Multi-Channel Operation (MCO); Part 3; MCO Concept

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). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and 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 and its members work in close cooperation with the European and international standardisation organisations.

Disclaimer

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Changes since last version

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2022-10-19	Initial setup of document	Release Management	Steering Committee

Table 1: Changes since last version

Changes since last version

Title:	Document Initial Framework
Explanatory notes:	This paper focus on the specification of a Multi-Channel Operation Scalable Concept for beyond Day-1 applications and part of C2C-CC BSP [IR-3] release. for the deployment of advanced C-ITS and CCAD applications with focus on the operation in the 5.9 GHz Safety related Band. This paper is part 3 of 3: 1. Functional requirements 2. Technology capabilities and limitations 3. MCO concept This part based on the identification of the key functional requirements and technical capabilities based on what has been analysed in Part 1 and 2. It defined the channel usage, the MCO architecture and MCO functionalities conceptually. The work is used as pre-studies for the standardisation work at ETSI TC ITS STF 585. It must therefore be seen as input to that work and not be compared. As later work from ETSI is consistent with the direction C2C-CC foresees, Contributions to ETSI have been seen as priority and therefore terminologies used in this document may differ with the final ETSI MCO document releases. It is recommended to follow the ETSI standards and only profile them there where needed. From the perspective of C2C-CC, the prioritization is based on the existing BSP 1, Release 1 ITS-G5 initial deployed technical specifications.

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Definitions

Unicast	Unicast is the term used to describe communication where a piece of information is sent from one point to another point. Unicast transmission, in which a packet is sent from a single source to a specified destination, is still the predominant form of transmission on LANs and within the Internet. All LANs (e.g. Ethernet) and IP networks support the unicast transfer mode, and most users are familiar with the standard unicast applications (e.g. http, smtp, ftp and telnet) which employ the TCP transport protocol.
Broadcast	Broadcast is the term used to describe communication where a piece of information is sent from one point to all other points. In this case there is just one sender, but the information is sent to all connected receivers. Broadcast transmission is supported on most LANs (e.g. Ethernet), and may be used to send the same message to all computers on the LAN (e.g. the address resolution protocol (Arp) uses this to send an address resolution query to all computers on a LAN). Network layer protocols (such as IPv4) also support a form of broadcast that allows the same packet to be sent to every system in a logical network (in IPv4 this consists of the IP network ID and an all 1's host number).
Multicast	Multicast is the term used to describe communication where a piece of information is sent from one or more points to a set of other points. In this case there is may be one or more senders, and the information is distributed to a set of receivers (there may be no receivers, or any other number of receivers). Multicasting is the networking technique of delivering the same packet simultaneously to a group of clients. IP multicast provides dynamic many-to-many connectivity between a set of senders (at least 1) and a group of receivers. The format of IP multicast packets is identical to that of unicast packets and is distinguished only by the use of a special class of destination address (class D IPv4 address) which denotes a specific multicast group. Since TCP supports only the unicast mode, multicast applications must use the UDP transport protocol. The majority of installed LANs (e.g., Ethernet) are able to support the multicast transmission mode. Shared LANs (using hubs/repeaters) inherently support multicast, since all packets reach all network interface cards connected to the LAN. The earliest LAN network interface cards had no specific support for multicast and introduced a big performance penalty by forcing the adaptor to receive all packets (promiscuous mode) and perform software filtering to remove all unwanted packets. Most modern network interface cards implement a set of multicast filters, relieving the host of the burden of performing excessive software filtering.
Scene	A scene shows one moment in the traffic environment. It includes relevant static and dynamic elements and provides the relationship of all involved actors to each other.
Scenario	A traffic scenario provides a chronological sequence of scenes, sequence of actions and events and describes the objectives and intensions of the actors.

Use Case	A use case represents a group of scenarios making use of a generalized functional system, identifies functional requirements and system boundaries and limits.
Application	An application is a technical implementation realizing one or more use cases. Internet applications are often referred to as provide functional services to users.
Service	Software functionality or set of software functionalities, such as the retrieval of specified information or the execution of a set of operations
Day-1 Applications	These are the applications identified by the Basic Set of Applications (BSA in the TR 102 638 V1.1.1 [ER-27][ER-27] additionally including those use cases identified in the ITS platform report form the EU commission [ER-29].

Abbreviations

ACP	Application Configuration Profiles
ALI	Access Layer Instance
ARP	address resolution protocol
ASIL	Automation Safety Integrity Level
BSP	Basic System Profile
CAM	Cooperative Awareness Message
CBTC	Communication Based Train Control
CAS	Cooperative Awareness Service
CC	Channel Coding
CCAD	Connected Cooperative Automated Driving
CCAM	Connected Cooperative Automation Mobility
C-ITS	Cooperative-Intelligent Transportation Systems Station
C-ITS-S	Cooperative-Intelligent Transportation Systems Station
CLR	Channel Load Ratio
CMM	Cooperative Manoeuver Message
CPM	Collective Perception Message
CPS	Collective Perception Service
DENM	Decentralized Environmental Notification Message
DENS	Decentralized Environmental Notification Service
DSCO	Detected Safety-Critical Objects
EC	European Commission
ETSI	European Telecommunications Standards Institute
EU	European Union
GAH	GeoNetworking ALI Handler
I2V	Infrastructure to Vehicle
IEEE	Institute of Electrical and Electronic Engineering
IMZM	Interference Management Zone Message
ISO	International Organization for Standardisation
ITS	Intelligent Transportation Systems
IVI	In Vehicle Information (The standard is a Dictionary)
I2X	Infrastructure to everything
kph	kilometres/kilometres per hour
LDMS	Local Dynamic Map Service
LDPC	Low Density Parity Coding
MAP	Map Message
MCM	Manoeuver Coordination Messages

MCO	Multi-Channel Operation
MCS	Manoeuver Coordination Service
PPDU	Presentation Protocol Data Unit
PoTi	Position and Time
QoS	Quality of Service
RSU	Road Site Unit
SAE	SAE International, formerly the Society of Automotive Engineers
SCH	Service Channel
SRD	Short Range Devices
STF	Special Task Force (Especially process used at ETSI)
SPAT	Signal Phase And Timing
TC	Turbo Code
VRU	Vulnerable Road User
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
WiFi	Wireless Fidelity
5GAA	5G Automotive Association

1 Introduction

1.1 Abstract

Initial deployment of Cooperative Intelligent Transportation Systems (C-ITS) Safety related applications has been established by front runners starting in 2018 and extended at large scale end 2019 confirmed by the C-ITS Deployment Group [ER-1]. In the meantime, many new application initiatives have been taking shape requiring additional information exchange making use of safety related spectrum channels.

For Day-1 Applications information exchange could be handled for initial deployment in one channel but for the exchange of data for new applications additional channels will have to be used. This report (part 3) provides a concept and based on the analyses of the application and service requirements provided in part 1 and the technical capabilities and limitations provided in part 2.

This paper only covers C-ITS and Automated Transport safety related multi-channel operation from a European perspective.

1.2 Survey of document

After the development of a harmonized set of C-ITS Interoperable and Backward Compatible (as defined in the MCO Functional Requirements (Part-1 [IR-1]), Release 1 C-ITS standards, C2C-CC [ER-2] and C-ROADS [ER-3] realised European Vehicular and Road ICT infrastructure related profiles to satisfy related C-ITS Day-1 applications supporting EU Directive 2010/40/EU [ER-4] principles. Related solutions have and are being deployed in the service channel SCH0 in the designated traffic safety spectrum band 5855 MHz to 5925 MHz according to ECC decision (08)01 [ER-5], ECC recommendation (08)01 [ER-6] and EC implementation decision C(2020)6773/F1 [ER-7]. New and advanced C-ITS and CCAD applications are currently being developed which is leading to a Release 2 set of standards and related vehicular, other road user and road ICT infrastructure related profiles followed by Release 2 deployments. For Release 2 additional channels will have to be used.

This paper presents an open MCO concept using multiple channels to facilitate the realisation of Release 2 new and advanced applications. Based on MCO Functional Requirements (Part-1 [IR-1]) and MCO Technical Capabilities and Limits (Part 2 [IR-2]) key functional and technical aspects have been identified. In this part, part 3, the MCO concept, its requirements and its functional and technical consequences are identified.

> NOTE: as Identified in 2.9.2, the term SCH0 has replaced CCH. CCH was initially used in line with SAE as the idea was to do channel switching and then you need a control channel. C2C-CC developed a system without channel switching and have abandoned the term CCH and therefore it was agreed to rename it to SCH0 in standardisation and regulation.

2 MCO Background considerations and clarifications

2.1 Introduction

In the following clauses a summary of the considerations and clarifications are given which are of relevance for Release 2 and beyond C-ITS Ad-Hoc communication systems and for MCO specifically. Most of the considerations identified are derived from earlier studies identified in Part 1 and Part 2 of the MCO papers.

2.2 C-ITS ECO system

Internet protocol point to point communication is based on knowing the IP addresses of both sourcing and consuming parts of the application by which the security method can be based on the same IP addresses, enabling trust build between the different acting parties and allows internet service providers to have full control over both the data sourcing and data consuming parts of the application realizing business agreements with their customers. An internet service provider is in control of the application end to end and the data exchange. Basically, everyone who likes can have his own business case(s) and own solutions and there is no need for technical agreements with other parties and therefor technology neutrality as the business case level. When a service provider wants to work in a closed business model with some or more business partners interoperability on the interfaces used are part of the cooperation agreement. The Internet ECO system provides many tools to realize Internet Business cases, IoT is one of the forms where data can be made available in a more open way which requires more interfaces to become interoperable. We can therefore speak about IoT ECO systems.

C-ITS is making use of direct communication without IP addressing. It allows information exchange only over a short range and there is no handshaking to confirm correct reception nor that there is identification is possible based on IP addressing. The main objective of C-ITS is just to share possible safety relevant information by which others may have safety benefit. With this view in mind all C-ITS Stations just share information in a predefined interoperable way. C-ITS Stations broadcast the information wireless the same way as this is realised in wired sensor networks such as CAN. To ensure that data received can be trusted a specific C-ITS security solution is realised, other than used in the Internet oriented ECO systems. The C-ITS ECO system therefore works with certificate exchange to confirm the trust which may be extended with encryption methods for specific Release 2 applications.

Within the C-ITS ECO system there is no service provider which manage the application end to end. Such a service provider may change anything within ITS system while the user may not notice anything. Within the C-ITS ECO system there is no service provider there is only information sharing. Whereas the service provider does not need to share ITS specifications and therefore does not need to have ITS specifications standardised, in the C-ITS ECO system, as it’s an open data sharing system, for each type of data sharing all information exchange influencing aspects shall be standardised to ensure proper operation of the applications using the information to allow all stakeholders to realize user safety supporting applications independently.

This means that especially what data and how the data is shared shall be standardised.

In Release 1 together with the C2C-CC BSP [IR-3] and harmonised C-Roads profile [ER-3], Interoperability is realized at all layers of the OSI model. Not only on the data level (applications and facilities layers) but also on the technical level (network and physical layers). Therefor data formats, data protocols, networking protocols and radio channel assignment including technologies, modulation etc have been locked and agreed for each type of specific data sharing. It specifies all aspects at the information sharing (transmitting side) are standardised and specified to allow any stakeholder to realise lifesaving applications as he wishes.

To realise a trust domain for C-ITS a different security system is realised based on security policies [ER-11] and ETSI ITS security standards. This results in a different business model where information is shared directly between the users. Release 2 specifications and standards shall follow the same rules. This does not mean it should be based on the same technologies as Release 1. For each application all functionalities should be considered based on the functional requirements and may result in using different technologies for each of the applications.

2.3 C-ITS scenes, scenarios, use cases, application, services

2.3.1 Introduction

To clearly understand the relations between the different aspects relevant for the realisation of Transport safety related Applications the relations between the different views need to clarify and in accordance used. Within Road Transport we consider the functional levels scenes, scenarios, use cases and applications providing requirements for the technical realisation.

2.3.2 C-ITS scenes and scenarios

All events start with a scene or situation. A scene shows one moment in the traffic environment. It includes relevant static and dynamic elements and provides the relationship of all involved actors to each other. A traffic scenario provides a chronological sequence of scenes, sequence of actions and events and describes the objectives and intensions of the actors (see Figure 1).

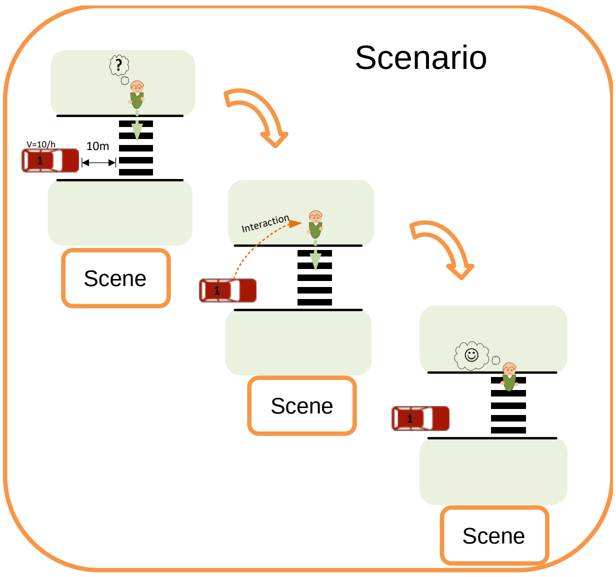

Figure 1: Traffic scenes and scenarios

2.3.3 C-ITS use cases, applications, and services

A use case represents a group of scenarios (a storyboard) identifying environmental, and technical requirements. An application is a technical implementation realizing one or more use cases (see Figure 2). Applications provide functional services to users by the realisation of the use cases. In the context of ITS, services provide technical facilitating services to applications, such as message services which generate and absorb messages as delegated task from the applications. A service may facilitate services to a single or multiple applications.

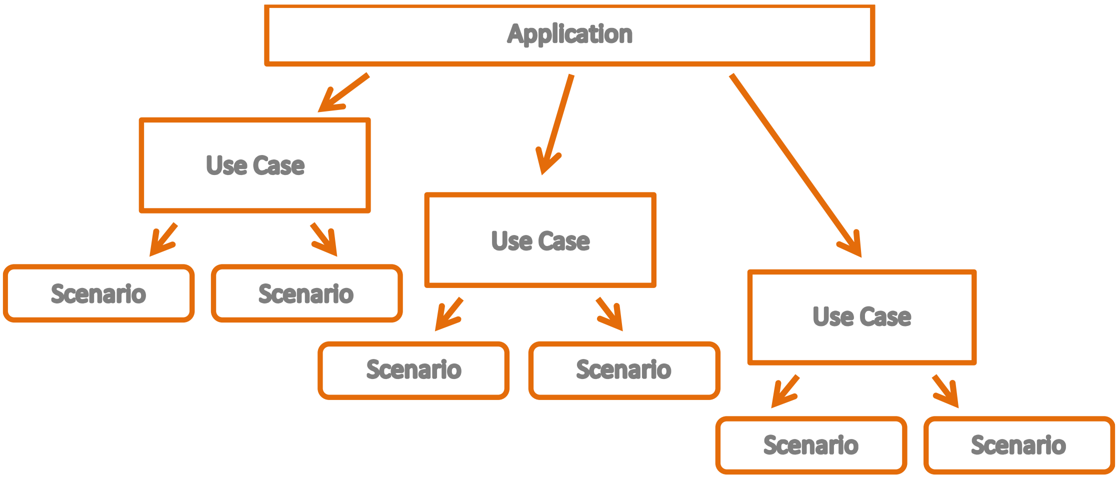

Figure 2: Relation between scenario, use case and application

2.4 Operation of application, service, and message

C-ITS applications may use information generated by any other C-ITS applications or awareness services and by that only consist of a consuming part. In release 1 there are no warning or informing C-ITS application defined. Instead, there are the triggering conditions defined for Release 1. When looking at these triggering conditions, they specify under what sensor input based information what message should be triggered. Triggering conditions initiate event-based message transmissions and are sourcing applications triggering event-based message generation by DENMs (ETSI EN 302 637-3 [ER-13]) for example providing input for the data consuming warning applications at the receiving side to inform the driver or the automated system, see Figure 3. The consuming application can be any application which may even use several types of messages and internal station information to make decisions. For more general awareness services such as CAS (ETSI EN 302 637-2 [ER-12]) which include specific message generation rules there are often no triggering conditions defined (see Figure 3). Conceptually the CAS can be seen as a service including an application part. Awareness services implement only simple awareness use cases. CAS brings awareness of the behaviour of its own C-ITS Station while CPS (ETSI TR 103 562 [ER-19]) brings awareness of the behaviour of differentiating categories of observed road users and obstacles. CPS supports several awareness uses cases as stated in MCO part 1 [IR-1].

Any consuming part could be able to receive and interpret all available related messages from any sourcing part in the area. Any interested C-ITS user (C-ITS-U) implementing a specific standardised C-ITS application and/or service must realise the C-ITS system and its applications interoperable (see [IR-1]).

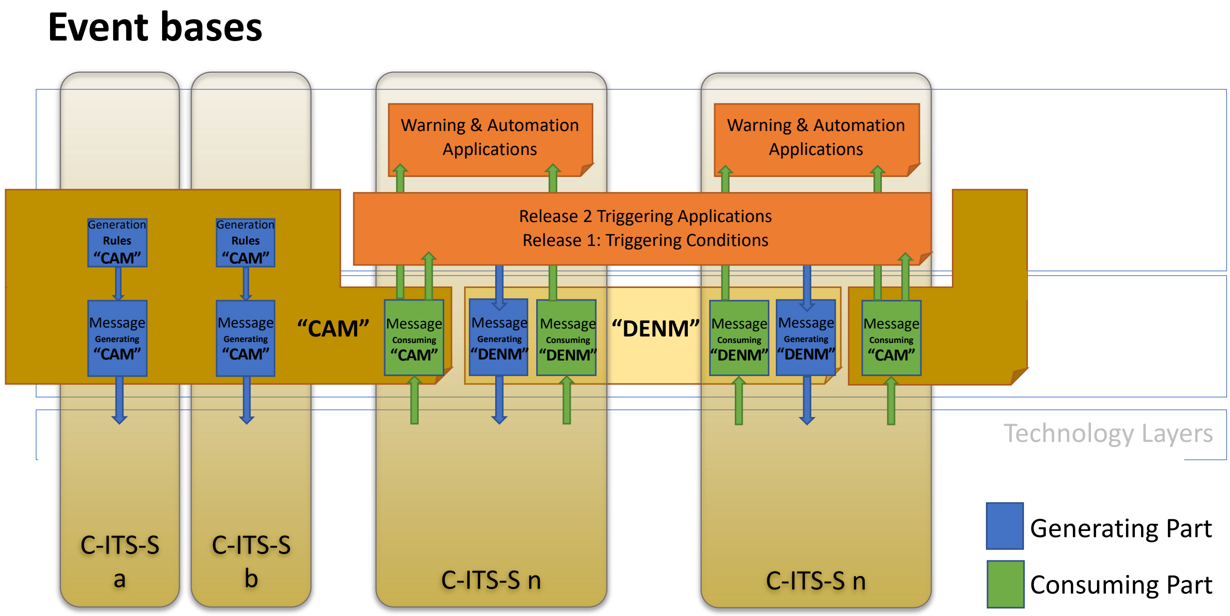

Figure 3: C-ITS Application partitioned into Sourcing and Consuming parts in C-ITS-Ss

Other Release 1 services are Traffic Light Maneuver (TLM) using SPATEMs (ETSI TS 103 301 [ER-18]) and Road and Lane Topology (RLT) using MAPEMs (ETSI TS 103 301 [ER-18]). RLT is an awareness service, while TLM is a message service which is triggered by the traffic light application and IVI (ISO TS 19321 [ER-17] and ETSI TS 103 301 [ER-18] for its trigger conditions). However, TLM can also be seen as an awareness service which then is triggered and/or controlled by an application.

2.5 Message behaviour

2.5.1 Introduction

MCO Part-1 Functional Requirements [IR-1] provides a comprehensive overview of the different use cases applications and awareness services, including those covering Release 1 and expected for Release 2. For the realisation of Release 1 applications and awareness services road situation analyses, use case specific tests, and large-scale tests have shown that a single channel is sufficient for a wide penetration of C-ITS stations in Vehicles and Road Infrastructure in the initial deployment years. It does not cover the case that all vehicles and other road users are equipped. It excludes the information dissemination by other road users such as bikes, pedestrians etc. as well as automation related use cases beyond Release 1. In this single channel configuration, the projected messages are prioritized with the most important messages, the DENMs occupying the 2 highest priorities followed by the CAM occupying the 3rd priority level with thereafter the SPATEM/MAPEM and IVIM occupying the lowest available priority level (traffic classes). In the following clauses the functional channelisation and Release 2 expectations are considered.

2.5.2 Channelisation

2.5.2.1 Introduction

For Release 1 a single channel bandwidth of 10 MHz was chosen. This choice was based on the CAM awareness service and the triggering dissemination requirements as initiated in related ETSI Standards and specified by C2C-CC as included in the C2C-CC BSP 1 [IR-3]. Although newer technologies may provide other possibilities, all possibilities are limited by the same physical limitations. Benefits of new methods and technologies shall be evaluated addressing all functional safety and system related requirements end to end. These Release 1 requirements were satisfied by the 10 MHz channel bandwidth approach in spectrum regulation and the realisation of Release 1 in vehicles and roadside equipment based on ITS-G5.

Essential for cooperative systems is, that any party who is interested in using the cooperative shared information shall also provide similar information. As parties may have different cooperative interest, take for instance vehicles and pedestrians, a C-ITS-S may serve different applications and may include varying communication functionalities. Besides that, this may differ by type of road user, and it may also differ by business case. Although Release 1 functionalities are realized in a single channel, SCH0, future developments may lead to uses of wider channels in case the functional requirements from new use cases, applications, or awareness services identify such requirements. Release 2 and beyond C-ITS-Ss therefore may include different C-ITS radio configurations, one, two, or more channels supporting various channel bandwidths. In the following clauses some detailing is provided.

2.5.2.2 Release 1 starting point

In Europe, over the last 15 years, the C2C-CC Basic System Profile (BSP) [IR-3] has profiled Release 1 ETSI and ISO standards with several improvements and adaptations to the latest standards and is the basis for equipment that has been rolled out and is operational in a single 10 MHz channel (SCH0).

The use of a single channel (SCH0) for Release 1 in Europe is a result of an analysis of several projects and research papers, like:

- SIMtd project [ER-29]
- the CONCORDA/5G-BLUEPRINT/5G-MOBIX project
- the IEEE paper “Experimental V2X Evaluation for C-V2X and ITS-G5 Technologies in a Real-Life Highway Environment” [ER-30]
- the KTH paper “A Simulation Study on the Performance Comparison of the V2X Communication Systems: ITS- G5 and C-V2X” [ER-31] [ER-31]
- the IEEE paper “Comparison of IEEE 802.11p and LTE-V2X: An Evaluation With Periodic and Aperiodic Messages of Constant and Variable Size” [ER-33]

These reports identify several relevant aspects which clarifies the considerations made when realizing the Release 1 specifications and C2C-CC BSP profile.

Confirmed statistics about road network usage by the German AutoBahn GmbH identified that for example at the Frankfurter Kreuz for the year 2015 an average of 150,000 vehicles/24h were counted and the RP Online Report [ER-32] identified that on the A100 at Berlin 165,000 veh/24h were counted. Numbers which lead to a theoretical average 6875 vehicles/hour driving with an average speed of 110 kph. Which brings us to a theoretical average of 63 vehicles/km. As this is an average and as it concerns safety, this average can be used as starting point but can’t be taken as a general value. Where safety is concerned also the worst case should be considered and further detailing is needed.

The last-mentioned IEEE report [ER-33] identifies the Van Aerde Model which is seen as best reference by many experts over the years providing a better reference and therefore is used in many studies, see **Figure 4**. This model provides a traffic density in dependence of the average vehicle speed and can be used to calculate the total number of vehicles for a given part of a road network.

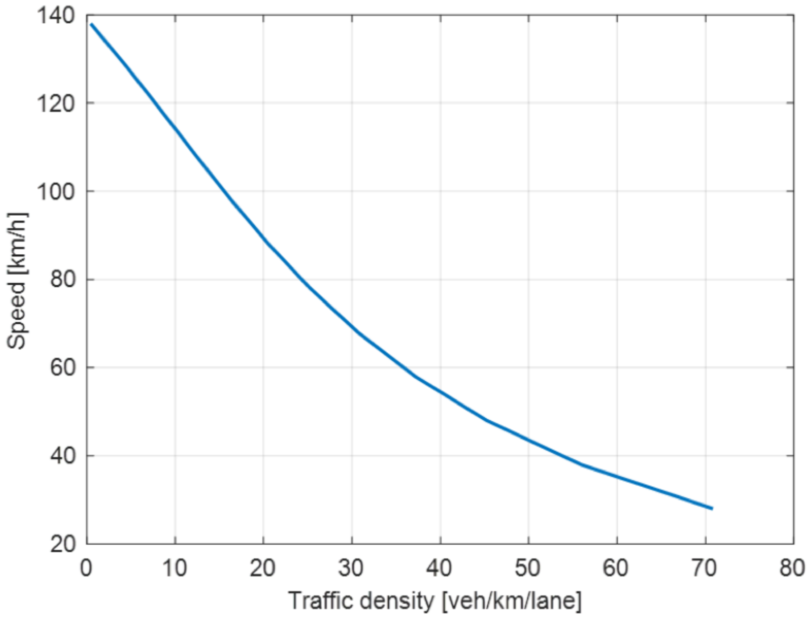

Figure 4: Van Aerde Model

Traffic density is an important part for the overall communication need. Additionally, the message exchange has to be considered. For a Release 1 deployment in vehicles, the focus is set to the dissemination of CAMs and DENMs. CAMs a generated continuously, while DENMs are mainly disseminated when there is a special situation. Thus, DENMs needs to be analysed separately as DENM generation is event driven while CAM generation is regularly for awareness. For general channel use in the first place the CAM dissemination, which is defined by the CAM generation rules as specified in the ETSI Release 1 EN 302 637-2 [ER-12], has a major impact on the channel use. The CAM rules identify that roughly every 4m distance travelled a CAM of varying size (including or not including the static parameters and security) is disseminated. In case a vehicle drives with a typical speed of 110 kph (highway) this results in a CAM transmission rate of about 8Hz. At a typical slower speed of 50 kph this is about 4Hz. When there is road congestion and vehicles driving slowly (about 15 kph) this is about 1 Hz.

The total amount of messages for a scenario like the Frankfurter Kreuz or A100 in Berlin as identified by the German Autobahn GmbH and RP Online report [ER-32], can be calculated by putting all of the above together. The highway consists for those scenarios of up to 4 lanes per direction, a total of 8 lanes, a crossing highway is not considered. The following number of messages can be received over a stretch of 1km of road:

- Use case 110kph: 13 vehicles * 8 lanes = 94 vehicles/km in reception range, each sending CAMs with a rate of 8Hz resulting in 94*8= 752 messages/s
- Use case 50kph: 30 vehicles * 8 lanes = 240 vehicles/km in reception range, each sending CAMs with a rate of 4Hz resulting in 240*4=960 messages/s
- Use case 30kph: 70 vehicles * 8 lanes= 560 vehicles/km in reception range, each sending CAMs with a rate of 2Hz resulting in 560*2= 1120 messages/s
- Use case 15kph: 100 vehicles * 8 lanes= 800 vehicles/km in reception range, each sending CAMs with a rate of 1Hz resulting in 800*1= 800 messages/s

The CAM rules and the total number of disseminated messages above show that the total amount of messages which can be received over a stretch of 1km is not too much dependent on the vehicle speed. The European CAM rules are sometimes called conservative generation rules while in the USA the BSM is disseminated with a fixed 10 Hz sometimes and therefore also called progressive generation rules. As result in the USA the channel comes in congestion much earlier than in Europe.

Considering the average numbers above, we can add some margin and assume a maximum average of 900 message/s (m/s) in a stretch of 1 km (the range assumed to be the reception range of a C-ITS-S. Considering safety related use cases one should also consider scenarios with worse conditions. Using the Frankfurter Kreuz a worst-case example, we need to consider a crossing of 2 highways with 8 lanes each, resulting in 2x 900 m/s to be expected.

As the data above is derived from statistics, the real value in such cases is probably somewhere between 900 and 1800 m/s at full penetration (all vehicles are equipped with a C-ITS-S).

Several papers identify that a message including the security header has a transmission duration of about 0.5ms – based on the access layer settings for Release 1. This means that about 0.45s (45% of the channel) is used when sending 900 m/s and 0.90s (90% of the channel) is used when sending 1800 m/s, at full penetration.

For enabling fair channel access even in such challenging situation, the concept of decentralized congestion control has been standardized. Considering the congestion limits specified for Release 1 (65% channel use limit), most CAMs will be disseminated in SCH0 without any problem, despite high density scenarios with close to full or full penetration.

As of today, an aftermarket solution for C-ITS equipment in vehicles is not existing. Stations are only installed by the vehicle manufacturers and as a result, the deployment speed can be derived from the sales number. It is known that the market replacement rate per year is about 10% (see yearly sales numbers and overall numbers or operational vehicles). When we consider current speed of deployment not all brands include the feature today. For the purpose here we estimate that the current replacement rate with C-ITS equipped vehicles is somewhere between 2-3%. It therefore may be assumed that not earlier then before the year 2028 - 2030 congestion may be occurring only based on the CAM dissemination rules.

In that case for the purpose of the CAS, it may be considered to extend the CAM dissemination rules allowing CAMs which can't be disseminated in SCH0 to be disseminated in another channel.

The transmission of DENMs is use case dependent and event driven. Such events are only happening in specific scenarios, practical experience show that only at specific moments there can be a peak in bandwidth used. In average it is very limited and only depends how we will extend the use of DENM in future by increased number of use cases making use of DENM disseminations. As in many critical cases when lots of DENMs are disseminated the vehicles are driving at low or very low speeds and therefore it is sufficient to allow DENMs having a higher priority over CAMs when disseminated.

Only later during the development of C-ITS use cases it was recognized that Infrastructure information is also of high importance and that also MAPEM and STATEM messages should be allowed to be disseminated. Analyses of the possibilities identified that MAPEM and SPATEM although are cyclic, they are only disseminated by roadside units (RSUs) so only by a very limited amount of C-ITS-Ss compared to the number of vehicles which can be present in a specific area. As result it has been assumed that the used bandwidth and the related impact are very limited. So, it was accepted that MAPEM and SPATEM are also disseminated on SCH0 but with the lowest priority. This acceptance was provided under the condition, that, especially for MAPEMs, their size do not exceed the size of the largest CAMs. As MAPEM and SPATEM have the lowest channel access priority they are the first to be affected when congestion occurs, thus, it will/may be required to extend the generation rules and/or channel access priorities in future as well.

Whether a message of a certain type initiated by a specific application or awareness service can be disseminated over the air depends on the availability of bandwidth and on the behaviour of other applications and awareness services. The influence of the message dissemination of one application or awareness service on another can only be evaluated and validated from out of the system level and not individually defined. For the realisation of the Release 1 C2C-CC BSP serious system validation at large scale and under several road scenarios where required only for the realisation of the CAS and DENS to operate in the same channel. Increasing the number of applications and awareness services in the same channel results in a significantly more complex validation and less predictable channel behaviour and therefore it is required to limit the number of applications being active in a specific channel. Further investigations are needed to see if off-loading to other channels is case of congestion is a supporting functionality to increase the robustness and predictability.

For Release 1 a single channel of 10 MHz has shown being sufficient and spectrum efficient. Furthermore, by limiting the bandwidth to 10 MHz also the number of applications and awareness services possibly influencing each other is limited, which keeps the system simple, ensures a sufficient level of predictability and limits the required effort for system testing and validation.

2.5.2.3 Release 2 starting point

In Release 1 the focus was to deploy basic safety related use cases and applications in relation to Vehicle safety, in Release 2 not only related use cases and applications are extended with more automated ones but there is also interest to realize a lot of new use cases and applications by additional C-ITS stakeholders e.g., agriculture, motorcycles, pedestrians, disabled people, public transport, transport monitoring (weight and dimensions). Various new forms of equipment shall be introduced as well. Whether they all will be supported by Release 2 specification or will be part of later releases is not yet clear. In general, Release 2 represents a set of specifications with changes and additions to Release 1 from which implementations shall lead to be backward compatible with Release 1 operating functionalities.

C2C-CC does its developments based on the C2C-CC roadmap and realized a paper with spectrum needs analyses [IR-4]. Also, the 5GAA [ER-36] identified Release 2 and beyond spectrum needs in their publications clearly showing the need for much more ITS and C-ITS data dissemination. Both papers show that for now the ITS designated spectrum in the 5.9 GHz band (70MHz) is sufficient, but when all above mentioned aspects are considered this band is not sufficient. When an additional band is identified and granted this will provide additional channels to disseminate ITS information.

Some of the intended Release 2 application and awareness service developments are already at a mature level e.g., Collective Perception Service (CPS) as identified in the ETSI TR 103 562 [ER-19], which specifies the Collective Perception Message (CPM). While CPMs may use a large portion of a single 10MHz channel, a wider channel is not envisioned for this awareness service. Compared to CAS, which supports one use case, the CPS is supporting several different use cases and it is being considered to separate the use cases, i.e., develop different profiles for the CPS for each use case. Except for raw data information sharing in the white paper MCO part 1 (MCO functional requirement [IR-1]) and the ETSI TR 103 439 [ER-15] there is no indication that more channel bandwidth will be required. As a single use case, only the raw data sharing use cases may require more bandwidth but also has different transmission requirements. Requirements which so far could be realized in the 64 GHz ITS band as there is sufficient spectrum available for these kind of use cases. So far, no applications nor awareness services have been announced requiring more than 10 MHz of bandwidth.

2.5.2.4 Spectrum efficiency

In general spectrum efficiency or bandwidth efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the medium access control (the channel access protocol) and is generally expressed in bit/s/Hz. It is a communication system technical parameter which only gives a measure of the capability of the network, it doesn’t say anything about the functional efficient use of the spectrum which at the end is envisioned. C-ITS information dissemination is dynamic and strongly scenario dependent.

When considering the Release 1 communication parameters and only changing the 10MHz channel bandwidth into 20 MHz the estimated spectrum efficiency is difficult to estimate and depends on the specific technology used. Also guard band aspects should be considered as well as technical solutions like extended control information exchange as introduced in cellular based solutions. For ITS-G5 the spectrum efficiency improvement is estimated to be between 5-10%. For cellular solutions it depends on what examples are used. When it is allowed to use the maximum transmission bandwidth, calculations from ETSI TS 138 101-1 [ER-35] show that the amount of resource blocks goes from 24 to 51, representing a gain of 3/51, which translates to a spectrum efficiency improvement of about 6%. When considering the subchannels this increases but the control overhead as well. For now, we consider these values as references, but further investigations will be needed. Be aware this improvement is a technical improvement, whether applications are able to use this efficiently should also be considered.

To identify the usability of these technical values we need to evaluate them in the context of how a channel can be functionally used.

When considering the dynamics of the CAM dissemination (not the DENM as this is even much more dynamic), we can consider the traffic light crossing scenario. At such a crossing the CAM transmission can peak and go from 1 to 10Hz in a few hundred milli-seconds due to acceleration and direction changes. The transmission frequency decreases later on, when the vehicle reaches “constant speed”. Because not all vehicles at a crossing will accelerate at the same time as in average only one direction gets green, it should be assumed that only 25% of the present vehicles accelerate. If the crossing has 4 approaches, each with 3-lanes per driving direction and it is a bit busy it is quite normal that about 10 vehicles per lane accelerate. As result the message rate will go from about 30 to about 300 messages/s for those vehicles, the other 3 directions do not change. The total amount of message increases from roughly about 120 messages to 390 messages which leads to an increase of about factor 3.5. When considering the identified number of disseminations at full penetration not in worst-case (900) in clause 2.5.2.2, we could conservatively say that we would go from about 10% (120/900) to an 40% (390/900) bandwidth usage in several seconds. These are very rough conservative numbers which show that there is a bandwidth usage variation of the available ITS spectrum. When the worst-case would be considered these numbers would be much more severe. As these realistic numbers in practice may still vary considerably when also other message types are considered, these variations are of a magnitude then the possible improvements for going from a two 10 MHz channel to a single 20 MHz configuration. When then also other functional aspects such as the increased complexity of applications and awareness services influencing each other, the limited benefit of going from two 10 MHz channels to a single 20 MHz configuration provide no reason to use a 20 MHz channel in favor of 2 10 MHz channels. Only the introduction of new applications requiring higher bandwidths would provide arguments to use wider channels. For Release 2 these requirements are currently not identified.

2.5.2.5 Release 2 General multi-channel considerations

When considering the current spectrum allocation in the context of the estimated needs from both the C2C-CC and 5GAA, the current 5.9 GHz band will not be sufficient in future to support all intended applications. This will lead to the use of C-ITS Ad-Hoc multi-channel operating communication systems having access to bands in the 5.9 GHz and additional spectrum bands and channels.

The already deployed Release 1 applications utilize the SCH0, a 10 MHz channel. Any future deployment and Release 2 solutions shall be backward compatible towards existing deployments. The upper part of the spectrum (SCH6) is shared with ITS applications for CBTC. In recognition of the of European Weight and Dimension regulation, which requires the realisation of information dissemination based on ITS-G5 in one of the other channels (than SCH0 or SCH6), a channel with 20 MHz bandwidth is almost impossible considering the adjacent channel interference requirements. Whether we should realize such as 20 MHz band is also not evident. Such a decision should be covered by functional and system requirements, technical reasons alone are not sufficient.

When considering the aspects identified in the previous clauses, 20 MHz bandwidth requirements have not yet been discovered and therefore there is no requirement to realize any 20 MHz channel in the 5.9 GHz at this moment. In case 20 MHz bandwidth requirements popup it must be suggested to realize such spectrum extension in alignment with ITS spectrum band extension in other spectra.

In any case, it is obvious that whatever choices are made, all lead to use of multiple channels and therefore a MCO system approach is required.

2.5.3 Release 2 Application expectations

The MCO part 1 report [IR-1], Functional Requirements illustrates the generally expected Release 2 functional requirements identifying a strong increase of message types and related varying message behaviour. A few main aspects to recognize:

- To enable the realisation of different sets Day-1, Day-2 and beyond use cases, different specification releases are realised. Release 1 allows the activation of a limited set of safety awareness use cases activating the exchange of relevant data to satisfy the applications realising the release supported use cases. Release 2 and following releases will support extension of previous release specifications and other additional sets of specifications realizing additional message dissemination. Each release shall be able to use different technical solutions selected based on the release specific functional requirements complying to the legal European boundary conditions set by EC and ECC regulations.
- As extended use cases may make use of several message types defined within the Release but also may make use of message types of previous releases, the releases shall be interoperable and backward compatible.
- As applications may make use of multiple message services (such as the Hazard Warning application makes use of DENM and IVI), Release 2 and beyond use cases may make use of multiple messages creating services for example of CAS and CPS while these are not shared in the same channel. As Release 1 CAS makes use of SCH0 and CPM can't do the same but will have to use one other channel, Release 2 and beyond applications may realise their use cases by exchanging their specific message independently of which type in the same channel or make use of general awareness e.g., CAS and CPS operated in different channels. This depends on the specific application and its use cases.
- Analyses of the awareness service implementations and scenario show that data disseminations are scenario dependent, however as there are so many dependencies which are not yet known and may even never be all known, for Release 2 it needs to be assumed that the dynamic behaviour of messages in size, regularity and transmission repetition are not really predictable as they are very environmental and scenario dependent and therefore the dependencies of transmission of various messages in the same channel needs to be evaluated, validated and managed carefully at the system level. The more dynamic behaviour applications or awareness services are active, the more influence they have on each other which increases the management exponentially. It therefore may be considered to put specific awareness services in separated channels to manage the behaviour in the channels and leave enough space for triggering event-based message transmission. For these services it could be considered that when congestion restricts the transmission of messages, that in the first this effects the awareness services. It could be considered to offload awareness information when in congestion.

In Release 1 the congestion, and thereby the predictability, is managed by means of an agreement on which C-ITS applications and awareness services are active and which are not. By having C2C-CC [IR-3] and C-Roads profiles [ER-3], the message exchange required to allow the Release 1 applications operate predictable with sufficient QoS (a requirement to realize the safety benefit and user trust) is ensured by limiting the supported Day-1 use cases and related messages dissemination. The number of supported use cases in SCH0 may still be increased within Release 1, but only when their dissemination behaviour does not affect the operation of the existing ones at full penetration.

As for the management of predictability, the number of supported use cases active in a channel has to be such that the channel is rarely getting congested. By limiting the bandwidth of the channels to 10 MHz, the applications can operate predictively under not too complex rules, resulting in testable solutions.

New releases should use the same approach; however, the applications requirements will have to drive the channel requirements which may require wider bands. MCO Part 1 [IR-1] identifies that most use cases require similar message behaviour as those for Release 1 and therefore no real other technical spectrum requirements need to be supported other than more channels. However, there is one general specific exception: the sharing of raw data requires wider channels.

Beside of that, ITS use cases have other differentiating functional requirements, such that in most cases the benefit of disseminating (raw) data is focused on sharing it predominantly which specific C-ITS-Ss in close vicinity of the originator. Realisation of such information exchange could benefit from existing spectrum regulations also in the 64 GHz band ECC/REC/(09)01 [ER-23] (already a C-ITS allocation in Europe) or in other xx GHz bands.

2.6 System Conditions

As Clarified in MCO Part-1 [IR-1], Release 1 solutions are implemented and in operation in SCH0 and some in SCH1 already. As so called, there is an installed base to be interoperable and backward compatible with. It can also be recognized that Release 2 developments as well as regulation sets some conditions to consider. This has a number of consequences.

- The Release 1 set of applications are satisfied by data exchange via ITS-G5 and on the SCH0 5.9 GHz channel as profiled in the C2C-CC BSP 1.x [IR-3] and currently Release 2 related use cases are evaluated in SCH1 (platooning and infrastructure specific).
- The Release 2 set of applications is an extension of the Release 1 set of applications. The implementation of the Release 2 set of applications may differ from vehicle to vehicle depending on the type of vehicle or just differ from model to model. There where the Release 1 set of applications occupies a single channel, the beyond Release 1 applications part of Release 2 may have various purposes. For example, the platooning application. This application is only used by trucks and not by other vehicles, but needs to exchange information and therefore requires the use of a channel, or at least of a part of the channel, while not influencing other applications and, vice versa, this application should not be influenced by other applications. This while other Release 2 applications also require information exchange in one or other channel but should not be required to implement the platooning channel while they are not supporting the application. Although it would be nice to agree and fix the number of channels this is not possible, and we will see multi-channel systems supporting various number of channels depending on the type of vehicle and the model. From a system point of view a Release 2 system may include a various amount of hardware channels which may access different spectrum channels at any given time. Currently those channels are only 10 MHz wide, whereas technically wider channels (e.g., 20MHz) in the 5.9 GHz ITS band are possible but functionally probably not desired, at least not with high level of congestion possibilities. In the first place Release 2, dual and triple channels may be expected.
- Release 2 and beyond releases may make use of different technologies to realize the functional objectives.
- Beyond Release 2 may support additional Radio Channels in other spectra. It is up to the stakeholders to identify what use cases Release 2 needs to support.

One other aspect is that currently the application specifications specify the message communication requirements without knowledge of the dynamic state of the communication and only based on assumed basic communication availability as identified in chapter 2.5 safeguarded by channel congestion management mechanism. This is a static predefined and fixed approach. For Multi-Channel operation this may need to be reconsidered with backward compatibility in mind. As Release 2 is assumed to support current spectrum regulations which limits the channel to 10 MHz in the 5.9 GHz band, any MCO solution should recognized that channels could also be wider such as regulated in the 64 GHz ITS band allocation and wider channels as supported by IEEE and 3GPP specifications.

2.7 Existing mechanisms of relevance to MCO

2.7.1 Introduction

In the following clauses some specific mechanisms and aspects for MCO are evaluated and considered of relevance to MCO.

2.7.2 Forwarding at Network layer

In the Release 1 ETSI EN 302 636-4-1 [ER-8], the TS 102 636-4-2 [ER-9] and TS 102 636-4-3 [ER-10] Media independent and Media dependent specifications forwarding has been enabled at the network layer. When a message is received the network-layer checks whether the message should be forwarded in the same channel. In the C2C-CC BSP [IR-3] triggering conditions and C-ROADS services [ER-3] make use of this type of forwarding in the same channel.

Currently forwarding is only considered in the same channel. For Release 2 MCO does not consider forwarding but requires putting the following requirements on forwarding functionality at the network layer and to the application or awareness service requirement specifications to ensure the operation of a stable system.

Forwarding in the same channel may only be implemented when:

- Handled in the originating channel at the same or lower priority level.
- Any Networking layer forwarding solution obey the congestion restrictions specified for each specific channel.

2.7.3 Service Announcement

The Service Announcement (Release 1 ETSI EN 302 890-1 [ER-10]) is an awareness message, making other stations aware of the availability of specific services. As it is an awareness service, it can be transmitted by any station (type) or any actor part of the C-ITS ECO system, like other awareness messages. Awareness messages services themselves should therefore not be announced. Services such as CAS, DENS, and CPS are therefore not announced.

Messages sent by specific station types or a specific actors can use announcements mechanisms as they address specific users which can be made aware of the specific operation. A Service provider may decide to announce a service in a channel depending on the congestion state of the individual channels and therefore dynamically allocate a channel. To ensure a stable operation of the system, operating limits shall be specified under what conditions such dynamic use can be accepted. This includes aspects which ensure that the dynamic use does not conflict with dynamic allocations which may be realised by any MCO mechanism.

Private and Open SA services can be recognized. In case of private services, the service provider may choose any non-safety channel to transmit the SA. Safety channels can’t be used as Private and Open SA’s as they are not cooperative oriented and are not managed within any standardized profile.

In case of an open service which could be of interest to anyone, some channel use rules need to be agreed to ensure that every C-ITS-S can have access to the service. In accordance with the spectrum regulation there are safety and non-safety channels assigned resulting in the following SA general use proposal:

- A dedicated channel allocation in the safety related band for general safety related announcements and for specific user groups each safety service may decide to use any safety channel for sending the Service Announcement.
- A dedicated channel allocation in the non-safety band for general non-safety related announcements and for specific user groups each non-safety service may decide to use any non-safety channel for sending the Service Announcement.

In all cases application specific SAMs shall be distributed with lowest priority when the application or service is not commonly standardized.

2.7.4 Channel off-loading

Channel off-loading is the dissemination of messages in a channel other than the original intended. This may occur when the original channel is congested. Applications and awareness services may initiate such actions in the form of conditional conditions by which the MCO functionality may decide whether a message is disseminated in the original or off-load channel.

2.8 Generic data exchange considerations

The number, of C-ITS Release 1 services is limited. First only CA and DEN services and later extended with TLM/RLT and IVI services are all supported in a single channel.

> Note: Early analyses identified that a single channel for these services is sufficient as long as there is not more then 60-70% penetration. This means that certainly no other messages can be allowed and even when heading toward 60-70% penetration solutions should be installed which overcome this limitation.

As Release 2 developments show the need for a set of extended applications and message types, these messages can only be exchanged on other channels and even extensions of the current use cases may be considered elsewhere.

It can also be recognized that the transmission of messages depends strongly on the specific use case and the dynamics of the environment e.g., highway, sub-urban and urban and number of participants. Data exchange requirements may differ extremely from one moment to one-other. To allow applications to operate in a multi-Channel operating environment providing sufficient QoS the following aspects must be considered (including generalized findings from previous sub-clauses):

- Awareness messages can be sent by any C-ITS-S, initiated by any actor, and be generated at any time. In case congestion situations are not considered dissemination of messages may be aborted by lower layers.
- Other messages can be sent depending on the specific nature of the C-ITS-S or the application which triggers service e.g., DENM, SPATEM and MAPEM.
- Specific applications may use one channel for transmission while incoming information is received on another channel. For instance, for public transport prioritisation a RSU may send information on one channel while a bus does this on a different channel.
- It is important that applications are aware about the station communication capabilities at any given time as this would allow the applications to make different decisions in case of being or not being connected. For instance, it could have influence on the supported Functional Safety level.
- As an application or awareness service has no knowledge of the existence of other applications and awareness services, it does not know whether a channel in which it expects to transmit ITS messages is available or whether it is used by any other application or awareness service. An MCO facilities service can have an overview of the need of all active applications and awareness services. While also being aware of the capabilities of the underlaying communications, it can reserve portions of the station’s on-time for specific applications and awareness services depending on their static or dynamic needs.

- Continuity of Service: Only the applications know the urgency of the data to be transmitted. Especially when more applications are active prioritisation-based scheduling mechanism could be an interesting asset. Aspects to consider:
    - All applications could provide the message validity duration to the lower layer service which has then the possibility to schedule the messages according to traffic class and data validity time.
    - Bandwidth limitation due to channel congestion, leads to messages not being transmitted when an application is not made aware of the lower layer limits. In case the lower layers detect not transmitted messages, applications should be made aware of the congestion state by lower layer mechanisms.
- Spectrum regulation identifies that the 5.9 GHz band is functionally allocated to safety relevant transportation (C-ITS) information exchange. It is not assigned generic such as RLAN or via auction such as with cellular. All these methods separately are technology neutral as required by EU regulations. When splitting the band, the technologies to be used are getting selected and limited and therefore are not technology neutral and therefore should be avoided. It should be ensured that various technologies can be used under spectrum technology non-interference requirements and listen before-talk.
- From the spectrum regulation we see that in one ITS channel (SCH6) only I2V transmissions are allowed. It is therefore advised to realize road infrastructure specific application data transmissions in SCH6. Thus, all extended SPATEM, MAPEM, IVI and pre-emption I2V transmissions should be realized in this channel. Messages of these types by other C-ITS-Ss could be sent on a different channel (for instance SCH5).
- Based on the use cases in which specific applications transmit more messages in an urban area than on highways and vice versa the transmission of opposite behaving applications could possibly use the same channel.
- The current tendency is that Functional Safety related requirements are mostly avoided by using received information not as the main sensor information on which automated decisions are made. As result for Release 2 it is assumed that no additional Functional Safety related requirements need to be realized and that mostly ASIL QM level support is required for Release 2 applications. This level does not require additional communications related solutions.
  Although it can be recognized that higher ASIL levels may be applicable, it is expected that first aspects such as resolving sensor data accuracy and confidence level improvements will be realized prior to adding additional communication requirements.
  Therefore, no Functional Safety requirements are considered for a Release 2 MCO concept.

2.9 Technical considerations

2.9.1 Introduction

The following clauses handle specific spectrum related capabilities and limitations which need to be taken in consideration for the development of a MCO concept.

2.9.2 Spectrum regulation, main capabilities, and limits (see [IR-2])

Even through the MCO Technical capabilities report [IR-2] shows static adjacent channel interference for 10MHz bandwidths, the dynamic analyses for 10MHz bandwidth channels as presented in the TR 103 439 [ER-15] show that the influence can stay acceptable when channel usages stays below agreed DCC levels for all channels as well as defined for the basic used channel. The TR 103 439 [ER-15] indicate some influence which can be managed by having a somewhat more stringent DCC level in adjacent bands for all channels having a 10 MHz bandwidth. The specific adjusted level needs to be defined. In case the adjacent channel would be wider (e.g., 20 MHz bandwidth), the energy in the channel is is higher, resulting in more interference requiring more advanced non-interference measures and further analyses.

The current spectrum regulation identifies safety related and non-safety related channels and one safety channel which for the time being may only be used for I2X communication while there are no coexistence rules specified between Urban Rail ITS and Road ITS.

With regards to the non-safety related channels a simple scenario analysis as presented in the TR 103 439 [ER-15] shows that these channels could also be used by selective safety related applications under certain circumstances.

To ensure no interference with Urban Rail, it is suggested to use SCH6/184 in the first place only for controlled environment related use cases. In the spectrum regulation only I2V are recognized as controlled environments as from roadside C-ITS-Ss it is known what their fixed location is and therefore what their fixed interference could be on Urban Rail ITS installations. Additionally, test fields are also controlled environments and therefore those should also be suitable to be realized in SCH6/184.

For MCO, only the 7x10MHz channels in the 5.9 GHz band are considered. Although there is additional safety related ITS spectrum designated in the 64 GHz band, the physical characteristic of this spectrum is very directional, line-of-sight, and range limited, such that it can't be seen just as a spectrum extension to be used by the same services being active in the 5.9 GHz. The 64 GHz band can be used for a specific class of C-ITS applications which address direct communication between specific C-ITS-Ss at a shorter range then possible in the 5.9 GHz band. In comparison in the 64 GHz band, it is easy to share large trunks of data such as raw camera feeds. The use of the 64 GHz may therefore be used for specific data intensive directional short distance (up to 100m) line-of-sight information exchange and be added as an additional channel capability to future MCO extensions. Now this is not foreseen to be part of Release 2 as currently the communication requirements are not known and need detailed analyses.

Figure 5 provides an overview of the available channels in the 5 GHz band.

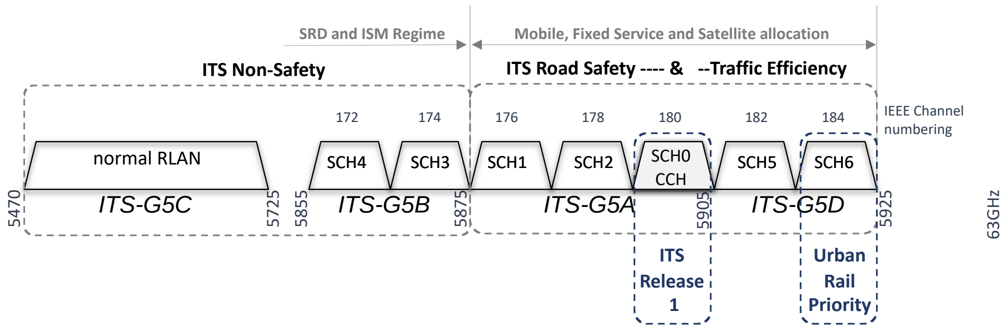

Figure 5: C-ITS spectrum allocation

The reason to use a channel width of 10 MHz and not wider for Release 1 has its background in the first place in its functional and system requirements as identified in earlier clauses. Technical capabilities have not been the real reason for this, although existing technologies at that time also provided some arguments in this direction. Newer technologies may not have such technical limitations; however, they may have other limitations as result of the chosen concept. As technical solutions may differ a lot and the application area is safety related, all changes to the system need to be finally evaluated and accepted based on system performance assessment. Any new technical solution should in the first place support all functional requirements.

Some current technical arguments:

Beside of other reason one technical argument to use 10 MHz channels is that it uses a longer "cyclic prefix" in the OFDM symbol, 1600 nsec for 10 MHz vs 800 nsec for 20 MHz. A longer cyclic prefix gives more immunity against inter-symbol interference in the face of delay spread. Delay spread for a dynamic vehicular environment includes multi-path delay caused by urban surfaces or even from rural structures like a barn or sign. Carnegie Mellon University (Prof. Daniel Stancil) in collaboration with GM did a delay spread study [ER-37] in 2007 that showed 800 nsec cyclic prefix is too short.

For LTE V2X PC5 most transmissions use sub-channels within the 10 or 20 MHz channel, e.g. 4 MHz is common. If one is starting with a greenfield spectrum, and if the size of the spectrum is an integer multiple of 20 MHz, it might be reasonable to do 20 MHz for LTE V2X. Something which require further study. When you have an existing 10 MHz channel it however is very disruptive to existing equipment to deploy 20 MHz channels. Also, you have 5 x 10 MHz safety channels, so if you switched to 20 MHz you would waste 10 MHz and interference would increase.

Although it may be expected that 10 MHz wide channels will be used in Release 2, the channel width may be extended in later versions based on functional and system requirements. A MCO concept therefore shall enable future extensions and needs to support extensions for the use of wider channels in future releases.

2.9.3 Impact of interference from adjacent channels

2.9.3.1 Introduction

Impact of interference from adjacent channels

In the TR 103 439 [ER-15], the impact of interference from adjacent channels for 10 MHz channel widths have been investigated through simulations in realistic scenarios. The objective was to derive an indication about the preferable traffic distributions from an interference point of view. Both balanced and imbalanced traffic in adjacent channel has been considered.

Results show:

- Influence of 2nd or 3rd adjacent channel has negligible impact
- Distributing the traffic over multiple channels allows to overall improve the performance in terms of packet reception ratio and range.
- The 1st adjacent channel causes some interference, reducing the reliability of the communications. With lower Congestion levels the interference is less.
- The impact from the 1st channel appears limited but it is preferable to distribute the data traffic over the channels.
- These observations need to be considered jointly with the other limitations, such as, the impossibility of some nodes to receive messages at the same time from all channels

2.9.3.2 Use of all available channels (7) for C-ITS road safety

SCH4/172 and SCH3/174 are allocated for non-safety related based on possible interference with SRD’s. The following however is applicable.

- The transmit power of SRD devices is limited compared to ITS devices. As result ITS devices have some level of priority over SRD devices.
- This is the case for ITS stations which are in similar range as possible SRDs.

The ETSI TR 103 439 [ER-15] realized basic analyses showing the possible use of these channels but further analyses are required to identify and evaluate worse case scenarios such as the in-car use of SRDs.

2.9.3.3 Allowed adjacent interference levels

Up until now it was assumed that adjacent channel interference is managed by using a “guard band principle”. This means, that in the adjacent channels the messages are disseminated with a lower transmit power (see Figure 6). Simulation results with this principle as presented in the TR 103 439 [ER-15] however show that this is not significant and that it is better to lower the congestion level instead of lowering the transmit power.

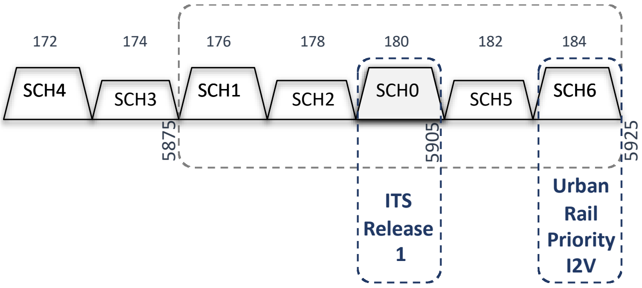

Figure 6: Guard band principle

In case of lowering the transmit power the reception distance decreases, which could be used for pedestrian use cases, but further research is required. One other example could be that a RSU on a highway may use higher transmit power to cover a longer range. Further research is needed for this use case as well as such transmissions may block the receptions of other messages.

As Identified in the TR 103 439 [ER-15], by lowering the allowed congestion level in the adjacent channels the adjacent channel interference is reduced. As identified in Figure 7 this could be realized statically in identified channels by specification, or dynamically by comparing congestion levels in the different channels.

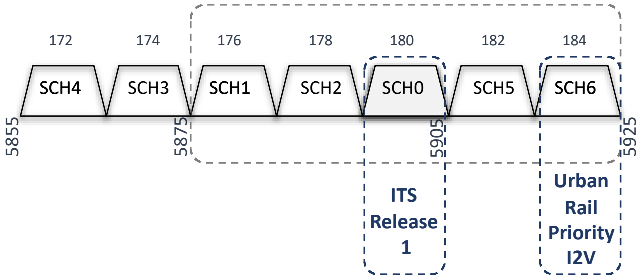

Figure 7: Static congestion level setting

The TR 103 439 [ER-15] didn’t analyse possible congestion limit settings on adjacent channels. It needs to be identified at what congestion levels in adjacent channels interference levels still can be acceptable. Further analyses are required to identify appropriate mechanisms to ensure acceptable inference both for static and dynamic mechanisms. Results shall be present before MCO architectures can be implemented.

3 MCO Concept

3.1 Introduction

The following clauses identify the MCO requirements and a MCO concept. The main objective is that MCO should coordinate and manage the channel usage and provide a consistence and predictable access to applications to the channels. The analyses from previous chapters and the MCO methodologies as described in the ETSI TR 103 439 [ER-15] are used as starting point for the concept described here.

The MCO functionality is a technology independent supporting functionality in the C-ITS Station architecture. It provides access and increased usability of available communication resources and reserve portions of the station's transmission-time in a predictable and spectrum efficient way to applications. An MCO functionality is depending on information from different layers and therefore is a cross layer technology agnostic functionality consisting of entities at the different layers of the C-ITS Station architecture.

The MCO functionality shall manage all C-ITS information exchange and therefore all applications will have to behave and communicate in a predefined way. It's a multichannel update of the cross layer ITS-G5 technology specific DCC functionality originating from the ETSI Release 1 as defined in ETSI TS 103 175 [ER-16].

3.2 MCO In C-ITS

3.2.1 Introduction

The MCO service operates as a central functionality in the C-ITS-S and as it manages the data flow to other C-ITS-Ss it has influence on the C-ITS. It is therefore important to commonly agree its functionality and its relations with other functionalities in the C-ITS-S to ensure QoS to all functionalities in the C-ITS-S, especially with technology agnostic applications and message services and MCO related technical functionalities at the lower layers. This chapter therefore describes the contextual aspects and requirements while in chapter 3.2.6 the specific functionalities are identified for Release 2.

3.2.2 Data exchange in the C-ITS ECO System

Data exchange in IP based Internet systems is realised transparently for services and applications. Based on the IP addressing method, knowing the destination or source of the data it is sufficient for applications to exchange data and it is not required to know anything about the underlying communication protocols. So, a user system needs to include a communications sub-system but how that looks like doesn't matter if the services get enough capabilities from the lower layers to get the data transferred. As we can see it often depends on where you are what communication sub-system you need, but when it is setup to the needs of the services and applications to be supported it works and is only depending on the behaviour of all other users in the network. IP based Internet systems connect you to the whole world, but you never know the performance and have no guaranty of minimal service. As we go along, this is not a problem for most especially consumer services and applications, but when we go to more automated and/or safety systems, this partly works but not for all. Of course, we could ask for guaranties in the network, but this comes with additions to those networks, risks, and costs, with the result that besides cellular technologies, many other but different IP based and non-IP based systems e.g., WiFi, UWB, Bluetooth, Radar, Fixed links, FM, AM, DAB, CEN-DSRC and ITS-G5 were developed. All these communication solutions fulfil specific functional requirements.

For transport mobility automation and road safety, IP systems are useful for the higher-level decision making ITS services such as parking, map updates and road congestion management. When going more in particular to equipment (vehicle and road) automation or road safety, the information exchange is relevant locally, and what happens at 2…. km is not relevant and therefore the data does not need to be shared with the whole world. Also, information from yesterday is not relevant but information in a split second is. Sharing such information through a network with intermediary nodes is more complex and not helpful, and probably such added complexity results in an increase of energy use. One other question is, who needs my information? This is never known, as transport is dynamic and only in a split second, we know whose information is (was) relevant for me. It is therefore obvious that C-ITS/CCAM (CCAM [ER-22]) information should be shared with everyone in the same area through direct communication and not through a network in which someone or something else decides what is exchanged when.

To support open sharing of information between C-ITS-Ss, in the C-ITS data is broadcasted or unicasted without reception notifications. In Europe, the Day 1 C-ITS services are operational based on ITS-G5 technology as defined in ETSI and CEN/ISO Release 1 specifications today.

For a Multi-Channel C-ITS Release 2 a technology agnostic extension allows the evaluation of newer releases of ITS-G5 as well as 5G-NR PC5 solutions.

As these solutions are broadcasting oriented, two aspects are important to realize interoperable and robust operation of C-ITS and CCAM [ER-22] applications.

- The spectrum to be used should be carefully managed from out of the application perspective. What applications are active, and which are not at a particular time shall be regulated.
- When broadcasting or multicasting data, it is required that the applications or awareness service selects the to be used underlying communication mechanisms, spectrum channel and other lower layer settings as identified above. These are only settings, at the application and facilities layer lower layer parameters are not manipulated and therefore although they may select lower layer settings, they do not alter them and therefore are these higher layer functionalities are technology independent. Such settings may be left to lower layers whenever possible, but it is the responsibility of the applications themselves to ensure the possibility that disseminated messages arrive at the appropriate destination.

3.2.3 MCO in the C-ITS System

The realisation of Release 1 interoperable specifications resulted in implementations of single channel C-ITS-Ss and limited two channel C-ITS-Ss implementations (the second channel being used by RSUs). Day 1 applications are operational on a single channel and only some traffic management applications are realizing their data exchange on another channel, not harmonized. Release 2 focuses on additional warning and extended awareness C-ITS and new CCAM [ER-22] services and by that require additional channels for the support of these services. As there will be many different C-ITS-Ss, these will support different Release 2 sets of services and therefore these C-ITS-Ss may be configured differently. One station may only use a single channel while an automated vehicle may use several channels. Vehicles like trucks may require other channels to realize services like Platooning. In practice, C-ITS-S equipment will vary in the numbers of channels implemented, further limiting channel selection methods at the lower layers.

3.2.4 MCO in the C-ITS Station architecture

3.2.4.1 Overall C-ITS MCO station architecture

MCO is a central data coordinating and managing functionality in the C-ITS Station architecture. It is technology agnostic to ensure that benefits of various technical solutions can be adopted and therefore resides at the facilities layer. It communicates with the lower technology layers to have knowledge about the technology capabilities, but also to be informed about the dynamic state of the active channels.

Figure 8 presents the MCO functionalities in the C-ITS Station architecture. It identifies both the data plane and management plane interfaces between inner layer and layer to layer entities.

To let the applications and service operate robustly, as they can't know the presence of other applications and services, MCO _FAC is the main MCO functionality. It is the station central data managing service which collects all needs of all applications and awareness services and, depending on the lower layer and radio capabilities, decides how to distribute the available resources to them.

Figure 8 illustrates that the MCO service is at the Facilities Layer (MCO_FAC) but that MCO also includes functionalities at the Networking & Transport Layer and at the Access Layer. It has no specific functionalities at the application layer but has interfaces directly to the applications.

MCO_FAC communicates with MCO lower layer functions as MCO_NET and GN Core (see Figure 8), and MCO_ACC (see 3.2.4.4) via the management plane to be informed about the static and dynamic capabilities of these lower layer MCO functions and to control some settings; it also exchanges data packets with the GN Core via the data plane.

As the MCO functionality enables applications and awareness services to initiate message dissemination, MCO_FAC interfaces (see 3.2.5) directly to these applications and awareness services at the management plane to allow those applications and awareness services to register for dissemination and reception of data at the data plane and inform MCO_FAC of there communication requirements. At the data plane it interfaces to the message generating services such that those services can provide the messages to be disseminated.

The MCO_FAC also handles the incoming messages received from lower layers and provide this information to any facility service, such as the CAS, DENS and LDMS.

As illustrated in Figure 8, MCO_FAC facilitates the transmission of messages generated by more than one application.

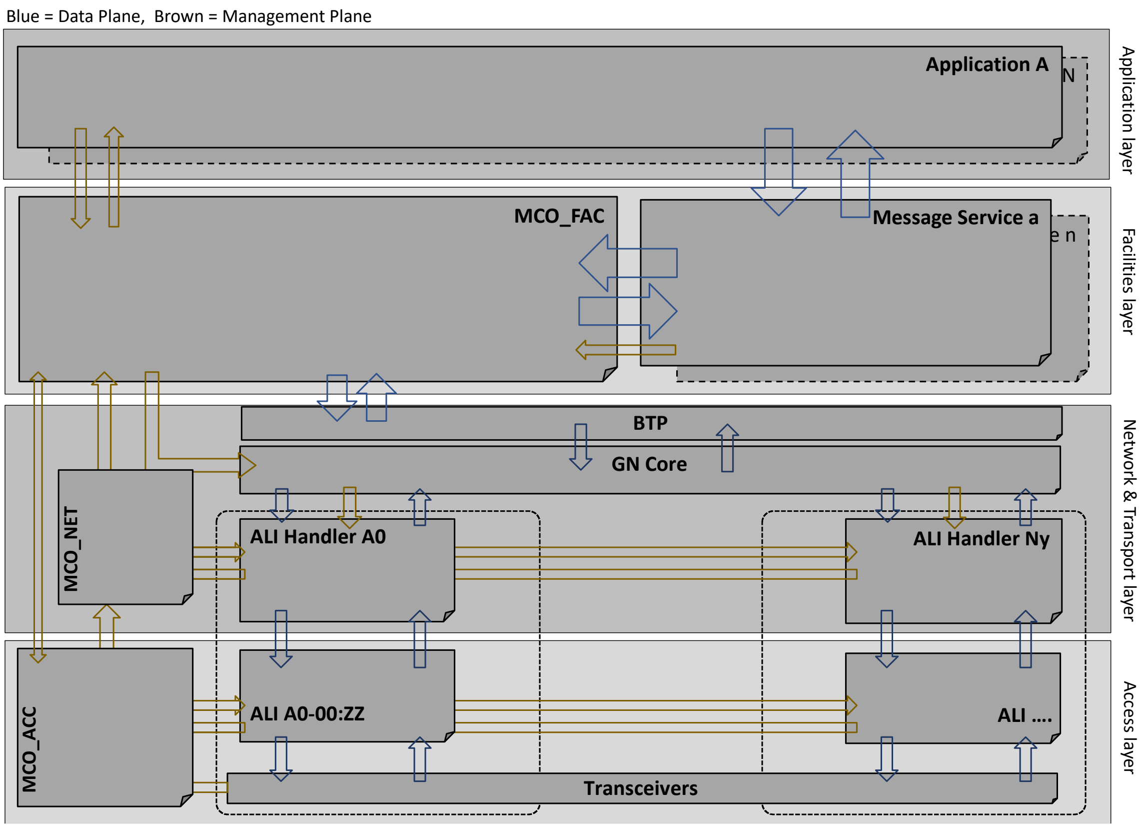

Figure 8: MCO functionalities in the C-ITS Station architecture

In Release 2 it is assumed that there is only one set of MCO functionalities present in a C-ITS-S but multiple would also be possible. In case there are more, applications may register to several MCO services (MCO_FAC), but physical channels can only be assigned to a single MCO service.

To allow applications to decide by what technical means data is transferred, related settings may be technology specific however the Application, awareness service and MCO functionalities themselves can use any technology settings and therefore are technology agnostic although technology setting must be selected. There were at the functional layers decisions must be made based on technical specific parameters, these parameters are generalized at the functionality layers such that the decision-making is technology agnostic. This means that in technology specific parameters are converted to technology agnostic parameters to allow a technology agnostic decision making at the functional layers.

At the Networking & Transport and Access layer technical solutions may be different and therefore interfaces in the lower layers themselves may be technology dependent but the MCO interfaces between the layers are technology agnostic.

To realise the required technology independency, the concept of an “Access Layer Instance” (ALI) is defined. An ALI represents a specific set of lower layer parameters settings. This concept allows us that an application provides the possible underlaying communication settings, which are used by the MCO_FAC to identify by which specific ALI(s) the related message or messages should be disseminated. This can be realised through the management plane (relatively static) or through the data plane message by message dynamically. Although the last is supported by the concept, this is seen as further development for a Release 3 or beyond.

In next clauses, the MCO functionalities are further described. Although the main MCO functionalities deal with the transmission of data, at the receiving side the information is collected by MCO_FAC and distributed to all the applications requesting C-ITS-S functionalities. Also at the receiving side, services may register to receive the content of the received messages. Depending on the setup of the C-ITS-S, this may only be the LDM, since often this fusing service can be the central data storage point for all relevant data.

3.2.4.2 MCO_FAC

The MCO_FAC shall be aware of all capabilities of the lower layers. This includes static capabilities, e.g., what technologies and radio parameters, but also dynamic parameters such as congestion levels and status flags, which again are provided by MCO_NET and MCO_ACC.

To ensure that all applications are served, the applications and services shall register through the management plane to the MCO_FAC and inform it what their needs are. There are at least static requirements, but it may also include dynamic requirements. While the technical capabilities are provided by the lower layers (like identifying the available ALIs), MCO_FAC allocates specific lower layer capabilities and amounts of bandwidth to specific applications statically and/or dynamically based on prioritisation criteria all at the management plane.

Applications and awareness services can then determine when and under what conditions to send information and provide messages to MCO_FAC at the data plane for distribution. Applications themselves do not select the ALI (transceiver specific settings ALI_ID) to use, but provide generalised basic communication requirements relevant for transmission to the MCO_FAC to allow the MCO_FAC to decide which ALI_ID to use.

For instance, this could mean that an application indicates that alternative channels can be used under certain conditions or that a validity time is provided. This way, the MCO_FAC service can schedule the message depending on urgency of messages to be received from other applications or can use a channel with less congestion. The ALI selection can be realized more statically at the management plane but also dynamically at the data plane; in the latter case, for every message the ALI may change. These dynamics can be decided for each parameter independently and is implementation dependent. Main objective is that MCO_FAC can manage the data efficiently in accordance with the expectations of the applications.

To efficiently exchange the applications communication requirements Application Configuration Profiles (ACP) are introduced (Figure 9). Applications and awareness services should inform the MCO service about their expected communication requirements. First the application can be activated. When it wants to transmit information to other stations and when the station has MCO functionality, the application shall inform the MCO service about its needs to allow the MCO service to provide any communication services to the application. This generally is realized statically trough the management plane just once, or dynamically on a time-interval basis, or triggered by a series of events, or when the requirement changes in the application. In return the MCO service provides application specific communication possibilities as guides of limitation. This can be realised on a time-interval basis or for instance only when the requested capabilities are not present. In Figure 9 the red arrow resembles this control flow at the management plane. This interaction can be seen as setting-up the application and maintaining the awareness at the MCO service of the application needs.

The interface between the MCO_FAC and applications communicates in an ACP standard interface format the different parameters according partly including a set of fixed parameter values and several variable parameters. Fixed are for instance the channel and the technology used and variable parameters represent parameters as expected bandwidth. Sets of varying fixed paraments represent specific ACP object, where ACP A_1 represents an object representing a set of fixed parameters and ACP A_2 an object representing one other set of parameters.

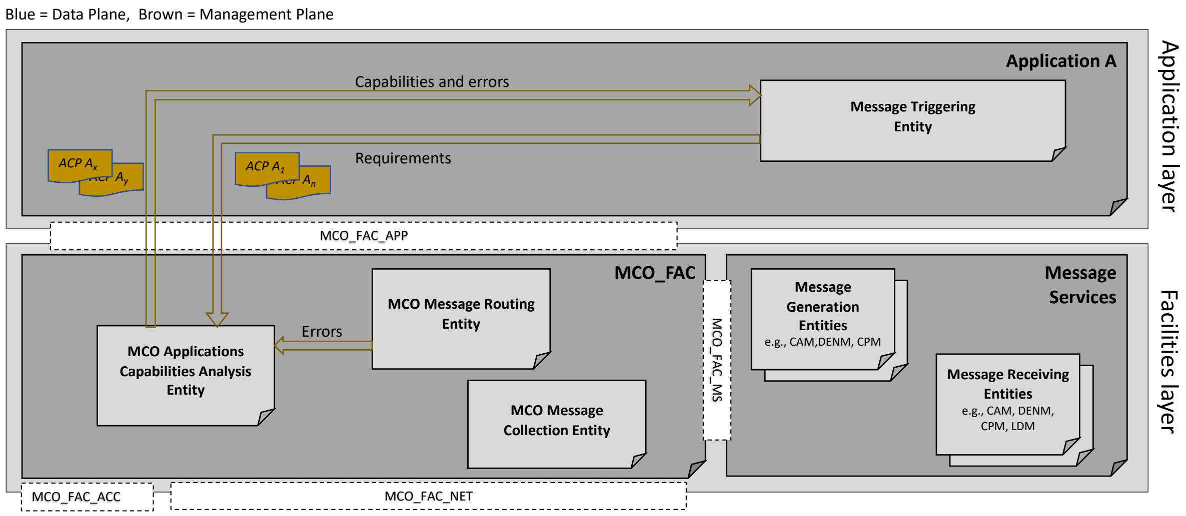

Figure 9:
ACP interfaces and flows at setting-up the interface to the MCO service

In normal operation, instead of providing all the required transmission parameters every time again, only the object number of ACP A_1 or ACP A_2 needs to be forwarded. There are 2 flow possibilities to do so, see Figure 10. These methods are optional but one or the other must be chosen.

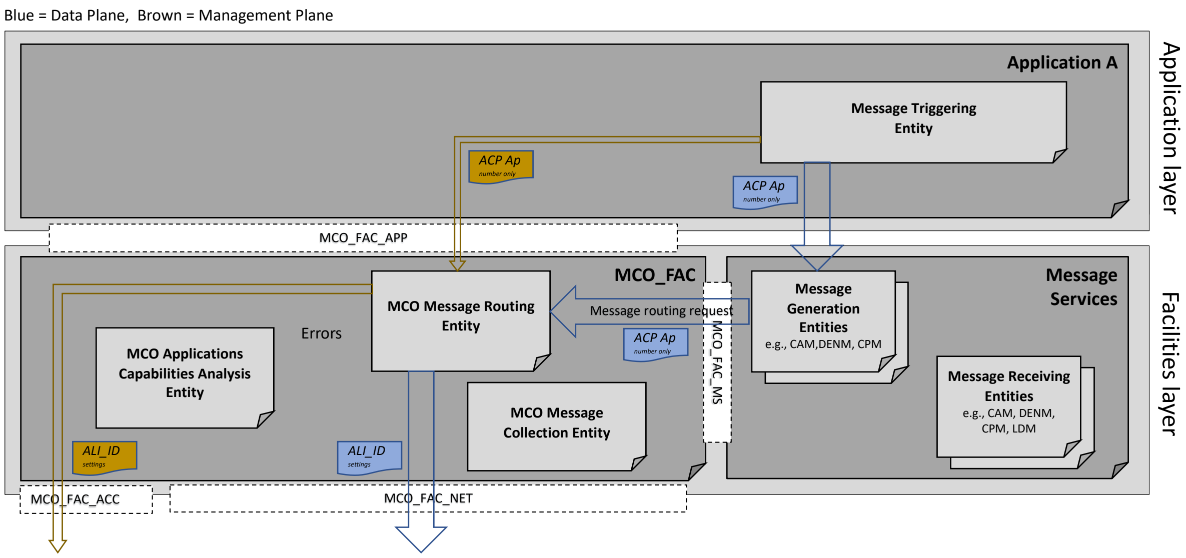

Figure 10:
ACP interfaces and flows at Data transmission to the MCO service

Option 1 is to do this through the management plane and setup the communication for all application specific messages or for a group of application specific message transmissions at a given time. This is rather static but can be sufficient and depends on the operation of the application.

Option 2 is to realize it with each message in the data flow. Especially with this option the system benefits from not always having to provide all communication parameters but only the right object. As depicted in Figure 10, the ACP object number is provided from the message triggering entity to the Message creation entities and by this passed through to the MCO Message routing entity (MCO-MRE) as part of the MCO service. Message services which include message generation rules must register themselves to the MCO service according to Figure 9.

A specific set of ACP parameters shall be identifiable by a unique ACP instance identifier, **ACP_ID**.

In both options several ACPs can be provided to the MCO service for use such that MCO can decide what to use under different congestion conditions. As such part of the variable set of parameters of congestions are selected to identify the conditions an ACP may be used by the MCO service.

As illustrated in Figure 9, the MCO Message Routing Entity (MCO_MRE) decides what ALI settings to use and forward related ALI_ID in accordance with the Option 1 through the management plane to MCO_ACC or in case of Option 2 with the data message to the Network layer.

Circumstances can arise that the MCO_FAC receives a message which can't be transmitted, whether this is caused by changes in the radio or lower layer dynamics or from not correctly behaving applications or services. MCO_FAC may include error handling mechanisms which informs applications and services about these errors.

One possible change of the lower layer dynamics can be caused by entering a protected communication zone. In this case, the functional impact is known, and proper behaviour is standardized. In case of CAM based protected zones, it is the obligation of the CAS to register itself at MCO_FAC and to check received CAMs if they contain protected communication zones. For received zones the CAS shall instruct the station accordingly and mitigation method(s) shall be applied (as it would be done without MCO capabilities). Changes on the lower layer, like a reduced transmission power, are forwarded from the ALIs back to MCO and may let MCO chose different policies for further message transmission. Other services and messages, like IMZM, shall behave like said before for CAMs. MCO supports the already existing service behaviour, but it does not replace the service's behaviour and obligations.

To allow applications and services to operate consistently, applications and awareness services shall operate in accordance with MCO requirements. These requirements are specified in 3.2.5.

3.2.4.3 MCO_NET and GN Core

At the Networking and Transport layer, the current GN Core originating Release 1 functionality as specified in the EN 302 636-4-1 [ER-8] is extended with the technology agnostic ALI handler functionality along with basic multi-channel networking functionalities allowing it to interface with the MCO_NET and directly to MCO_FAC and MCO_ACC.

The GN Core may be statically instructed by the MCO_FAC at the management plane to use specific ALIs for specific data packet streams or it may be dynamically instructed what ALI to use data packet by data packet at the data plane. It may use ALI flags from the MCO_ACC for the realisation of ITS functionalities.

The GN Core may include technology specific entities, since the MCO_NET entity is technology agnostic, but may include a load balancing technology dependent functionality. The Release 1 technology specific DCC_NET as specified in the ETSI TS 103 175 [ER-16] is replaced by the MCO_NET for Release 2.

The MCO_NET entity is made aware of the existing GN ALI handlers by the GN Core. This may be realised by registration of active GN ALI Handlers or just presented as a list.

The MCO_NET can ask the GN ALI Handlers to provide global technology dependent congestion levels for all active channels from the GN ALI Handlers by having direct access to synchronised measured local technology dependent congestion levels from the access layer MCO_ACC entity. The MCO_NET entity's load scaling functionality will realise a global technology agnostic value to be provided to the MCO_FAC. It also forwards the MCO_ACC status flags to the MCO_FAC.

The MCO_NET provides the technology specific local congestion value directly to the appropriate GN ALI Handler for sharing mechanisms to other stations.

Figure 11 illustrates that technology dependent parameters, specifically channel load values are scaled in the MCO_NET to create a technology agnostic parameter which can be used by the upper layers. Technology dependent values can be provided by the access layer or by the Media dependent entities in the GN ALI Handler.

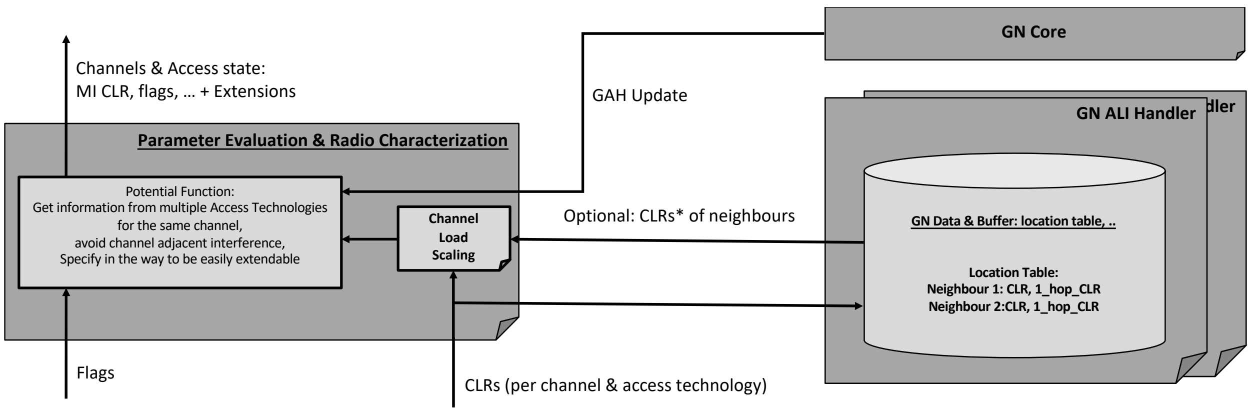

Figure 11:
MCO Network & Transport layer, Load scaling principle

3.2.4.4 MCO_ACC

The Access layer represents physical implementations, and it is therefore principally technology specific. The introduction of the Access Layer Instance (ALI) concept enables the use of many technologies in the same system as it makes the interface to the higher layers itself technology independent.

Physical layer implementations can often be configured in many ways to operate in various settings. As an ALI represents a specific configuration of a physical layer implementation, such implementation might have many ALIs.

In the MCO_ACC entity the ALI operations functionality is aware of all possible ALIs from all active transceivers. The MCO_ACC provides the MCO_FAC access to this information at the management plane.

The MCO_FAC instructs the MCO_ACC entity's ALI Operations functionality what ALIs to activate, after which the ALI Operations sets up the transceivers so that communication can take place in accordance with required settings.

The MCO_ACC entity's Channel Load database receives technology dependent channel loads from all active transceivers for access by the MCO_NET entity.

The access layer of an MCO capable C-ITS Station will have to implement and operate more than a single transceiver simultaneously. This set of transceivers can be capable of implementing different access layer technologies (e.g. ITS-G5, LTE-V2X, etc.). Each of these transceivers can be parameterized to be adapted to the requirements of the application and the related messages. A single transceiver can be instantiated with using a set of different access layer parameters. These parameters are:

- Access layer technology (ITS-G5, enhanced ITS-G5, LTE-V2X, 5G-NR-V2X, …)
- Used physical channel (SCH0, …, SCH6)
- Modulation and coding scheme (MCS)
- Channel coder (CC, TC, LDPC, ..)
- Channel Coding rate
- Modulation scheme
- TX power

A parametrized transceiver, “Access Layer Instance” (ALI), represents a specific access layer instantiation of a transceiver. This instantiation and thus the ALI can be changed from message to message or from group of messages to another group of messages. The ALI implements the access layer technology (ITS-G5, LTE-V2X, 5G-NR, enhanced ITS-G5), the channel coding, the modulation, the transmit power and the used physical channel.

A specific set of access layer parameters shall be identifiable by a unique access layer instance identifier, **ALI_ID**.

The data plane and a management plane operation of the MCO capable access layers are depicted in Figure 11 and Figure 12 with respect to a flexible transceiver design approach and a configuration of separate sets of transceivers approach. In these figures a combination of the access layer and the network & transport layer is depicted, presenting the close interaction and relation between these two layers.

The access layer data plane as depicted in Figure 12 shall provide all functionalities required to transmit a PPDU over the physical channel defined as part of the ALI-ID. In the presented figure it is assumed that the set of transceivers can be flexibly parametrized to provide different access layer technology functionalities, thus can be instantiated as technology agnostic transceivers based on the actual ALI-ID.

Another implementation representation of an MCO technology agnostic C-ITS-Ss is also depicted in Figure 12'; as there is no clearly 'alternative' or 'option' visible in figure 12, where the different access layer technologies are limited to a technology specific set of transceivers. Here, an access layer instance can only run on a transceiver that can implement the access layer technology associated to that ALI.

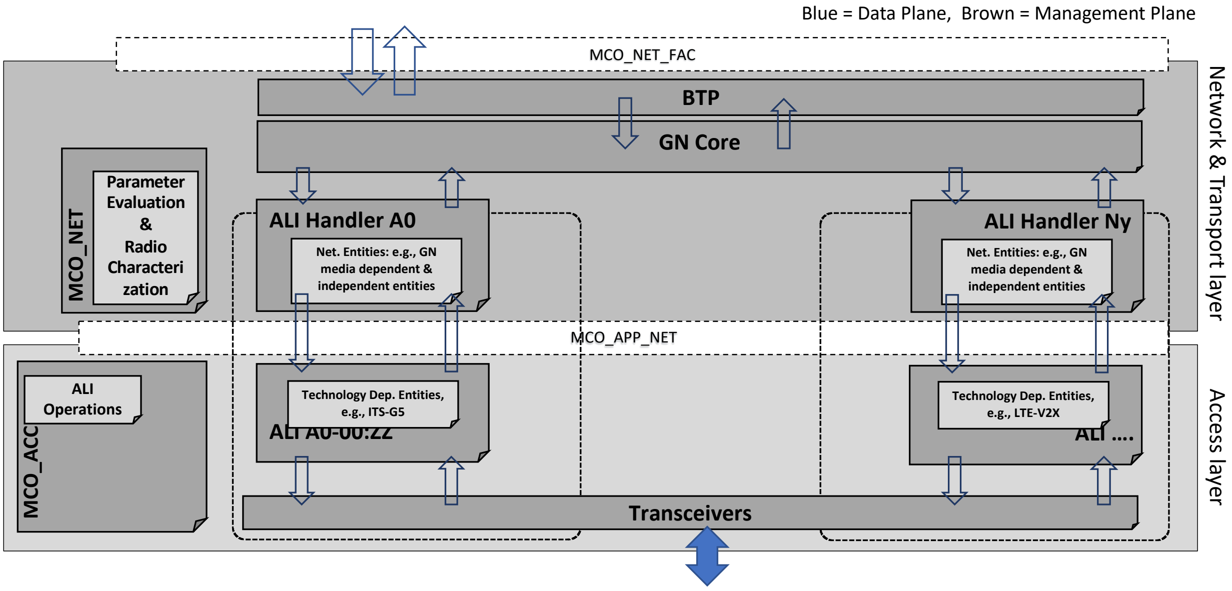

Figure 12:
MCO Access layer and Network & Transport layer, Data plane with full flexible transceiver approach

At the management plane in the network & transport layer and access layer as depicted in Figure 13, the ALI operations may get directly from the MCO_FAC the required ALI parameters through the ALI_ID and based on that configure the transceivers as option 1 for MCO_FAC implementation. In case the ALI_ID is provided via the data path (option 2) it is provided through the ALI Handler at the Network layer.

The used channel and the access technology are semi dynamic characteristics whereas the other parameters (MCS, TX power) can change on a message-by-message basis. Semi dynamic means that these parameters need a longer configuration time. The actual required configuration time for the semi dynamic characteristics is implementation dependent. The ALI operation entity shall provide the actual state of all transceivers to the higher layer.

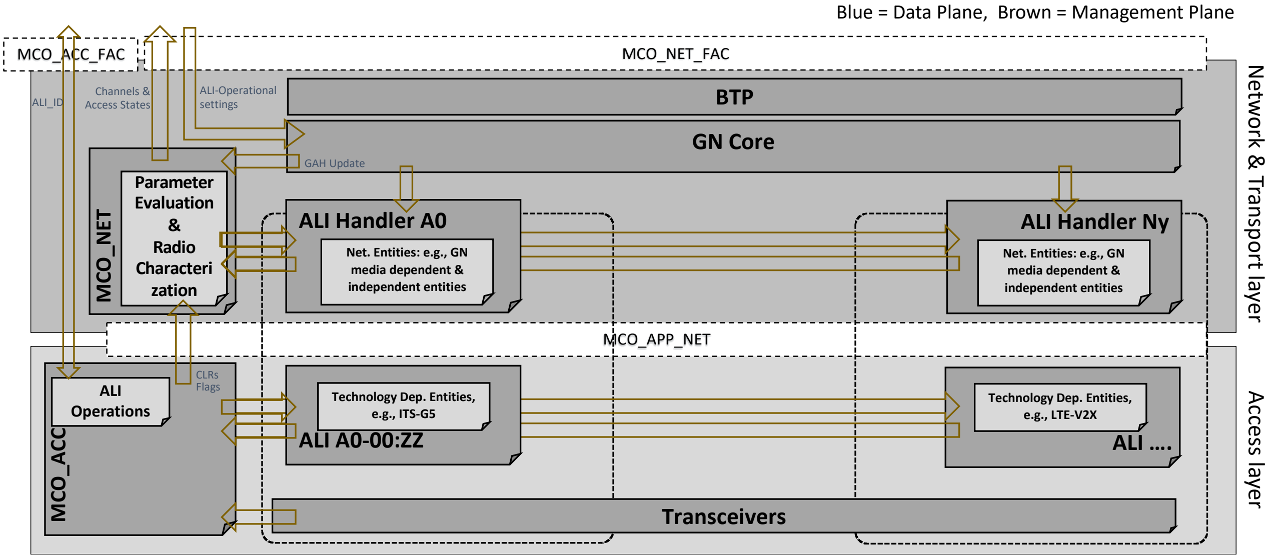

Figure 13:
MCO Access layer and Network & Transport layer, Management plane

3.2.5 System and Application requirements

3.2.5.1 Introduction

As identified in 3.2.2, to allow a multi-channel C-ITS system to operate robustly and predictably, applications and awareness services require to operate in a predefined manner. As MCO is the common functionality, applications and awareness services shall therefore operate according to some MCO requirements.

While Release 1 C-ITS services (applications) limit themselves to awareness and driver warning services, Release 2 focus on the extension of those services, and in addition to C-ITS services extending transport automation including automated driving functionalities. Vehicle automated functions can do a lot with the vehicle sensors such as cameras, but all information is line-of-sight, not including what is blocked by the driving car in front or what is in a crossing street, leading to missing crucial safety related information. C-ITS realises sharing information beyond line of sight, seeing what is beyond the car in front or what is present in a crossing street. C-ITS is and will become more important along with the increase of automation levels. Release 2 C-ITS services require more data, higher QoS and increased accuracy, in relation with functional safety requirements, all together requiring Multi-Channel Operation (MCO).

After a first clause providing a summarized context, the following clauses identify relevant system considerations and a clear set of MCO related requirements for applications and awareness specific services to facilitate the required robust operation of a C-ITS multi-channel system.

3.2.5.2 Operation of many C-ITS applications in an MCO C-ITS

3.2.5.2.1 Wider channel versus multi-Channel

The C-ITS ECO system supports the operation of many awareness, warning and automated C-ITS and CCAM [ER-22] safety related services. There are two extreme ways to support a collection of these services. We could put them all in a single channel or we could give all services their own channel. The last is practically impossible as each application has different dynamics in use and size of the data transfer resulting in requiring various narrow and wide channels in the same ITS spectrum. It would be spectrum inefficient, although it would be the most robust.

We can also put everything in a single wide channel. As long as the width of that channel complies to the worst-case scenario (worst case because of safety, having all applications active) so that congestion never occurs, this would also be robust as well.

General communication systems, such as the mostly used IP Internet access methodology-based communication system, are best effort systems, where successful data exchange depends on application external factors. As having all applications active doesn't happen often such approach makes the system too expensive to be carried by all participants; as only a limited number will require such safety related requirements. As only a limited number of transceivers will be requiring worst case support, Operators see no business case to support this in the telecom networks as general functionality.

The data exchange based on traffic dynamics (ITS-Ss are moving around with medium to high speed) related to urban, sub-urban and highway scenario's, as well as automated and non-automated equipment, is not predictable as can be seen from data evaluations realized based on the real-life Luxemburg Model, in which highly dynamic data exchange behaviour can be recognized depending on various predictable and unpredictable conditions. Radio use and spectrum congestion can't be predicted but only estimated.

As C-ITS concerns safety related user and automated services, they are influenced by external factors, whether these are transmission capabilities or various behavioural conditions, and as such influence can't be avoided, it should be proactively managed. As the functional responsibility for the safe functioning of services lays with the applications, the applications shall be able to manage all situations with a quality level applicable to the required level of the application and scenario(s) it is being used in.

Considering that a continuing creation of C-ITS applications is foreseen (see the C2C-CC roadmap) it is impossible to predict the impact of new applications becoming active and to oversee the impact of activation of services. In case the channel width would be endless this would not be a problem, but the available bandwidth has an end and congestion will happen. As C-ITS applications realize safety related services, the C-ITS shall enable the correct operation of these applications and allow predictable data exchange. Also considering that the more applications in a highly dynamic environment depending on and influencing each other can easily lead to unpredictability, the C-ITS-S system shall include mechanisms to increase the predictability beyond a best effort system. As conceptually the impact that applications have on each other increases exponential with the number of active applications, it is obvious to limit the possibility of influence.

Additionally, it needs to be considered that applications need to be validated at the system level. When increasing the number of applications also the validation complexity increases exponentially. The required system validation should be reduced as much as possible as the costs are significant as well as the time it will take to realise those; exponential increase is therefore not even seen as an option.

Beside this it is impossible to just extend the ITS 5.9 GHz band with some more spectrum at the bottom or top when we would like to do all in a single channel, and therefore not even considering the practical spectrum related possibilities; a single wide channel is eventually not an option. The maximum flexibility is a multi-channel environment in which mixed channels of varying widths may exist. At least a multi-channel environment can't be avoided.

3.2.5.2.2 Data types in ITS and C-ITS

ITS makes use of data exchange of different kind. In case of map updates or vehicle fleet management we can speak about bulk data exchange, where the amounts of data are high and the timing not that critical. Besides bulk data there is video like streaming kinds of information exchange which not really can be interrupted and could be non-time critical but also time critical. As third possibility there is control data exchange which can be non-time critical or time critical.

Although all 3 types of data exchange can be recognized in ITS data exchanges, C-ITS recognizes only time critical sensor awareness and control-oriented data exchange and streaming (raw sensor) data flows.

The ITS spectrum allocation in the 5.9 GHz was originally intended for basic awareness and control and not for streaming but when this is considered it should be noted that related information streams will be used for detailing and therefore required to be of high quality. When looking at the currently considered video streaming use case this requires to be at least from an HD quality level and may be even. An HD stream has a max rate 7.4 Mbps (see Restream [ER-38]). In case even Ultra HD streaming is used this is even 25 Mbps as identified by Highspeed Internet [ER-39]. When considering the Release 1 operational channel settings 6 Mbps can be transferred. A single video stream very quickly does not sit in such operational channel.

C-ITS applications are based on openly sharing information, when raw data streams sharing is required, this directly leads to sharing of multiple video streams. When for example we take a platooning use case in which it is expected that no more than 5 trucks are part of and where there are considerations to exchange video streams, we can expect that 5 video streams. When then considering that a truck platoons may overtake one other platoon, already 10 video streaming can be active at the same time. Such a scenario then results in information exchange with a total of somewhere between 70-250 Mbps. A use case which even can't be realised in the full ITS cand currently available (42 Mbps). Additionally, it needs to be considered that such video information is only relevant for specific road users from which their C-ITS-S would become unusable for other C-ITS applications. Streaming is therefore not an option in the 5.9 GHz band. In the 64 GHz ITS band there is 2 GHz bandwidth available and therefore could be used for such streaming use cases. A band which is quite usable for such use cases but also for other properties.

3.2.5.2.3 Message exchange by applications

For Release 1 the use of wider bands was considered but it was decided to use 10 MHz channel as allocated in spectrum regulation based on the application requirements characterised by their data package size and keeping the number of applications influencing each other low. It would also allow next generation applications to be developed independently of those existing not influencing each other.

For Release 2 such same principles should be followed and therefore only applications which change functional requirements from Release 1 may lead to changing the channel width.

For Release 2 the Collective Perception Service (CPS) can be taken as reference as enough evaluation has been realized to provide any prediction of the message behaviour. So far, we do not see too many other concrete application or services being evaluated sufficiently enough to give different or additional functional requirements. Currently, Platooning is the only other to be considered with higher spectrum requirements. From other services such as Manoeuver Coordination Service (MCS) only some selective use cases are recognized not yet indicating similar requirements (probably to be expected as part of Release 3).

Analyses of the CPMs exchange (see TR 103 562 [ER-19]) show that in principle when all use cases are handled in a single message, the message size increases beyond the message size capabilities (possibly leading to linked messages being transmitted) but also may exceed the 10 MHz bandwidth requirement in some scenarios. Both cases are to be avoided. Instead of supporting all use cases at once, the CPMs could be made specific to the use case it serves. In that way the messages could become smaller, and although the number of messages would increase these can be handled differently for each use case. By defining criteria for each use case, e.g., type of use case and confidence level, the individual use case related messages could be assigned with different priority in the same channel, could be off-loaded in case of congestion, or just could simply be transmitted on different channels.

Platooning (see reports from the EU project ENSEMBLE [ER-21]) is a singular use case needing extended CAM awareness and additional control information exchange. The extended CAMs can be easily accommodated by creating an additional Platooning oriented CAM generation rule, generating additional CAMs. Such a CAM rule could lead to transmission of these additional CAMs in another channel or still in SCH0 with lower priority as any currently operating services from Release 1 and off-load them when in congestion. The message exchange for the platooning control needs much more certainty of reception (as decisions may have larger impact on the safety situation) but are not large and do not require high bandwidth. The Platooning use cases communication requirements are, besides certainty, not different from the Release 1 data exchange requirements and can be handled in an additional channel and do not require a wider channel.

Similar to CPS, Manoeuver Coordination Service (MCS) supports several and possibly many use cases. The main use cases currently recognized are the emergency and public transportation prioritisation use cases. The automated vehicle movement use cases are in a very immature state and therefore can’t be considered currently. So far it is assumed that automated vehicle movement use cases will be developed for Release 3. Considering only the emergency and public transportation prioritisation use cases, communication will mainly be between related vehicles and infrastructure except for use cases such as emergency corridors which are V2V.

MCS is C-ITS Station specific and may include control related messaging. The communication is therefore not many to many but some to some. Awareness of the exchanged MC information could be helpful but are not really required for all in the same area. The size of the messages is small, and the number limited. It is open whether the message exchange is still broadcast, multicast or unicast oriented but from the perspective of channel requirements also here no additional functional requirements can be expected.

With regards to Backward compatibility, it does need to be considered that in Release 1 all priority levels are in use. This doesn’t allow to differentiate new Release 2 use cases making use of SCH0 from Release 1 use cases operating in the SCH0. Two considerations can be suggested:

- Extend the priority levels at the Facilities layer from 4 to 8 and map each 2 to one EDCA protocol prioritised queue, creating additional priority levels to allow the required additional differentiation. This is backward compatible as this is station internal.
- Limit Release 2 and beyond use cases not to operate in SCH0 but in other channels, to avoid any interference with Release 1 use cases in SCH0 to maintain backward compatibility.

NOTE: Backward compatibility requires to consider that Release 1 message extensions for Release 2 are not only realised in SCH0, but also in other channels.

3.2.5.2.4 Effects of the spectrum regulation

From out of the perspective of spectrum regulation (see 2.9.3) it is required to consider the current situation and how wider channels could fit into this. Figure 5 illustrates the current spectrum allocation in Europe in which the band is divided in 10 MHz channels not allowing wider channels. Currently the SCH0 is in operational use by at least half a million, rapidly increasing, number of C-ITS-Ss. As SCH3 and SCH4 are falling under an SRD regime while the other channels are falling under a mobile radio regime and SCH6 can only be conditionally used there would be only one option to put a 20MHz channel in SCH1/SCH2; however, as identified in the “general multi-channel considerations” (2.5.2.5) no functional or system requirements are currently identified to realize 20 MHz channels for Release 2, but this could be the case for Release 3. As it is also identified that additional spectrum is needed such 20 MHz channels could be realized in related additional spectrum.

3.2.5.2.5 Application behaviour effects on the C-ITS

Besides applications requirements, effects of the applications behaviour on the system such as complexity and testability have been assessed. As earlier stated, the data transmission activity of a single C-ITS-S and therefore of in the C-ITS a whole (because of the presence of many C-ITS-Ss and the never-ending number of scenarios), is very dynamic and in that sense unpredictable, requiring an as much as possible predictable system enabling applications and awareness services to be proactively aware of dynamic circumstances. The operation of applications and awareness services influencing each other in the same channel is made possible in Release 1 by limiting the applications supporting a well-defined number of use cases in a successful implementable way in a channel with limited 10 MHz bandwidth. Considering the arguments as presented in 2.5.2, 3.2.5.2.1, 3.2.5.2.2, 3.2.5.2.3 and 3.2.5.2.4 an approach in setting limits and capabilities is defined based on use case and application requirements, as well as system capabilities and limitations.

For the realisation of a stable operational system environment in which use cases realized by applications can operate robustly, an approach of limiting the influence of applications may have on each other from release to release or within a release towards each other is essential.

Four main considerations:

- Realize each Release set of applications and awareness services in a different set of ITS channels to manage backward compatibility and interoperability. While updating previous release specification in next release the operation in the originating channel needs to be carefully considered.
- Within a Release, applications and awareness services must limit the used channel bandwidth. Preferably, make limits use cases or use case group specific.
- Increase the priority levels to 8 for each Release and while creating a first release do not use all levels to create redundancy for later use ensuring backward compatibility.
- Based on the findings in 3.2.5.2.4 only 10 MHz channels with possible 20 MHz bonding could be allowed in the 5.9 GHz ITS spectrum. Wider channels are possible in ITS spectrum at the 64 GHz.

Implementing these considerations will support a more efficient spectrum usage. When in next releases also offloading mechanisms can be used, further increase of spectrum efficiency can be achieved.

Additionally, it needs to be recognized that applications influence each other at the system level and therefore only system testing can be used for validation. It is therefore not difficult to recognize that, with the increase of complexity, also the testing effort will grow exponentially, which is a real challenge considering the dynamic behaviour and safety requirements. From out of the perspective of testing, high complexities should be avoided.

3.2.5.3 C-ITS Service requirements

C-ITS communication is not an IP oriented Internet like network in which an application only needs to know the destination of the data. C-ITS communication is more like a music radio station. When we want to listen to a specific radio station, we need to know its frequency and modulation (for instance, AM stations cannot be received with a FM tuner). For C-ITS services this is not different. For a C-ITS application it shall be known in what channel or channels and with what channel properties the data packets shall be transmitted independent of technology. This is something which should be already known to the application. To realise Interoperability, this shall be specified for each application or awareness service.

3.2.5.4 MCO Generic Application related System Requirements

The following application and awareness service requirements are specified to accommodate that MCO solutions can provide a Release related QoS sufficient to allow a correct sustainable operating of application and awareness services in several ITS channels without interference.

REQ_MCO_APPL_001: Release A+1 C-ITS applications and awareness services shall not interfere with the operation of Release A and earlier released C-ITS applications and awareness services and ensure backward compatibility with Release A and earlier releases.

REQ_MCO_APPL_002: Extensions of Release A use cases, applications, or awareness services (not considering error handling) shall be considered as part of Release A+1 set of specifications.

REQ_MCO_APPL_003: Extensions as identified in REQ_MCO_APPL_002 shall be considered not to be extended in Release A used channels. In case extensions are required in previous release related bands, backward compatibility shall be ensured.

REQ_MCO_APPL_004: Release A+1 use cases, applications, or awareness services (not considering error handling) intended to use spectrum bands used by Release A and earlier releases, shall provide evidence that backward compatibility is ensured.

REQ_MCO_APPL_005: For each Release, the set of applications or awareness services the operation in terms of used channels and related resources shall be managed commonly to realise QoS for all applications and awareness services,) services, by aligning use cases, applications or awareness related priorities and channel use.

REQ_MCO_APPL_006: Based on REQ_MCO_SYS_003, such set of use cases, applications and awareness services should not use all priority levels to create redundancy to enable future extension.

REQ_MCO_APPL_007: Release A+1 C-ITS applications and awareness services shall trigger message generation in accordance with MCO interface and MCO operational requirements as specified in the MCO set of specifications, specifications being specified in the ETSI Work Items is for MCO_ACC; DTS/ITS-004204 (ETSI TS 103 695); MCO_NET: DTS/ITS-003203 (ETSI TS 103 836-4-1) and MCO_FAC: RTS/ITS-001956 (ETSI TS 103 141.

REQ_MCO_APPL_008: For all Release A+1 application and awareness services Application Communication Profiles (ACP) shall be specified in which the communication related requirements are identified.

3.2.5.5 MCO Specific Application related System Requirements

For the purpose of realizing a predictable operating C-ITS system some service operations should be specifically fixed. The following requirements reflect them, but are requirements likely to be included in the original ETSI specifications, see 2.7.3.

REQ_MCO_APPL_009: General Safety Related Service Announcement shall be transmitted in SCH1, with the appropriate priority ensuring correct operation of previous released applications and awareness services in the same channel.

REQ_MCO_APPL_010: General Non-Safety Related Service Announcement shall be transmitted in SCH4, with the appropriate priority ensuring correct operation of previous released applications and awareness services in the same channel.

3.2.6 Further developments

3.2.6.1 Introduction

The following clauses represent aspects which shall or can be considered as extensions to the current concept.

3.2.6.2 Controlled adjacent channel interference in MCO

As identified in ETSI TR 103 439 [ER-15] when channels are not close to congestion yet, interference in adjacent channels is acceptable, but when one or some get into congestion this can't be tolerated.

Based on the calculations in 2.5.2, congestion may not happen too often, but will happen even with not to high penetrations and is managed by the defined congestion control mechanisms.

When starting to use multiple channels, adjacent channel influences can't be excluded any more, and therefore MCO Release 2 standards shall be extended with congestion level adjustment methods to overcome the possible interference, even before related specifications are implemented for practical use.

As the message transmission is managed by MCO entities using congestion level measurement results as input for the decision making of message transmissions, extension of the MCO mechanisms to facilitate acceptable interference can be included at a later stage.

It is therefore recommended that after the realisation of the MCO concept a study is initiated to identity if congested level reductions are needed and what measures to take.

3.2.6.3 Use of the non-safety related channels for safety related use

As identified in ETSI TR 103 439 [ER-15] the non-safety related channels, SCH3 and SCH4 in Europe are part of the SRD (Short Range Devices) regime but ITS devices may transmit with rather more power than SRDs and therefore are prioritized users of those channels under the condition that only a limited range is used. This is a conclusion in the ETSI TR 103 439 [ER-15] but the range by which it could be used for safety related information exchange is not defined. A study defining the level(s) is therefore proposed.

4 Appendix 1 – References

4.1 Internal References

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[IR-2] MCO Technical Capabilities and Limits – Part 2: https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2084_MCO-TechnicalCapabilies_V1.0.pdf

[IR-3] C2CCC BSP: https://www.car-2-car.org/fileadmin/documents/Basic_System_Profile/Release_1.1.0/C2CCC_RS_2001_BasicSystemProfile_R110.pdf

[IR-4] Car2Car Communication Consortium: "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving"

4.2 External References

[ER-1] C-ITS Deployment Group: http://c-its-deployment-group.eu

[ER-2] Car2Car-CC: https://www.car-2-car.org

[ER-3] C-ROADS: https://www.c-roads.eu/platform.html

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[ER-11] EU ITS certification and security policies: https://ec.europa.eu/transport/themes/its/c-its_en

[ER-12] ETSI EN 302 637-2 V1.4.0: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service."

[ER-13] ETSI EN 302 637-3 V1.3.1: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service."

[ER-14] ISO TS 19091 (2017): "Intelligent Transport Systems – Cooperative ITS – Using V2I and I2V communications for applications related to signalized intersections."

[ER-15] ETSI TR 103 439 V2.1.1: "Intelligent Transport Systems (ITS); Multi-Channel Operation study; Release 2"

[ER-16] ETSI TS 103 175 : "Intelligent Transport Systems (ITS); Cross Layer DCC Management Entity for operation in the ITS G5A and ITS G5B medium"

[ER-17] ISO TS 19321 (2020): "Intelligent Transport Systems – Cooperative ITS – Dictionary of in-vehicle information (IVI) data structures."

[ER-18] ETSI TS 103 301 V2.1.1: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services; Release 2"

[ER-19] ETSI TR 103 562 V2.1.1: "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS); Release 2"

[ER-20] EC Decision 2008/671/EC: "Decision on the harmonised use of radio spectrum in the 5 875-5 905 MHz frequency band for safety-related applications of Intelligent Transport Systems (ITS).": https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32008D0671

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