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Technical Specification

**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**

Reference
DTS/ITS-0040013

Keywords
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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Intelligent Transport System (ITS).

Introduction

Without the use of special mitigation techniques, European CEN Dedicated Short Range Communication (DSRC) equipment operating in the frequency range from 5 795 MHz to 5 815 MHz might suffer from harmful interference caused by Intelligent Transport Systems (ITS) using adjacent frequency bands. The present document specifies methods to ensure coexistence of both systems.

1 Scope

As shown in TR 102 654 [i.10] and TR 102 960 [i.16] previously, interference from ITS-G5 A/B to CEN DSRC might occur in close proximity to ETC zones if no mitigation techniques are applied. The present document deals in detail with different techniques to ensure coexistence of ITS-G5A/B and CEN DSRC.

2 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 reference document (including any amendments) applies.

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2.1 Normative references

The following referenced documents are necessary for the application of the present document.

[1] CEN EN 12253: "Road transport and traffic telematics - Dedicated short-range communication - Physical layer using microwave at 5,8 GHz".

[2] ETSI EN 300 674 (parts 1, 2-1 and 2-2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Dedicated Short Range Communication (DSRC) transmission equipment (500 kbit/s / 250 kbit/s) operating in the 5,8 GHz Industrial, Scientific and Medical (ISM) band".

[3] ISO 21218: "Intelligent transport systems - Communications access for land mobiles (CALM) - Medium service access points".

[4] ISO 24102: "Intelligent transport systems - Communications access for land mobiles (CALM) - Management".

[5] IEEE 802.11: "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".

[6] ETSI EN 302 571: "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[7] ETSI ES 202 663: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band".

[8] ETSI TS 102 724: "Intelligent Transport Systems (ITS); Harmonized Channel Specifications for Intelligent Transport Systems operating in the 5 GHz frequency band".

2.2 Informative references

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] CVIS project: "CVIS COMM Interference measurements test report", February 2010.

[i.2] CEN EN 12795: "Road transport and traffic telematics - Dedicated Short Range, Communication (DSRC) - DSRC data link layer: medium access and logical link control".

[i.3] CEN EN 12834: "Road transport and traffic telematics - Dedicated Short Range Communication (DSRC) - DSRC application layer".

[i.4] CEN EN 15509: "Road transport and traffic telematics - Electronic fee collection; Interoperability application profile DSRC".

[i.5] CEPT ECC Report 127: "The impact of receiver parameters on spectrum management".

[i.6] L. Cheng, B. E. Henty, F. Bai, and D. D. Stancil: "Highway and rural propagation channel modeling for vehicle-to-vehicle communications at 5.9 GHz" in Proc. IEEE Antennas Propagation Soc. Int. Symp., July 2008, pp. 1-4.

[i.7] J. Kunisch and J. Pamp: "Wideband car-to-car radio channel measurements and model at 5.9 GHz" in Proc. IEEE Veh. Technol. Conf. 2008 fall, September 2008.

[i.8] J. Karedal, N. Czink, A. Paier, F. Tufvesson, and A. F. Molisch: "Pathloss Modeling for Vehicle-to-Vehicle Communications", to appear in IEEE Transactions on Vehicular Technology, 2010.

[i.9] L. Bernadó, T. Zemen, N. Czink, P. Belanovic: "Physical Layer Simulation Results for IEEE 802.11p using Vehicular non-Stationary Channel Model", IEEE International Communications Conference (ICC) 2010 Workshop on Vehicular Connectivity, Cape Town, South Africa, May 23-27, 2010.

[i.10] ETSI TR 102 654: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Co-location and Co-existence Considerations regarding Dedicated Short Range Communication (DSRC) transmission equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range and other potential sources of interference".

[i.11] CEN/ISO EN 14906: "Road transport and traffic telematics; Electronic fee collection; Application interface definition for dedicated short-range communication".

[i.12] CEN/ISO TS 14907-1: "Road transport and traffic telematics - Electronic fee collection - Test procedures for user and fixed equipment - Part 1: Description of test procedures".

[i.13] CEN/ISO TS 14907-2: "Road transport and traffic telematics - Electronic fee collection - OBU conformance test procedures".

[i.14] ETSI TS 102 486: "Intelligent Transport Systems (ITS); Road Transport and Traffic Telematics (RTTT); Test specifications for Dedicated Short Range Communication (DSRC) transmission equipment".

[i.15] CEN EN 15876: "Electronic fee collection - Conformity evaluation of on-board unit and roadside equipment to EN 15509".

[i.16] ETSI TR 102 960: "Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (RTTT DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range; Evaluation of mitigation methods and techniques".

[i.17] ETSI TR 100 028-2: "ETSI TR 100 028 -2: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics; Part 2".

3 Symbols and abbreviations

3.1 Symbols

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

A	Coefficient for T_{off} definition
α	opening angel of CEN DSRC OBU antenna
a_1	CEN DSRC signal level "high"
a_2	CEN DSRC signal level "low"
a_{thresh}	CEN DSRC decision threshold
B	Coefficient for T_{off} definition
BP_{Toff}	break point parameter: lower limit for T_{off}
BP_{Ton}	break point parameter: lower limit for T_{on}
C	Coefficient for T_{off} definition
c_0	speed of light in vacuum ($2{,}99792458 \cdot 10^8$)
d	distance
d_0	reference distance for path loss model (1 m)
d_a	distance to CEN DSRC RSU when approaching the Tolling Zone
d_l	distance to CEN DSRC RSU when leaving the Tolling Zone
d_{lane}	separation of two lanes
d_{min}	minimum effective distance
$E_{\mathrm{OFDM}}^{(\mathrm{max})}$	maximum OFDM signal electrical field strength at the CEN DSRC OBU antenna
f_{D}	CEN DSRC carrier frequency
f_{O}	ITS-G5 A/B carrier frequency
$F_{LP}(t)$	impulse response of LP filter
i	power index for CEN DSRC power level (either 1 or 2)
I_{PL}	Isolation from interferer to ensure coexistence (path loss)
L_{ant}	antenna loss due to polarization or windscreen
$\mathrm{l_c}$	detection distance margin
$\mathrm{l_d}$	detection distance
$\mathrm{l_m}$	minimum distance to CEN DSRC OBU
m	modulation index
N	number of interferers
n	path loss coefficient
P	CEN DSRC average power level
P_1	CEN DSRC power level for the "high" signal
P_2	CEN DSRC power level for the "low" signal
P_{Dsens}	CEN DSRC detector sensitivity
P_{DSRC}	maximum CEN DSRC RSU EIRP output power level
P_{i}	CEN DSRC power level for power index i
PL	free space path loss
PL_0	free space path loss in 1 m distance
$P_{\mathrm{OFDM}}^{(\mathrm{max})}$	maximum OFDM signal power level at the CEN DSRC OBU antenna
$P_{\mathrm{OFDM}}^{(\mathrm{norm})}$	normalisation power level (1 W)
P_{Rx}	receive power level
P_{RX_ITS}	receive power level at ITS-G5 A/B antenna
P_{sens}	CEN DSRC OBU RX sensitivity
P_{Tx}	transmit power level
P_{TXmax}	maximum transmit power level
σ	fading loss for path loss model

$s(t)$	time domain signal at CEN DSRC receiver
$S_{\mathrm{OFDM}}^{(\mathrm{max})}$	maximum OFDM signal power density at the CEN DSRC OBU antenna
$s_I(t)$	imaginary part of complex ITS-G5 A/B baseband signal
$s_{\mathrm{i\ DSRC}}(t)$	time domain CEN DSRC signal for power index *i*
$s_{\mathrm{DSRC}}(t)$	time domain CEN DSRC signal
$s_{\mathrm{LP}}(t)$	time domain signal after LP filter
$s_{\mathrm{LP\text{-}OFDM}}(t)$	time domain ITS-G5 A/B signal after LP filter
$s_{\mathrm{LP-OFDM}}^{(\mathrm{peak})}$	peak value of time domain ITS-G5 A/B signal after LP filter
$s_{\mathrm{OFDM}}(t)$	time domain ITS-G5 A/B signal
$s_R(t)$	real part of complex ITS-G5 A/B baseband signal
t	time
T_{off}	Minimum time between two transmissions in the DCR method

3.2 Abbreviations

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

ADC	Analog Digital Converter
BER	Bit Error Ratio
CDMA	Code Division Multiple Access
CEN	Comité Européen de Normalisation
CH	Channel
CVIS	Cooperative Vehicle-Infrastructure Systems
DAA	Detect And Avoid
DCR	Duty Cycle Restrictions
DENM	Decentralised Environmental Notification Message
DL	Down Link
DSRC	Dedicated Short Range Communication
ECC	Electronic Communications Committee
EFC	Electronic Fee Collection
EIRP	Equivalent Isotropic Radiated Power
EN	European Norm
ETC	Electronic Toll Collection
ETSI	European Telecommunication Standard Institute
GNSS	Global Navigation Satellite System
IEEE	Institute of Electrical and Electronics Engineers
IPR	Intellectual Property Rights
ISO	International Standardisation Organisation
ITS	Intelligent Transport System
ITS-G5	5,9 GHz vehicular adhoc network PHY
ITS-G5A/B	vehicular adhoc network PHY for the frequency range 5 855 MHz to 5 925 MHz
ITS-S	ITS Station
ITU	International Telecommunication Union
LDM	Local Dynamic Map
LHCP	Left Hand Circular Polarized
LoS	Line of Sight
LP	Low Pass (filter) or Linear Polarized
MAC	Medium Access Control
MLFF	MultiLane Free Flow
OBU	OnBoard Unit
OFDM	Orthogonal Frequency Division Multiplex
PHY	PHYsical (OSI layer)
RF	Radio Frequency
RSU	RoadSide Unit
RX	Receive

SA	Spectrum Analyzer
TS	Technical Specification
TX	Transmit
UL	UpLink

4 General overview

4.1 Introduction to coexistence

To ensure coexistence between CEN DSRC and ITS-G5A/B stations, the transmission behaviour of the ITS-G5A/B station shall fulfil restrictions related to the transmission power level, to the transmission duty cycle, or to both, depending on the separation distance to the Tolling Zone and the number of interfering ITS-G5A/B stations. The present document specifies the limits and methods that shall be applied to ensure coexistence. Additionally, the technical specification on ITS-G5A/B Channel configuration [8] defines how these limits and methods shall be used under DCC control.

The complexity of the coexistence measure depends on the ITS-G5A/B output power level, the actual spatial density of the ITS-G5A/B stations and the actual separation distance between the IT-G5A/B station and the potential victim tolling station. The higher the actual maximum output power level and the more ITS-G5A/B stations are actually in range of the potential victim tolling station, the more sophisticated coexistence measures are necessary.

Different possible coexistence measures and the corresponding limits are specified in clauses 4.2, 4.3, 5, and 6.2, their applicability is summarized in table 4.1.

As shown in table 4.1, the applicable coexistence measure depends mainly on the actual maximum output power range and the ITS-G5A/B antenna type used by the mobile ITS station. Which coexistence measure shall be applied in some special cases with alternative ITS-G5A/B antenna types not included in Table 4.1 is specified by electrical field strength limits given in clause 5.2.

Clauses 4.2.3.3 and 6.1 describe how the Tolling Zone can be detected and identified in case additional mitigation techniques are needed that adapt the ITS-G5A/B transmission power level and/or the transmission duty cycle to the separation distance to the Tolling Zone.

Methods to ensure coexistence of fixed ITS-G5A/B stations and CEN DSRC devices (OBU or RSU) are given in clause 7. Examples how these limits can be met are given in clause B.7.

An implementation example for mobile ITS-G5A/B stations is given in clause B.8.

4.2 Restrictions and mitigation methods overview

4.2.1 Power restrictions and muting of ITS-G5A/B stations

An ITS-G5A/B station can restrict the TX power level to a value where no harmful interference will occur to a CEN DSCR victim tolling station. The maximum allowed TX power level is in general dependent on the radio isolation between the interferer (ITS-G5A/B station) and the victim (tolling station). The lower the isolation and thus the distance between the two systems the lower the maximum allowed TX power level for the ITS-G5A/B system. For different isolation values and thus distances between the two systems the maximum TX power levels can be evaluated, see clauses 6.2.2.1 and B.7.

For ITS-G5A/B installations where the transmit antenna has no fixed position, e.g. hand held devices, or where the ITS-G5A/B antenna is mounted very close to the CEN DSRC OBU, the ITS-G5A/B transmit signal shall be muted during a CEN DSRC toll transaction. Alternatively the ITS-G5A/B device can transmit short bursts of data with long pauses in between to avoid harmful interference. The timing of these bursts and pauses is specified by the duty cycle restrictions (DCR).

ITS-G5A/B installations with a fixed transmit antenna position that is more than 1,5 m away from the CEN DSRC OBU and that transmit with a power level of up to 10 dBm will not generate any interference to the CEN DSRC tolling system. Closer distances to the CEN DSRC OBU are possible if the field strength limit at the CEN DSRC OBU is not exceeded as described in clause 6.2.1.1.

4.2.2 Duty cycle restrictions (DCR) of ITS-G5A/B stations

The basic coexistence investigation and evaluation are based on the assumption that an ITS-G5A/B system is continuously transmitting a signal, thus having a duty cycle of 100 %. Since the CEN DSRC protocol is based on a packet communication, a restriction of the duty cycle of the ITS-G5A/B system will lead to a significantly lower potential of harmful interference to the CEN DSRC system even the maximum allowed TX power level is exceeded.

Based on exhaustive simulations, a duty cycle restriction can be defined which can guarantee coexistence between the two systems without the risk of harmful interference generated from ITS-G5A/B to CEN DSRC (see clause 5.3).

This restriction shall been taken into account in the G5A/B channel configuration specification [8].

4.2.3 Additional coexistence measure for mobile ITS stations

4.2.3.1 Additional coexistence measure introduction

In case an ITS-G5A/B station needs to operate outside the limits (TX power, Duty Cycle, separation distance), which are given for an interference free operation, additional coexistence techniques shall be implemented based on the actual situation and distance to the tolling station.

The additional coexistence measures can essentially be split into two main operations:

- Tolling Zone detection operation
- Interference avoidance operation

Therefore, this additional measure is called "Detect and Avoid" (DAA). In the first step the need for an interference avoidance operation will be identified by detecting the presence of a CEN DSRC tolling station in the near vicinity. As a result of this detection process, if required the suitable interference avoidance operation will then be taken.

In the present document a Tolling Zone detection method and the appropriate interference avoidance operations are specified.

In annex D a ranking of different detection methods is summarized.

4.2.3.2 Detect and Avoid principle

Detect and Avoid is a combination between a victim identification operation and an interference avoidance operation. In general, the detection of the victim to be protected can be performed by doing any feasible identification method.

E.g. the detection process can be done by evaluating the isolation between the ITS-G5A/B station and the CEN DSRC tolling station based on radio measurements, by beaconing information, or by geographical information contained in static or dynamic maps (see clause 4.2.3.3).

Based on the result of the isolation evaluation the interference avoidance can then apply and configure the required coexistence mechanism process (e.g. TX power reduction, duty cycle restriction, …).

4.2.3.3 Detection of tolling stations

4.2.3.3.1 Radio Identification of the tolling station

The radio identification of a CEN DSRC tolling station is based on a signal strength measurement of the CEN DSCR RSU signal at the position of the potentially interfering ITS-G5A/B station. Based on the actual measured signal strength and the known EIRP level of the CEN DSCR RSU the ITS-G5A/B station can estimate the isolation towards the possible victim tolling station (see clause 6.1). In the present document three isolation zones are given as example in clause B.8 to protect the CEN DSRC tolling stations. The corresponding requirements are in clause 6.2.2.1. For isolation values above 85 dBm the TX power restriction of 33 dBm as already specified in [6] is sufficient.

4.2.3.3.2 Beaconing

The ITS-G5A/B system could implement a message that commands a specific behaviour of the ITS-G5A/B station in a defined geographical area around a potential victim. In the scope of the present document this victim is a CEN DSCR tolling station. The message could include control parameter for the cross layer DCC Management entity overwriting the standard settings for the DCC control. The ITS beacon would be installed close to the potential victim tolling station and would send out the beaconing message in fixed periodicity. This message and the corresponding applications need to be specified elsewhere and are out of scope of the present document.

4.2.3.3.3 Static and dynamic Map-based identification

In a map based identification approach the geographical positions of the potential victim station would be stored in the ITS-G5A/B station entirely, or they would be transferred to the ITS-G5A/B station for a specific region when needed. The actual position of the vehicle could be compared to the stored positions and based on the evaluated distance the required mitigation method could be applied. No further investigations of this detection method have been performed. The topic is for further studies and is not specified in the present document.

4.2.4 Implementation guide of basic coexistence measures

4.2.4.1 Coexistence measures for fixed ITS-G5A/B stations

Since fixed ITS-G5A/B stations cannot move through the Tolling Zone, the maximum transmit power level that avoids harmful interference to CEN DSRC can be evaluated from the isolation distance to the victim tolling station. If the maximum transmit power level is exceeded, either duty cycle restrictions shall be applied or the CEN DSRC signal shall be synchronised with the ITS-G5A/B transmission in a way that they are communicating in different time slots.

4.2.4.2 Coexistence measures for mobile ITS-G5A/B stations

Since CEN DSRC OBUs and mobile ITS-G5A/B stations can be mounted in the same vehicle, the distance between the two devices can be short. Especially handheld ITS-G5A/B stations can be mounted only some centimetres away from the OBU, therefore these devices shall mute their transmission at least temporally while passing a toll station (see clause 4.2.1). Other mobile ITS-G5A/B stations need to have coexistence measures implemented only when they are transmitting with more than 10 dBm output power level.

The present document specifies following mitigation techniques and combinations that can avoid harmful interference to CEN DSRC under the restrictions listed in table 4.1:

- Only DCR:
  Duty cycle restrictions (DCR) in combination with a transmit power control are used continuously without detection of the Tolling Zone (see clause 6.2.3). In this case DCR applies to transmissions with a transmit power level above 10 dBm only.

- Muting with DCR:
  Duty cycle restrictions in combination with a transmit power control are used continuously without detection of the tolling zone (see clause 6.2.3). In this case DCR applies to all transmissions (no transmissions are possible during T_{off}).

- DAA + power regulation:
  Detection of the distance to the Tolling Zone and control of the ITS-G5A/B transmit power level accordingly (see clause 6.2.2).

- DAA + DCR:
  Detection of the distance to the Tolling Zone and application of DCR (see clause 6.2.3) to all transmissions that exceed the ITS-G5A/B transmit power levels specified in clause 6.2.2.1. Usually this also includes an ITS-G5A/B transmit power control as supplement to DCR.

- DAA + muting:
  Detection of the Tolling Zone and muting of the ITS-G5A/B transmission while a CEN DSRC transaction is performed or while the Tolling Zone is passed (see clause 6.2.1).

- DAA + muting and power regulation:
  Detection of the Tolling Zone and muting of the ITS-G5A/B transmission while a CEN DSRC transaction is performed or while the Tolling Zone is passed (see clause 6.2.1). Outside the Tolling Zone the transmit power levels are controlled according to the detected distance to the Tolling Zone as specified in clause 6.2.2.1.

- DAA + muting with DCR:
  Detection of the distance to the Tolling Zone and application of DCR (see clause 6.2.3) to all transmissions that exceed the ITS-G5A/B transmit power levels specified in clause 6.2.2.1. Within the Tolling Zone or while a CEN DSRC transaction is performed, DCR is applied to all ITS-G5A/B transmissions. Usually this combination also includes an ITS-G5A/B transmit power control as supplement to DCR.

Table 4.1 summarises the applicability of these coexistence measures.

Table 4.1: Summary of coexistence measures for mobile ITS stations (for details see clause 6.2)

ITS-G5A/B output power range	ITS-G5A/B antenna type	
	External vehicle antenna and field strength limit at CEN DSRC OBU for P_{TX} = 10 dBm not exceeded	**Internal antenna (included in the ITS station) or field strength limit at CEN DSRC OBU for P_{TX} = 10 dBm exceeded**
≤ 10 dBm	No coexistence measures	Muting with DCR or DAA + muting
> 10 dBm ≤ 33 dBm	Only DCR or DAA + power regulation or DAA + DCR	Muting with DCR or DAA + muting and power regulation or DAA + muting with DCR

Calculations, measurements, and further examples of coexistence measures of mobile ITS-G5A/B stations are given in clauses B.3 and B.5.

4.3 Summary of limits and methods for interference free operation of ITS-G5A/B and CEN DSRC

In general the following limits and methods apply to an ITS-G5A/B system for an interference free operation toward a CEN DSRC tolling station:

TX power limitation: For ITS-G5A/B station with a TX power level equal or below 10 dBm no interference towards a CEN DSRC tolling system will occur if the ITS-G5A/B antenna is mounted in a fixed position more than 1,5 m away from the CEN DSRC OBU (e.g. on the rooftop of the car). In this case no additional limitations related to the duty cycle are required.

TX power level muting: In case of handheld devices with no fixed mounting positions, or fix mounted ITS antennas in close vicinity to the OBU mounting position, the transmission shall be at least temporarily muted within the CEN DSRC Tolling Zone. The duty cycle of the muting is defined by the Duty Cycle Restrictions (DCR).

Duty Cycle Restrictions: For ITS-G5A/B station with a maximum packet burst duration of 5 ms and a minimum packet burst spacing of T_{off} according to equation (5.1) in clause 5.3 no harmful interference will occur toward a CEN DSRC tolling system. The ITS-G5A/B TX power level influences the number of interferers N and thereby has an impact on the outcome of equation (5.1). Depending on whether ITS muting (clause 6.2.1) applies, the transmission shall be stopped (muted) or can be continued with a TX power level of up to 10 dBm during T_{off}. The highest possible transmission duty cycle can be reached when no other ITS-G5A/B station is exceeding the electric field strength limit at the victim CEN DSRC OBU. In this case of a single interferer a 5 ms transmission burst shall be followed by a 50 ms transmission pause, resulting in 9,1 % duty cycle.

Separation distance: Assuming the limitation of 33 dBm to the TX power level of an ITS-G5A/B station. No harmful interference will occur toward a CEN DSRC tolling system form an ITS-G5A/B station operating in a distance of more than 170 m away.

In the ITS-G5A/B channel configuration specification [8] these limits have been taken into account to define a proper operation of the ITS-G5A/B system under DCC control.

4.4 Document structure

The present document is structured in the following way:

Clause 5	summarises all normative limits and specifications to define appropriate techniques to ensure coexistence of CEN DSRC [1] and [2], ITS-G5A/B [6] and [7] devices.
Clause 6	describes the coexistence measures for mobile ITS stations in detail.
Clause 6.1	defines Tolling Zone detection methods.
Clause 6.2	defines methods to avoid interference.
Clause 7	specifies the coexistence measures for fixed ITS stations.
Annex A	recommends interference limits of CEN DSRC receivers (RSU and OBU).
Annex B	contains calculations and examples.
Clause B.1	shows examples of coexistence scenarios.
Clause B.2	outlines the path loss model used for calculation of all coexistence limits.
Clause B.3	provides a thorough calculation and examples of the interference to CEN DSRC OBUs by ITS-G5A/B stations.
Clause B.4	contains the calculation of the CEN DSRC detector sensitivity, necessary to invoke interference avoidance methods.
Clause B.5	shows measurement results of CEN DSRC uplink blocking.
Clause B.6	describes the interference from CEN DSRC to ITS-G5 mobile stations.
Clause B.7	shows examples of coexistence scenarios with fixed ITS stations.
Clause B.8	gives an implementation example of a mobile ITS-G5A/B station with power regulation and radio detection of CEN DSRC RSU.
Annex C	is a summary of CEN DSRC and EFC basics.
Annex D	compares different coexistence options.

5 Coexistence measures and limits

5.1 Coexistence scenarios

Some examples of coexistence scenarios are given in clause B.1. These examples show scenarios where techniques for coexistence are necessary, because the electrical field strength limits defined for coexistence of CEN DSRC devices (OBU or RSU) and ITS-G5A/B are exceeded (see clause 5.2).

The most important scenario is the passage of a CEN DSRC Tolling Zone by a mobile ITS-G5A/B station, where interference to the CEN DSRC uplink and down link could happen.

5.2 Field strength limits within the Tolling Zone

To ensure coexistence with the CEN DSRC downlink from the RSUs, according to table B.1 the electric field strength caused by a continuous ITS-G5A/B signal shall not exceed 0,11 V/m (-51,6 dBm) within the Tolling Zone. For non continuous signals, the field strength limit within the Tolling Zone can be exceeded for a time span of up to 5 ms under the conditions described in clause 5.3.

The Tolling Zone shall be approximated by a box with 10 m length measured from the RSU position against the driving direction and a width that includes all lanes of one direction (see figure 5.1). The height of this box is measured from ground up to 3 m.

To ensure coexistence with the CEN DSRC uplink from the OBUs, according to clause B.5.2 the electric field strength caused by a continuous linear polarized ITS-G5A/B signal shall not exceed 0,21 V/m (-46 dBm) at the CEN DSRC RSU antenna. The DCR coexistence requirements for non continuous signals as described in clause 5.3 also account for this type of uplink interference.

Clauses B.7 and B.8 show examples how this field strength limits can be met by balancing ITS-G5A/B output power level and distance to the Tolling Zone.

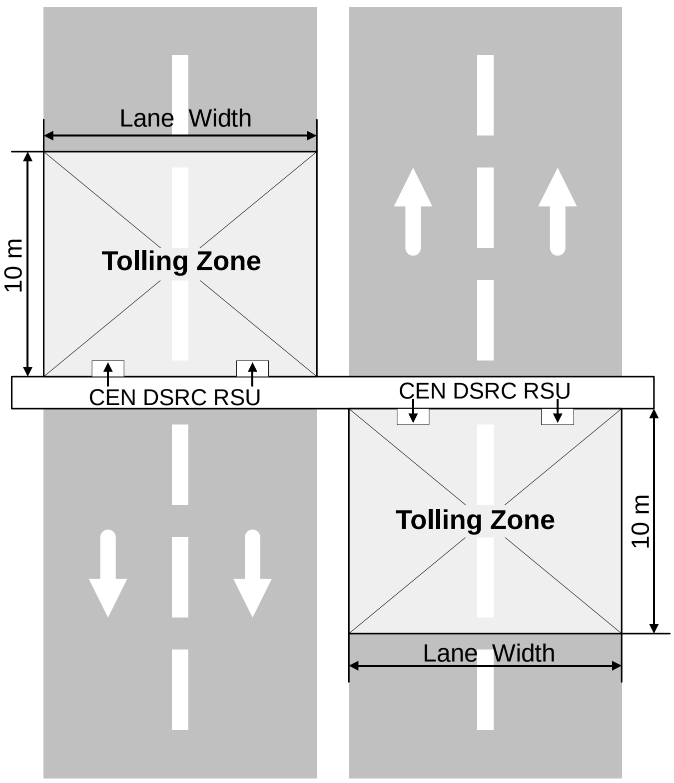

Figure 5.1: Approximation of Tolling Zone geometry

5.3 Duty cycle limits for ITS-G5A/B stations

When the field strength limits for the Tolling Zone or the RSU antenna given in clause 5.2 cannot be met for a certain ITS-G5A/B transmission, the transmitter shall ensure that the transmission lasts for less than 5 ms, and that the minimum time to the next transmission T_{off} in milliseconds that exceeds the field strength limit is determined by equation (5.1).

$$T_{off} = \max\left\{A \cdot N + B \mid BP_{Toff}\right\} + C \cdot (N-1) \cdot \left(\max\left\{T_{on} \mid BP_{Ton}\right\} - 1\,\text{ms}\right) \quad (5.1)$$

Where N is the number of independent interferers and A to C are the following coefficients:

$$A = 45 \text{ ms} \quad (5.2)$$
$$B = -51 \text{ ms} \quad (5.3)$$
$$C = 15{,}4 \quad (5.4)$$

The break point parameters of the piecewise linear model are:

$$BP_{Toff} = 50 \text{ ms} \quad (5.5)$$
$$BP_{Ton} = 1 \text{ ms} \quad (5.6)$$

T_{on} is the duration of the transmission in milliseconds.

EXAMPLE: For 6 interferers and T_{on} of 1 ms, T_{off} results in 219 ms, for 12 interferers in 489 ms, and for 16 interferers in 669 ms.
For 6 interferers and T_{on} of 5 ms, T_{off} results in 527 ms, for 12 interferers in 1 167 ms, and for 16 interferers in 1 593 ms.

Details on how equation (5.1) was derived are reported in [i.16]. Figure B.7 and table B.3 in clause B.3.7 show results of equation (5.1) for a typical parameter range.

Clause 6.2.3 specifies a duty cycle restriction (DCR) mode that describes in detail how these requirements shall be handled by an implementation.

6 Coexistence measures for mobile ITS-G5A/B stations

6.1 Tolling Zone radio detection methods

6.1.1 Introduction to radio detection and power regulation methods

For coexistence methods based on power regulation methods an ITS-G5A/B system needs to evaluate the isolation to the Tolling Zone area in order to identify the coexistence measures to be deployed. The maximum allowed level of interference in a Tolling Zone shall not exceed -51,6 dBm in order to protect the OBU from blocking (see clause 5.2). This value is the worst-case value under the assumption that the ITS system operates at the lowest available channel (5 855 MHz to 5 865 MHz) in the allocated ITS band.

Equation (6.1) shall be used to calculate the isolation I_{PL} (path loss) necessary to ensure coexistence for a given ITS-G5A/B transmit power level P_{Tx} in dBm.

$$I_{PL} / dB = 51{,}6 + P_{Tx} \quad (6.1)$$

EXAMPLE: For an ITS-G5A/B system operating with a TX power level of 33 dBm EIRP a minimum isolation towards a Tolling Zone would need to be 84,6 dB to ensure that this signal is attenuated to the allowed -51,6 dBm within the Tolling Zone.
For a 25 dBm system the minimum isolation would be 76,6 dB, for a 10 dBm system this value would be 61,6 dB.

Details how this necessary isolation can be realized by a spatial separation are described in clause 6.2.2.1.

If the necessary isolation limit cannot be met by a spatial separation or a power reduction, a DCR method as described in clause 6.2.3 shall be used.

6.1.2 Detection of CEN DSRC radio signals

A radio device that senses the radio emissions of the CEN DSRC RSU can be used to detect the existence of a Tolling Zone ahead. Clause B.4 shows how the sensitivity values of such a radio detector are calculated.

The higher the ITS-G5A/B output power level, the more sensitive the detector shall be, to detect the tolling station at a greater distance as described in clause 6.2.2. This is possible, since the RSU uses a fixed standardised output power level of 33 dBm and a standardised antenna characteristic.

Due to fading effects, the radio channel in a mobile environment is to some extent probabilistic. The radio path-loss at a certain distance can be described by a deterministic path-loss coefficient of 1,8 and a probabilistic fading margin of ±6 dB. Details of this path-loss model are shown in clause B.2.

When the detector monitors the radio channel continuously, short fading drops can be neglected. In this case the detector sensitivity results from the average path-loss, determined by the path-loss coefficient, and the RSU TX power level in direction of the detector. Detectors that evaluate the radio channel for less than 50 % of a 100 ms time frame might fall into a fading drop. Therefore these sampling detectors shall have 6 dB more sensitivity than continuously working detectors. Detectors that monitor the channel less than every 100 ms are not effective and shall not be used.

According to clause B.4 the detector sensitivity P_{Dsens} for continuously working detectors can be calculated from the ITS-G5A/B TX power level P_{TX} (given in dBm) by use of equation (6.2).

$$P_{\mathrm{Dsens}} / dBm = -32{,}7 - 18 \cdot \log\left(10 + 10^{(P_{TX} + 6{,}8)/18}\right) \quad (6.2)$$

Detector sensitivities P_{Dsens} for typical ITS-G5A/B output power levels are given in table 6.1. These values correspond to the power level at the detector antenna.

The detection distance l_d is the distance to the RSU when the received power level at the detector antenna equals P_{Dsens} and the electric field strength caused by P_{TX} at the beginning of the Tolling Zone reaches the limit given in clause 5.2.

Table 6.1: CEN DSRC detector sensitivities at detector antenna

ITS-G5A/B Tx power level P_{TX} / dBm	Detection distance l_d / m	Detector sensitivity P_{Dsens} / dBm (continuously monitoring)	Detector sensitivity P_{Dsens} / dBm (sampling detector)
10	20	-55,5	-61,5
20	40	-61,7	-67,7
25	70	-65,7	-71,7
30	120	-70,2	-76,2
33	170	-73,0	-79,0

For declaration of conformity, the measurement uncertainties should be determined according to [i.17]. Taking these measurement uncertainties into account, the detector sensitivity values shall be at least the values listed in table 6.1.

At its sensitivity limit the detector shall identify 99 % of the frames transmitted by the CEN DSRC RSU.

The precision of the mitigation zone detection is depending on the precision of the path loss estimation, the precision of the detected power level, and the precision of the CEN DSRC RSU EIRP TX power level.

NOTE 1: The detector can either share the ITS-G5A/B antenna or use an additional one.

NOTE 2: For obvious reasons, detection of CEN DSRC signals is only possible while the mobile ITS-G5A/B station in the same vehicle is not transmitting concurrently.

6.2 Methods to avoid interference

6.2.1 ITS muting

6.2.1.1 Introduction to ITS muting

The ITS muting functionality delays or avoids the transmission of ITS messages for the time a CEN DSRC transaction is performed (typically 50 ms to 100 ms). ITS muting does not apply for time critical safety messages.

ITS muting or a combination of muting and DCR (see clause 6.2.3) is mandatory in case of ITS devices **with internal antennas that are mounted inside a car** (e.g. hand held devices), or when the maximum electrical field strength caused by a continuous 10 dBm EIRP ITS-G5A/B signal exceeds 0,11 V/m (-51,6 dBm) at the anticipated mounting position of a CEN DSRC OBU.

EXAMPLE: The electric field strength limit might be applicable for ITS devices with antennas in front of the windscreen e.g. on the bonnet, or anywhere else closer than 1,5 m to the centre of the windscreen. Usually, ITS-G5A/B antennas are mounted in the back of the roof top and will not be affected by this limit.

NOTE: For handheld devices with internal antennas the mounting position is undefined. Most probably they are mounted close to the CEN DSRC OBU on the windscreen. In some cases the distance between the two devices might be only several centimetres. Therefore even output power levels below 0 dBm would disturb the CEN DSRC reception. Since such low ITS-G5A/B output power levels cannot guarantee proper ITS communication, the simplest solution is to avoid ITS-G5A/B transmission while a CEN DSRC transaction is performed.

When implemented, ITS muting shall be active within the Tolling Zone. Depending on the detection method, delay, and accuracy, different measures are necessary to ensure the correct muting behaviour.

- Clause 6.2.1.2 specifies the use of a direct interface to a CEN DSRC OBU as defined in [3] and [4].
- Clause 6.2.1.3 specifies the use of a CEN DSRC detector (clause 6.1.2).

6.2.1.2 Direct interface to a CEN DSRC OBU to invoke ITS muting

If a direct interface to a CEN DSRC OBU is used to detect an ongoing toll transaction, the muting time is given by the actual detected CEN DSRC transaction time. This method is specified in [3] and [4].

This implies that ITS muting shall be activated instantaneously when the first CEN DSRC data frame is detected. The maximum tolerable delay between detection and muting of the ITS-G5A/B output signal is 5 ms (measured with an accuracy of ±500 µs).

Muting shall be switched off when the CEN DSRC transaction was closed with a RELEASE command, or when no CEN DSRC signal was detected for more than 100 ms (measured with an accuracy of ±1 ms), or 1 s (measured with an accuracy of ±100 ms) elapsed since start of the CEN DSRC transaction.

NOTE: Since a car always moves less than 30 m within 100 ms, these requirements imply, according to table 5.1, that the ITS-G5A/B power level will be set to 10 dBm or the DCR method is applied when switching off muting.
The timeout of 100 ms was chosen according to the recommended parameter AwakeT_expired in [i.4].

Depending on the maximum output power level of the ITS-G5A/B transmitter, muting shall be combined with the appropriate output power regulation method as described in clause 6.2.2, or with a DCR method as described in clause 6.2.3.

6.2.1.3 Use of RF detection unit to invoke ITS muting

An RF detection unit estimates the distance to the transmitter from the received signal strength. Due to the stochastic nature of the radio channel and uncertainties of the antenna characteristics this estimation deviates from the real distance. By its nature, this deviation can be modelled as relative error to the estimated distance. Therefore it is important that the transmitter, which shall be detected by the RF unit, is close to the Tolling Zone, since the absolute distance estimation error gets small in this case. The easiest way to ensure this is to use the CEN DSRC transmitter itself.

Not only the distance estimation error, but also the time delay between distance estimation and muting has to be taken into account, since on a motorway a car at 130 km/h can move 0,36 m in 10 ms. For a protection area of 10 m length (Tolling Zone), more than 10 ms delay shall not be neglected.

Following example illustrates how distance estimation uncertainties and delay shall be handled to determine the RF detector threshold that defines whether ITS muting is active or not.

EXAMPLE: Assuming the transmitter to be mounted on the tolling gantry, and the distance estimation having a relative accuracy of ±32 % and a delay of 100 ms, muting should be activated at an estimated distance of 20 m in front of the gantry, to account for 6,4 m distance inaccuracy and 3,6 m driving distance until muting is activated (The Tolling Zone starts 10 m in front of the gantry - see figure 5.1).
When using a CEN DSRC detector the detector thresholds for a detection distance of 20 m are given in table 6.1, or can be calculated by use of equation (6.2).

6.2.2 Output power regulation

6.2.2.1 Basic requirements of the output power regulation

When DCR or ITS muting is not active, the ITS-G5A/B output power level shall be regulated to ensure coexistence of mobile ITS-G5A/B stations with CEN DSRC systems. The underlying calculations are summarized in clause B.3, an implementation example is given in clause A.8.

For ITS-G5A/B devices with an output power level ≤ 10 dBm no additional measures to ensure coexistence are necessary, except the special conditions for ITS muting apply (see clause 6.2.1).

When DCR is not active, the output power level of ITS-G5A/B messages shall be not above the values given in table 6.2. This output power level restriction does not apply for time critical safety messages.

In table 6.2 the distance of the ITS-G5A/B station is measured positive when approaching the Tolling Zone, and negative when leaving it. Since the Tolling Zone location relative to the CEN DSRC RSU depends on the driving direction (see figure 5.1) the coexistence distance differs by the communication zone length (10 m) when approaching or leaving the tolling station.

The coexistence distances to the CEN DSRC RSU for certain ITS-G5A/B power levels P_{Tx} (given in dBm) shall be calculated from equation (6.4) when approaching and from equation (6.3) when leaving the tolling station.

$$d_l \,/\, \text{m} = -10^{(P_{Tx}+6,8)/18} \qquad (6.3)$$

$$d_a \,/\, \text{m} = 10 - d_l \qquad (6.4)$$

Table 6.2: ITS-G5A/B output power levels as function of the distance to the CEN DSRC gantry

ITS-G5A/B Tx power for the given distance range P_{TX} / dBm	distance to the CEN DSRC RSU (approaching) d_a / m	distance to the CEN DSRC RSU (leaving) d_l / m
≤ 10	-30 to 40	-30 to 40
≤ 20	40 to 70	-60 to -30
≤ 25	70 to120	-110 to -60
≤ 30	120 to 170	-160 to -110
≤ 33	> 170	< -160

6.2.2.2 Use of RF detection unit to control the ITS-G5A/B output power level

When approaching the Tolling Zone, the distance to the tolling gantry can be estimated from the received signal strength (for the CEN DSRC detector see table 6.1, clause 6.1.2).

Due to the stochastic nature of the radio channel and uncertainties of the antenna characteristics this estimation deviates from the real distance. By its nature, this deviation can be modelled as relative error to the estimated distance. Therefore it is important that the transmitter, which shall be detected by the RF unit, is close to the Tolling Zone, since the absolute distance estimation error gets small in this case. The easiest way to ensure this is to use the CEN DSRC transmitter itself.

Not only the distance estimation error, but also the time delay between distance estimation and muting has to be taken into account, since on a motorway a car at 130 km/h can move 0,36 m in 10 ms. Therefore, for a protection area of 10 m length (Tolling Zone), more than 10 ms delay shall not be neglected.

Example 1 illustrates how distance estimation uncertainties and delay shall be handled to determine the ITS output power control characteristic when approaching the Tolling Zone.

EXAMPLE 1: Assuming the transmitter to be mounted on the tolling gantry, and the distance estimation having a relative accuracy of ±30 % and a delay of 28 ms, the ITS output power level should be reduced to 10 dBm at an estimated distance of 30 m in front of the gantry, to account for 9 m distance inaccuracy and 1 m driving distance until muting is activated (The Tolling Zone starts 10 m in front of the gantry - see figure 5.1).
When using a CEN DSRC detector the detector thresholds for a detection distance of 30 m can be calculated by use of Equation (6.2).

After passage of the Tolling Zone, the CEN DSRC detector cannot be used to estimate the distance to the tolling gantry since the CEN DSRC antenna characteristic is only specified in forward direction. A method based on the geographic position shall be used to determine the distance to the Tolling Zone in this case. The absolute GNSS position error can be corrected by use of the more precise gantry position obtained from the detector data.

Example 2 illustrates how GNSS position uncertainties shall be handled to determine the GNSS position reading where the power control algorithm shall change the power value.

EXAMPLE 2: Assuming the GNSS reading to have an accuracy of ±5 m. When leaving the Gantry this position uncertainty should be considered, hence the ITS output power level can be changed to 20 dBm at a GNSS reading of 35 m distance from the gantry (The ITS-G5A/B output power level can be increased to 20 dBm 30 m after the gantry - see table 6.2).

NOTE: The GNSS readout is updated in certain time intervals. At high speeds this update cycle can introduce an additional position error when the position readout is outdated in the instant the last CEN DSRC signal was detected.

6.2.3 Duty Cycle Restriction (DCR) mode

Alternatively to ITS muting as described in clause 6.2.1 or output power control as described in clause 6.2.2 a duty cycle restriction mode can be used to avoid harmful interference to a CEN DSRC station. By these measures, interference to CEN DSRC cannot be avoided, but a CEN DSRC transaction can be recovered by use of the standardised CEN DSRC retry-mechanism.

To ensure that the CEN DSRC retry-mechanism can recover a transaction, the interference signal of each ITS-G5A/B station shall last less than 5 ms.

The DCR mode shall be initiated and switched off in the same way as the equivalent ITS muting or power regulation mode. It can be combined with ITS muting and handled as equivalent alternative to the power regulation mode. E.g. when the used ITS-G5A/B output power level exceeds the limits given in table 6.2, or the electric field strength at the anticipated mounting position of a CEN DSRC OBU exceeds the limits given in clause 6.2.1.1. This also includes that all combinations of these methods shall fulfil the requirements given in clause 5.

Simulations and measurements [i.16] have shown that the relative number of broken CEN DSRC toll transactions can be kept below a threshold of 10^{-4} when the delay between consecutive ITS-G5A/B transmissions that can cause interference is chosen according to the number of interferers and the length of the transmission bursts.

Since the exact position of a Tolling Zone and the antenna diagram of the interfered OBU are unknown to the ITS-G5A/B station, the number of interferers N to a toll transaction can be estimated only. This estimation shall be based on the isolation distances when leaving the tolling station listed in table 6.2. All ITS stations in the station location table that are within the isolation distance d_I given by equation (6.3) shall be counted as possible interferer. This also includes the station that is performing the estimation i.e. the first matching entry in the station location table is counted as second interferer.

The estimated number of interferers N shall than be used in equation (5.1) to evaluate the minimum idle time T_{off} to the next transmission that can cause interference.

In case of many surrounding ITS-G5A/B stations, the resulting idle time T_{off} could be unacceptable long and it will be necessary to regulate (decrease) the ITS-G5A/B output power level P_{Tx} to reduce the estimated number of interferers N and thereby the length of T_{off} (see note 3).

Several cued data packets can be clustered to a burst transmission of a maximum length of T_{on} = 5 ms, in this case the minimum idle time T_{off} to the next transmission that can cause interference shall also be computed from T_{on} and N by use of equation (5.1) (see note 4).

ITS muting and DCR can be combined to avoid the implementation of a toll station detection unit. In this case the ITS-G5A/B station shall not transmit during idle time.

NOTE 1: If the restrictions given for ITS muting (clause 6.2.1) do not apply, all transmissions with an output power level below or equal to 10 dBm do not cause interference and can therefore be performed at any time.

NOTE 2: A message with high output power level delays succeeding messages. This ensures lowest possible delay for the first high priority message in a row.

NOTE 3: Since d_l in equation (6.3) depends on the transmit power level P_{Tx} of the station that is performing the estimation, the idle time T_{off} from equation (5.1) will strongly increase with the spatial interferer density and with P_{Tx} (see example in clause 5.3).

NOTE 4: Clustering of several data packets uses the channel capacity more efficient than transmitting them separately.

7 Coexistence measures for fixed ITS-G5A/B stations

7.1 Coexistence by field strength and duty cycle limitation

To ensure coexistence by limiting field strength and duty cycle of fixed ITS-G5A/B stations with fixed CEN DSRC installations, the limits given in clauses 5.2 and 5.3 shall apply.

Since the distance between fixed stations is constant and known, coexistence can be achieved by appropriate reduction of the ITS-G5A/B output power level as specified in table 6.2. Where the positive distance values apply to ITS stations in front of the tolling station, and the negative distance values apply to ITS stations beside or behind the tolling station.

Alternatively, coexistence can be achieved by use of the DCR mode as specified in clause 6.2.3.

7.2 Coexistence by CEN DSRC MAC synchronization with ITS

When using this type of coexistence method, the CEN DSRC protocol and the transmissions of a fixed ITS-G5A/B station shall be synchronised in a way that neither the CEN DSRC OBU or RSU nor the ITS-G5A/B station are transmitting at the same time.

By aligning the duty cycles with each other, a joint operation of a CEN DSRC station and a fixed ITS-G5A/B station shall be achieved. In this case no output power restrictions to the ITS-G5A/B station apply.

Annex A (informative): Recommendations for interference limits of CEN DSRC receivers

A.1 CEN DSRC RSU receiver blocking capability

In accordance to clause B.5, it is recommended that a CEN DSRC RSU tolerates interfering linear polarized ITS signals with a power level of less than -46 dBm with a bit error rate not exceeding 10^{-6} when the received CEN DSRC signal from the OBU has a power level of -100 dBm at the RSU antenna. It is recommended that this limit is tolerated for all ITS-G5A/B channels specified in Europe and when the RSU is tuned to one of the CEN DSRC channels 1 to 4 as used for tolling in Europe [1].

When following this recommendation, the measurement uncertainties should be calculated according to [i.17]:

- The ITS signal power level including the measurement uncertainties should be below the limit of -46 dBm,
- the received CEN DSRC signal including the measurement uncertainties should be above the limit of -100 dBm.

A.2 CEN DSRC OBU receiver blocking capability

It is recommended that a CEN DSRC OBU at least tolerates interfering linear polarized ITS signals with power levels specified in table A.1 with a bit error rate not exceeding 10^{-6} when the received CEN DSRC signal from the RSU has a power level of -47 dBm or smaller. It is recommended that these limits should be tolerated for all ITS-G5A/B channels specified in Europe and for the CEN DSRC channels 1 to 4 as used for tolling in Europe.

For both, the CEN DSRC signal from the RSU, and the linear polarized ITS signal the measurement uncertainties should be calculated according to [i.17], and should be taken into account, so that the CEN DSRC signal does not exceed -47 dBm and the ITS-G5A/B power levels are above the values listed in table A.1.

Table A.1: Power levels of a LP ITS signal, which a CEN DSRC OBU should tolerate for a received CEN DSRC signal from the RSU with a maximum power level of -47 dBm

ITS-G5A/B Data rate (Mbit/s)	Minimum LP ITS-G5A/B power level limit at CEN DSRC OBU antenna, that the DSRC OBU should tolerate
3 or 4,5	> -51,6 dBm
6 or 9	> -46,9 dBm
12 or 18	> -47,3 dBm
24 or 27	> -47,6 dBm

The evaluation of the values given in table A.1 is done in annex B.

Annex B (informative): Calculations and examples

B.1 Examples of coexistence scenarios

B.1.1 Overview of coexistence scenario examples

The following elementary interference scenarios to CEN DSRC by ITS-G5A/B signals have been identified:

a) Interference to the RSU receiver at CEN DSRC UL frequency [1] and [2]

b) Interference to the RSU receiver at frequencies within a vicinity of the CEN DSRC UL frequency [1] and [2] (blocking)

c) Interference to CEN DSRC OBU receiver

These interference scenarios are elementary. Most practical cases are represented by one or more of those elementary interference scenarios.

While scenario a) is handled by means of frequency regulation, e.g. unwanted emission restrictions for ITS-G5A/B, scenarios b) and c) also address the OBU and RSU manufacturers to amend their designs to reduce the susceptibility to interference caused by the receiver bandwidth. This aspect is also recognized in ECC Report 127 [i.5] and in the limits recommended in clauses A.1 and A.2.

Since in Europe more than 10 million OBUs and more than 10 thousand RSUs are in the market at the time of creation of the present document, such hardware improvements will not have an instantaneous effect. However, such improvements will only reduce the impact of the interference but cannot avoid it completely. Strong interferers like mobile ITS-G5A/B stations need to implement additional coexistence techniques on their own as specified in clause 6.

B.1.2 Example of interference to a CEN DSRC RSU

Scenarios a) and b) as described in clause B.1.1 and depicted in figure B.1 apply to interference to the RSU receiver at the UL frequency or at frequencies close to the UL frequency. For fixed or mobile ITS stations case a) applies to interference caused by spurious and other unwanted emissions and case b) applies to interference caused by the ITS signal.

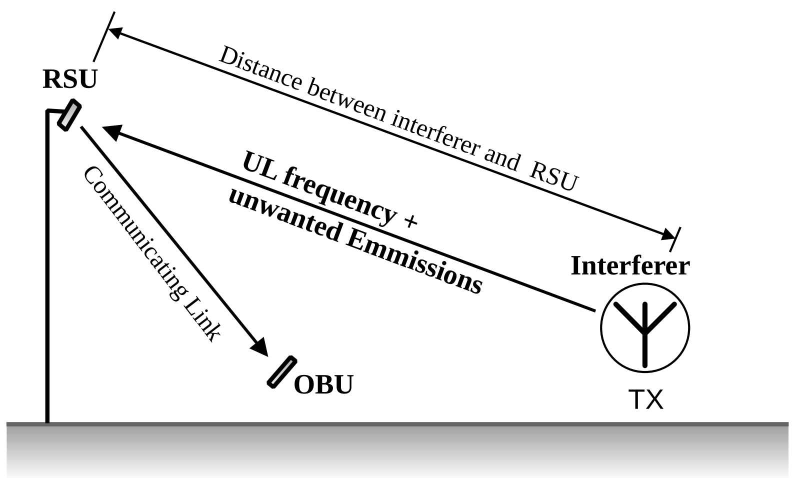

Figure B.1: Schematic of interference scenarios a) and b)

B.1.3 Example of interference to a CEN DSRC OBU

The RF front end of the CEN DSRC OBU has a broadband design to cope with typical tolling scenarios on highways (multilane free flow), where it is essential that all CEN DSRC channels are processed simultaneously. The significant parameter that defines the interference limit for this receiver design is the total incident RF peak power level at the OBU within the DSRC band from 5 795 MHz to 5 815 MHz and its adjacent bands. Therefore, the maximum tolerable interference TX power level can be calculated, which is in relation to the distance of the interferer to the OBU.

Scenario c) from clause B.1.1 is depicted in figure B.2. It describes the interference to OBUs located within the communication zone of an RSU. This interference is caused by fixed or mobile ITS stations located inside or outside the RSU communication zone.

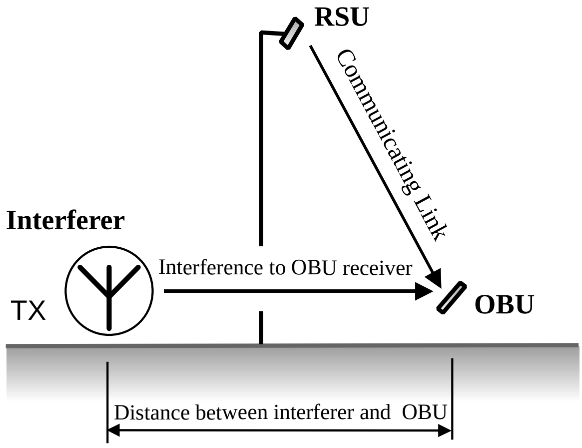

Figure B.2: Schematic of interference scenario c)

B.2 Path loss model

The following path loss model was used in the present document:

$$PL(d) = PL_0 + n \cdot 10\log_{10}\left(\frac{d}{d_0}\right) + \sigma, \qquad \text{(B.1)}$$

where $PL_0 = 47{,}9\,\text{dB}$ (free space path loss at 5,9 GHz in $d_0 = 1$ m distance), d is the distance in meters, and the path loss coefficient is $n = 1{,}8$. The margin is set to $\sigma = \pm 6$ dB, which includes both shadow fading (±5 dB peak, according to [i.8]) and 1 dB transmitter calibration offsets. The margin accounts for the worst case and is thus either added or subtracted from the path loss value. Since there are no standardized path loss models for vehicular communications in current ITU standards available, these values were chosen from [i.6], [i.7] and [i.8] for highway scenarios excluding tunnels.

The received power is thus calculated as:

$$P_{Rx}(d) = P_{Tx} - PL(d) - L_{\text{ant}}, \qquad \text{(B.2)}$$

where P_{Tx} is the EIRP (transmitted power), L_{ant} covers antenna losses due to different polarizations (where applicable), and $P_{Rx}(d)$ is the received power level.

Often a guard distance to ensure coexistence is of interest. This distance can be calculated by use of equations (B.3) and (B.4).

$$d = d_0 \cdot 10^{\frac{PL(d) - PL_0 - \sigma}{10 \cdot n}} \qquad \text{(B.3)}$$

$$PL(d) = P_{Tx} - P_{Rx}(d) - L_{\text{ant}}, \qquad \text{(B.4)}$$

B.3 Calculation of the coexistence limit for the CEN DSRC down link

B.3.1 Calculation outline

For ensuring coexistence between CEN DSRC and ITS-G5A/B, the calculation of the ITS-G5A/B power limit at the CEN DSRC OBU antenna was done in three steps:

1) Calculating the CEN DSRC receiver threshold value,
i.e. the maximum interference that does not degrade the CEN DSRC OBU's performance.

2) Calculation of the ITS signal statistics,
i.e. specifying the (peaky) interference of OFDM system in a practical CEN DSRC OBU.

3) Deriving the maximum output power of the interfering ITS station,
i.e. calculating a distance-dependent maximum RF output power level.

B.3.2 CEN DSRC OBU receiver structure

The general structure of a CEN DSRC OBU receiver unit is shown in figure B.3.

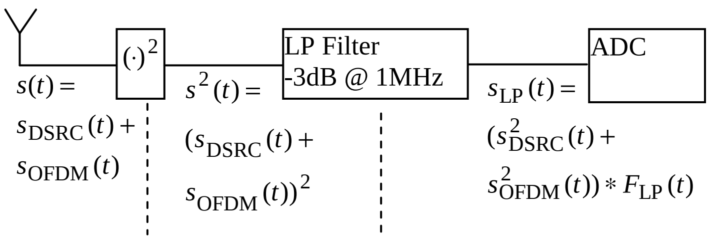

Figure B.3: General CEN DSRC OBU structure.
Symbols are explained in clauses B.3.3 and B.3.4

This structure represents the simplest implementation possible and can thus be seen as a worst-case CEN DSRC receiver. The filter is assumed to be a simple first-degree low pass with 10 dB attenuation per decade. The derivations in clauses B.3.3 and B.3.4 base on this structure. Only the base band signal (envelope) is taken into account, high order intermodulation products are neglected because of the LP filter before the ADC.

B.3.3 Calculation of the CEN DSRC receiver threshold value

On the downlink, the CEN DSRC OBUs are specified to achieve a $\text{BER} = 10^{-6}$ [1] and [2] at a typical receiver sensitivity of $P_{\text{sens}} = -50$ dBm (average input power). The CEN DSRC downlink signal uses amplitude modulation with a modulation index of $m = 0{,}8$ [1] and [2]. Hence, the transmit signal $s_{\text{DSRC}}(t)$ can be written as:

$$s_{\text{DSRC}}(t) = \begin{cases} \sqrt{P_1}\, sin(2\pi f_{\text{D}} t) & \text{...for the "high" level} \\ \sqrt{P_2}\, sin(2\pi f_{\text{D}} t) & \text{...for the "low" level} \end{cases} \quad \text{(B.5)}$$

Where f_{D} is the CEN DSRC carrier frequency, P_1 is the power level for the "high" signal, and P_2 is the power level for the "low" signal. The square-roots denote the normalized amplitudes. For the given modulation index, $P_2 = (1-m)^2 P_1 = 1/25 \cdot P_1$. For an average power of P, we derive $P_1 = 50/13 \cdot P$, and $P_2 = 2/13 \cdot P$. For P equal to the receiver sensitivity threshold of $P = P_{\text{sens}} = -50\,\text{dBm} = 10\,\text{nW}$, it follows that $\sqrt{P_1} = 6{,}2\sqrt{\text{nW}}$, and $\sqrt{P_2} = 1{,}24\,\text{nW}$. When this signal passes through the diode (modelled by a quadratic characteristic) in the CEN DSRC OBU receiver, we obtain for each power index i (1 or 2).

$$s^2_{\text{i DSRC}}(t) = (\sqrt{P_i}\, sin(2\pi f_{\text{D}} t))^2 = 1/2 \cdot P_i (1 - cos(2\pi (2 f_{\text{D}}) t)). \quad \text{(B.6)}$$

The RF part is filtered in the low-pass filter F_{LP}, i.e. the resulting signal becomes:

$$s^2_{\text{i DSRC}}(t) * F_{\text{LP}}(t) = 1/2 \cdot P_i. \tag{B.7}$$

This implies that the two signal levels in the receiver are $a_1 = 19{,}23\sqrt{\text{nW}}$, and $a_2 = 0{,}77\sqrt{\text{nW}}$. We assume that the receiver puts the decision threshold (high or low) into the middle of these two values, i.e. $a_{\text{thresh}} = 10\sqrt{\text{nW}}$. Whenever an interferer excites this signal over the value of $a_{\text{err}} = a_{\text{thresh}} - a_2 = 9{,}23\sqrt{\text{nW}}$, a bit error will occur, hence this value is the threshold value which interference is supposed not to exceed in the CEN DSRC OBU.

B.3.4 Calculation of the OFDM signal statistics

The European Profile Standard for ITS systems [7] uses OFDM on the physical layer. OFDM signals can be problematic for interference because they may have strong short peaks in the transmitted signal. These peaks determine the maximum possible interference to CEN DSRC OBUs.

In the same way as calculated in clause B.3.3, one can calculate the impact of the OFDM signal on the total received signal within the CEN DSRC OBU. For that, the OFDM received signal $s_{\text{OFDM}}(t)$ at the CEN DSRC OBU receiver antenna is denoted by:

$$s_{\text{OFDM}}(t) = s_{\text{R}}(t)\cos(2\pi f_{\text{O}} t) + s_{\text{I}}(t)\sin(2\pi f_{\text{O}} t)\,. \tag{B.8}$$

Where $s_{\text{R}}(t)$ is the real and $s_{\text{I}}(t)$ the imaginary part of the complex ITS-G5A/B baseband signal and f_{O} is the ITS-G5A/B carrier frequency. The combined signal $s_{\text{LP}}(t)$ at the input of the ADC can thus be written as:

$$s_{\text{LP}}(t) = (s_{\text{DSRC}}(t) + s_{\text{OFDM}}(t))^2 * F_{\text{LP}}(t). \tag{B.9}$$

Assuming that the low-pass filter completely removes RF components (high order intermodulation products), it follows straight-forward that:

$$s_{\text{LP}}(t) = \frac{1}{2}P_i + \frac{1}{2}(s_{\text{R}}^2(t) + s_{\text{I}}^2(t)) * F_{\text{LP}}(t), \tag{B.10}$$

with:

$$s_{\text{LP-OFDM}}(t) = \frac{1}{2}(s_{\text{R}}^2(t) + s_{\text{I}}^2(t)) * F_{\text{LP}}(t). \tag{B.11}$$

Thus, $s_{\text{LP-OFDM}}(t)$ denotes the error that the OFDM signal can generate, which is supposed to stay below the value of a_{err}.

By using a calibrated OFDM link-level simulator [i.9], one can simulate the OFDM signal $s_{\text{OFDM}}(t)$, and thus $s_{\text{LP-OFDM}}(t)$. Using random transmit data, we obtain different statistics of the peak values of this error signal for each coding and modulation scheme (i.e. data rate). Figure B.4 shows the inverse cumulative distribution function of this peak signal level (for a normalized OFDM output power of 1 W).

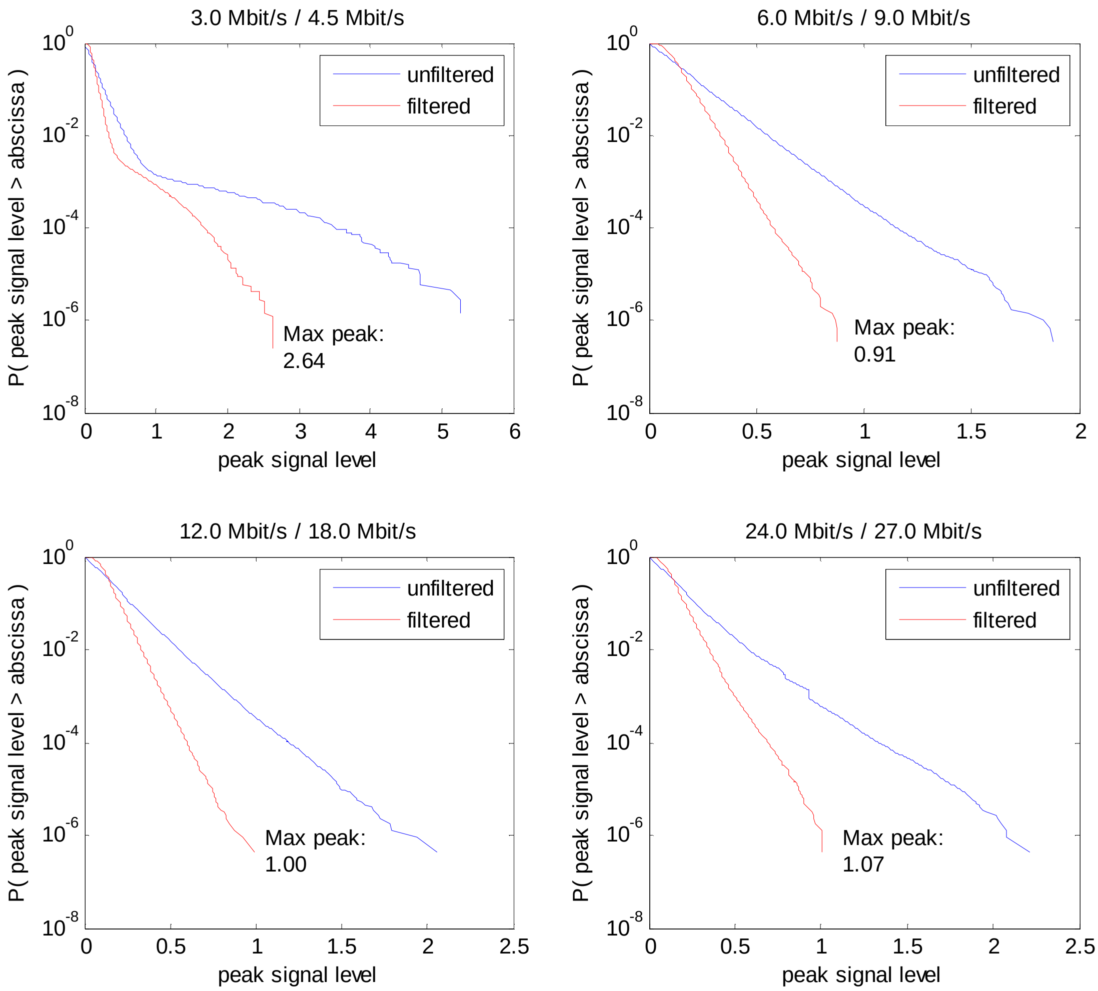

Figure B.4: Maximum peak levels for the different coding and modulation schemes for a transmit power normalized to $P_{\text{OFDM}}^{(\text{norm})} = 1W$

The maximum levels in figure B.4 are due to the random data combined with the convolutional encoder and interleaver of the IEEE 802.11 PHY. The theoretically possible maximum peak signal levels would be significantly higher; however these levels occur with much lower probability than the CEN DSRC target BER of 10^{-6}, and are thus negligible. From these maximum peaks presented in figure B.4, one can derive the maximum OFDM signal power level $P_{\text{OFDM}}^{(\max)}$ at the CEN DSRC OBU antenna as:

$$P_{\text{OFDM}}^{(\max)} = \frac{2a_{\text{err}}}{s_{\text{LP-OFDM}}^{(\text{peak})}} P_{OFDM}^{(norm)}, \quad \text{(B.12)}$$

where the factor $P_{\text{OFDM}}^{(\text{norm})} = 1W$ normalises the scale and unit. For the different modulation and coding schemes this leads to the power thresholds given in table B.1.

The power level $P_{\text{OFDM}}^{(\max)}$ can be transformed to a power density value $S_{\text{OFDM}}^{(\max)}$ by:

$$S_{\text{OFDM}}^{(\max)} = P_{\text{OFDM}}^{(\max)} \frac{4\pi f_{\text{O}}^{2}}{c_0^2}, \quad \text{(B.13)}$$

where c_0 is the speed of light in vacuum (2,99792458 $\cdot 10^8$).

From the power density value the electric field strength can be expressed:

$$E_{\text{OFDM}}^{(\max)} = \sqrt{377\,\Omega \cdot S_{\text{OFDM}}^{(\max)}} \quad \text{(B.14)}$$

Table B.1: Maximum receive power levels, power densities, and electrical field strengths at the CEN DSRC OBU to avoid interference from ITS stations

Data rate (Mbit/s)	Maximum OFDM power level $P_{\text{OFDM}}^{(\text{max})}$	Maximum OFDM power density $S_{\text{OFDM}}^{(\text{max})}$	Maximum OFDM electric field strength $E_{\text{OFDM}}^{(\text{max})}$
3 or 4,5	-51,6 dBm	$3,4 \times 10^{-05}$ W/m²	0,113 V/m
6 or 9	-46,9 dBm	$9,9 \times 10^{-05}$ W/m²	0,193 V/m
12 or 18	-47,3 dBm	$9,1 \times 10^{-05}$ W/m²	0,185 V/m
24 or 27	-47,6 dBm	$8,4 \times 10^{-05}$ W/m²	0,178 V/m

B.3.5 Maximum output power of an interfering ITS station being in a CEN DSRC communication zone

B.3.5.1 Example of cars driving in adjacent lanes

This example shows the scenario when one car equipped with an ITS-G5A/B transmitter overtakes another car equipped with a CEN DSRC OBU on the windscreen.

The minimum distance d_{min} between cars driving in adjacent lanes is calculated as follows (see figure B.5).

The minimum separation of two lanes along a highway is assumed to be 3,5 m. Given an opening angle of the CEN DSRC OBU antenna of $\alpha = 35°$, we derive a minimum effective distance between the cars of $d_{min} = 6,1$ m.

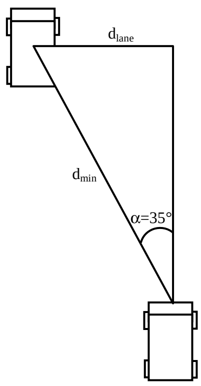

Figure B.5: Minimum distance between cars. d_{lane} = 3,5 m, d_{min} = 6,1 m

For the minimum distance of 6,1 m, the received signal power level at the CEN DSRC OBU is supposed not to exceed the smallest value given in table B.1, hence -51,6 dBm. For the calculations, we use the path loss model from clause B.2 using L_{ant} = +6 dB (3 dB polarization loss, another 3 dB for the antenna pattern at $\alpha = 35°$) and σ = -6 dB margin.

From this worst case path loss model we obtain a receive power of -52 dBm, for an ITS device with 10 dBm transmit power level. Thus, a limiting of the transmit power to 10 dBm is deemed to be safe in overtaking scenarios.

This result corresponds to measurements done in similar scenarios [i.1].

B.3.5.2 Example of cars driving behind each other

This example assumes two cars driving behind each other, where the first car is equipped with a mobile ITS-G5A/B station and the second car has a CEN DSRC OBU mounted to the windscreen. This coexistence scenario is similar to c) described in clause B.1.1.

With the path loss model from clause B.2 using σ = -6 dB worst case fading margin the path loss can be calculated to be higher than 58,6 dB.

Using L_{ant} = +3 dB (3 dB polarization loss) and the interference limit of -51,6 dBm (3 Mbit/s) from table B.1 shows that for worst case fading, and neglecting the windscreen attenuation, an ITS-G5A/B output power level of 10 dBm ensures coexistence at more than 8,5 m distance.

For the same 10 dBm ITS-G5A/B output power level at 6 Mbit/s (interference limit of -46,9 dBm) with best case fading of σ = 6 dB and a windscreen attenuation of 3 dB (L_{ant} = +6 dB) the coexistence is ensured at more than 0,7 m distance.

This results show that at motorways at full speed with high distances between the cars, the CEN DSRC system will not be interfered by a linear polarized 10 dBm ITS-G5A/B signal. At lower speeds when cars are closer together coexistence is still ensured, since the passage of the Tolling Zone lasts longer and fading effects as well as the transmit pauses between the ITS-G5A/B CDMA frames can be used by CEN DSRC to perform the tolling transaction.

This result corresponds to measurements done in similar scenarios [i.1].

B.3.6 Maximum output power level of an interfering ITS station after leaving a CEN DSRC communication zone

After leaving the CEN DSRC communication zone, ITS devices can only gradually increase their power in order to avoid interference to CEN DSRC OBUs.

Using the path loss model from clause B.2, with L_{ant} = +3 dB (circular polarization loss, windscreen attenuation neglected) and a shadow fading margin of σ = -6 dB, the guard distances are calculated as shown in figure B.6.

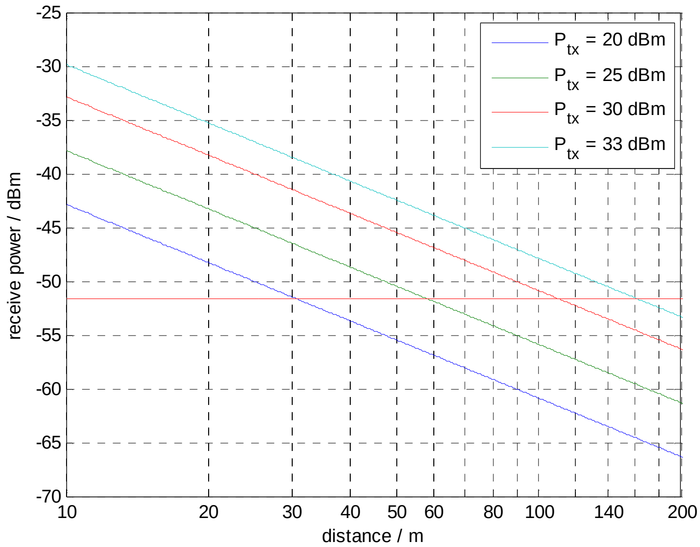

Figure B.6: Minimum distances for ramping up the ITS transmit power level after leaving a CEN DSRC communication zone for a receiver threshold of -51 dBm

From figure B.6 we obtain the following minimum guard distance values as listed in table B.2.

Table B.2: Minimum distances for ramping up ITS-G5A/B output power level after leaving the CEN DSRC communication zone

ITS-G5A/B output power level in direction to the Tolling Zone (EIRP)	Minimum distance to CEN DSRC OBU l_m
< 20 dBm	> 30 m
< 25 dBm	> 60 m
< 30 dBm	> 110 m
< 33 dBm	> 160 m

B.3.7 Idle time T_{off} as function of the number of interferes

Several investigations of the interference impact of non continuous ITS-G5A/B signals to tolling systems have been performed per measurements and computer simulations [i.16]. Most important are the results for several independent ITS-G5A/B stations that transmit frames with up to 5 ms length. For these interference signals a lower bound for the idle time T_{off} was be found that is specified in equation (5.1) as function of the upper bound of the transmission burst length T_{on} and the number of interferers N. The results are depicted in figure B.7 and listed in table B.3. When applying this requirement, the relative number of broken CEN DSRC transactions caused by interference is limited to 10^{-4}.

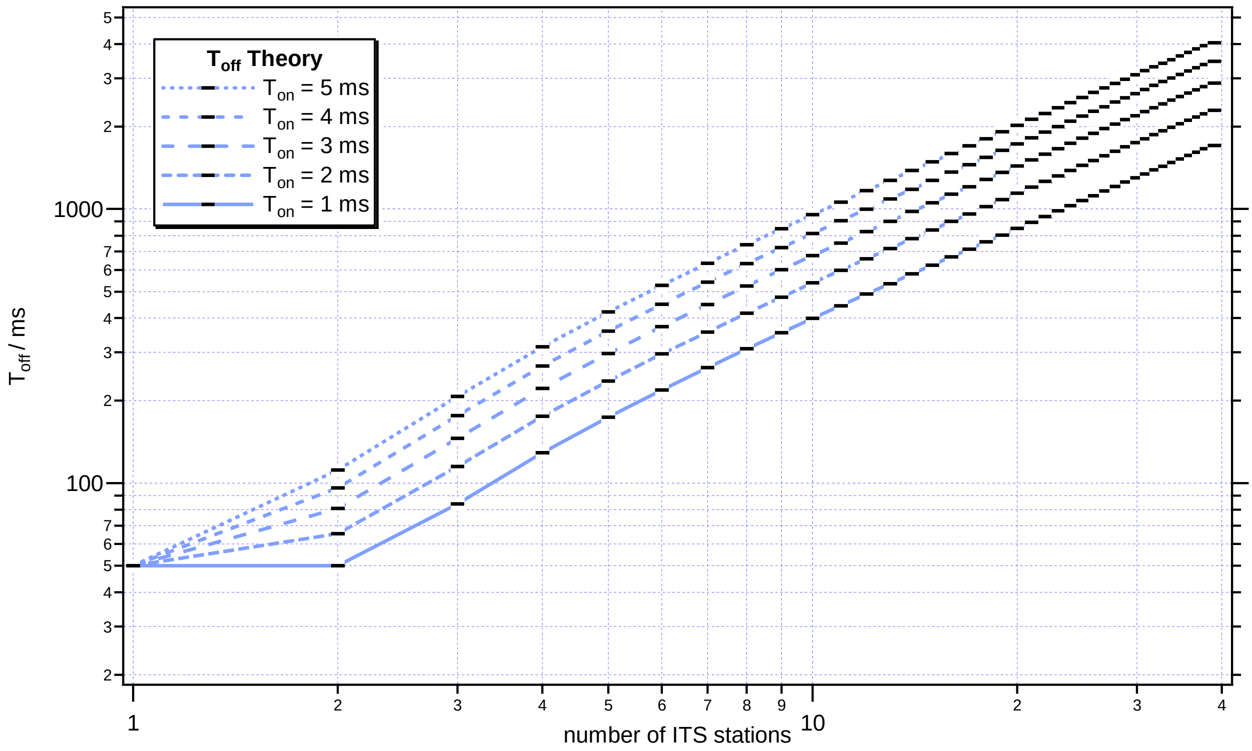

Figure B.7: Lower bound of the DCR idle time T_{off} to limit the relative number of broken CEN DSRC tolling transactions to 10^{-4} according to equation (5.1) (see also [i.16])

Table B.3: Lower bound of the DCR idle time T_{off} for transmit times up to T_{on} and the number of interferers N according to equation (5.1) to limit the relative number of broken CEN DSRC tolling transactions to 10^{-4} (see [i.16])

Minimum T_{off} / ms	***Maximum T_{on} / ms***				
N	**1**	**2**	**3**	**4**	**5**
1	50	50	50	50	50
2	50	65,4	80,8	96,2	111,6
3	84	114,8	145,6	176,4	207,2
4	129	175,2	221,4	267,6	313,8
6	219	296	373	450	527
8	309	416,8	524,6	632,4	740,2
10	399	537,6	676,2	814,8	953,4
12	489	658,4	827,8	997,2	1 166,6
14	579	779,2	979,4	1 179,6	1 379,8
16	669	900	1 131	1 362	1 593
18	759	1 020,8	1 282,6	1 544,4	1 806,2
20	849	1 141,6	1 434,2	1 726,8	2 019,4
22	939	1 262,4	1 585,8	1 909,2	2 232,6
24	1 029	1 383,2	1 737,4	2 091,6	2 445,8
26	1 119	1 504	1 889	2 274	2 659
28	1 209	1 624,8	2 040,6	2 456,4	2 872,2
30	1 299	1 745,6	2 192,2	2 638,8	3 085,4
32	1 389	1 866,4	2 343,8	2 821,2	3 298,6
34	1 479	1 987,2	2 495,4	3 003,6	3 511,8
36	1 569	2 108	2 647	3 186	3 725
38	1 659	2 228,8	2 798,6	3 368,4	3 938,2
40	1 749	2 349,6	2 950,2	3 550,8	4 151,4

B.4 Calculation of CEN DSRC detector sensitivity

To ensure timely muting or power level reduction of the ITS-G5A/B radio, CEN DSRC stations need to be detected within a certain minimum distance, depending on the ITS output power (device class). These distances imply a certain DSRC detector sensitivity, which are calculated in the following.

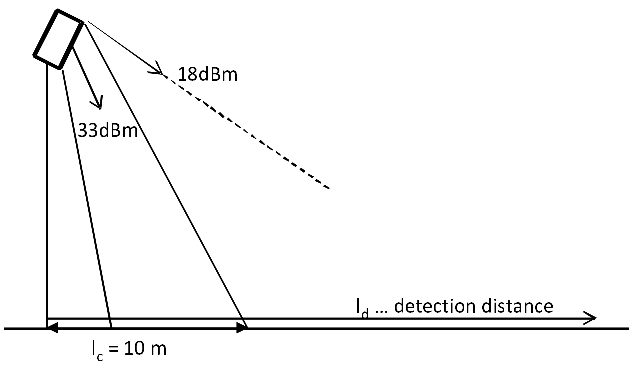

Figure B.8: CEN DSRC detection distance

The transmitted power outside the DSRC communication zone is equal to 18 dBm EIRP, [1] and [2], (see also figure B.8).

Given the minimum distances l_m from table B.2, the detection distance can be calculated as $l_d = l_m + l_c$, i.e. the detection distance is l_c = 10 m larger than the minimum distance.

For the calculations, we distinguish two cases:

(i) continuous detection - in this case, the fading margin can be set to zero, since the environment is continuously monitored while the mobile ITS-G5A/B station is in receive mode,

(ii) sampled detection - in this case, the full fading margin needs to be applied, since the radio channel is monitored for short time periods only (e.g. between received ITS-G5A/B data frames).

Applying the path loss model from clause B.2 with L_{ant} = +3 dB (polarization margin) and fading margin $\sigma \in \{0, +6$ dB$\}$ (continuous vs. sampled), we obtain the following detector sensitivities:

Table B.4: Detector sensitivities at antenna

Max Tx power	Detection distance l_d	Continuous detection	Sampled detection
< 10 dBm detection necessary only for muting	~20 m (depending on RSU antenna pattern)	-55,5 dBm	-61,5 dBm (6 dB fading margin)
< 20 dBm	> 40 m	-61,7 dBm	-67,7 dBm
< 33 dBm	> 170 m	-73,0 dBm	-79,0 dBm

The sensitivity values in table B.4 correspond to the power at the detector receive antenna. For signal processing, the receive antenna gains and cable losses should be taken into consideration.

B.5 CEN DSRC uplink blocking

B.5.1 Measurement setup for the determination of CEN DSRC RSU blocking characteristics

The bit error ratio (BER) of a CEN DSRC link was determined by evaluation of CEN DSRC ECHO frames. Figure B.9 shows the corresponding test setup.

The CEN DSRC TX power level was adjusted by an attenuator to operate the OBU in a distance of 4,45 m at its sensitivity limit, which is defined by a BER of 10^{-6} [1].

The periodic service advertisement messages of an ITS-G5A/B station [i.1] were used as interfering signal. These messages are always sent with a data rate of 6 Mbit/s. A 19 dBi linear polarized directional antenna concentrated the interference mainly to the RSU. The power level of the interfering signal was adjusted by a step attenuator and measured with a spectrum analyser, to find the correspondence between CEN DSRC BER and incident ITS-G5A/B signal power level. Only the lowest ITS-G5A/B frequency channel (CH 172. 5,86 GHz) was used, since it is closest to the CEN DSRC frequency range.

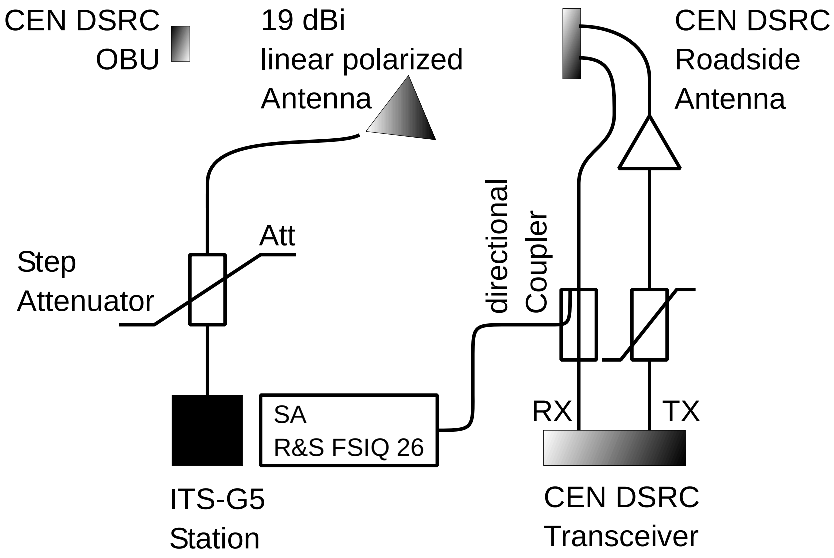

Figure B.9: Test setup of ITS-G5A/B TX to CEN DSRC UL interference

B.5.2 Measurement results of CEN DSRC RSU blocking characteristics

The result obtained with the test setup described in clause B.5.1 is shown in figure B.10. As a black line the fit to the average of several BER measurements of the 2 MHz CEN DSRC sub channel and the 5,8125 GHz CEN DSRC channel (CH 4) is shown. The green and blue lines show a fit to different CEN DSRC (sub) channels. The deviation between the three results lies within the measurement uncertainty.

At the worst case, at the OBU sensitivity limit and for ITS CH 172 (5,86 GHz) the CEN DSRC BER raised significantly when the ITS-G5A/B power level at the RSU RX connector exceeded -35 dBm.

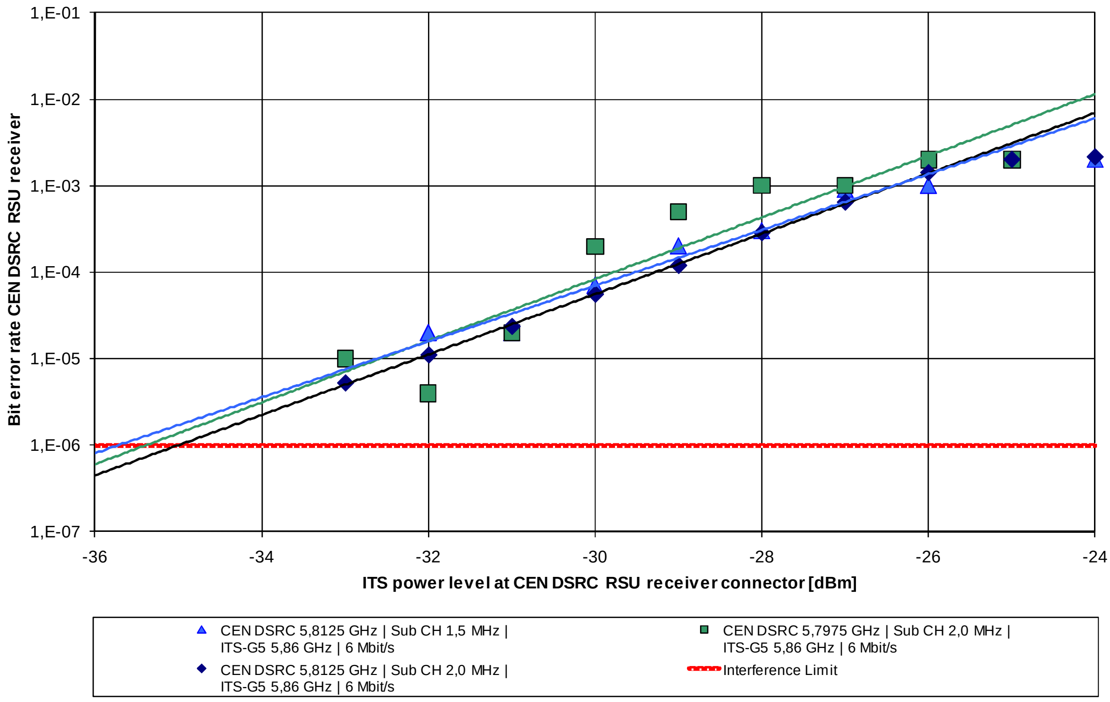

Figure B.10: Measured BER of a CEN DSRC link degraded by an ITS-G5A/B signal blocking the RSU receiver (details see text)

B.5.3 CEN DSRC RSU blocking: Summary and conclusions

Measurements have shown that the CEN DSRC UL can be disturbed when the ITS-G5A/B signal level at the CEN DSRC receiver exceeds -35 dBm. In this value the CEN DSRC receiver antenna gain is not included. In a MLFF tolling station left hand circular polarized (LHCP) antennas with typically 13 dBi gain are used. Hence the LHCP RX interference power level of the ITS signal at the antenna should not exceed -48 dBm. (Note that for this value, spurious and unwanted emissions of the ITS transmitter in the DSRC band were neglected.) A linear polarized interferer has to meet only a limit of -46 dBm, since an additional attenuation value of 2 dB should be considered (1 dB margin to handle imperfect antenna patterns, and elliptic polarization outside the main lobe of the antennas).

In summary, the maximum tolerable linear polarized total channel power of an ITS-G5A/B signal at the CEN DSRC RSU antenna is -46 dBm when the CEN DSRC input power is at its sensitivity limit (BER of 10^{-6}).

B.5.4 CEN DSRC RSU blocking: Example

The RSU is usually mounted at a height of 5,5 m to 6,5 m above ground with its RX bore sight pointing downwards. An interfering device mounted on the rooftop of a truck, can be expected to be at least 2 m in bore sight away from the RSU. Assuming free space propagation for this short distance, without shadowing or fading ($\sigma = 0$, n = 2), the attenuation is calculated by Equation (B.1), resulting in an attenuation value of 54 dB for a distance *d* of 2 m.

From this worst case calculation, the transmit power level of an ITS-G5A/B transmitter mounted on a truck should not exceed 8 dBm EIRP. In practice the mounting geometry of the OBU and the ITS antenna should be considered. Either the RSU is not at its sensitivity limit, or the OBU is even outside the Tolling Zone, or the ITS antenna is out of RSU bore sight.

To make a more realistic assumption the antenna characteristics of both, the RSU receiver and the ITS-G5A/B transmitter, as well as the CEN DSRC DL power profile over the whole Tolling Zone, and the OBU receiver antenna characteristics should be considered. Since the antenna pattern of the ITS antenna should not point upwards, an additional attenuation can be expected, by which the limit of 10 dBm set in clause 4.2.4.2 holds.

Also the spurious and unwanted ITS emissions are of interest. If they do not comply with [6] severe interference could happen.

B.6 Calculation of maximum CEN DSRC receive power level at ITS-G5 mobile station

Considering the same geometry and radio channel of the CEN DSRC RSU and a mobile ITS-G5 antenna as described in clause B.5.3, a minimum distance of 2 m between them can be assumed. According to Equation (B.1) the free space attenuation at 5,8 GHz is 54 dB for this distance.

CEN DSRC is specified to use a maximum EIRP output power level of P_{DSRC} = 33 dBm [1], hence the receive power level P_{RX_ITS} at the ITS-G5 antenna is -21 dBm (see equation (B.15)).

$$P_{RX\_ITS} = P_{DSRC} - PL = 33\,dBm - 54\,dB = -21\,dBm \qquad \text{(B.15)}$$

B.7 Examples of coexistence scenarios with fixed ITS stations

Clause 5.2 defines the field strength limit for an ITS-G5A/B signal within the Tolling Zone, and the geometry of this zone to ensure coexistence of fixed ITS-G5A/B stations and CEN DSRC OBUs.

Using the radio channel model from clause B.2, the minimum distance to the Tolling Zone to meet the requirements for a given output power level of the fixed ITS-G5A/B station can be calculated.

The channel parameters used for the calculation of table B.4 that shows the minimum distance between the Tolling Zone and a fixed ITS station with given output power level are:

n = 1,8 (from clause B.2)

σ = -6 dB (worst case fading)

d_0 = 1 m (from clause B.2)

L_{ant} = 3 dB (polarization, windscreen attenuation neglected)

$P_{Rx}(d)$ = -51,6 dBm (from clause 5.2)

Table B.4: Coexistence power levels of fixed ITS-G5A/B stations related to the minimum distance to the CEN DSRC OBU

ITS-G5A/B output power level P_{tx} in direction to the Tolling Zone (EIRP)	minimum distance to the Tolling Zone (distance to CEN DSRC OBU)
≤ 10 dBm	> 8,5 m
< 20 dBm	> 30 m
< 25 dBm	> 58 m
< 30 dBm	> 109 m
< 33 dBm	> 161 m

To avoid interference to the CEN DSRC RSU the minimum distance between the ITS antenna and the CEN DSRC RSU is given in table B.5. The distance values were calculated according to the radio channel model from clause B.2 with following channel parameters:

n = 1,8 (from clause B.2)

σ = -6 dB (worst case fading)

d_0 = 1 m (from clause B.2)

L_{ant} = 3 dB (polarization)

$P_{Rx}(d)$ = -46 dBm

For the calculation of the distance between CEN DSRC RSU and ITS-G5A/B antenna the mounting heights of both antennas are to be considered. The CEN DSRC RSU is usually mounted at a height of 5,5 m to 6,5 m.

Table B.5: Coexistence power levels of fixed ITS-G5A/B stations related to the minimum distance to the CEN DSRC RSU

ITS-G5A/B output power level in direction to the CEN DSRC RSU (EIRP)	minimum distance to CEN DSRC RSU
≤ 10 dBm	> 4 m
< 20 dBm	> 15 m
< 25 dBm	> 28 m
< 30 dBm	> 53 m
≤ 33 dBm	> 78 m

B.8 Implementation example of a mobile ITS-G5A/B station with power regulation and radio detection of CEN DSRC RSU

For coexistence methods based on power regulation methods an ITS-G5A/B system needs to evaluate the isolation to the Tolling Zone. Table B.6 shows the minimum isolation necessary to ensure coexistence between CEN DSRC and ITS-G5A/B.

Table B.6: Minimum isolation needed towards Tolling Zones for the different ITS TX power levels

ITS-G5A/B TX power	Minimum isolation
33 dBm	84,6 dB
25 dBm	76,6 dB
10 dBm	61,6 dB

Based on the path loss calculation in clause B.2 the following separation distances to the CEN DSRC RSU are needed when approaching the Tolling Zone to reach the minimum isolation for the different TX power levels:

- 33 dBm EIRP: 170 m
- 25 dBm EIRP: 70 m
- 10 dBm EIRP: no restriction of operation needed

These distance values are valid for a worst-case path-loss model with a path loss coefficient of 1,8 and taking into account that the Tolling Zone is 10 m in front of the CEN DSRC RSU when approaching the toll station.

Beside the separation distance, different other mitigation factors can be taken into account in order to guarantee the needed protection of the victim system. If no LoS conditions between the tolling area and the potentially interfering ITS-G5A/B system is possible in a specific environment, the distance values given in table B.5 will be significantly reduced, since the path-loss exponent will be much higher than the assumed 1,8 (typical values are in the range of 3,0 and 3,5).

Based on the given minimum isolations needed and the corresponding mitigation distances, three different mitigation Zones can be defined around a tolling station to simplify the implementation:

- In mitigation Zone 3 with a separation distance *d* larger than 170 m from any CEN DSRC RSU, an ITS-G5A/B system can operate without any duty cycle restrictions up to a TX power level of 33 dBm EIRP.
- In mitigation Zone 2 with a separation distance 70 m < *d* < 170 m from any CEN DSRC RSU, an ITS-G5A/B system can operate without any duty cycle restrictions up to a TX power level of 25 dBm EIRP.
- In mitigation Zone 1 for a distance closer than 70 m from any CEN DSRC RSU, an ITS-G5A/B system can operate without any duty cycle restrictions up to a TX power level of 10 dBm EIRP.

The described power regulation mode can be combined with the DCR method described in clause 6.2.3 to meet the requirements given in clause 5.3.

For more sophisticated implementations this zone concept can be extended by additional mitigation Zones. Intermediate maximum TX power levels P_{TXmax} can be calculated from the distance *d* to the CEN DSRC RSU by use of equation (B.16) in accordance to clause B.2.

$$P_{TX\,\max} \;/\; dBm = \max\left[10\,,\,18 \cdot \log(d-10) - 6{,}8\right] \qquad \text{(B.16)}$$

Where for distances *d* closer than 20 m to the CEN DSRC RSU the ITS-G5A/B transmit power level is limited to 10 dBm EIRP.

If no DCR method is used, at least the Zones as shown in table B.7 should be implemented for the applicable maximum output power levels of the implementation. Figure 11 depicts the values used for this simple implementation.

Table B.7: Summary of zone model for mitigation operations

Zone number	Distance from CEN DSRC RSU	Allowed maximum TX power (EIRP)	Sampling detector sensitivity
3	> 170 m	33 dBm	-79 dBm
2	70 m < d < 170 m	25 dBm or DCR	-72 dBm
1	< 70 m	10 dBm or DCR	-62 dBm

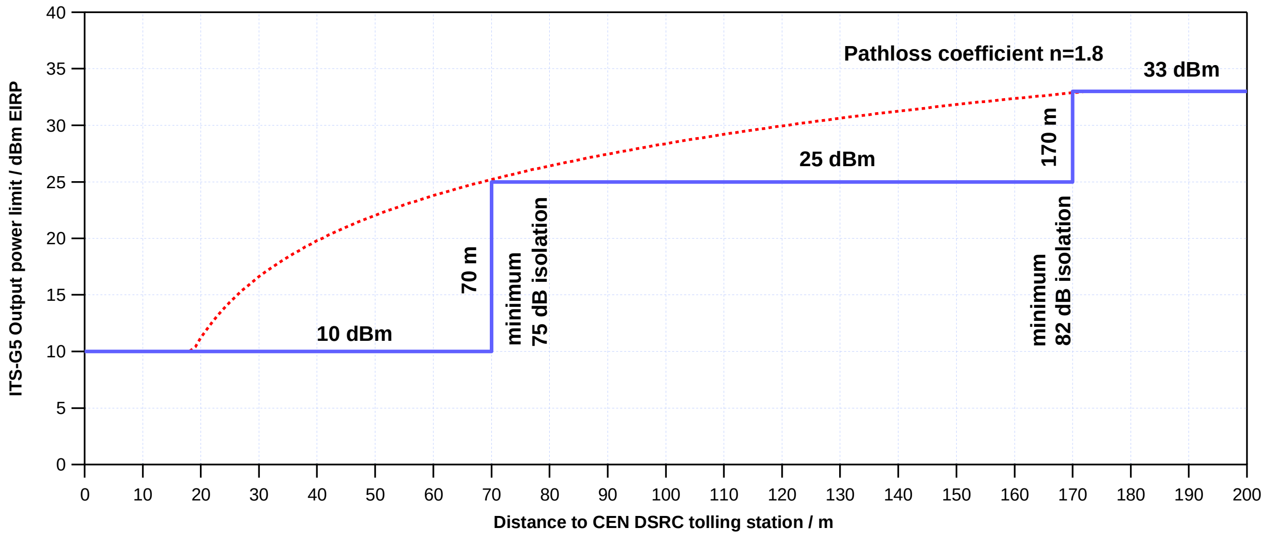

Figure B.11: Power level steps for a simple implementation of the power regulation method

The sensitivity level thresholds of a sampling detector for this implementation can be taken from table 6.1 and are also listed in table B.7. Figure B.12 summarises all values necessary for the described implementation.

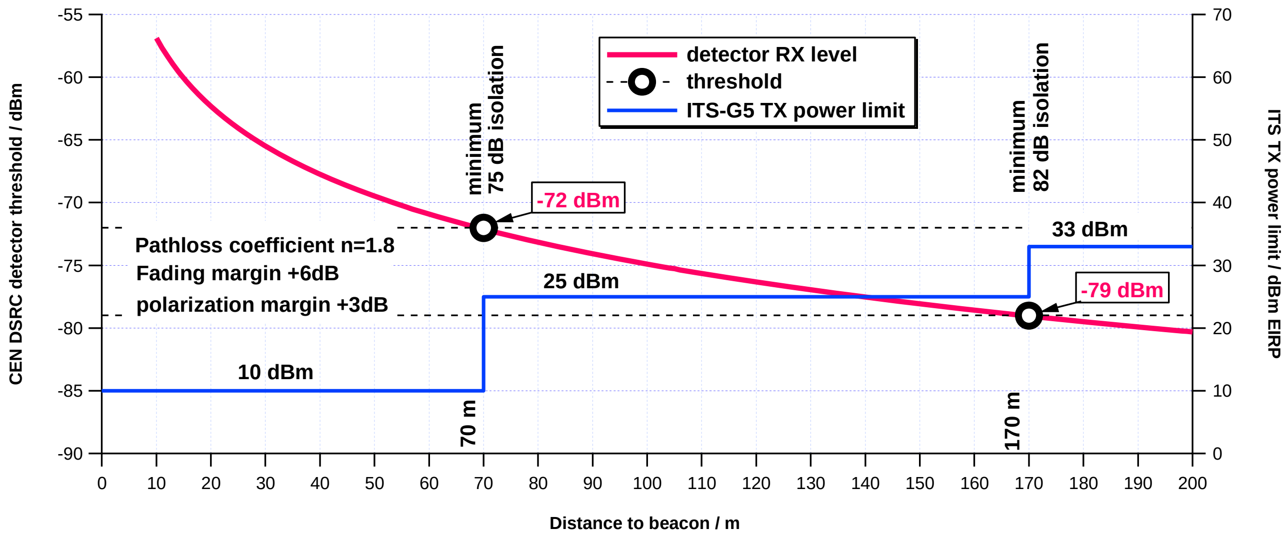

Figure B.12: Detector sensitivities and power level steps for a simple implementation of the power regulation method

Annex C (informative): CEN DSRC station types

C.1 CEN DSRC basics

CEN DSRC is designed to provide a short range data transmission between semi passive mobile tags called on board unit (OBU) and fixed transceivers called roadside unit (RSU). Usually the RSU antenna forms a small communication area covering a lane. This small area offers the possibility to use CEN DSRC for several automotive location based services where fast and secure authentication or even secure payment is necessary. The most important ones are listed in the following clauses of annex C. CEN DSRC is mainly based on the CEN standards [1], [i.2], and [i.3]. The basic ETC functionality is standardised at ISO and CEN in [i.4] and [i.11]. And the conformance test standards for DSRC and ETC are [2], [i.12], [i.13], [i.14], and [i.15].

C.2 Toll plazas and access applications

Because of the small RSU antenna footprint, CEN DSRC can be used to authenticate a vehicle waiting in front of a barrier. This functionality is used at toll plazas or parking lot entries to automatically open the barrier for registered users.

If the gate is equipped with an enforcement camera the barrier can be omitted, and the vehicles can pass the gate without stop. For all vehicles with an invalid contract or without a CEN DSRC OBU an enforcement picture will be generated automatically.

C.3 Multilane free flow tolling

Since CEN DSRC provides fast and secure authentication mechanisms it can be used at motorway speeds to pay toll while passing a gantry as shown in figure C.1. In combination with a camera system these gantries can be used for automatic enforcement.

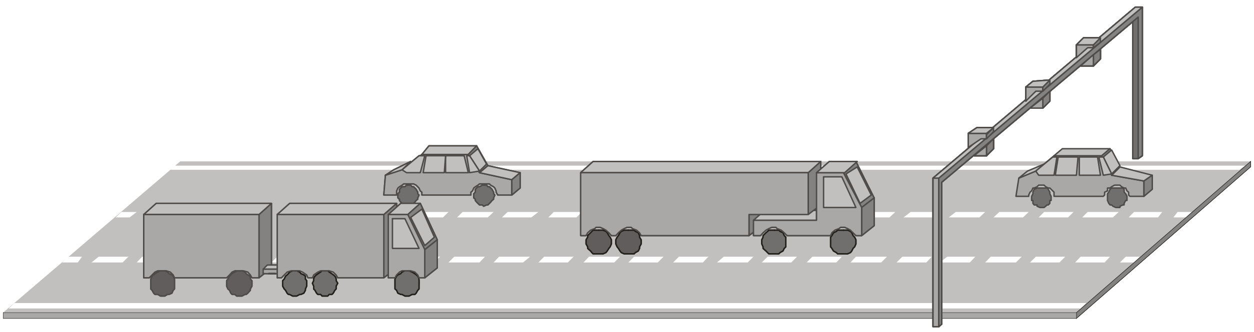

Figure C.1: CEN DSRC multilane free flow tolling station

C.4 Mobile enforcement

To verify the validity of a CEN DSRC OBU outside tolling stations, mobile enforcement vehicles carrying a CEN DSRC transceiver are used. They can readout CEN DSRC OBUs in parking lots, on the motorway at full driving speed, or where ever necessary to check a CEN DSRC OBU.

Annex D (informative): Ranking of coexistence options

D.0 Ranking criteria and summary

Following clauses show some different coexistence approaches that were discussed during generation of the present document. Some of them are "detect" methods, others are "avoid" methods (see DAA in clause 4.2.3.2). They were ranked according to these criteria:

- Complexity (Implementation effort)
- Availability (Time to market)
- Testability (Test effort)

Table D.1 shows a summary of this ranking. Low Complexity and high Availability as well as high Testability is preferable.

The arguments brought up during discussion and ranking details are summarized in clause D.1 to D.5

Table D.1: Ranking of discussed coexistence options

	Type	Complexity	Availability	Testability
CEN DSRC Detector	Detect	low	high	high
DCR method	Avoid	medium	high	high
ITS beacon	Detect	medium	medium	medium
LDM of all CEN DSRC stations	Detect	medium	low	low
CEN DSRC MAC synchronization with ITS	Avoid	high	low	high

D.1 CEN DSRC Detector

A detector that signals the existence of a DSRC RSU needs to be implemented by an extra hardware, or the detector can be an integral part of the ITS station and use the same antenna.

Pros:

- Existing CEN DSRC infrastructure unchanged
  - Protection of mobile and small DSRC installations
  - No additional infrastructure necessary - No reservations from highway operators expected
  - ITS mobile stations can be deployed immediately
- Hardware already available (see CVIS project [i.1])
  - Short time to market
- No changes of existing standards necessary

Cons:

- (Low) additional cost for each detector

D.2 DCR method

Depending on the transmission burst length, the used transmit power level and the spatial density of ITS-G5A/B stations the time delay between consecutive ITS-G5A/B transmissions is controlled.

Pros:

- Existing CEN DSRC infrastructure unchanged
  - Protection of mobile and small DSRC installations
  - No additional infrastructure necessary - No reservations from highway operators expected
  - ITS mobile stations can be deployed immediately
- No additional or changed RF hardware needed at the ITS stations

Cons:

- Reasonable software implementation effort
- Computational effort to process ITS station distances

D.3 ITS beacon

An ITS station is communicating the location of all CEN DSRC communication zones within its vicinity (similar to DENM of roadwork warning). An amendment to the DENM and LDM standards is necessary.

Pros:

- No additional RF hardware needed at the ITS stations

Cons:

- Needs upgrade of all CEN DSRC installations:
  - Needs approval of local authorities
  - Upgrade is supposed to be finalised before mobile ITS stations can be used, leads to possible delay of ITS deployment
- High additional costs for small DSRC stations (e.g. enforcement vehicles, access systems)

D.4 Dynamic geographic database of all CEN DSRC stations

A database containing the locations of all CEN DSRC stations is kept at the mobile ITS station. This includes only already existing CEN DSRC stations. New stations or mobile CEN DSRC stations need to announce themselves as described by clause D.3. Additionally, a regional update of the location information could be transmitted to the ITS stations.

Pros:

- No upgrade of existing CEN DSRC installations necessary
- No additional RF hardware needed at the ITS stations

Cons:

- Needs upgrade of all new CEN DSRC installations:
  - Needs approval of local authorities
  - Schedule of introducing ITS mobile stations and upgraded CEN DSRC stations is supposed to be aligned. This may lead to a delay of ITS deployment
- Comprehensive software including local maps is required:
  - Map material is supposed to be up to date and correct on deployment date, comprehensive tests are necessary
  - Map updates may be needed frequently (unsolved)

D.5 CEN DSRC MAC synchronization with fixed ITS stations

The duty cycles of CEN DSRC and ITS-G5A/B RSU could be aligned with each other, such that a joint operation of CEN DSRC and ITS-G5A/B is achieved. This design of duty cycles would most probably be done on the MAC layer. Additional research would be necessary to fully specify this option.

Pros:

- No power constraints for ITS stations in the communications zone of a CEN DSRC station

Cons:

- Needs additional hardware and software at RSUs for fixed ITS stations and CEN DSRC
  - E.g. joint transceiver hardware at the RSU

D.6 Transition for road tolling technology from CEN DSRC to ITS

Due to the European legislation this is not an option for the time being.

A transition for road tolling technology from CEN DSRC to ITS-G5A/B type technology would include the definition of a new set of standards. While this possibility seems to be in the far future, it could provide a possibility to use only a single infrastructure for tolling and safety.

Due to the long-term perspective of this possibility, we omit discussions to avoid any speculations.

History

Document history		
V1.1.1	October 2012	Publication