Position Paper on

Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). Today, the Consortium comprises 73 members, with 12 vehicle manufacturers, 33 equipment suppliers and 28 research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands as well as other road users. As a key contributor, the CAR 2 CAR Communication Consortium works in close cooperation with the European and international standardisation organisations such as ETSI and CEN.

Disclaimer

Document Qualification

Number:	TR 2050	**Version:**	2.00	**Date:**	02-26-2020
Title:	Position Paper on Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving			**Document Type:**	TR (Position Paper)
Release:	External Publication				
Release Status:	Released for public sharing				
Status:	**Released** / Functional Completed / Completed				

Changes since last version

Date	Changes	Edited by	Approved
03/03/2020	Spectrum calculation and related explanations in Annex A, B, summarized in figure 7 page 19 and figure 8 page 21, recommending summary	Release Management	Steering Committee
01/12/2018	Initial release	Release Management	Steering Committee

Content

About the C2C-CC 1
Disclaimer 1
Document Qualification 2
Changes since last version 2
1 Introduction 4
2 Recommending summary 5
3 Spectrum regulation 9
4 Spectrum allocation for initial C-ITS applications 10
5 Spectrum requirements for C-ITS and cooperative automated driving 13
5.1 European spectrum needs. 13
5.2 Functional Safety. 20
5.3 USA spectrum needs. 20
6 Annex A 5.9 GHz C-ITS and cooperative automated driving spectrum requirement calculations, Europe 23
7 Annex B 5.9 GHz C-ITS and cooperative automated driving spectrum requirement calculations, USA 35

1 Introduction

This white paper provides an overview of Cooperative Intelligent Transportation Systems (C-ITS) and Cooperative Automated Driving application information needs. It provides an overview of the current regulation [chapter 3], it confirms the spectrum needs for the first C-ITS awareness related applications as being implemented today [chapter 4] and it provides an outlook on expected spectrum requirements as can be expected for road safety related and road efficiency related information exchange for the extended list of C-ITS and Cooperative Automated Driving applications [chapter 5]. For the analyses, results from European projects have been used and in consensus with key vehicle manufacturers C-ITS message exchange calculations are presented. In the Recommending Summery [chapter 2] the recommendations are presented.

2 Recommending summary

The CAR 2 CAR Communication Consortium (C2C-CC) recognizes many Cooperative-Intelligent Transportation Systems (C-ITS), including cooperative automated driving applications leading to various functional and technical requirements. It sees a large growth of Automated / Autonomous Driving and C-ITS applications, exchanging related information between vehicles and between vehicles and other road users as well as road infrastructure.

Evaluating C-ITS Day-1 application regarding spectrum needs show that C-ITS basic awareness applications will require 10 MHz bandwidth during the initial 10 years. The spectrum needs analysis of applications for Day-2 and beyond was done based on European C-ITS projects and based on already in ETSI or SAE specified advanced C-ITS applications and their message types, see Table 1:

Table 1: Relationship of V2X applications to message types to phases of V2X application roadmap

Phases of V2X application roadmap[2]	Message types[1]			Examples of applications based on the message types
	Europe	USA	Abbreviations explained	
Awareness driving	CAM, DENM	BSM	Cooperative Awareness message, Decentralized Environmental Notification Message, Basic Safety Message	Intersection Collision Warning Emergency Vehicle Warning Dangerous Situation Warning Stationary Vehicle Warning Traffic Jam warning Pre-/Postcrash Warning
	SPaT, MAP, IVI	SPaT, MAP, IVI	Signal Phase and Time, MAP message, In-Vehicle-Information message	Enabling Infrastructure-to-Vehicle Communication at e.g. traffic lights
	VAM	PSM	VRU Awareness Message, Personal Safety Message	VRU warning for (C-ITS) equipped Vulnerable Road Users
Sensing Driving / sensor sharing	CPM	CPM	Collective Perception Message	Overtaking Warning Extended Intersection Collision Warning Vulnerable Road User Warning for non-equipped VRU´s Cooperative Adaptive Cruise Control Long-term Road Works Warning Special Vehicle Prioritisation
Cooperative Driving with Coordinated maneuvering and cooperative automated driving	MCM, PCM	MCM, PCM	Maneuver Coordination Message, Platooning Control Message	(Static or dynamic) Platooning Area reservation Cooperative Merging Cooperative Lane Change Cooperative Overtaking

[1] CAM, Cooperative Awareness Message, specified in ETSI EN 302 637-2

DENM, Decentralized Environmental Notification Message, specified in ETSI EN 302 637-3

SPATEM, Signal, Phase, and Timing, ISO/TS 19091:2017

MAPEM, road/lane topology and traffic maneuver ISO/TS 19091:2017

VAM, Vulnerable Road User (VRU) Awareness Message ETSI TS 103 300-3, Pedestrian protection with Personal Safety Messages (PSM) according to SAE J2735, SAE J2945/9_201703 https://www.sae.org/standards/content/j2945/9_201703/

PCM, Platooning Control Message draft specification in ETSI TR 103 298, currently being drafted in the European H2020 project ENSEMBLE (multi-brand truck platooning) https://platooningensemble.eu/ https://platooningensemble.eu/news/using-its-g5-for-efficient-truck-platooning5c1a203e7a226

CPM Collective Perception Message, draft ETSI TS 103 324, ETSI TR 103 562

MCM Manoeuvre Coordination Message, according to ETSI TR 103 578 (draft) “Informative report for the Manoeuvre Coordination Service”; https://imagine-online.de/en/home/

A communication technology independent spectrum analyses presented in this paper confirmed by vehicle manufacturers show that at least 70 MHz bandwidth will be needed for today's well defined C-ITS applications, based on the C-ITS messages to enable the C2C-CC application roadmap[2] from (these phases follow table 1 and C2C-CC application roadmap):

- awareness driving (day-1) over
- sensing driving up to
- cooperative automated driving

The spectrum needs for European and US market show very similar that 70 MHz of spectrum for safety is a minimum requirement, see Table 2 and Table 3.

Table 2: European V2X spectrum needs for safety in 5.9 GHz

Safety spectrum needs for a single short-range V2X communication technology in MHz bandwidth, in 5.9 GHz safety band

	environment			
message type	**urban**	**suburban**	**Rural** (Highway)	min number of 10 MHz Channels
CAM cooperative awareness message	9	10	10	0,9
DENM decentralized environmental notification message	4	2	1	0,1
SPATEM signal phase and timing**, MAPEM** road/lane topology and traffic maneuver **, IVI** in-vehicle-information and other I2V messages	1	1	1	0,5
VAM VRU awareness message	4	0,2	2	0,5
PCM platooning control message	3	6	10	1,0
CPM collective perception message	23	26	24	2,0
MCM maneuver coordination message	23	26	24	2,0
Minimum basic spectrum needs in MHz	**67**	**72**	**72**	
total number of 10 MHz channels required				**7**

[2] https://www.car-2-car.org/fileadmin/downloads/PDFs/roadmap/CAR2CAR_Roadmap_Nov_2018.pdf

Table 3: US V2X spectrum needs for safety in 5.9 GHz

Safety spectrum needs for a single short-range V2X communication technology in MHz bandwidth, in 5.9 GHz safety band

	environment			
message type	**urban**	**suburban**	**Rural** (Highway) light traffic, high speed	number of 10 MHz Channels
BSM Basic Safety Message	9	10	9	1
SPAT signal phase and timing**, MAP** road/lane topology and traffic maneuver **, IVI** in-vehicle-information and other **I2V messages**	1	1	1	0,5
PSM personal safety message	4	1	2	0,5
PCM platooning control message	3	6	10	1
CPM collective perception message	23	26	24	2
MCM maneuver coordination message	23	26	24	2
Minimum basic spectrum needs in MHz for safety	**63**	**70**	**70**	
number of 10 MHz channels required				**7**

The C2C-CC recommends the following for V2X spectrum for allowing the growth of road safety and road efficiency information exchange in the 5.9 GHz band and reach ambitious goals to reduce road accident and fatalities as well as to enable cooperative automated driving:

- Protecting 70 MHz in 5.9 GHz of spectrum for transportation safety V2X communication in US and Europe.
- Following the WRC recommendation 208 in conjunction with Recommendation ITU-R M.2121-0, to allocate 70 MHz Band in 5.9 GHz for ITS in all regions worldwide.
- - as in USA 70 MHz of C-ITS spectrum is designated-
    - keeping 70 MHz plus 5 MHz of guard band for C-ITS / V2X for safety communication. With less than 70 MHz either cooperative automated driving (see MCM, PCM messages) or protection of VRU´s through sensing driving (see CPM messages) will be impossible.
- - as in Europe already 70 MHz of C-ITS spectrum are available or reserved-
    - Updating the current ECC via ECC Decision (08)01[3] to safeguard the foreseen upper 20 MHz for future ITS and designate in total 50 MHz (5 bands of 10 MHz) from 5875-5925 MHz for traffic safety;
    - Supporting the update of the related EU regulation based on the Commission Decision 2008/671/EC (2008)[4] to enable full access for V2V, V2I, V2P communication for transportation safety from 5875 – 5925 MHz.
    - -as 20 MHz of spectrum are available for non-safety ITS communication (according to Commission Implementing Decision (EU) 2019/1345)-

[3] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC0801.PDF

[4] http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008D0671

Finding suitable solutions with regulators how this spectrum can be enhanced for the use of transportation safety in 5850 – 5875 MHz.

- Recognizing that the currently allocated spectrum may not be sufficient and thus consider possible further extensions in other spectra .

These above recommendations are derived based on this paper analysis confirming the robust prediction of spectrum needs as specified in the ETSI TR 102 492-2 from 2008.

3 Spectrum regulation

In Europe, the band 5855-5925 MHz has been identified specifically to road safety and traffic efficiency based on the available land mobile service identification in the band:

- The European Commission has harmonised the band 5875-5905 MHz for traffic safety related applications in the European Union via the legally binding Commission Decision 2008/671/EC (2008)[5].
- The CEPT[6] harmonisation is applied by the ECC via ECC Decision (08)01[7] from 2008, which additionally indicates that CEPT administrations shall consider the designation of the frequency sub-band 5905-5925 MHz for an extension of ITS spectrum.
- CEPT also recommends, via ECC Recommendation (08)01[8] from 2008, that CEPT administrations should make the frequency band 5855-5875 MHz available for traffic non-safety applications. Based on Commission Implementing Decision (EU) 2019/1345 the band 5855-5875 MHz is now designated for non-safety ITS.

The above regulatory measures from the ECC refer to the ETSI Harmonized Standard EN 302 571[9] and define requirements for operation of ITS equipment in 5855-5925 MHz, covering the essential requirements of article 3.2 of the Radio Equipment Directive (2014/53/EU)[10]. According to ECC DEC (08)01 and ECC REC (08)01, equipment complying with EN 302 571 are exempt from individual licensing for operating in this band.

The EU's New Radio Equipment Directive (RED) 2014/53/EU has required an update of EN 302 571. The specification was accepted early 2017 and published in the OJEU on 9 June 2017.

While the current EU regulatory framework designated the 5855-5905 MHz band to C-ITS, several European Union member states follow CEPT ECC DEC (08)01 and have designated the full band 5855-5925 MHz for Cooperative Intelligent Transport Systems (C-ITS).

[5] http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008D0671

[6] https://cept.org

[7] http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCDEC0801.PDF

[8] http://www.erodocdb.dk/Docs/doc98/official/pdf/REC0801.PDF

[9] https://portal.etsi.org/Portals/0/TBpages/edithelp/Docs/en_302571v2.1.1_Compared%20with%20previous%20version.pdf

[10] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32014L0053

4 Spectrum allocation for initial C-ITS applications

As basis for the realisation of the installed spectrum regulation of 2008 as described in chapter 3, analyses were conducted at ETSI TC ERM in the period of 2004-2006. These analyses resulted in the proposed regulation and licensing conditions described in two ETSI ERM reports, TR 102 492-1[11] in 2005 and TR 102 492-2[12] in 2006. In TR 102 492-1 an initial set of safety related applications (see **Figure 2**) was defined (which can be seen the basis for the Basic Set of Application (BSA) ETSI TR 102 638[13]) to identify the spectrum requirements, and in the ETSI TR 102 492-2 this led to the spectrum allocation proposal which is regulated in the Current Regulation (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

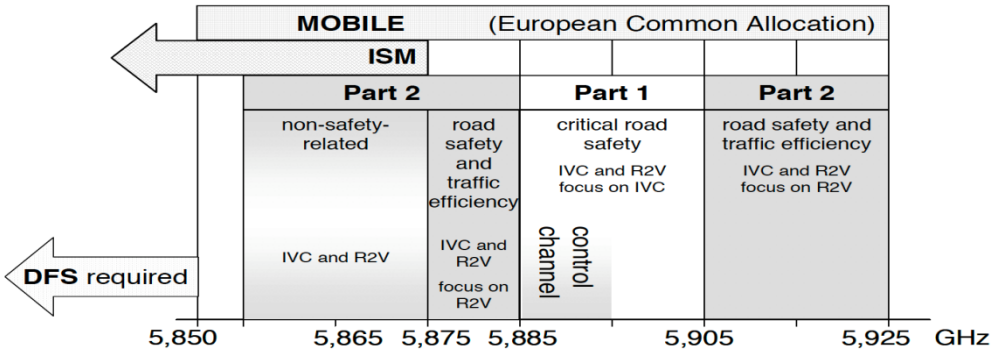

Figure 1: ETSI TR 102 492-2 proposed spectrum allocation

[11] http://www.etsi.org/deliver/etsi_tr/102400_102499/10249201/01.01.01_60/tr_10249201v010101p.pdf

[12] http://www.etsi.org/deliver/etsi_tr/102400_102499/10249202/01.01.01_60/tr_10249202v010101p.pdf

[13] http://www.etsi.org/deliver/etsi_tr%5C102600_102699%5C102638%5C01.01.01_60%5Ctr_102638v010101p.pdf

Application	Description
Cooperative Collision Warning	Cooperative collision warning collects surrounding vehicle locations and dynamics and warns the driver when a collision
Work Zone Warning	Work zone safety warning refers to the detection of a vehicle in an active work zone area and the indication of a warning to
Approaching Emergency Vehicle Warning	This application provides the driver a warning to yield the right of way to an approaching emergency vehicle.
Traffic Signal Violation Warning	communication to warn the driver to stop at the legally prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation.
Emergency Vehicle Signal Pre-emption	This application allows an emergency vehicle to request right of way from traffic signals in its direction of travel.
In-Vehicle Signage	The in-vehicle signage application provides the driver with information that is typically conveyed by traffic signs.
Road Condition Warning	to nearby vehicles when the road surface is icy, or when traction is otherwise reduced.
Low Bridge Warning	especially to commercial vehicles when they are approaching a bridge of low height.
Highway/Rail Collision Warning	Railroad collision avoidance aids in preventing collisions between vehicles and trains on intersecting paths.
Wrong Way Driver Warning	This application warns drivers that a vehicle is driving or about to drive against the flow of traffic.
Emergency Electronic Brake Lights	Brake light application sends a message to other vehicles following behind.
The Left Turn Assistant	The Left Turn Assistant application provides information to drivers about oncoming traffic to help them make a left turn at a signalized intersection without a phasing left turn arrow.
Curve Speed Warning	Curve speed warning aids the driver in negotiating curves at appropriate speeds.
Vehicle-Based Road Condition Warning	conditions using on-board systems and sensors (e.g. stability control, ABS), and transmit a road condition warning, if required, to other vehicles via broadcast.
Low Parking Structure Warning	This application provides drivers with information concerning the clearance height of a parking structure.
Lane Change Warning	intended lane change may cause a crash with a nearby vehicle.
Highway Merge Assistant	another vehicle is in its merge path (and possibly in its blind spot).
Cooperative Glare Reduction	automatically switch from high-beams to low-beams when trailing another vehicle.
Control	Alerts driver to other vehicles at intersections.

Figure 2: ETSI TR 102 492-1 safety related ITS applications

The safety related application information exchange identified in ETSI TR 102 492-1 used two different message types. The Cooperative Awareness Message (CAM, ETSI EN 102 637-2[14]) which provides other road users awareness information about the location and traffic behaviour of the transmitting road user and the Decentralized Environmental Notification Message (DENM, ETSI EN 102 637-3[15]) to notify others about hazardous situation recognized by the transmitting road user. These two message types are the basis for the first set of applications as defined in the ETSI TR 102 638. Three channels were designated to facilitate this list of applications.
Many projects e.g. CVIS[16], Safespot[17], SimTD[18], DriveC2X[19] and SCOOP@F[20] have evaluated the possibilities that the most interesting applications can be implemented with some restrictions like e.g. limited message length such that most functionally still fit on a single channel. A second channel was foreseen for the exchange of security certificates. Also, this second and other channels will be used for additional message types enabling other applications. The Day-1 list of applications as defined in the EC C-ITS Deployment Platform report phase 1[21], includes the green wave optimisation application (also known as Green Light Optimum Speed Advise GLOSA[22])

[14] http://www.etsi.org/deliver/etsi_en/302600_302699/30263702/01.03.01_30/en_30263702v010301v.pdf

[15] http://www.etsi.org/deliver/etsi_en/302600_302699/30263703/01.02.01_30/en_30263703v010201v.pdf

[16] http://www.ecomove-project.eu/links/cvis/

[17] http://www.safespot-eu.org

[18] http://www.simtd.de/index.dhtml/enEN/index.html

[19] http://www.drive-c2x.eu/project

[20] http://www.scoop.developpement-durable.gouv.fr/en/

[21] https://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf

[22] http://www.drive-c2x.eu/use-13

which makes use of the Signal Phase and Timing (SPATEM) and road/lane topology and traffic maneuver (MAPEM) messages as defined in the ETSI TS 103 301[23] and ISO TS 19091[24]/SAE 2735[25]. As these messages may be complex, these are limited in size at initial deployment but are expected to make use of one of the additional channels.

[23] https://www.etsi.org/deliver/etsi_ts/103300_103399/103301/01.03.01_60/ts_103301v010301p.pdf

[24] https://www.iso.org/standard/69897.html

[25] http://standards.sae.org/j2735_200911/

5 Spectrum requirements for C-ITS and cooperative automated driving

5.1 European spectrum needs.

In parallel with the started deployment of the ITS-G5[26] technology further innovation is progressing. Currently ongoing as well as recently finished projects enhanced our view showing a large extended list of C-ITS and cooperative automated driving applications far beyond the original list as identified in the TR 102 638. Today we distinguish three levels of safety related phases such as shown in Figure 3.

- The "Active Safety" phase: this is the normal driving mode in which the driver and its ITS-system is informed or warned. All applications as defined for Day-1 or as identified in the TR 102 492 are Active Safety related.
- The "Integral Safety" phase: in this phase the vehicle can intervene or take reversible preventive actions. This is the period before a possible impact in which automation aspects have a key role like e.g. active intervention with braking or steering.
- The "Passive Safety" phase: this phase is related to accident severity reduction and non-reversible measures take place. When needed this phase will also include rescue facilities.

For the Passive Safety phase the information exchange is intended for none-versatile measures and rescue facilities such as E-call. In case the E-call can't be executed via the standard cellular networks, forwarding via ITS-G5 could be an option but isn't considered at the moment and is excluded from this analysis. ITS-G5 is in the first place intended for Active and Integral Safety information exchange.

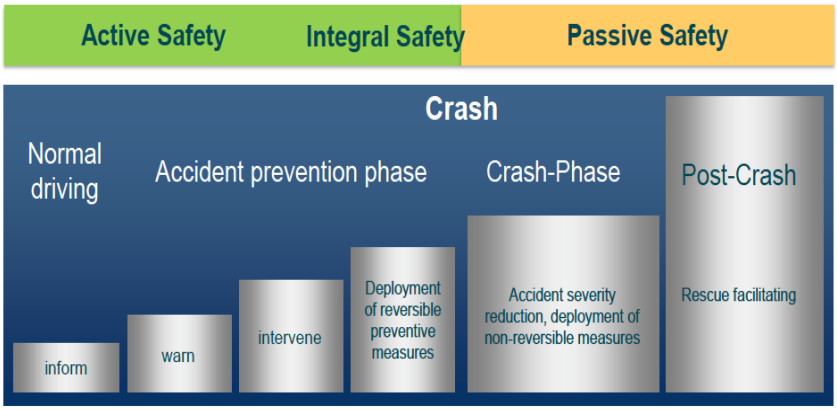

Figure 3: Phases of the vehicular safety system (Ref: C2C-CC)

In parallel with deployment of ITS-G5 Day-1 applications innovation is progressing, and C-ITS will merge with Vehicle Automation/Autonomous driving as agreed in the Declaration[27] of Amsterdam (see Figure 4). This can be seen especially in the development of the Platooning and C-ACC applications. Effort is put into both Active Safety as well as Integral Safety applications.

[26] ITS-G5 is the road safety and road efficiency communication architecture based on the physical specification of the IEEE 802.121p and specified in the EN 302 665.

[27] https://www.regjeringen.no/contentassets/ba7ab6e2a0e14e39baa77f5b76f59d14/2016-04-08-declaration-of-amsterdam---final1400661.pdf

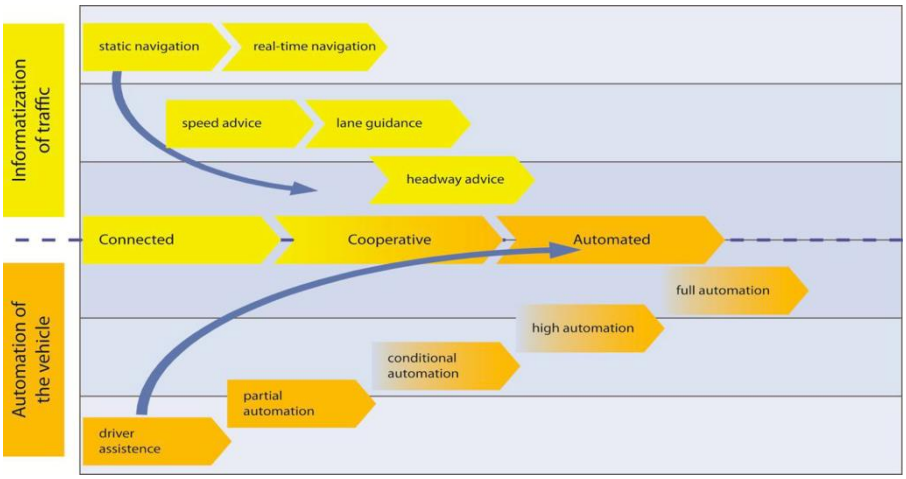

Figure 4: Merge of C-ITS and Vehicular Automation as agreed in the EU "Declaration of Amsterdam".

There are and already have been many innovative project looking at beyond Day-1 applications. Just finished or currently active are for example: VRUITS[28], AutoNet2030[29], HIGHTS[30], TIMON[31], RoadArt[32] and there are new ones upcoming. There is quite a grow of applications, and new possibilities are getting recognized. There are several application lists going around. For instance, there is the EC C-ITS Deployment Platform Phase 1 report with Day-1.5 applications and Phase 2 report[33] this year included more Urban applications and in the deliverable D2.3 from HIGHTS a large overview of C-ITS applications is presented. This HIGHTS application list is composed based on the roadmaps as provided by the European commission C-ITS platform phase I report, the Amsterdam Group[34] (AG), C2C-CC[35], ACEA[36], 5GAA[37], EATA[38], and the European projects C-ROADS[39], InterCor[40], CODECS[41] and country specific overviews (see Figure 6).
From this table about 80% of the applications benefit from safety related short-range communication and 67% of it involves Active or Integral Safety information. A lot of the applications do require some information exchange however there are some specific applications which require relative more attention. This concerns the C-ACC, Platooning and Vulnerable Road Users (VRUs) applications. The growth of information exchange can also be recognized as presented in the C2C-CC Message roadmap (Figure 5).

[28] http://www.vruits.eu
[29] http://www.autonet2030.eu
[30] http://hights.eu
[31] https://www.timon-project.eu
[32] http://www.roadart.eu
[33] https://ec.europa.eu/transport/sites/transport/files/2017-09-c-its-platform-final-report.pdf
[34] https://amsterdamgroup.mett.nl/default.aspx
[35] https://www.car-2-car.org/index.php?id=5
[36] http://www.acea.be
[37] http://5gaa.org
[38] http://erticonetwork.com/european-automotive-telecom-alliance-presents-automated-driving-roadmap/
[39] https://www.c-roads.eu/platform.html
[40] http://intercor-project.eu
[41] http://www.codecs-project.eu/index.php?id=5

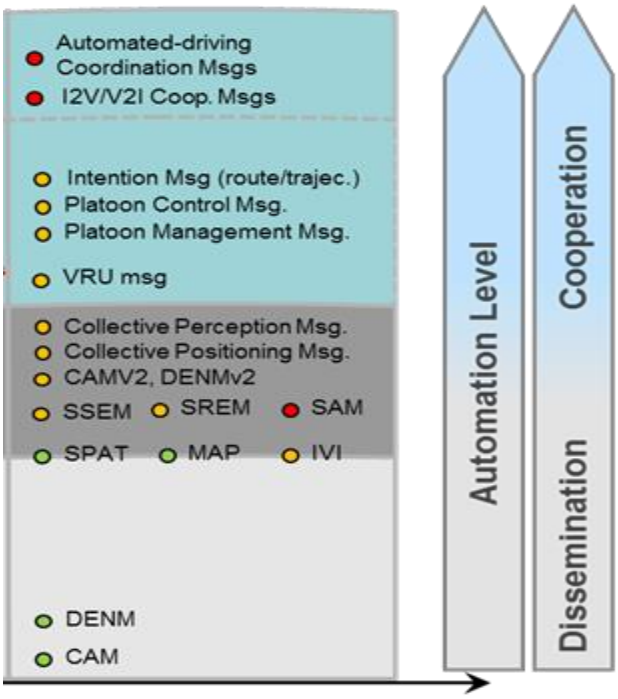

Figure 5: C2C-CC Message Roadmap

Group	Applications
Traffic Safety Avoidance L1&2	Traffic Jam Ahead Warning
	Hazardous Location Warning
	Emergency Vehicle Warning
	Emergency Brake Light
	Slow Vehicle Warning
	Stationary Vehicle Warning
	Overtaking Warning
	Intention Sharing
	Overtaking Assistance
	Overtaking Assistance Advances (including Motor Cycles
	Collision risk warning
	Intersection collision warning
	Wrong Way driving warning
	Motorcycle Approaching Indication
Cooperative Awareness	Behaviour CAM (awareness)
	Road Status (awareness) holes in the road etc by Infra
	Driver Status CAM (awareness)
	Vehicle Status CAM (awareness)
Intervene Awareness	Cooperative Intension CIM (awareness)
	Collective perception CPM (awareness)
	Pre-crash mitigation,
	Advanced crash notification
	Critical Speed advisory
Vehicular Automation	Basic ACC (level 2)
	Basic (level 2-3) C-ACC
	Advanced (level 3-4) C-ACC (Increase 20Hz small CAMs + CIM + CLP)
	Basic (level 3-4) Platooning (Increase 20Hz small CAMs + Platoon Management)
	Advanced (level 4-5) Platooning (as Basic including CIM + CPM Camera/Radar sensor data)
	Automation level 4-5 Vehicles (As Advanced C-ACC + Camera/Radar sensor data)
	Basic Merging Assistant (inter Vehicular nigotiations / Roadside management)
	Advanced Merging Assistant (As Basic + Increase x10Hz small CAM's)
	Automatic parking (Basic and Automated Parking)
	Automation assist in Tunnels (Location precision assist)
	Automation level road assignment Static and Dynamic
Road Works Warning	Short Term Mobile
	Basic Short Term Static (only road allocation awareness)
	Advanced Short Term Static (as basic + dynamic speed management depending on traffic density)
	Basic Long Term Static (only road allocation awareness)
	Advanced Long Term Static (as basic + dynamic speed management depending on traffic density)
	Emurgency road works Mobile (As Short Mobile with Additional Notifications)
Traffic Flow	In Vehicle Signage Navigation (MAP-Cloud Services)
	In Vehicle Signage Local (Dynamic or not managed by Traffic Management)
	Dynamic Speed (Direct + MAP-Cloud Service)
	Dynamic Sign Information (Short-Term Direct + MAP-Clous Service)
	Road Topology (MAP) provisioning by authorities
	Network Flow Optimization
	Shockwave Damping
	Efficient traffic flow Urban/HighWay
	Complex Lane Marking
	Regulatory / Contextual Speed limits notification
	Traffic light optimal Speed advisory
	Zone access control for urban areas notification
	Zone access control for urban areas enforcement
	Enhanced Route guidance and navigation
	Public Transport Vehicle Approaching
	Green Light Optimal Speed Advice

Group	Applications
Intersections Safety	Energy Efficient Intersection Service
	Stopping Behaviour Optimization
	Red Light Violation Warning
	Intersection Obstacle Indication
	Queue Warning
	Left Turn assist
	Stop Sign assist
	Disabled Vehicle warning
Traffic Priority	Priority Request Business Transport Local
	Priority Request Publik Transport Local
	Priority Request Emurgency Local
	Priority Request Group of Cyclists Local
	Priority Request Publik Transport Via Emergency centre
	Priority Request Emurgency Via Emergency centre
	Priority Request Group of Cyclists Via Emergency centre
Vulnerable Road Users (VRU)	Bicycle Safety Awareness (CAM or CPM)
	Bicycle Priority
	Bicycle Approaching Indication
	Pedestrian Awareness (CAM or CPM)
	Motorcycle Awareness (CAM)
Traffic Information	Virtual VMS
	Traffic Information Service
	Virtual VRI in Traffic center
Incident Management	Automatic Incident Detection (Detection by Vehicle)
	Automatic Incident Detection (Detection by Infrastructure)
	Incident Warning
Navigation	Intermodal Route Planner
	Standard Navigation
	HD-MAP general MAP updates
	HD-MAP local updates by Vehicles and Infrastructure for Autonomous driving Strategic (Cloude)
	HD-MAP local updates by Vehicles and Infrastructure for Autonomous driving Tactile
	HD-MAP and Navigation MAP updates
	Highway Chauffeur (L2/3)
	Rerouting
	Eco Route Planner
	Basic Parking Assist (directions)
	Advanced Parking Assist (specific parking lot)
Media	Point of Interest notification
	ITS local electronic commerce
	Media downloading
	Multimodality support
	Information on AFV fuelling & charging stations
Vehicle Services	EV Charging Point Planner
	Insurance and financial services
	Pay How You Drive
	Probe Vehicle Data
	IMMA Interface
	Fleet management
	Loading zone management
Railway	Railway-Road Crossing
	Urban Rail Safety
Security Privacy	Sequrity Key updates
Geolocation Referencing	Geolocation Improvement Info exchange (POTI) 2Hz
System Operations	Vehicle Software / Data provisioning and update
	Vehicle and RSU data calibration and system management
	Vehicle and RSU data calibration and system management ITS-G5 Specific
	ITS System management

Figure 6: Safety related applications list[42]

[42] list used by the EU projects HIGHTS and CODECS (the grouping is based on the input provided, but has no official status)

The European innovation of safety related applications is progressing and the information provides an initial view on the safety related communication requirements from which the following key elements can be recognized:

- The truck manufactures are expecting to use multiple ITS-G5 channels. Multiple platooning project such as AutoNet[43] and ENSEMBLE[44] have shown that for reaching best performance CAM rates of up to 30Hz are expected. These CAMs will be smaller but still 3 times the normal CAM rate. Additionally, to the CAMs there is information exchange required to manage the platoon. For C-ACC similar values are seen.
- The project VRUITS shows that for Vulnerable Road User (VRU) awareness the transmission rate (1Hz) of the awareness messages can be much lower but the density is much higher. Therefore it is expected that this requires additional communication bandwidth at peak moments. As safety is at stake, the system needs to accommodate these requirements.
- For more Integral Safety awareness we will require more predictive information (Figure 5) such as the Cooperative Intention Message (CIM), Manoeuvre Coordination Services, ETSI TS 103 561[45] and the Collective Perception Service (CPM), ETSI TS 103 324[46]). Similar services as the CAM service having similar bandwidth demands.
- New applications also have higher requirements for the Geolocation reference, for instance to identify a motorcycle or pedestrian as well as for platooning. To realize this additional information exchange between stations is required as identified in the HIGHTS project leading to standardisation in the ETSI EN 302 890-2[47].

While European projects show these needs, separate message analyses for spectrum needs[48] confirmed by OEM's in **Figure 7: Summary of spectrum needs for safety C-ITS message types, EuropeFigure 7** provide further evidence that more than 70 MHz of spectrum is needed for the realisation of road safety applications. For more details see chapter 6 Annex A for Europe and chapter 7 Annex B for USA.

[43] http://www.autonet2030.eu/

[44] https://platooningensemble.eu/

[45] https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=53496

[46] https://portal.etsi.org/webapp/workProgram/Report_WorkItem.asp?wki_id=46541

[47] https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=51379&curItemNr=1&totalNrItems=15&optDisplay=10&titleType=all&qSORT=HIGHVERSION&qETSI_ALL=&SearchPage=TRUE&qINCLUDE_SUB_TB=True&qINCLUDE_MOVED_ON=&qSTOP_FLG=N&qKEYWORD_BOOLEAN=OR&qCLUSTER_BOOLEAN=OR&qFREQUENCIES_BOOLEAN=OR&qMandate_List=%27M%2F546%27&qSTOPPING_OUTDATED=&butExpertSearch=Search&includeNonActiveTB=FALSE&includeSubProjectCode=FALSE&qREPORT_TYPE=SUMMARY

[48] Spectrum needs = $\frac{packet\ size \times periodicity \times ITS\ stations\ in\ comm\ range}{spectrum\ efficiency \times max\ channel\ load}$

Safety spectrum needs for a single short-range V2X communication technology in MHz bandwidth, in 5.9 GHz safety band

	environment			
message type	**urban**	**suburban**	**Rural** (Highway)	min number of 10 MHz Channels
CAM cooperative awareness message	9	10	10	0,9
DENM decentralized environmental notification message	4	2	1	0,1
SPATEM signal phase and timing**, MAPEM** road/lane topology and traffic maneuver **, IVI** in-vehicle-information and other I2V messages	1	1	1	0,5
VAM VRU awareness message	4	0,2	2	0,5
PCM platooning control message	3	6	10	1,0
CPM collective perception message	23	26	24	2,0
MCM maneuver coordination message	23	26	24	2,0
Minimum basic spectrum needs in MHz	**67**	**72**	**72**	
total number of 10 MHz channels required				**7**

Figure 7: Summary of spectrum needs for safety C-ITS message types, Europe[49]

Figure 7 summarizes the calculation of spectrum needs done in Annex A. The today well defined message types enable all applications of the C2C-CC application roadmap, summarized in **Table** 1. and lead to the total need of minimum seven 10 MHz channels.

- **Two 10 MHz channels for Awareness Driving**: necessary message types are Cooperative Awareness message CAM, Decentralized Environmental Notification Message DENM, signal phase and timing SPaTEM, road/lane topology and traffic maneuver MAPEM, in-vehicle-information IVI, VRU awareness message VAM
- **Two to three 10 MHz channels for Sensing Driving** / sensor sharing: necessary message type is collective perception message CPM

[49] CAM, Cooperative Awareness Message, specified in ETSI EN 302 637-2

DENM, Decentralized Environmental Notification Message, specified in ETSI EN 302 637-3

SPATEM, Signal, Phase, and Timing, ISO/TS 19091:2017

MAPEM, road/lane topology and traffic maneuver ISO/TS 19091:2017

VAM, Vulnerable Road User (VRU) Awareness Message ETSI TS 103 300-3, Pedestrian protection with Personal Safety Messages (PSM) according to SAE J2735, SAE J2945/9_201703 https://www.sae.org/standards/content/j2945/9_201703/

PCM, Platooning Control Message draft specification in ETSI TR 103 298, currently being drafted in the European H2020 project ENSEMBLE (multi-brand truck platooning) https://platooningensemble.eu/ https://platooningensemble.eu/news/using-its-g5-for-efficient-truck-platooning5c1a203e7a226

CPM Collective Perception Message, draft ETSI TS 103 324, ETSI TR 103 562

MCM Manoeuvre Coordination Message, according to ETSI TR 103 578 (draft) “Informative report for the Manoeuvre Coordination Service”; https://imagine-online.de/en/home/

- **Three to four 10 MHz channels for Cooperative Driving** and **cooperative automated driving**: necessary message types are maneuver coordination message MCM, platooning control message PCM.

5.2 Functional Safety.

The focus on safety-critical applications in the automotive market is significantly growing in general. Functional Safety requirement increased especially now that we are moving towards vehicular automation. The automotive industry is under pressure to provide new and improved vehicle safety systems, ranging from basic airbag deployment systems to extremely complex advanced driver assistance systems (ADAS) with accident prediction and avoidance capabilities. These safety functions are increasingly carried out by electronics. The ISO 26262[50] standard is intended to enable the design of electronic systems that can prevent dangerous failures and control them if they occur. One of the key elements in realising resilient systems, mainly realized by smartly integrating redundancies.

The sharing of safety related information via short-range ITS-G5 V2X is a redundancy for existing other sensors in the vehicle for the basic functions they fulfil. C-ITS applications combined with active interventions (like braking) and cooperative automated driving applications rely on information exchange and functional safety analysis is required. Possible communications redundancy might be established by using several technologies in principle complementary but having overlapping capabilities. One example is mentioned earlier in this report. In case the cellular communications network does not work the E-Call[51] could be forwarded to other ITS-Stations via the ITS-G5 short-range communication.

5.3 USA spectrum needs.

In the USA similar discussions with regards of C-ITS and Automated Driving road safety and road efficiency information exchange have been resulting in standardisation of these needs. The channel allocation for this has been captured in the SAE standard the SAE J2945.0[52].
Figure 9 provides an illustration of what has been specified. It confirms the European analyses for the need of more than 50 MHz In the USA the expectation is to require the full 75 MHz band as allocated.
Figure 8 summarizes the spectrum needs[53] of vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-pedestrian communication known today. The already known message types of V2X are relevant to realize all V2X applications which are part of the V2X roadmap, additional messages with additional spectrum needs may come on top of that picture. Some messages like Basic Safety Message (BSM), Messages used by traffic lights (SPAT, MAP), Personal Safety Message (PSM) cover applications listed in the live saving category of safety in Connected vehicle Reference Implementation Architecture (CVRIA) some of them like CPM, MCM, PCM go beyond CVRIA applications and climb the V2X roadmap towards cooperative automated driving.

For more details see ANNEX B [7].

[50] https://www.iso.org/standard/43464.html

[51] https://ec.europa.eu/transport/themes/its/road/action_plan/ecall_en

[52] http://standards.sae.org/wip/j2945/

[53] Spectrum needs = $\frac{packet\ size \times periodicity \times ITS\ stations\ in\ comm\ range}{spectrum\ efficiency \times max\ channel\ load}$

Safety spectrum needs for a single short-range V2X communication technology in MHz bandwidth, in 5.9 GHz safety band

	environment			
message type	**urban**	**suburban**	**Rural** (Highway) light traffic, high speed	number of 10 MHz Channels
BSM Basic Safety Message	9	10	9	1
SPAT signal phase and timing**, MAP** road/lane topology and traffic maneuver **, IVI** in-vehicle-information and other **I2V messages**	1	1	1	0,5
PSM personal safety message	4	1	2	0,5
PCM platooning control message	3	6	10	1
CPM collective perception message	23	26	24	2
MCM maneuver coordination message	23	26	24	2
Minimum basic spectrum needs in MHz for safety	**63**	**70**	**70**	
number of 10 MHz channels required				**7**

Figure 8: Summary of spectrum needs for safety message types, USA[54]

[54] BSM Basic Safety Message, SAE J2945/1, SAE J2735

SPAT, Signal, Phase, and Timing, ISO/TS 19091:2017, SAE J2735, SAE J2945/10

MAP, road/lane topology and traffic maneuver ISO/TS 19091:2017, SAE J2735, SAE J2945/10

PSM Pedestrian protection with Personal Safety Messages according to SAE J2735, SAE J2945/9

PCM, Platooning Control Message draft specification in ETSI TR 103 298, currently being drafted in the European H2020 project ENSEMBLE (multi-brand truck platooning) https://platooningensemble.eu/https://platooningensemble.eu/news/using-its-g5-for-efficient-truck-platooning5c1a203e7a226

CPM Collective Perception Message, draft ETSI TS 103 324, ETSI TR 103 562, SAE J2945/8

MCM Manoeuvre Coordination Message, according to ETSI TR 103 578 (draft) “Informative report for the Maneuvre Coordination Service”; https://imagine-online.de/en/home/ ,SAE J2945 /6

Channel Number (see IEEE 802.11)	Channel Spacing (MHz)	Maximum EIRP[1] (dBm)	System Types	Application Types	J2735 Messages or Protocol	Notes
172 (5.855 to 5.865 GHz)	10	FCC: 33, Recommended maximum: 20 w/ Class C mask	V2V, I2V	- V2V safety, situational awareness - Intersection safety	BSM, SPAT, MAP, RTCM, WSA	- Only time-critical safety-of-life and property applications may use this channel - Private light vehicles: BSM per SAE J2945/1 - RTCM: Only time-sensitive messages (typically updated at 1 Hz): For example message types 1, 1004 and 1012 - WSA should be used only to advertise an SCMS connection under appropriate circumstances
174	10	FCC: 33, Recommended maximum: 20 w/ Class C mask	I2V	- I2V safety and mobility Miscellaneous/private use (non-priority)	WSMP, IPv6 data	- Use system design constraints to prevent adjacent channel interference with the vehicle safety channel (see Annex E) - Use primarily for I–V. - See FCC rules.
176	10	FCC: 33 Recommended maximum: 20 w/ Class C mask	D2V, I2D, I2V	- VRU - SCMS	WSMP, IPv6 data	Use system design constraints to prevent adjacent channel interference with the control channel
178	10	FCC: 33 or 44.8, Recommended maximum: 20 w/ Class C mask	I–V	- Service Advertisements (Public & Private) - Broadcast-based I–V applications	TIM, RTCM support mesasges, RSA, WSA	- No unicast messages - No internet protocol (IPv6) - Broadcast-based I–V applications should use no more bandwidth than would be required to advertise the service on another channel via the WSA
180	10	FCC: 23, Recommended maximum: 20 w/ Class C Mask	V2I, V2V	- Future V2V safety (e.g. CACC) Miscellaneous/private use (non- - SCMS - Mobility applications (e.g. freight movement, probe data collection,	WSMP, IPv6 data	- Use system design constraints to prevent adjacent channel interference with/from the control channel and/or the public safety channel 184 - 182 should be primarily for I–V to avoid cross channel interference (interference from radios within the same vehicle)
182	10	FCC: 23 Recommended maximum: 20 w/ Class C Mask	V2I, V2V	Same as for Channel 180	WSMP, IPv6 data	Same as for Channel 180
184, (5.915 to 5.925 GHz)	10	FCC: 33 or 40 Recommended maximum: 33 w/ Class C Mask	x↔x	- Public Safety - Public Transit	SSM, SRM, RSA	- Only public safety or government systems may transmit on this channel - I2V, V2V, V2D allowed for public safety communication to non-government devices

Figure 9: Channel usage List SAE 2945.0 illustration

6 Annex A 5.9 GHz C-ITS and cooperative automated driving spectrum requirement calculations, Europe

These calculations are confirmed by the Vehicle OEM's. Spectrum needs in MHz calculated according to

Spectrum needs = $\frac{packet\ size \times periodicity \times ITS\ stations\ in\ comm\ range}{spectrum\ efficiency \times max\ channel\ load}$

are based on safety message types (each may enable several safety use cases) and only a relevant safety communication range (=radius). In most times communication ranges depending on environment are 2-3 times higher than safety range => more ITS stations will be in communication range and exchange messages at the same time which lead to multiple higher spectrum needs.

Figure 10

Table: European spectrum requirement in MHz, CAM (Cooperative Awareness Message) in different environments

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN (Geonetworking)
	TX periodicity (Hz)	3,00	slowly moving traffic,
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6 MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for CAMs
	Spectrum requirements (MHz)	**9,31**	
Sub-Urban	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	6,00	medium moving traffic,
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for CAMs
	Spectrum requirements (MHz)	**10,47**	
Rural (Highway/ Autobahn) light traffic high speed scenario	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	10,00	fast moving traffic
	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz

	maximum channel load	0,60	Maximum target channel load for CAMs
	Spectrum requirements (MHz)	**9,70**	
Rural (Highway/ Autobahn) high traffic low speed scenario, traffic jam	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	1,00	slow moving or standing traffic,
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for CAMs
	Spectrum requirements (MHz)	**7,76**	

Figure11: European spectrum requirement in MHz, DENM (Decentralized Environmental Notification Message, event triggered message)

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	10,00	10 additional messages per second and per event
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	Ratio of stations transmitting a DENM	0,05	5% of the station in the relevance area transmit a DENM
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for DENMs
	Spectrum requirements (MHz)	**3,88**	
Sub-Urban	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	10,00	10 additional messages per second and per event
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	Ratio of stations transmitting a DENM	0,05	5% of the station in the relevance area transmit a DENM
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for DENMs
	Spectrum requirements (MHz)	**2,18**	
Rural (Highway/ Autobahn) light traffic scenario	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	10,00	10 additional messages per second and per event

	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 180 stations in reach
	Ratio of stations transmitting a DENM	0,05	5% of the station in the relevance area transmit a DENM
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for DENMs
	Spectrum requirements (MHz)	**1,21**	

Fehler! Keine gültige Verknüpfung.

Figure12: European spectrum requirement in MHz, VAM (VRU Awareness Messages for pedestrian, bicycle, motorcycle protection) in different environments[55]

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	350,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	1,00	pedestrian messages 1 per seconds
	ITS pedestrian stations in relevance area	500,00	Urban crossing: 50m x 5 m walk side x 2 x 2 with density 0,5 persons/m2 --> 500 persons
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for periodic messages
	Spectrum requirements (MHz)	**4,24**	
Sub-Urban	Packet size (byte)	350,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	1,00	medium moving traffic,
	ITS pedestrian stations in relevance area	20,00	Sub-Urban crossing: 50m from centre, area 8000m2, minus street area (4000m2) minus building area (2000m2) density 0,01 persons/m2 --> 10

[55] VRU awareness message according to ETSI TR 103 300-1 V2.1.1; draft TS 103 300-2 , draft TS 103 300-3

	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for periodic messages
	Spectrum requirements (MHz)	**0,17**	
Rural (Highway/ Autobahn)	Packet size (byte)	350,00	
	TX periodicity (Hz)	10,00	
	ITS stations in relevance area	20,00	Road Works worker / pedestrians around vehicles e.g. broken-down vehicle
	spectrum efficiency	0,55	
	maximum channel load	0,60	
	Spectrum requirements (MHz)	**1,70**	
Urban Square	Packet size (byte)	350,00	Including security and higher layer overhead
	TX periodicity (Hz)	1,00	pedestrian messages 1 per seconds
	ITS pedestrian stations in relevance area	1712,50	Urban square: 50m from centre, minus street area (1000m2), density 0,25- persons/m2
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for periodic messages
	Spectrum requirements (MHz)	**14,53**	

Figure13: European spectrum requirement in MHz, CPM (Collective Perception Message) in different environments[56]

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1000,00	Including security/overhead (750 Byte payload including around 25 objects)
	TX periodicity (Hz)	3,00	depends on speed of objects and own speed as well as protection level (high for VRU), mixed Tx rates assumed, average Tx rate 3
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**23,27**	
Sub-Urban	Packet size (byte)	1000,00	Including security/overhead (750 Byte payload including around 25 objects)
	TX periodicity (Hz)	6,00	depends on speed of the object and protection level (high for VRU), does not depend on vehicle speed
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from center, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**26,18**	
Rural (Highway/ Autobahn) light traffic	Packet size (byte)	1000,00	Including security/overhead (750 Byte payload including around 25 objects)
	TX periodicity (Hz)	10,00	fast moving traffic,

[56] ETSI TR 103 562 V2.1.1 Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS)

high speed scenario	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load for CAMs
	Spectrum requirements (MHz)	**24,24**	
Rural (Highway/ Autobahn) high traffic low speed scenario, traffic jam	Packet size (byte)	1000,00	Including security
	TX periodicity (Hz)	1,00	slow moving or standing traffic,
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**19,39**	

Figure14: European spectrum requirement in MHz, SPAT and MAP (Signal Phase and Time and Map message for traffic lights) in different environments

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1200	Including security and higher layer overhead for several I2V messages like SPAT, MAP, IVI, traffic efficiency,.. together
	TX periodicity (Hz)	10,00	slowly moving traffic, assumed aggregated Tx rate for several message types (5 x 2 Hz), Tx rate after SPaT phase change will be 10 Hz, too
	ITS stations in relevance area	2,00	Urban crossing: 100m from center, two RSU at complex crossings
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target load for SPAT/MAP
	Spectrum requirements (MHz)	**0,58**	
Sub-Urban	Packet size (byte)	1200	Including security and higher layer overhead for several I2V messages like SPAT, MAP, IVI, traffic efficiency,.. together
	TX periodicity (Hz)	25,00	medium moving traffic, assumed aggregated Tx rate for several message types (5 x 5 Hz), Tx rate after SPaT phase change will be 10 Hz, too
	ITS stations in relevance area	1,00	Sub-Urban environment: 150m from center, single RSU per crossing or critical road position
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target load for SPAT/MAP
	Spectrum requirements (MHz)	**0,91**	
Rural (Highway/ Autobahn)	Packet size (byte)	1200	Including security and higher layer overhead for several I2V messages like SPAT, MAP, IVI, traffic efficiency,.. together
	TX periodicity (Hz)	50,00	fast moving traffic, assumed aggregated Tx rate for several message types (5 x 10 Hz)

	ITS stations in relevance area	1,00	Rural high way environment: 500m from relevance center, single station at exit or tolling booth
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target load for SPAT/MAP
	Spectrum requirements (MHz)	**1,45**	

Figure15: European spectrum requirement in MHz, PCM (Platooning Control Message for truck platooning)

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	50,00	slowly moving traffic,
	ITS stations in relevance area	6,00	100m from centre, two platoons with three participants
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**2,91**	
Sub-Urban	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	50,00	medium moving traffic
	ITS stations in relevance area	12,00	Sub-Urban environment: 150m from centre, four platoons with three participants
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**5,82**	
Rural (Highway/ Autobahn)	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	50,00	

	ITS stations in relevance area	20,00	Rural high way environment: 500m from relevance centre, four platoons with five participants in range
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**9,70**	
Truck parking area or toll station very dense truck penetration	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	50,00	
	ITS stations in relevance area	30,00	Rural high way environment: 200m from relevance centre, 10 platoons with three participants in range
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**14,55**	

Figure16: European spectrum requirement in MHz, MCM (Maneuvre Coordination Message for cooperative automated driving)

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN (Geonetworking) and 750 Byte Payload, Payload (w/o OH, security) size with several traces could be in the range of 400-800 Byte or even 1000 Byte
	TX periodicity (Hz)	3,00	slowly moving traffic,
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**23,27**	

Sub-Urban	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	6,00	medium moving traffic,
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**26,18**	
Rural (Highway/ Autobahn) light traffic high speed scenario	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	10,00	fast moving traffic,
	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**24,24**	
Rural (Highway/ Autobahn) high traffic low speed scenario, traffic jam	Packet size (byte)	1000,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	1,00	slow moving or standing traffic,
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**19,39**	

7 Annex B 5.9 GHz C-ITS and cooperative automated driving spectrum requirement calculations, USA

Spectrum needs are calculated according to Spectrum needs = $\frac{packet\ size \times periodicity \times ITS\ stations\ in\ comm\ range}{spectrum\ efficiency \times max\ channel\ load}$

Following assumptions for safety relevant communication ranges are taken into consideration: 100 m urban, 150 m suburban, 500 m highway/rural.
Real communication ranges can be much higher which accordingly will require more spectrum.

Figure17: USA spectrum requirement for BSM (Basic Safety Message) in different environments

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	380,00	Including security and higher layer overhead
	TX periodicity (Hz)	3,00	slowly moving traffic, already in congested mode (BSM sent with 10 Hz if not in congested mode)
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target load for BSM
	Spectrum requirements (MHz)	**8,84**	
Sub-Urban	Packet size (byte)	380,00	Including security and higher layer overhead
	TX periodicity (Hz)	6,00	medium moving traffic, in congested mode
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target load for BSMs

	Spectrum requirements (MHz)	**9,95**	
Rural (Highway/ Autobahn) light traffic high speed scenario	Packet size (byte)	380,00	Including security and higher layer overhead
	TX periodicity (Hz)	10,00	fast moving traffic, in congested mode
	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for BSMs
	Spectrum requirements (MHz)	**9,21**	
Rural (Highway/ Autobahn) high traffic low speed scenario, traffic jam	Packet size (byte)	380,00	Including security and higher layer overhead
	TX periodicity (Hz)	1,35	slow moving or standing traffic
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for BSMs
	Spectrum requirements (MHz)	**9,95**	

Figure18: USA spectrum requirement for PSM (Personal Safety Message for pedestrian protection) in different environments

Environment	Parameter	Value	Comment
Urban Square	Packet size (byte)	350,00	Including security and higher layer overhead

	TX periodicity (Hz)	1,00	pedestrian messages 1 per seconds
	ITS pedestrian stations in relevance area	500,00	Urban crossing: 50m x 5 m walkside x 2 x 2 with density 0,5 persons/m2 --> 500 persons
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for periodic messages
	Spectrum requirements (MHz)	**4,24**	
Sub-Urban	Packet size (byte)	350,00	Including security and higher layer overhead
	TX periodicity (Hz)	1,00	medium moving traffic,
	ITS pedestrian stations in relevance area	20,00	Sub-Urban crossing: 50m from centre, area 8000m2, minus streed area (4000m2) minus building area (2000m2) density 0,01 persons/m2 --> 10
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for periodic messages
	Spectrum requirements (MHz)	**0,17**	
Rural (Highway/ Autobahn) **Not applicable**	Packet size (byte)	350	Including security and higher layer overhead
	TX periodicity (Hz)	10	fast moving traffic
	ITS stations in relevance area	20	Road works worker or pedestrians around vehicles e.g. broken-down vehicles
	spectrum efficiency	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,6	Maximum load for periodic messages
	Spectrum requirements (MHz)	**1,7**	

Urban Square	Packet size (byte)	350,00	Including security and higher layer overhead
	TX periodicity (Hz)	1,00	pedestrian messages 1 per seconds
	ITS pedestrian stations in relevance area	3425,00	Urban square: 50m from centre, minus street area (1000m2), density 0,5 persons/m2
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for periodic messages
	Spectrum requirements (MHz)	**29,06**	

Figure19: USA spectrum requirement in MHz, CPM (Collective Perception Message) in different environments

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1000	Including security/overhead (750 Byte payload including around 25 objects)
	TX periodicity (Hz)	3,00	depends on speed of objects and own speed as well as protection level (high for VRU), mixed Tx rates assumed, average Tx rate 3
	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for CPM
	Spectrum requirements (MHz)	**23,27**	
Sub-Urban	Packet size (byte)	1000,00	Including security, overhead
	TX periodicity (Hz)	6,00	depends on speed of objects and own speed as well as protection level (high for VRU), mixed Tx rates assumed, average Tx rate 6

	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for CPM
	Spectrum requirements (MHz)	**26,18**	
Rural (Highway/ Autobahn) light traffic high speed scenario	Packet size (byte)	1000,00	Including security. overhead
	TX periodicity (Hz)	10,00	fast moving traffic
	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load
	Spectrum requirements (MHz)	**24,24**	
Rural (Highway/ Autobahn) hight traffic low speed scenario, traffic jam	Packet size (byte)	1000,00	Including security
	TX periodicity (Hz)	1,00	slow moving or standing traffic,
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for CAMs

	Spectrum requirements (MHz)	**19,39**	

Figure20: USA Spectrum requirement SPAT, MAP (Signal Phase and Time and Map message for traffic lights), IVI (in-vehicle-information) and other I2V (Infrastructure-to-vehicle) messages in different environments

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1200	Including security and higher layer overhead for several I2V messages like SPAT, MAP, IVI, traffic efficiency,.. together
	TX periodicity (Hz)	10,00	slowly moving traffic, assumed aggregated Tx rate for several message types (5 x 2 Hz), Tx rate after SPaT phase change will be 10 Hz, too
	ITS stations in relevance area	2,00	Urban crossing: 100m from centre, two RSU at complex crossings
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for SPAT/MAP
	Spectrum requirements (MHz)	**0,58**	
Sub-Urban	Packet size (byte)	1200	Including security and higher layer overhead
	TX periodicity (Hz)	25,00	medium moving traffic, assumed aggregated Tx rate for several message types (5 x 5 Hz), Tx rate after SPaT phase change will be 10 Hz, too
	ITS stations in relevance area	1,00	Sub-Urban environment: 150m from center, single RSU per crossing or critical road position
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for SPAT/MAP
	Spectrum requirements (MHz)	**0,73**	
	Packet size (byte)	1200	Including security and higher layer overhead

Rural (Highway/ Autobahn)	TX periodicity (Hz)	50,00	fast moving traffic, assumed aggregated Tx rate for several message types (5 x 10 Hz)
	ITS stations in relevance area	1,00	Rural high way environment: 500m from relevance centre, single station at exit or tolling booth
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load for SPAT/MAP
	Spectrum requirements (MHz)	**1,45**	

Figure21: USA spectrum requirement in MHz, PCM (Platooning Control Message for truck platooning)

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	400,00	Including security and higher layer overhead
	TX periodicity (Hz)	50,00	slowly moving traffic,
	ITS stations in relevance area	6,00	Urban crossing: 100m from centre, two RSU at complex crossings
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**2,91**	
Sub-Urban	Packet size (byte)	400,00	Including security and higher layer overhead, e.g. GN
	TX periodicity (Hz)	50,00	medium moving traffic
	ITS stations in relevance area	12,00	Sub-Urban environment: 150m from centre, four platoons with three participants
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load

	Spectrum requirements (MHz)	**5,82**	
Rural (Highway/ Autobahn)	Packet size (byte)	400,00	Including security and higher layer overhead
	TX periodicity (Hz)	50,00	fast moving traffic
	ITS stations in relevance area	20,00	Rural high way environment: 500m from relevance centre, four platoons with five participants in range
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**9,70**	
Truck parking area toll station very dense truck penetration	Packet size (byte)	400,00	Including security and higher layer overhead
	TX periodicity (Hz)	50,00	
	ITS stations in relevance area	50,00	Rural high way environment: 200m from relevance centre, 10 platoons with five participants in range
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**24,24**	

Figure22: USA spectrum requirement in MHz, MCM (Maneuver Coordination Message for cooperative driving and cooperative automated driving)

Environment	Parameter	Value	Comment
Urban	Packet size (byte)	1000,00	Including security and higher layer overhead and 750 Byte payload, payload with several traces, depending on number of traces can be 400-1000 Byte
	TX periodicity (Hz)	3,00	slowly moving traffic,

	ITS stations in relevance area	320,00	Urban crossing: 100m from centre, 3 lanes in each direction, distance between cars: 7,5m --> 320 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**23,27**	
Sub-Urban	Packet size (byte)	1000,00	Including security and higher layer overhead
	TX periodicity (Hz)	6,00	medium moving traffic,
	ITS stations in relevance area	180,00	Sub-Urban environment: 150m from centre, 3 lanes in each direction, distance between cars: 20m --> 180 stations in reach
	spectrum efficiency (bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load
	Spectrum requirements (MHz)	**26,18**	
Rural (Highway/ Autobahn) light traffic high speed scenario	Packet size (byte)	1000,00	Including security and higher layer overhead
	TX periodicity (Hz)	10,00	fast moving traffic
	ITS stations in relevance area	100,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 60m --> 100 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum load
	Spectrum requirements (MHz)	**24,24**	

Rural (Highway/ Autobahn) high traffic low speed scenario, traffic jam	Packet size (byte)	1000,00	Including security and higher layer overhead
	TX periodicity (Hz)	1,00	slow moving or standing traffic,
	ITS stations in relevance area	800,00	Rural environment: 500m from relevance centre, 3 lanes in each direction, distance between cars: 7,5m --> 800 stations in reach
	spectrum efficiency(bits/Hz)	0,55	6MBit/s minus Phy header and overhead in 10MHz
	maximum channel load	0,60	Maximum target channel load
	Spectrum requirements (MHz)	**19,39**	