Position Paper
LTE-V2X & IEEE802.11p/ITS-G5
Spectrum Sharing at 5.9 GHz
DG-CONNECT Workshop 5 September 2017

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 88 members, with 18 vehicle manufacturers, 39 equipment suppliers and 31 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 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

This document has been developed within the CAR 2 CAR Communication Consortium by Ing. P.T. Spaanderman (InnoMo), Dr. Friedbert Berens (FBConsulting S.à r.l) and Prof. Dr. Jérôme Härri (Eurecom). This document might be further elaborated within the CAR 2 CAR Communication Consortium.

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Content

1 Introduction

In strong consensus of the Car2Car communication consortium (C2C-CC)[1], this paper provides a response towards the 5.9 GHz European spectrum discussion at the DG CONNECT Spectrum Workshop on 5 September 2017. As guiding documents the invitation "Workshop invitation 5_9GHz-20170905"[2] and the report of the workshop as provided to stakeholders are used. This paper also includes feedback to the 5GAA[3] channel splitting proposal in line with Qualcomm's splitting initiative[4].

The vehicle industry represented by the C2C-CC is committed to improve comfort and safety for the vehicle user and other road users. Improvement of this is achieved by means of sharing relevant Automation/Autonomous driving and Cooperatives-Intelligent Transportation Systems (C-ITS) road safety and road efficiency related information among vehicles and between vehicles, the road infrastructure and service providers. The vehicle Industry expects to use several radio technologies to satisfy this information exchange and respects the spectrum neutrality.

The C2C-CC was founded in 2002 to collectively develop safety related information exchange and therefor developed a detailed expertise in the short-range road safety related information exchange, C-ITS requirements and ITS-G5 communications. In strong consensus, the C2C-CC supports the ACEA "Connectivity Strategy"[5] in which the general vehicle industry connectivity strategy is presented as well as the ACEA position paper "Frequency Bands for V2x"[6] (2016).

The C2C-CC embraces the objective to reach the highest level of road safety, where currently still 26000 deaths are counted every year. The C2C-CC recognizes the need to efficiently use the spectrum, a scarce resource, and sees technology neutrality as a principle. The C2C-CC considered and analysed the scenarios in the invitation of the DG CONNECT workshop.

This position paper includes a view on the current deployed equipment in chapter 4. Chapter 3 provides a clarification of the Cooperative-ITS principles as identified in the DG-CONNECT workshop as boundary conditions for the coexistence analyses in chapter 5. As C-ITS research ir looking at beyond day 1 applications chapter 6 provides an overview of the expected applications and their spectrum extended Day-2 and beyond spectrum requirements. Finally, in chapter 7 considerations concerning to the scenarios are provided as were presented in the DG CONNECT Workshop invitation.

[1] https://www.car-2-car.org/index.php?id=5
[2] Workshop invitation 5_9GHz-20170905.docx
[3] http://5gaa.org
[4] accelerating-LTE-V2x-commercialization.pdf
[5] http://www.acea.be/publications/article/strategy-paper-on-connectivity
[6] http://www.acea.be/publications/article/position-paper-frequency-bands-for-v2x

2 Executive Summary

The CAR 2 CAR Communication Consortium (C2C-CC) recognizes many Cooperative-Intelligent Transportation Systems (C-ITS), Automated applications and services representing various functional and technical requirements. The C2C-CC members are committed to the European strategy of C-ITS (COM(2016) 766)[7]. As underpinned by ACEA in its “Connectivity Strategy” paper and by the C-ITS deployment platform report phase 1 from beginning 2017, it is clear, that for the realisation of these applications multiple communications are required. The C2C-CC embraces the principles as expressed in the DG CONNECT workshop from 5 September 2017 as well as the C-ITS deployment platform Hybrid Communication strategies driven by DG MOVE. The C2C-CC supports the EU promotion of sharing radio spectrum as defined in the European digital single market strategy[8]. Additionally the C2C-CC acknowledges the ACEA Hybrid communication strategy and sees spectrum technology neutrality as a principle.

Based on the DG CONNECT principles (chapter 3) the C2C-CC recognized that it is not enough to realize only radio technical non-interfering coexistence. Essential cooperative principles (providing every road user an equal level of access to safety information such that all have a similar safety change) shall be followed. These principles lead to additional functional and technical coexistence requirements. Requirements resulting in interoperability and backward compatibility requirements to Eco-Systems targeting the same safety related applications and the same users in the same area of reception.

As confirmed by the 5GAA at the DG CONNECT workshop, safety related sensor information (chapter 4) sharing based on IEEE802.11p/ITS-G5 (ITS-G5) ad-hoc short-range communication is the first technology being available, implementable and validated end to end. The 5GAA, in cooperation with Qualcomm, expresses that LTE-V2x is superior to ITS-G5 and see this as a liable reason to propose to wait with implementation and deployment of C-ITS services based on ITS-G5 to allow further evaluate of the LTE-V2x technology before any C-ITS services are deployed. Other studies, such as from NXP and Autotalks, however come to significant different conclusions (in case advanced coding is introduced into ITS-G5, initiatives to realize IEEE 802.11px are on the way). Research institutes are currently evaluating the technologies and can’t confirm any advantage as well. Publications of these research results are expected later this year.

ITS-G5 technology has been available already from before 2008 and equipment for implementation from 2014. LTE-V2x technology was promised end 2017, now announced to be available later in 2018 for evaluation. ITS-G5 is years ahead and have started a second research and innovation cycle, equipment is currently being provided to the market.

In strong consensus C2C-CC members and other C-ITS stakeholders represented in by the C-ROADS platform support the report EC C-ITS deployment platform and see no reason to wait for other technology and delay any decreasing of the level of 26000 deaths yearly. A significant group of stakeholders are convinced about the technology and are committed to implement the ITS-G5 technology. Others may continue the development of other technologies e.g. LTE-V2x but should not be allowed the block the early adoption of ITS-G5 by stakeholders interested to do so. Any new technology e.g. LTE-V2x should follow legislated neutrality and the DG-CONNECT principles. They are obligated to realize non-interference and ensure correct operation of the implemented incumbent ITS-G5, Fixed Satellite Services (FSS), Fixed Services

[7] http://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v5.pdf

[8] https://ec.europa.eu/digital-single-market/en/promoting-shared-use-europes-radio-spectrum

(FS) and CEN DSRC services. The Quality of Service (QoS) of these services may not be jeopardized.

The proposal from the 5GAA strongly supported by Qualcomm to split the channels (scenario 3 from the DG CONNECT invitation) is not following the neutrality principle ensured by regulation as after splitting new technologies can’t enter the market any more. Functionally the proposal is also not possible as the 176 and 180 channels are both in use by ITS-G5 and used for different services. Technically a split as proposed will lead to adjacent band interference and incorrect functioning of the ITS-G5 system as explained in chapter 5. It is also not a spectrum efficient use. The only possibility is to investigate coexistence under normal spectrum under normal sharing conditions based on existing regulation and DG CONNECT guiding principles.

Under these given circumstances, the C2C-CC in strong consensus sees ITS-G5 being the incumbent technology and LTE-V2x as the new technology to ensure non-interference ensuring that the QoS of ITS-G5 is not harmed in line with the cooperative principles and spectrum regulations. In case coexistence in the same 5.9 GHz band can be realized, the coexistence, interoperability and backward compatibility must be realized under suspicion of the European Commission with regards to the services and the ECC/CEPT with regards to the spectrum. Although this may lead to required changes to technical and functional standards these changes shall be backwards compatible with the current versions of the standards to be updated.

The C2C-CC sees benefits in the LTE-V2x technology as complementary technology and promotes the further development as such. The C2C-CC is investigating its potentials and suggests to further developing LTE-V2x and 5G safety related technologies at least in first instance in other spectrum. The C2C-CC supports coexistence and interoperability studies in cooperation with EATA and 5GAA and at the relevant authorized bodies, Commission, ECC/CEPT and ETSI, in case coexistence in the same spectrum is envisioned.

The C2C-CC sees a large growth of Automation/Autonomous Driving and C-ITS applications and related information exchange between vehicles and between vehicles, other road users and infrastructure. It also sees an increase of more demanding communication requirements such as higher QoS and levels of ensured bandwidth. The C2C-CC therefore recommends 2 things:

- The extension of the currently designated spectrum from 30 MHz to 50 MHz also incorporating the support for Urban Rail. Realizing a designated 5875-5925 MHz band for traffic safety related.
- The development of 5G cellular technology (including peer to peer V2x communications) supporting high levels of QoS and predictable ensured bandwidth realized in licenced and/or un-licenced spectrum outside the 5855-5925 MHz range at such a distance that non-interference is guaranteed so that both systems can be implemented in the same vehicle.

3 Regulatory Framework in Europe

3.1 Introduction

The regulatory framework for safety related information exchange is driven by the European commission, ECC and CEPT. In the DG CONNECT Workshop on "short range communications in the 5.9 GHz band"[9] a number of principles have been identified and verified in the workshop. It is stated that regardless of market development the following principles shall be considered:

- Uncompromised safety services for all users in case of multiple technologies implementation (in compliance with the European C-ITS Strategy COM(2016)766[10]);
- Technology neutrality of spectrum regulation (such as in the 5.9 GHz band for safety-related applications, pursuant to Commission Decision 2008/671/EC[11]);
- Efficient spectrum use (an overarching principle of Union's Radio Spectrum Policy, also encompassed in the provisions of the Radio Equipment Directive 2014/53/EU[12]);
- Opportunity offered by CAD for early development and deployment of 5G communication technology[13] and the need to ensure complementarity and coexistence with existing communication technologies such as ITS G5 and LTE (Rome Letter of Intent of Member States).

These principles result in different requirements to the systems realizing safety related applications and therefore directly have consequences for coexistence of different technologies operating in this safety related spectrum in the 5.9 GHz band.

3.2 Uncompromised safety services

This principle ensured the uncompromised access to available road safety related information by all users so they have an equal opportunity to improve their safe situation as a road user. Voluntary cooperation on equal bases is the foundation of Cooperative-ITS (C-ITS). A cooperation based on equal access to safety related information and equal access to safety related spectrum. The ECC Decision (08) 01[14] identifies the effective protection for traffic safety and traffic efficiency applications and as the objective of cooperative in ITS is identified as "an autonomous association of persons or systems united voluntarily to meet their common road safety focussed traffic efficient comfort traveling needs and aspirations through a jointly-owned and democratically-controlled system", in the context of spectrum results in that all users of the spectrum are equal in the case of safety related and traffic management related information exchange.

This aspect has big consequences in how to look at coexistence. It is not sufficient to look at the radio technical interference alone, additionally the varying systems targeting the same C-ITS objective must behave equally without information sharing advantages. They therefore need to be interoperable at the information exchange level as otherwise no equality among the road users can be realized. Cooperative-ITS therefore introduces additional communication coexistence requirements with the following functional and spectrum technical consequences:

[9] DG_CONNECT_minutesByTheHeadOfUnit_rapport_20170905

[10] http://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v5.pdf

[11] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008D0671

[12] http://eur-lex.europa.eu/eli/dir/2014/53/oj

[13] https://www.regjeringen.no/contentassets/0eb274b9428d4598bc79504fb902f819/letter_of_intent.pdf

[14] http://www.erodocdb.dk/docs/doc98/Official/Pdf/ECCDec0801.pdf

- All road participants shall cooperatively share all safety related information under the privacy regulation such that all road users can benefit. There cannot be differentiation only equality in the access of safety related information. Everyone should have an equal chance to receive safety related information provided by others whatever technology is used.
- Functional interoperability is required as information send by one should be understood by any other in a single predictable behavioural way whatever technology is used. As one type of safety related information may be more important than other some prioritisation is implemented. This prioritisation needs to be common to technologies to ensure equality.
- As the functional behaviour depends on technical capabilities and therefore also technical interoperability is required.
- Based on these Interoperability requirements backward compatible cannot be avoided.

When different technologies with equal importance are seeking to use the same spectrum and as the information exchange is of safety relevance, the fairness[15], as defined by Raj Jain[16] must be ensured to let the technologies to operate reliably.

- Sharing safety related information can be a matter of live or death, therefore the fairness needs to be maximized.
- To realize fairness between different systems each of the systems may not use more bandwidth to exchange the same information. At least, new may not use more than earlier systems.
- To realize Fairness no technology may use more channel capacity than the previous one which means that it must use the same access methodology and the same algorithm as all others and therefore as the initial user.

Sharing the same safety related information via different technologies shall not lead to more packet collisions and unpredictable behaviour of the initial technology used. It should not result in harmful interference leading to in unsafe situations. As Jeopardising the correct functioning of the initial technology may lead to injuries, liability is an issue.

3.3 Spectrum regulation

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

- The European Commission has harmonised the band 5875-5905 MHz for traffic safety- and traffic efficiency related applications in the European Union via the legally binding Commission Decision 2008/671/EC (2008).
- The CEPT harmonisation is applied by the ECC via ECC Decision (08)01 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. In the ECC amendment the spectrum mask has been relaxed.
- ECC also recommends, via ECC Recommendation (08)01[17] from 2008, that CEPT administrations should make the frequency band 5855-5875 MHz available for traffic non-safety applications.

[15] $\mathcal{J}(x_1, x_2, \dots, x_n) = \frac{(\sum_{i=1}^n x_i)^2}{n \cdot \sum_{i=1}^n {x_i}^2}$ rates the Fairness of a set of values where there are *n* users and x_i is the throughput for the i th connection. The result ranges from *1/n* (worst case) to 1 (best case), and it is maximum when all users receive the same allocation. This index is *k/n* when *k* users equally share the resource, and the other *n/k* users receive zero allocation.

[16] https://en.wikipedia.org/wiki/Raj_Jain

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

The above regulatory measures from the ECC refer to the ETSI Harmonized Standard EN 302 571[18] and defines 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). 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 mobile industry representatives provided a large number of editorial comments with main focus on having the specification being technology neutral. No technical parameters to allow LTE to operate in the 5.9 GHz were proposed[19]. The specification was accepted early 2017 and published in the OJ[20] on 9 June 2017.

While the current regulatory framework sets only the 5875-5905 MHz band as designated to road safety and traffic efficiency, the regulatory framework allows European to extend this to the other 2 bands. Several European Union member states therefore have designated the band 5855-5925 MHz for C-ITS.

The principle of technology neutrality in spectrum regulations implies that any radio technology which can demonstrate conformance with the essential requirements of the Radio Equipment Directive (e.g. through compliance with EN 302 571) can operate in the 5855-5925 MHz Band.
Spectrum neutrality and efficient spectrum used are monitored and managed by ECC and CEPT.

3.4 Regulatory extension

Only the radio conformance is regulated through the compliance with the EN 302 571, the functional interoperability is not covered and currently there is no mechanism to ensure this. In case coexistence between competitive technologies targeting the same safety applications and same users in the same radio environment is envisioned it must be advised to realize harmonized interoperability norms linked to the same regulations. Practically it therefore is suggested to leave the regulatory responsibility for this at the ECC/CEPT and realize harmonized interoperability norms at the European telecommunications standardisation body ETSI.

[18] http://www.etsi.org/deliver/etsi_en/302500_302599/302571/02.00.00_20/en_302571v020000a.pdf

[19] To be noted: Harmonized standards spectrum related parameters are defined to ensure proper operation of equipment in the band; these parameters are generally tailored to the technologies operating in the band, e.g. 3G and 4G in their specific bands. Any other technology can't operate in the 3G and 4G bands therefore by default.

[20] https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/red_en

4 Readiness of short-range communication technologies

4.1 Introduction

Any technology introduction is preceded by several research and innovation phases. This chapter clarifies the processes which have been followed and shows where each of the technologies under discussion is. The next phases have been followed:

Phase 1. Research
Phase 2. Innovation and Predevelopment
Phase 3. Verification and Radio Interoperability
Phase 4. Realisation and Development
Phase 5. Validation and Functional Interoperability
Phase 6. Commercialisation and Implementation

The next paragraphs show where the IEEE802/11/ITS-G5 and LTE-V2x technologies are related to these phases and in the last paragraph the overall observations are provided.

4.2 Development and status IEEE802.11/ITS-G5

The vehicle industry represented by the C2C-CC is committed to improve comfort and safety for the car user, by means of the exchange of relevant safety and none safety related information between vehicle and between vehicles, road infrastructure and service providers independently of the technology used to achieve the above mentioned general objective.

4.2.1 Phase 1 Research

Research on Cooperative Intelligent Transportation Systems (C-ITS) by the vehicular industry and others already started in 1986–1994 when the EUREKA-PROMETHEUS-Project[21] (PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety) was established. PROMETHEUS did innovative R&D on vehicle to vehicle communication, automated driving and ITS services (e.g. navigation). Many projects followed recognizing that there was a need for different levels of vehicular information exchange ranging from strategic (e.g. allowing to make changes in directions, type of transportation or general speed adjustment of what comes ahead) and tactical information exchange, e.g. safety related information exchange at short-range. This is underpinned today by ACEA in its “Connectivity Strategy”[22] paper, and recognized by the C-ITS deployment platform in its Final Report[23] from 2016.

Related to safety, many analyses were done to identify what technology to use. Specifically, for sharing safety related sensor information and warnings the RLAN technology IEEE 802.11 was identified for its safety related physical behavioural capabilities, its availability and its low cost to form the bases of this safety sensor network.

4.2.2 Phase 2 Innovation and Predevelopment

In 2002, the CAR 2 CAR Communication Consortium (C2C-CC) was established with the purpose to drive the development of interoperable safety related information exchange based on the short-range IEEE802.11p/ITS-G5 (ITS-G5) communications. This interest of the industry was strongly supported by the publicly funded project Network on Wheels (NoW, between 2004-2008)[24]. IEEE 802.11 became the basis for the physical layers for both the European and USA 5.9 GHz safety related information exchange. In Europe we use the ETSI ITS-G5 architecture

[21] http://www.eurekanetwork.org/project/id/45

[22] http://www.acea.be/publications/article/strategy-paper-on-connectivity

[23] http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf

[24] http://www.festag-net.de/doc/WIT-2008_now-achievem_festag-etal.pdf

and specifications for the other layers, in the USA the IEEE 1609 (WAVE)[25] specifications are used. To ensure flawless road safety information exchange, the allocation of a specific part of spectrum was initiated in 2006, which in 2008 led to the spectrum allocation and designation as presented in chapter 3.
To realize a common objective, the European Commission initiated Mandate M/453 Standardisation addressed to CEN, CENELEC and ETSI in the field of information and communication technologies to realize interoperability specifications of C-ITS in the EC. Initial standardisation led in 2009 to the definition of the road safety and road efficiency Basic Set of Applications ETSI report TR 102 638 and the European communication architecture defined in the EN 302 665 in 2010.

4.2.3 Phase 3 Verification and Radio Interoperability (large-scale test)

In 2008 the first interoperability demonstration of V2V ITS-G5 was realized at Dudenhofen[26] in Germany, and in the German project simTD[27] large-scale tests with 400 vehicles were executed. In 2009 first automotive tailored IEEE 802.11p technology came available and a large-scale test of nearly 3000 ITS stations with IEEE 802.11 equipment was executed collectively between authorities and vehicular industry in Ann Arbor[28], Michigan USA in 2011 to confirm proper operation under dense radio stations situations. Compliancy testing started in 2011 at the ETSI ITS-G5 Plugtest.

4.2.4 Phase 4 Realisation, development

During the years more than 30 project such as simTD (D, 2008-2014), CVIS(EU)[29], SafeSpot[30] (EU), Freilot (EU)[31], EcoMove[32], Drive-C2X[33], Converge (D)[34], Score@F (F)[35], EasyWay[36] (EU) and Compass4D[37] (EU) confirmed the operation and contributed to the development of the ITS-G5 based services from which now the Day-1 (see the C-ITS deployment Platform report phase 1[38]) services are deployed. Founding the Amsterdam Group[39] by the key stakeholder organisations ASECAP[40], CEDR[41], POLIS[42] and C2C-CC in 2011 brought the deployment of this technology also towards authorities and infrastructure. Supported by the EC delegated act 886/2013, the Amsterdam Group boosted the early deployment of this technologies by simply focussing towards the deployment of a simple set of use cases, e.g. Road Work Warning (RWW) supported by the ETSI[43] standards such as the ETSI EN 102 637-3 (DENM), followed

[25] https://standards.ieee.org/develop/wg/1609_WG.html

[26] http://www.broadbit.net/portal/?tag=demonstration

[27] http://www.simtd.de/index.dhtml/deDE/index.html

[28] http://www.aacvte.org/get-connected/586-2/

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

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

[31] http://www.ecomove-project.eu/links/freilot/

[32] http://www.ecomove-project.eu

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

[34] http://www.converge-online.de

[35] http://www.scoref.fr

[36] https://www.its-platform.eu/highlights/easyway-programme-2007-2020-and-its-projects

[37] http://www.compass4d.eu

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

[39] https://amsterdamgroup.mett.nl/default.aspx

[40] http://www.asecap.com

[41] http://www.cedr.eu

[42] POLIS

[43] http://www.etsi.org

by other services such as Probe Vehicle Data (PVD, first version aggregated CAM's, ETSI EN 102 637-2) and In Vehicle Signage (IVS) supported later by the IVI standard ISO[44] TS 19321 in 2015 for the information exchange via ITS-G5.

A full set of initial ITS-G5 functional, technical and test specifications was published as captured in the ETSI published in the technical report TR 101 607 in 2013.

The importance of C-ITS towards the European safety objectives led to further European Commission initiatives to further develop and deploy C-ITS, and installed the C-ITS platform in 2015 to identify open especially regulatory issues and to stimulate the further development and deployment of C-ITS applications and technologies. The C-ITS platform is supported by expert representatives of all interested stakeholders. It delivered a first phase platform report beginning 2017. The C-ITS platform experts recognized that to support a wide range of services such as the Day-1 use cases, as well as automation and beyond Day-1 related services, a future-proof Hybrid Communication approach supported by complementary operating radio communications is needed. A hybrid complementary multiple-radio approach is also recognized as required to support redundancy. A hybrid communication environment is initially supported by 2 (RDS-TMC[45] (ISO) not counted) main complementary technologies: standard cellular technologies 3G/4G for the strategic long-range information exchange and ITS-G5 for the tactical safety short-range oriented information exchange, these had all their specifications ready and technical solutions available in 2015.

4.2.5 Phase 5 Validation and Functional Interoperability

Although compliancy ETSI Plugtest[46] were realized in 2011, 2012, 2013 and 2015, new compliance testing with extended End2End interoperability testing was realized in 2016 to be followed by the next in 2018. These plugtest were organized in Helmond (the Netherlands), Versailles (France), Essen (Germany) and Livorno. The plugtest resulted in qualified test specifications. To accommodate the deployment of ITS-G5, the European Commission was asked to revise the spectrum regulation to accommodate the deployment of ITS-G5 as the technology was ready. The proposed change was captured in the ETSI (RSDoc) TR 103 083 in 2014 and brought to European regulation. Automotive compliant solutions had been tested for several years and automotive compliant high temperature qualified products are available since 2014.

With the installation of the C-ITS Deployment Platform[47] the EU commission stimulated the progress of interoperability validation. To further stimulate the involvement of EU Member States and realize European C-ITS interoperability, the European Commission installed the European C-ROADS[48] platform (so far supported by 15 Member States and Switzerland see Annex B) in 2016 to support a wider European deployment of safety related use cases to increase safety and traffic efficiency and safe fives. Also projects like Scoop@F[49], Eco-AT[50] and InterCor are focused in realizing European interoperability.

[44] https://www.iso.org/home.html

[45] https://nl.wikipedia.org/wiki/Traffic_Message_Channel

[46] http://www.etsi.org/about/what-we-do/plugtests

[47] https://ec.europa.eu/transport/themes/its/c-its_en

[48] https://www.C-ROADS.eu/platform.html

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

[50] ASFiNAG main project: http://www.eco-at.info

4.2.6 Phase 6 Commercialisation and Implementation

Today ITS-G5 equipment is available in the market, and is implemented and operational in both Vehicular On-Board Units (OBU) and Road Site Systems (RSU). Just in France, 1000 Renault Megane (Figure 2, first vehicle were ordered early 2017 (France only) and will be delivered in in about 1 month). PSA will upgrade Citroën C4 and DS4 C4 series with ITS-G5 (about 1000) vehicles sold into the market. Authorities and others will retrofit another 1000 vehicles. These vehicles are be equipped with dual channel ITS-G5 systems using channels 176 and 180 (Figure 1) in the Scoop@F project. Volkswagen[51] will introduce ITS-G5 equipment in the Golf VIII before summer 2019 and in strong consensus the C2C-CC published[52] their commitment to start deploy C-ITS services based on ITS-G5 technology.

Many, mostly dual channel, ITS-G5 infrastructural systems have been installed in various Europe Member States, and an increasing amount of Member States follow the European Hybrid Communication interoperability approach as recognized in the C-ITS platform report phase 1. Austria has started to deploy ITS-G5 in 2016. From 2018, onwards 300 km of roads will be equipped with ITS-G5 (ASFINAG[53], Eco-AT). Deployment in France, England, the Netherlands, Norway and Sweden also started in 2016 based on country projects, Germany and Slovenia are equipped in 2017, and Hungary was already implementing ITS-G5 in 2016. Other C-Road Member States will follow in 2018.

The basic use cases, as defined in the ETSI TR 102 638, realize their information exchange by the simple CAM and DEMN messages which are exchanged on channel 180. Additionally, based on the obligated PKI support, channel 176 is used for certificate exchange via ITS-G5.

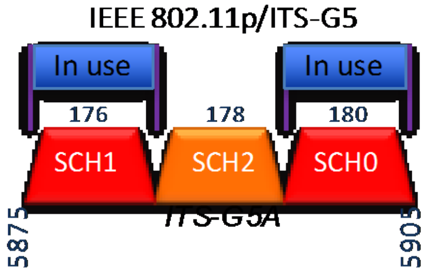

Figure 1: ECC Decision (08)01 C-ITS channels used by ITS-G5 in Europe today.

[51] http://www.automobilwoche.de/article/20170422/HEFTARCHIV/170429981/133. AW, VW lässt Autos kommunizieren, S. 10.pdf

[52] https://www.car-2-car.org/index.php?eID=tx_nawsecuredl&u=0&g=0&t=1502657446&hash=27016cc347d2b7c636e58b085a4f27364276ea5a&file=fileadmin/downloads/PDFs/C2C-CC_Press_Information_on_EC_Masterplan_final.pdf

[53] https://www.asfinag.at

Figure 2: Hybrid Communication in Europe

The European ITS Strategy as defined in the COM(2016)766[54], a milestone towards cooperative, connected and automated mobility, is focused on the deployment of C-ITS services based on the existing ITS-G5 short-range communication for the tactical traffic safety related and efficiency related information exchange as proven in the many projects over the last 20 years. The C-ROADS Platform Member States are committed to follow the COM(2016)766, the European ITS strategy and the Declaration of Amsterdam[55]. The C-ROADS Member States are focused to deploy C-ITS applications based on the Hybrid Communication environment as agreed in the EU C-ITS platform final report phase 1. To accomplish this, the C-ROADS Platform and the C2C-CC have agreed a Memorandum of Understanding (MoU[56]) to ensure the required European Interoperability.

Beside the commitment to start deploying ITS-G5 in 2019 by C2C-CC OEM's, the motorcycle companies' OEM's expect to follow the vehicle, specifically for the realisation of ITS-G5 in their products, have organized themselves in the Motorcycle Consortium[57] and expressed to follow the car OEM's in the C2C-CC with the realisation of ITS-G5. World Wide GM and in Europe, Volkswagen[58] officially announce their commitments to implement this technology and Score@F members have equipped products sold into the market and expects that this will be followed by others. Six truck OEMs (MAN, Scania, DAF, Iveco, Daimler, and Volvo) have expressed to realize platooning based on ITS-G5 communication equipment. The Truck manufactures are expecting to use multiple ITS-G5 channels as they need a higher CAM rate of up to 30Hz and additional platooning management information exchange.

4.2.7 Next Phase 1 and 2 for Research and predevelopment for Beyond Day-1.

Already a new research and predevelopment cycle has started. New Day-2 and beyond C-ITS and Automation use cases and applications are investigated and developed. The European Commission installed new projects on research, innovation and deployment to stimulate the further growth of new C-ITS and automation use cases making use of Hybrid Communication architectures to increase the effect on the European safety objectives. Some of these projects

[54] https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v5.pdf

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

[56] MOU between C2C-CC and the C-ROADS project: https://www.car-2-car.org/index.php?eID=tx_nawsecuredl&u=0&g=0&t=1502657446&hash=05b5e1a152fc4427f1645c0eac282963efa92248&file=fileadmin/downloads/PDFs/C-ITS_Cooperation_between_C2C-CC_and_C-ROADS_Platform.pdf

[57] http://www.cmc-info.net

[58] http://www.automobilwoche.de/article/20170422/HEFTARCHIV/170429981/133.

are already closed, e.g. VRUITS[59] (project on Vulnerable Road Users (VRU). Others are ongoing such as TIMON[60], AutoNet 2030[61], and HIGHTS[62]. New ones will start later in 2017.

The industry is also looking at technology enhancement, improved QoS and extended services. Extended Hybrid Communication, Functional Safety and Multi-Channel Operation (MCO) for ITS-G5 are the next things on which work has started. As the ITS-G5 concerns the exchange of safety related information and the Beyond Day-1 applications will be more critical, Functional Safety (ISO 26262) aspects will have an important influence on the Hybrid Communications, therefore discussed in chapter 6. Initial MCO concepts to manage multiple channels are presented and development of a MCO concept is ongoing.
Current research projects such as Scoop@F, InterCor, AutoNET 2030, TIMON and HIGHTS confirm that deployed ITS-G5 and standard cellular technologies are ready for the tasks of Day-1 and recognize the growth of information exchange. New use cases such as platooning applications (see chapter 6) are implemented and evaluated by the European Truck manufacturers (MAN, Scania, DAF, Iveco, Daimler, and Volvo) to reduce operational cost, increase safety and provide lower CO^2 emissions based on ITS-G5. Now they are collectively focussed in realizing interoperability commonly based on ITS-G5. At this stage, they are past the moment no change the technology as this will influence the progress and delay to cash on the benefits.

4.3 Development and status LTE-V2x

4.3.1 Phase 1, Research

Research on LTE technologies servicing vehicular applications started in 2012 with projects such as METIS II[63] (2012-2015), SHARING[64] (2012-2016) and SYSUF[65] (2013-2016) which are working on LTE-V2x (see related references for more details) and some other German projects. Research on LTE-V2X stems from early work to offer Device-to-Device (D2D) via LTE Proximity Services (ProSe) since LTE release 12 from 2012-2013.
Since the early designs and still on the latest LTE-V2X specifications, D2D communication relies on an Uplink (UL) Physical layer (i.e. SC-FDM), as all devices are capable of transmitting in UL and it is easier to implement a UL receiver than a DL transceiver in each device. Accordingly, D2D communications operate in UL resources on a new logical link name called 'Sidelink' (SL). In release 14, LTE-D2D can only be provided in Unicast and under the coverage of a cellular operator, with the exception of First Responders. However, the LTE-V2X extension (an extension of the LTE-D2D) specifically allows V2X communication in unicast and broadcast, under coverage or out-of-coverage, either in infrastructure or in ad-hoc mode.

From a research perspective, D2D communications underlying the LTE cellular network have been researched since it was in the earliest stages of its specification[66]. The Survey paper[67] contains an review of the literature on cellular D2D communications until 2014, classified by type: based on the type of spectrum they occupy, D2D communications can in fact be "inband" or "outband". In the former case, D2D transmission are assigned a subset of resources within

[59] www.vruits.eu/

[60] https://www.timon-project.eu

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

[62] http://hights.eu

[63] https://www.metis2020.com

[64] https://www.celticplus.eu/new-lte-advanced-innovations-developed-celtic-plus-sharing-project/

[65] https://sourceforge.net/projects/openlte/

[66] K. Doppler, M. Rinne, C. Wijting, C. Ribeiro, K. Hugl, Device-to-device communication as an underlay to LTE-advanced networks, IEEE Communications Magazine 47 (2009) 42–49.

[67] A. Asadi, Q. Wang, V. Mancuso, A Survey on Device-to-Device Communication in Cellular Networks, IEEE Communications Surveys & Tutorials 16 (2014) 1801–1819.

an operator's own frequency bands (typically the UL ones), whereas in the latter scenario they are operated in a separated band. Inband D2D can be further split into "overlay" and "underlay", with overlay D2D users being assigned orthogonal resources to the legacy cellular users, whereas the "underlay" paradigm has D2D users reutilize the same channel resources as cellular users. This latter paradigm has proven very attractive as it improves spectral efficiency by exploiting proximity gain. On the other hand, outband D2D can be of "controlled" or "autonomous" type: controlled D2D communications are scheduled by the base station, despite physically taking place on a separate band.

More recently in 2013-2014, D2D cellular communications have attracted increasing attention in the vehicular community, with several studies investigating their suitability to support automotive safety-critical applications. In Aranti et al.[68], 3G and LTE cellular communications are compared to WiFi for vehicular networking, and LTE D2D is featured as an appealing solution. Radio Resource Management is stressed as the key aspect to ensure an adequate coexistence of legacy cellular and V2V communications. In Cheng et al.[69], D2D for Intelligent Transportation Systems are studied in terms of spectral efficiency, concluding that the inband underlay paradigm is a better option. In Piro et al.[70] the authors evaluate the influence that V2V specific PHY and MAC configuration, and traffic patterns have on the performances of LTE D2D, reaching the conclusion that LTE D2D offers adequate performances (in upper bound) to support this type of traffic. In Matolak et. al[71], on the other hand, the performance evaluation focuses entirely on the PHY layer, using multiple MIMO modes: based on analytic channel models, the authors confirm the feasibility of LTE D2D based V2V in terms of achievable throughput. The book chapter[72] takes a detailed view on all the flavours of LTE (both legacy and ProSe) for both safety and non-safety vehicular communications, discussing the challenges for 5G to become an enabler for Vehicle-to-Device Communications.

Whereas all previously cited work investigated LTE-D2D adapted to vehicular environments, they mostly focused on the Physical layer. None of them investigated Radio Resource Management (RRM) compliant with the on-going 3GPP[73] LTE-V2X. Gallo et Härri published in 2013 the first paper[74] proposing LTE-V2X Broadcast RRM adapted to C-ITS safety-related applications. Further studies followed between 2014-2016[75][76] investigating RRM bounds for

[68] G. Araniti, C. Campolo, M. Condoluci, A. Iera, A. Molinaro, LTE for vehicular networking: a survey, IEEE Communications Magazine 51 (2013) 148–157.

[69] X. Cheng, L. Yang, X. Shen, D2D for Intelligent Transportation Systems: A Feasibility Study, IEEE Transactions on Intelligent Transportation Systems 16 (2015) 1784–1793.

[70] G. Piro, A. Orsino, C. Campolo, G. Araniti, G. Boggia, A. Molinaro, D2D in LTE vehicular networking: System model and upper bound performance, in: Ultra-Modern Telecommunications and Control Systems and Workshops (ICUMT), 2015 7th International Congress on, IEEE, 2015, pp. 281–286.

[71] D. W. Matolak, Q. Wu, J. J. Sanchez-Sanchez, D. Morales-Jimenez, M. C. Aguayo-Torres, Performance of LTE in Vehicleto-Vehicle Channels, in: IEEE Vehicular Technology Conference (VTC Fall), IEEE, 2011, pp. 1–4.

[72] C. Lottermann, M. Botsov, P. Fertl, R. Müllner, G. Araniti, C. Campolo, M. Condoluci, A. Iera, A. Molinaro, Vehicular ad hoc Networks: Standards, Solutions, and Research, Springer International Publishing, pp. 457–501.

[73] http://www.3gpp.org

[74] Gallo, Laurent; Härri, Jérôme Short paper: A LTE-direct broadcast mechanism for periodic vehicular safety communications (VNC 2013), IEEE Vehicular Networking Conference, December 16-18, 2013, Boston, USA

[75] W. Sun, E. Strom, F. Brännström, K. Sou, Y. Sui, Radio Resource Management for D2D-based V2V Communication, IEEE Transactions on Vehicular Technology (2016) 6636–6650.

[76] M. Botsov, M. Klugel, W. Kellerer, P. Fertl, Location dependent resource allocation for mobile device-to-device communications, in: IEEE Wireless Communications and Networking Conference (WCNC), IEEE, 2014, pp. 1679–1684.

V2X communications. In 2017, Gallo et Härri[77] compared different RRM (random vs. TDMA) adapted to broadcast communications.

From the research initiated between 2013 and 2017, LTE-V2X showed to be possible both from a Physical and MAC layer perspective, and cleared the way to the Innovation/Predevelopment phase. However, several challenges need to be addressed before LTE-V2X communication can be brought to product. First, the SC-FDM requires an equalized received power from all transmission in a same timeslot across all LTE Resource Blocks (RBs), which is practically impossible to fulfil in a broadcast mode. Second, LTE-V2X communication in Ad-Hoc mode is strongly dependant to half-duplex impairment. Finally, unlike all 3GPP products, a common scheduler must be standardized for all operators and all equipment, which is not yet available even in the latest LTE-V2X rel 14 standard.

4.3.2 Phase 2, Innovation and Predevelopment

3GPP started the development of the direct mode LTE-V2x communication specifications for the vehicular environment by analysing available C-ITS standards and other documents. ETSI TC ITS provided comment to these 3GPP specifications but the comments were not accepted. The first publication of release 14 in 2016 was missing many required elements, the final publication of release 14 happened end 1st half 2017. No new publications of the release 14 will be made hereafter as the next focus is 5G cellular which will start with release 15. In this final published release 14 the exact harmonized parameters of the EN 302 571 are included, however several important aspects are still not specified. The 5GAA[78] expects that this will happen in the coming year.

Since 2016 there are 2 associations, the 5GAA and the EATA[79] (part of ERTICO) active to develop C-ITS services and realize first implementations of the LTE-V2X technologies. An MoU[80] between the 5GAA and EATA has been established. There are no authorities' member of neither these associations and only one infrastructure company is member of EATA.

The EATA has 13 vehicle manufacturer members. It focusses on Hybrid Communications including ITS-G5 for short-range communication. The EATA is not outspoken about a preference between the 2 short-range technologies ITS-G5 and LTE-V2x but has a focus on Mobile Edge Computing (MEC). Within the EATA corresponding project Concorda[81] it expects to develop some interesting vehicular applications, such as Valet Parking which interests the Vehicle industry. The EATA European project Concorda has been accepted with limited budget compared to what was requested.

The 5GAA so far has 5 vehicle manufacturer members and focus on C-ITS and Automated applications. They do not reference to any specific C-ITS application standards, and application titles do not correspond to those used in these C-ITS standards identified as Day-1 applications defined by the EC C-ITS Deployment Platform. The 5GAA-White Paper[82] from 23 Nov 2016 expresses that the 5GAA purely focus on LTE-V2x and will seek for coexistence with ITS-G5. The 5GAA provided a position paper "Coexistence of LTE-V2X and 802.11p at 5.9 GHz"[83]

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[77] Unsupervised LTE D2D - Case study for safety - Critical V2X communications, IEEE Vehicular Technology Magazine, Special Issue on Emerging Technologies, Applications, and Standardizations for Connecting Vehicles, Vol.: PP, Issue: 99, June 2017

[78] http://5gaa.org/

[79] http://www.eatanews.org/eata-2/about-eata/

[80] https://www.gsma.com/newsroom/press-release/connected-and-automated-driving-eata-presents-deployment-roadmap/

[81] http://www.concorde-project.eu

[82] http://5gaa.org/pdfs/5GAA-whitepaper-23-Nov-2016.pdf

[83] http://5gaa.org/pdfs/5GAA_News_neu.pdf

including a proposal to split the band. In chapter 5 we will come back on the technical aspects of this. The 3GPP release 14 is not complete and 5GAA expects to come with additional specifications in 2018. Test, validation and interoperability specifications are expected in 2018.

4.3.3 Phase 3 Verification and Radio Interoperability (large-scale test)

Tests of technology based on LTE-V2x are planned in China. In Germany, first LTE-V2x tests will be realized on the A9, and there are ideas of having several test sites. In the USA, Ford has informed NHTSA that they are working with partners on validation of LTE-V2X by leveraging CAMP know-how. This effort will be completed by mid-next year, but no large-scale test such as the one done for IEEE 802.11p at Ann Arbor, Michigan USA (3000 stations) have been announced. The 5GAA testing is realized by a few vehicle manufacturers. Verification is ongoing and further expected in 2018. No further details could be found are could be provided. For realizing compliance no assessment at ETSI has been foreseen yet. No ETSI Plugtest for LTE-V2x is foreseen so far.

4.3.4 Phase 4 Realisation, development

As far as known to the authors (based on what is published and partly communicated), hardware will be available end of 2017 for 5GAA members and probably in 2018 for other interested parties. Whether this comes with a full set of tools is not known. No test specifications can be found and Safety System Automotive quality requirements are not confirmed.

The 5GAA white paper states that LTE-V2x support different modes and can be realized in both licensed and unlicensed spectrum. The white paper also indicates that LTE-V2x will use existing ETSI ISO, SAE[84], IEEE standards for the higher layers and by doing so it will be possible to swap out the existing IEEE802.11p radio. How this is realized is significant but not specified. It is indicated that it will support a ITS-G5 interface. Today nothing is standardized related to this.

4.3.5 Phase 5 Validation and Functional Interoperability

Validation within 5GAA with selected partners is indicated for 2018. There is no wide stakeholder interoperability validation planned so far.

4.3.6 Phase 6 Commercialisation and Implementation

Beginning September 2017 cellular manufacturers have announced to come with first LTE-V2x samples by mid 2018 including evaluation material. At that moment solutions will come available for evaluation of its potential. Specifications of the products are not yet seen but automotive compliance is moved from silicon to the module supplier resulting in a more expensive module. It is still a question how radio and functional interoperable and integrated into the C-ITS stacks is ensured. Thereafter the market will be able to evaluate. There are no commitments for implementation.

4.4 Technology Readiness Observations

As also clearly illustrated in Figure 3, ITS-G5 went through all the development phases realizing the objectives based on the C-ITS principles (See paragraph 3.1) over time and taking care of all the physical challenges, the technology and functional developments, the radio interoperability, the coexistence with other systems, large-scale radio testing, Functional interoperability. For ITS-G5 there are functional, technical and testing standards and profiling specifications published. Vehicular safety system quality requirements are met by radio equipment operational already for some years. Radio solutions have been available since 2009 and ITS-G5 equipment is being productized sins 2015 in vehicles and roadside infrastructure.

[84] http://www.sae.org

The LTE-V2X (release 14) specifications have been finalized end of the 1st half of 2017, missing essential elements. Some but not all missing element are mentioned in Chapter 5. No test specifications can be found, no large-scale tests have been planned, compliance assessment just started and no European functional interoperability activity is initiated.
At this moment, LTE-V2x interested parties' express superior performance of LTE-V2x over ITS-G5 and provide this as argument that delay of the introduction is allowed and interoperability is not required (stated in the presentation by the 5GAA at the DG CONNECT workshop). The different analyses such as those from Qualcomm[85] and from NXP[86] focus on different parameters and show there is mainly one key difference, LTE-V2x uses advanced coding which is not supported by IEEE 802.11p yet. The basic WiFi has further developed into IEEE 802.11ax in which this advanced coding is used, as next step a IEEE 802.11px including the advanced coding is obvious and currently being initiated. Other research investigations to be published later in 2017 indicate favouring ITS-G5 for C-ITS even. From a significance difference, we therefore can't speak and therefore there is no reason to delay the deployment of ITS-G5, blocking of early adopters can't be justified.

The technological development histories brought together in this report clarifies the situation as recognized in the background document (ANNEX 2) of the DG CONNECT invitation. ITS-G5 is the current user of the 5855-5925 MHz band following the guiding principles as discussed in the DG CONNECT 5 September 2017 workshop as part of the Regulated Framework in chapter 3.
It is clear that IEEE802.11p/ITS-G5 equipment is operational making use of 2 bands of the 5.9 GHz C-ITS safety related spectrum according to the neutral regulations as identified in Chapter 3. As the ITS-G5 equipment is operational and stakeholders have commercialisation committed, this is in contrast with others only investigating this and other technologies e.g. LTE-V2x. Early adopters of ITS's-G5 shall not be blocked in their deployment by others with any commercialisation commitments yet. Any new technologies e.g. LTE-V2x, who likes to operate in this band shall not interfere the operation of ITS-G5 with possible consequence of a traffic accidence. As lives are at stake any new technology may be liable in case interference still happens and may require proving non-interference.

[85] https://www.qualcomm.com/documents/path-5g-cellular-vehicle-everything-LTE-V2x

[86] Whitepaper_LTE-V2V_USletter__05.pdf

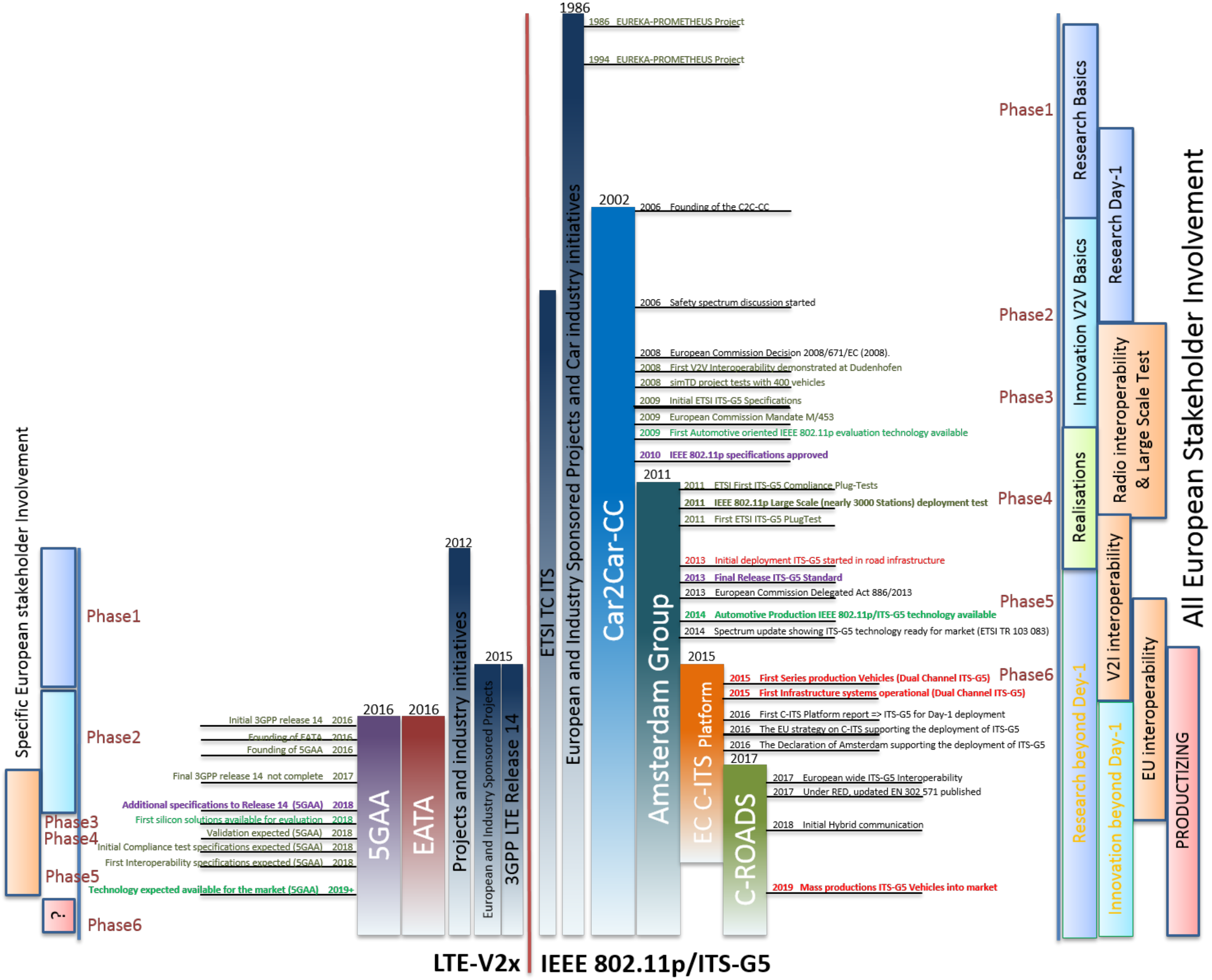

Figure 3: European Readiness of LTE-V2x and ITS-G5

5 Interoperability in the Safety related 5.9 GHz band

5.1 Introduction

There are many examples where more than 1 Communication Eco-system makes use of the same spectrum. This also is takes place in the 5.9 GHz band where C-ITS shares with ground to satellite communications and others. In these cases, in each of these cases the ECO-Systems are targeting different users, have stakeholder groups and are addressing different services. In all cases one has priority either caused by service priority in the band or one is incumbent as one was implemented earlier. In the case of ITS-G5 and LTE-V2x the same applications, the same user group, the same stakeholders and the same functionalities are addressed with the same priority. Additionally, as identified in chapter 3 it is not enough to look at the technical spectrum coexistence only. It is required to verify that the C-ITS Interoperability principles as recognized in chapter 3 as applied by ITS-G5 are also applied by new technologies e.g. LTE-V2x.

5.2 C-ITS Functional Coexistence Observations. (Interoperability and Backward compatibility).

As described in the previous paragraph Interoperability is key and is not limited to radio non-interference, functional cooperative coexistence is a fundamental requirement to achieve. Realizing cooperativeness leads to commonalities among all systems to ensure equal safety benefit for all.

In the case of coexistence between ITS-G5 and LTE-V2x (PC5[87]) we speak about spectrum sharing between mutual interfering wireless systems where the targeted applications, the targeted users, the radio transmission area and the priority are the same. As result of the principles, whatever technology used, every road participant needs to have equal access to the available safety related information and to the safety related spectrum depending on the priority assigned to the specific information exchanged and whatever ECO-System used.

Therefore, any new communication technology needs to ensure equal access to the spectrum as realized by the incumbent system, can't influence the behaviour of incumbent system, act similar to realize equality and to comply with the European legislation. Decentralized channel management, including the DCC methodology as well as message prioritisation can't be so much different among the used ECO-Systems otherwise there is no equality between stations and therefore safety benefit to all users. As cooperation is driven by equality, superiority can't be an objective.

There are 2 possibilities to realize the existence of more than one ECO-System to service the safety related objectives:

- The different ECO-Systems are almost identical in behaviour (for equality) and information sent by one can be received and interpreted by the other and vice versa.
- The different ECO-Systems are almost identical in behaviour (for equality) but can't receive nor interpret the information from the other ECO-System which is compensated by implementing both ECO-Systems and use the same application and facility layer services.

In case of ITS-G5 being the incumbent and LTE-V2x (PC5) the entering technologies:
ITS-G5 is build and now operational based on these principles resulting in the related standards. Specifications are based on these principles and for these reasons limitations to parameters have been introduced.

[87] http://www.3gpp.org/news-events/3gpp-news/1798-v2x_r14

LTE-V2x (RC5) therefore needs to function similar to ITS-G5 in case of operation in the same band but when it can provide other Quality of Service benefits for Automation this technology could be complementary providing additional/different advantages, however this needs then to be realized under licensed or unlicensed conditions in other spectrum. In case LTE-V2x (RC5) expects to operate in the same 5.9 GHz spectrum as ITS-G5 Interoperability and Backward compatibility and none interference needs to be ensured.

5.3 Current standard Coexistence in the 5.9 GHz band

This and the following paragraphs focus on the technological Coexistence only.

The operation of a C-ITS system in the band 5855MHz to 5925MHz requires the careful consideration of existing incumbent in-band and adjacent band services and application. Any system operating in that band needs to respect these protection requirements.

Specifically, the following coexistence aspects need to be taken into account:

1. Fixed Satellite Services (FSS) are the main primary service in the band. Here the protection of the earth-to-space segment must be guaranteed by adequate system characteristics.
2. Coexistence with tolling equipment in the 5.8 GHz band. As installed tolling equipment has sensitive receivers in the scenario that vehicles enter a tolling zone ITS equipment operating in the 5.9 GHz the tolling zone entering may harm the correct operation of the tolling equipment. It has been agreed that ITS equipment complies with the TS 102 792 to ensure the correct operation of the tolling systems.
3. Fixed services operating in the band above 5925MHz. These services operating in the adjacent channel need to get special attention by limiting the out-of-band emissions of any ITS system operating up to 5925MHz.
4. Coexistence with similar IEEE 802.11 RLAN technology is currently being identified at ETSI BRAN standardisation group in report TR 103 319.
5. Short Range Device operation in the band 5725MHz to 5875MHz with an overlapping band of 5855MHz to 5875MHz.

The output of these studies showed that a transparent coexistence is not possible, regardless of the protocol or strategy used to avoid interference. As such, any technology operating in same or near-by spectrum that ITS-G5 will impact its reliability. It has been emphasized that mutual detection is critical and challenging in order to avoid near-far problems.

Coexistence between ITS-G5 and WLAN took already 2 years of studies and standardization work, while the coexistence with road tolling took half a decade.

The coexistence between these systems is not easy to be achieved and include environmental requirements such as operational direction or area. They all have different objectives, user groups and support different applications. When not taking the principles in consideration but only look at the technical coexistence it is expected that any new technology with the same functional and user group objectives, using the ITS-G5 A/B/D spectrum will lead to increased complex investigation timelines and delay.

5.4 Coexistence Situation ITS-G5 and LTE-V2x

5.4.1 Introduction

Due to the significant different channel access technology used in ITS-G5 based on 802.11p based on CSMA/CA using an OFDM modulation scheme and the actual 3GPP D2D mode defined in 3GPP release 14 based on a synchronized SC-FDM (single carrier FDMA[88]) approach, a coexistence based on equal priorities in the same band is not possible. The signal characteristics in time and frequency and the channel access operation of the two systems are fundamentally different. A device using ETSI ITS-G5 always operates over the whole spectrum band of 10MHz using the spectrum for a given specific time duration between e.g. 400µs and 1000µs, whereas a LTE-D2D/V2X device operates in fixed frequency and time blocks (i.e. resource blocks - RB) of the 3GPP LTE D2D/V2X. By combining individual RBs in LTE a user can occupy the whole frequency band depending on the RB allocation strategy and policy. The deployed modulation scheme in ETSI ITS-G5 is based on a OFMD[89] multicarrier modulation with a carrier modulation of up to 64QAM. LTE-D2D/V2X uses a SC-FDMA modulation scheme which has originally been optimised for an uplink transmission of power and battery limited handheld devices with high data rates and high duty cycles. In a V2X AdHoc network scenario these requirements are not significant due to the limited data rate and the low duty cycle of the system.

The SC-FDMA modulation scheme has very good properties in the time domain but at the costs of a significantly higher out-of-band emission level in the frequency domain. An example spectrum comparison between a OFDM modulation and a SC-FDMA modulation is depicted in figure 4. The out-of-band emission can be optimized but at the cost of additional complexity. A SC-FDMA signal receiver is more complex and in general less robust against multipath fading and the operation in highly dynamic environments. In a typical LTE uplink situation, these complexity issues are handled by the base station receivers.

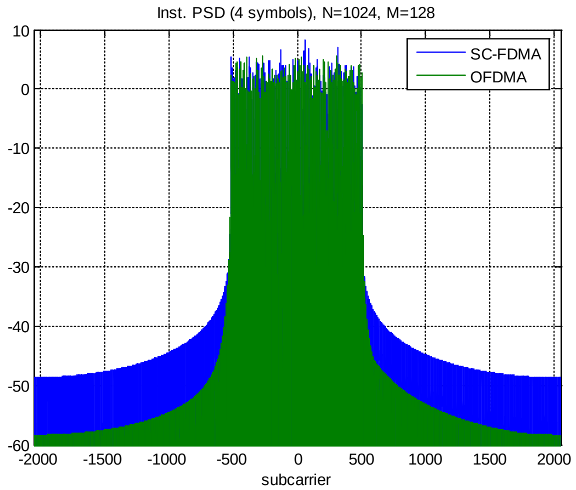

Figure 4: Comparison of spectrum between SC-FDMA and OFDM modulation scheme (source: Alamouti. Mobile WiMAX: Vision & Evolution. Intel presentation. 2007)

Accordingly, a coexistence of equal priority and same band would lead to a significant penalty for the CSMA/CA[90] based ITS-G5 system, which is against the technology neutrality of the ITS-G5 spectrum.

88 https://en.wikipedia.org/wiki/Single-carrier_FDMA

89 https://en.wikipedia.org/wiki/Orthogonal_frequency-division_multiplexing

90 https://en.wikipedia.org/wiki/Carrier-sense_multiple_access_with_collision_avoidance

Two different solutions could be envisaged:

1. Update the 3GPP air-interface to be compatible with the ITS-G5 interface including a new access method or reuse the ITS-G5 approach.
2. Use a different frequency band for the operation of the two systems including a sufficiently large frequency separation.

The most spectrum efficient approach would be solution 1, which also would solve the interoperability issues. For example, the ITS-G5/WLAN coexistence study led WLAN to require a compulsory 10MHz PHY detector when operating in the ITS-G5A/B/D band in order to be able to decode ITS-G5 preambles. The solution 2, as proposed today by 5GAA, will lead to a significant decrease in spectrum efficiency and interoperability capabilities.

Considering non-coordinated harmonized and coordinated systems operating in adjacent channels we must take into account different effect of the potential interference:

- RX effect with interference towards the RX signal
    - reduced visibility and RX range
- TX effect due to the CSMA/CA energy detection process
    - this effect will lead to a TX delay
- Blocking of the receiver due to limited adjacent channel rejection capabilities

These effects must be taken into account.

5.4.2 Single station scenario

5.4.2.1 Overview

In order to investigate the effect of adjacent channel interference from a 3GPP direct mode into an incumbent application like ITS-G5 in a first stage an Minimum Coupling Loss (MCL) calculation will give an inside in the potential interference level without taking into account the timing characteristics of the interfering and victim systems. The timing characteristics of the 3GPP direct mode systems are not yet fully available and are heavily related to the used resource allocation procedures. Depending on the used strategy the transmission time for a given ITS packet could have significantly different air times.

A similar approach can be taken into account for the calculation of the mitigation distances for the mentioned TX delay effect due to the reach of the energy threshold of the ITS system. Some example calculations are included in the Annex A of this document. In these calculations, an additional noise level of 1dB coming from the 3GPP direct mode communication system has been taken into account.

The mentioned blocking effects from a signal operating in an adjacent or 2nd adjacent channel can even be more significant. Initial results using the values given in the ETSI EN 302 571 and in the 3GPP release 14 specification show a required mitigation distance of 25m for the 2nd adjacent channel and 96m for a 1st adjacent channel. The blocking effect will also lead to a reduction in the reachable distance.

5.4.2.2 Multiple station scenario

In LTE-V2X the resource allocation strategy between the different devices is not yet specified. For interoperability reasons between different operators, manufactures or countries this is a crucial point for an AdHoc V2X system. Today, it is neither possible to evaluate the effects of the allocation onto an ETIS ITS-G5 system nor to evaluate the detailed behaviour of a LTE-V2X system itself.

The detailed effect of the multiple station interference can only be evaluated when a resource allocation strategy and policy is defined and evaluated in large scale field trials.

5.4.3 Detect and Vacate (D&V)

The 5GAA proposal for the reuse of the middle channel between the proposed ITS-G5 and the 3GPP direct mode designation is to use a detect and vacate procedure. This would mean that no real sharing operation would be implemented in this channel. A D&V procedure is a method to mitigate the interference effect from a new system toward an incumbent system having a higher priority but not a method of sharing. In this procedure one system has a priority over the other system. This could be a possible procedure to protect the C-ITS system from other potential interference in the band, but it will not lead to a proper sharing ensuring operation for safety related applications.

A D&V equal priority so far has never been proposed nor realized. Available D&V specifications use vacate times of at least seconds which will not work for safety related information exchange as that requires much faster access times and therefore a solution can't be foreseen in close future. More appropriate sharing mechanisms would have to be studied in detail.

5.5 Technical Coexistence observations

An LTE-V2X system operating in an adjacent channel will significantly influence the operation of the incumbent ITS-G5 system in any of the 5.9 GHz road safety bands. The possible communication distance of the ETSI ITS-G5 could be reduced by a factor of 2 (interference from a V2X system into a ETIS ITS-G5 devices, 2nd adjacent channel, 23dBm TX power, around 2m distance → car side by side) when a 3GPP direct mode communication system would be in close vicinity of ITS-G5 systems. In addition, the CSMA/CA access method of the ETSI-G5 system will detect the energy of a LTE-V2X system which will lead to a blocking and delay of the transmission a signal.

For co-located (on the same car, antenna, closer than 1m or when the antennas are built into the side mirrors from car to car) LTE-V2X and ITS-G5 systems the figures in the Annex show that a proper operation of both systems would not be possible having in mind the safety critical characteristics of the planned communication. Both mentioned effects, link range reduction and especially TX timing delay, must be considered under this condition. Beside these considerations, the blocking effects are also important and therefore need to be additionally taken into account.

The considered scenarios are only preliminary evaluation based on known 3GPP direct mode physical layer characteristics. Several properties of 3GPP direct mode are not yet specified which are of significant importance for the further evaluation. Especially the resource allocation strategy and policy in the side-link communication is not defined yet. With the actual available data, the typical timing behaviour and duty cycle of the 3GPP direct mode cannot be fixed.

For the DCC process in an ITS-G5 systems mainly the timing parameter are of importance. Depending on the resource allocation settings of a 3GPP direct mode communication system the influence could lead to a reduced available capacity in the ITS-G5 system.

6 Day-2 and beyond spectrum requirements.

In the late 90s, it was recognized that information exchange would help support road safety and automation, in Europe no in-depth spectrum needs were analysed and we referred to the analyses done by the National Telecommunication & Information Administration (NTIA)[91] in the USA in which 85 MHz is recognized as required for C-ITS. In Europe, as basis for the realisation of the installed spectrum regulation of 2008 as described in chapter 3, analyses were realized at ETSI TC ERM in the period of 2004-2006. These analyses resulted in the proposed regulation and licensing conditions described in 2 ETSI ERM reports, the TR 102 492-1 in 2005 and TR 102 492-2 in 2006. In the TR 102 492-1 an initial set of safety related applications (see Figure 6) were identified (which as can be found as part of the Basic Set of Application (BSA) the TR 102 638) to identify the spectrum requirements, and in the TR 102 492-2 this led to the spectrum allocation proposal which is regulated in the Current Regulation (see Figure 5).

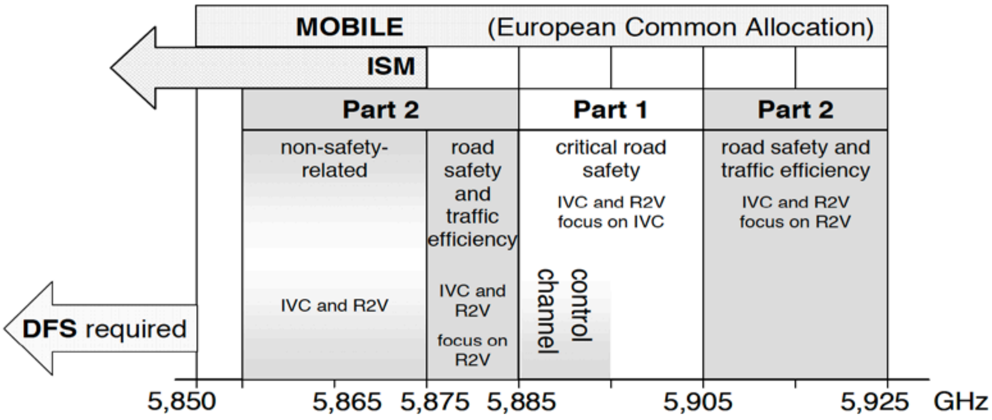

Figure 5: TR 102 492-2 proposed spectrum allocation

91 https://www.ntia.doc.gov/page/land-mobile-spectrum-planning-options-chapter-2-spectrum-requirements

Application	Description
ntrol	Alerts driver to other vehicles at intersections.

Figure 6: TR 102 492-1 proposed spectrum allocation

The safety related application information exchange identified at that time consisted out of 2 message types. The Cooperative Awareness Message (CAM, ETSI EN 102 637-2) 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) to notify others about safety situation recognized by the transmitting road user. These 2 message types are the bases for the first set of applications as identified in the TR 102 492-1 and TR 102 638. Three channels were designated to facilitate this list of applications.

Many projects e.g. CVIS, Safespot, SimTD and SCOOP@F have evaluated the possibilities that the most interesting applications can be implemented with some restrictions such as limited message length such that most functionally fit on a single channel. A second channel is used for the exchange of certificates see 4.2). For additional applications, this second and other channels will be used. The Day-1 list of applications as defined in the EC C-ITS Deployment Platform report phase 1, includes the green wave optimisation (GLOSA) application which makes use of the Signal/Phase and Timing (SPAT) and MAP messages as defined in the ISO TS 19091/SAE 2735. 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.

In parallel with the started deployment of the ITS-G5 technology further innovation is progressing. Currently just closed and running project enhanced our view showing a large extended list of C-ITS and automation/autonomous driving applications far beyond the original list as identified in the TR 102 638. Today we distinguish 3 levels of safety related, active, integral and passive safety phases such as shown in Figure 7Figure 7.

- The “Active Safety” phase in which in the normal driving mode the driver and its ITS-system is informed or warned. All application as defined for Day-1 or as identified in the TR 102 492 are Active Safety related.

- The "Integral Safety" phase in which the vehicle can intervene or take reversible preventive actions. This is the period before possible impact in which Automation aspects have a key role.
- The Passive Safety" phase in which the accident severity reduction and non-reversible measured take place. When needed this includes 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.

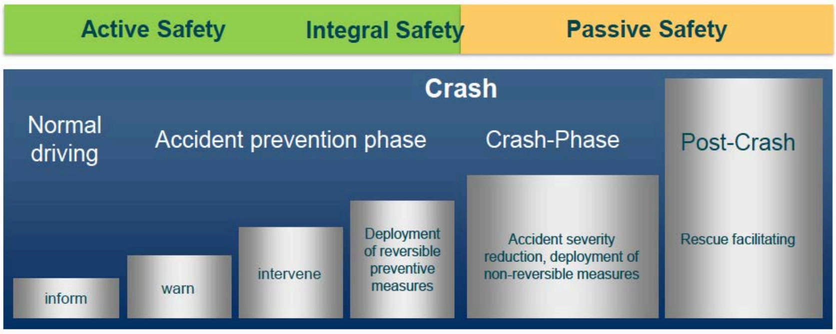

Figure 7: Phases of the vehicular safety system (Ref: C2C-CC)

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[92] of Amsterdam (see Figure 8). 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.

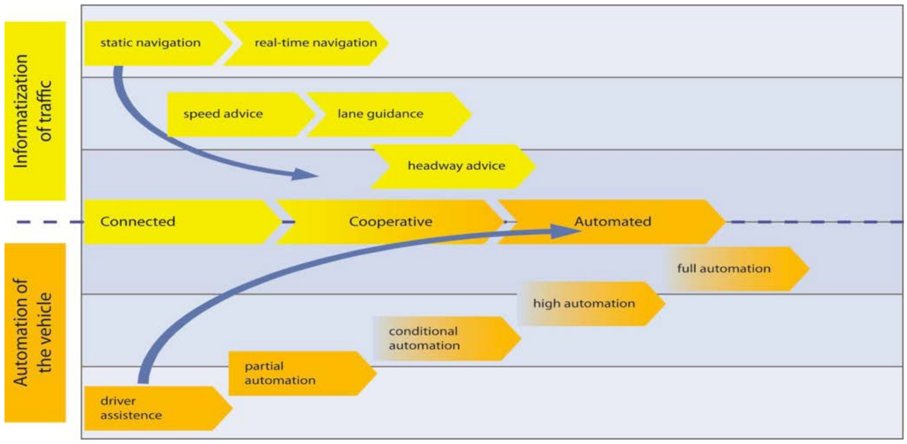

Figure 8: Merge of C-ITS and Vehicular Automation as agreed in the EU "Declaration of Amsterdam".

There are and already have been many innovative project looking at beyond Day-1 applications. Just finished or currently active are for example: VRUITS, AutoNet, HIGHTS, TIMON, RoadArt and there are new ones upcoming. There is a quite growing 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 which will have an extension in the Phase 2 report this year included more Urban applications and in the

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

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 (AG), C2C-CC, ACEA, 5GAA, EATA, and the European projects C-ROADS[93], InterCor[94], CODECS[95] and country specific overviews (see Table **1**).

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 9).

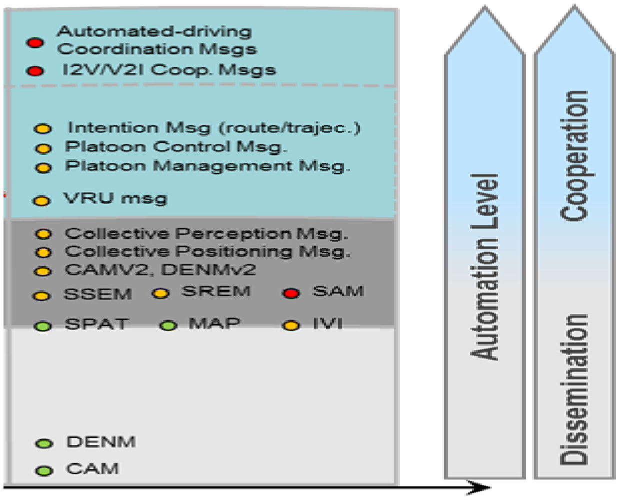

Figure 9: C2C-CC Message Roadmap

93 https://www.c-roads.eu/platform.html

94 http://intercor-project.eu

95 http://www.codecs-project.eu/index.php?id=5

Group	Applications
Traffic Safety Avoidance 1 &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 ≤10Hz 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 Trun 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

Table 1: safety related applications list[96]

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

As can be seen 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 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 and 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 9) such as the Cooperative Intention Message (CIM), Manoeuvre Coordination Services, ETSI TS 103 561 and the Collective Perception Service (CPM), ETSI TS 103 324). 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 30-2 890-2.

These are just the cases which are clearly require significant additional information exchange, but when we go back to the extensive application list (**Table 1**) we can recognize more additional information exchange requirements coming up from new applications in the area of Traffic Priority Railway-Road Crossing; Urban Rail; Intersection Safety; Enhanced Traffic Safety Avoidance; Tunnel Safety; extended roadworks warning; Parking Assist and Traffic Flow applications.

6.1 Functional Safety

The focus on safety-critical applications in the automotive market is significantly growing in general, within the vehicular safety system basic knowledge has been there but the focus on Functional Safety 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, and ISO 26262 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 is smartly integrating redundancies.

The sharing of safety related information via short-range ITS-G5 is a redundancy for existing other sensors in the vehicle for the basic functions they fulfil. C-ITS and Automated applications such as identified in this chapter rely on information exchange and therefore redundancy measures in the Hybrid Communications. Possible communications redundancy could be established by using several technologies in principle complementary but having overlapping capabilities. One example is mentioned earlier in this report. In case the communications network does not work the E-Call could be forwarded to other ITS-Stations via the ITS-G5 network.

6.2 Spectrum Observations

When the Day-1 applications on themselves require at least one single channel then it is clear we would need at least additional 2 channels for Platooning, C-ACC and VRU's to be complemented by one for Infrastructure safety related and efficiency related applications. Something which does not fit in the current 30MHz designated spectrum at 5875-5905 MHz as depicted in Figure 5. It is clear that the early estimates done by the NTIA in the USA and the early ERM analyses as presented in the TR 102 492 were not wrong and we therefore with certainty know that the current designated 30 MHz is not enough. That we need to extend this with the upper allocated 20 MHz between 5905-5925 and as in Europe the lower 20 MHz can't be used have to look for other spectrum to come into the direction of the 85 MHz calculated by the NTIA in the late 90s. The 5GAA also confirms that the current is not sufficient. The developments in the USA related to the channel use as specified in the SAE J2945.0 standard (**Table 2** provides an illustration of what has been specified) shows that our analyses here are in line with the ideas in the USA.

To enable the decrees of accidents and road death in Europe the growth of the safety related information exchange in the 5.9 GHz band and other spectrum must be supported. It therefore is proposed to update the current spectrum regulation for the 5.9 GHz band to designate the total 50MHz band from 5875-5925 MHz for traffic safety and traffic efficiency related and to investigate finding another 30-40 MHz band for further extensions. This extension is possibly something to support higher QoS.

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, etc.)	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↔r	- 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

Table 2: Channel usage List SAE 2945.0 illustration

7 Recommendations

7.1 Scenario Recommendation proposed Scenarios

In answer to the considered scenarios, the C2C-CC has analysed the different options and comes to the following considerations as response to each of the scenarios:

1. Cellular expands to full V2x and operates within licensed spectrum bands (not at all in 5.9 GHz) while G5 expands at 5.9 GHz → full spectrum and functional split; cellular and ITS-G5 could provide different services; ecosystem could be independent;

    - The C2C-CC observes this as the beyond Day-1 Hybrid Communication approach in which a combination of 5G long-range IP based and LTE-V2x based short-range cellular oriented services, recognized as the "Connected Car" concept (ACEA Connectivity strategy paper[97]), can complement existing 4G and ITS-G5 services to support the higher QoS and bandwidth ensuring requirements from the beyond Day-1 Automated and C-ITS services in a complementary way. The interest for these additional communication services is confirmed by Volkswagen in their Hybrid Communication[98] view in which they are looking for high QoS services.
    - Not having LTE-V2x and ITS-G5 technologies in the same spectrum will also bring the Functional Safety required redundancy which cannot be reached when these technologies operate in the same spectrum.
    - Following an approach in which LTE-V2x is using other spectrum as ITS-G5 will enable to exploration for all the LTE-V2x functional and technical capabilities form an addition key Vehicle Automation/Autonomous driving complementary communication element in the Hybrid Communication architecture. It especially will be possible to provide varying QoS focussed on the automation applications like D2D communications for Industry and other pillars.
    - As chapter 6 shows the large increase of C-ITS and Automation information can be expected realizing this in separated spectrum will provide robustness and other benefits.

ITS-G5 and LTE-V2x share the 5.9 GHz band; a set of agreed milestones to attain backward interoperability using the 5.9 GHz band → initial deployment of ITS-G5 only, LTE-V2x is only deployed when avoidance of harmful interference with existing ITS-G5 is ensured, transits to backward interoperability, ecosystem competition for short-range;

As safety is of concern, communication must be based on cooperative neutrally sharing of information. In the case when 2 competitive ECO-systems focused in offering the same C-ITS cooperative services to the same users operating in the same physical and communication environment they must follow the principles as confirmed in the DG CONNECT workshop chapter 3 otherwise the cooperative nature of the C-ITS system can't be ensured.

As result of these requirements ECO-systems do not only need to be able to coexist without interfering each other in the spectrum, but also needs to be functional interoperable which result in interoperability requirements for most layers in the communication system. As ITS-G5 equipment must be seen as being the incumbent system (chapter 4.4), new communication Eco-systems must follow not only the normal spectrum coexistence principles bus also must cooperate and be

[97] http://www.acea.be/uploads/publications/ACEA_Strategy_Paper_on_Connectivity.pdf

[98] http://www.codecs-project.eu/index.php?id=48

interoperable with the incumbent system. Based on the following considerations coexistence is currently not that obvious.

- Looking from the functional perspective: To realize equal chance of being safe on the road for all road users, all systems need to have the same access to all safety information shared. There are 2 ways to realize this:
  - At the air interface, to allow transmitted information to be received and understood what ever technology is used in an interoperable way.
  - By implementing all the different communications equipment which shares safety related information.

  The first is only possible when a new technology e.g. LTE-V2x aligns its MAC/PHY to the incumbent ITS-G5, IEEE 802.11p standard. The current 3GPP release 14 specifications shows that based on this specification only the second option is applicable. To implement 2 systems with the same purpose is not desirable.

- Due to the significant different channel access technology used in ITS-G5 based on 802.11p based on CSMA/CA using an OFDM modulation scheme and the actual 3GPP D2D mode defined in 3GPP release 14 based on a synchronized SC-FDM (single carrier FDMA) approach, a coexistence based on equal priorities in the same band is not possible (See 5.4.1). The introduction of LTE-V2x, as it is currently specified, in the same band as ITS-G5 will lead to a significant penalty for the CSMA/CA based ITS-G5 system (chapter 5), which is against the technology neutrality and the safety related fare use of the 5.9 GHz spectrum.
- Depending on the resource management settings of the 3GPP direct mode communication systems this could lead to a potential additional interference effect of 3dB to 6dB which could lead to a reduced visibility of the ITS-G5 system by a factor of 1.4 to 2 under line-of-sight (LoS) conditions. Currently the resource allocation has not been designed not fixed therefor no evolutions can be done. For this would be suggested to initiate CEPT studies to evaluate the issues.
- An LTE-V2X system operating in an adjacent channel will significantly influence the operation of the incumbent ITS-G5 system in any of the 5.9 GHz road safety bands (chapter 5).
- For co-located (on the same car, antenna, closer than 1m or when the antennas are built into the side mirrors from car to car) LTE-V2X and ITS-G5 systems proper operation of both systems would not be possible having in mind the safety critical characteristics of the planned communication (chapter 5).
- Further analyses of the direct mode characteristics as specified in the 3GPP standards is not possible as several properties of the 3GPP direct mode are not specified which could be important for further evaluation.
- If the safety related information exchange is influenced by Interference, this may create live or death situations and therefore may have liability implications for which CEPTS studies are suggested.
- Looking from the technical possibilities:
  - Create a new technology or update the 3GPP air-interface to be interoperable and backward compatible with the ITS-G5 interface including a new access method or reuse the ITS-G5 approach based on the Cooperative data sharing principles leading to no real functional differences.
  - Use a different frequency band for the operation of the two systems including a sufficiently large frequency separation with possibility to functionally differentiate.

Any other form is not expected to lead to functional and technology coexistence. Based on these considerations, the C2C-CC sees many obstacles and does not see how to reach any safety benefits and only recognizes additional complexity, less spectrum efficiency and more costs.
In case any stakeholder wants to pursue the introduction of a similar technology targeting the same safety applications, this technology accepting the Cooperative-ITS safety related coexistence principle related interoperability and backward compatibility and is intended to ensure non-interference with the incumbent ITS-G5 equipment, the C2C-CC will support the coexistence evaluation process.

2. ITS-G5 and LTE-V2x share the 5.9 GHz band; a set of agreed milestones to attain backward interoperability using the 5.9 GHz band → time-limited band split transits to time-limited co-channel coexistence (backward compatibility) transits to backward interoperability, ecosystem competition for short-range;

A band split as proposed by the 5GAA in their position paper "Coexistence between LTE-V2x and 802.11p at 5.9 GHz"[99] is basically not possible under the proposed conditions based on:

- That the spectrum neutrality as heavenly brought forward by the 5GAA is not followed here as splitting blocks the introduction of other new technologies hereafter.
- This proposal does not follow the safety related interoperability principles. In case one OEM's would implement one technology and another the other technology each of them would not reach maximum benefit of sharing. Others are forced to implement two technologies to reach maximum benefit.
- That the proposed split conflicts with already deployed ITS-G5 equipment already using the channel 176 and 180 (see Figure 1).
- That analyses in chapter 5 show that side-band interfere from the second adjacent channel is at such level that other communication equipment operating in the second adjacent channel will harmfully interfere with the existing incumbent communications equipment. The analyses show that this side-band interference will interfere also with the incumbent communications equipment in neighbouring vehicles in the close proximity.
- That based on the technical analyses a spit leads to a fragmentation of the band resulting in an inefficient spectrum use.
- There are single and dual channel ITS-G5 vehicles and infrastructural equipment implemented which are using channel 176 and 180 for the safety related information exchange. The 5GAA assumes that ITS-G5 systems only use a single channel (180). This is incorrect and the proposed split is therefore functionally not possible. Additionally, also spectrum-wise as identified in Chapter 5 this is also not technically possible.
- This proposal is quick and dirty fix that only postpone the problem and limits future ITS development.
- Using Detect and Vacate mitigation technique where both technologies have the same priority is not really smart. Who will take the responsibility to say that technology A has a priority on B?

Based on the above arguments the C2C-CC suggests not to support this scenario.

[99] http://5gaa.org/pdfs/5GAA_News_neu.pdf

7.2 Recommendation beyond Day-1 Spectrum requirement

Chapter 6 provides an extended overview on beyond Day-1 spectrum requirements. In 2006 the TR 102 492 predicted the use of the current designated 30 MHz spectrum and today chapter 6 confirms this and shows that a large grows of safety related information exchange is expected making the current designated 30 MHz spectrum not sufficient. In accordance of the analyses it is recommended to extend the designation to the currently allocated 50 MHz safety related band and update the European Commission Decision 2008/671/EC to identify the upper 50 MHz, 5875-5925 MHz as designated for traffic safety and traffic efficiency. It is further proposed that coexistence with Urban Rail (see chapter 5) is established on the bases that as Urban Rail will use the same access mechanism ITS-G5 such that both can make efficient use of the spectrum based on functional prioritisation and non-interference principles.

Annex A Example MCL calculations

Figure 10: Minimum Coupling Loss Calculation 1. Adjacent channel, EN Values

LINK BUDGET	Value	Units	**G5 RX**	**Comments**
Emission part: LTE-V2X				
Bandwidth	10	MHz		
Tx out, eirp	33	dBm	33,0	
Tx Out eirp per MHz	23	dBm/MHz	23,0	
effect of TPC (dB)	0	dB	0,0	
OoB Attenuation	40	dBr	40,0	1. Adjacent channel
Net Tx Out eirp		dBm/MHz	-17,0	
Antenna Gain	0	dBi	0,0	
Frequency (GHz)	5900	MHz	5900,0	
Reception part: ETSI G5				
Receiver Noise bandwidth	10	MHz	10,0	
Receiver sensitivity QPSK	-82	dBm	-82,0	sensitivity in EN
Required SNR	6	dB	6,0	
Antenna gain	0	dBi	0,0	
Polarisation mitigation factor	0	dB	0,0	
I/N	6	dB	6,0	
Allowable Interfering power level '*I*' at receiver antenna input		dBm	**-94,0**	
Propagation model (LOS only)				
Propagation models				
first exponent			2,0	
MAIN LOBE LTE - MAIN LOBE ETSI-G5				
Allowable Interfering power level at receiver antenna input		dBm	-94,0	
Required Attenuation (dB)			**77,0**	
Separation distance LTE->ETSI-G5 (m)		**m**	**28,6**	

Figure 11: Minimum Coupling Loss Calculation 1. Adjacent channel, Measured Values

LINK BUDGET	Value	Units	G5 RX	Comments
Emission part: LTE-V2X				
Bandwidth	10	MHz		
Tx out, eirp	33	dBm	33,0	
Tx Out eirp per MHz	23	dBm/MHz	23,0	
effect of TPC (dB)	0	dB	0,0	
OoB Attenuation	40	dBr	40,0	1. Adjacent channel
Net Tx Out eirp		dBm/MHz	-17,0	
Antenna Gain	0	dBi	0,0	
Frequency (GHz)	5900	MHz	5900,0	
Reception part: ETSI G5				
Receiver Noise bandwidth	10	MHz	10,0	
Receiver sensitivity QPSK	-92	dBm	-92,0	Measured sensitivities
Required SNR	6	dB	6,0	
Antenna gain	0	dBi	0,0	
Polarisation mitigation factor	0	dB	0,0	
I/N	6	dB	6,0	
Allowable Interfering power level 'I' at receiver antenna input		dBm	**-104,0**	
Propagation model (LOS only)				
Propagation models				
first exponent			2,0	
MAIN LOBE LTE - MAIN LOBE ETSI-G5				
Allowable Interfering power level at receiver antenna input		dBm	-104,0	
Required Attenuation (dB)			**87,0**	
Separation distance LTE->ETSI-G5 (m)		**m**	**90,5**	

Figure 12: Minimum Coupling Loss Calculation 2. Adjacent channel, EN Values

LINK BUDGET	Value	Units	G5 RX	Comments
Emission part: LTE-V2X				
Bandwidth	10	MHz		
Tx out, eirp	33	dBm	33,0	
Tx Out eirp per MHz	23	dBm/MHz	23,0	
effect of TPC (dB)	0	dB	0,0	
OoB Attenuation	50	dBr	50,0	2. Adjacent channel
Net Tx Out eirp		dBm/MHz	-27,0	
Antenna Gain	0	dBi	0,0	
Frequency (GHz)	5900	MHz	5900,0	
Reception part: ETSI G5				
Receiver Noise bandwidth	10	MHz	10,0	
Receiver sensitivity QPSK	-82	dBm	-82,0	sensitivity in EN
Required SNR	6	dB	6,0	
Antenna gain	0	dBi	0,0	
Polarisation mitigation factor	0	dB	0,0	
I/N	6	dB	6,0	
Allowable Interfering power level 'I' at receiver antenna input		dBm	**-94,0**	
Propagation model (LOS only)				
Propagation models				
first exponent			2,0	
MAIN LOBE LTE - MAIN LOBE ETSI-G5				
Allowable Interfering power level at receiver antenna input		dBm	-94,0	
Required Attenuation (dB)			**67,0**	
Separation distance LTE->ETSI-G5 (m)		**m**	**9,0**	

Figure 13: Minimum Coupling Loss Calculation 2. Adjacent channel, Measured Values

LINK BUDGET	Value	Units	**G5 RX**	**Comments**
Emission part: LTE-V2X				
Bandwidth	10	MHz		
Tx out, eirp	33	dBm	33,0	
Tx Out eirp per MHz	23	dBm/MHz	23,0	
effect of TPC (dB)	0	dB	0,0	
OoB Attenuation	50	dBr	50,0	2. Adjacent channel
Net Tx Out eirp		dBm/MHz	-27,0	
Antenna Gain	0	dBi	0,0	
Frequency (GHz)	5900	MHz	5900,0	
Reception part: ETSI G5				
Receiver Noise bandwidth	10	MHz	10,0	
Receiver sensitivity QPSK	-92	dBm	-92,0	Measured sensitivities
Required SNR	6	dB	6,0	
Antenna gain	0	dBi	0,0	
Polarisation mitigation factor	0	dB	0,0	
I/N	6	dB	6,0	
Allowable Interfering power level 'I' at receiver antenna input		dBm	**-104,0**	
Propagation model (LOS only)				
Propagation models				
first exponent			2,0	
MAIN LOBE LTE - MAIN LOBE ETSI-G5				
Allowable Interfering power level at receiver antenna input		dBm	-104,0	
Required Attenuation (dB)			**77,0**	
Separation distance LTE->ETSI-G5 (m)		**m**	**28,6**	

Figure 14: Blocking Interference calculation from LTE-V2x to ETSI-G5 (MCL, Minimum Coupling Loss)

LINK BUDGET	Value	Units	G5 RX	Comments
Emission part: LTE-V2X				
Bandwidth	10	MHz		
Tx out, eirp	33	dBm	33,0	
Tx Out eirp per MHz	23	dBm/MHz	23,0	
effect of TPC (dB)	0	dB	0,0	
OoB Attenuation	0	dBr	0,0	
Net Tx Out eirp		dBm/MHz	23,0	
Antenna Gain	0	dBi	0,0	
Frequency (GHz)	5900	MHz	5900,0	
Reception part: ETSI G5				
Receiver Noise bandwidth	10	MHz	10,0	
Receiver sensitivity QPSK	-82	dBm	-82,0	sensitivity in EN
Required SNR	6	dB	6,0	
Antenna gain	0	dBi	0,0	
Polarisation mitigation factor	0	dB	0,0	
I/N	6	dB	6,0	
blocking rejection	13	dB	13,0	1. Adjacent channel
Allowable Interfering power level 'I' at receiver antenna input		dBm	**-69,0**	
Propagation model (LOS only)				
Propagation models				
first exponent			2,0	
MAIN LOBE LTE - MAIN LOBE ETSI-G5				
Allowable Interfering power level at receiver antenna input		dBm	-69,0	
Required Attenuation (dB)			**92,0**	
Separation distance LTE->ETSI-G5 (m)		**m**	**160,9**	

Annex B The C-ROADS European Member States

Summary of the public available information as given on the C-ROADS :

- **Austrian**: Deployment has started in 2016, from Q3 2018 on, 300km of the Austrian pilot sites are fully operational with connections between a Traffic Management Centre and the central C-ITS-stations and the service distribution to all C-ITS stations.
- **Belgium/Flanders**: Deployment will start from Q3 2018 on, the plan is that the system is operational in Q4 2019. Evaluation will take place between Q2 2019 - Q3 2020
- **Czech Republic**: Deployment will start from Q1 2018 on, evaluation will take place between 2019 – 2020 in order to find out reliability and safety issues.
- **Denmark**: Uses the project NordicWay for initial deployment, the project has started in 2015 the current status and plans are not published on the C-ROADS portal.
- **Finland**: Uses the project NordicWay for initial deployment, the project has started in 2015 the current status and plans are not published on the C-ROADS portal.
- **France**: Deployment has started in 2016, and is expected to be ready for driving for the first deployment areas by the end of 2019.
- **Germany**: Deployment will start from Q3 2017 on, deployment of the different Day-1-C-ITS-services will be finished in 2019 (fist application will be road works warning, it is expected that all 3500 mobile warning trailers for the safety trailers will be equipped until mid of 2019). First deployment of traffic lights has been started in 2016.
- **Hungary**: The motorway M1 is already equipped and it is planned to continue C-ITS deployment in the near future, in order to extend and upgrade the existing system, and implement new use case. The System is based on the Austrian specifications for national public tender.
- **Ireland**: The M50 (Dublin Orbital Motorway) is designated as a road where traffic and safety conditions require the deployment of a road safety-related traffic information service. No information on start of Deployment.
- **Netherlands**: Deployment has started in 2016, and is expected to be ready for driving for the first deployment areas by the end of 2019. Road shows are planned for 2020.
- **Norway**: Uses the project NordicWay for initial deployment, the project has started in 2015 the current status and plans are not published on the C-ROADS portal.
- **Slovenia**: Deployment is planned from 2017 on, an upgrade of ITS infrastructure will happen including the installation of necessary Roadside Units which are connected to the central C-ITS-station with live traffic data feeds from the Traffic Management Centre. Connected cars and Cloud information services will go on parallel. In 2019 the first deployment areas will become operational.
- **Sweden**: Uses the project NordicWay for initial deployment, the project has started in 2015 the current status and plans are not published on the C-ROADS portal.
- **United Kingdom**: Deployment has started in 2016, and is expected to be ready for driving for the first deployment areas by the end of 2019. Road shows are planned for 2020.
- Switzerland and Queensland/Australia have recently stepped in the C-ROADS platform and would like to contribute to the C-ROADS platform as an associated partner.
- New partners will join the C-ROADS platform under the commitment that already archived solutions are taken to facilitate and speed up the deployment in the member stat.

■ End of Document ■