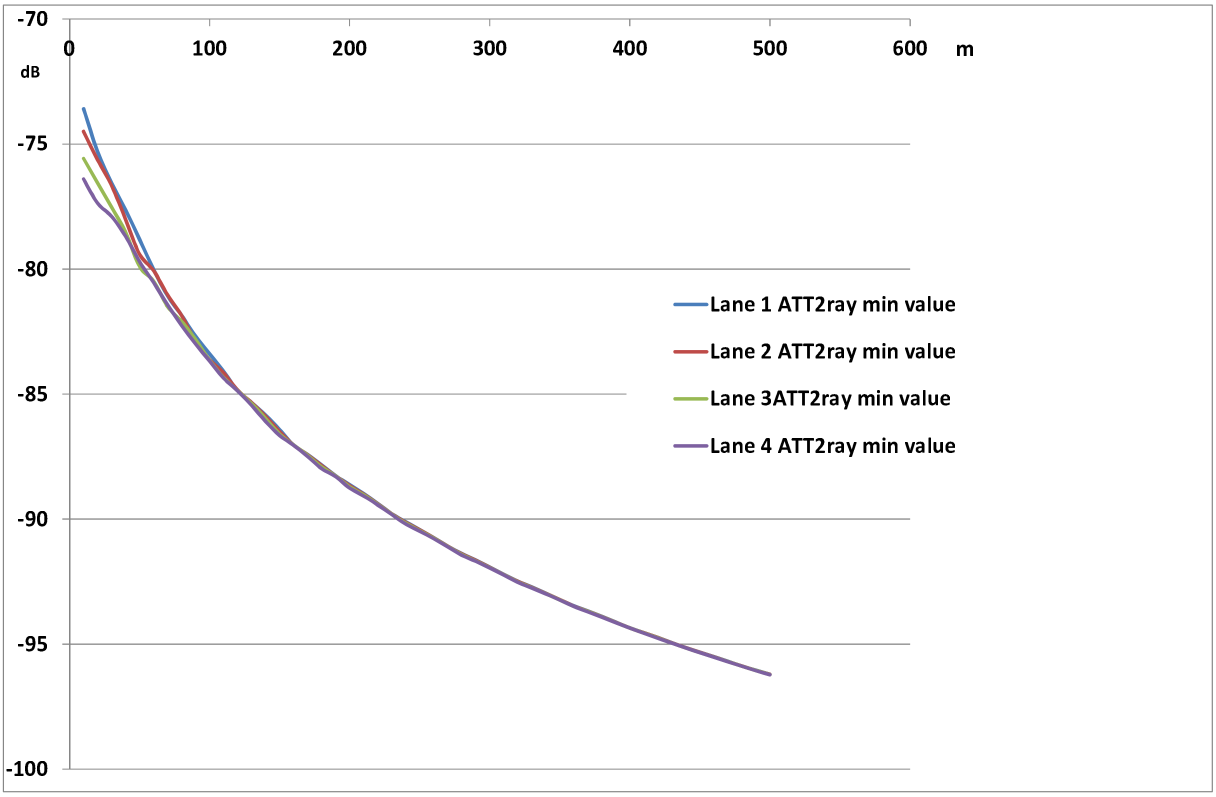


Figure D.15: Attenuation between Urban Rail antenna and Road Vehicle Antenna on a road with four lanes

It can be observed that the curves of attenuation versus distance are very close for distance above 80 m.

The maximum difference between 0 m and 80 m is less than 3 dB.

It makes sense to define a reference function to define the attenuation versus distance between the Urban Rail antenna and antennas of a road vehicles running on a parallel road.

The attenuation obtained with the two-ray propagation modem for road vehicle running on the first lane can be used as a reference.

Figure D.16 shows the attenuation versus distance based on the two propagation models and its best fitted curve.

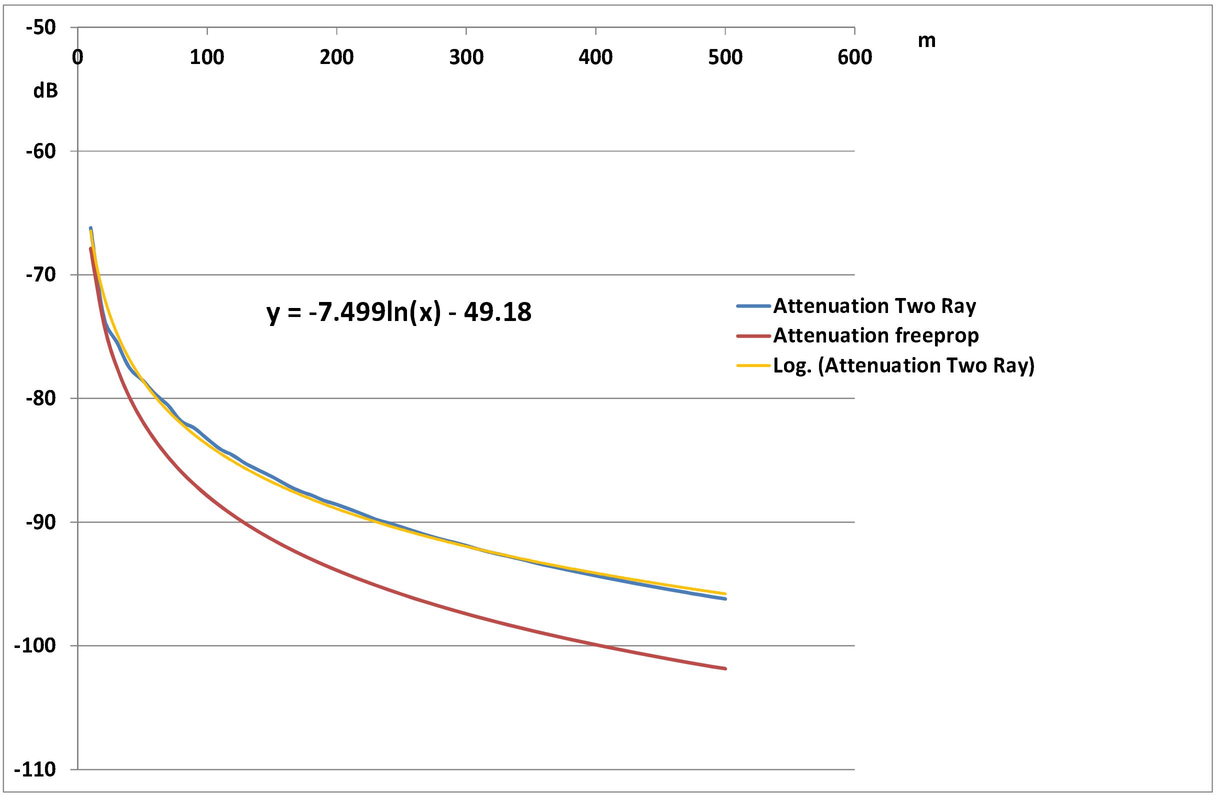


Figure D.16: Best Fit curve to the attenuation versus distance based on two-ray model

The best fit curve for the attenuation versus distance based on the two-ray propagation model for vehicle antenna height varying from 1,5 m to 4 m is:

Attenuation= 7,499 x Ln(d) - 49,18

This best fit curve is only valid over 500 m between the Urban Rail base station antenna and the Road vehicle antenna.

The other parameters are:

- Antenna pattern.
- Minimum Signal to Interference ratio in dB at Urban Rail access point input.
- Typical feeder, coupler and jumper loss.

Annex E: Proposed process for the Urban rail Updatable database

E.1 process description

The proposed process is composed of two main phases:

- Phase 1: Generation of the first version of the Urban Rail Updatable database.
- Phase 2: Maintenance of the Urban Rail updatable database and behaviour of Road vehicle.

Phase 1 can be split into the following steps:

- Collection of the information from Urban rail operators about all the outdoor areas of existing Urban Rail lines and new Urban Rail lines foreseen for commercial operation.
- For each metro line, identification of all the critical places of outdoor area where protection from road vehicles is necessary, such as:
  - Parallel roads to the Urban Rail line (No transmission allowed).
  - Bridge with crossing roads (No transmission allowed).
  - Other roads impacting the Urban Rail communication (Transmission allowed with restriction).

  The results of the analysis will be the definition of a set of records that specifies the Protected Zones as described in clause 5.2.
- Creation of the first version of Urban Rail updatable Rail Database.
- Validation and storage of the first version of the Urban Rail updatable database:
  - Before definitive storage, a version of the Urban Rail updatable database should be checked and signed.
  - A date for limit of validity should be defined.
  - The Urban Rail updatable database should be stored on a secure server or set of secure servers.
- The first version of the Urban Rail updatable database is loaded into the new road vehicle.

The Phase 2 can be composed of the following steps:

- Steps for the maintenance of the Urban Rail updatable database:
  - Collection of the information from Urban Rail operator about all the outdoor area of new Urban Rail lines or extension of Urban Rail foreseen for commercial operation.
  - Definition of a set of new records that specify the Protected Zones as described in the the present document.
  - Identification of existing records to be updated.
  - Modification of the Urban Rail updatable database.
  - Validation and storage of the Urban Rail updatable database with definition of the date for limit of end of validity.
- Steps for the expected behaviour from road vehicles:
  - Two cases should be considered:
    - First case: road vehicle fitted with an Urban Rail updatable database that is valid.

- Second case: road vehicle fitted with an Urban Rail updatable database that has exceeded its validity date.

- Steps for the first case:
  - Check if the validity date of the Urban Rail database at start-up.
  - Independently of the check result, use information stored in the database to execute appropriate actions when entering a Protected Zone: switch off transmission or transmission with restriction.
  - If the result of the validity check test is true, no more specific action is required.

- Steps for the second case:
  - Check the validity date of the Urban Rail updatable database at start-up.
  - Independently of the check result, use information stored in the data base to execute appropriate actions when entering a Protected Zone: switch off transmission or transmission with restriction.
  - If the result of the validity check test is false, tries to set-up a secure connection with the certified server via available communication means:
    - If the road vehicle is equipped with Wi-fi interface, and at driver's home if Wi-Fi is available and if the driver has configured the road vehicle to use this one (without obligation) the computer of the road vehicle can set-up a connection with the secure server and update the database without informing the driver.
    - If the car is equipped with a cellular radio modem (4G or 5G), the computer of the Road vehicle can perform automatically the update of the Urban Rail database without informing the driver.
    - If road vehicle computer fails to set-up a connection with the secure server hosting the Urban-tail database for any reason, the computer of the road vehicle should generate a warning on the dashboard with an error code inviting the driver to read the manual of the vehicle for information.

      The manual should explain that the warning shown on the dashboard is not a blocking issue and provide a procedure for the update of the urban Rail database that can be:
      - Activate wi-fi interface at home.
      - Enable connection with cellular network if the vehicle is equipped with a 4G or 5G Radio modem.
      - Propose a connection via the driver's smartphone.

NOTE 1: Manual should not present the procedure as mandatory.

- At car workshop, if the maintenance worker sees the warning on the dashboard, it should be mandatory for him to perform the update of the Urban Rail database using available communication means:
  - Wi-fi interface if the vehicle is equipped with this one.
  - Connection with cellular network if the vehicle is equipped with a radio modem 4G or 5G.
  - If the car is not equipped with Wi-fi, a tool should be made available at car workshop to perform the update of the database.

NOTE 2: The probability that new cars are sold without any communication means in the coming years is low. The possibility to connect a car to the net is used as a commercial advantage.

- Maintenance workers should update the data base if a warning is present on the dashboard. This task should be inserted in the maintenance check list.

Figure E.1, Figure E.2 and Figure E.3 show a summary of the process.

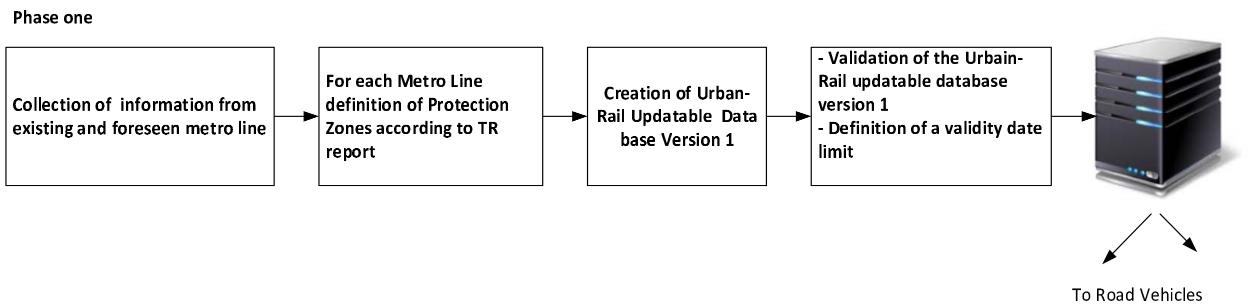


Figure E.1: Process for phase 1

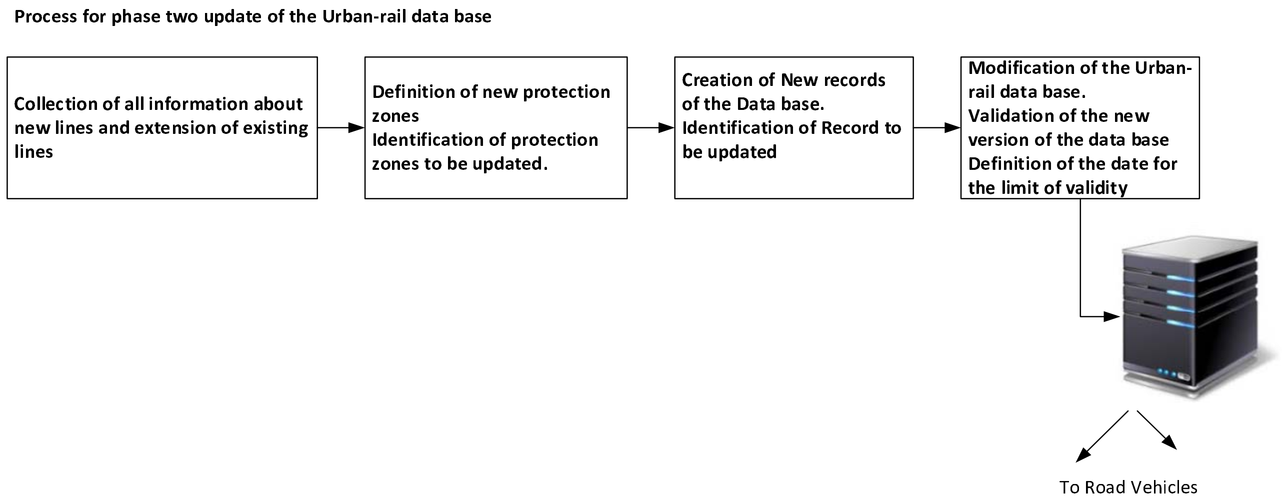


Figure E.2: Process for phase 2 update of the Urban Rail data base

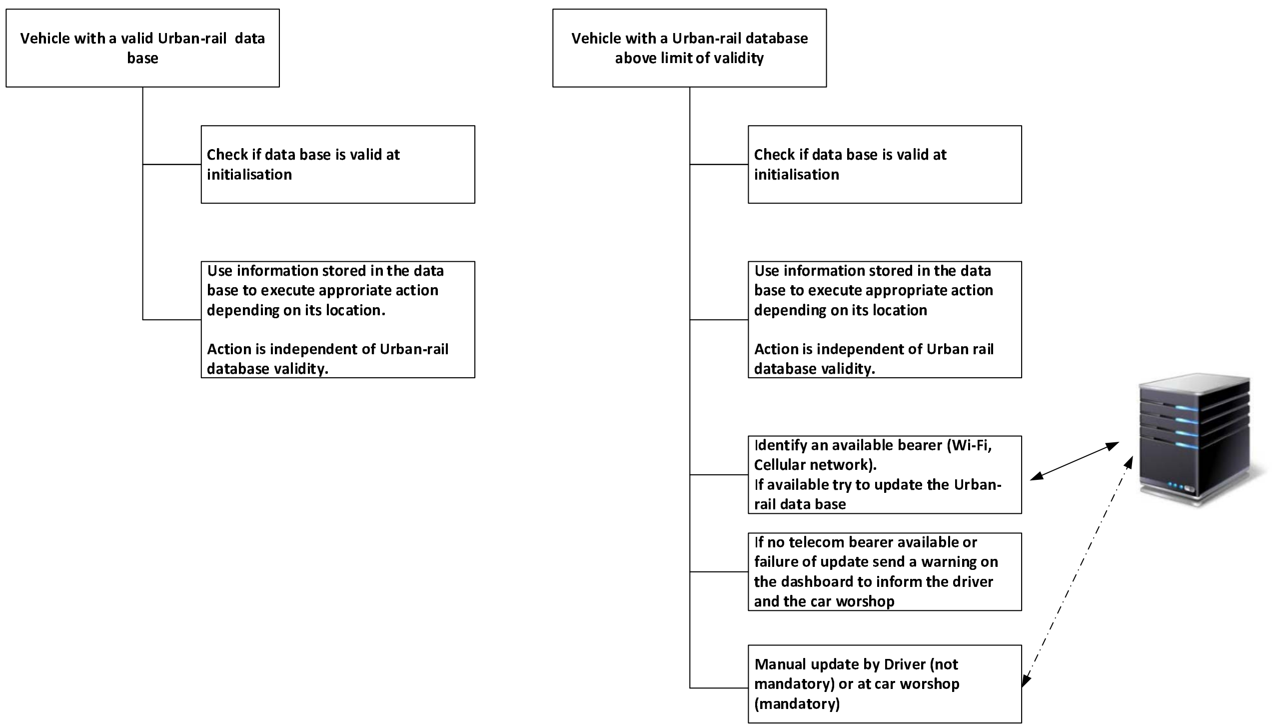


Figure E.3: Process for phase two expected behaviour of a road vehicle

E.2 Consideration about storage capacity inside road vehicles for the Urban Rail updatable database

The amount of storage required in road vehicle to store the first version of the Urban Rail updatable database can be evaluated after the generation of the version 1 of the database.

The first version of the data base will contain the records covering all the existing Urban Rail lines of Europe and foreseen new Urban Rail lines or extension of existing Urban Rail lines.

For the new foreseen lines, and line extensions, all the Protected Zones will probably not be optimally defined but the quantity of records required will be close to the required one.

Records for new foreseen lines or extension of existing lines will probably have to be updated in a next version of the Urban Rail database.

The updated information required for new foreseen lines and extension of lines will not increase significantly the dimension of the next versions of the Urban Rail database.

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 lower than two.

It is reasonable to assume that a 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 also reasonable to assume that, it will be enough to revise the dimension of the required memory to store the Urban Rail updatable database after a period of 10 years.

For Road vehicles that are still in use 10 years after manufacturing, a selective upgrade of the Urban Rail data base can be considered depending on their area of movement.

It makes sense to consider that a road vehicle that never drives in European city equipped with Urban Rail lines does not need a complete update of the Urban Rail database.

The conclusion is that it is possible to find a solution to dimension the memory required in road vehicle to store the Urban Rail data base. The dimension of this memory cannot be considered as an issue.

History

Document history		
V1.1.1	August 2019	Publication