ECC Report 290

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

approved 25 January 2019'

0 EXECUTIVE SUMMARY

This Report contains an assessment whether the assumptions and conclusions in ECC Reports 101 [1] and 228 [13] are valid for LTE-V2X and Urban rail such as Communication Based Train Control (CBTC).

Requirements in EN 302 571 [14], related to coexistence with road tolling below 5815 MHz and Fixed Service above 5925 MHz, are based on ECC Report 228, which supersedes ECC Report 101 on these topics.

Co-frequency operation between Urban rail and FS in 5925-5935 MHz was not assessed in this Report as it was considered out of scope.

Table 1: Summary of the analysis performed in this Report

Service	Conclusions of ECC Reports 101 and 228		Conclusions on CBTC	Conclusions on LTE-V2X
	ITS as interferer	ITS as victim		
Radio amateur (5830-5850 MHz)	Compatibility is achieved	Compatibility is achieved	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid
FSS (5850-6725 MHz)	Compatibility is achieved	Compatibility is achieved in most cases taking into account the limited number of earth stations and real terrain shielding	ECC Report 101 remains valid	ECC Report 101 remains valid Note 1a
Radiolocation (5725-5850 MHz)	Compatibility is achieved with ITS unwanted power of -55 dBm/MHz, below 5850 MHz	Between 5855-5875 MHz ITS may suffer from interference	For CBTC as interferer, ECC Report 101 remains valid. For CBTC as victim, systems design margin should ensure compatibility above 5875 MHz	ECC Report 101 remains valid Note 1b
SRD (5725-5875 MHz)	Compatibility is achieved if ITS are operating above 5875 MHz. Mitigation techniques are required in the frequency range 5855-5875 MHz	Mitigation techniques are needed in the frequency range 5855-5875 MHz LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid Note 1b

FWA (5725-5875 MHz)	Compatibility is achieved if ITS are operating above 5875 MHz. Mitigation techniques are required in the frequency range 5855-5875 MHz	Mitigation techniques are needed in the frequency range 5855-5875 MHz. LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid Note 1b
RTTT, road tolling (5795-5815 MHz)	Compatibility is achieved if ITS unwanted emissions are limited below 5815 MHz: ▪ to -65 dBm/MHz without mitigation techniques; to -45 dBm/MHz taking into account the specifications given for ITS in ETSI EN 302 637-2 [12], EN 302 571 [14] and timing requirements according to ECC Report 228	Interference depends on the antenna beams alignment and is limited to the RTTT communication zone.	Compatibility is achieved above 5875 MHz. In case of proximity to the RTTT communication zone, adequate system design is required.	Compatibility is achieved under mode A*. Note 2a Under mode B*, compatibility could be achieved if timing requirements (Ton & Toff) and the aggregated spurious emissions do not exceed those of ITS in ECC Report 228 in the interference zone Note 2b
FS (5925-6425 MHz)	An unwanted emission limit of -40 dBm/MHz is able to avoid harmful interference (I/N=-20dB) to the Fixed Service or an unwanted emission limit of -30 dBm/MHz may be sufficient to avoid harmful interference to the Fixed Service with mitigation techniques	ITS within the band 5905-5925 MHz may suffer from interference	When tracks and FS beam are aligned, an unwanted emission limit of -40 dBm/MHz for CBTC should be applied FS will have limited impact on CBTC operating in the band 5905-5925 MHz taking into account the system margin	ECC Reports 101 and 228 remain valid Note 1b

* Modes A and B are specified in ETSI TS 102 792 [15] Table 5.3, which is part of the requirements defined in EN 302 571.

Note 1a: As per *considering n)* in ECC/DEC/(08)01 [24], duty cycle restrictions and specified frequency re-use conditions are beneficial for the compatibility with other systems and for the efficient use of the spectrum by cooperative ITS systems.

Note 1b: LTE-V2X systems have to comply with the technical conditions defined in ECC/DEC/(08)01 and with the requirements given in EN 302 571 related to unwanted emissions. With regard to the Fixed Service, requirements given in EN 302 571 are based on ECC Report 228.

Note 2a: On compatibility between LTE-V2X and road tolling in Mode A:

For LTE-V2X devices in coexistence mode A, an aggregation of spurious emissions from multiple vehicles is considered not to be an issue. In ECC Report 228 it was shown that for spurious emissions of -65 dBm/MHz per ITS device practically no interference zone exists. Therefore contributions of simultaneously transmitting devices from multiple vehicles are assumed to be negligible due to additional propagation losses in comparison with a single dominant device.

Note 2b: On compatibility between LTE-V2X and road tolling in mode B:

using repeated retransmissions of CAM within a road tolling RSU interference zone may result in lost road toll transactions;

if CAM retransmissions occur, the average air time of LTE-V2X transmissions within the road tolling RSU interference zone may be longer than the average air time requirements in ECC Report 228 derived for CAM. Compatibility can be achieved if LTE-V2X stations reduce their average air time within the road tolling RSU interference zone in accordance with the timing requirements in ECC Report 228. For a 1 second interval, the air time of the transmissions is the number of used sub-frames times the sub-frame length of 1 ms;

the requirements regarding air time issues (Ton & Toff) are not yet specified in the current versions of 3GPP LTE-V2X specifications.

It should be noted that LTE-V2X has been studied in this Report based on 3GPP TR 36.786. Furthermore, studies on Smart Tachograph are covered in ECC Report 291 [35] and thus not part of the present Report.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
3GPP	Third generation partnership project
AP	Access point
BLER	Block error rate
BPSK	Binary phase shift keying
CAM	Cooperative awareness message
CBTC	Communication based train control
CEN	European Committee for standardization
CEPT	European Conference of Postal and Telecommunications Administrations
C/I	Carrier to interferer ratio
C/(I+N)	Carrier to interference plus noise ratio
CSMA/CA	Carrier sensing multiple access/collision avoidance
C-V2X	Cellular V2X
DCC	Distributed congested control
DENM	Decentralised environmental notification message
DL	Downlink
DSRC	Dedicated Short-Range Communications
DSSS	Direct spread spectrum sequence
e.i.r.p.	Effective isotropically radiated power
ECC	Electronic Communications Committee
ERC	Electronic Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
EU	European Union
FSS	Fixed-Satellite Service
FS	Fixed Service
FWA	Fixed Wireless Access
IEEE	Institute of Electrical and Electronics Engineers
I/N	Interferer to noise ratio
ITS	Intelligent transport systems
ITU	International Telecommunication Union
MAC	Medium access control
MCL	Minimum coupling loss
LTE	Long term evolution

Abbreviation	Explanation
OBU	On board unit
OOB	Out of band
OFDM	Orthogonal Frequency-Division Multiplexing
PDU	Packet data unit
PER	Packet error rate
PSD	Power spectral density
PR	Protection ratio
PRB	Physical resource block
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase-shift keying
RAT	Radio access technology
RL	radiolocation
RLAN	Radio local area networks
RSU	Road side unit
RTTT	Road Transport and Traffic Telematics
Rx	Receiver
SDO	Standard development organisation
TB	Transport block
TDMA	Time division multiple access
TPC	Transmit power control
TTT	Transport and Traffic Telematics
Tx	Transmitter
UE	User equipment
UL	Uplink
VMS	Variable message signs
V2I	Vehicle to pedestrian
V2P	Vehicle to roadside infrastructure
V2V	Vehicle to vehicle
V2X	Vehicle to everything

1 INTRODUCTION

A Mandate has been issued by the European Commission to CEPT to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz [16].

As part of the study to be conducted by CEPT in response to the Mandate, ECC carried out the following actions.

Based on ECC Reports 101 and 228, the following items were verified by taking into account the need for reliable safety related operation in the 5875-5925 MHz band:

- For LTE-V2X, whether the assumptions and conclusions made in ECC Reports 101 and 228 are valid. This included considerations about TPC, duty cycling and overall transmission activity, coexistence with TTT road tolling;
- For Urban rail CBTC, whether the assumptions and conclusions made in ECC Reports 101 and 228 are valid;
- Whether the conclusions of ECC Report 101, stating that between 5875 MHz and 5925 MHz ITS will not suffer from excessive interference resulting from systems/services other than ITS, are also valid for Road ITS based on LTE-V2X (PC5 air interface), and for Urban Rail CBTC;
- Coexistence of Smart Tachograph as a new TTT application, different in its usage scenario from road tolling, with ITS.

ECC decided to expand the frequency range (5875-5935 MHz) to be considered for possible use by CBTC in their response to the mandate issued by the European Commission to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz.

This Report provides the results of the studies solely based on ECC Reports 101 and 228. As the scope of these ECC Reports only cover the frequency range 5875-5925 MHz, this Report does not provide any results for the potential use of CBTC in 5925-5935 MHz.

2 DEFINITIONS

Term	Definition
C-V2X	C-V2X (Cellular Vehicle-to-Everything) is a unified connectivity platform designed to offer vehicles low-latency vehicle to vehicle (V2V), vehicle to roadside infrastructure (V2I) and vehicle to pedestrian (V2P) communication to enable communication between different transportation modes. The current realization of C-V2X is LTE-V2X .
LTE-V2X	LTE-V2X is a technology specified to support the V2X communications in an ad hoc network to be used at the 5.9 GHz frequency band allocated in Europe basing on 3GPP specifications for LTE beginning from Release 14.
ITS-G5	ITS-G5 is a set of standards developed by the European SDOs using IEEE 802.11 based access layer technology supporting V2X communications in an ad hoc network to be used at the 5,9 GHz frequency band allocated in Europe
Urban rail	An Urban rail System is a public transport system permanently guided at least by one rail, intended for the operation of local, urban and suburban passenger services with self-propelled vehicles. Urban rail systems include metros, trams and other light rail systems in networks that are functionally separate from the rest of the rail system.
CBTC	CBTC is the system that controls some urban rail trains. It includes radio communications between track and trains. Reference to CBTC in this Report is intended as Urban Rail using CBTC.

3 EXAMINATION OF ECC REPORT 101

3.1 TECHNICAL CHARACTERISTICS OF ITS SYSTEMS CONSIDERED IN ECC REPORT 101

Table 2: Systems parameters (not exhaustive) used in ECC Report 101 [1]

Parameter	Value	Comments
Frequency stability	1 ppm	This figure takes account of the frequency tolerance allowed by IEEE 802.11a [17], together with the expected Doppler variation from a vehicle closing speed of 400 km/h
Maximum radiated power (e.i.r.p.)	Equipment classes: A 10 dBm B 20 dBm C 33 dBm	Transmitter power control (TPC) with a 30 dB range
Antenna beam shape/gain	RSU: 10 dBi OBU: 5 or 8 dBi	See section 2.5 in ECC Report 101
Polarisation	TBD	Circular and linear polarisations each have certain benefits. Some degree of rejection of emissions from oppositely travelling vehicles may be required
Modulation scheme	BPSK QPSK 16QAM 64QAM	This is the standard set within IEEE 802.11a [17] and p [18]
Data rates	3, 4.5, 6, 9, 12, 18, 24 and 27 Mbit/s	This is the standard set within IEEE 802.11a [17], j [19]and p [18]. As an option two channels may be combined to produce double data rates (up to 54 Mbit/s). Default data rate is 6 Mbit/s
Channel bandwidth	10 MHz, option 20 MHz	This is the standard set within IEEE 802.11a [17], j [19] and p [18]
Communication mode	Half-duplex, broadcast	Half-duplex and broadcast are believed to be adequate for the applications considered to date
Receiver sensitivity	-92 dBm/MHz	Based on a -82 dBm for a bandwidth of 10 MHz
Protection criterion	C/I=6 dB	For a classical BPSK signal

Communication channels will be open for the applications within the respective usage category (either road safety related or not, i.e. used for traffic management).

The required power levels (e.i.r.p.) range from 3 dBm to 33 dBm to achieve communication distances of up to 1000 m.

3.2 ASSESSMENT OF ECC REPORT 101 FOR LTE-V2X

3.2.1 System parameters for LTE V2X

Table 3: Technical parameters of LTE-V2X

Parameter	Value	Comments
Maximum radiated power (e.i.r.p.)	33 dBm e.i.r.p. with 6 dBi antenna gain and 23 dBm/MHz max power spectral density (PSD) . 14 PRB (Physical Resource Block): 27 dBm e.i.r.p. 20 PRB: 28.5 dBm e.i.r.p.	According to 3GPP TR 36.786 V14.0.0 (2017-03) [11] Table 6.2.2.2-1: Simulation assumptions: V2X communications
Antenna beam shape/gain	0 dBi or 6 dBi	According to 3GPP TR 36.786 V14.0.0 (2017-03) Table 6.2.2.2-1: Simulation assumptions: V2X communications
Polarisation	Omni Antenna or Recommendation ITU-R F.1336	According to 3GPP TR 36.786 V14.0.0 (2017-03) Note: For coexistence scenarios such as CEN DSRC vs LTE-V2X studied in 3GPP, omni antennas are assumed. Nevertheless, the antenna pattern assumed in ECC Report 101 based on an Recommendation ITU-R F.1336 [20] model could also be used/supported
Modulation and Coding Scheme	QPSK, target rate 1/2 QPSK, target rate 3/4 16QAM, target rate 1/2 16QAM, target rate 3/4	According to 3GPP TR 36.786 V14.0.0 (2017-03) Section 5.3.1.1
Data rates	56.6 kbps to 15.1 Mbps	Calculated based on various modulation and coding scheme
Channel bandwidth	10 MHz	
Communication mode	Half-duplex, broadcast	Half-duplex and broadcast are believed to be adequate for most applications considered to date
Receiver noise power	-91 dBm	According to 3GPP TR 36.786 V14.0.0 (2017-03) Section 5.3.2 Where noise floor is -91 dBm coming from thermal noise of -104 dBm and noise figure of 13 dB
Receiver sensitivity		According to 3GPP TR 36.786 V14.0.0 (2017-03) Section 5.3.1.1
TPC	TPC with range > 30 dB (The minimum output power is down to -40 dBm)	According to 3GPP TS 36.101 V14.7.0 (2018-03) [2] Section 6.3.2G defines minimum output power to -40 dBm

Parameter	Value	Comments
Duty Cycle	2% based on the assumptions given in Note 1	1% based on the assumptions given in Note 2 Peak rate of 2% is assumed in case of retransmissions
Message length	190 Bytes / 300 Bytes	According to 3GPP TR 36.786 V14.0.0 (2017-03) Table 6.2.2.2-1: Simulation assumptions: V2X communications
Transmitter unwanted emissions		According to 3GPP TS 36.101 V14.7.0 (2018-03) section 6.6.2.2.4
Note 1: In ECC Report 101, duty cycle is defined as "possibility for active ITS devices to transmit messages simultaneously". It is assumed that one vehicle is transmitting at a time within a given communication range (Section 3.2.1.1.3 in ECC Report 101), while in LTE-V2X one or several transmission may occur simultaneously. Information on ITS message generation was not available at the time of writing ECC Report 101. Note 2: For duty cycle calculation for LTE-V2X it is considered: i) the fact that multiple vehicles may transmit simultaneously, ii) the availability of information on CAM message generation. The results are based on assumptions following the given references. CAMs are the dominant factor for duty cycle 1 CAM transmission every 100ms (10 Hz maximum as of ETSI EN 302 637-2 [9]) Each message has 1ms duration (190-300 Bytes as of 3GPP TR 36.786 [4]) No repetition of messages has been considered		

Table 4: Comparison of regulatory sensitivity and LTE V2V sensitivity (TR 36.786 V14.0.0 (2017-03) Section 5.3.1.1)

Modulation	Coding rate	Sensitivity requirement in EN 302 571 [14] (dBm)	Sensitivity for V2V from (dBm)	Margin (dB)
QPSK	1/2	-82	-90.01	8.01
QPSK	3/4	-80	-86.50	6.5
16-QAM	½	-77	-83.85	6.85
16-QAM	¾	-73	-80.30	7.3

Table 5: Spectrum Emission limit (3GPP TS 36.101 V14.7.0 (2018-03) Section 6.6.2.2.4)

Spectrum emission limit (dBm) / Channel bandwidth		
ΔfOOB (MHz)	**For 10 MHz channel bandwidth**	**Measurement bandwidth**
± 0-0.5	$-13 - 12\left(\lvert\Delta fOOB\rvert / MHz\right)$	100 kHz
± 0.5-5	$-19 - \frac{16}{9}\left(\lvert\Delta fOOB\rvert / MHz - 0.5\right)$	100 kHz
± 5-10	$-27 - 2\left(\lvert\Delta fOOB\rvert / MHz - 5.0\right)$	100 kHz

3.2.2 Co-existence Scenarios

In ECC Report 101 [1] each of the following 7 services/systems was studied within the frequency range illustrated in Figure 1. Note that allocation of these other services/systems is not limited to those covered in the study, e.g. FSS has primary allocation in Region 1 in the bands 5725-5875 MHz and 5925-6725 MHz, aside from the covered 5875-5925 MHz.

1 Fixed Satellite Service;

2 Radiolocation service;

3 Non-Specific Short-Range Devices (SRD);

4 Fixed Wireless Access devices;

5 Fixed Service (above 5925 MHz;)

6 Radio amateur (below 5850 MHz);

7 RTTT (below 5815 MHz).

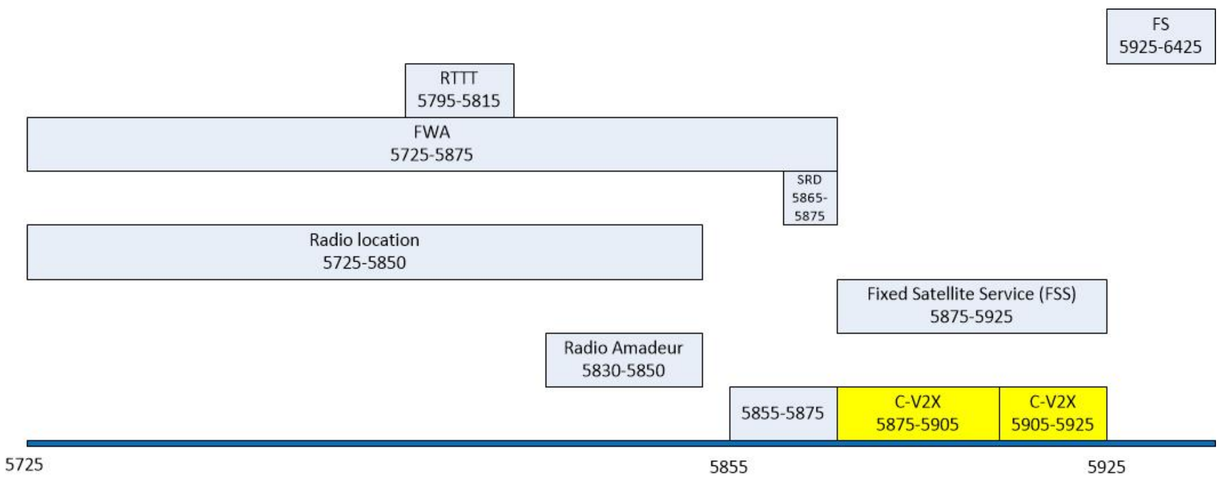


Figure 1: In-band and adjacent band systems to LTE-V2X and the ITS system used in ECC Report 101 (LTE-V2X is added to the figure only for information purposes)

As illustrated in Figure 1, LTE-V2X will share the same band as FSS from 5875 to5925 MHz and this results in an in-band coexistence scenario, while for all the other services, only adjacent band coexistence scenarios need to be studied. In the next section, these two types of co-existence scenarios will be discussed by comparing different sets of parameters.

3.2.3 Compatibility between LTE-V2X and FSS

This section evaluates the impact of LTE-V2X on FSS system. In ECC Report 101, the interference from the ITS into the satellite receivers is treated as an increase in thermal noise in the wanted FSS network earth-to-space receiver. The thermal noise increase is further converted into a noise temperature increase and the tolerable percentage of the noise temperature increase is set to be less than 6% or 1%.

The total interference which contributes into the noise temperature increase is the aggregated e.i.r.p. of the all simultaneously transmitting ITS devices in the direction towards the satellite receiver beam in 10 MHz channel.

In section 3.2.3.1, all parameters which play a role in the total interference calculation are compared.

3.2.3.1 IEEE 802.11p based ITS and LTE-V2X system comparison

From ITS system side, both ITS parameters in ECC Report 101 and LTE-V2X system parameters are listed for comparison. Maximum radiated power of both system is of 33 dBm/10 MHz and the transmit antenna patterns are assumed to be the same as well.

Table 6: Technical Characteristics Comparison for ITS in ECC Reports 101 and 228 with LTE-V2X Release 14

System Parameters and Assumptions		
	ITS in ECC Reports 101 and 228	**LTE-V2X (3GPP Release 14)**
Maximum radiated power (e.i.r.p.)	33 dBm/10 MHz or 23 dBm/MHz	33 dBm/10 MHz or 23 dBm/MHz [3]
Channel bandwidth	10 MHz, optional 20 MHz	10 MHz, optional 20MHz
Transmit Power Control (TPC)	TPC with 30 dB range	TPC with range > 30 dB (The minimum output power is down to -40 dBm) [2]
Antenna Pattern	Recommendation ITU-R F.1336	Omni or Recommendation ITU-R F.1336 antenna
Duty Cycle	2% based on the assumptions given in Note 1	1% based on the assumptions given in Note 2 Peak rate of 2% is assumed in case of retransmissions
Additional Mitigation Techniques	Coexistence CEN DRSC (RTTT): ETSI TS 102 792	Specific TPC inside protection zone based on interference mitigation techniques from ETSI TS 102 792

Note 1: In ECC Report 101, duty cycle is defined as “possibility for active ITS devices to transmit messages simultaneously”. It is assumed that one vehicle is transmitting at a time within a given communication range (Section 3.2.1.1.3 in ECC Report 101), while in LTE-V2X one or several transmission may occur simultaneously. Information on ITS message generation was not available at the time of writing ECC Report 101.

Note 2: For duty cycle calculation for LTE-V2Xit is considered: i) the fact that multiple vehicles may transmit simultaneously, ii) the availability of information on CAM message generation. The results are based on assumptions following the given references.
CAMs are the dominant factor for duty cycle
1 CAM transmission every 100ms (10 Hz maximum as of ETSI EN 302 637-2 [9])
Each message has 1ms duration (190-300 Bytes as of 3GPP TR 36.786 [4])
No repetition of messages has been considered.

A further refinement of the estimation can be done taking into account vehicle density and vehicle velocity leading to a reduced CAM frequency, which may lead to lower duty cycle than 1%. See ANNEX 1: for further details on CAM generation.

It should be noted that in 3GPP, no ITS antenna pattern is specified. However, it is realistic to assume the antenna pattern used for ITS device in ECC Reports 101 and 228 are applicable to LTE-V2X ITS devices.

3.2.3.2 FSS system parameters and deployment of ITS devices given in ECC Report 101

As mentioned above, the total interference which contributes into the noise temperature increase is the aggregated e.i.r.p. of the all simultaneously transmitting ITS devices in the direction towards the satellite receiver beam in 10 MHz channel.

For simplicity, in ECC Report 101, the e.i.r.p. of each ITS device in the direction of satellite was calculated by deriving the transmit power from the on-axis e.i.r.p. and then adding the gain (in dBi) in the elevation plane for the appropriate elevation angle from the country being considered by assuming that propagation losses and discrimination angle would be the same for all locations in a same country.

In Table 7, the deployment/spreading of ITS devices in each of the main cities of the EU15 countries is described. It determines the ITS antenna discrimination in the elevation plane in the direction of the chosen satellite. The calculated elevation angles to the satellites using the latitude and longitude of a representative city in each country is applied equally to both ITS parameters in ECC Report 101 and LTE-V2X.

For reference purposes, the FSS system parameters are also provided in Table 8

Table 7: Latitude/Longitude of representative cities in European countries & Elevation Angle in degrees to the satellites

European Countries (Cities)	Latitude (°)	Longitude (°)	A @ 5W	B @ 14W	C @ 31.5W	D @ 3E	E @ 18W	F @ 53E	G @ 59.5E	H @ 66 E	I @ 359E
Austria (Vienna)	48.2	16.4	30.9	27.4	18.3	33.2	25.5	24.4	21.0	17.3	32.2
Belarus (Minsk)	53.9	27.6	21.7	17.9	**9.1**	24.5	16.0	24.2	22.0	19.3	23.2
Belgium (Brussels)	50.8	4.4	31.1	29.3	22.8	31.8	28.1	16.3	12.7	**8.9**	31.6
Bulgaria (Sofia)	42.7	23.3	33.1	28.1	16.7	36.6	25.7	32.4	28.8	24.8	34.9
Czech Republic (Prague)	50.1	14.4	29.7	26.6	18.3	31.6	24.9	22.1	18.7	15.1	30.8
Denmark (Copenhagen)	55.7	12.6	24.6	22.2	15.5	25.9	20.9	17.1	14.2	11.1	25.4
Estonia (Tallinn)	59.5	24.8	17.9	15.0	**7.8**	20.0	13.5	18.4	16.4	14.0	19.0
Finland (Helsinki)	60.0	25.0	17.4	14.5	**7.4**	19.4	13.0	17.9	16.0	13.7	18.5
France (Paris)	48.5	2.4	33.8	32.1	25.5	34.3	30.9	16.5	12.6	**8.5**	34.2
Germany (Frankfurt)	50.1	8.7	31.1	28.7	21.2	32.3	27.2	19.1	15.5	11.8	31.8
Greece (Athens)	38.0	23.7	36.8	31.1	18.5	40.9	28.4	36.5	32.4	28.0	39.0
Hungary (Budapest)	47.5	19.1	30.6	26.7	17.1	33.2	24.7	26.3	23.0	19.3	32.0
Ireland (Dublin)	53.0	-6.3	29.4	29.0	25.1	28.8	28.4	**9.3**	**5.6**	**1.9**	29.2
Italy (Rome)	41.9	12.1	38.6	34.8	24.8	40.7	32.8	26.4	22.2	17.7	39.8
Latvia (Riga)	56.9	24.1	20.3	17.1	**9.4**	22.6	15.5	20.4	18.2	15.6	21.5
Lithuania (Vilnius)	54.7	25.3	21.9	18.4	**9.9**	24.5	16.6	22.8	20.4	17.7	23.3
Luxembourg	49.6	6.1	32.1	30.0	22.9	33.1	28.6	18.0	14.3	10.4	32.7
Netherlands (Amsterdam)	52.4	4.9	29.4	27.6	21.3	30.1	26.4	15.7	12.2	**8.6**	29.9
Norway (Oslo)	59.9	10.8	20.7	18.9	13.3	21.7	17.8	13.3	10.8	**8.0**	21.3
Poland (Warsaw)	52.3	21.0	25.5	22.0	13.4	27.9	20.3	23.3	20.5	17.4	26.8
Portugal (Lisbon)	38.7	-9.1	44.9	44.9	39.5	43.4	44.2	12.9	**7.9**	**2.9**	44.4
Romania (Bucharest)	44.4	26.1	30.2	25.3	14.1	33.9	22.8	32.2	29.0	25.4	32.1
Russia (Moskow)	55.0	37.6	16.6	12.4	**3.1**	20.0	10.3	25.8	24.2	22.3	18.4
Slovakia (Bratislava)	48.2	17.1	30.7	27.1	17.9	33.0	25.2	24.8	21.4	17.7	32.0
Spain (Madrid)	40.3	-3.4	43.4	42.2	35.2	43.0	41.1	16.7	11.8	**7.0**	43.4
Sweden (Stockholm)	59.3	18.1	19.8	17.3	10.8	21.4	16.0	16.4	14.1	11.5	20.7
Switzerland (Zurich)	47.4	8.5	34.0	31.3	23.2	35.3	29.7	20.8	16.9	12.9	34.8
Turkey (Ankara)	39.8	31.9	30.4	24.4	11.6	35.2	21.6	39.0	35.9	32.1	32.9
UK (London)	51.5	0.0	30.9	29.6	24.1	31.0	28.7	13.6	**9.9**	**6.0**	31.1
Ukraine (Kiev)	50.4	30.6	23.2	18.8	**8.8**	26.6	16.6	28.4	26.1	23.3	25.0
Max el angle (deg.)			44.9	44.9	39.5	43.4	44.2	39.0	35.9	32.1	44.4
Min el angle (deg.)			16.6	12.4	3.1	19.4	10.3	9.3	5.6	1.9	18.4

Table 8: Derivation of acceptable aggregate e.i.r.p. from interferers in the satellite beam

Satellite	Satellite orbital position	Receiver Gain, Gsat (dBi)	Satellite Receiving System Noise Temperature Tsat (K)	Aggregate e.i.r.p. dB(W Hz-1) from ITS for ΔTsat/Tsat=1%	Satellite Name	Administration	Beam
A	5° West	34	773	-54.1	TELECOM-2B	F	MET
B	14° West	26.5	1200	-44.7	EXPRESS-2	RUS	ZER
C	31.5° West	32.8	700	-53.3	INTELSAT8	USA	9Z3
D	3° East	34	773	-54.1	TELECOM-2C	F	MET
E	18°	32.8	700	-53.3	INTELSAT8	USA	9Z3

Satellite	Satellite orbital position	Receiver Gain, Gsat (dBi)	Satellite Receiving System Noise Temperature Tsat (K)	Aggregate e.i.r.p. dB(W Hz-1) from ITS for ΔTsat/Tsat=1%	Satellite Name	Administration	Beam
	West						
F	53° East	26.5	1200	-44.7	EXPRESS-5	RUS	ZER
G	59.5° East	34	1200	-52.2	No longer existing		
H	66° East	34.7	700	-55.2	INTELSAT9	USA	9Z1
I	359° East	32.8	700	-53.3	INTELSAT8	USA	9Z3

3.2.3.4 Simulation results comparison

Upon the above parameter comparisons, the allowed number of active ITS devices transmitting simultaneously obtained in ECC Report 101, for which the aggregated interference cause less than 1% thermal temperature increase as shown in the second last column in Table 9, is valid for LTE-V2X. It indicates the allowed number of active LTE-V2X devices which transmit simultaneously is the same as that for ITS in ECC Report 101 without having to recalculate the aggregated interference from each LTE-V2X ITS device into satellite receiver beam given the ITS maximum transmitter radiated power, antenna pattern, path loss model, ITS distribution in Europe as well as the satellite system parameters for both ITS systems are the same.

Table 9: Maximum number of ITS devices (Class C) in Europe to meet ΔTsat/Tsat noise temperature thresholds for Satellites A to I in ECC Report 101

	Max # of ITS in satellite beam (millions) per 10 MHz channel		Max # of ACTIVE ITS in satellite beam (millions) per 10 MHz channel		Max # of ACTIVE ITS in satellite beam (millions) per 10 MHz channel simultaneously in use	
	e.i.r.p. = 33 dBm (OBU G_{max}=5 dBi) dc = 2% (Equation (8) [1])		e.i.r.p. = 33 dBm (OBU G_{max}=5 dBi) dc = 2% (Equation (8) [1])		e.i.r.p. = 33 dBm (OBU G_{max}=5 dBi) dc = 2% (Equation (8) [1])	
Satellite	$\frac{\Delta T_{sat}}{T_{sat}}=1\%$	$\frac{\Delta T_{sat}}{T_{sat}}=6\%$	$\frac{\Delta T_{sat}}{T_{sat}}=1\%$	$\frac{\Delta T_{sat}}{T_{sat}}=6\%$	$\frac{\Delta T_{sat}}{T_{sat}}=1\%$	$\frac{\Delta T_{sat}}{T_{sat}}=6\%$
A	>300	>300	>30	>30	>0.6	>0.6
B	>300	>300	>30	>30	>0.6	>0.6
C	>300	>300	>30	>30	>0.6	>0.6
D	195	>300	19.3	>30	0.4	>0.6
E	>300	>300	>30	>30	>0.6	>0.6
F	>300	>300	>30	>30	>0.6	>0.6

	Max # of ITS in satellite beam (millions) per 10 MHz channel		Max # of ACTIVE ITS in satellite beam (millions) per 10 MHz channel		Max # of ACTIVE ITS in satellite beam (millions) per 10 MHz channel simultaneously in use	
G	NA	NA	NA	NA	NA	NA
H	>300	>300	>30	>30	>0.6	>0.6
I	128	>300	12.6	>30	0.26	>0.6

Thus, as illustrated in Table 9 the allowed active LTE-V2X devices which transmit simultaneously is also of 0.6 million.

The number of active equipment which transmit simultaneously are defined as

$$N_{active,sim} = N * R_p * Dc * AF$$

Where:

- N is the number of all vehicles in use in Europe;
- R_p is the penetration rate of ITS;
- Dc is the maximum average duty cycle;
- AF is the activity factor which accounts for the active hours in use per day for an ITS device.

Following the same definition as well as using the same values of $N, R_{p,}AF$, the active LTE-V2X devices which transmit simultaneously are:

$N_{active,sim} = N * R_p * Dc * AF$=215*50%*1%*8%=0.09 million

Where:

- N =215 million (in Table 7 in ECC Report 101);
- AF= 8% (in 3.2.1.1.1 in ECC Report 101 and it represents 2 hours in use per day for a vehicle);
- R_p = 50%
- Dc = 1.0 %

The forecast of 0.09 million LTE-V2X devices transmitting simultaneously in the EU countries is much smaller than the allowed number of 0.6 million, which leaves a significantly large margin for protection of FSS systems.

3.2.4 Compatibility between LTE-V2X and services and applications in the adjacent bands

This section discusses the impact of LTE-V2X system on all the 6 services and applications in adjacent bands:

1. Radiolocation service;
2. Non-Specific Short-Range Devices (SRD);
3. Fixed Wireless Access devices;
4. Fixed Service (above 5925 MHz);
5. Radio amateur (below 5850 MHz);
6. RTTT (below 5815 MHz).

In fact, for all the 6 adjacent coexisting scenarios, the performance criteria as well as the receiver characters of victim systems vary from one scenario to another. Nevertheless, from the transmit side, only maximum radiated power, antenna pattern and unwanted emission mask play a role in the interference calculations. As analysed in the previous section for in-band coexistence, both ITS in ECC Report 101 and LTE-V2X ITS have the same maximum radiated transmit power and antenna pattern.

Table 10: Unwanted Emission Mask of LTE-V2X system

Spectrum emission limit (dBm) / Channel bandwidth		
ΔfOOB (MHz)	**For 10 MHz channel bandwidth**	**Measurement bandwidth**
± 0-0.5	$-13 - 12\left(\text{\|ΔfOOB\|}/_{MHz}\right)$	100 kHz
± 0.5-5	$-19 - \frac{16}{9}\left(\text{\|ΔfOOB\|}/_{MHz} - 0.5\right)$	100 kHz
± 5-10	$-27 - 2\left(\text{\|ΔfOOB\|}/_{MHz} - 5.0\right)$	100 kHz

Table 11: Transmitter spectrum mask for 10 MHz channel bandwidth in ETSI EN 302 571 [14]

Frequency offset to centre carrier frequency	± 4,5 MHz offset	± 5,0 MHz offset	± 5,5 MHz offset	± 10 MHz offset	± 15 MHz offset
Relative power reduction (dBc)	0	-26	-32	-40	-50

Table 12: Transmitter spectrum mask for 10 MHz channel bandwidth in ECC Report 101 [1]

	e.i.r.p. (dBm/MHz)	± 4.5 MHz offset (dBr)	± 5.0 MHz offset (dBr)	± 5.5 MHz Offset (dBr)	± 10 MHz offset (dBr)	± 25 MHz offset (dBr)	>± 25 MHz offset (dBr)
Class A	0	0	-10	-20	-28	-40	-60
Class B	10	0	-16	-20	-28	-40	-60
Class C	23	0	-26	-32	-40	-50	-70

Requirements given in EN 302 571 are based on ECC Report 228 and corresponding regulations. LTE-V2X systems deployed in Europe have to comply with EN 302 571, and thus, they are in line with the ECC Report 228 in relation to the unwanted emissions in the adjacent channel and in the spurious domain.

3.2.5 Conclusions

The evaluation and comparison between ITS in ECC Report 101 and LTE-V2X system demonstrated that using the parameters defined in the ECC Report 101, the LTE-V2X system does not cause more interference to the FSS receiver in the same frequency range of 5875-5925 MHz than the ITS technology considered in ECC Report 101 under worst case simulation assumptions such as 1% duty cycle without considering DCC which will further reduce the duty cycle. The interference from FSS to LTE-V2X was not assessed.

Regarding the systems in the adjacent bands, ECC Report 228 [13] replaced ECC Report 101 [1] and requirements given in EN 302 571 [14] are based on ECC Report 228. LTE-V2X systems deployed in Europe have to comply with EN 302 571, and thus, they are in line with the ECC Report 228 with respect to the unwanted emissions in the adjacent channel and in the spurious domain.

Thus the results and conclusions made for compatibility studies for ITS with other systems in the adjacent bands and for ITS interfering into FSS in the same frequency band in ECC Report 101 are valid for LTE-V2X systems.

It should be noted that the assessment in this Report is made purely to compare ITS in ECC Report 101 and LTE-V2X system, thus coexistence studies between these services and other services existing in the band or adjacent bands were beyond the scope of the work conducted.

3.3 ASSESSMENT OF ECC REPORT 101 FOR URBAN RAIL CBTC

3.3.1 Background

There are currently two families of Urban Rail CBTC systems using the 5.9 GHz band, using a communication system based either;

- On a DSSS proprietary modulation technique, and using TDMA as method to manage the access to the radio channel, or
- On OFDM modulation as described in IEEE 802.11 standard, using CSMA/CA as method to manage the access to the radio channel.

Technical parameters for these 2 families are given in 3.3.2.

3.3.2 Technical description of the existing CBTC communication systems

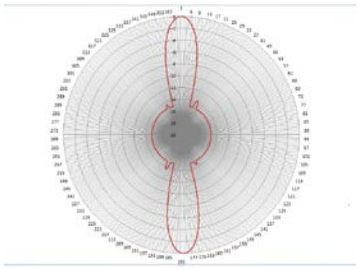
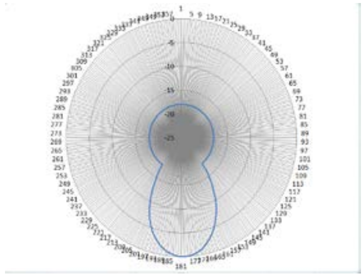
3.3.2.1 Technical characteristics of CBTC communication system using DSSS/TDMA communication system

The first CBTC communication systems are based on Direct Spread Spectrum Sequence (DSSS) technique, with long spreading sequences, and use a time division multiple access (TDMA) cycle to share access to the channel between wayside transmission and trains transmission, in large cells (typically 2 inter-station so up to 3 kilometres).

Main characteristics regarding sharing aspects are a very good resistance to interference, a low transmission rate and specific organisation of the transmission of the application data in common messages transmitted by wayside devices for all trains of a cell, resulting in a large duty cycle, especially for wayside transmitters.

Table 13: Technical characteristics of CBTC TDMA/DSSS based system

	CBTC Wayside Base Station	CBTC Train Unit
Frequency	5907.5 MHz / 5912.5 MHz / 5917.5 MHz / 5922.5 MHz / 5927.5 MHz / 5932.5 MHz	5907.5 MHz / 5912.5 MHz / 5917.5 MHz / 5922.5 MHz/ 5927.5 MHz / 5932.5 MHz
Bandwidth	5 MHz	5 MHz
e.i.r.p.	30 dBm	30 dBm
Antenna gain (including feeder and splitter and shield losses) Note 1	9 dBi (18 dBi -3 dB for the splitter- 6 dB for feeder)	10 dBi (14 dBi -4 dB for losses)

	CBTC Wayside Base Station	CBTC Train Unit
Typical Antenna pattern Note 1	 Note: combined diagram for an antenna done with 2 back to back antennas and a splitter	
Protection ratio (PR) (Protection Ratio is the minimum C/N+I criterion ensuring BLER< 10^{-2})	-3 dB	-3 dB
Sensitivity	=10log10(kTB) + F + PR : -105dBm	=10log10(kTB) + F + PR: -105dBm
Adjacent channel selectivity	50 dB	50 dB
Note 1: Based on information from industry as per existing deployments		

Time:

- Duty cycle for wayside transmitters (all transmitters of the same cell transmitting in a synchronised way):
  - 50 ms of transmission – then 68 ms off, resulting in a duty cycle of 42.4%.
- Duty cycle for a train:
  - 6.5 ms of transmission – then 111.5 ms off, resulting in a duty cycle of 5.5 %

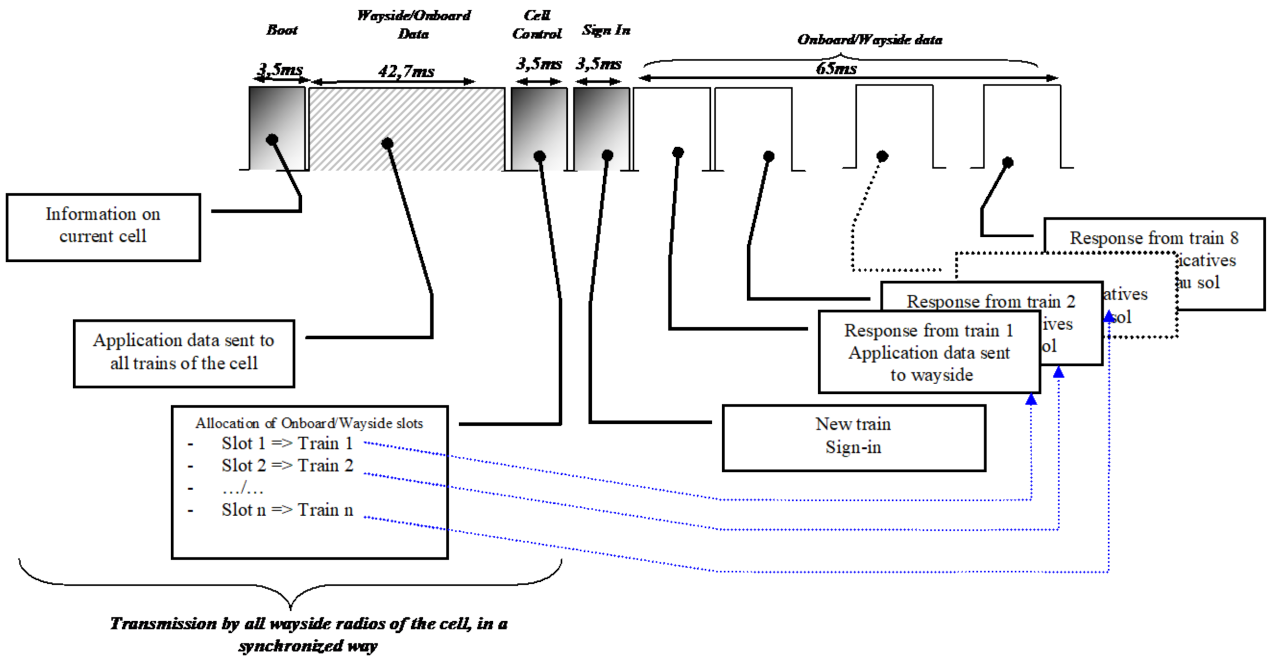


Figure 2: Duty cycle characteristics of CBTC communication system using DSSS/TDMA

Maximum packet loss: 1%

No listen before talk mechanism is in place

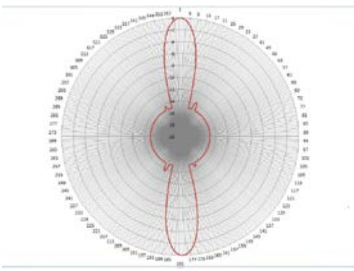
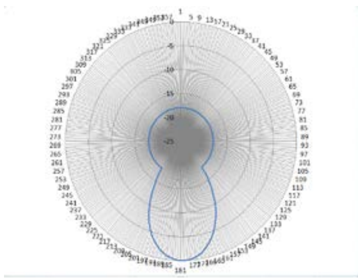
Radio planning rules:

- In order to guarantee a link between train and wayside in more than 99% of the location, a margin of 15 dB is used to take into account worst cases of fading.

3.3.2.2 Technical characteristics of IEEE 802.11 based CBTC communication system

The second CBTC communication system is close to IEEE 802.11a, using OFDM as modulation and CSMA/CA as spectrum access technique. In order to balance the CSMA/CA drawbacks (in particular collisions due to hidden node effect), a low channel load is ensured, and redundancy with several multiple repetitions of each message are considered to ensure the required level of transmission reliability. With that system, application payload data is sent as unicast messages to/from each train.

Table 14: Technical characteristics of IEEE 802.11 based CBTC system

	CBTC Wayside Base Station	CBTC Train Uunit
Frequency	5910 MHz, 5915 MHz, 5920 MHz, 5925 MHz, 5930 MH	5910 MHz, 5915 MHz, 5920 MHz, 5925 MHz, 5930 MHz
Bandwidth	5 MHz	5 MHz
Maximum e.i.r.p. for a channel of 5 MHz	30 dBm	30 dBm
Typical Antenna gain including feeder and splitter and shield losses (Based on information from industry as per existing deployments)	9 dBi (18 dBi -3 dB for the splitter-6 dB for feeder)	10 dBi (14 dBi -4 dB for losses)
Typical Antenna pattern (Based on information from industry as per existing deployments)	 Combined diagram for an antenna done with 2 back to back antennas and a splitter	
Protection ratio (PR) (Protection Ratio is the minimum C/N+I criterion ensuring PER < 10^{-2})	9 dB	9 dB
Radio Transmission speed 1.5 Mbits/s. Modulation BPSK and Coding rate 1/2 Sensitivity (for BER 10^{-5})	< -88 dBm	< -88 dBm
Radio Transmission speed 3	< -85 dBm	< -85 dBm

	CBTC Wayside Base Station	CBTC Train Uunit
Mbits/s Modulation QPSK coding rate ½ (for BER 10^{-5}) Minimum Sensitivity (QPSK modulation)		
Minimum Adjacent channel selectivity	For 1.5 Mbits/s: > 29 dB For 3 Mbits/s: > 27 dB	For 1.5 Mbits/s: > 28 dB For 3 Mbits/s: > 27 dB
Note: UL and DL are unbalanced. Operating mode is TDD		

Time:

- CSMA/CA and Automatic Repeat Request at MAC layer level are used
- Duty cycle for wayside transmitters:
  - Between 6% and 60% for a wayside access point (worst case when 6 trains are associated with a wayside access point).
- Duty cycle for a train:
  - Average value between 6% and 12%;
  - In particular circumstances (train communication with three wayside safety related zone controllers and entering a station with platform screen doors) the throughput of a train can reach 25% of duty cycle temporarily.

Maximum packet loss: 1%

Maximum latency: 100ms

Radio planning rules:

- In order to guarantee a reliable link between train and wayside in more than 99% of the location, a margin of 15 dB is used to take into account worst cases of fading.

3.3.3 Assessment of ECC Report 101 for urban rail CBTC as an interferer

The examination of the ECC Report 101 shows that impact of ITS transmissions on other services are calculated using the following parameters of ITS transmitters:

- Tx e.i.r.p. per MHz;
- Transmitter spectrum mask;
- Antenna gain.

The characteristics in terms of timing (duty cycle) are used only for the specific case of impact on FSS.

The use of mitigation techniques is considered to protect SRD and FWA only from ITS operating below 5975 MHz, which is not a case to be considered for Urban rail CBTC in this study.

Compared to the parameters, the Urban Rail CBTC transmission systems:

- Fulfil the Tx e.i.r.p. per MHz limits given by EN 302 571, but use channels of 5 MHz instead of 10 MHz;
- Fulfil the same transmitter mask (for “IEEE 802.11” family) or more stringent ones (for DSSS family) outside of the ITS band;
- Use much more directive antenna than road ITS stations in the horizontal plane (at least 18 dBi instead of 8 dBi), and a similar directivity in the vertical plane;
- Can use spectrum above the band studied in ECC Report 101.

Therefore, for all studies using only the transmission parameter:

- In the direction of the beam of the Urban rail CBTC antenna, the transmitted Tx e.i.r.p. per MHz will be the same as the one of the road ITS, so the e.i.r.p. level received by the “victim” receiver at a given distance will be similar for both Urban rail CBTC and for the ITS system used in ECC Report 101 (or 3 dB less for Urban Rail if the receiver band is larger than 5 MHz);
- outside the beam, the received level from Urban Rail CBTC will be much lower than the one received from the ITS system used in ECC Report 101;
- and due to the directive antenna, the area included in the direction of the Urban Rail CBTC beam is also narrower than the one of the road ITS;
- Co-frequency use with FS above 5925 MHz has not been studied.

Regarding the specific case of FSS, where the duty cycle parameter is also taken into account:

- The result is given in Table 9 of the ECC Report 101, which evaluates to 0.6 million the maximum number of road ITS stations of class C transmitting at the same time in the footprint of a satellite to meet its deltaT/T noise temperature threshold;
- Even if the worst case of CBTC transmissions 100% of the time is considered, the number of CBTC transmitters in open air area in Europe will be negligible compared to the maximum number of 0.6 Million, and will not increase significantly the level of disturbance originating from ITS.

3.3.4 Examination of ECC Report 101, for CBTC as victim

3.3.4.1 Introduction

The purpose of this section is to study whether the conclusions of ECC Report 101 on the compatibility of other services with ITS as a victim are valid in the specific case of Urban rail (CBTC) ITS which is based on the available CBTC systems today.

3.3.4.2 Main sensitivity parameters of CBTC systems

Table 15 compares the parameters used in the different paragraphs of the ECC Report 101 where ITS as victim is considered with the same parameters for the different CBTC cases.

Table 15: Comparison between parameters used in ECC Report 101 and CBTC parameters

	DSSS / Wayside	DSSS / Train	IEEE 802.11 based / Wayside	IEEE 802.11 based / Train	ITS (ECC Report 101)	Unit
Antenna gain (including feeder and power splitter)*	9	10	9	10	8	dBi
Side lobe rejection	15	18	15	18	12	dB
Sensitivity	-105	-105	-88	-88	-82	dBm
Sensitivity	-111.98	-111.98	-94.98	-94.,98	-92	dBm/MHz
C/I	-3	-3	9	9	6	dB
I_{max} at antenna input in main lobe, dBm/MHz	-118	-119	-113	-114	-106	dBm/MHz
I_{max} at antenna input in side lobe	-103	-101	-98	-96	-94	dBm/MHz
(*) Refer to Table 13 and Table 14 in section 3.3						

From Table 15, it can be concluded that CBTC supports less interference than what was indicated in the ECC Report 101. This is due to its higher sensitivity and different antenna gain.

The difference, ranging from 2 to 13 dB between CBTC and ITS I_{max} level at antenna input does not change fundamentally the results of the compatibility studies.

In addition, CBTC radio planning typically considers a maximum distance between APs in open area lower than the one that could be allowed by the sensitivity.

Typical levels of –77 dBm (for wayside) or -76 dBm (for trains) are taken into account which are considered as margins to allow higher level of interference into CBTC. These levels correspond to the minimum value that can be observed between a train and the AP when the distances between APs are limited to 400 metres.

Table 16 gives the Maximum Interference level at the antenna input taking into account such radio planning.

In this case, it can be observed that the maximum Interference level can be significantly higher.

Table 16: Maximum Interference level at the antenna input

	DSSS / Wayside	DSSS / Train	IEEE 802.11 based / Wayside	IEEE 802.11 based / Train	ITS (ECC Report 101)	Unit
Antenna gain (including feeder and power splitter)	9	10	9	10	NA	dB
Side lobe rejection	15	18	15	18	NA	dB
Lowest Level of received signal at receiver connector Input for a radio cell maximum 400 m simulated	-77	-76	-77	-76	NA	dBm
Received Level in dBm/MHz	-84	-83	-84	-83	NA	dBm/MHz
C/I	-3	-3	9	9		dB
I_l at antenna input, in main lobe, dBm/MHz with system margin obtained with shorter radio cell outdoor.	-90	-90	-102	-102	NA	dBm/MHz
I_{max} at antenna input in side lobe with system margin	-75	-72	-87	-84	NA	dBm/MHz

Further calculations are therefore done in both situations, which are around the situation taken into account for ITS in ECC Report 101.

The tables in this section represent the result of the calculations made. However, there is no intention to request for protection of the CBTC systems as indicated in ECC Report 101 for the ITS systems taken into account in the Report.

3.3.4.3 FSS as interferer

ECC Report 101 stated the use of the C-Band FSS in 5.850-6.725 GHz for earth stations (Earth-to-space direction). Therefore, in-band interference needs to be taken into account.

As shown in the ECC Report 101, separation distances are highly dependent on whether the ITS victim is located within the main lobe of the FSS or not. It is expected that FSS antenna gain and mast height limit the area where the victim is in the main lobe.

Separation distances calculated in the ECC Report 101 are high for the case of FSS interfering into ITS (depending on the type of FSS earth station, ITS OBU and RSU, from up to 25 km to up to 9 km). Considering a system margin for CBTC as described above, these distances are also applicable for CBTC.

It has also to be taken into account that the majority of FSS earth stations are installed in rural areas, which is not the case for CBTC systems.

Anyway, since FSS are fixed systems, and CBTC tracks are also known, specific studies can be done when one of these systems has to be deployed, to adapt the CBTC system margin (e.g. adjusting the distance between wayside CBTC access points) if required.

The conclusion of ECC Report 101 is “Compatibility achieved in most cases taking into account the limited number of earth stations and real terrain shielding”. This conclusion holds for CBTC.

3.3.4.4 Radars as interferer (radiolocation service)

The conclusion of ECC Report 101 on compatibility of radars with ITS as a victim is:

“It can be seen that for high power radar systems (i.e. Type L), even in the case of side lobe to side lobe configuration, the separation distances are quite high.

In case of lower power radars (i.e. Type X&Y), the separation distances are lower but in the case where the radar system is pointing in the ITS direction, it can be seen that the resulting separation distances will still be quite high.

From this, it may be concluded that the frequency separation between the frequency range identified for ITS and the radiodetermination band (5850 MHz) should be at least in the order of the out of band domain of the radiodetermination system (i.e. 2 times the necessary bandwidth of radiodetermination systems), which means a lower frequency for ITS devices above 5875 MHz. Between 5855 MHz and 5875 MHz, ITS may suffer interference.”

Based on the analysis performed in this section, the conclusion holds for CBTC above 5875 MHz.

Table 17 of the ECC Report 101 gives the e.i.r.p. of the radars in the ITS band. The information in this table is used to compute the minimum separation distance required between Radar and CBTC radio equipment to protect the latter, as it has been done in Table 21 of ECC Report 101.

The analysis for the Radar system has been made for two cases: without taking into account the system margin and taking into account the system margins.

Two analyses have been done, one for CBTC Radio system based on DSSS and another one for radio system based on the IEEE 802.11.

Table 17 and Table 18 give the analysis for the CBTC radio system based on DSSS for CBTC base station and train if the CBTC sensitivity wants to be preserved, therefore without system margin.

Table 17: Minimum separation distance between CBTC wayside and radar for CBTC based on DSSS without system margin

Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/ MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/ MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/ MHz	-118	-118	-118	-118	-118	-118	-118
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/ MHz	-118	-118	-118	-118	-118	-118	-118
Required Attenuation	dB	199.7	189.8	184.9	173.2	162.5	157.8	168
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	115.7	105.8	100.9	89.2	78.5	73.8	84
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	104.36	94.8	89.9	78.2	67.5	62.8	73
Separation Distance CBTC->RL	m	34199	20127	15482	8274	4665	3627	6263
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/ MHz	-118	-118	-118	-118	-118	-118	-118
Required Attenuation	dB	179.7	169.8	162.9	151.2	137.5	117.8	128
Separation Distance CBTC->RL	m	11719	6897	4766	2547	1223	426	735
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation	dB	15	15	15	15	15	15	15
Allowable Interfering power level at receiver antenna input	dBm/ MHz	-103	-103	-103	-103	-103	-103	-103
Required Attenuation	dB	184.7	174.8	169.9	158.2	147.5	142.8	153
Separation Distance CBTC->RL	m	15317	9014	6934	3706	2090	1625	2805
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	15	15	15	15	15	15	40
Side lobe Radar Antenna	dB	20	20	22	22	25	40	40

Radar Type		L	M	N	O	Q	X&Y	Z
rejection								
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/ MHz	-103	-103	-103	-103	-103	-103	-103
Required Attenuation	dB	164.7	154.8	147.9	136.2	122.5	102.8	113
Separation Distance CBTC -> RL	m	5249	3089	2135	1141	548	191	329
Note: The given e.i.r.p. Tx power values are peak values for very short pulses. Due to this limited time duration, resulting interference energy levels are expected to be low and thus the effect on the communication performance is negligible.								

Table 18: Minimum separation distance between train antenna and radar for CBTC based on DSSS without system margin

DSSS Train without system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-119	-119	-119	-119	-119	-119	-119
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-119	-119	-119	-119	-119	-119	-119
Required Attenuation	dB	200.7	190.8	185.9	174.2	163.5	158.8	169
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	116.7	106.8	101.9	90.2	79.5	74.8	85
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	105.36	95.8	90.9	79.2	68.5	63.8	74
Separation Distance CBTC->RL	m	36080	21234	16333	8729	4922	3827	6608
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation (dB)	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-119	-119	-119	-119	-119	-119	-119
Required Attenuation	dB	180.7	170.8	163.9	152.2	138.5	118.8	129

DSSS Train without system margin								
Separation Distance CBTC->RL	m	12364	7276	5029	2688	1290	449	776
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation	dB	18	18	18	18	18	18	18
Allowable Interfering power level at receiver antenna input	dBm/MHz	-101	-101	-101	-101	-101	-101	-101
Required Attenuation	dB	182.7	172.8	167.9	156.2	145.5	140.8	151
Separation Distance CBTC->RL	m	13761	8099	6230	3330	1877	1460	2520
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	18	18	18	18	18	18	18
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-101	-101	-101	-101	-101	-101	-101
Required Attenuation	dB	162.7	152.8	145.9	134.2	120.5	100.8	111
Separation Distance CBTC -> RL	m	4716	2775	1918	1025	492	171	296

Table 19 and Table 20 give the analysis for the CBTC radio system based on DSSS for CBTC base stations and train taking into account the system margin used for CBTC radio planning.

It is to be noted that the given e.i.r.p. Tx values are peak values for very short pulses. Due to this limited time duration, resulting interference energy levels are expected to be low and thus the effect on the communication performance is negligible.

Table 19: Minimum separation distance between CBTC wayside and radar for CBTC based on DSSS with system margin

DSSS Wayside with system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input main lobe	dBm/MHz	-90	-90	-90	-90	-90	-90	-90
MAIN LOBE CBTC - MAIN LOBE RL								

DSSS Wayside with system margin								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-90	-90	-90	-90	-90	-90	-90
Required Attenuation	dB	171.7	161.8	156.9	145.2	134.5	129.8	140
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	87.7	77.8	72.9	61.2	50.5	45.8	56
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	76.36	66.8	61.9	50.2	39.5	34.8	45
Separation Distance CBTC->RL	m	7636	4494	3457	1847	1042	810	1398
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation Radar (dB)	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-90	-70	-68	-68	-65	-50	-50
Required Attenuation	dB	151.7	141.8	134.9	123.2	109.5	89.8	100
Separation Distance CBTC->RL	m	2617	1540	1064	569	273	95	164
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation CBTC	dB	15	15	15	15	15	15	15
Allowable Interfering power level at receiver antenna input side lobe	dBm/MHz	-75	-75	-75	-75	-75	-75	-75
Required Attenuation		156.7	146.8	141.9	130.2	119.5	114.8	125
Separation Distance CBTC->RL	m	3420	2013	1548	827	467	363	626
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	15	15	15	15	15	15	15
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' at the antenna side lobe	dBm/MHz	-75	-75	-75	-75	-75	-75	-75
Required Attenuation	dB	136.7	126.8	119.9	108.2	94.5	74.8	85
Separation Distance CBTC -> RL	m	1172	690	477	255	122	22	68

Table 20: Minimum separation distance between train antenna and radar for CBTC based on DSSS with system margin

DSSS Train with system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-90	-90	-90	-90	-90	-90	-90
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-90	-90	-90	-90	-90	-90	-90
Required Attenuation	dB	171.7	161.8	156.9	145.2	134.5	129.8	140
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	87.7	77.8	72.9	61.2	50.5	45.8	56
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	76.36	66.8	61.9	50.2	39.5	34.8	45
Separation Distance CBTC->RL	m	7636	4494	3457	1847	1042	810	1398
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation (dB)	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-90	-90	-90	-90	-90	-90	-90
Required Attenuation	dB	151.7	141.8	134.9	123.2	109.5	89.8	100
Separation Distance CBTC->RL	m	2617	1540	1064	569	273	91	164
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation	dB	18	18	18	18	18	18	18
Allowable Interfering power level at antenna side lobe	dBm/MHz	-72	-72	-72	-72	-72	-72	-72
Required Attenuation	dB	153.7	143.8	138.9	127.2	116.5	111.8	122
Separation Distance CBTC->RL	m	2912	1714	1318	705	397	309	533

DSSS Train with system margin								
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	18	18	18	18	18	18	18
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-72	-72	-72	-72	-72	-72	-72
Required Attenuation	dB	133.7	123.8	116.9	105.2	91.5	71.8	82
Separation Distance CBTC -> RL	m	998	587	406	217	104	16	63

It can be observed that when the system margin is taken into account the separation distance required to protect the CBTC system is significantly shorter: as an example for the Radar type L the distance is 36080 m without system margin and 7636 m with system margin for the CBTC wayside.

Table 21 and Table 22 give the analysis for the CBTC radio system based on IEEE 802.11 for CBTC base station and train without system margin.

Table 21: Minimum separation distance between CBTC wayside and radar for CBTC based on IEEE 802.11 technology without system margin

Wayside IEEE 802.11 without system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	9	9	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input main lobe	dBm/MHz	-113	-113	-113	-113	-113	-113	-113
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I at receiver antenna input	dBm/MHz	-113	-113	-113	-113	-113	-113	-113
Required Attenuation	dB	194.7	184.8	179.9	168.2	157.5	152.8	163
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	110.7	100.8	95.9	84.2	73.5	68.8	79
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	99.36	89.8	84.9	73.2	62.5	57.8	68

Wayside IEEE 802.11 without system margin								
Separation Distance ITS->RL	m	26166	15399	11845	6331	3570	2775	4792
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation Radar	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-113	-93	-91	-91	-88	-73	-73
Required Attenuation	dB	174.7	164.8	157.9	146.2	132.5	112.8	123
Separation Distance CBTC->RL	m	8966	5277	3647	1949	936	326	563
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation CBTC (dB)	dB	15	15	15	15	15	15	15
Allowable Interfering power level at receiver antenna input side lobe	dBm/MHz	-98	-98	-98	-98	-98	-98	-98
Required Attenuation	dB	179.7	169.8	164.9	153.2	142.5	137.8	148
Separation Distance CBTC->RL	m	11719	6897	5305	2835	1599	1243	2146
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	15	15	15	15	15	15	15
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' at the antenna side lobe	dBm/MHz	-98	-98	-98	-98	-98	-98	-98
Required Attenuation	dB	159.7	149.8	142.9	131.2	117.5	97.8	108
Separation Distance CBTC -> RL	m	4016	2363	1633	873	419	146	252

Table 22: Minimum separation distance between train antenna and radar for CBTC based on IEEE 802.11 technology without system margin

Train IEEE 802.11 without system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3

Train IEEE 802.11 without system margin								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-114	-114	-114	-114	-114	-114	-114
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-114	-114	-114	-114	-114	-114	-114
Required Attenuation	dB	195.7	185.8	180.9	169.2	158.5	153.8	164
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	111.7	101.8	96.9	85.2	74.5	69.8	80
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	100.36	90.8	85.9	74.2	63.5	58.8	69
Separation Distance ITS->RL	m	27605	16246	12497	6679	3766	2928	5056
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-114	-114	-114	-114	-114	-114	-114
Required Attenuation	dB	175.7	165.8	158.9	147.2	133.5	113.8	124
Separation Distance CBTC->RL	m	9460	5567	3847	2056	987	344	594
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation	dB	18	18	18	18	18	18	18
Allowable Interfering power level at antenna side lobe	dBm/MHz	-96	-96	-96	-96	-96	-96	-96
Required Attenuation	dB	177.7	167.8	162.9	151.2	140.5	135.8	146
Separation Distance CBTC->RL	m	10529	6197	4766	2547	1436	1117	1928
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	18	18	18	18	18	18	18
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-96	-96	-96	-96	-96	-96	-96
Required Attenuation	dB	157.7	147.8	140.9	129.2	115.5	95.8	106
Separation Distance CBTC -> RL	m	3608	2123	1467	784	377	131	226

Table 23 and Table 24 give the analysis for the CBTC radio system based on IEEE 802.11 for CBTC base station and train taking into account the system margin.

Table 23: Minimum separation distance between CBTC wayside antenna and radar for CBTC based on IEEE 802.11 technology with system margin

Wayside IEEE 802.11 system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emissions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	9	9	9	9	9	9	9
Allowable Interfering power level 'I' at receiver antenna input main lobe	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
Required Attenuation	dB	183.7	173.8	168.9	157.2	146.5	141.8	152
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	99.7	89.8	84.9	73.2	62.5	57.8	68
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	88.36	78.8	73.9	62.2	51.5	46.8	57
Separation Distance CBTC->RL	m	14518	8544	6572	3513	1981	1540	2659
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation Radar	dB	20	20	22	22	25	40	40
Allowable Interfering power level at CBTC receiver antenna input	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
Required Attenuation	dB	163.7	153.8	146.9	135.2	121.5	101.8	112
Separation Distance CBTC->RL	m	4975	2928	2023	1081	519	181	312
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation CBTC	dB	15	15	15	15	15	15	15
Allowable Interfering power level at receiver antenna input side lobe	dBm/MHz	-87	-87	-87	-87	-87	-87	-87
Required Attenuation	dB	168.7	158.8	153.9	142.2	131.5	126.8	137
Separation Distance CBTC->RL	m	6502	3827	2944	1573	887	690	1191
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	15	15	15	15	15	15	15

Wayside IEEE 802.11 system margin								
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' at the antenna side lobe	dBm/MHz	-87	-87	-87	-87	-87	-87	-87
Required Attenuation	dB	148.7	138.8	131.9	120.2	106.5	86.8	97
Separation Distance CBTC -> RL	m	2228	1311	906	484	233	81	140

Table 24: Minimum separation distance between Train antenna and radar for CBTC based on IEEE 802.11 technology with system margin

Train IEEE 802.11 system margin								
Radar Type		L	M	N	O	Q	X&Y	Z
Radar e.i.r.p.	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110
Spurious emisions	dBpp	60	60	60	60	60	60	60
Spurious Level in CBTC frequency band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50
Protection Criterion C/I for CBTC	dB	-3	-3	-3	-3	-3	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
MAIN LOBE CBTC - MAIN LOBE RL								
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
Required Attenuation	dB	183.7	173.8	168.9	157.2	146.5	141.8	152
Attenuation at first break point	dB	84	84	84	84	84	84	84
Margin	dB	99.7	89.8	84.9	73.2	62.5	57.8	68
Attenuation at the second Break point	dB	95.34	95	95	95	95	95	95
Margin	dB	88.36	78.8	73.9	62.2	51.5	46.8	57
Separation Distance CBTC->RL	m	14518	8544	6572	3513	1981	1540	2659
MAIN LOBE CBTC - SIDE LOBE RL								
Side lobe attenuation	dB	20	20	22	22	25	40	40
Allowable Interfering power level at receiver antenna input	dBm/MHz	-102	-102	-102	-102	-102	-102	-102
Required Attenuation	dB	163.7	153.8	146.9	135.2	121.5	101.8	112
Separation Distance CBTC->RL	m	4975	2928	2023	1081	519	181	312
SIDE LOBE CBTC - MAIN LOBE RL								
Side lobe attenuation	dB	18	18	18	18	18	18	18

Train IEEE 802.11 system margin								
Allowable Interfering power level at antenna side lobe	dBm/MHz	-84	-84	-84	-84	-84	-84	-84
Required Attenuation	dB	165.7	155.8	150.9	139.2	128.5	123.8	134
Separation Distance CBTC->RL	m	5537	3259	2507	1340	755	587	1014
SIDE LOBE CBTC - SIDE LOBE RL								
Side lobe CTBC Antenna rejection	dB	18	18	18	18	18	18	18
Side lobe Radar Antenna rejection	dB	20	20	22	22	25	40	40
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-84	-84	-84	-84	-84	-84	-84
Required Attenuation	dB	145.7	135.8	128.9	117.2	103.5	83.8	94
Separation Distance CBTC -> RL	m	1898	1117	772	412	198	63	118

As for the CBTC radio system based on the DSSS technology, when the system margin is taken into account, the separation distances required to protect CBTC system based on the IEEE 802.11 technology are significantly reduced.

Table 25 gives a summary of the required minimum separation distance between Radar and CBTC Antennas (Wayside and Train) for CBTC radio system based on the DSSS and the IEEE 802.11 technology taking into account the system margin.

Table 25: Summary of the minimum separation distance in metres between radar and CBTC antennas (wayside and train)

Minimum separation distance between Radar and CBTC Wayside for DSSS with system margin							
Radar Type	L	M	N	O	Q	X&Y	Z
MAIN LOBE CBTC - MAIN LOBE RL	7636	4494	3457	1847	1042	810	1398
MAIN LOBE CBTC - SIDE LOBE RL	2617	1540	1064	569	273	95	164
SIDE LOBE CBTC - MAIN LOBE RL	3420	2013	1548	827	467	363	626
SIDE LOBE CBTC - SIDE LOBE RL	1172	690	477	255	122	22	68
Minimum separation distance between Radar and CBTC Train Antenna for DSSS with system margin							
Radar Type	L	M	N	O	Q	X&Y	Z
MAIN LOBE CBTC - MAIN LOBE RL	7636	4494	3457	1847	1042	810	1398
MAIN LOBE CBTC - SIDE LOBE RL	2617	1540	1064	569	273	91	164
SIDE LOBE CBTC - MAIN LOBE RL	2912	1714	1318	705	397	309	533
SIDE LOBE CBTC - SIDE LOBE RL	998	587	406	217	104	16	63
Minimum separation distance between Radar and CBTC Wayside for IEEE 802.11 with system margin							
Radar Type	L	M	N	O	Q	X&Y	Z
MAIN LOBE CBTC - MAIN LOBE RL	14518	8544	6572	3513	1981	1540	2659

Minimum separation distance between Radar and CBTC Wayside for IEEE 802.11 with system margin							
MAIN LOBE CBTC - SIDE LOBE RL	4975	2928	2023	1081	519	181	312
SIDE LOBE CBTC - MAIN LOBE RL	6502	3827	2944	1573	887	690	1191
SIDE LOBE CBTC - SIDE LOBE RL	2228	1311	906	484	233	81	140

Minimum separation distance between Radar and CBTC Train Antenna for IEEE 802.11 with system margin							
Radar Type	L	M	N	O	Q	X&Y	Z
MAIN LOBE CBTC - MAIN LOBE RL	14518	8544	6572	3513	1981	1540	2659
MAIN LOBE CBTC - SIDE LOBE RL	4975	2928	2023	1081	519	181	312
SIDE LOBE CBTC - MAIN LOBE RL	5537	3259	2507	1340	755	587	1014
SIDE LOBE CBTC - SIDE LOBE RL	1898	1117	772	412	198	63	118

It can be observed that the maximum separation distance is obtained with the CBTC radio system based on the IEEE 802.11 technology and the Radar type L for the case MAIN LOBE CBTC - MAIN LOBE RL: 14518 m.

This separation distance is lower than the same distance computed for the Road ITS, that is 17903 m.

3.3.4.5 SRD interfering with CBTC as a victim

The CBTC Radio systems are operating in the frequency band 5905-5925 MHz and the SRD devices are operating in the frequency band 5725-5875 MHz.

The SRD devices shall be compliant with the standard: ETSI EN 300 440 V2.2.1 [21].

To evaluate the impact of SRD devices it is important to define the spurious – out of band boundary as specified by the standard ETSI EN 300 440 V2.2.1.

Table 26 gives the frequency of spurious-out of band boundary for each type of SRD devices.

Table 26: SRD spurious-out of band boundary

		Centre frequency		Comments
	SRD I	SRD II	SRD III	
Channel bandwidth in MHz	0.25	20	8	
Centre frequency in MHz	5874.875	5865	5871	
250% of occupied bandwidth in MHz	0.625	50	20	
Boundary between out of band and spurious domain in MHz	5875.5	5915	5891	First Channel URBAN rail centred at 5905 MHz
Applicability of §4.2.4.3.4 of ETSI EN 300 440 V2.2.1	yes	no	yes	If applicability is "yes", spurious level when operating to be considered: 1 µW or -30 dBm Note: the bandwidth is not specified: Assuming dBm/MHz
Spurious level to be considered in dBm/MHz	-30	NA	-30	
Out of band level to be considered in dBc	NA	-40	NA	Assuming spectrum mask similar to ETSI EN 301 893 [22]

Table 27 to Table 30 give the impact analysis of each type of SRD device on CBTC systems, in case the CBTC sensitivity wants to be preserved, therefore without taking into account the system margin considered for CBTC radio planning.

a) **SRD I and III with 2 dB antenna**

Table 27: SRD I and III with 2 dB antenna minimum separation distance

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Bi/Bv	0.2	0.2	0.2	0.2
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) in the victim band (dBm)	-30	-30	-30	-30
	Gv side lobe attenuation	15	18	15	18
	Interferer side lobe attenuation	4	4	4	4

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	Wall Loss Attenuation	15	15	15	15
ML to ML	L	-73	-74	-68	-69
	Separation distance (m)	19	21	11	12
SL_interferer to ML	L	-69	-70	-64	-65
	Separation distance (m)	12	13	7	8
ML to SL_victim	L	-58	-56	-53	-51
	Separation distance (m)	3	3	2	2
SL to SL	L	-54	-52	-49	-47
	Separation distance (m)	2	2	1	1

b) **SRD II with 2 dB antenna**

Table 28: SRD II with 2 dB antenna minimum separation distance

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Bi/Bv	4	4	4	4
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) in the victim band (dBm)	-26	-26	-26	-26
	Gv side lobe attenuation	15	18	15	18
	Interferer side lobe attenuation	4	4	4	4
	Wall Loss attenuation	15	15	15	15
ML to ML	L	-64	-65	-59	-60
	Separation distance (m)	7	8	4	4
SL_interferer to ML	L	-60	-61	-55	-56
	Separation distance (m)	4	5	2	3
ML to SL_victim	L	-49	-47	-44	-42
	Separation distance (m)	1	1	1	1
SL to SL	L	-45	-43	-40	-38
	Separation distance (m)	0.75	0.60	0.42	0.34

c) **SRD I with 20 dB antenna**

Table 29: SRD I with 20 dB antenna minimum separation distance

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside0	IEEE 802.11/ Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. spurious level in dBm (dBm)	-30	-30	-30	-30
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	20	20	20	20
ML to ML	L	-81	-82	-76	-77
	Separation distance (m)	48	53	27	30
SL_interferer to ML	L	-61	-62	-56	-57
	Separation distance (m)	5	5	3	3
ML to SL_victim	L	-66	-64	-61	-59
	Separation distance (m)	8	7	5	4
SL to SL	L	-46	-44	-41	-39
	Separation distance (m)	1	1	0.48	0.38

d) **SRD II with 20 dB antenna**

Table 30: SRD II with 20 dB antenna minimum separation distance

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Bi/Bv	4	4	4	4
	Gv main lobe (dB)	9	10	9	10

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	e.i.r.p. (including TPC impact) in the victim band (dBm)	-26	-26	-26	-26
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	20	20	20	20
	Wall Loss attenuation (dB)	15	15	15	15
ML to ML	L	-64	-65	-59	-60
	Separation distance (m)	7	8	4	4
SL_interferer to ML	L	-44	-45	-39	-40
	Separation distance (m)	1	1	0	0
ML to SL_victim	L	-49	-47	-44	-42
	Separation distance (m)	1	1	1	1
SL to SL	L	-29	-27	-24	-22
	Separation distance (m)	0.12	0.09	0.07	0.05

It can be concluded that SRD devices will have low impact on the CBTC transmission.

Table 31 gives a summary of the results for the worst cases of SRD system using 2 dB antenna gain.

Table 31: SRD summary minimum separation distances

Minimum Separation distance in m					
SRD Type	Cases	DSSS / Wayside	DSSS / Train	802.11 / Wayside	802.11 / Train
SRD I and III	Main lobe SRD to Main lobe CBTC	19	21	11	12
	Side lobe SRD to Main lobe CBTC	12	13	7	8
	Main lobe SRD to Side lobe CBTC	3	3	2	2
	Side lobe SRD to Side lobe CBTC	2	2	1	1
SRD II	Main lobe SRD to Main lobe CBTC	7	8	4	4
	Side lobe SRD to Main lobe CBTC	4	5	2	3
	Main lobe SRD to Side lobe CBTC	1	1	1	1
	Side lobe SRD to Side lobe CBTC	0,75	0,60	0,42	0,34

Due to the fact that CBTC Radio systems are operating in the channels 5905-5925 MHz, they are affected only by spurious emissions generated by SRD type I and type III and by the out of band signal for SRD of type II. The separation between CBTC system and SRD can be significantly lower than the separation distance between ITS road system using lower channels, and SRD devices.

3.3.4.6 FWA system as interferer

For FWA systems, the OOB attenuation mask value is given as 40 dBr, therefore the separation distance for the different situation can be calculated.

Requested propagation loss L to avoid harmful interference is given by the following formula:

$$S = \frac{C}{I} = C + 10Log\left(\frac{Bi}{Bv}\right) - Gv - L - e.i.r.p.$$

Therefore:

$$L = C + 10Log\left(\frac{Bi}{Bv}\right) - Gv - e.i.r.p - S$$

With:

- S=C/I is the protection criterion;
- C is the sensitivity of the victim at the antenna input in dBm;
- Bi is the bandwidth of the interferer in MHz;
- Bv is the bandwidth of the victim in MHz;
- Gv is the victim antenna gain in dBi;
- e.i.r.p. is the e.i.r.p. of the interferer in dBm in the band of the victim.

Table 32 provides the results of the impact analysis of FWA on CBTC, for the case where the receiver sensitivity of the CBTC systems is taken into account.

Table 32: FWA minimum separation distance with CBTC system without system margin

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Bi/Bv	4	4	4	4
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) in the victim band (dBm)	-14	-14	-14	-14
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	15	15	15	15
ML to ML	L	-91	-92	-86	-87
	Separation distance (m)	**98**	**104**	**72**	**77**
SL_interferer to ML	L	-76	-77	-71	-72
	Separation distance (m)	**26**	**29**	**14**	**16**
ML to	L	**-76**	**-74**	**-71**	**-69**

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
SL_interferer	Separation distance (m)	**26**	**20**	**14**	**11**
SL to SL	L	-61	-59	-56	-54
	Separation distance (m)	**5**	**5**	**3**	**2**

Table 33 provides the results of the analysis for the cases where the system margin of the CBTC systems is taken into account.

Table 33: FWA minimum separation distance with CBTC system with system margin

		DSSS / Wayside	DSSS / Train	IEEE 802.11 /Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-77	-76	-77	-76
	Bi/Bv	4	4	4	4
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) in the victim band (dBm)	-14	-14	-14	-14
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	15	15	15	15
ML to ML	L	-63	-63	-75	-75
	Separation distance (m)	**6**	**5**	**22**	**22**
SL_interferer to ML	L	-48	-48	-60	-60
	Separation distance (m)	**1**	**1**	**4**	**4**
ML to SL_interferer	L	**-48**	**-45**	**-60**	**-57**
	Separation distance (m)	**1**	**1**	**4**	**3**
SL to SL	L	-33	-30	-45	-42
	Separation distance (m)	**0**	**0**	**1**	**1**

It can be observed that the system margin has a very strong impact.

The conclusion is that taking into account the system margin the FWA will have very limited impact on the CBTC radio systems.

3.3.4.7 RTTT as interferer

For RTTT interferer, using the technical parameters given for RTTT in Annex 4 of ECC Report 101, the impact of RTTT on CBTC is considered, taking into account the CBTC sensitivity (see Table 34).

Table 34: RTTT minimum separation distance without system margin

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-105	-105	-88	-88
	Bi/Bv	1	1	1	1
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) (dBm)	-23	-23	-23	-23
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	20	20	20	20
ML to ML	L	-88	-89	-83	-84
	Separation distance (m)	107	120	60	67
SL to ML	L	-68	-69	-63	-64
	Separation distance (m)	11	12	6	7
SL to SL	L	-53	-51	-48	-46
	Separation distance (m)	2	2	1	1

When taking into account the system margin for CBTC, the separation distances can be reduced, as shown in Table 35.

Table 35: RTTT minimum separation distance with system margin

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	S (dBm)	-3	-3	9	9
	C (dBm)	-77	-76	-77	-76
	Bi/Bv	1	1	1	1
	Gv main lobe (dB)	9	10	9	10
	e.i.r.p. (including TPC impact) (dBm)	-23	-23	-23	-23
	Gv side lobe attenuation (dB)	15	18	15	18
	Interferer side lobe attenuation (dB)	20	20	20	20
ML to ML	L	-60	-60	-72	-72
	Separation distance (m)	4	4	17	17
SL to ML	L	-40	-40	-52	-52
	Separation distance (m)	0.4	0.4	1.7	1.7
SL to SL	L	-25	-22	-37	-34

		DSSS / Wayside	DSSS / Train	IEEE 802.11 / Wayside	IEEE 802.11 / Train
	Separation distance (m)	0.08	0.05	0.30	0.21

3.3.4.8 FS as interferer

a) **FS with channel bandwidth of 29.65 MHz**

The CBTC system operating between the 5905-5925 MHz will be more affected by the out of band transmission of the FS system. It is due to the fact that CBTC channels are very close to the first FS channel with 5945 MHz as centre frequency.

The impact of the FS system has been analysed in from Table 36 to Table 39 for FS with 29.65 MHz channel bandwidth.

The FS spectrum mask B2 proposed in the ECC Report 101 figure 17 has been considered to compute the out of band level in the CBTC channel centred on 5920 MHz.

The studies assume that there is a 25 MHz frequency offset. This gives an additional attenuation of 37 dB of the power received at the input of the CBTC receiver from FS system transmission, relative to the co-frequency transmission e.i.r.p. of the FS system. Co-frequency situation was not considered in this Report.

Table 36 gives the analysis for the CBTC radio system based on DSSS without taking into account the system margin.

Table 36: Minimum separation distance between CBTC based on DSSS and FS without system margin

DSSS Without system margin		DSSS Wayside	DSSS Train
FS e.i.r.p.	dBm/MHz	60	60
Out Of band attenuation (channel FS 29.5 MHz)	dBr	37	37
Spurious Level in CBTC frequency band	dBm/MHz	23	23
Protection Criterion C/I for CBTC	dB	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-118	-119
MAIN LOBE CBTC - MAIN LOBE FS			
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-118	-119
Required Attenuation	dB	141	142
Separation Distance CBTC->FS	m	1598	1580
MAIN LOBE CBTC - SIDE LOBE FS			
Side lobe attenuation	dB	50	50
Allowable Interfering power level at receiver antenna input	dBm/MHz	-118	-119
Required Attenuation	dB	91	92
Separation Distance CBTC->FS	m	103	109

DSSS Without system margin		DSSS Wayside	DSSS Train
SIDE LOBE CBTC - MAIN LOBE FS			
Side lobe attenuation	dB	15	18
Allowable Interfering power level at receiver antenna input	dBm/MHz	-103	-101
Required Attenuation	dB	126	124
Separation Distance CBTC->FS	m	671	603
SIDE LOBE CBTC - SIDE LOBE FS			
Side lobe CTBC Antenna rejection	dB	15	18
Side lobe FS Antenna rejection	dB	50	50
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-103	-101
Required Attenuation	dB	76	74
Separation Distance CBTC -> FS	m	27	21

Table 37 gives the analysis for the CBTC radio system based on DSSS taking into account the system margin.

Table 37: Minimum separation distance between CBTC based on DSSS and FS with system margin

DSSS with system margin		DSSS Wayside	DSSS Train
FS e.i.r.p.	dBm/MHz	60	60
Out Of band attenuation (channel FS 29.5 MHz)	dBr	37	37
Spurious Level in CBTC frequency band	dBm/MHz	23	23
Protection Criterion C/I for CBTC	dB	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-90	-90
MAIN LOBE CBTC - MAIN LOBE FS			
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-90	-90
Required Attenuation	dB	113	113
Separation Distance CBTC->FS	m	334	334
MAIN LOBE CBTC - SIDE LOBE FS			
Side lobe attenuation	dB	50	50
Allowable Interfering power level at receiver antenna input	dBm/MHz	-90	-90
Required Attenuation	dB	63	63
Separation Distance CBTC->FS	m	6	6
SIDE LOBE CBTC - MAIN LOBE FS			
Side lobe attenuation	dB	15	18
Allowable Interfering power level at receiver antenna input	dBm/MHz	-75	-72

DSSS with system margin		DSSS Wayside	DSSS Train
Required Attenuation	dB	98	95
Separation Distance CBTC->FS	m	150	128
SIDE LOBE CBTC - SIDE LOBE FS			
Side lobe CTBC Antenna rejection	dB	15	18
Side lobe Radar Antenna rejection	dB	50	50
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-75	-72
Required Attenuation	dB	48	45
Separation Distance CBTC -> FS	m	1	1

Table 38 gives the analysis for the CBTC radio system based on IEEE 802.11 without taking into account the system margin.

Table 38: Minimum separation distance between CBTC based on IEEE 802.11 technology and FS without system margin

IEEE 802.11 Without system margin		IEEE 802.11 Wayside	IEEE 802.11 Train
FS e.i.r.p.	dBm/MHz	60	60
Out Of band attenuation (channel FS 29.5 MHz)	dBr	37	37
Spurious Level in CBTC frequency band	dBm/MHz	23	23
Protection Criterion C/I for CBTC	dB	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-113	-114
MAIN LOBE CBTC - MAIN LOBE FS			
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-113	-114
Required Attenuation	dB	136	137
Separation Distance CBTC->FS	m	1146	1209
MAIN LOBE CBTC - SIDE LOBE FS			
Side lobe attenuation	dB	50	50
Allowable Interfering power level at receiver antenna input	dBm/MHz	-113	-114
Required Attenuation	dB	86	87
Separation Distance CBTC->FS	m	74	78
SIDE LOBE CBTC - MAIN LOBE FS			
Side lobe attenuation	dB	15	18
Allowable Interfering power level at receiver antenna input	dBm/MHz	-98	-96
Required Attenuation	dB	121	119

IEEE 802.11 Without system margin		IEEE 802.11 Wayside	IEEE 802.11 Train
Separation Distance CBTC->FS	m	513	461
SIDE LOBE CBTC - SIDE LOBE FS			
Side lobe CTBC Antenna rejection	dB	15	18
Side lobe Radar Antenna rejection	dB	50	50
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-98	-96
Required Attenuation	dB	71	69
Separation Distance CBTC -> FS	m	15	12

Table 39 gives the analysis for the CBTC radio system based on IEEE 802.11 taking into account the system margin.

Table 39: Minimum separation distance between CBTC based on IEEE 802.11 technology and FS with system margin

IEEE 802.11 with system margin		IEEE 802.11 Wayside	IEEE 802.11 Train
FS e.i.r.p.	dBm/MHz	60	60
Out Of band attenuation (channel FS 29.5 MHz)	dBr	37	37
Spurious Level in CBTC frequency band	dBm/MHz	23	23
Protection Criterion C/I for CBTC	dB	-3	-3
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-102	-102
MAIN LOBE CBTC - MAIN LOBE FS			
Allowable Interfering power level 'I' at receiver antenna input	dBm/MHz	-102	-102
Required Attenuation	dB	125	125
Separation Distance CBTC->FS	m	636	636
MAIN LOBE CBTC - SIDE LOBE FS			
Side lobe attenuation	dB	50	50
Allowable Interfering power level at receiver antenna input	dBm/MHz	-102	-102
Required Attenuation	dB	75	75
Separation Distance CBTC->FS	m	24	24
SIDE LOBE CBTC - MAIN LOBE FS			
Side lobe attenuation	dB	15	18
Allowable Interfering power level at receiver antenna input	dBm/MHz	-87	-84
Required Attenuation	dB	110	107
Separation Distance CBTC->FS	m	285	242
SIDE LOBE CBTC - SIDE LOBE FS			

IEEE 802.11 with system margin		IEEE 802.11 Wayside	IEEE 802.11 Train
Side lobe CTBC Antenna rejection	dB	15	18
Side lobe Radar Antenna rejection	dB	50	50
Allowable Interfering power level 'I' on the antenna in side lobe	dBm/MHz	-87	-84
Required Attenuation	dB	60	57
Separation Distance CBTC -> FS	m	4	3

Table 40 gives a summary of the analysis of the impact of FS system on CBTC system.

Table 40: Summary of FS system impact on CBTC in 5905-5925 MHz

Minimum separation distance(m) between FS and CBTC system without system margin				
	DSSS Wayside	DSSS Train	IEEE 802.11 Wayside	IEEE 802.11 Train
MAIN LOBE CBTC - MAIN LOBE FS	1598	1580	1146	1209
MAIN LOBE CBTC - SIDE LOBE FS	103	109	74	78
SIDE LOBE CBTC - MAIN LOBE FS	671	603	513	461
SIDE LOBE CBTC - SIDE LOBE FS	27	21	15	12
Minimum separation distance (m) between FS and CBTC system with system margin				
	DSSS Wayside	DSSS Train	IEEE 802.11 Wayside	IEEE 802.11 Train
MAIN LOBE CBTC - MAIN LOBE FS	334	334	636	636
MAIN LOBE CBTC - SIDE LOBE FS	6	6	24	24
SIDE LOBE CBTC - MAIN LOBE FS	150	128	285	242
SIDE LOBE CBTC - SIDE LOBE FS	1	1	4	3

Despite the higher out of band transmissions level (23 dBm/MHz instead of 11 dBm/MHz), due to the fact that one CBTC channel is at the edge of the FS frequency band, the minimum separation distances are not significantly higher than those for the Road ITS.

b) **FS with channel bandwidth of 90 MHz**

The analysis made in the ECC Report 101 §3.7.2.2 shows that at the edge of the FS band (5925 MHz) the radiated out of band transmission is 4 dBm/MHz, it means 19 dB lower than the 23 dBm/MHz considered for FS system operating with channel bandwidth of 29.65 MHz.

FS system operating with channel bandwidth of 90 MHz will not have significant impact on the CBTC system.

3.3.4.9 Amateur Service as interferer

Amateur Service is allowed in the 5830-5850 MHz range.

ECC Report 101 relied on the compatibility analysis made between Amateur Service and FWA in ECC Report 68 [23], noting in addition that the ITS in 5855-5925 MHz and the Amateur Service would co-exist not in co-channel but in adjacent bands. This is even more the case for CBTC which is not considered to be relevant for 5855-5875 MHz.

Therefore, no constraint is foreseen from Amateur Service to CBTC as a victim.

3.3.5 Summary of studies

For Radar, SRD and FWA interferers the analysis on CBTC , shows that the CBTC Radio systems can support as much or more interference than the Road ITS when taking into consideration a system margin.

For SRD interferers it is also the case even without taking into consideration the system margin because CBTC systems do not operate in co-channel with SRDs and only receive out of band or spurious emissions from the SRD devices.

ECC Report 101 shows a need for large separation distance between ITS and FSS which is also applicable to CBTC.

The next table summaries for each system the impact it has on the Road ITS system used in ECC Report 101 and on CBTC system.

Co-frequency operation between urban rail and FS in 5925-5935 MHz was not assessed in this Report as it was considered out of scope.

Table 41: Summary of the analysis of the impact of other systems on Road ITS system used in ECC Report 101 and on CBTC system

Service	Road ITS as a victim (conclusion of ECC Report 101)	CBTC as a victim
Radio amateur (5830-5850 MHz)	Compatibility is achieved	Compatibility is achieved above 5875 MHz
FSS (5850-6725 MHz)	Compatibility achieved in most cases taking into account the limited number of earth stations and real terrain shielding	Compatibility achieved in most cases taking into account the limited number of earth stations, real terrain shielding and system margin taken into account for radio planning
Radiolocation (5725-5850 MHz)	Between 5855-5875 MHz ITS may suffer from interference	System design margin should ensure compatibility above 5875 MHz
SRD (5725-5875 MHz)	Mitigation techniques are needed in the frequency range 5855-5875 MHz. LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz
FWA (5725-5875 MHz)	Mitigation techniques are needed in the frequency range 5855-5875 MHz. LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz
RTTT (5795-5815 MHz)	Interference depends on the antenna beams alignment and is limited to the RTTT communication zone	Compatibility is achieved above 5875 MHz. In case of proximity with the RTTT communication zone, adequate system design could be required
FS (5925-6425 MHz)	ITS within the band 5905-5925 MHz may suffer from interference	FS will have limited impact on CBTC operating in the band 5905-5925 MHz taking into account the system margin

The general conclusion of ECC Report 101: "Between 5875 MHz and 5905 MHz ITS will not suffer from excessive interference resulting from other systems/services" remains valid for CBTC.

CBTC system below 5925 MHz will not suffer significantly from adjacent band interference generated by FS system when the system margin is taken into account.

4 EXAMINATION OF ECC REPORT 228

4.1 SYSTEM PARAMETERS OF ITS, USED IN ECC REPORT 228

Table 42: System parameters of ITS, used in ECC Report 228 [13]

Parameter	Value	Comments
Frequency ranges	5875-5925 MHz according to ECC/DEC(08)01 [24] 5855-5875 MHz according to ECC/REC(08)01 [25]	
Maximum radiated power (e.i.r.p.)	33 dBm, 23 dBm/MHz with TPC of 30 dB	According to existing regulation [24] [25]
Antenna beam shape/gain	For RSU and OBU use antenna model Recommendation ITU-R F.1336-1 [20]with parameters G_0 5 dB, k 1.2, max gain in +10 deg elevation.	See figure 2 in ECC Report 101 [1] there are 2 possible antennas, one very directional and one omnidirectional Recommendation ITU-R F.1336-1. However actual ITS systems development shows that the omnidirectional will be the dominant type and therefore only this should be used in these compatibility studies. There is a new version of models in Recommendation ITU-R F.1336-1, which should be used. Both versions 1 and 3 results in exactly the same antenna performance with these parameter settings.
Polarisation	Vertical linear	The antenna performance is not described in ETSI ITS [14] however the vertical linear polarisation is dominant.
Modulation scheme	BPSK QPSK 16QAM 64QAM	According to ETSI EN 302 571 V1.2.1 (2013-09) [14] and ETSI EN 302 663 V1.2.1 (2013-07) [26]
Data rates	3/4.5/6/9/12/1 /24/27 Mbit/s Mandatory: 3/6/12 Mbit/s	According to ETSI EN 302 571 V1.2.1 (2013-09) and ETSI EN 302 663 V1.2.1 (2013-07)
Channel bandwidth	10 MHz	According to ETSI EN 302 571 V1.2.1 (2013-09) and ETSI EN 302 663 V1.2.1 (2013-07)
Communication mode	Half-duplex, broadcast	Half-duplex and broadcast are believed to be adequate for the applications considered to date
Receiver noise power	-100 dBm	Typical performance, same value is used with the RLAN technology
Receiver sensitivity	-92dBm/MHz	Based on -82 dBm for a bandwidth of 10 MHz. ETSI EN 302 571 V1.2.1 (2013-09) specifies minimum required sensitivity
Duty Cycle	Typically < 1.0% over one hour, maximum 3% in one second	The duty cycle of the ITS systems is under control of mandatory congestion control and dynamic message generation rules in order to guarantee an access to the channel for safety critical message. The average duty cycle value of 1% over one hour is assumed for the periodic awareness messages (CAM) of an ITS station. The peak value of 3% is assumed to be related to safety critical event based messages like

Parameter	Value	Comments
		DENM. In addition to the periodic CAM messages. Higher duty cycle for specific application might be required in the future. The presented duty cycles are will cover the day one application requirements
Additional Mitigation techniques	See ETSI TS 102 792 V 1.1.1 (10-2012)	ETSI TS 102 792 defines a set of mitigation techniques to protect CEN DSRC tolling systems in the band 5795-5815 MHz. These techniques are mandatory included in the harmonised standard ETSI EN 302 571 In addition a specific message set has been specified in the CAM specification [12] which will allow for the protection of a tolling station. Those additional mitigation techniques are not considered in this Report
Message length	Cooperative awareness messages (CAM): < 1 ms Decentralised Environmental Notification Message (DENM): < 2 ms	

Communication channels will be open for the applications within the respective usage category (either road safety related or not, i.e. used for traffic management). The required power levels (e.i.r.p.) range from 3 dBm to 33 dBm to achieve communication distances of up to 1000 m. To avoid collisions of radio messages in areas with a lot of vehicles, a distributed congestion control (DCC) mechanism in the ITS system used in ECC Report 228 will, when necessary, reduce the output power level and the available time to transmit.

Specific mitigation techniques are already considered in order to protect the operation of CEN DSRC based road tolling systems in close vicinity (see above). These mechanisms are included in the relevant ETSI standards (e.g. ETSI EN 302 571 [14]). This Report will analyse what the required unwanted limit with those mitigation techniques are.

Unwanted emission levels are given in ETSI EN 302 571 V1.2.1 (2013-09) [14] for the out of band domain and Recommendation ITU-R SM.329 [27] and ERC Recommendation 74-01 [28] for the spurious domain.

4.2 ASSESSMENT OF ECC REPORT 228 FOR LTE-V2X

4.2.1 Introduction

ECC Report 228 provides “Compatibility studies between Intelligent Transport Systems (ITS) in the band 5855-5925 MHz and other systems in adjacent bands”.

Based on the methodology applied in ECC Report 228, the present Reportcomplements existing compatibility studies, in particular, existing studies build on ITS system used in ECC Report 228. With the present Report, the considerations are extended to cover LTE-V2X.

4.2.2 Coexistence scenarios

In ECC Report 228 (compatibility study between ITS in the band 5855-5925 MHz and other systems in adjacent bands) the following two services/systems are studied and the frequency range for each service is illustrated in Figure 1.

- Road tolling systems operating between 5795 MHz and 5815 MHz;

- Fixed Service (point-to-point links) above 5925 MHz.

In the next section, these two co-existence scenarios will be discussed by comparing different set of parameters:

Requirements given in EN 302 571 are based on ECC Report 228 and corresponding regulations. LTE-V2X systems deployed in Europe have to comply with EN 302 571, in order to be in line with the ECC Report 228 in relation to the unwanted emissions in the adjacent channel and in the spurious domain.

4.2.2.1 Technical characteristics of LTE-V2X system

Technical parameters of LTE-V2X system are given in section 3.2.1 of this Report.

4.2.2.2 ITS antennas

The same antennas with the same radiation patterns can be employed for LTE-V2X and ITS system used in ECC Report 228. Consequently, the same assumptions and consequences of this fact in ECC Report 228 are applicable to LTE-V2X.

4.2.3 Compatibility between LTE-V2X and other systems operating in adjacent frequency bands

4.2.3.1 Road tolling (CEN DSRC) protection in standards

It can be noted that in 3GPP specifications and reports TS 36.300 [7], TS 36.101 [2] and TR 36.786 [3] some measures are considered to protect CEN DSRC tolling stations: TS 36.300 defines an indication which is sent from upper protocol stack layers to lower layers, when the UE is within the proximity of a CEN DSRC tolling station. Further, TS 36.101 specifies a transmit power limit of 10 dBm when a UE is within the CEN DSRC station protection area. A study is presented in TR 36.786 on the CEN DSRC protection,

To protect operation of electronic toll collection in the frequency band 5795 MHz to 5815 MHz from harmful interference, mitigation techniques have to be implemented as defined in ETSI TS 102 792 [15]. Different co-existence modes to protect CEN DSRC and HDR DSRC are defined in ETSI TS 102 792.

NORMAL MODE

ECC Decision (08)01, ECC Recommendation (08)01, and ETSI EN 302 571 regulate output power level and unwanted emissions for ITS stations (see Table 43). Operation limited only by these requirements is referred to as normal mode..

Table 43: Rx blocking for Normal mode

ITS-G5 output power level in the frequency range 5855-5925 MHz (dBm e.i.r.p.)	ITS-G5 unwanted emissions in the frequency range 5855-5925 MHz (dBm/MHz e.i.r.p.)
≤ 33	≤ -30

COEXISTENCE MODES

Additional restrictions apply in coexistence mode. These restrictions apply to output power level, unwanted emissions and transmit timing. The restrictions are designed to decrease the interference from ITS stations to a level which implies no harmful performance degradation of CEN DSRC based toll stations.

An ITS station may be designed to operate in coexistence mode all the time. Four different coexistence modes, designated A, B, C, and D are defined in ETSI TS 102 792 V1.2.1 (2015-06) and reproduced in Table 44. An ITS station shall choose one of these modes when applicable.

It should be noted, that the parameters Ton and Toff of Table 44 are defined in ETSI TS 102 792. The level of the V2X unwanted emissions is specified in 3GPP TS 36.101. These specified values correspond to those of the coexistence modes A and B of Table 44. The maximum Ton time and the minimum Toff time in case of -45 dBm/MHz for mode B for spurious emissions are not defined in the relevant LTE-V2X3GPP specifications.

In case of LTE-V2X retransmissions, the timing requirement of Ton time of 1 ms is exceeded. The parameter "allowed number of retransmissions" is specified in ETSI TS 103 613 [33]. The value of this parameter is variable and implementation specific, but not limited to 1. Therefore, retransmissions occur according to the implementation of the LTE-V2X protocol stack implementation.

Table 44: Rx blocking for coexistence mode

Coexistence mode	ITS output power level in the frequency range 5855-5925 MHz (dBm e.i.r.p)	ITS unwanted emissions in the frequency range 5795-5815 MHz (dBm/MHz e.i.r.p.)	T_{on} time	T_{off} time
A	≤ 10	≤ -65	No limit	No limit
B	≤ 10	≤ -45	≤ 1 ms	≥ 50 ms
C	≤ 33	≤ -30	≤ 1 ms	Equation 5.1
D	≤ 33	≤ -30	1ms to 7 ms	Equation 5.2

4.2.4 Investigation of coexistence with road tolling

4.2.4.1 ITS antenna model

Details of ITS antenna model is described in ECC Report 228.

4.2.4.2 General considerations

In this section the interference from LTE-V2X systems into the road tolling systems is investigated. The study is performed in the same way as the study done for the ITS system in ECC Report 228. Since only the out of band emissions are investigated, the main focus of the evaluation is on the interference into the road toll Road Side Units (RSU) operating in the band 5795 MHz to 5815 MHz with an operational bandwidth of 500 kHz. The impact of ITS unwanted emissions on the road tolling OBU (On Board Unit) has not been considered. Due to the limited sensitivity of the OBU of around -50 dBm, no harmful interference towards the road tolling OBU is expected from the unwanted emission of ITS.

4.2.4.3 Method for interference calculations as applied in ECC Report 228

The coexistence investigation takes into account both radio propagation performance and timing considerations in the following way.

CAM messages: For ITS the CAM-based duty cycle is not based on the maximum allowed duty cycle according to ETSI TS 102 792 V1.2.1 (2015-06) and ETSI EN 302 571. The CAM-based duty cycle is based on CAM messages defined in ETSI EN 302 637-2. The use of CAM messages is considered more realistic than maximum allowed duty cycle which allows up to 20 times higher duty cycle (coexistence mode B) than the duty cycle given by the CAM generation rule.

Duty cycle limits: Calculations are based on the number of interferers and their transmission duty cycle. They indicate the maximum possible number of ITS transmissions allowed per time unit within the interference zone. The calculation method was developed in ETSI based on measurements and advanced simulations and further detailed in ETSI TR 102 960 [29].

Interference zone: The size of the interference zone has been estimated using MCL calculations. The MCL calculations include detailed models of typical antennas for victim and interferer.

Vehicle density: Three different tolling scenarios were studied. The different scenarios results in different density of vehicles. With decreased vehicle speed, the density of vehicles increases.

Number of vehicles within interference zone: Based on the calculations on size of the interference zone and the density of vehicles, the number of vehicles within the interference zone is calculated.

Interference evaluation: The same methodology as in ECC Report 228 was adopted in this section.

4.2.4.4 Studied scenarios

3 different road tolling scenarios are investigated, details described in ECC Report 228.

The use of ITS by pedestrians (Vehicle-to-Pedestrian application [15]) has not been studied in ECC Report 228. Therefore, this case was not assessed in this Report.

4.2.4.5 Technical characteristics of road tolling Road Side Units (RSU)

Technical characteristics of road toll system are described in ECC Report 228.

4.2.4.6 Detailed MCL calculations - Interference zone

Detailed MCL calculation to define size of the interference zone is described in ECC Report 228.

4.2.4.7 Number of vehicles in the interference zone

Based on the detailed MCL calculations, the number of vehicles in the interference zone has been estimated for the three different scenarios.

4.2.4.8 Number of vehicles in scenario 1

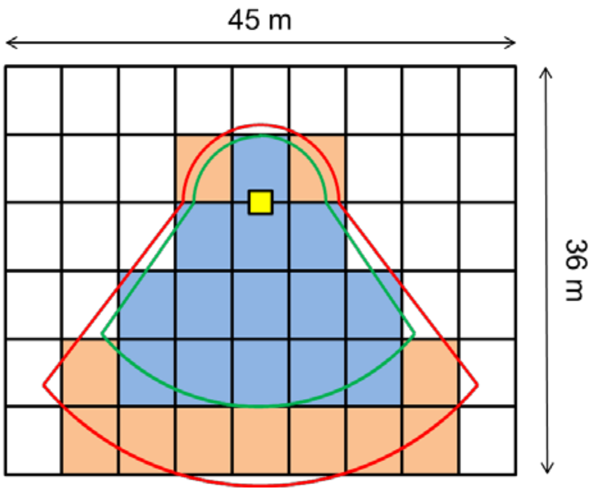


Figure 3: Toll plaza scenario at very low vehicle speed. ITS unwanted emissions of -40 dBm/MHz are possible from within the red area and -45 dBm/MHz from within the green area

In Figure 3, it can be seen that a maximum of:

- 25 ITS stations can contribute to the interference towards the CEN DSRC link at -40 dBm/MHz;
- 14 ITS stations can contribute to the interference towards the CEN DSRC link at -45 dBm/MHz.

4.2.4.9 Number of vehicles in scenario 2

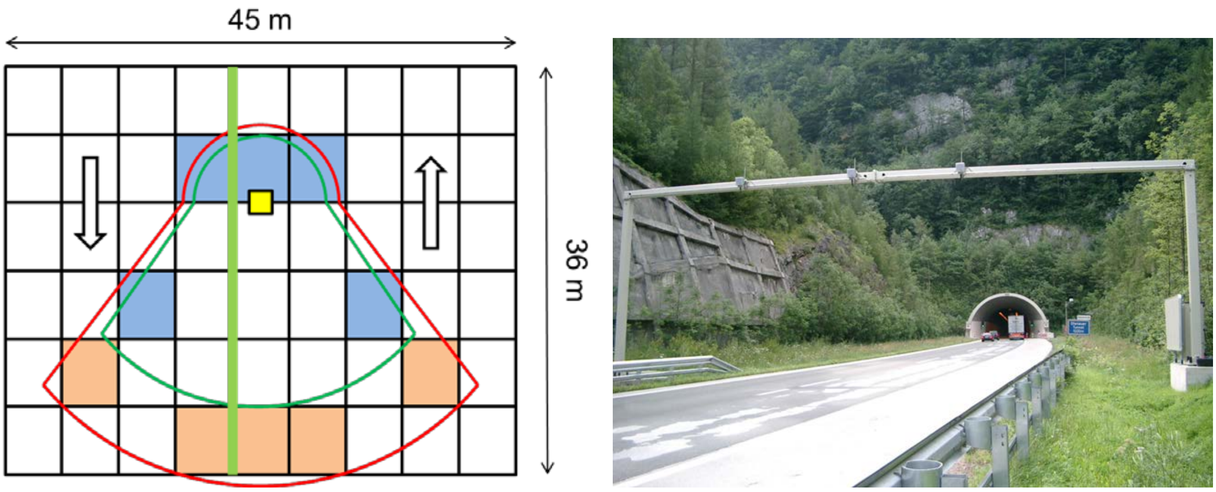


Figure 4: Free-flow scenario, with 75 km/h speed. ITS unwanted emissions of -40 dBm/MHz are possible from within the red area and -45 dBm/MHz from within the green area

In Figure 4 it can be seen that a maximum of:

- 10 ITS stations can contribute to the interference towards the CEN DSRC link at -40 dBm/MHz;
- 5 ITS stations can contribute to the interference towards the CEN DSRC link at -45 dBm/MHz.

4.2.4.10 Number of vehicles in scenario 3

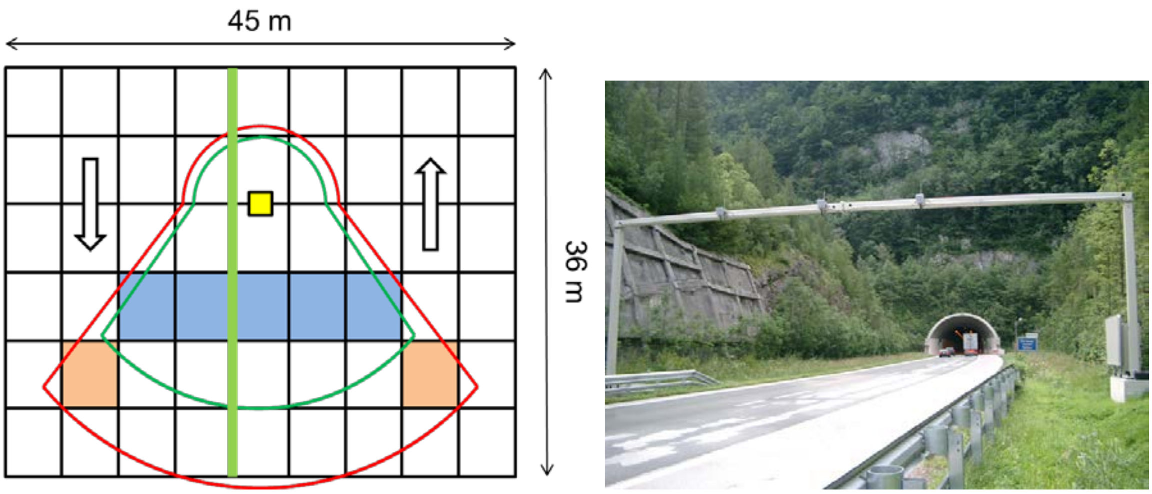


Figure 5: Free flow scenario: 130 km/h. ITS unwanted emissions of -40 dBm/MHz are possible from within the red area and -45 dBm/MHz from within the green area

In Figure 5 it can be seen that a maximum of:

- 7 ITS stations can contribute to the interference towards the CEN DSRC link at -40 dBm/MHz;
- 5 ITS stations can contribute to the interference towards the CEN DSRC link at -45 dBm/MHz.

4.2.4.11 Road tolling Protocol (CEN DSRC)

Duty cycle performance of the road toll protocol is described in ECC Report 228.

4.2.4.12 Consideration of the Duty Cycle limitations for ITS

ETSI TR 102 960 contains several compatibility investigations based on the protocol parameters of CEN DSRC and ITS systems. Some of these results are given in the following section.

For a given number of active ITS stations in the interference range a minimum Toff time between two consecutive frame transmissions can be evaluated. The worst-case results are given in Figure 6 taken from the ETSI TS 102 792. Here it can be seen that up to a number of 3 ITS stations in the interference range and a Toff time of 100 ms between two frames no harmful interference will occur to the CEN DSRC link. With an increased number of ITS station in the interference range the required minimum Toff time has to be increased.

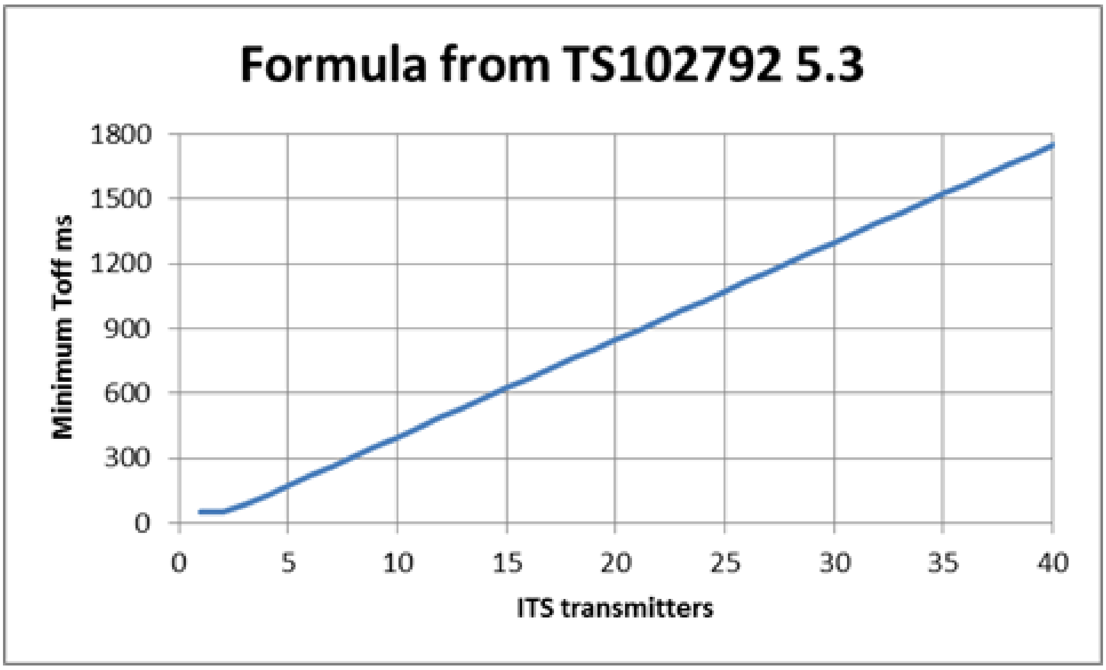


Figure 6: Required Toff time as of ETSI TS 102 792 between two packets for interference-free operation of tolling RSU [13]

Taking into account the ITS frame duration of 1 ms, Figure 7 depicts the maximum allowed frame rate for each ITS station for a given number of ITS stations in the interference range. These values can be taken into account in the evaluation of the interference risk in the different scenarios.

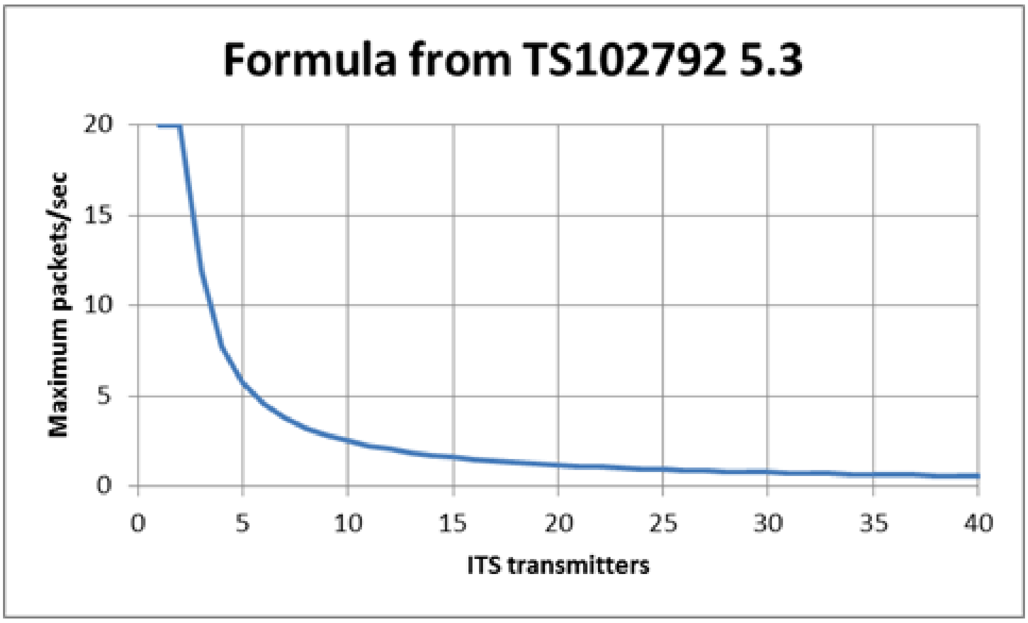


Figure 7: Maximum allowed packet rate as function of the ITS stations in the interference range, packet length 1 ms [13]

The main message transmitted by an ITS system will be the so called CAM (Cooperative Awareness Message) [12]. The CAM generation rules and processes described in ECC Report 228 and detailed in ANNEX 1: of this Report.

4.2.5 Evaluation of interference

4.2.5.1 Timing parameters of ITS used in ECC Report 228

A CAM message is always transmitted within a single frame with an approx. duration of 1 ms.

4.2.5.2 Evaluation interference from ITS used in ECC Report 228

In summary, the results with ITS-G5 from ECC Report 228 show that the most critical case is the high speed scenario 3. A limit of -45 dBm/MHz used for ITS-G5 unwanted emissions is considered enough to protect road toll transactions from being interfered by ITS-G5 CAM transmissions.

4.2.5.3 Timing parameters LTE-V2X

It is assumed LTE-V2X will transmit CAM messages according to ETSI EN 302 637-2. This means LTE-V2X will use the same CAM generation rate as ITS-G5. The smallest unit of channel allocation in time domain is called sub-frame. Each LTE-V2X sub-frame is of 1 ms length and is subdivided (in the frequency domain) into physical resource blocks (PRB). Several PRBs then form a transport block (TB). The size of data that fits into a TB is limited and depends on the used modulation and coding scheme (MCS) as well as the PRBs selected by the scheduling strategy. The exact scheduling strategy itself is not specified in 3GPP and left to implementations. If the higher layer data does not fit into an allocated TB, a further TB is needed. This way the data transmission is scheduled into more than one sub-frame. The consequences for coexistence with road toll are summarised below.

Sub-frames per CAM message: Depending on the length of a CAM, as determined by upper layers, and depending on the scheduling strategy, there is sometimes a need to transmit several 1 ms sub-frames for one CAM. Real-life CAM logging has shown occasional long CAMs, which can't fit a single 1 ms sub-frame.

Consecutive sub-frames: If several sub-frames are used to transmit one CAM, there is no guarantee that these will be transmitted consecutively. If two sub-frames with duration of 1 ms are transmitted consecutively, it is seen from the victim side as one single frame with 2 ms duration. This will result in less interference than if the data is transmitted in two non-consecutive sub-frames of 1 ms each. For more details, see Figure 7.

Simultaneous transmissions: The 10 MHz channel may be divided (in the frequency domain) into sub-channels by several LTE V2X radios. In fact, this is the default operating model to allow sufficient transmission slots for all users. As a consequence, the total unwanted emissions received by the road toll receiver will be higher, such as in the typical case of two LTE V2X simultaneously transmitting -45 dBm/MHz unwanted emissions.

Retransmissions: Retransmissions are generally foreseen at low channel busy rate (<0.3). In case of simultaneous transmissions, the LTE-V2X transmitters using the same sub-frame do not hear each other. By using retransmissions, it is possible to schedule all transmissions in such a way that the LTE-V2X devices have the possibility to hear each other.

Table 45 below shows which combinations of LTE V2X configurations were investigated in this study.

Table 45: Combinations of LTE V2X configurations studied

LTE V2X configuration	Distinct sub-frames used per CAM	CAM Retransmissions	Simultaneous transmissions
A (CAM message fits a single sub-frame / single user transmitting)	1	0	1
C (long CAM message fits two sub-frames / single user transmitting)	2	0	1
D (CAM message fits a single sub-frame / single user transmitting with one retransmission)	1	1	1
E (CAM message fits into two half sub-frames / two users transmitting simultaneously with one retransmission) (Note 1)	2	1	2
Note 1: When several LTE V2X transmitters use parts of the10 MHz bandwidth, it is assumed to combine it with retransmissions. It is difficult to receive and transmit at the same time. By using retransmissions it is possible to schedule all transmissions in such a way that all LTE V2X devices have the possibility to hear each other			

.

4.2.5.4 Evaluation of interference from LTE V2X

Table 46 below shows summary of the LTE V2X interference contributions based on assumptions given in Table 45 above.

Table 46: Summary of interference calculations use case 1, 2 and 3 with LTE V2X

LTE V2X configuration	Unwanted emissions limit (dBm/MHz)	Vehicles in interference zone	CAM rate (Hz)	Sub frame rate (Hz)	Sub frame rate limit for no interference (Hz)
Scenario 1 – Toll plaza, very low speed, < 10 km/h					
A	-45	14	1	1	1.7
C	-45	14	1	2	1.7
D	-45	14	1	2	1.7
E	-48 (Note 1)	14	1	2 (Note 2)	1.7
Scenario 2 – Free flow tolling, medium speed, 75 km/h					
A	-45	5	5	5	5.7
C	-45	5	5	10	5.7
D	-45	5	5	10	5.7
E	-48 (Note 1)	5	5	10 (Note 2)	5.7
Scenario 3 – Free flow tolling, high speed, 130 km/h					
A	-45	4	9	9	7.8
C	-45	4	9	18	7.8
D	-45	4	9	18	7.8
E	-48 (Note 1)	4	9	18 (Note 2)	7.8

Note 1: A lower unwanted emission limit is considered here because simultaneous transmissions in the same sub-frame cause higher unwanted emissions.

Note 2: For this configuration, it is assumed that all transmissions by the LTE-V2X transmitters within the interference zone are scheduled pairwise such that two transceivers always share a sub-frame in the frequency domain. Otherwise a CAM could be allocated to up to four distinct sub-frames (two sub-frames for the initial CAM and two sub-frames for the retransmitted CAM).

4.2.6 Conclusion for coexistence of road tolling and LTE-V2X

Table 47: Summary of the analysis performed for road tolling and LTE-V2X

Service	Conclusions of ECC Reports 101 and 228		Conclusions on CBTC	Conclusions on LTE-V2X
	ITS as interferer	ITS as victim		
RTTT, road tolling (5795-5815 MHz)	Compatibility is achieved if ITS unwanted emissions are limited below 5815 MHz: ▪ to -65 dBm/MHz without mitigation techniques; ▪ to -45 dBm/MHz taking into account the specification given for ITS in ETSI EN 302 637-2 [12], EN 302 571 [14] and timing requirements according to ECC Report 228	Interference depends on the antenna beams alignment and is limited to the RTTT communication zone.	Compatibility is achieved above 5875 MHz. In case of proximity to the RTTT communication zone, adequate system design is required.	Compatibility is achieved under mode A*. Note 1 Under mode B*, compatibility could be achieved if timing requirements (Ton & Toff) and the aggregated spurious emissions do not exceed those of ITS in ECC Report 228 in the interference zone Note 2

* Modes A and B are specified in ETSI TS 102 792 [15] Table 5.3, which is part of the requirements defined in EN 302 571.

Note 1: On compatibility between LTE-V2X and road tolling in Mode A:

For LTE-V2X devices in coexistence mode A, an aggregation of spurious emissions from multiple vehicles is considered not to be an issue. In ECC Report 228 it was shown that for spurious emissions of -65 dBm/MHz per ITS device practically no interference zone exists. Therefore contributions of simultaneously transmitting devices from multiple vehicles are assumed to be negligible due to additional propagation losses in comparison with a single dominant device.

Note 2: On compatibility between LTE-V2X and road tolling in mode B:

using repeated retransmissions of CAM within a road tolling RSU interference zone may result in lost road toll transactions;

if CAM retransmissions occur, the average air time of LTE-V2X transmissions within the road tolling RSU interference zone may be longer than the average air time requirements in ECC Report 228 derived for CAM. Compatibility can be achieved if LTE-V2X stations reduce their average air time within the road tolling RSU interference zone in accordance with the timing requirements in ECC Report 228. For a 1 second interval, the air time of the transmissions is the number of used sub-frames times the sub-frame length of 1 ms;

the requirements regarding air time issues (Ton & Toff) are not yet specified in the current versions of 3GPP LTE-V2X specifications.

4.3 ASSESSMENT OF ECC REPORT 228 FOR CBTC SYSTEMS

4.3.1 Transmitter spectrum mask for the CBTC systems

4.3.1.1 Transmitter spectrum mask CBTC using IEEE 802.11 cards

Figure 8 comes from the IEEE 802.11-2012 standard.

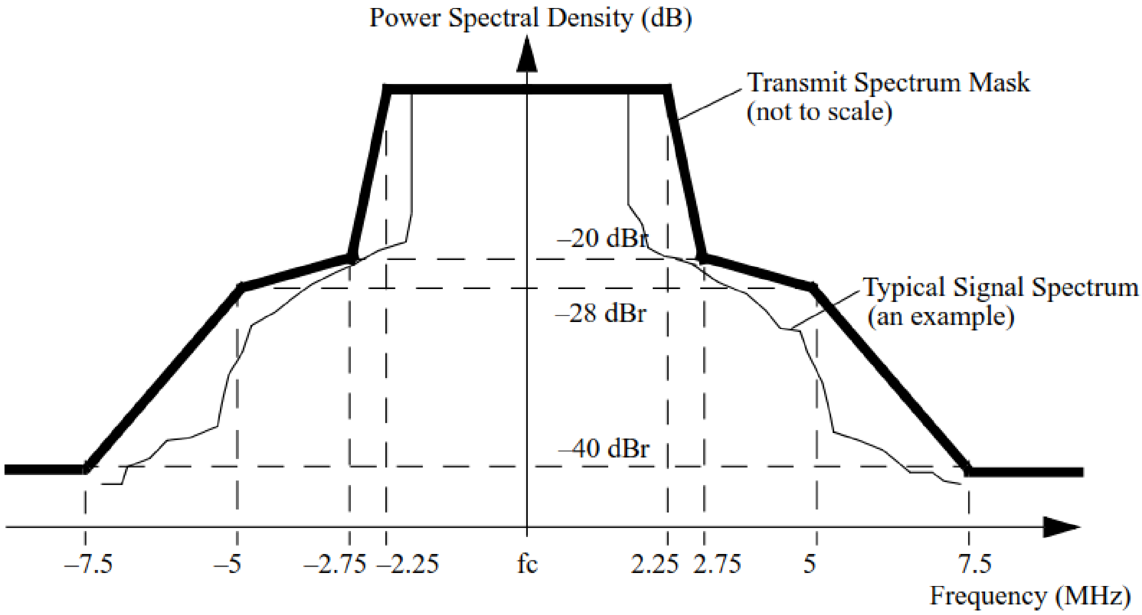


Figure 8: Transmitter spectrum mask for the CBTC transmitter

CBTC systems also use an additional filter with the following characteristics:

- In-band 5875 MHz-5925 MHz
- Rejection 15 dBc @ 5855 MHz and 5945 MHz

For a channel using central frequency 5920 MHz:

- Rejection for 5927.5 MHz < f < 5940 MHz: -40 dBr
- Rejection for f > 5940 MHz: -55 dBr

4.3.1.2 Transmitter Spectrum mask for CBTC using DSSS/TDMA system

Figure 9 comes from ETSI TR 103 111 [30].

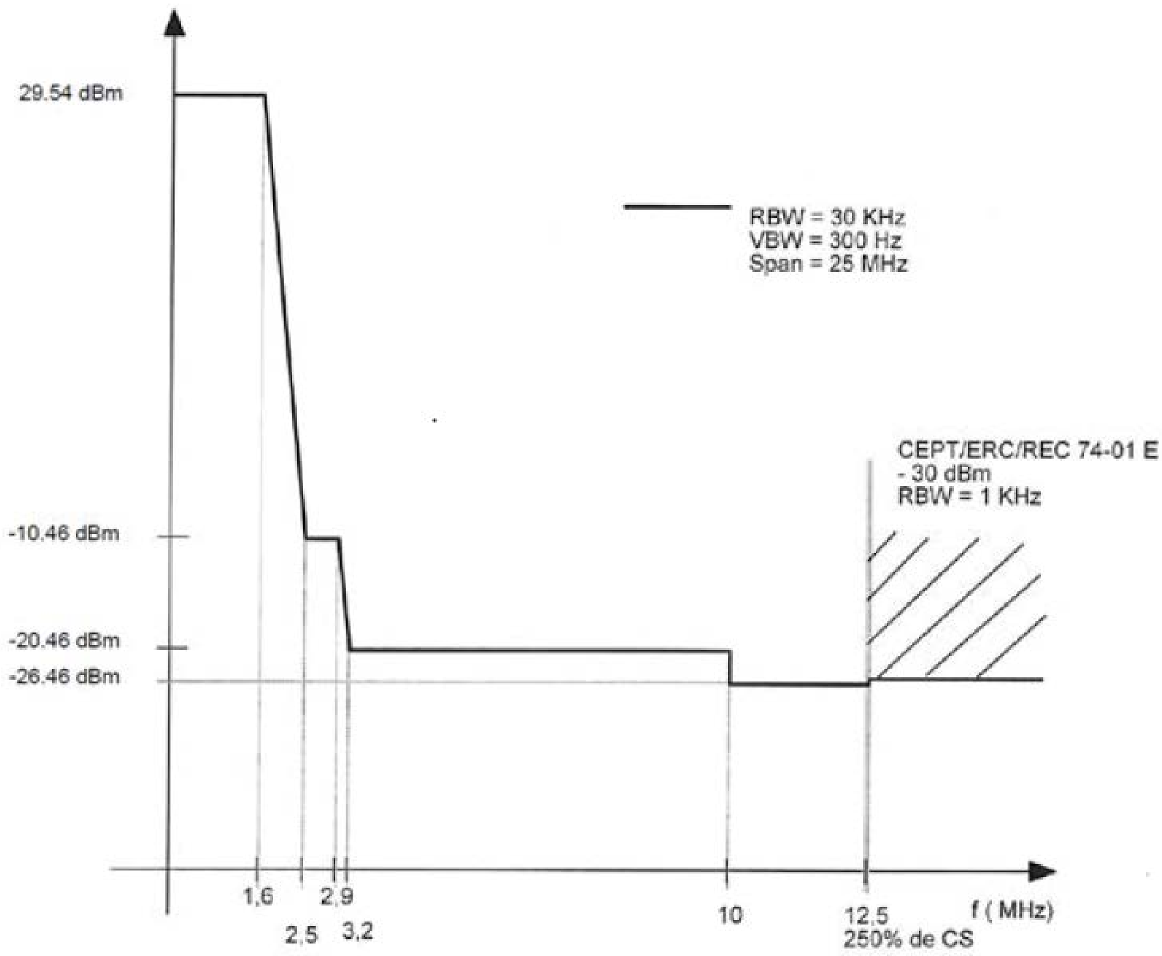


Figure 9: Spectrum mask of the system

The transmitted power is given for the complete band of transmission but not per MHz:

- For the 29.54 dBm as reference, rejection is -50 dBc for +/- 3.2 MHz around the central frequency;
- For the channel at 5922.5 MHz, rejection is -50 dBc.

4.3.1.3 Corresponding e.i.r.p. in Road tolling channels

For a CBTC communication system using its lowest channel, the e.i.r.p. in dBm/MHz in the road tolling band (< 5815 MHz) is given in Table 48

Table 48:e.i.r.p. (dBm/MHz) in the road tolling band from CBTC system using the lowest channel

	Nominal IEEE 802.11	DSSS / TDMA
Below 5815 MHz	-32 dBm/MHz	-42 dBm/MHz

4.3.1.4 Corresponding e.i.r.p. in FS channels

For a CBTC communication system using its highest channel below 5925 MHz, the e.i.r.p. in dBm/MHz in an FS channel is given in Table 49.

Table 49: e.i.r.p. (dBm/MHz) in a FS channel from CBTC system using the highest channel below 5925 MHz

	Nominal IEEE 802.11	DSSS / TDMA
First FS channel	-17 dBm/MHz	-33 dBm/MHz
Since 2nd FS channel	-32 dBm/MHz	-33 dBm/MHz

4.3.2 Impact of CBTC train transmission on road tolling systems

Metro using CBTC systems are obviously not using the road line equipped with road tolling systems, therefore there is an inherent separation due to the combination of the directional antennas used for both road tolling and CBTC systems.

The worst case is the one described in Figure 10, where a CBTC track is parallel to the road lines equipped with road tolling system. In the study different separation distances are considered between the position of the road tolling RSU and the axis of the CBTC track.

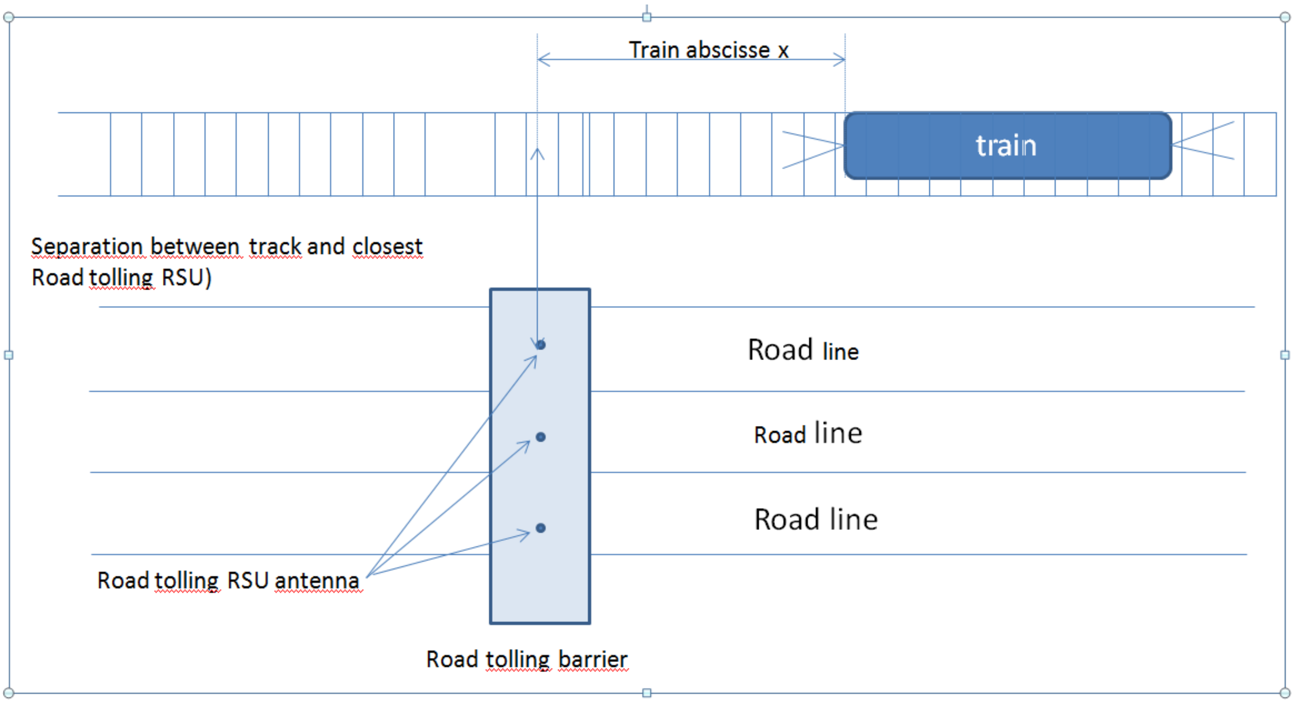


Figure 10: CBTC vs Road tolling – worst case

Combining the characteristics of road tolling antennas given in ECC Report 228, chapter 3.3.2.2, and the characteristics of the train and wayside antenna used for CBTC systems, the following situations occurs.

In the very close area:

- CBTC transmitter is outside of the -50° azimuth zone, but in the active beam of the tolling RSU, and the RSU is outside of the main beam of the CBTC antenna.

Then:

- CBTC transmitter is still outside of the -50° azimuth zone, and goes out of the active beam of the tolling RSU which is larger in that area, and the RSU is still outside of the main beam of the CBTC antenna.

Then:

- CBTC transmitter is inside of the -50° azimuth zone, and possibly back in the active beam of the tolling RSU which is larger in that area, and the RSU is still outside of the main beam of the CBTC antenna. This situation doesn't exist when the separation between the Road tolling RSU and the axis of the track is large enough.

Then:

- CBTC transmitter is still inside the 50° azimuth zone, but outside of the active beam of the tolling RSU, and the RSU is still outside of the main beam of the CBTC antenna.

Finally:

- CBTC transmitter is still outside of the active beam of the tolling RSU, but the RSU enters in the main beam of the CBTC antenna.

Figure 11 shows, for different separation distances, the received level from CBTC train transmitter when the train is moving on its axis, and compares them with the interference threshold of the road tolling RSU.

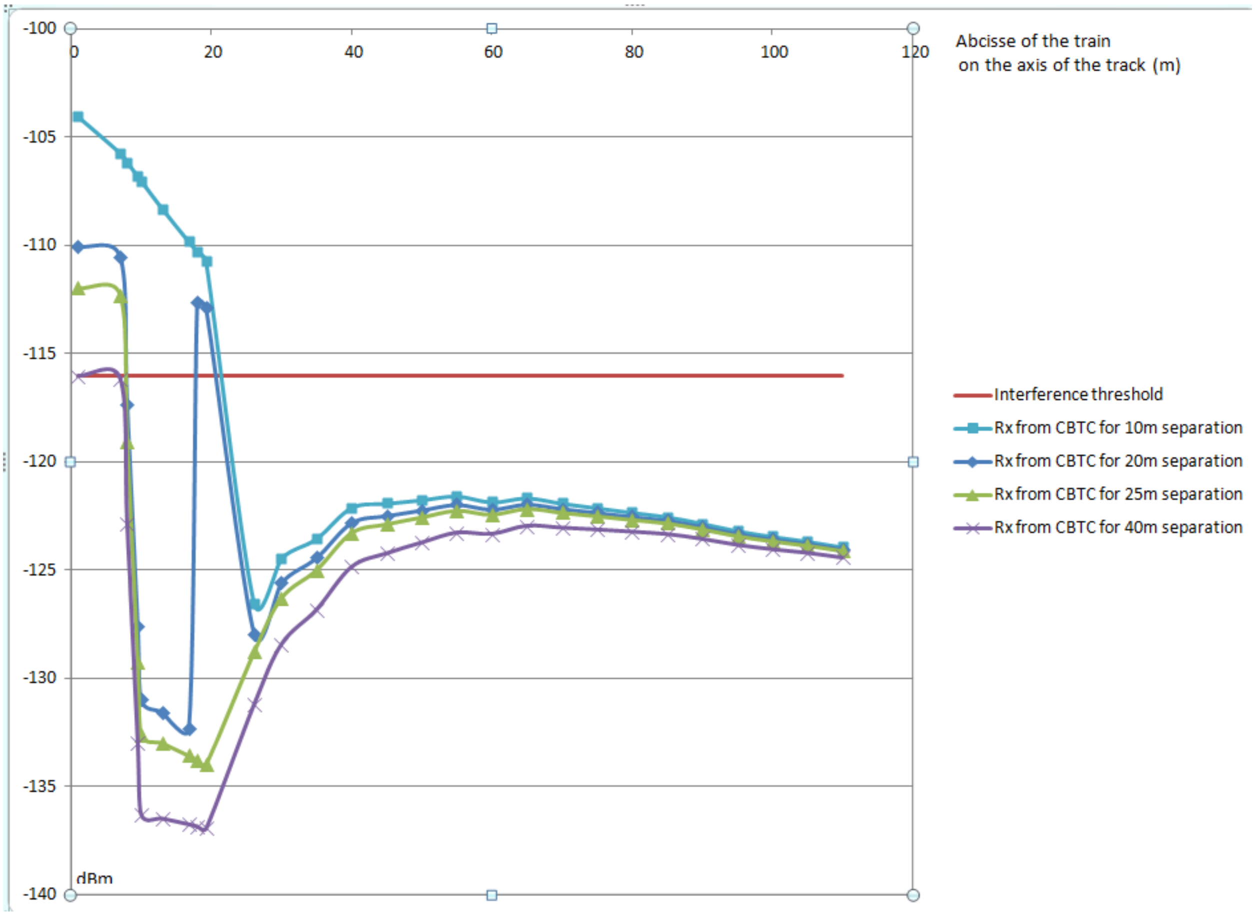


Figure 11: Received level from CBTC train transmitter for different separation distances

Regarding CBTC AP, main difference is the fact that these APs are using even more directive antennas as the on-board radio, so the RSU will be in the main beam of the CBTC AP antenna even further from the RSU.

4.3.2.1 Conclusion on impact from CBTC on the road tolling system

Based on the previous analysis, the conclusions are as follows:

CBTC AP should be installed at a distance of more than 20 metres from an RSU, without any need for other mitigation on CBTC transmitter.

For trains:

- If the distance of track from the road tolling system is larger than 40 metres, there is also no need for specific mitigation on CBTC transmitter.
- If the distance of track from the road tolling system is shorter than 40 metres, a transmit power reduction of up to 12 dB (depending on the separation) should be applied locally at 50 metres around the road tolling position.

4.3.3 Impact of CBTC transmission on FS

The ECC Report 228 study is presented below with CBTC characteristics.

Only urban and suburban propagation models are considered, due to the fact that CBTC systems are used only in these environments and not in rural environment. Only CBTC usage below 5925 MHz is considered.

4.3.3.1 MCL calculations CBTC: operating below 5925 MHz first FS channel with I/N of -20 dB, for different CBTC families

Table 50: MCL calculations CBTC: first FS channel with I/N of -20 dB, for different CBTC families

Link budget	Units	Urban, IEEE 802.11	Suburban, IEEE 802.11	Urban, DSSS	Suburban, DSSS
Emission part: CBTC					
Bandwidth	MHz	5	5	5	5
Tx power e.i.r.p in FS lower channel	dBm/MHz	-17	-17	-33	-33
Frequency (worst case)	MHz	5920	5920	5922.5	5922.5
Reception part: FS					
Receiver Noise bandwidth	MHz	22.6	22.6	22.6	22.6
Long term interference criterion (I/N=-20 dB)	dBm/ MHz	-130	-130	-130	-130
Feeder Loss	dB	3	3	3	3
Antenna Gain	dBi	44	44	44	44
Allowable interference level "I" at receiver antenna input (for FS main lobe)	dBm/MHz	-170.7	-170.7	-170.7	-170.7
Propagation models: see section 2.3 of ECC Report 228					
Main lobe CBTC / Main lobe FS					
Allowable interference level "I" at receiver antenna input (for FS main lobe)	dBm/ MHz	-170.7	-170.7	-170.7	-170.7

Link budget	Units	Urban, IEEE 802.11	Suburban, IEEE 802.11	Urban, DSSS	Suburban, DSSS
Required attenuation (dB)	dB	153.7	153.7	137.7	137.7
Separation distance	m	2993	6892	1271	2614
Main lobe CBTC / Side lobe FS					
Side lobe attenuation	dB	50	50	50	50
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/ MHz	-120.7	-120.7	-120.7	-120.7
Required attenuation (dB)	dB	103.7	103.7	87.7	87.7
Separation distance	m	206	334	84	105
Side lobe CBTC / Main lobe FS					
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/ MHz	-170.7	-170.7	-170.7	-170.7
Side lobe attenuation	dB	18	18	18	18
Required attenuation (dB)	dB	135.7	135.7	119.7	119.7
Separation distance	m	1142	2614	485	879
Side lobe CBTC / Side lobe FS					
Side lobe attenuation	dB	68	68	68	68
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/ MHz	-120.7	-120.7	-120.7	-120.7
Required attenuation	dB	85.7	85.7	69.7	69.7
Separation distance	m	74	84	14	14

4.3.3.2 *MCL calculations CBTC: operating below 5925 MHz FS channels above 5945 MHz with I/N of -20 dB, for different CBTC families*

Table 51: MCL calculations CBTC: FS channels above 5945 MHz with I/N of -20 dB, for different CBTC families

Link budget	Units	Urban, IEEE 802.11	Suburban, IEEE 802.11	Urban, DSSS	Suburban, DSSS
Emission part: CBTC					
Bandwidth	MHz	5	5	5	5
Tx power e.i.r.p. in FS lower channel	dBm/MHz	-32	-32	-33	-33
Frequency (worst case)	MHz	5920	5920	5922.5	5922.5
Reception part: FS					
Receiver Noise bandwidth	MHz	22.6	22.6	22.6	22.6
Long term interference criteria (I/N=-20 dB)	dBm/MHz	-130	-130	-130	-130
Feeder Loss	dB	3	3	3	3
Antenna Gain	dBi	44	44	44	44
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/ MHz	-170.7	-170.7	-170.7	-170.7
Propagation models: see section 2.3 of ECC Report 228					
Main lobe CBTC / Main lobe FS					
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/MHz	-170.7	-170.7	-170.7	-170.7
Required attenuation (dB)	dB	138.7	138.7	137.7	137.7
Separation distance	m	1341	2777	1271	2614
Main lobe CBTC / Side lobe FS					
Side lobe attenuation	dB	50	50	50	50
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/MHz	-120.7	-120.7	-120.7	-120.7
Required attenuation (dB)	dB	88.7	88.7	87.7	87.7
Separation distance	m	89	118	84	105
Side lobe CBTC / Main lobe FS					
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dBm/MHz	-170.7	-170.7	-170.7	-170.7
Side lobe attenuation	dB	18	18	18	18

Link budget	Units	Urban, IEEE 802.11	Suburban, IEEE 802.11	Urban, DSSS	Suburban, DSSS
Required attenuation (dB)	dB	120.7	120.7	119.7	119.7
Separation distance	m	512	933	485	879
Side lobe CBTC / Side lobe FS					
Side lobe attenuation	dB	68	68	68	68
Allowable interference level “I” at receiver antenna input (for FS main lobe)	dB/MHz	-120.7	-120.7	-120.7	-120.7
Required attenuation	dB	70.7	70.7	69.7	69.7
Separation distance	m	15	15	14	14

4.3.3.3 Initial conclusions on impact from CBTC on FS

The separation distances to avoid interference between FS and CBTC systems are higher than the ones calculated for ITS in ECC Report 228 due to the higher CBTC transmit e.i.r.p. in the FS lower channel and the FS subsequent higher frequency channels.

Although the separation distances are reduced due to the CBTC side lobe attenuation they are still greater than previous results for ITS in ECC Report 228.

A study similar the study 2 done in ECC Report 228 could be done in order to take into account the combination of the antenna diagrams of CBTC and of FS and to evaluate the areas of the different situations (main lobe/main lobe, side lobe/main lobe or side lobe/side lobe), depending on the FS antenna height and on the propagation model used. But as the study in ECC Report 228 is done for the worst case where road and FS beam are aligned so in the main lobe/main lobe situation, similar results should be obtained, that is: “It can be seen that with ITS unwanted emissions of -40 dBm/MHz e.i.r.p. an I/N value of -10dB can be achieved with FS antenna heights of ≥20 m in all environments; An I/N -20 dB can be achieved with FS antenna heights of ≥35 m in all environments. With ITS unwanted emissions of -30 dBm/MHz e.i.r.p. an I/N of -10 dB can be achieved with FS antenna heights of ≥35m and I/N -20 dB with FS antenna heights ≥75 m.”

Two factors are limiting CBTC impact on FS:

- CBTC lobes are narrower than ITS ones, in particular in azimuth when ITS is omnidirectional and CBTC is directive, so the areas in a main lobe/ main lobe situation are smaller for CBTC than for ITS;
- CBTC trains are only circulating on their track, so that it is easy to check for a real implementation the real situation regarding side lobes. If additional transmit power control is necessary on certain portions of tracks, in case of FS low antenna height and tracks in the FS beam direction, it can be taken into account by trains (and appropriate AP planning, to maintain the necessary link budget for CBTC link).

4.3.4 Summary for CBTC

Main conclusions for this section are as follows:

- If CBTC tracks parallel to road lines are separated from closest road tolling RSU by more than 40 m, then the CBTC communication system doesn’t have any harmful influence on the road tolling system;
- If CBTC tracks parallel to road lines are separated from closest road tolling RSU by less than 40 m, a transmit power reduction up to 12 dB in order to reach a e.i.r.p. limit of -44 dBm/MHz max (real value depending on the real separation) should be applied locally up to 50 m away from the RSU;
- Regarding FS, the lowest FS channel may be more disturbed than the higher ones due to the vicinity of the highest CBTC channel below 5925 MHz, however coordination may be possible in the deployment phase to avoid that situation. For CBTC in 5925-5935 MHz, the feasibility of coordination in deployment still needs to be analysed;

- For other channels, if the FS antenna height is greater than 75 m, then no additional mitigation is necessary to reach the recommended I/N of -20 dB for FS.
- For FS antennas between 35 m and 75 m, and if there is a situation where a CBTC track is parallel to the FS beam, a maximum e.i.r.p. limit of -40 dBm/MHz (real value depending on the real separation) should be applied for trains in some portion of the track to reach the same I/N of -20 dB for FS (either using TPC based on the train location or a better OOB filter).

5 CONCLUSION

This Report contains an assessment whether the assumptions and conclusions in ECC Reports 101 [1] and 228 [13] are valid for LTE-V2X and Urban Rail such as Communication Based Train Control (CBTC).

Requirements in EN 302 571 [14], related to coexistence with road tolling below 5815 MHz and Fixed Service above 5925 MHz, are based on ECC Report 228, which supersedes ECC Report 101 on these topics.

Co-frequency operation between urban rail and FS in 5925-5935 MHz was not assessed in this Report as it was considered out of scope.

Table 52: Summary of the analysis performed in this Report

Service	Conclusions of ECC Reports 101 and 228		Conclusions on CBTC	Conclusions on LTE-V2X
	ITS as interferer	ITS as victim		
Radio amateur (5830-5850 MHz)	Compatibility is achieved	Compatibility is achieved	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid
FSS (5850-6725 MHz)	Compatibility is achieved	Compatibility is achieved in most cases taking into account the limited number of earth stations and real terrain shielding	ECC Report 101 remains valid	ECC Report 101 remains valid Note 1a
Radiolocation (5725-5850 MHz)	Compatibility is achieved with ITS unwanted power of -55 dBm/MHz, below 5850 MHz	Between 5855-5875 MHz ITS may suffer from interference	For CBTC as interferer, ECC Report 101 remains valid. For CBTC as victim, systems design margin should ensure compatibility above 5875 MHz	ECC Report 101 remains valid Note 1b
SRD (5725-5875 MHz)	Compatibility is achieved if ITS are operating above 5875 MHz. Mitigation techniques are required in the frequency range 5855-5875 MHz	Mitigation techniques are needed in the frequency range 5855-5875 MHz. LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid Note 1b

FWA (5725-5875 MHz)	Compatibility is achieved if ITS are operating above 5875 MHz. Mitigation techniques are required in the frequency range 5855-5875 MHz	Mitigation techniques are needed in the frequency range 5855-5875 MHz. LBT may help avoiding interference to ITS	Compatibility is achieved above 5875 MHz in both ways	ECC Report 101 remains valid Note 1b
RTTT, road tolling (5795-5815 MHz)	Compatibility is achieved if ITS unwanted emissions are limited below 5815 MHz: ▪ to -65 dBm/MHz without mitigation techniques; ▪ to -45 dBm/MHz taking into account the specification given for ITS in ETSI EN 302 637-2 [12], EN 302 571 [14] and timing requirements according to ECC Report 228	Interference depends on the antenna beams alignment and is limited to the RTTT communication zone.	Compatibility is achieved above 5875 MHz. In case of proximity to the RTTT communication zone, adequate system design is required.	Compatibility is achieved under mode A*. Note 2a Under mode B*, compatibility could be achieved if timing requirements (Ton & Toff) and the aggregated spurious emissions do not exceed those of ITS in ECC Report 228 in the interference zone Note 2b
FS (5925-6425 MHz)	An unwanted emission limit of -40 dBm/MHz is able to avoid harmful interference (I/N=-20dB) to the Fixed Service or an unwanted emission limit of -30 dBm/MHz may be sufficient to avoid harmful interference to the Fixed Service with mitigation techniques	ITS within the band 5905-5925 MHz may suffer from interference	When tracks and FS beam are aligned, an unwanted emission limit of -40 dBm/MHz for CBTC should be applied FS will have limited impact on CBTC operating in the band 5905-5925 MHz taking into account the system margin	ECC Reports 101 and 228 remain valid Note 1b

* Modes A and B are specified in ETSI TS 102 792 [15] Table 5.3, which is part of the requirements defined in EN 302 571.

Note 1a: As per considering n) in ECC/DEC/(08)01 [24], duty cycle restrictions and specified frequency re-use conditions are beneficial for the compatibility with other systems and for the efficient use of the spectrum by cooperative ITS systems.

Note 1b: LTE-V2X systems have to comply with the technical conditions defined in ECC/DEC/(08)01 and with the requirements given in EN 302 571 related to unwanted emissions. With regard to the Fixed Service, requirements given in EN 302 571 are based on ECC Report 228.

Note 2a: On compatibility between LTE-V2X and road tolling in Mode A:

For LTE-V2X devices in coexistence mode A, an aggregation of spurious emissions from multiple vehicles is considered not to be an issue. In ECC Report 228 it was shown that for spurious emissions of -65 dBm/MHz per ITS device practically no interference zone exists. Therefore contributions of simultaneously transmitting devices from multiple vehicles are assumed to be negligible due to additional propagation losses in comparison with a single dominant device.

Note 2b: On compatibility between LTE-V2X and road tolling in mode B:

using repeated retransmissions of CAM within a road tolling RSU interference zone may result in lost road toll transactions;

if CAM retransmissions occur, the average air time of LTE-V2X transmissions within the road tolling RSU interference zone may be longer than the average air time requirements in ECC Report 228 derived for CAM. Compatibility can be achieved if LTE-V2X stations reduce their average air time within the road tolling RSU interference zone in accordance with the timing requirements in ECC Report 228. For a 1 second interval, the air time of the transmissions is the number of used sub-frames times the sub-frame length of 1 ms;

the requirements regarding air time issues (Ton & Toff) are not yet specified in the current versions of 3GPP LTE-V2X specifications.

ANNEX 1: REQUIREMENTS FOR ROAD TOLLING PROTECTION

For handling Road Tolling interference mitigation, 3GPP RAN4 included additional configured transmitted power requirements and UE to UE coexistence spurious emission requirements were specified in 3GPP TS 36.101.

The LTE-V2X UE is allowed to set its configured maximum output power $P_{CMAX,c}$ for component carrier c. The configured maximum output power $P_{CMAX,c}$ is set within the following bounds:

$P_{CMAX\_L,c} \le P_{CMAX,c} \le P_{CMAX\_H,c}$

with

- $P_{CMAX\_L,c}$ = MIN {$P_{EMAX,c}$ – $\Delta T_{C,c}$, $P_{PowerClass}$ — MAX(MPR_c + A-MPR_c + $\Delta T_{IB,c}$ +$\Delta T_{C,c}$ + ΔT_{ProSe}, P-MPR_c), $P_{Regulatory,c}$ }
- $P_{CMAX\_H,c}$ = MIN {$P_{EMAX,c}$, $P_{PowerClass}$, $P_{Regulatory,c}$ }

Where:

- For the total transmitted power $P_{CMAX,c}$ of P_{SSCH} and P_{SCCH}, $P_{EMAX,c}$ is the value given by IE *maxTxPower*, defined by [4], when the UE is not associated with a serving cell on the LTE-V2X carrier;
- For $P_{CMAX,PSBCH}$, $P_{EMAX,c}$ is the value given by the IE *maxTxPower* in [4] when the UE is not associated with a serving cell on the LTE-V2X carrier;
- For $P_{CMAX,SSSS}$, the value is as calculated for $P_{CMAX,PSBCH}$ and applying the MPR for SSSS as specified in Section 6.2.3D of 3GPP TS 36.101;
- $P_{PowerClass}$ is the maximum UE power specified in Table 6.2.2-1 of 3GPP TS 36.101 without taking into account the tolerance specified in the Table 6.2.2-1 of 3GPP TS 36.101;
- MPR_c and A-MPR_c for serving cell c are specified in subclause 6.2.3G and subclause 6.2.4G of 3GPP TS 36.101, respectively;
- $\Delta T_{IB,c}$, $\Delta T_{C,c}$, ΔT_{ProSe} and P-MPR_c are specified in subclause 6.2.5 of 3GPP TS 36.101;
- $P_{Regulatory,c}$ = 10 dBm when the CEN DSRC tolling system is nearby V2X UE; $P_{Regulatory,c}$ = 33 dBm otherwise.

P-MPR_c is the allowed maximum output power reduction for

a) ensuring compliance with applicable electromagnetic energy absorption requirements and addressing unwanted emissions / self-defence requirements in case of simultaneous transmissions on multiple RAT(s) for scenarios not in scope of 3GPP RAN specifications;

b) ensuring compliance with applicable electromagnetic energy absorption requirements in case of proximity detection is used to address such requirements that require a lower maximum output power.

The UE shall apply P-MPR_c for serving cell c only for the above cases. For UE conducted conformance testing P-MPR shall be 0 dB.

NOTE 1: P-MPR_c was introduced in the $P_{CMAX,c}$ equation such that the UE can report to the eNB the available maximum output transmit power. This information can be used by the eNB for scheduling decisions.

NOTE 2: P-MPR_c may impact the maximum uplink performance for the selected UL transmission path.

UE to UE coexistence spurious emission requirements are specified in Table 53.

Table 53: Requirements

E-UTRA Band	Spurious emission						
	Protected band	Frequency range (MHz)			Maximum Level (dBm)	MBW (MHz)	NOTE
…							
47	E-UTRA Band 1, 3, 5, 7, 8, 22, 26, 28, 34, 39, 40, 41, 42, 44, 45, 65, 68	FDL_low	-	FDL_high	-50	1	
	Frequency range	5925	-	5950	-30	1	1, 2
	Frequency range	5815	-	5855	-30	1	38
48	E-UTRA Band 2, 4, 5, 12, 13, 14, 17, 24, 25, 26, 29, 30, 41, 66, 70	FDL_low	-	FDL_high	-50	1	
65	E-UTRA Band 1, 7, 8, 20, 22, 28, 31, 32, 38, 40, 42, 43, 65, 68, 69	FDL_low	-	FDL_high	-50	1	

NOTE 1: Applicable when NS_33 or NS_34 is configured by the pre-configured radio parameters.
NOTE 2: In the frequency range x-5950 MHz, SE requirement of -30 dBm/MHz should be applied; where x = max (5925, fc + 15), where fc is the channel centre frequency.

When "NS_33" or "NS 34" is configured from pre-configured radio parameters or the cell and the indication from upper layers has indicated that the UE is within the protection zone of CEN DSRC devices or HDR DSRC devices, the power of any V2X UE emission shall fulfil either one of the two set of conditions in Table 54.

Table 54: UE emissions within protection zones

	Maximum Transmission Power (dBm e.i.r.p.)	Emission Limit in Frequency Range 5795-5815 MHz (dBm/MHz e.i.r.p.)
Condition 1	10	-65
Condition 2	10	-45

UEs that comply with the total transmitted power requirements described above in combination with the spurious emission requirements and further requirements from ETSI TS 102 792 (Version 1.1.1), such as Ton and Toff requirements shown in Figure 6, will meet the protection requirements for CEN DSRC tolling systems and no further interference from such LTE-V2X system UE is expected when CAM messages based on EN 302 637-2 are transmitted with one sub-frame per CAM.

ANNEX 2: CAM GENERATION RULES AND PROCESSES

A2.1 INTRODUCTION

In this section the rules for the generation of a cooperative awareness message (CAM) in a cooperative ITS systems will be presented. The CAM is the main message type of a cooperative ITS system and it has been estimated that it will represent around 70% the traffic load of such a system. The generation rules are specified in ETSI EN 302 672-2 [36]. The rules specified here can be used as the basis for the calculation of the maximum CAM rate and the possible CAM sizes.

A2.2 CAM GENERATION RULES

The cooperative awareness message (CAM) is the basic message in all cooperative ITS and builds the basis for a broad range of applications and use cases.

The CAM is a message which is transmitted by any ITS-Station (e.g. vehicle and infrastructure devices). The CAM can be seen as a container to carry different information. The periodicity of the CAM ranges between 1Hz and 10Hz depending on the dynamic behaviour of the vehicle (speed, steering, acceleration, path history, etc.). The CAM also includes security content like security certificates. The size of the CAM can vary between around 200 Bytes and up to 800 Bytes depending on the data content. The size of the CAM can vary from one CAM to the next one. Especially the content of the high frequency container can change rapidly.

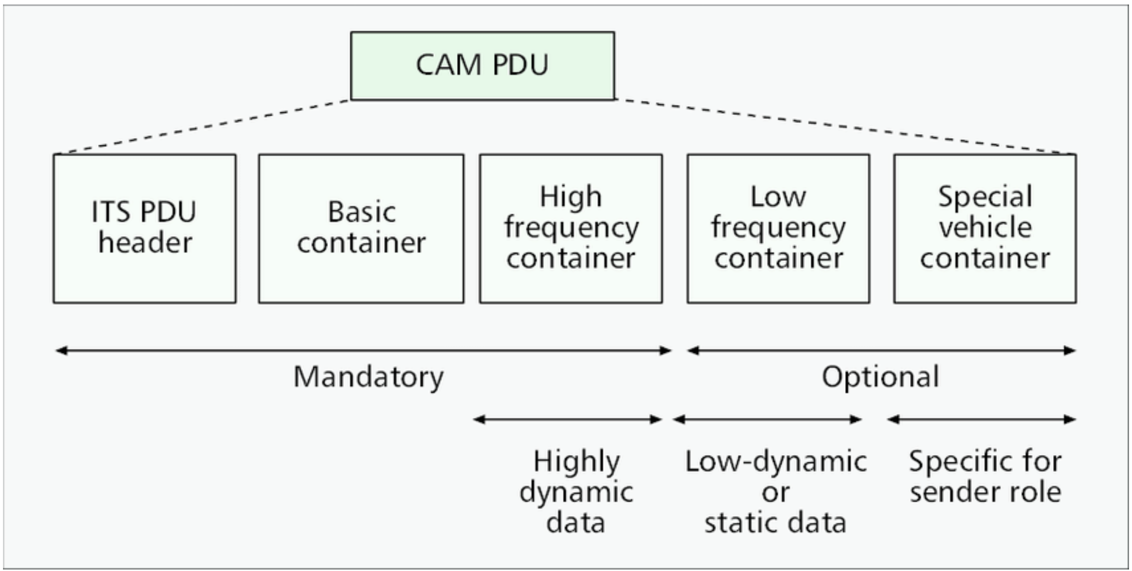


Figure 12: Overview CAM Structure [12]

The details can be found in the ETSI EN 302 637-2 [12]. An overview over the structure is depicted in figure 1 where PDU means Packet Data Unit.

The CAM generation process considers the speed of the vehicle, the change in direction (heading) and the change in speed. Each of these parameters can trigger the generation of a CAM when reaching a specified threshold. These thresholds are defined in [12]:

Speed: A change in position by more than 4m

Heading: A change of direction of equal or more than +/- 4°

Change of speed: A change of speed equal to or larger than 0,5m/sec

If none of these conditions are fulfilled for 1 second or more a CAM is generated. The smallest time gap between two consecutive CAMs is set to 0,1sec. This leads to a maximum CAM frequency of 10Hz and a minimum CAM frequency of 1Hz. Repetition operations on the physical layer of an ITS transmission process can lead to higher message rates in the air.

The dynamic non-deterministic generation of the CAM leads to a very efficient use of the spectrum and can help to avoid congestion in the wireless channel maintaining the required information deliverable to the surrounding vehicles and devices.

Due to the number of relevant parameters in the CAM generation process the CAM time interval (time between two successive CAMs) can vary significantly. The results of a test drive are given in Figure 13. The x-axes depicts the CAM number and the time between two successive CAMs is given on the y-axes. In this measurement the inter CAM spacing varies from 1 second corresponding to 1Hz to 0,1 second corresponding to 10Hz.

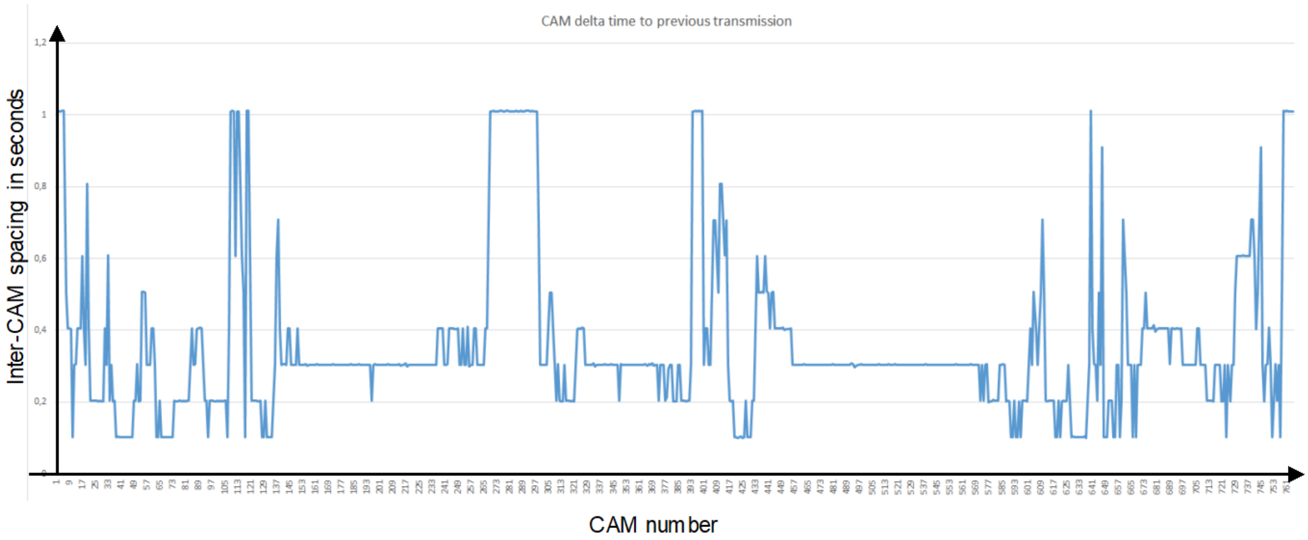


Figure 13: CAM time interval recorded during a real measurement drive:
X-axes: CAM number
Y-axis: inter CAM timing in seconds

The vehicular speed during this test drive was well below 60km/h and the environment was a sub urban industrial area with office buildings. In this case the main factor for the triggering of a CAM generation was the steering direction and the acceleration of the vehicle. It has to be mentioned that also the CAM size varies for successive CAM messages which has not been measured during this test drive.

An additional set of actual test drive data for the CAM time-interval are given in Figure 14, Figure 15 and Figure 16.

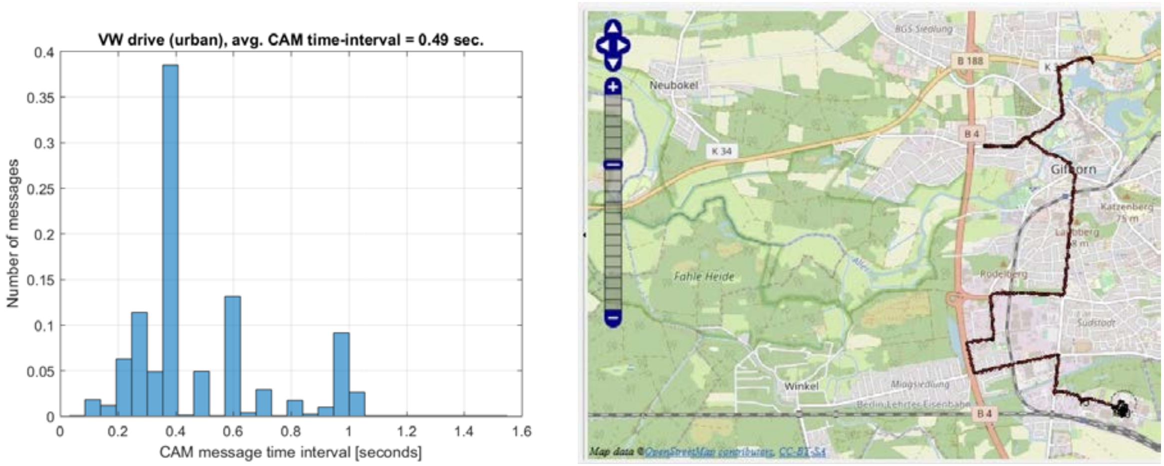


Figure 14: CAM Time-interval in Urban environment and map

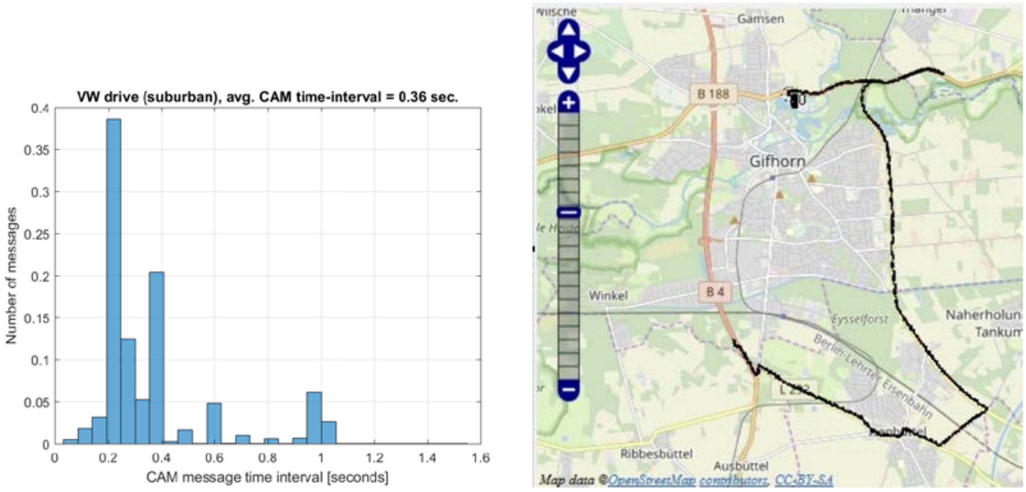


Figure 15: CAM Time-interval in Urban environment and map

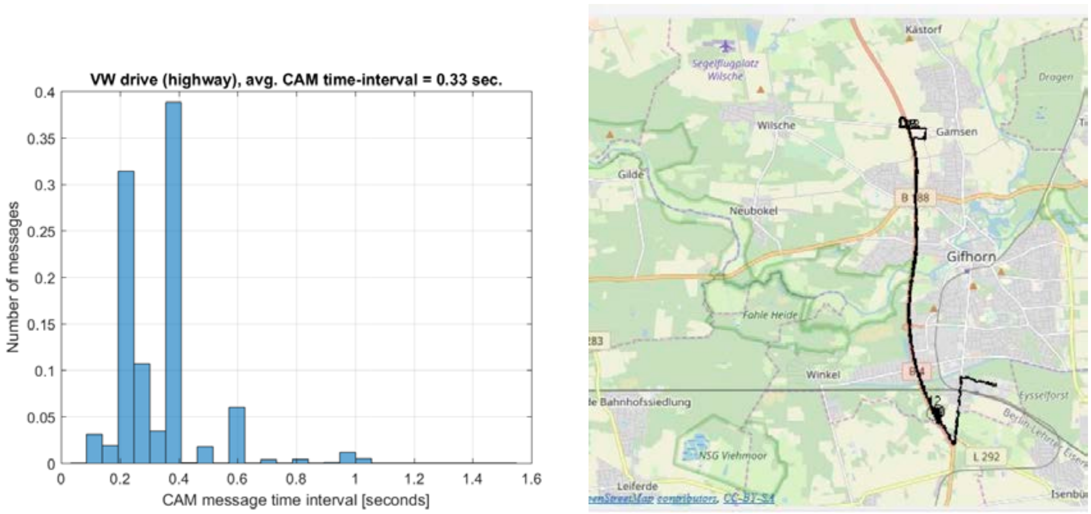


Figure 16: CAM Time-interval in highway like environment and map

In another test performed in a highway scenario the varying message size has been recorded.

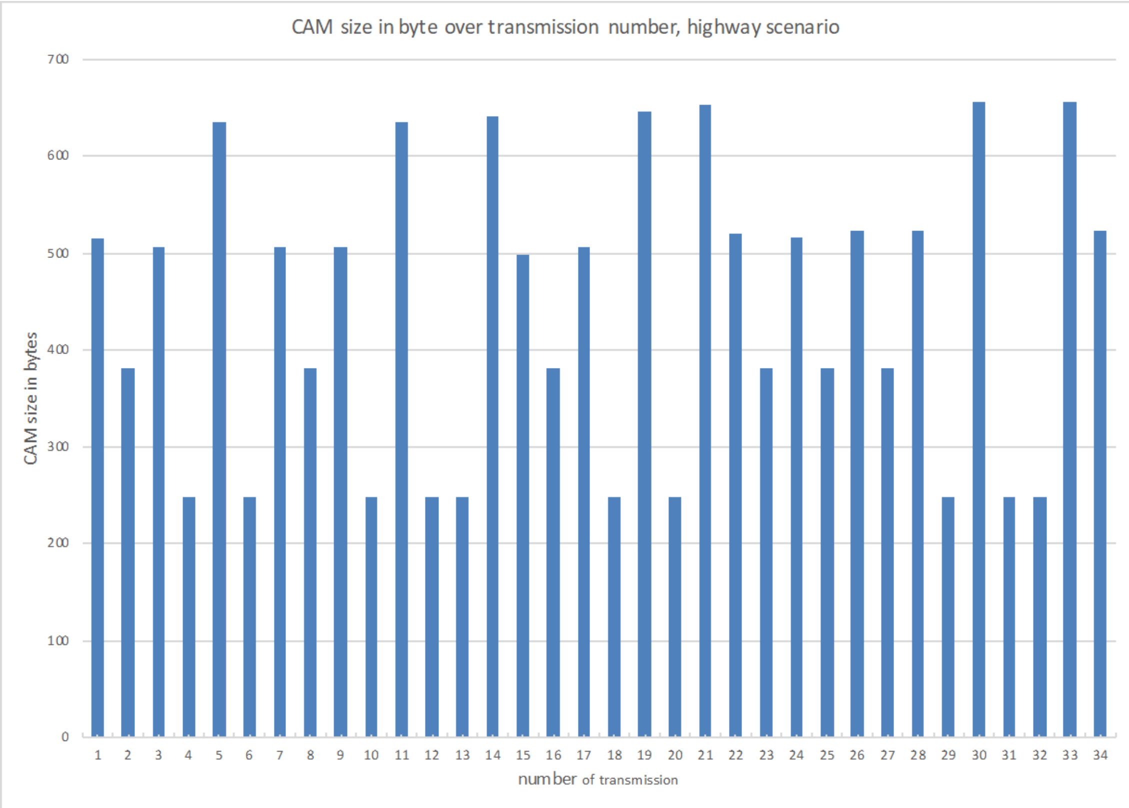


Figure 17: Dynamic CAM sizes in an Highway scenario

In the CAM sizes are depicted for 33 CAM transmitted over a time span of around 13s. It can be seen that the CAM size is not predictable during the measurement duration. In this case the sizes vary between around 250 Bytes and 650Bytes.

Figure 18: Dynamic CAM sizes in a traffic light scenario

In the dynamic CAM sizes in a traffic light scenario is depicted. Here the vehicle accelerates starting from 0km/h to around 50km/h. Here the CAM size values vary from 250 Bytes to 720 bytes.

Size distribution results from longer test drives given in Figure 14 to Figure 16 are given in the following figures including the corresponding average values for the size.

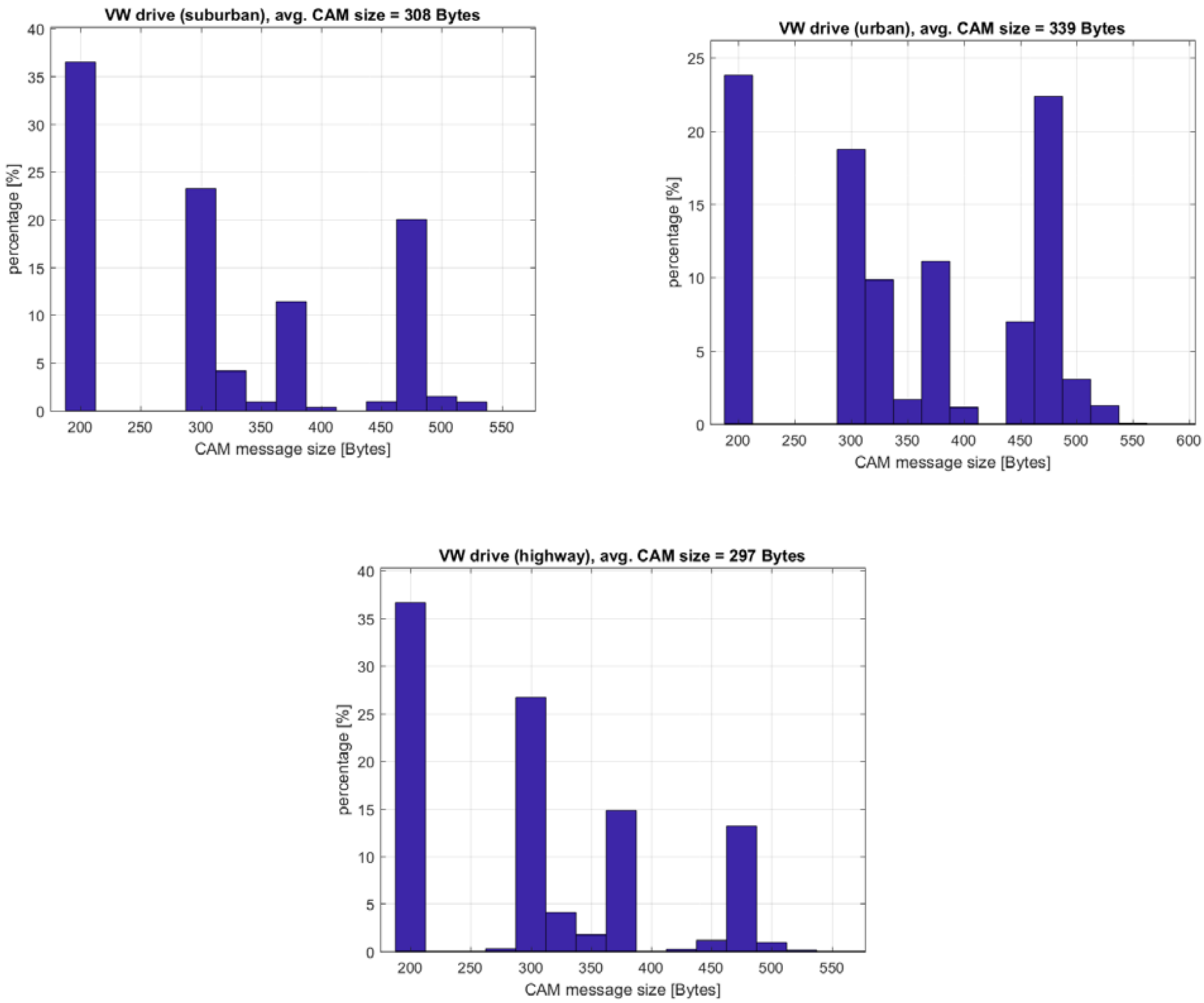


Figure 19: Dynamic CAM sizes Urban, sub-urban and highway scenario (maps given in Figure 14 to Figure 16

More results from a different implementation and different test drives in Vienna, Austria are given in Figure 20.

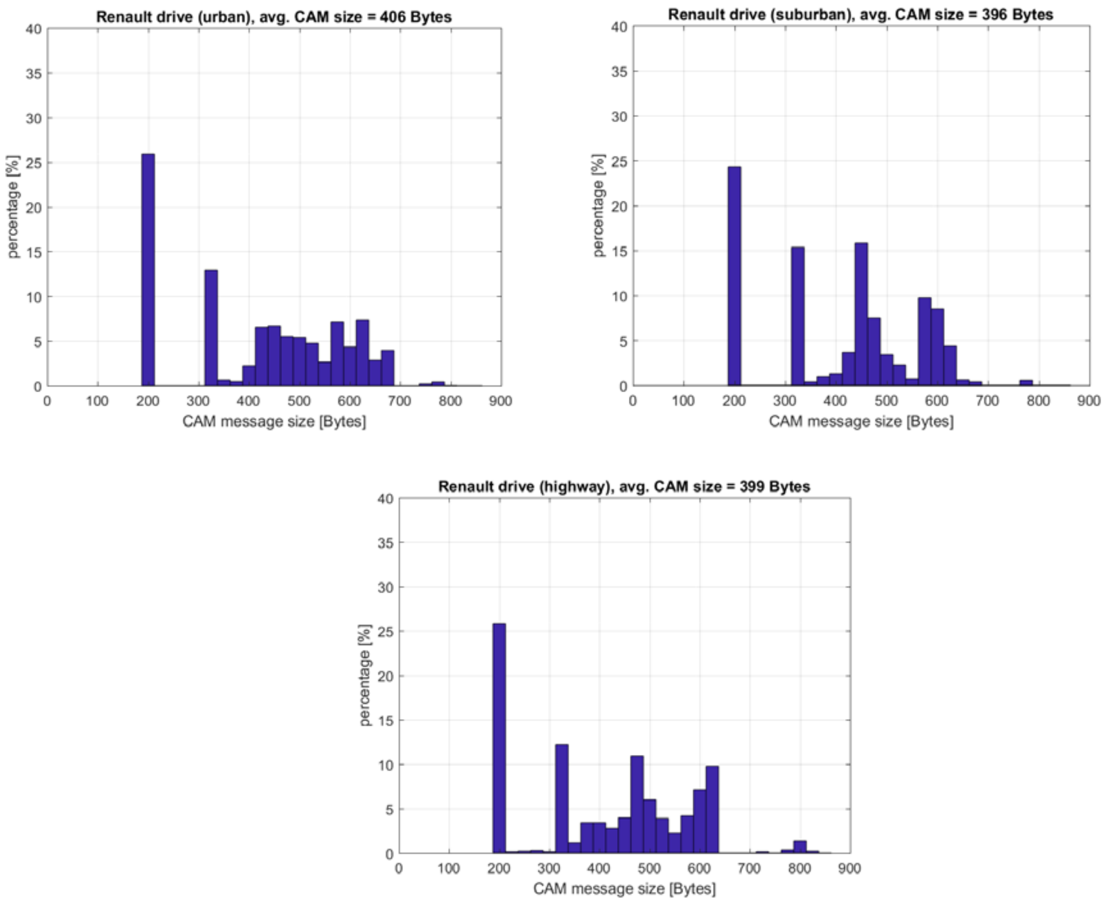


Figure 20: Dynamic CAM sizes in test drives in Vienna, Austria in different environments

A2.3 CONCLUSION

In this section the CAM generation rules have been presented. The maximum CAM rate specified is 10Hz. The CAM rate itself is not fixed and not periodic but varies from one CAM to another. The generation of a CAM is not predictable.

The CAM size in presented measurements varies between around 200 Bytes and over 800 Bytes. The CAM size cannot be predicted in advance. The overall CAM generation process is a non-deterministic operation. The average size in the different test drives varies from around 300 bytes up to 406 bytes depending in the actual implementation and environment.

ANNEX 3: LIST OF REFERENCES

[1] ECC Report 101: “Compatibility studies in the band 5855 – 5925 MHz between Intelligent Transport Systems (ITS) and other systems”, Bern, 2007

[2] 3GPP TS 36.101: “Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception”, v14.7.0, Release 14, March 2018

[3] 3GPP TR 36.786: "Technical Specification Group Radio Access Network; Vehicle-to-Everything (V2X) services based on LTE; User Equipment (UE) radio transmission and reception V14.0.0", March 2017

[4] 3GPP TS 36.331: “Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification”, v14.3.0, Release 14”, July 2017

[5] 3GPP TS 36.321: “Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification” ,v14.3.0, Release 14, June 2017

[6] 3GPP TS 36.213: “Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures (v14.3.0, Release 14)”, June 2017

[7] 3GPP TS 36.300: “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2”, v14.7.0, Rel. 14 and v15.2.0, Rel. 15,” June 2018

[8] 3GPP TS 36.211: “Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation”, v14.7.0, Rel. 14 and v15.2.0, Rel. 15”, June 2018

[9] 3GPP TS 23.285: “Architecture enhancements for V2X services”, v14.7.0, Rel. 14 and v15.1.0, Rel. 15,” June 2018

[10] 3GPP TS 36.785: “Vehicle to Vehicle (V2V) services based on LTE sidelink; User Equipment (UE) radio transmission and reception”, v14.0.0”, October 2016

[11] 3GPP TS 36.786: “Vehicle-to-Everything (V2X) services based on LTE; User Equipment (UE) radio transmission and reception”, v14.0.0, March 2017

[12] ETSI EN 302 637-2: “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service”

[13] ECC Report 228: "Compatibility studies between Intelligent Transport Systems (ITS) in the band 5855-5925 MHz and other systems in adjacent bands", January 2015

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

[15] ETSI TS 102 792: “Intelligent Transport Systems (ITS); Mitigation techniques to avoid interference between European CEN Dedicated Short Range Communication (CEN DSRC) equipment and Intelligent Transport Systems (ITS) operating in the 5 GHz frequency range", V1.2.1 (2015-06)

[16] RSCOM17-26 rev.3: "Mandate to CEPT to study the extension of the Intelligent Transport Systems (ITS) safety-related band at 5.9 GHz", 18 October 2017.

[17] IEEE 802.11a: "Information Technology - Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements"

[18] IEEE 802.11p: "Wireless Access in Vehicular Environments (WAVE) "

[19] IEEE 802.11j: "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- Amendment 7: 4.9 GHz–5 GHz Operation in Japan"

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

[21] ETSI EN 300 440 V2.2.1: “Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range; “Harmonised Standard for access to radio spectrum”

[22] ETSI EN 301 893: “5 GHz RLAN; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU”

[23] ECC Report 68: “Compatibility studies in the band 5725-5875 MHz between Fixed Wireless Access (FWA) systems and other systems”

[24] ECC/DEC(08)01: “Harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS)”

[25] ECC/REC/(08)01: “Use of the Band 5855-5875 MHz for Intelligent Transport Systems (ITS)”

[26] ETSI EN 302 663: "Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band", (V1.2.1) (11-2012)

[27] Recommendation ITU-R SM.329: “Unwanted emissions in the spurious domain”

[28] ERC Recommendation 74-01E: “Spurious Emissions”

[29] 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"
[30] ETSI TR 103 111: "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Spectrum requirements for Urban Rail Systems in the 5,9 GHz range"
[31] CEN EN 12253 (2004): "Road transport and traffic telematics - Dedicated short-range communication - Physical layer using microwave at 5,8 GHz"
[32] CEN EN 13372 (2004): "Road Transport and Traffic Telematics (RTTT) - Dedicated short-range communication - Profiles for RTTT applications"
[33] ETSI TS 103 613 V1.1.1 (2018-11) Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems using LTE Vehicle to everything communication in the 5,9 GHz frequency band
[34] ETSI TS 122 185: "LTE; Service requirements for V2X services (3GPP TS 22.185 version 14.4.0 Release 14), V14.4.0 (2018-07)
[35] ECC Report 291: "Compatibility studies between smart tachograph, weight&dimension applications and systems operating in the band 5795-5815 MHz and in the adjacent bands"
[36] ETSI EN 302 217-2: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2: Digital systems operating in frequency bands from 1 GHz to 86 GHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU"